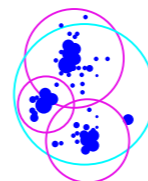


# Boost 2012

Valencia, July 23<sup>rd</sup>-27<sup>th</sup>

Centro cultural Bancaja, Plaza Tetuan, Valencia



## Programme

We aim to “boost” the physics potential of high-energy collider experiments developing new techniques for boosted objects – decays of energetic top quarks, gauge and Higgs bosons and non-hadronic jets.

## Experimental Summary

### Scientific committee:

Jon Butterworth (UCL)  
Tancredi Carli (CERN)  
Steve Ellis (U. Washington)  
Chris Hill (Ohio State University)  
Muge Karagoz (U. Oxford)  
Hilmar Plehn (U. Heidelberg)

**Sal Rappoccio (Johns Hopkins/FermiLab)**

Andrea Rizzi (INFN and University of Pisa)

Albert de Roeck (CERN/U. Antwerpen)

Gavin Salam (CERN/Princeton/LPTHE)

Mike Seymour (U. Manchester)

Ariel Schwartzman (SLAC)

Jesse Thaler (MIT)

Marcel Vos (IFIC-Valencia)

Jay Wacker (SLAC)

Lian-Tao Wang (U. Chicago)

### Local organizing committee:

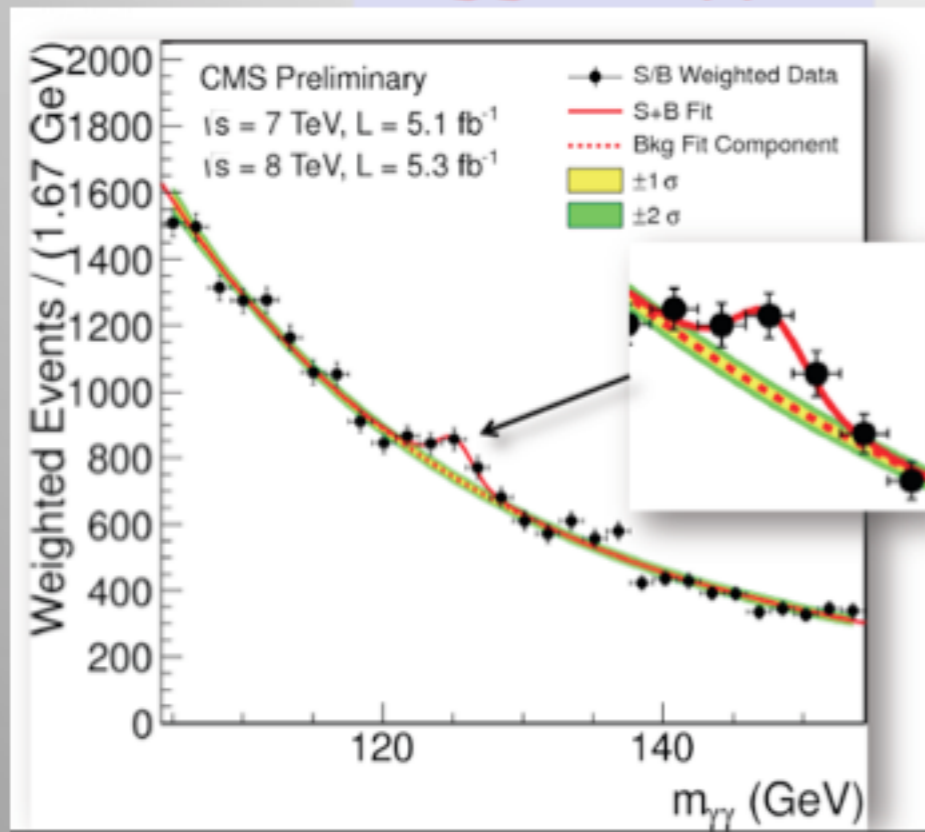
Farida Fasi  
Santiago Gonzalez de la Hoz  
Mohamed Amin el Hyaya  
Elena Oliver  
José Salt  
Miguel Villaplana  
Marcel Vos (chair)

BOOST 2012

# A new context

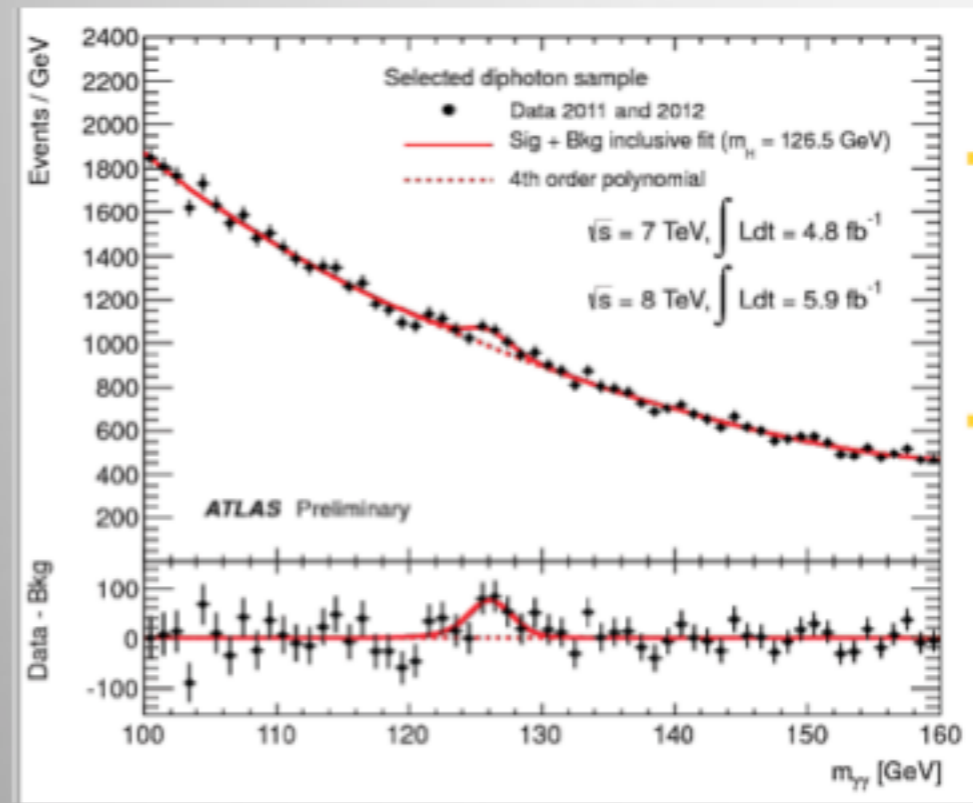
## CMS

### Higgs to $\gamma\gamma$



## ATLAS

### Higgs to $\gamma\gamma$

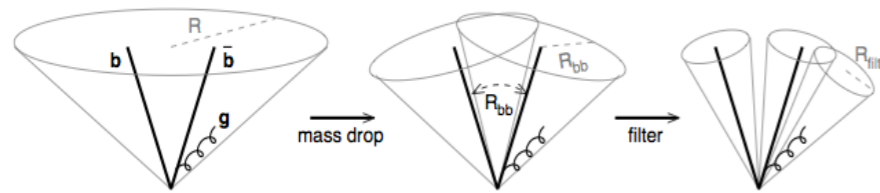


Albert de Roeck

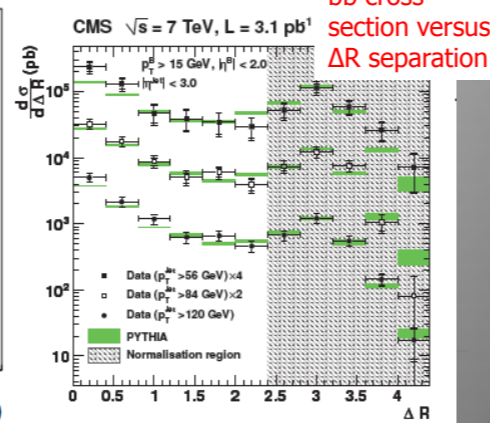
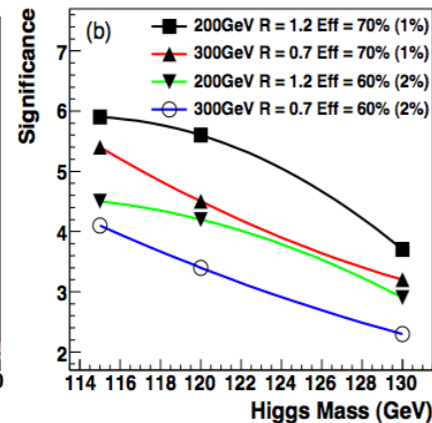
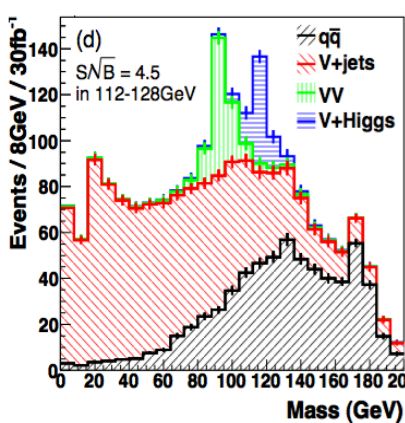
# A new context

## H → bb will be a crucial channel...

- See Butterworth et al. arXiv:0802.2470/Phys.Rev.Lett. 100 (2008) 242001
- Use high P<sub>T</sub> associated WH production (boosted production)
- Use subjet analysis techniques



arXiv:1102.3194



Higgs Searches  
Tilman Plehn  
Discovery  
Higgs couplings  
Bottom Yukawa  
Top Yukawa

## Top Yukawa

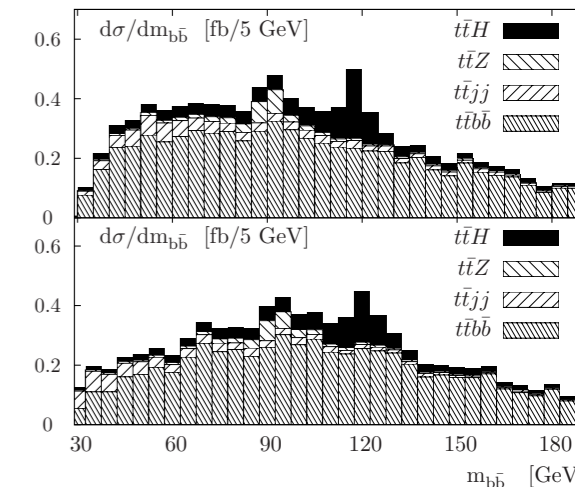
Direct measurement  $t\bar{t}H, H \rightarrow b\bar{b}$  [Atlas-Bonn: Jochen Cammin]

- trigger:  $t \rightarrow bW^+ \rightarrow bl^+\nu$   
reconstruction and rate:  $\bar{t} \rightarrow \bar{b}W^- \rightarrow \bar{b}jj$
- continuum background  $t\bar{t}b\bar{b}, t\bar{t}jj$  [weighted by b-tag]
- not a chance:
  - 1– combinatorics:  $m_H$  in  $pp \rightarrow 4b_{tag} 2j \ell\nu$
  - 2– kinematics: peak-on-peak
  - 3– systematics:  $S/B \sim 1/9$

Fat jets analysis [TP, Salam, Spanowsky]

- require tagged top and Higgs trigger on lepton
- remove 'Higgs' as  $t_\ell \rightarrow b$  plus QCD
- 3rd b tag in continuum only continuum  $t\bar{t}b\bar{b}$  left
- ⇒ side band etc missing in CMS note

[not a single non-ANN plot in there]



Albert de Roeck

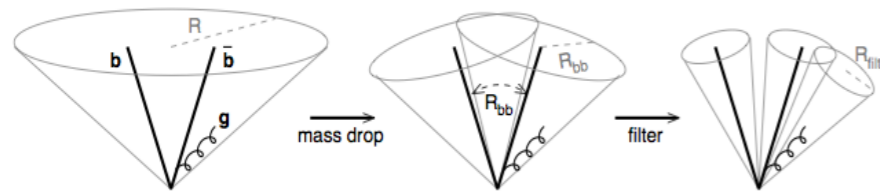
Tilman Plehn

- What does this mean for substructure? Still interesting?
- Fermion couplings?
- Boosted H?
- Boosted tops?

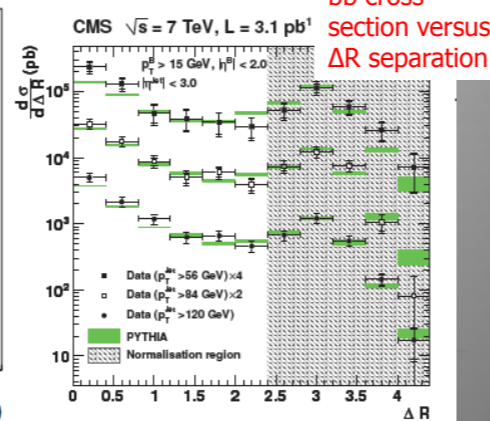
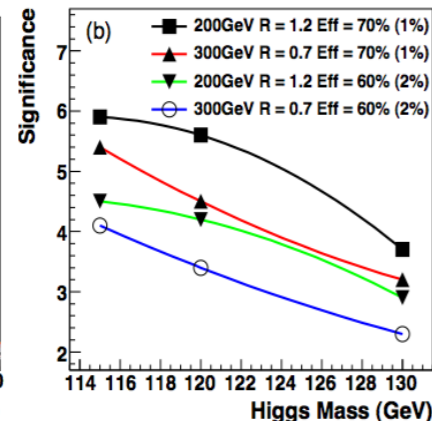
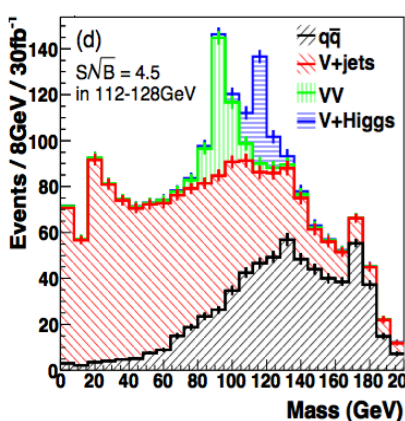
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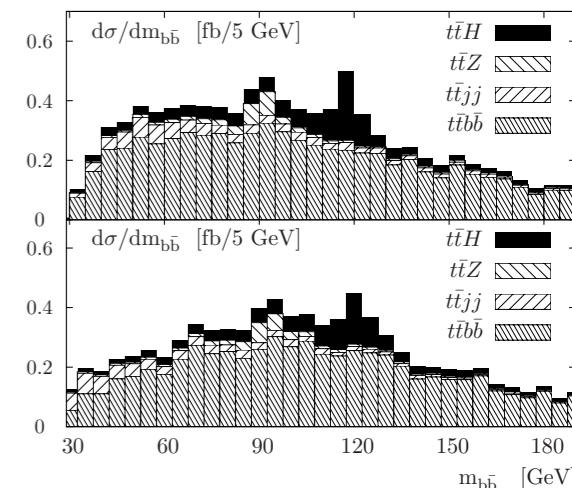
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only continuum  $t\bar{t}b\bar{b}$  left

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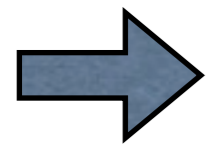
Albert de Roeck

Tilman Plehn

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YES!

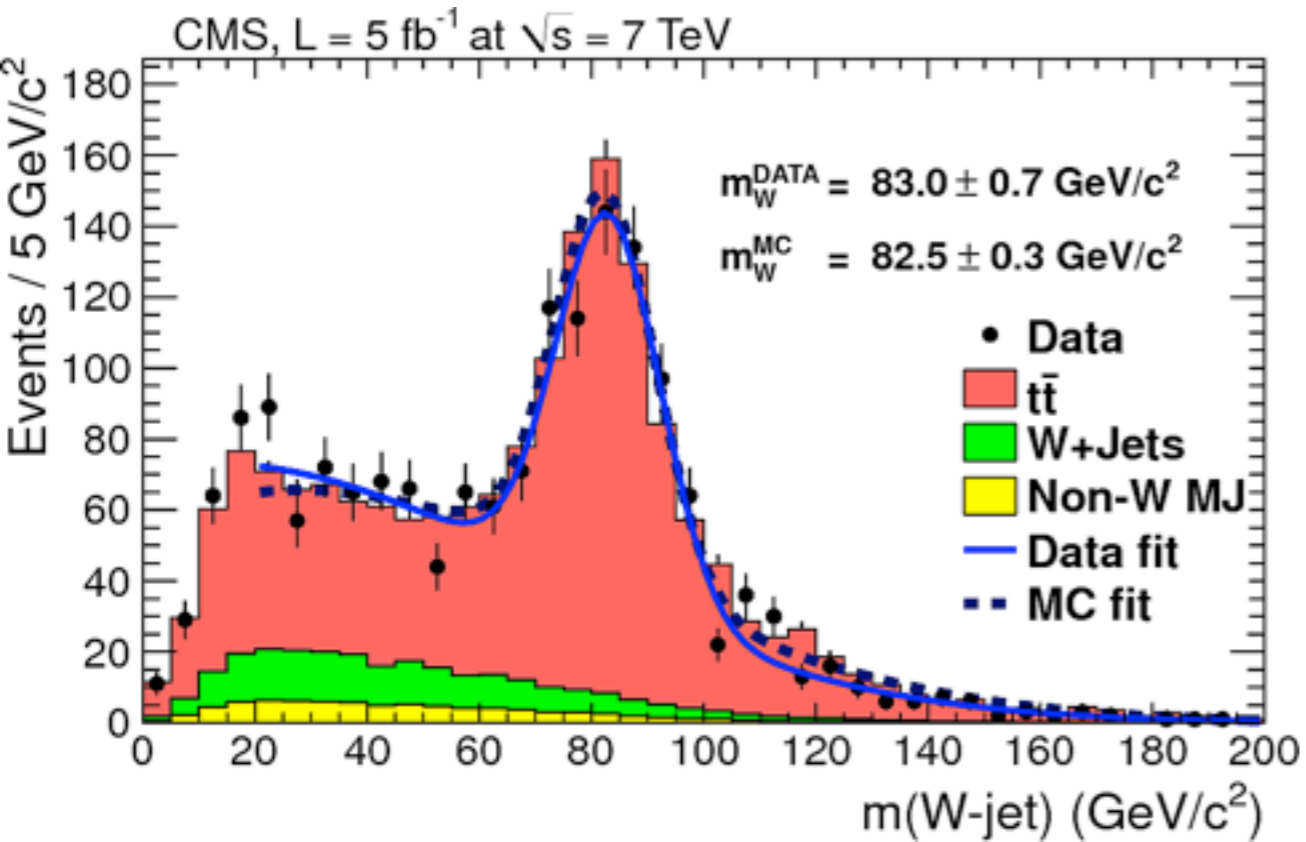
# Outline



- ✦ A new context
- ✦ Merged jets in data
- ✦ Pileup
- ✦ Studies on tools
- ✦ Substructure measurements
- ✦ Applications to searches
- ✦ Future colliders
- ✦ Conclusion

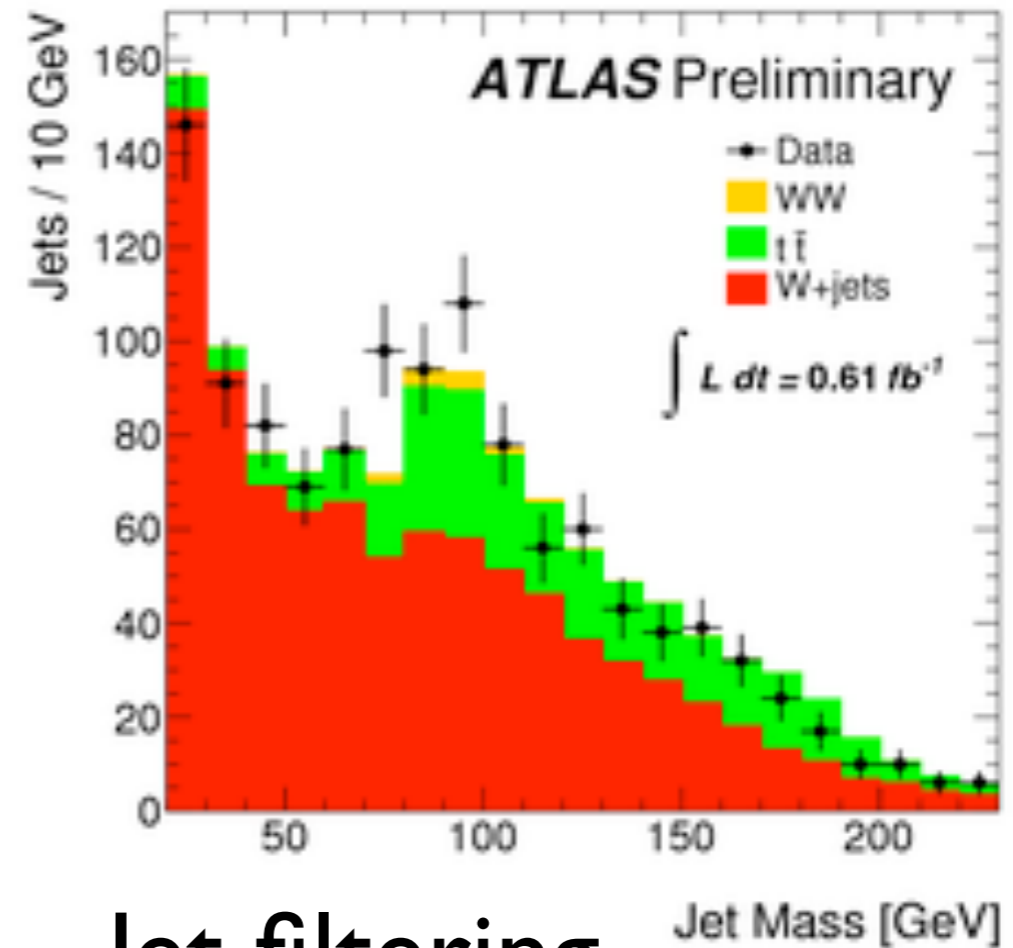
# Boosted W in data

## CMS



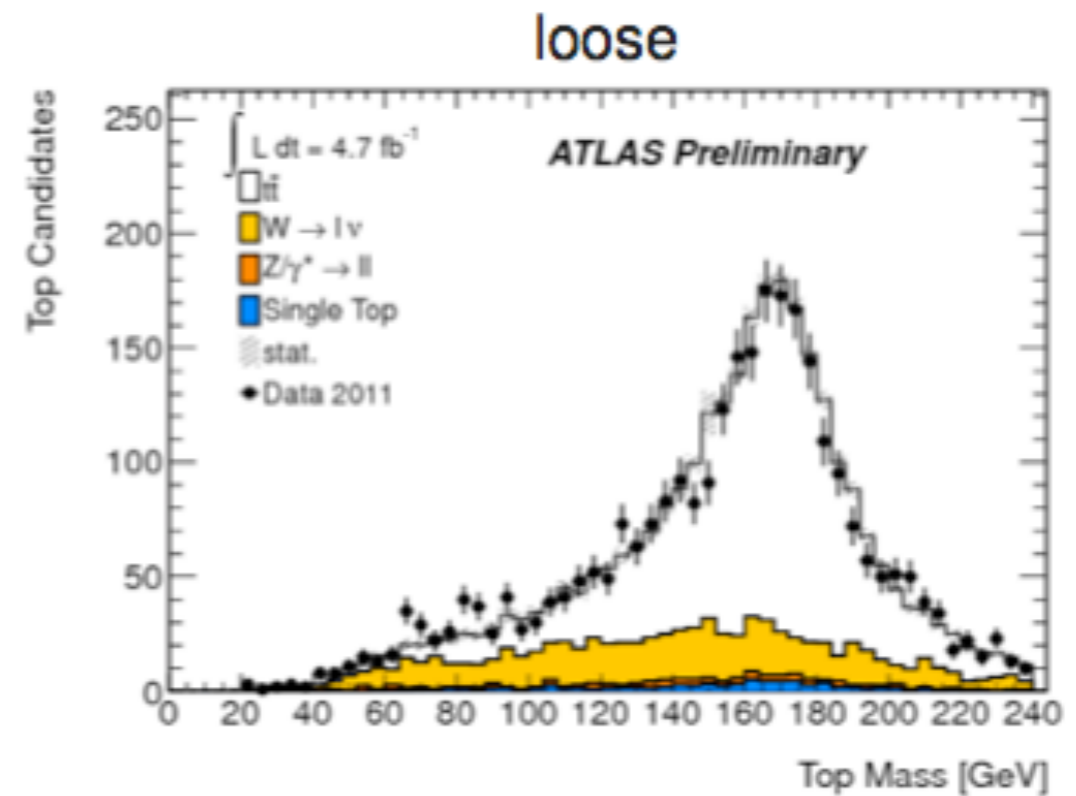
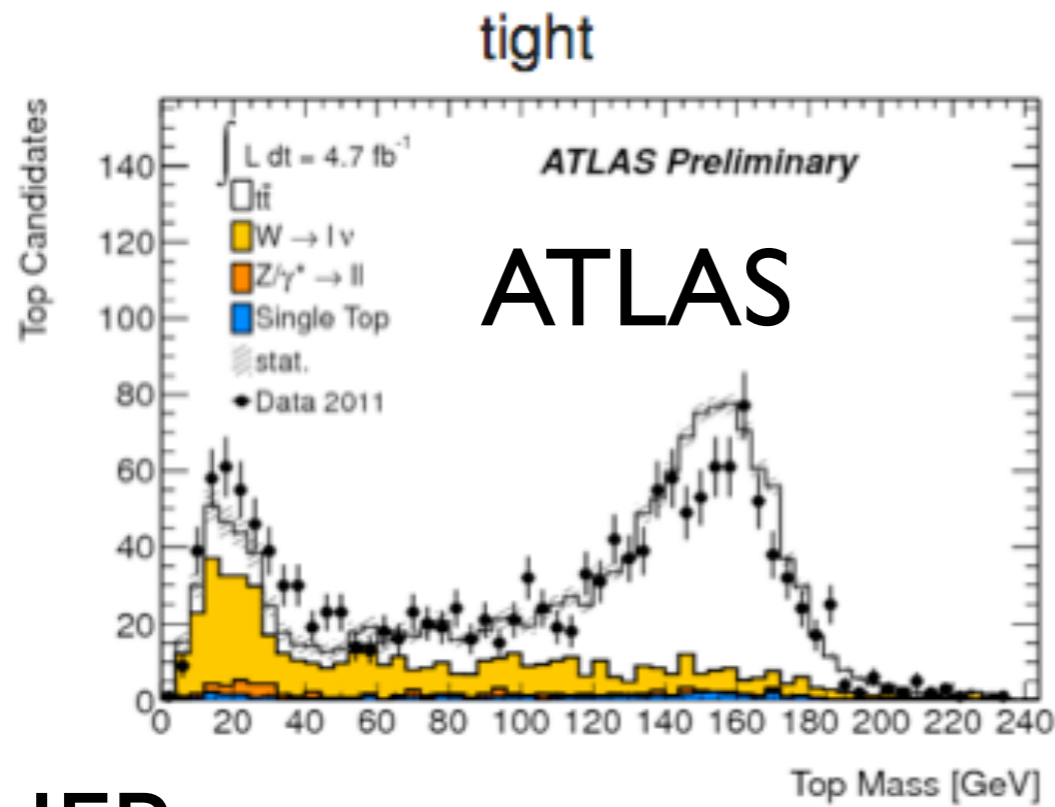
Jet pruning

## ATLAS



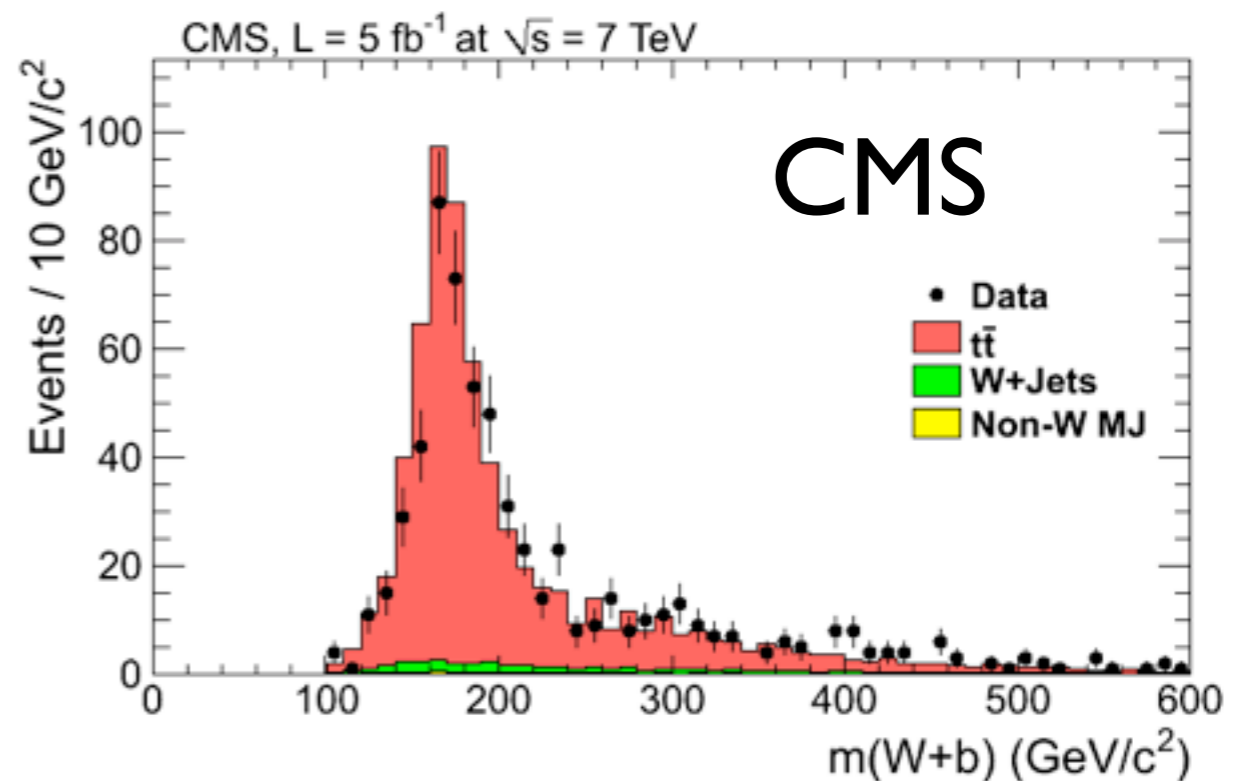
Jet filtering

# Boosted top in data



HEP top tagger

W-tagger + jet



# Boosted Higgs in data

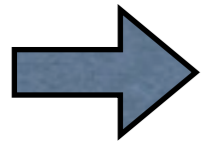


# Boosted Higgs in data

Just kidding

# Outline

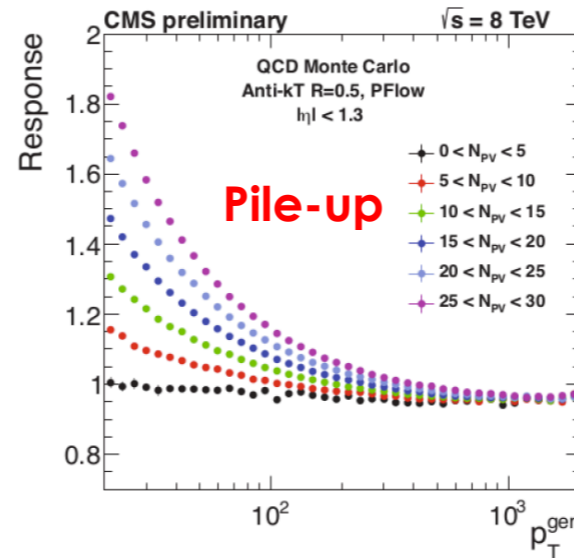
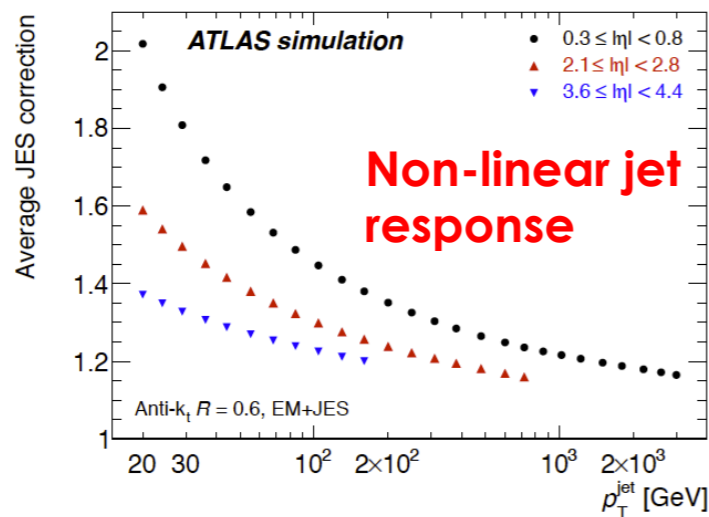
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- ✦ Conclusion



# Pileup

Ariel Schwartzman

## Challenges for jet reconstruction

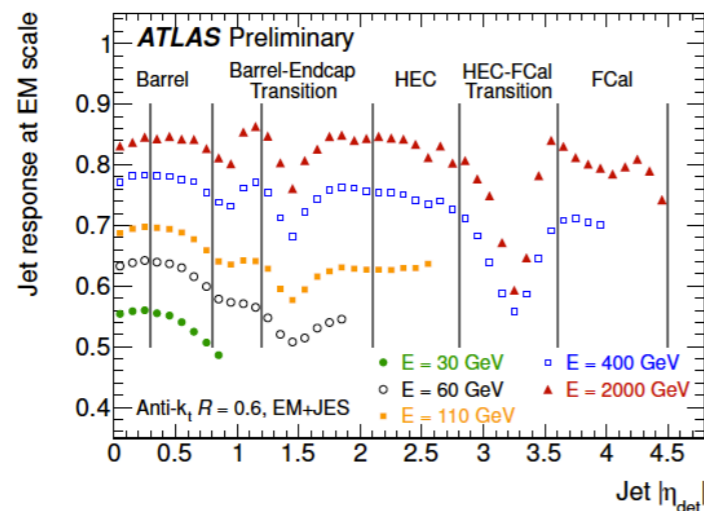


- **Non-compensating calorimeters ( $e/h > 1$ ):**

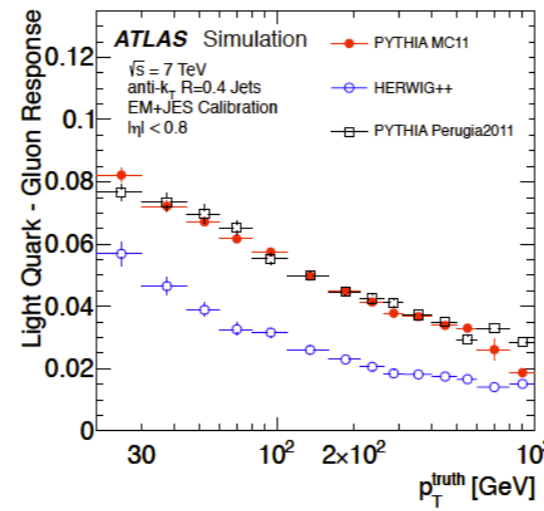
- Non-linear response
- Flavor dependence
- Energy resolution

- **Pile-up:**

- Luminosity-dependent jet performance
- Increased fluctuations (noise term of the jet energy resolution)



**Eta-dependent response**



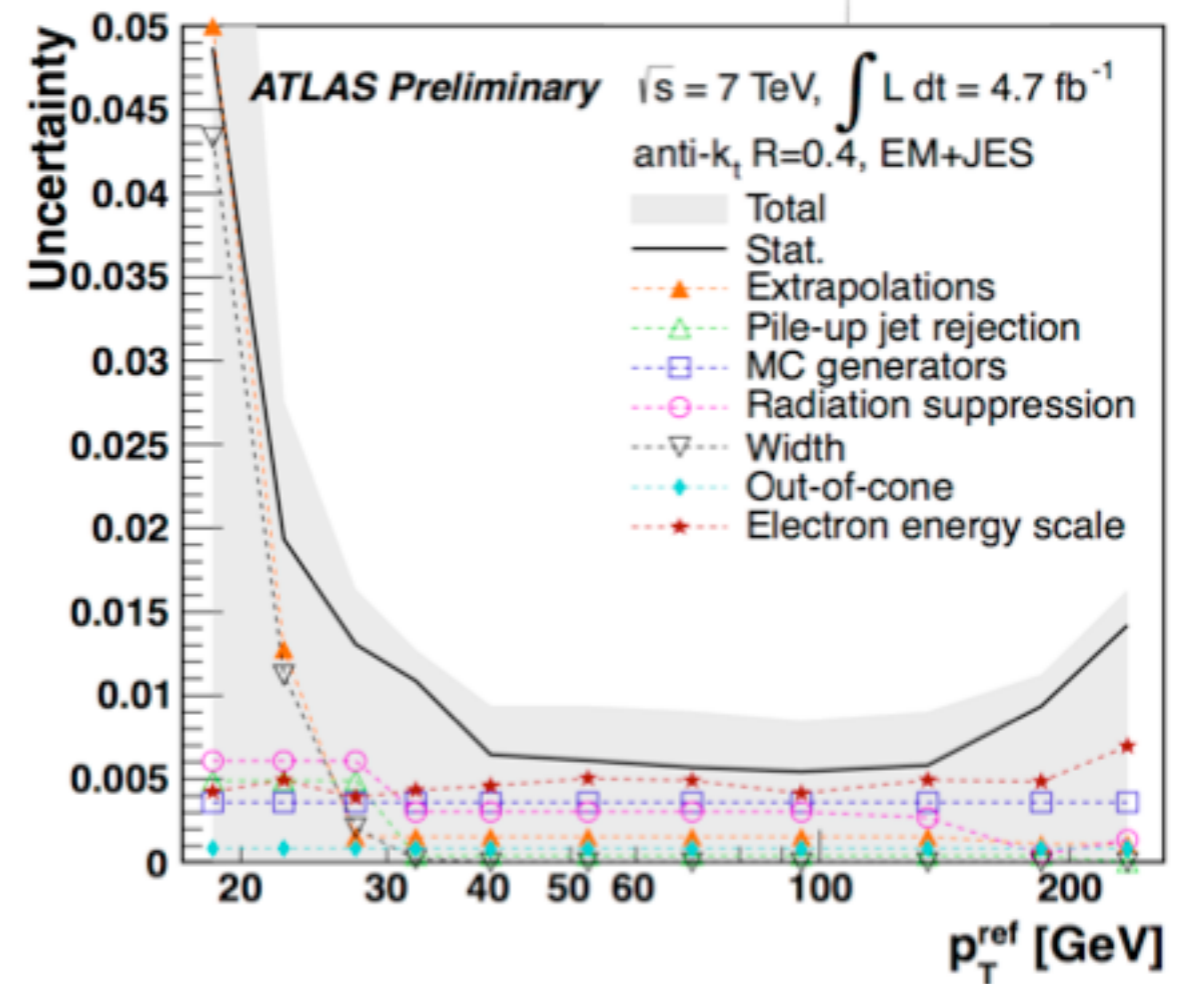
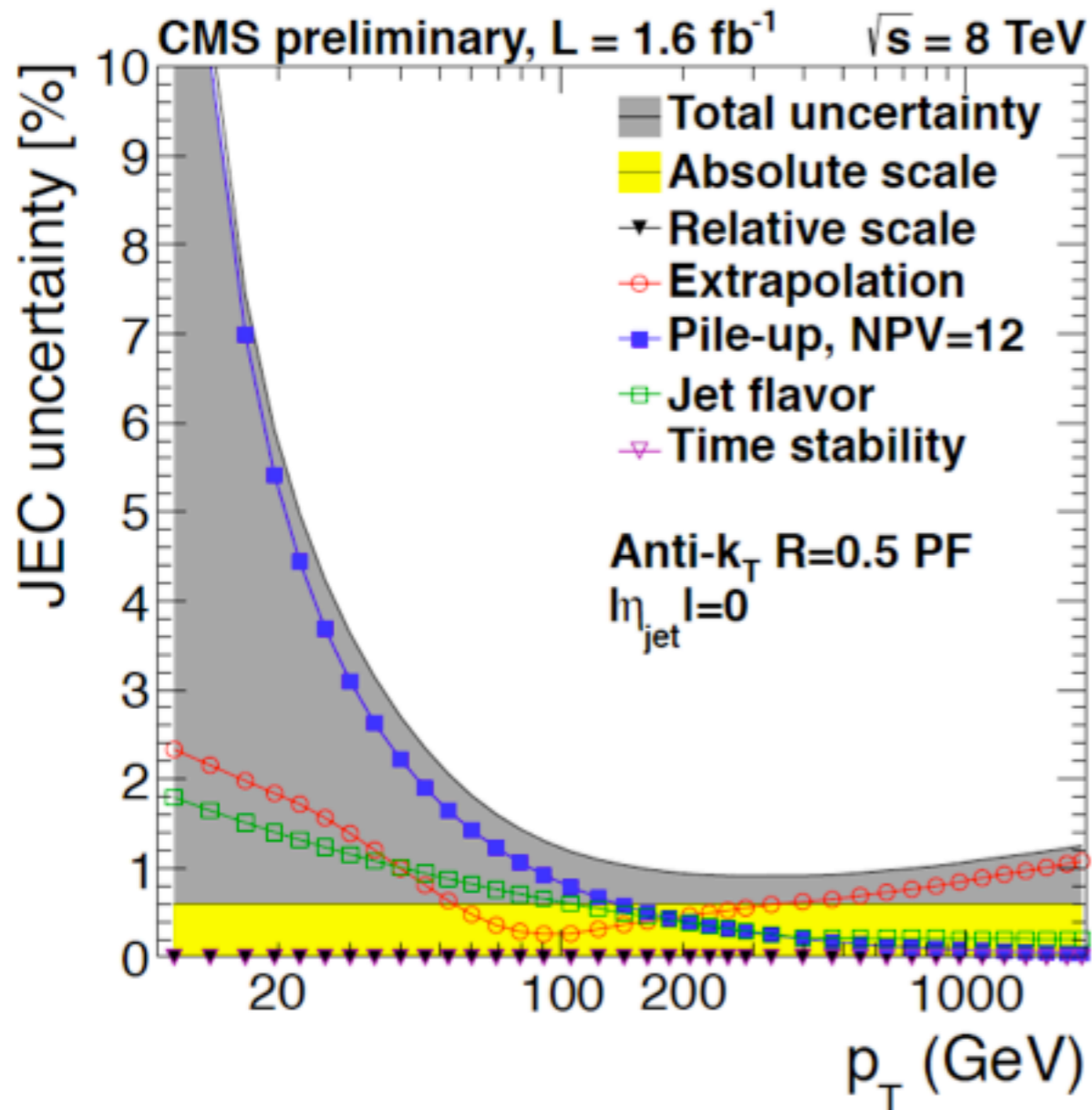
**Flavor dependence**

- **ATLAS/CMS:** different approaches exploiting different detector capabilities

- **Distinguish EM/HAD depositions**

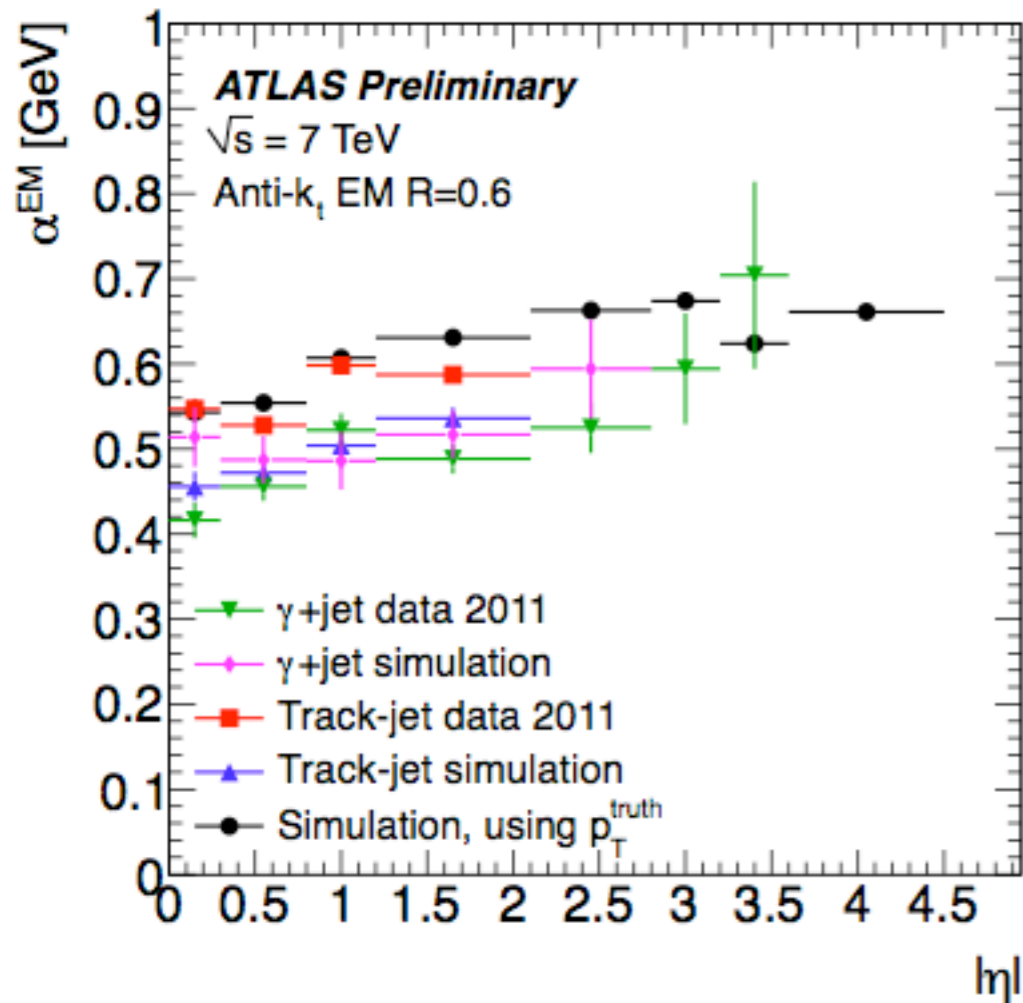
# Pileup

Ariel Schwartzman

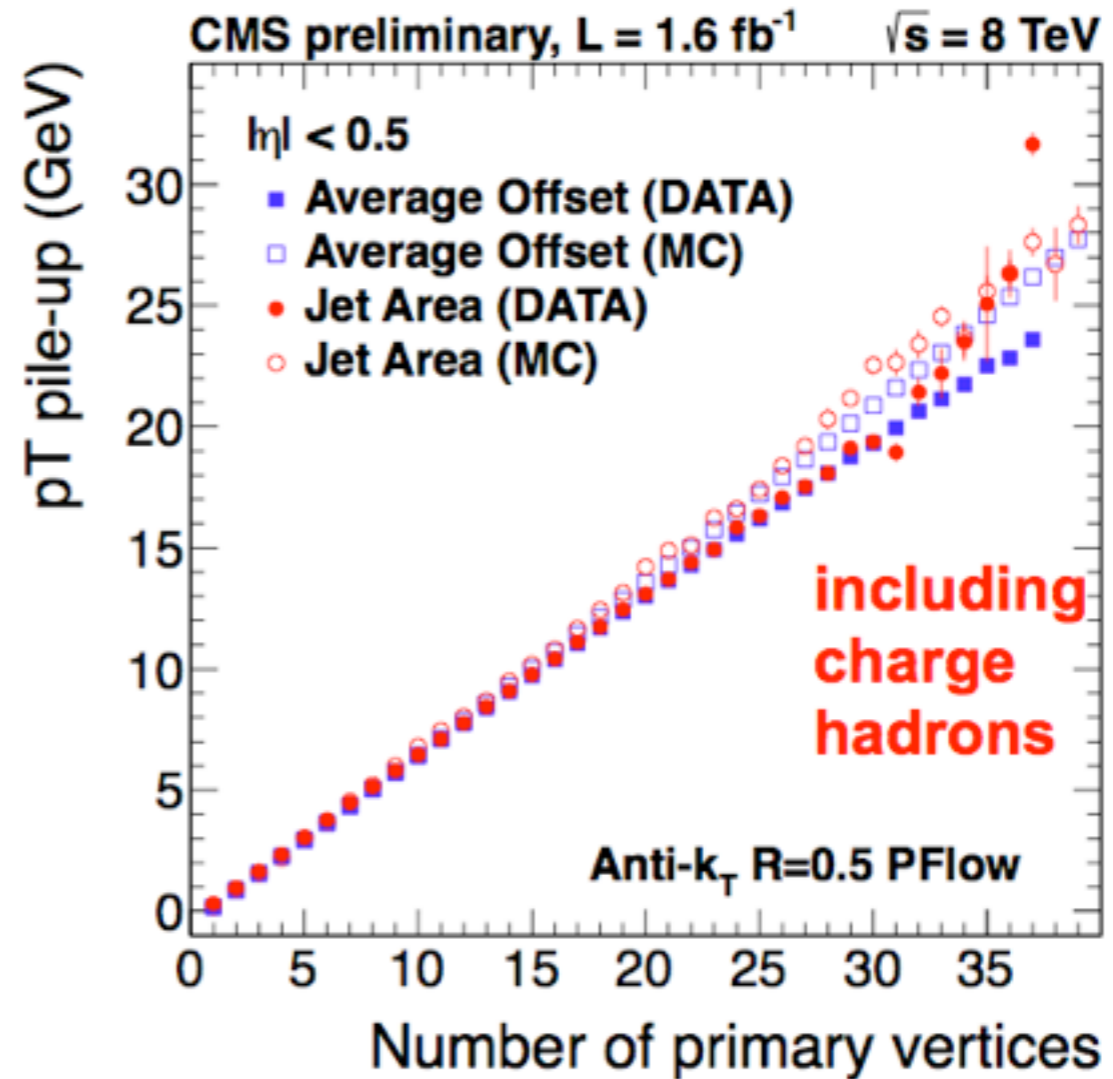


- Both experiments controlling jets to 1% level

# Pileup



John Backus Mayes



Kalanand Mishra

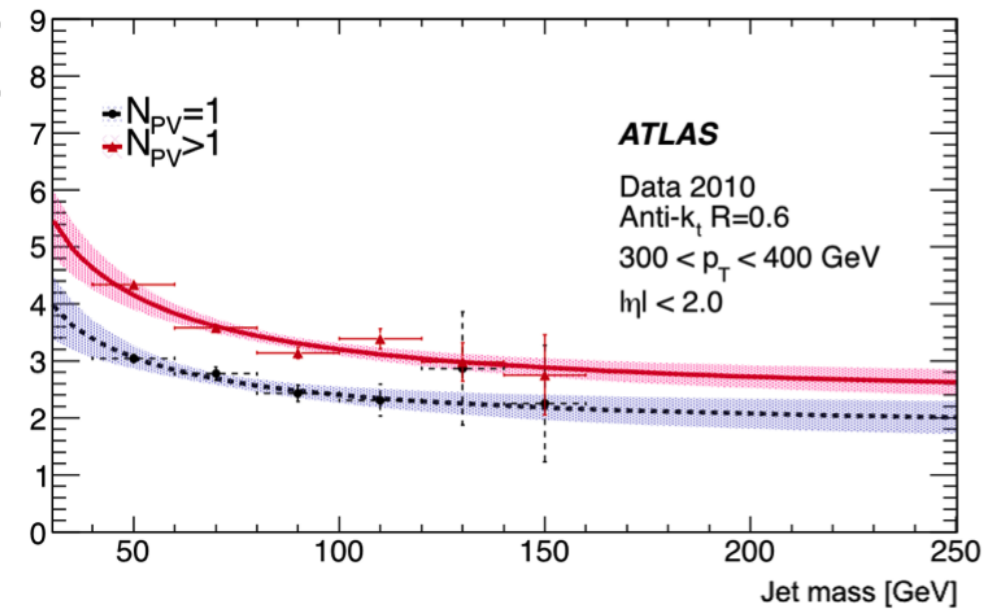
- ✦ Pileup appropriately being handled so far

# Pileup

## Controlling pileup

Lily Asquith

Single vertex events contain only the UE contribution → characterise pileup by comparing events with single and multiple vertices.



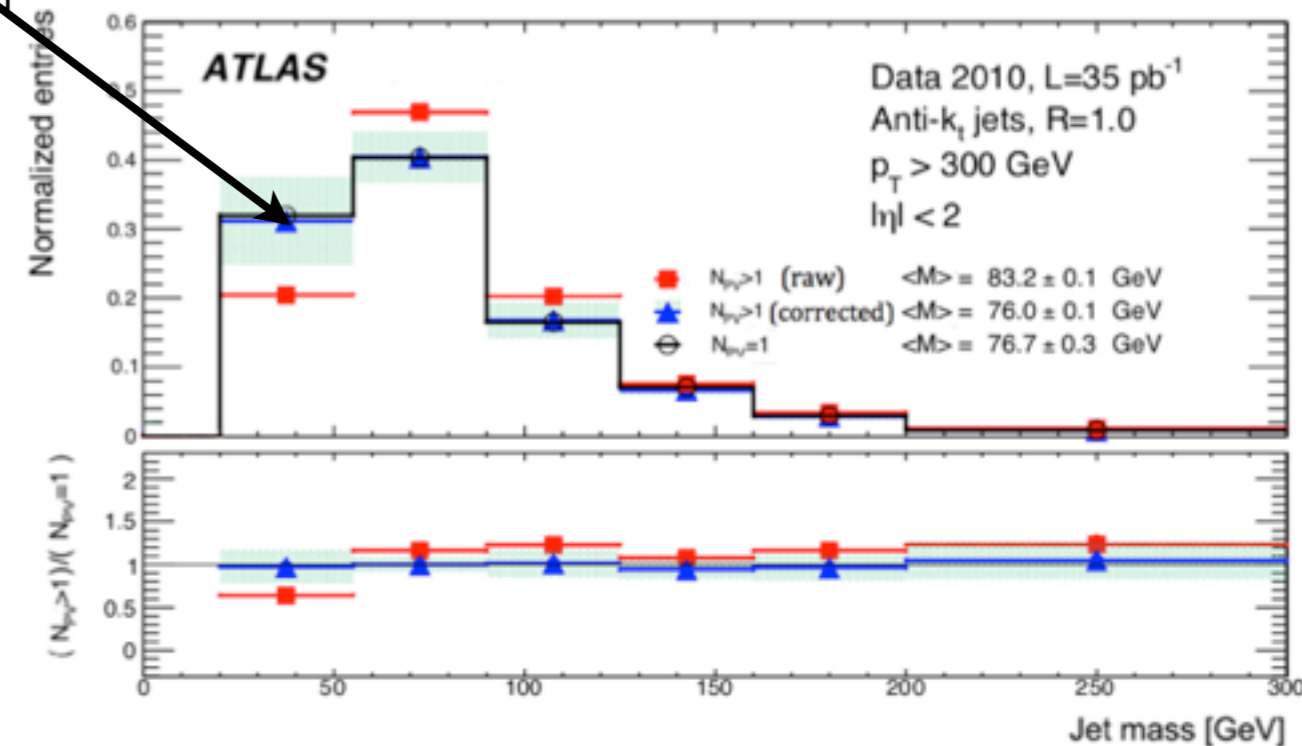
[arxiv:1206.5369](https://arxiv.org/abs/1206.5369)

$$\Delta M = p_{0M} + \frac{p_{1M}}{M}$$

Can then find the scaling of e.g.  $\Delta M$  with  $R$  → obtain subtractions for  $R=1$  jets.

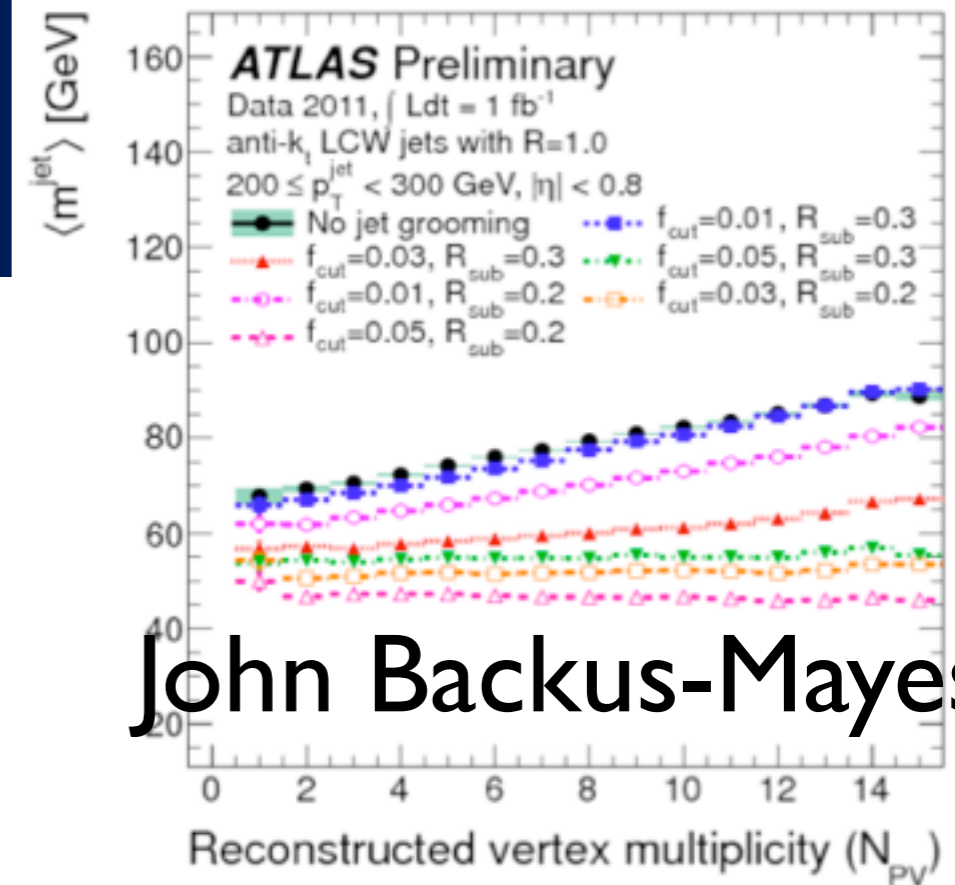
expected measured

$$\Delta M : p_{iM} \sim R^4 \quad (R^{3.5})$$

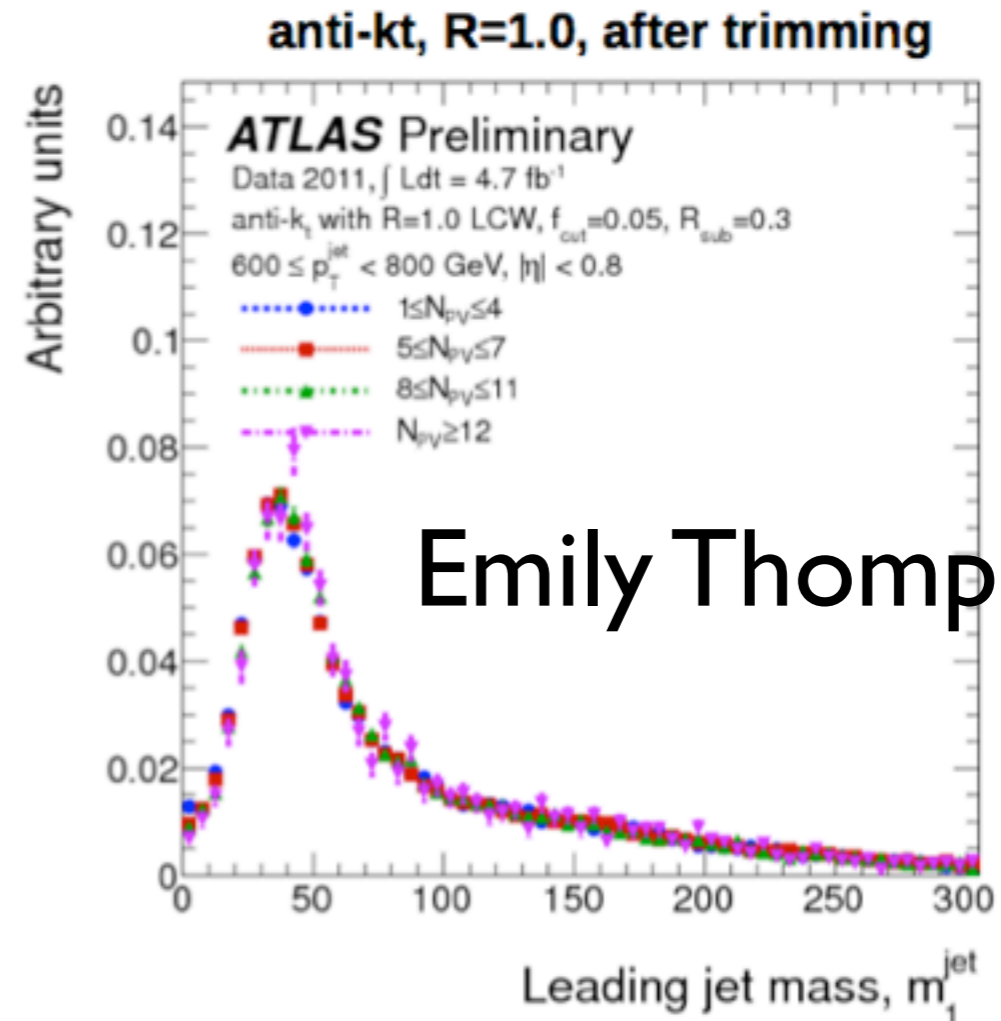
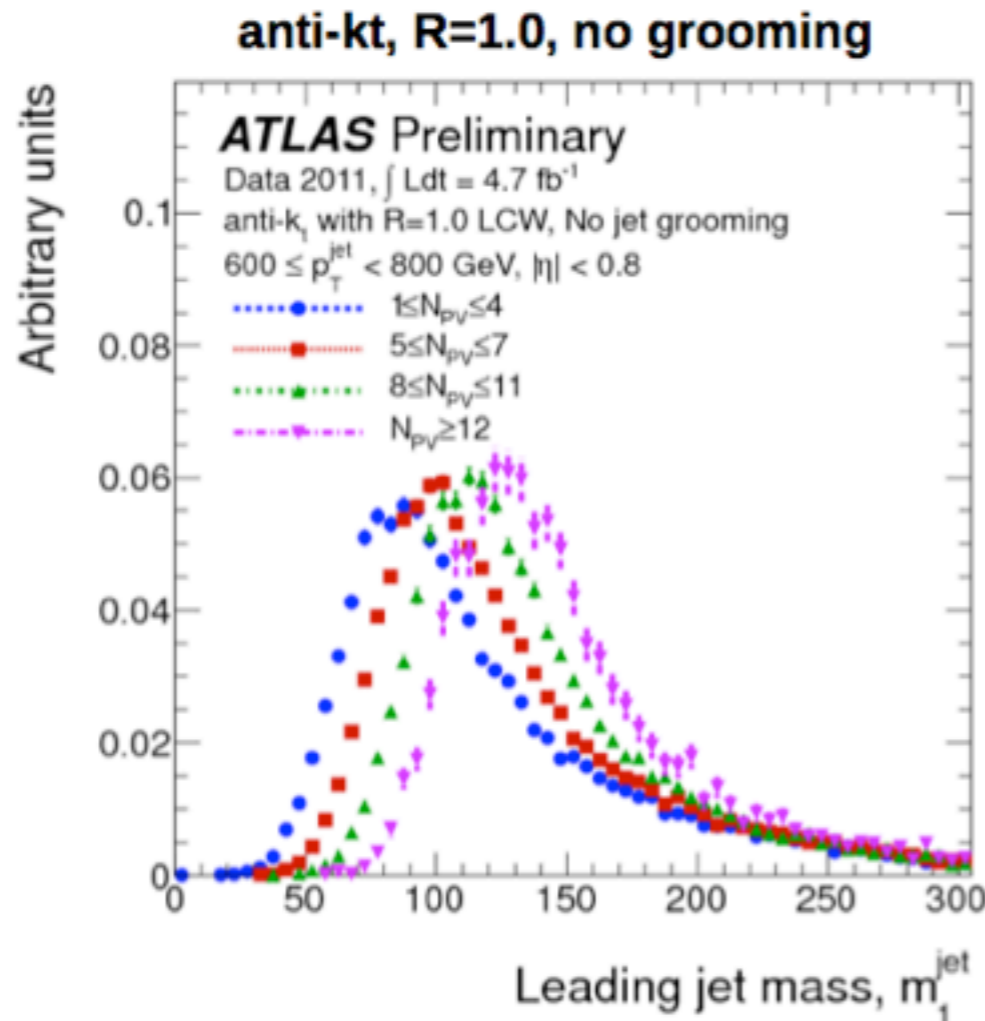


# Pileup

- ✦ Grooming helps pileup dependence dramatically!



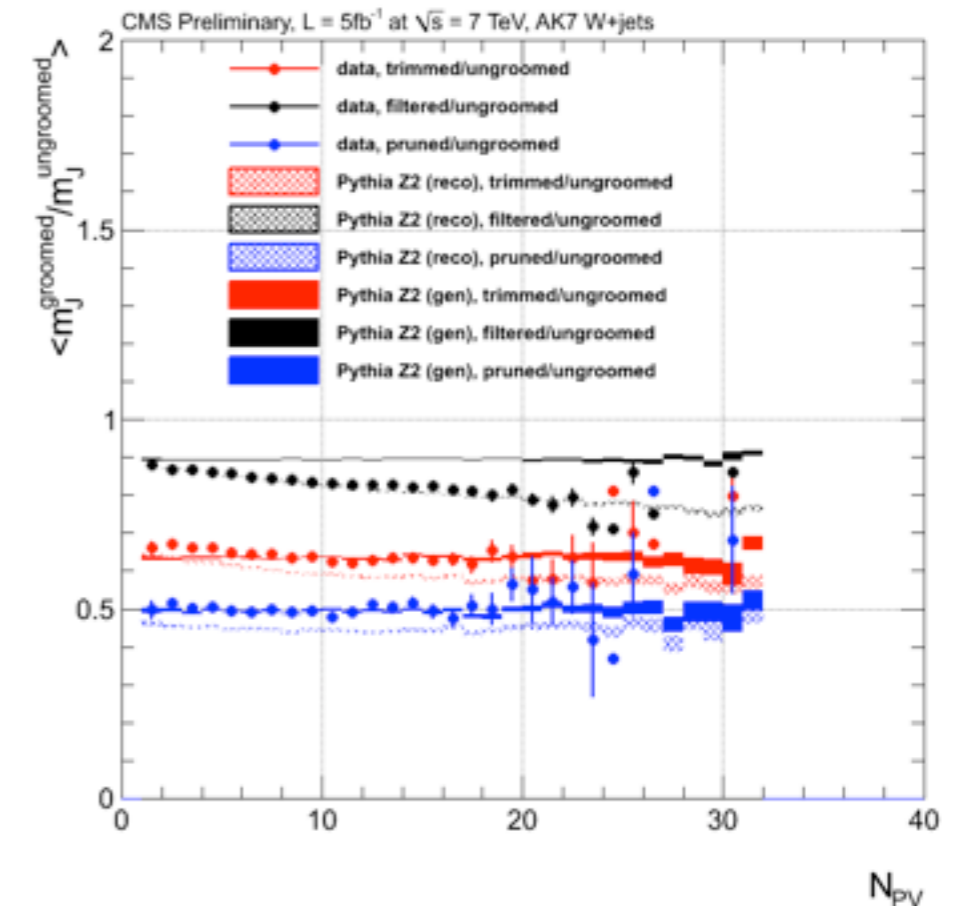
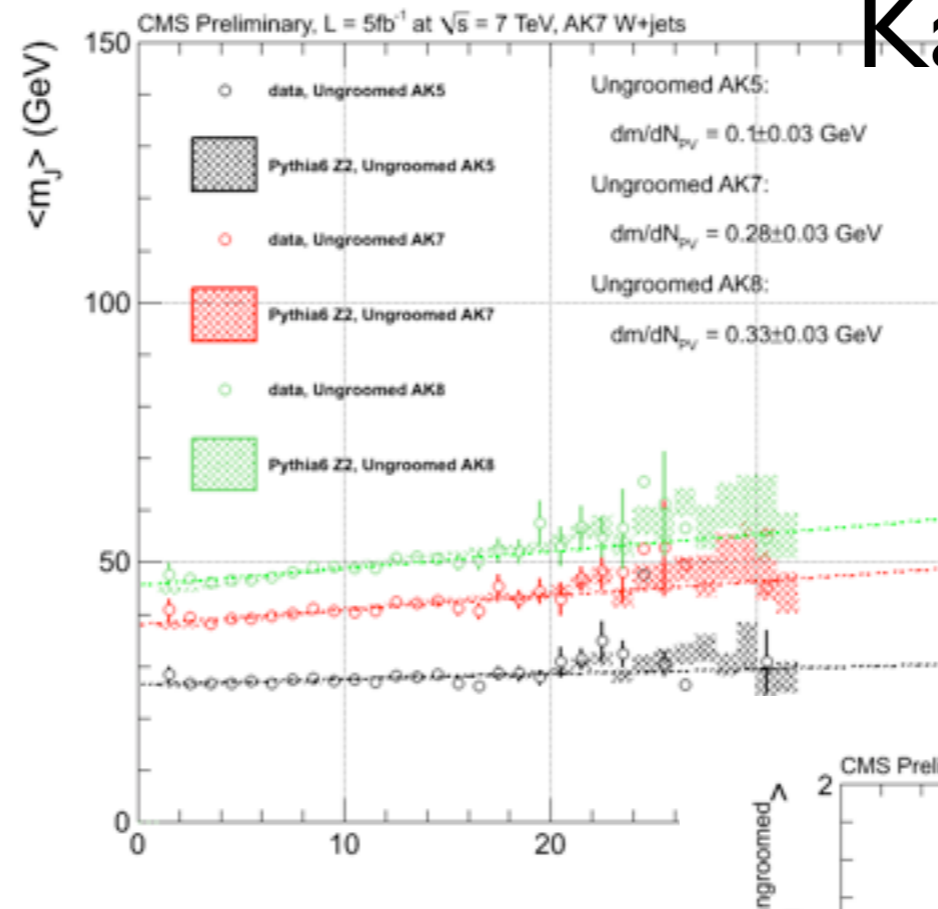
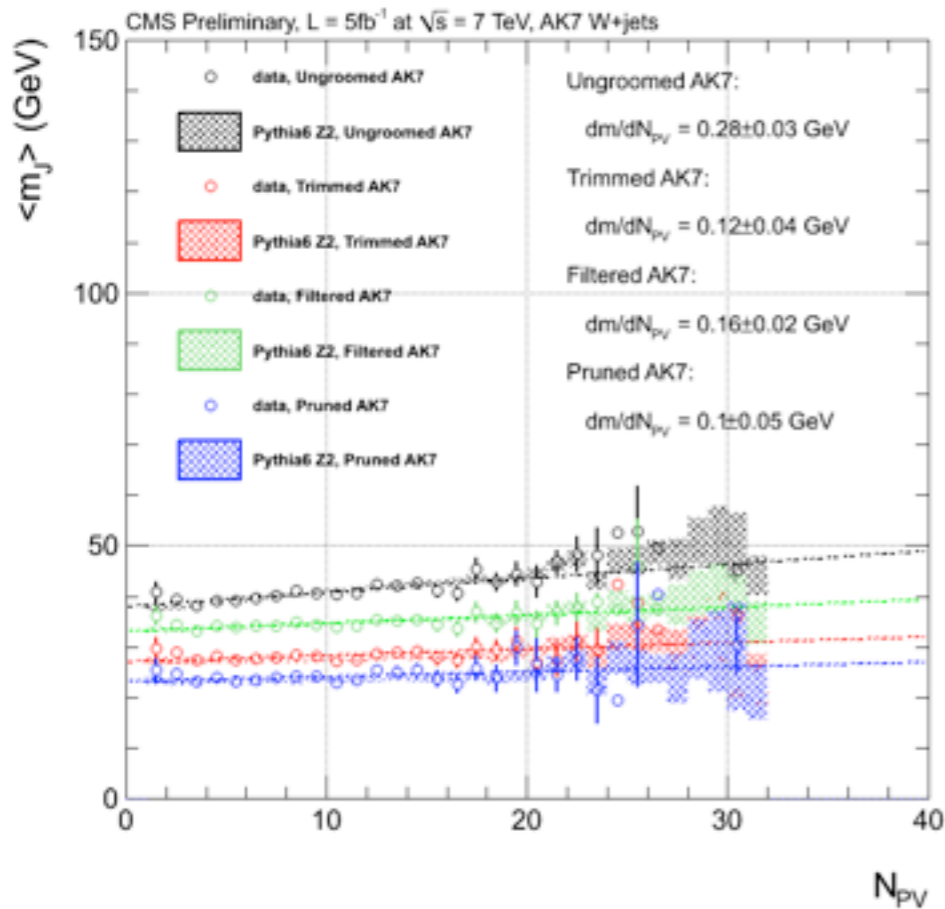
John Backus-Mayes



Emily Thompson

# Pileup

Kalanand Mishra



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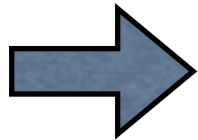


# Pileup

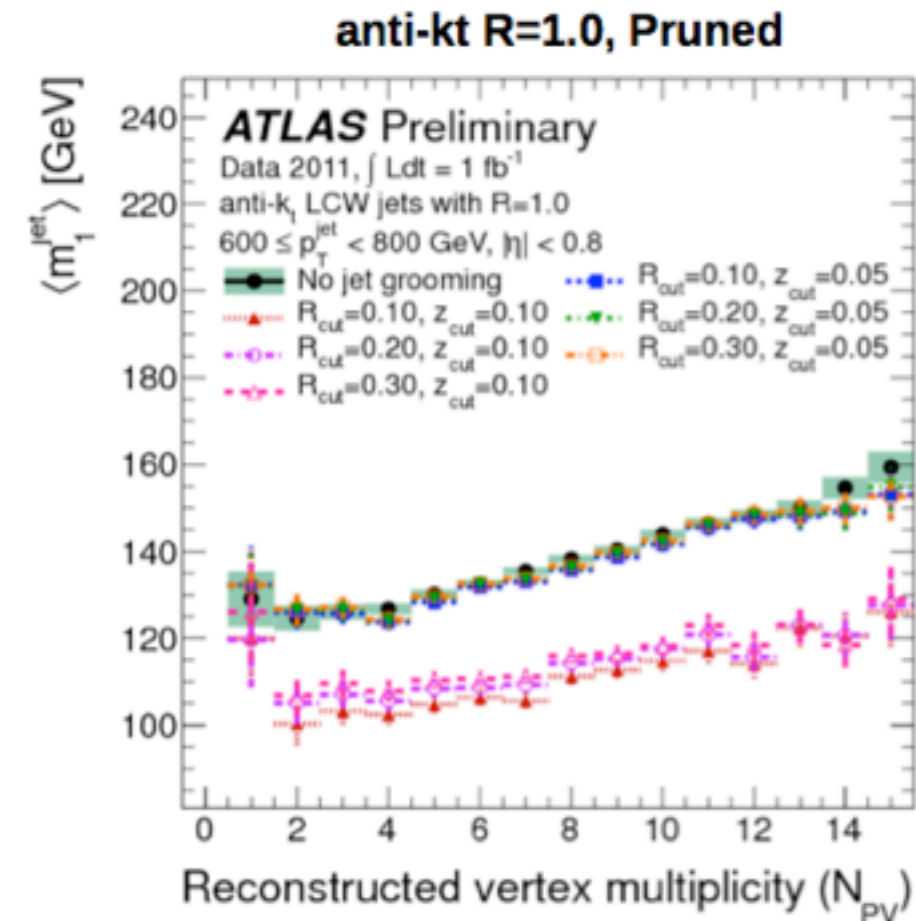
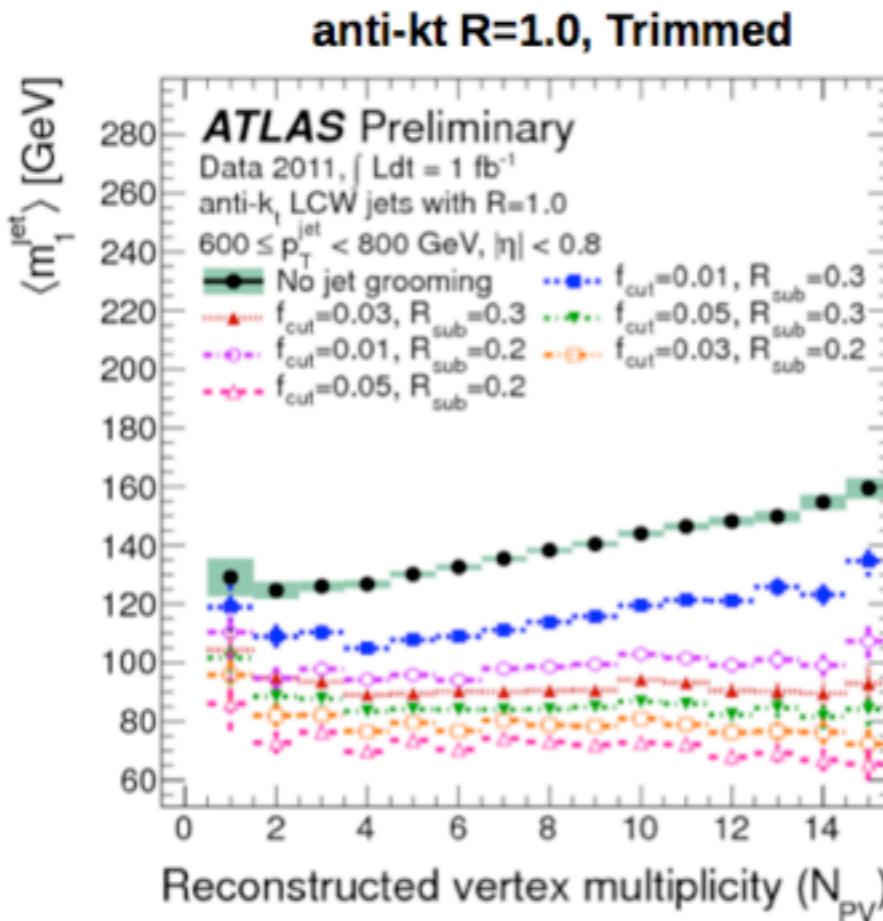
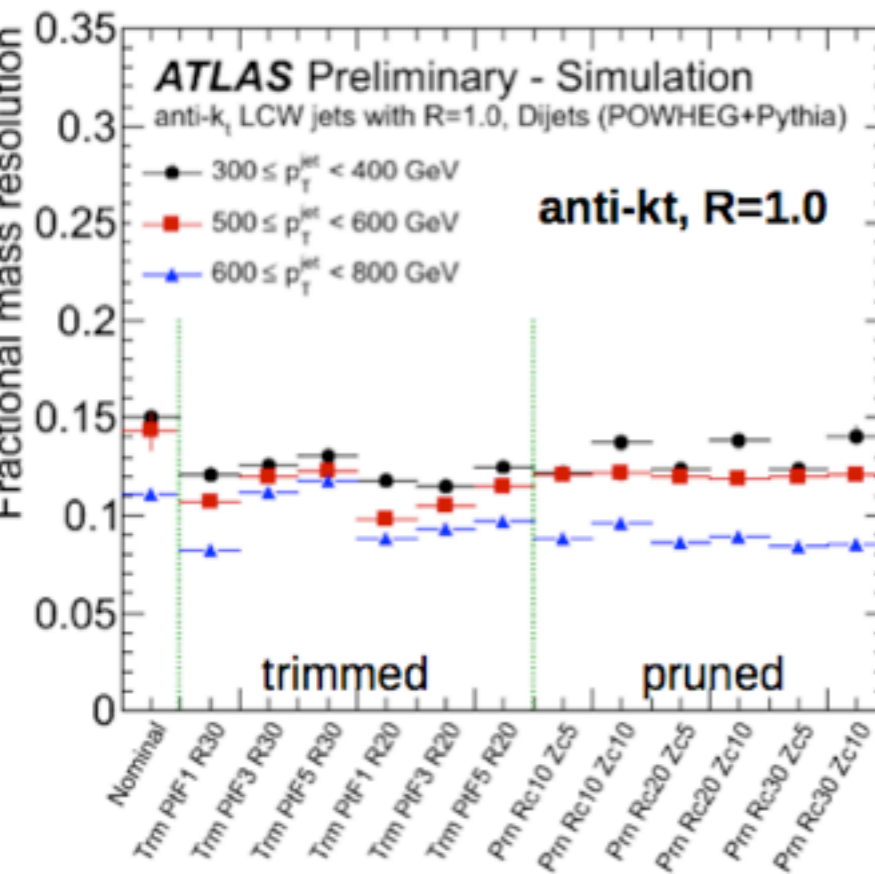
- ✦ Take-home message:
  - Pileup is hard, but so far, we have it covered
  - Grooming helps enormously!
- ✦ But, continuous, arduous battle!

# Outline

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# ATLAS : Grooming studies

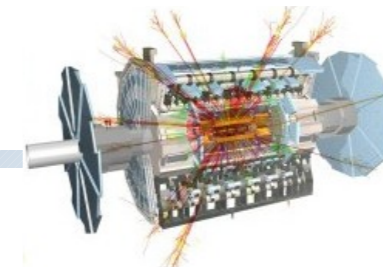


Emily Thompson

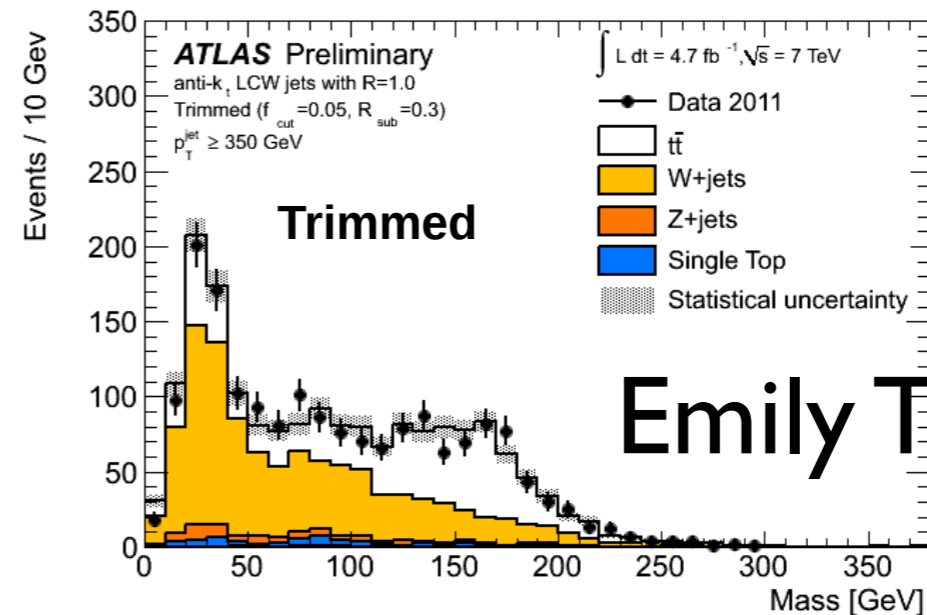
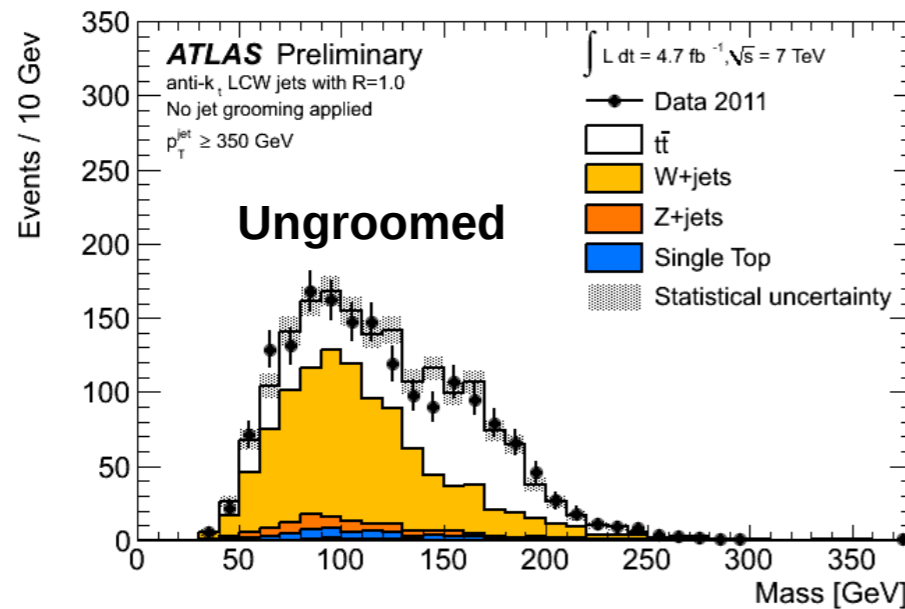
- ✦ Exploring parameter space of the taggers wonderfully

# ATLAS : Effect of grooming in top

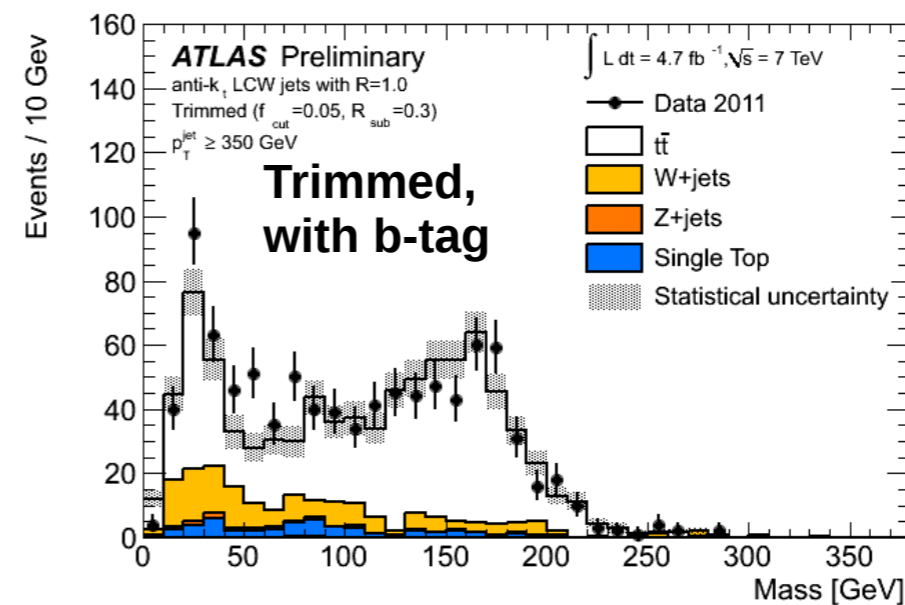
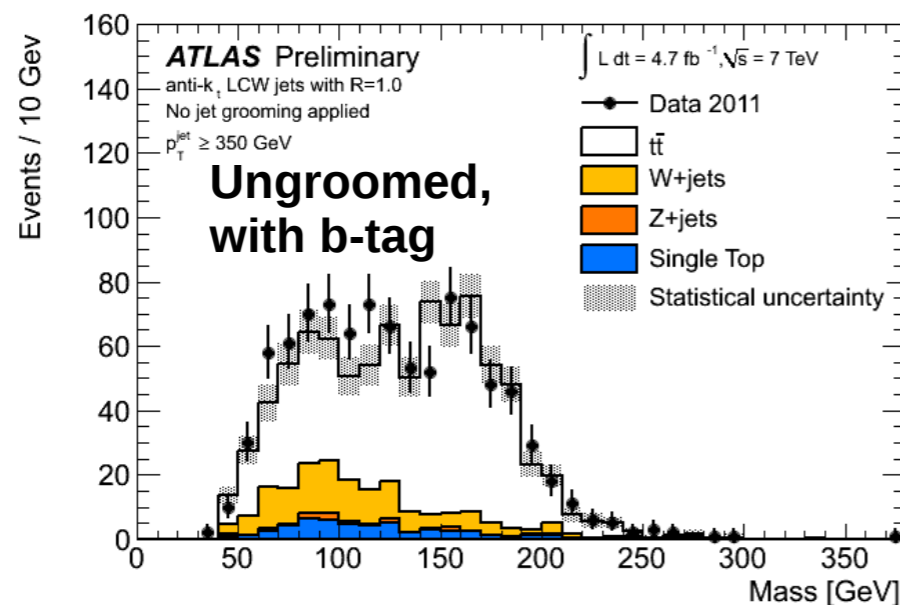
## SM ttbar events in data



- **Jet Mass** (leading  $p_T$  anti-kt R=1.0 jet,  $p_T > 350$  GeV)

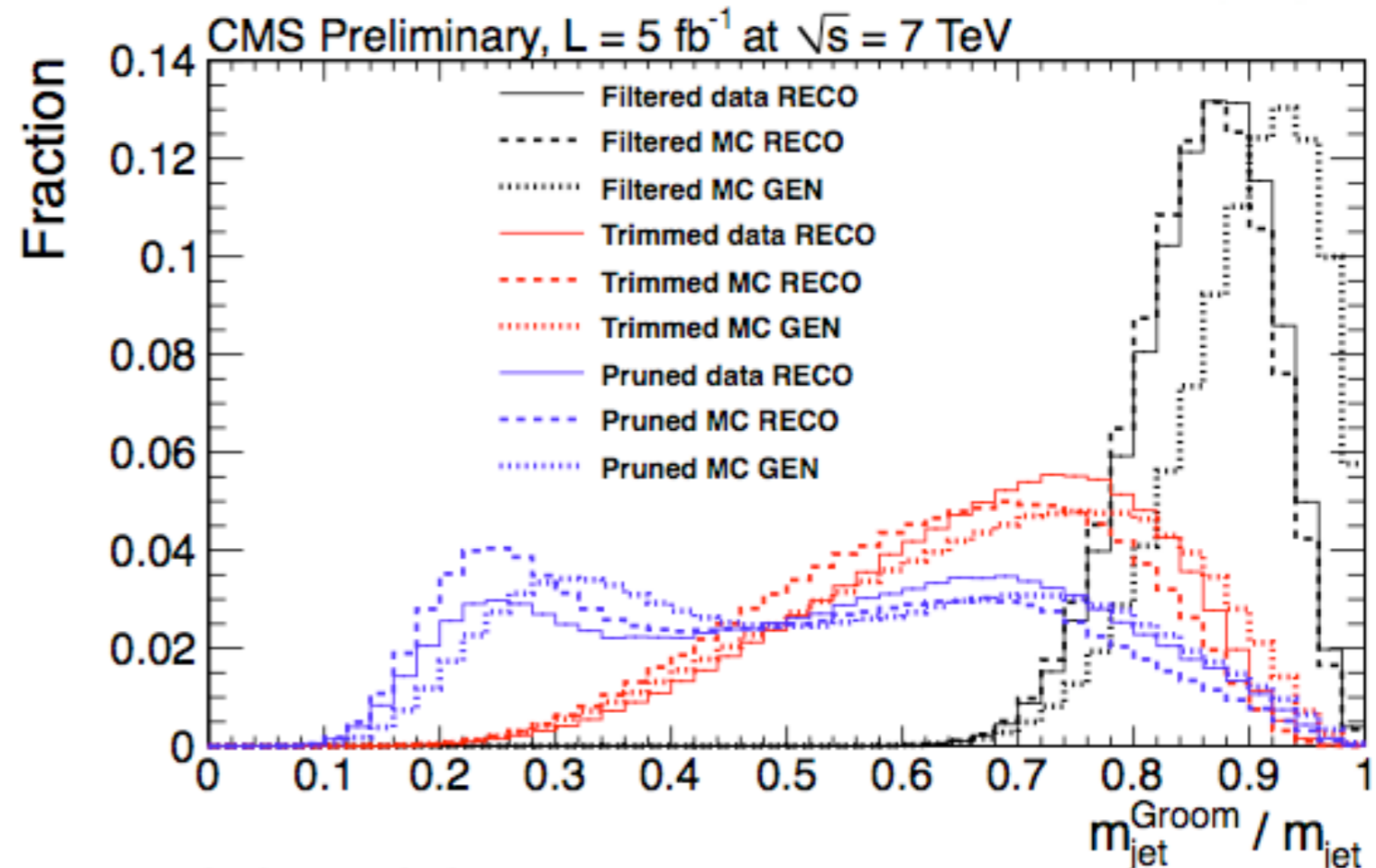


Emily Thompson

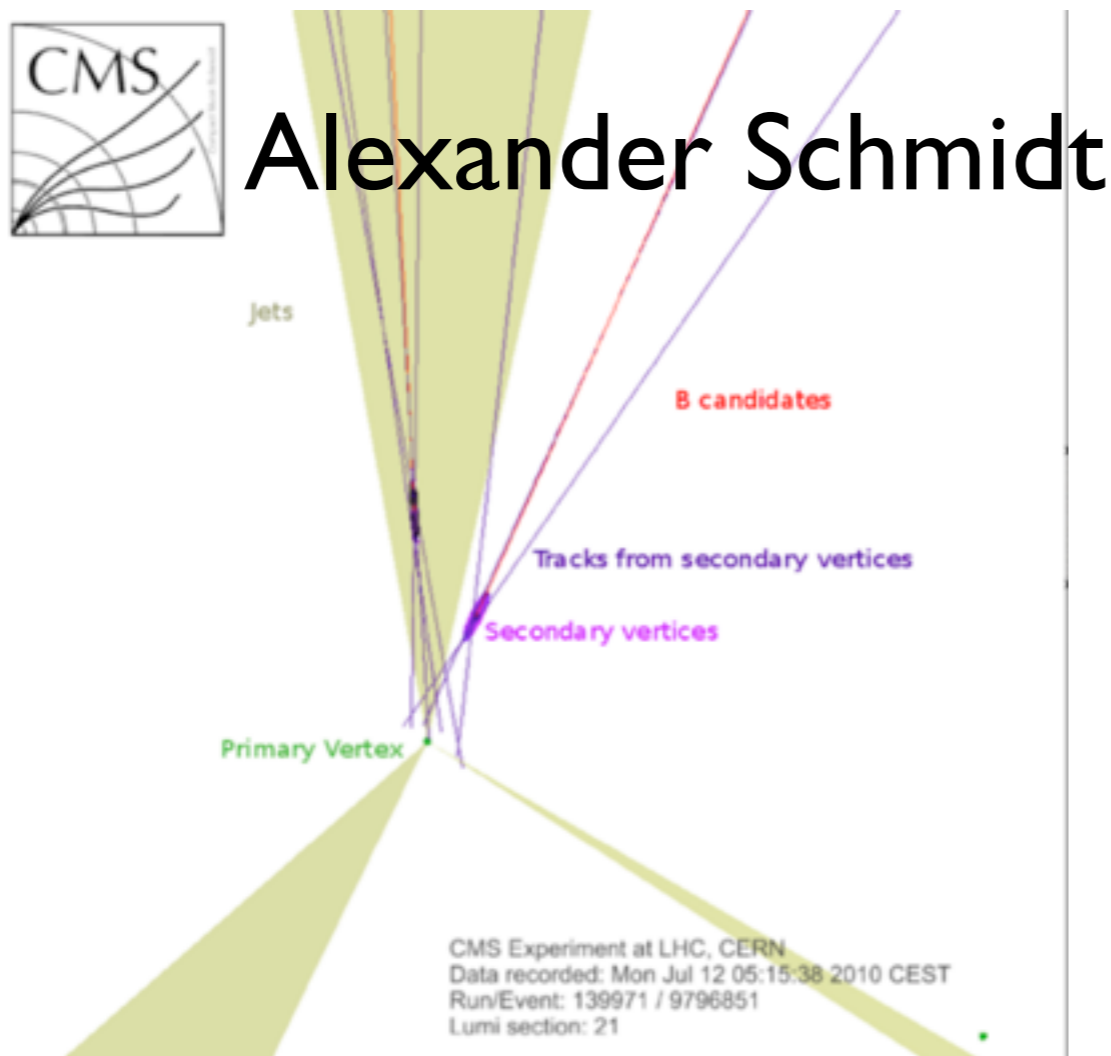


# CMS : Grooming studies

- ✦ Using default algorithm parameters, here are the “working points”:
  - Most aggressive: Pruning
  - Moderately aggressive: Trimming
  - Most conservative: Filtering
- ✦ Different analyses will want different “working points”, can also tune with algorithm parameters

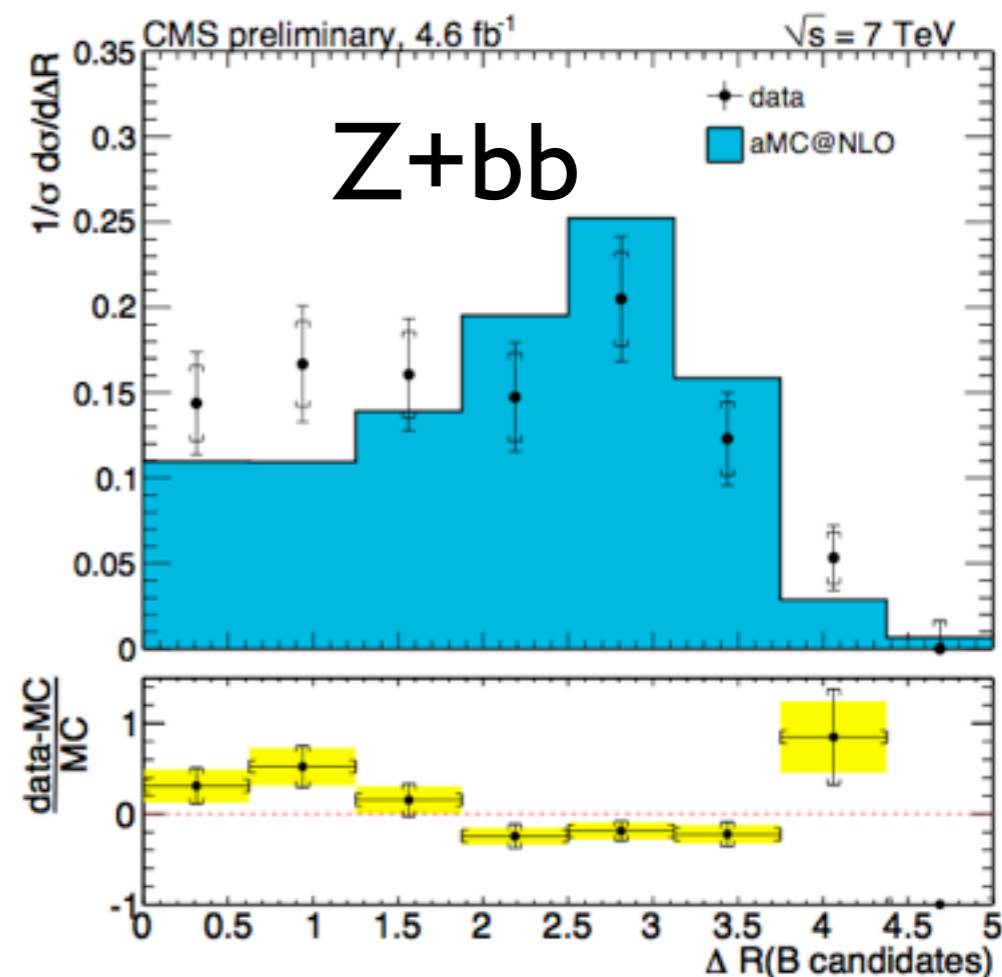
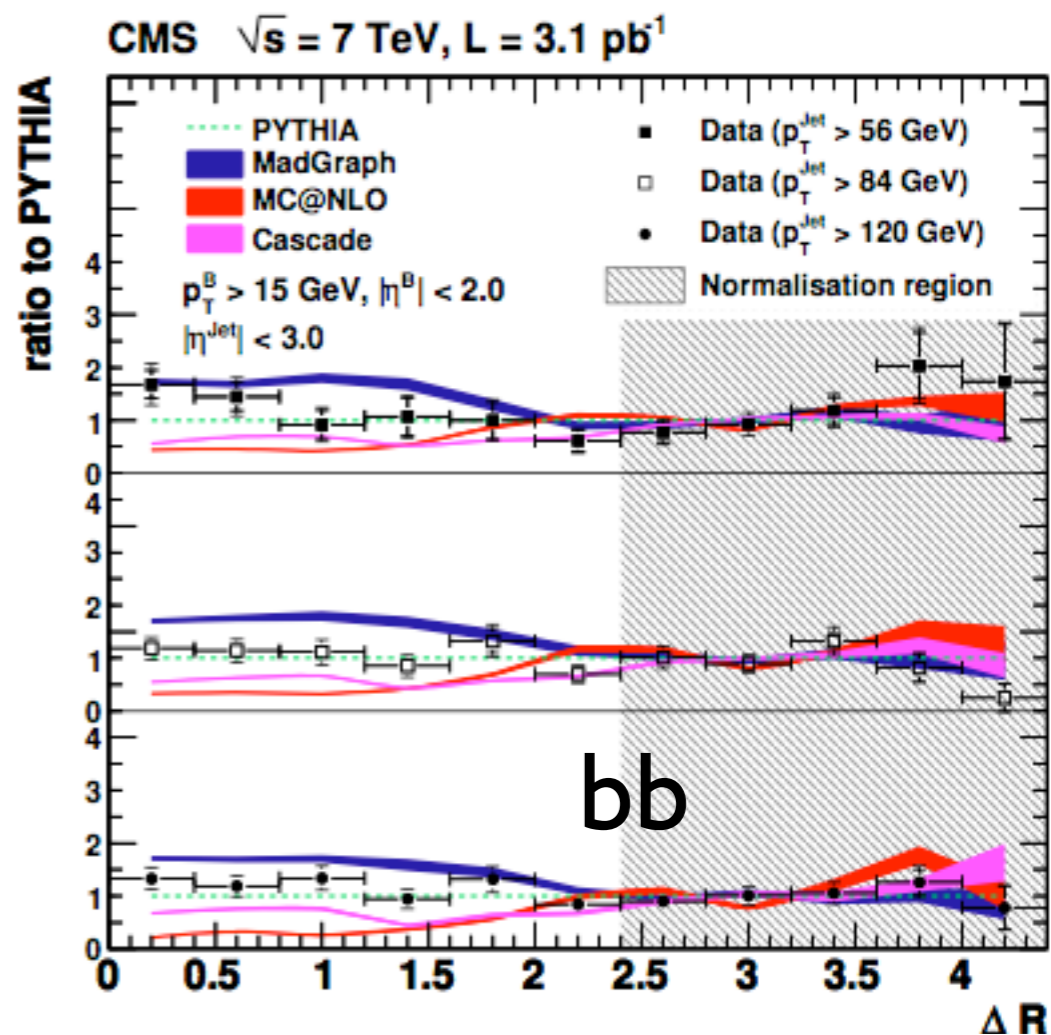


# CMS : B-tagging



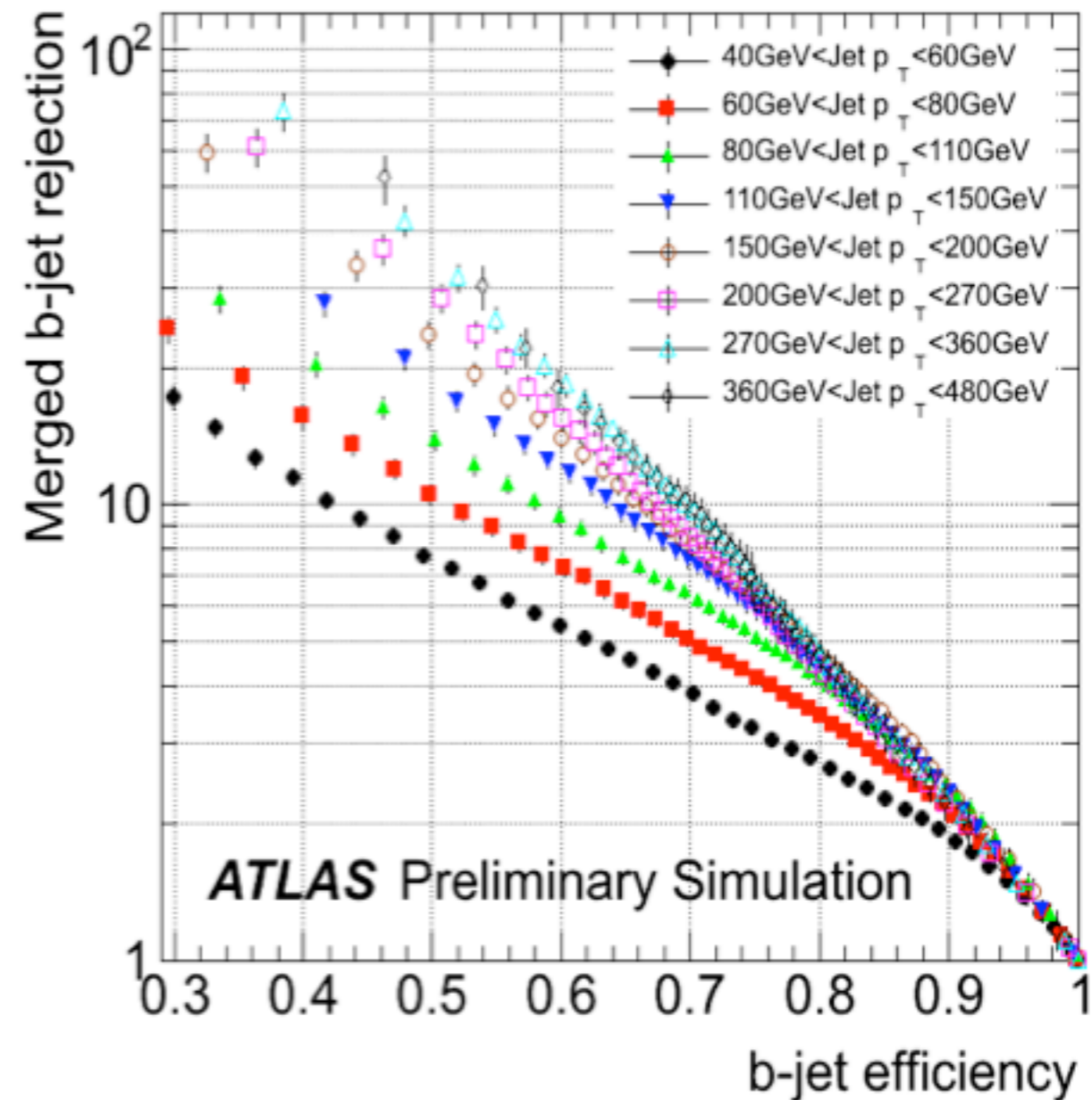
Alexander Schmidt

- ✦ Experimental tools available to unleash upon merged b-jets
- ✦ Theoretical tools in progress also
- ✦ Stay tuned here!



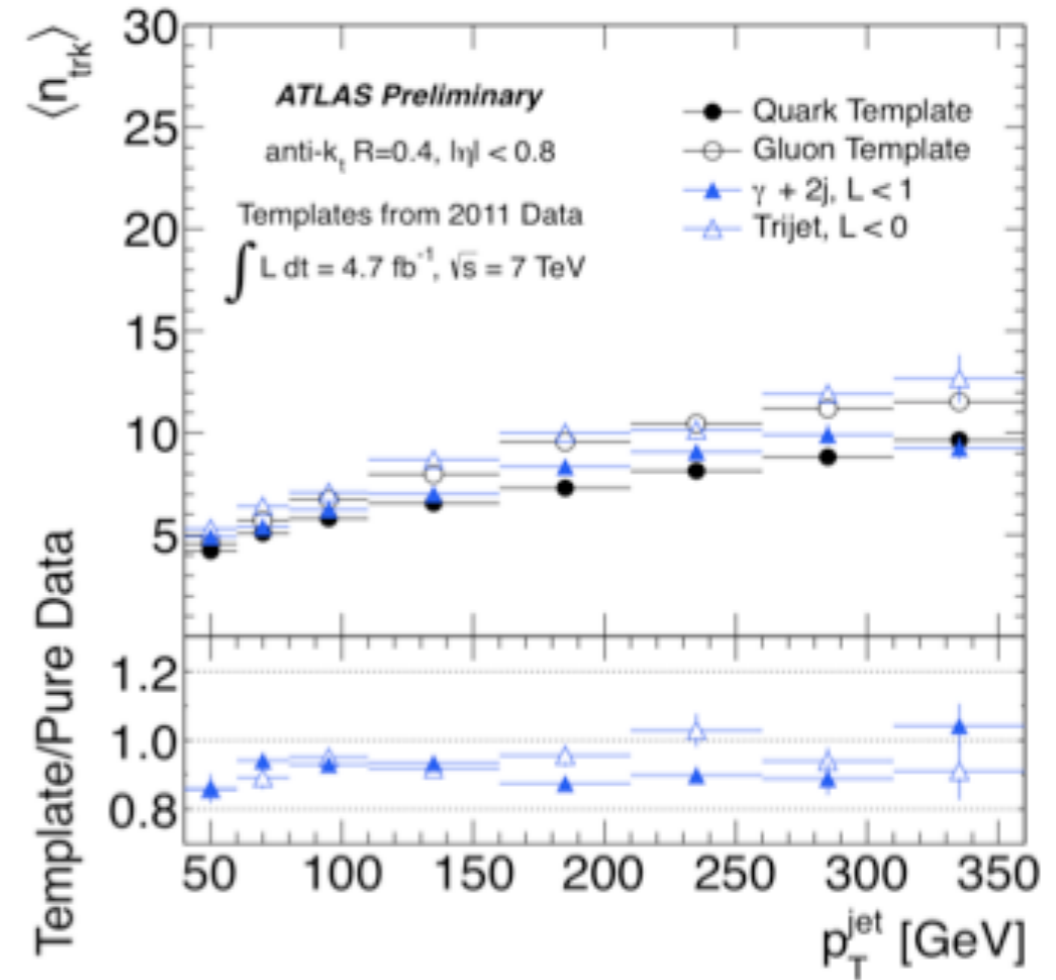
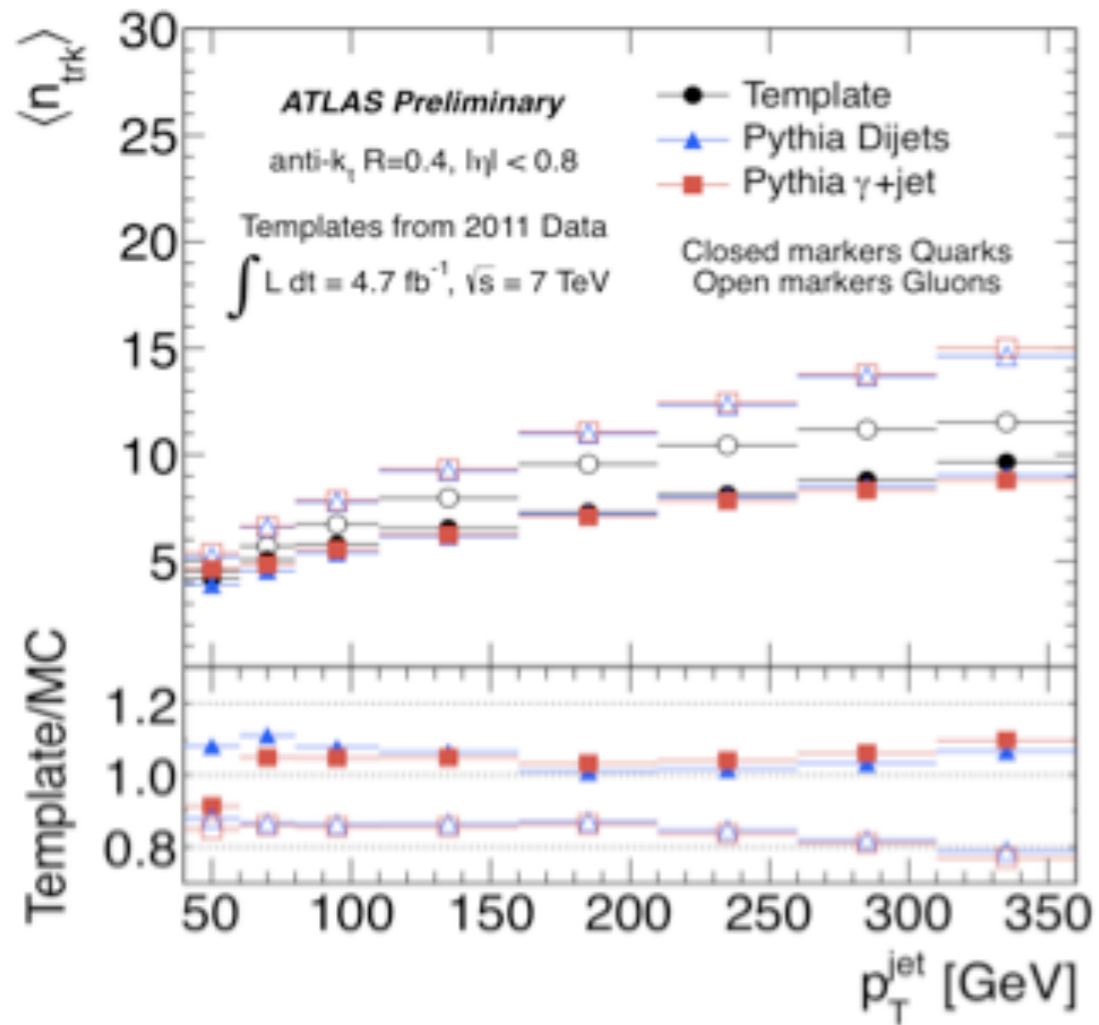
# ATLAS : Merged b-jets

- Slightly different context, but proof of principle works



Maria Laura Gonzalez Silvia

# ATLAS : Quarks vs Gluons



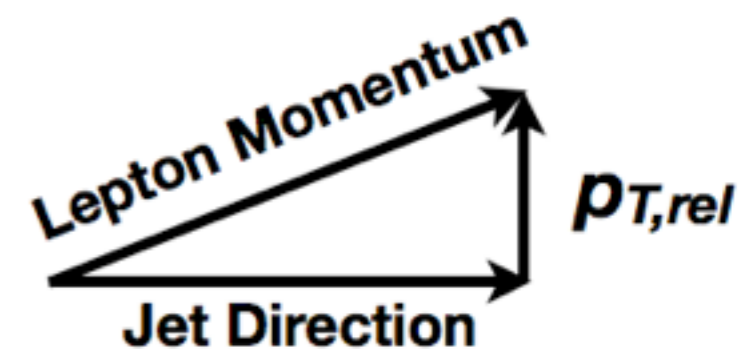
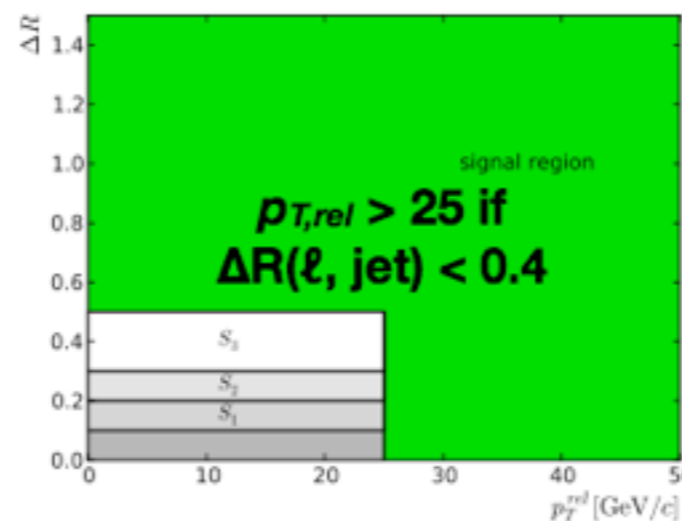
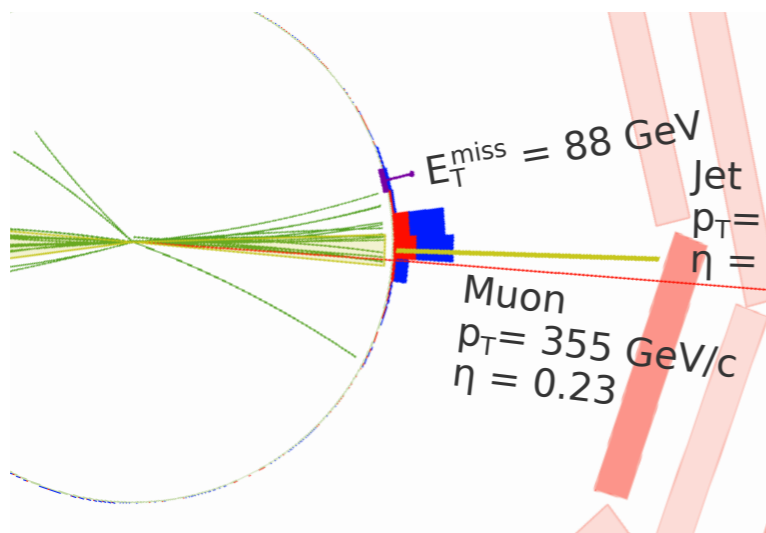
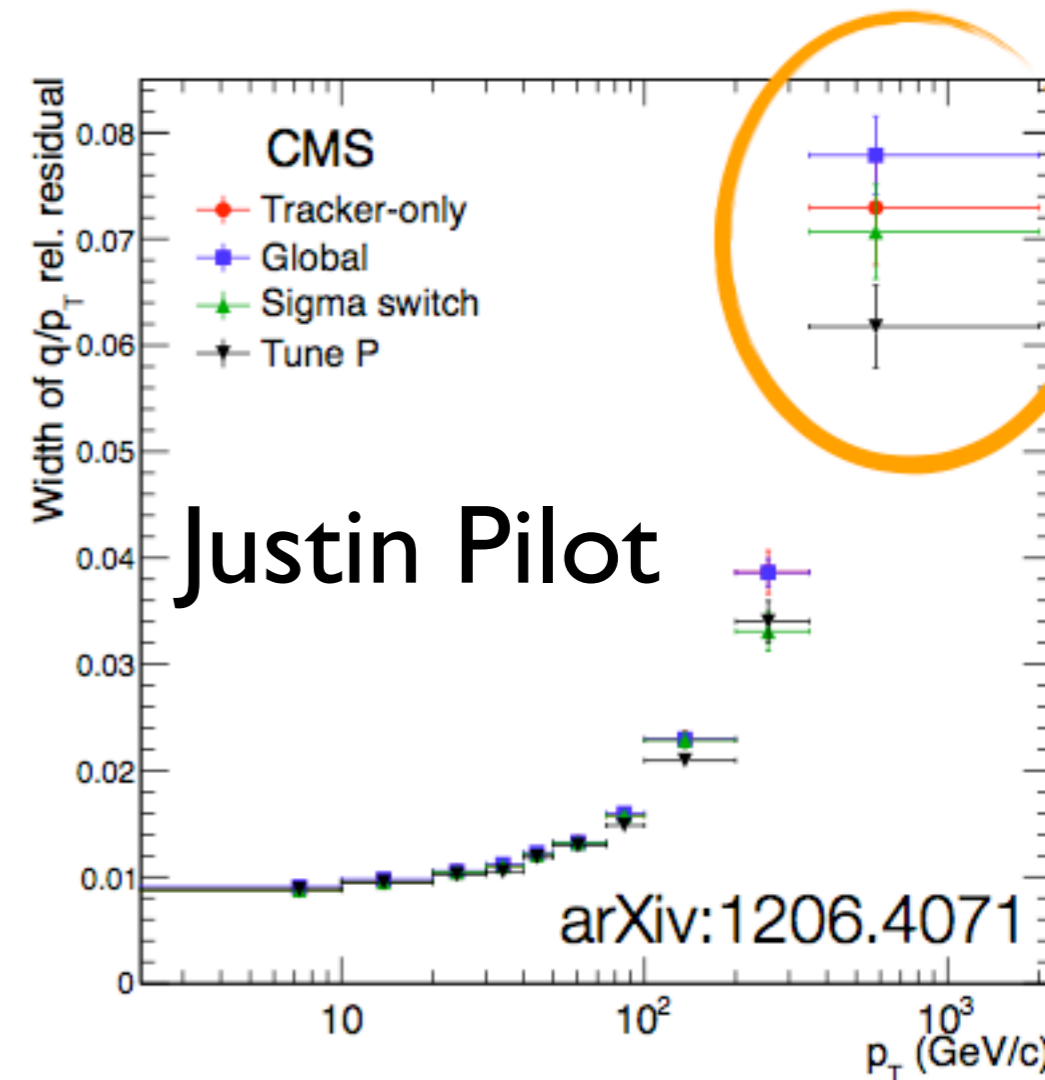
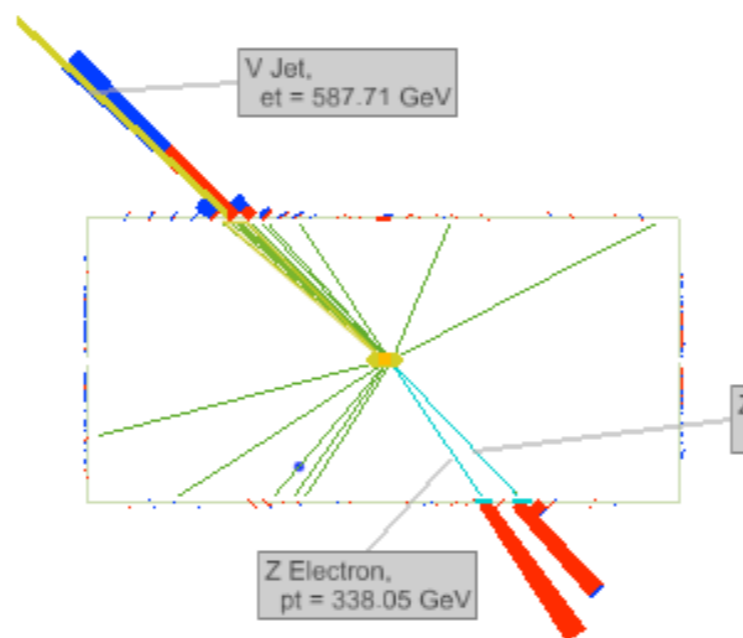
- ✦ Exploiting jet structure already paying off here!



# Leptons from boosted objects

## Isolation

- ▶ Special consideration is required when using lepton isolation in the boosted regime
- ▶ For Z decays to lepton pairs, subtract the other lepton from the isolation cone
  - ▶ Make sure they are from the same interaction!
- ▶ Another example is leptons merging with jets, as in boosted top decays
  - ▶ Custom isolation cuts required



# Studies on tools

- ✦ Take-home message :
  - Work already very advanced
  - Time to start unleashing these very broadly!

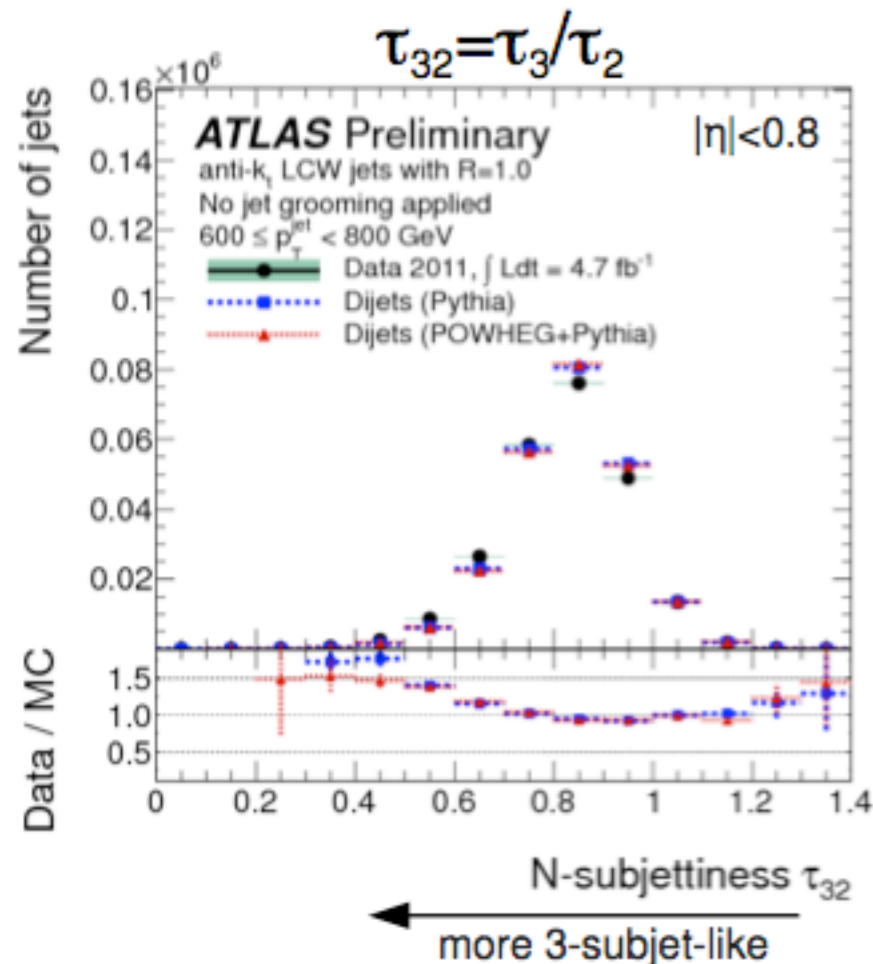
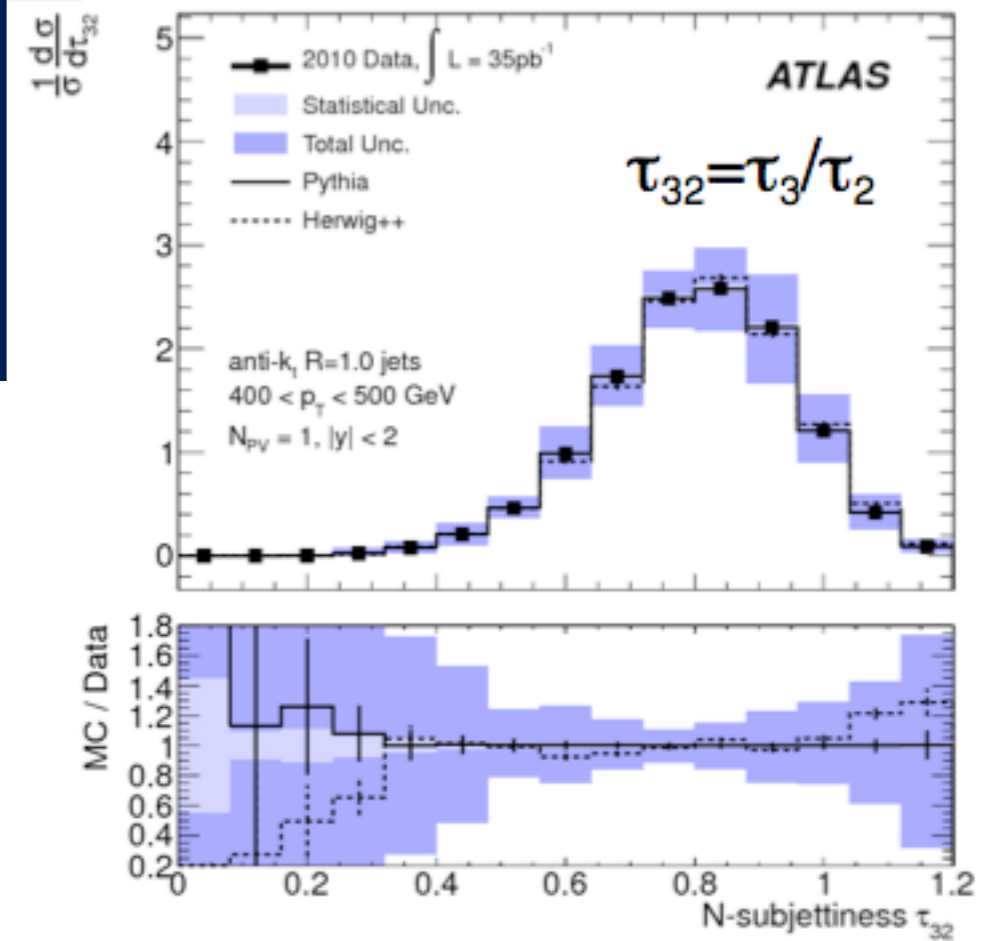
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- ✦ Applications to searches
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- ✦ Conclusion

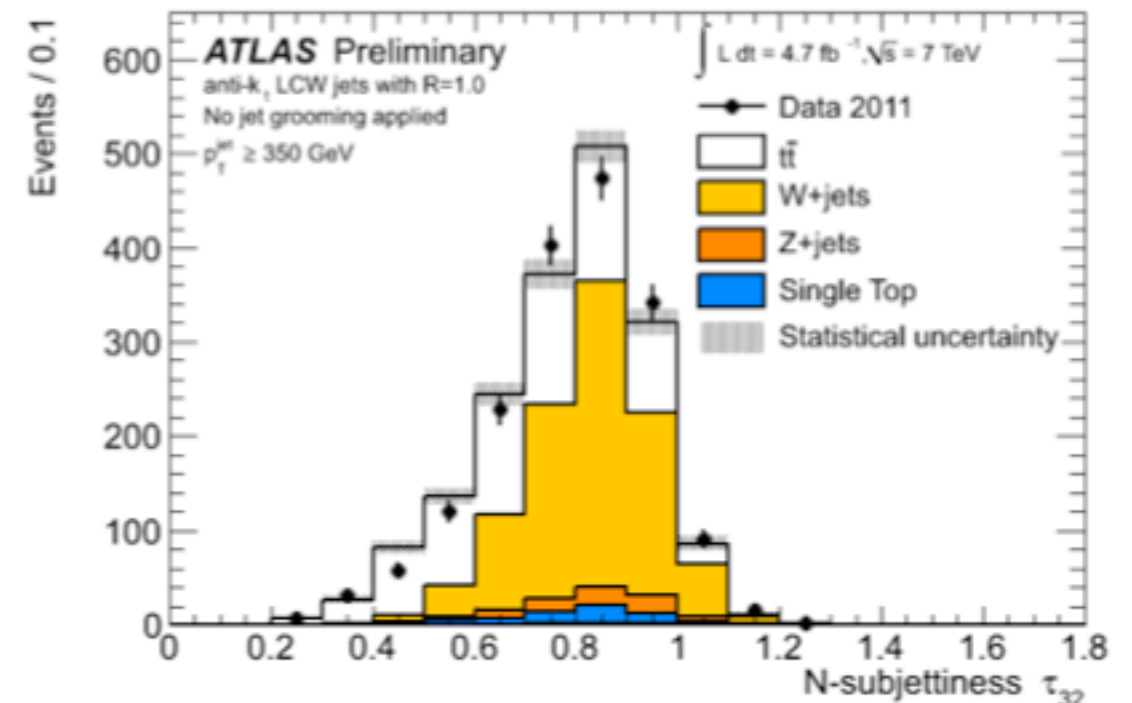
# ATLAS : Jet substructure

Sebastian Schaetzel

## ✦ N-subjettiness



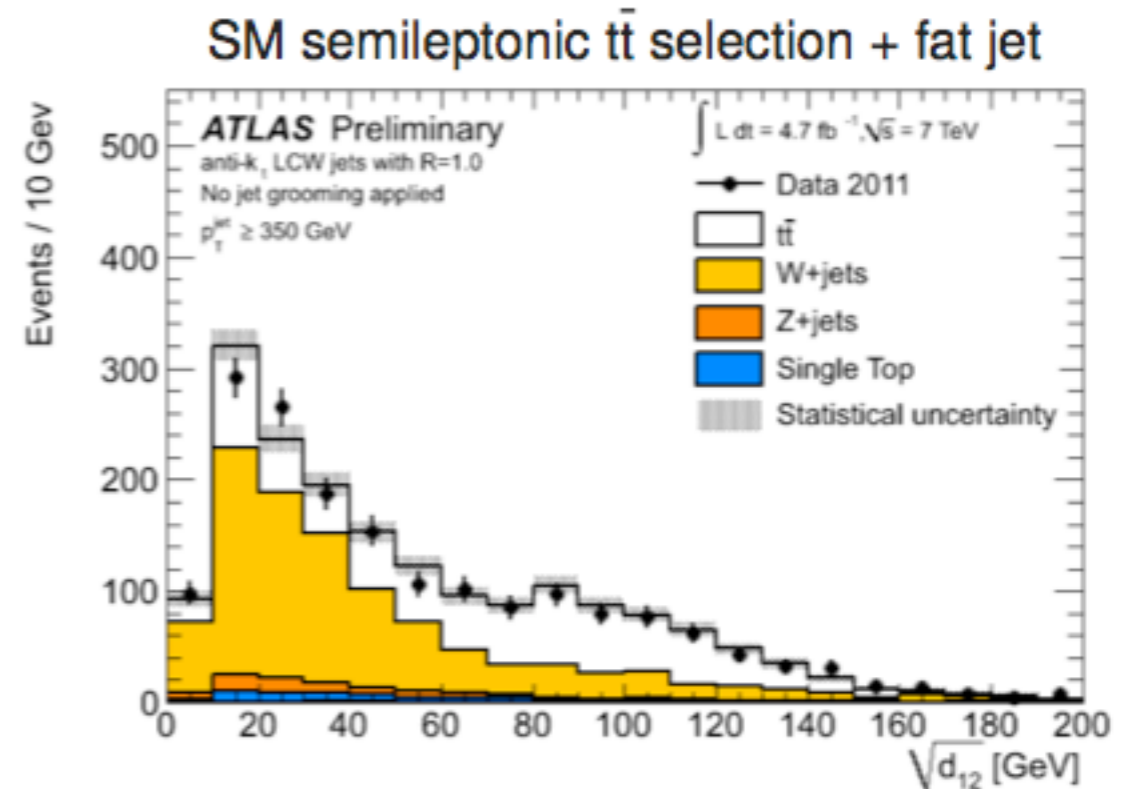
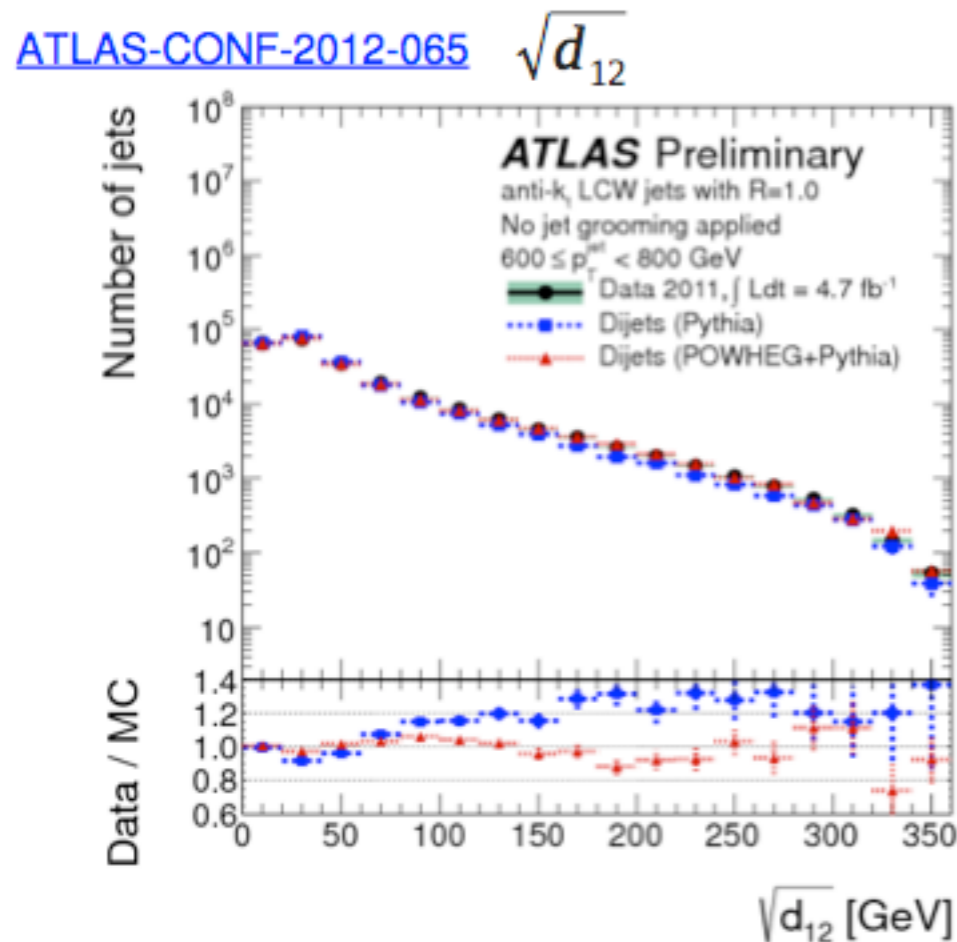
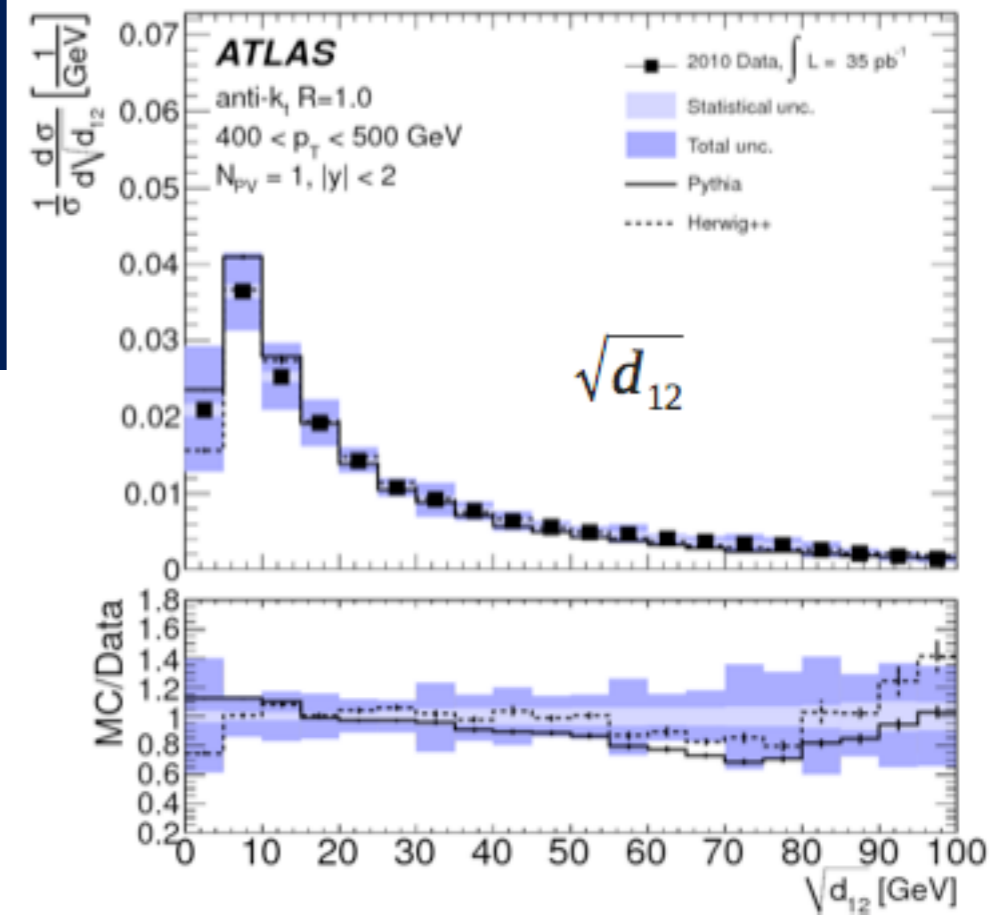
## SM semileptonic $t\bar{t}$ selection + fat jet



# ATLAS : Jet substructure

Sebastian Schaetzel

- ✦ kT-splitting scales

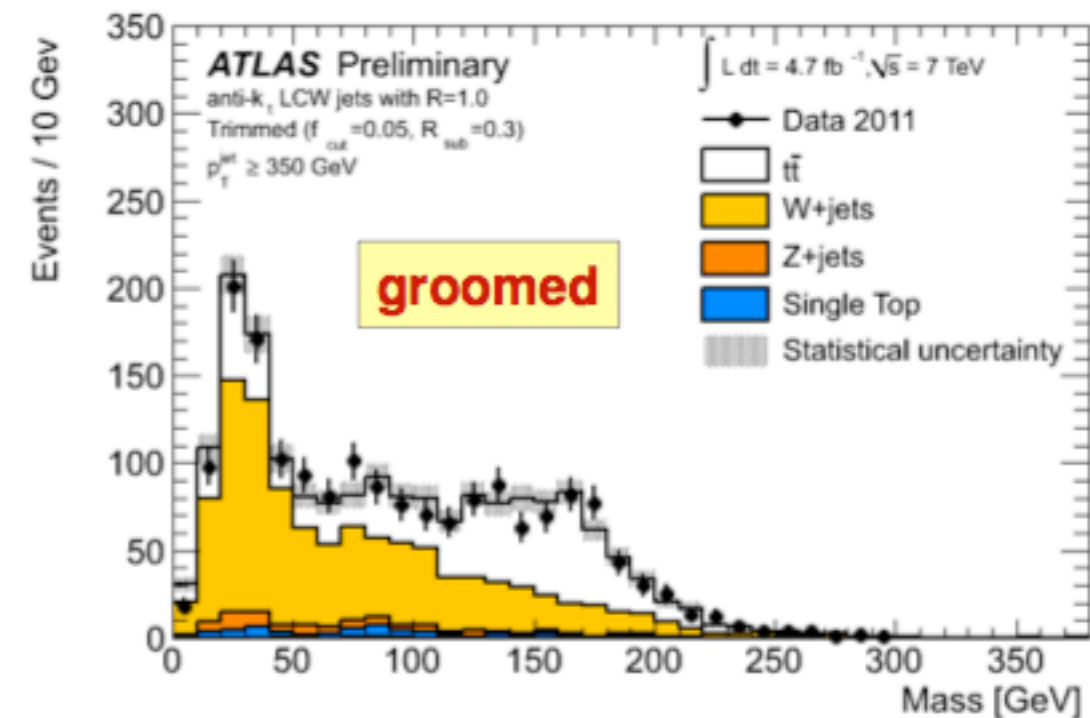
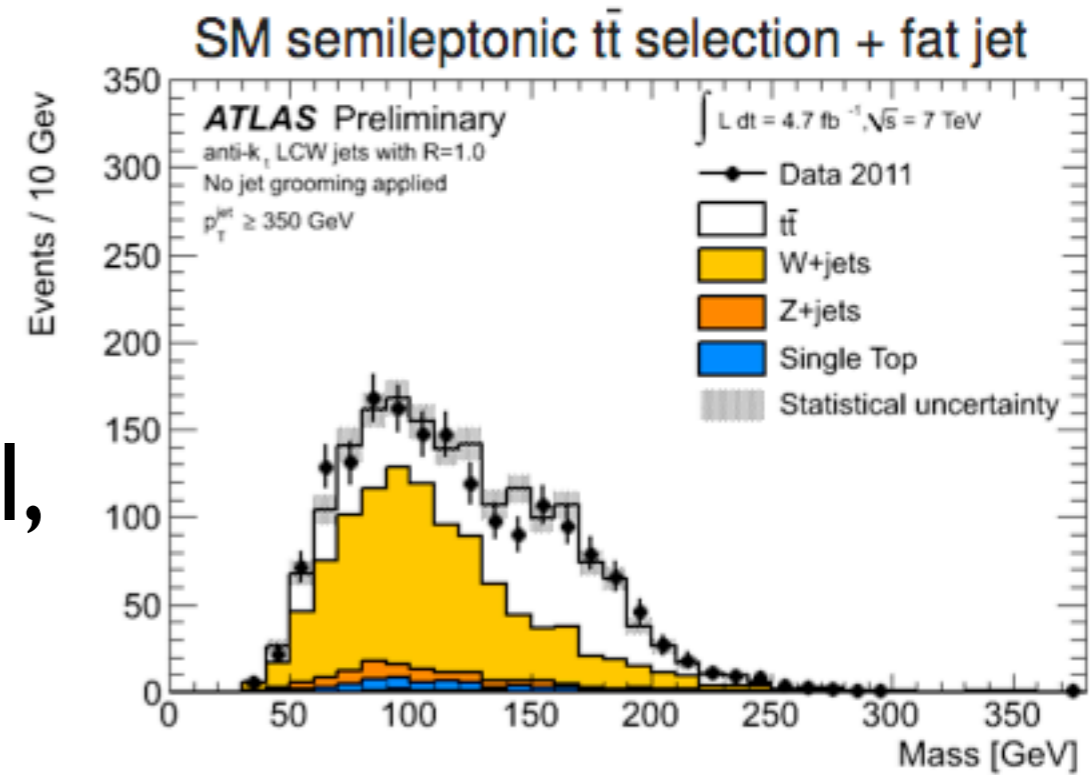
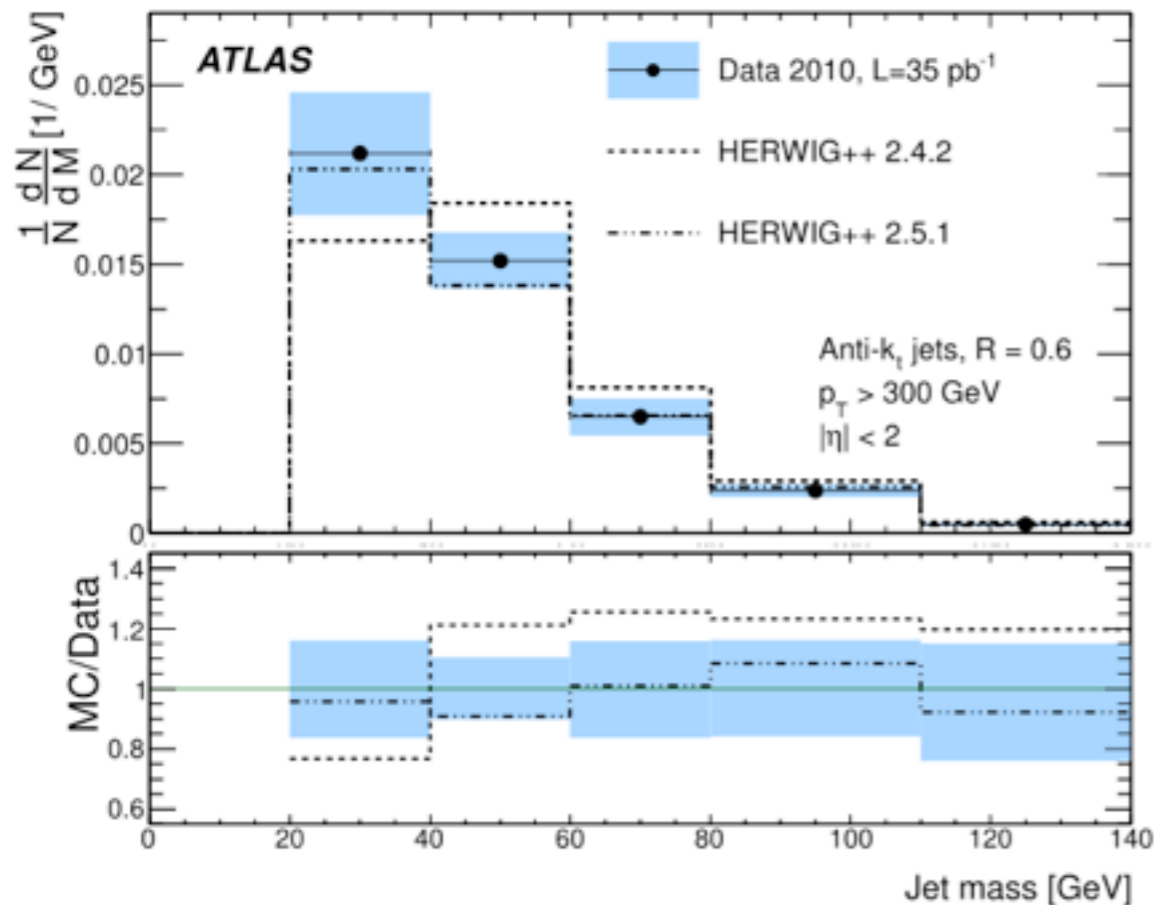


# ATLAS : Jet substructure

Sebastian Schaetzel,  
Lily Asquith

## ✦ Jet mass

HERWIG++ 2.4.2, 2.5.1



# ATLAS : Jet substructure

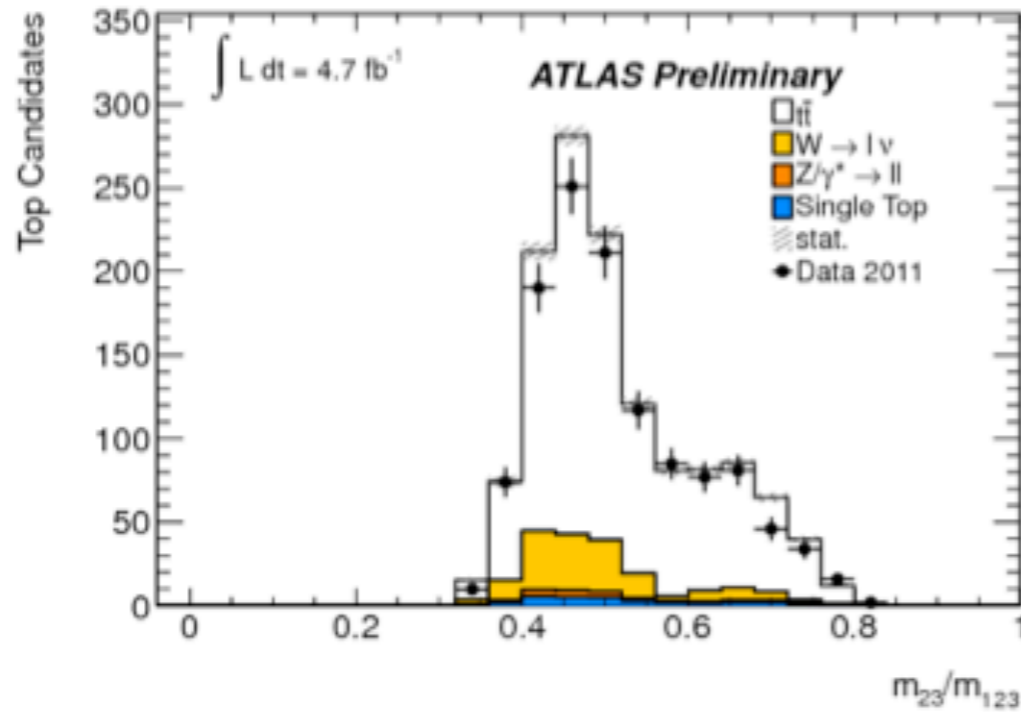
## HEP Top Tagger

Sebastian Schaetzel

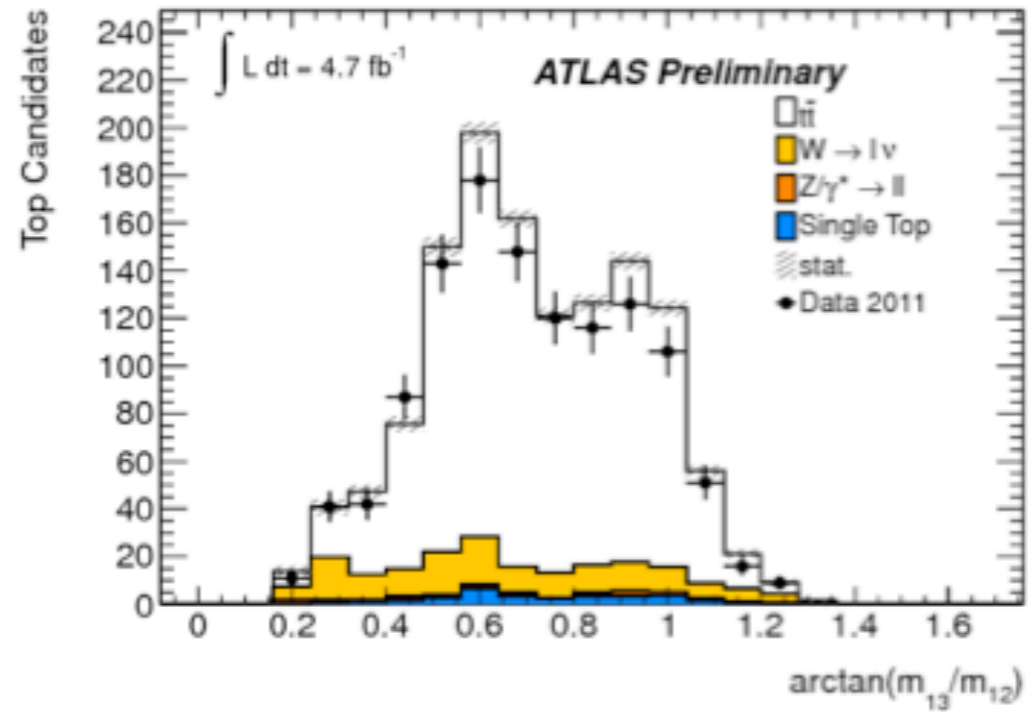
[ATLAS-CONF-2012-065](#)

SM semileptonic  $t\bar{t}$  selection + top tag

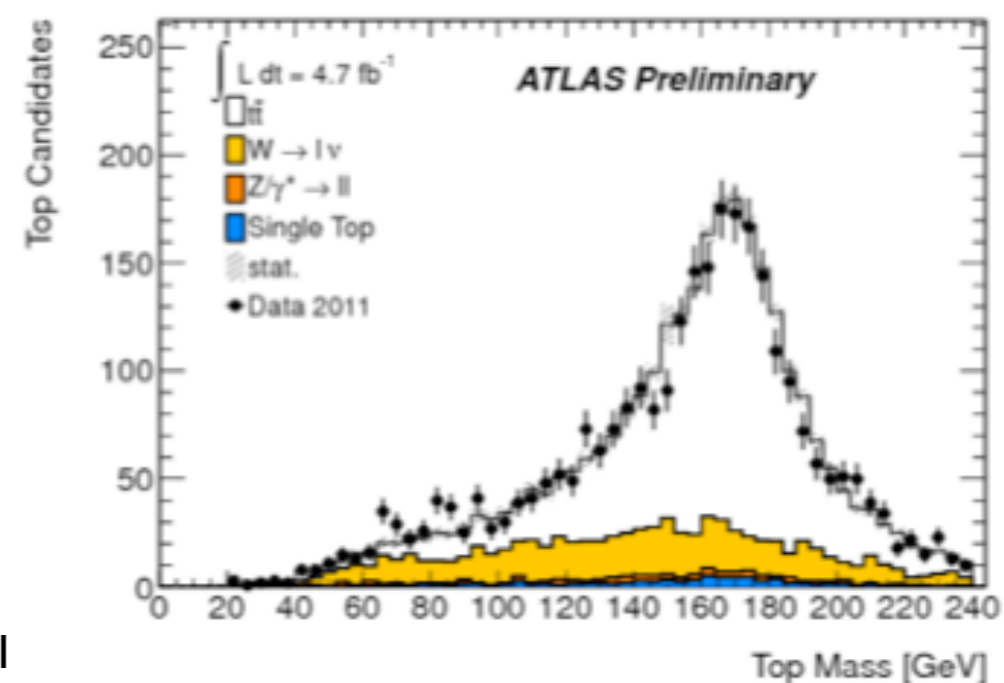
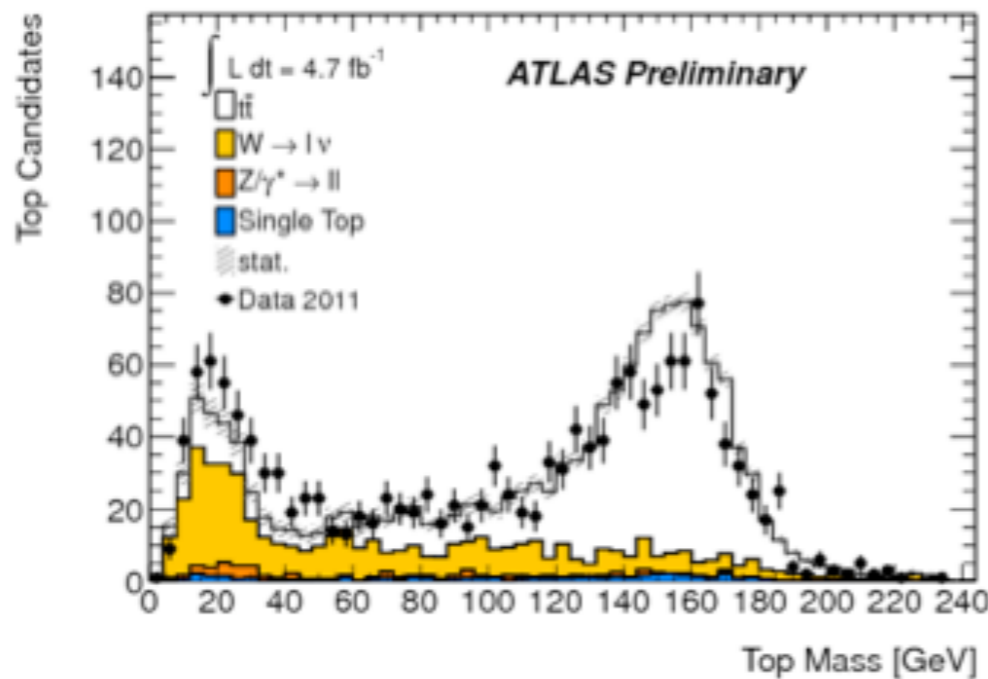
$p_{T,t} > 200$  GeV  
 $140 < m_t < 200$  GeV



tight

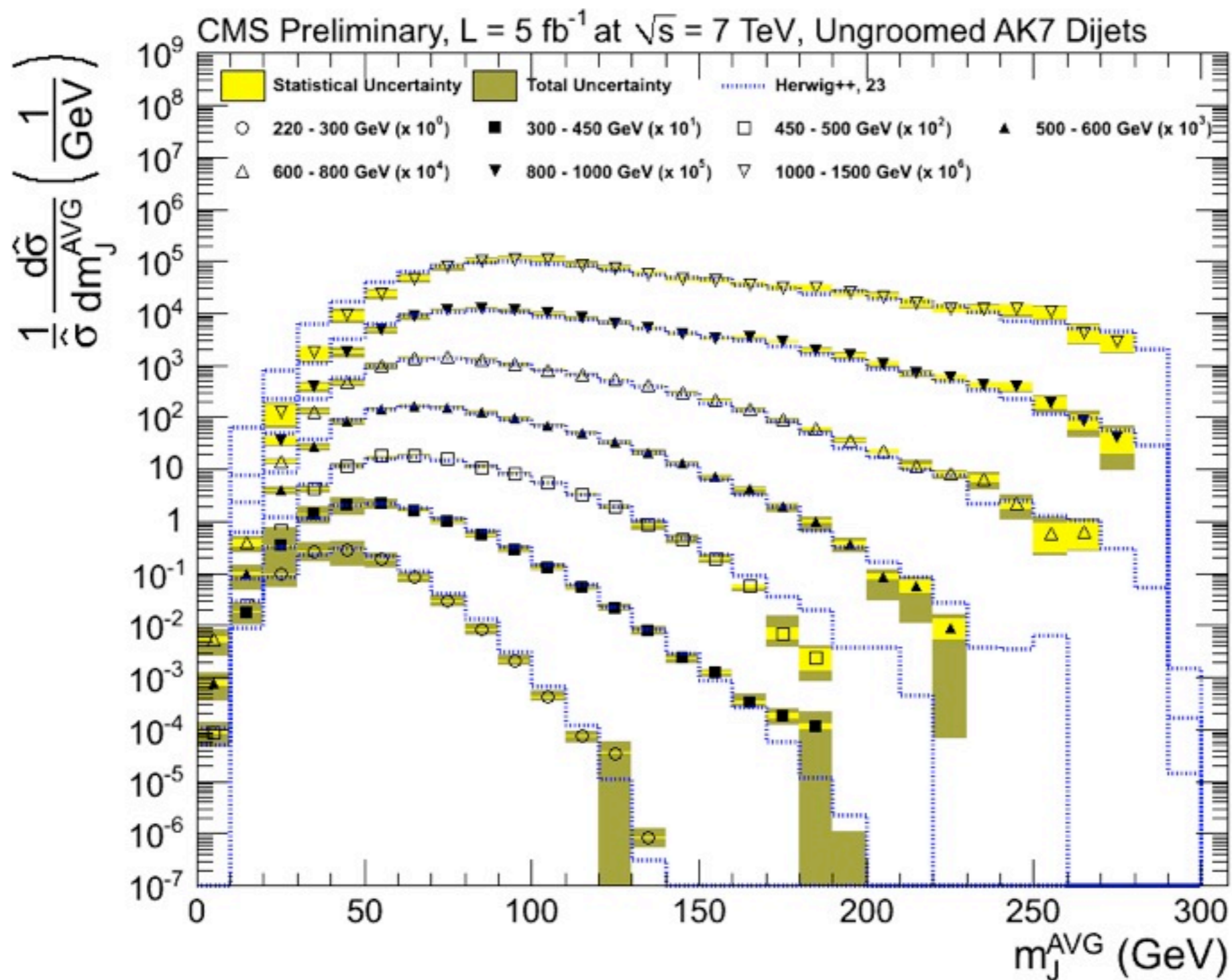


loose



# CMS : Jet substructure

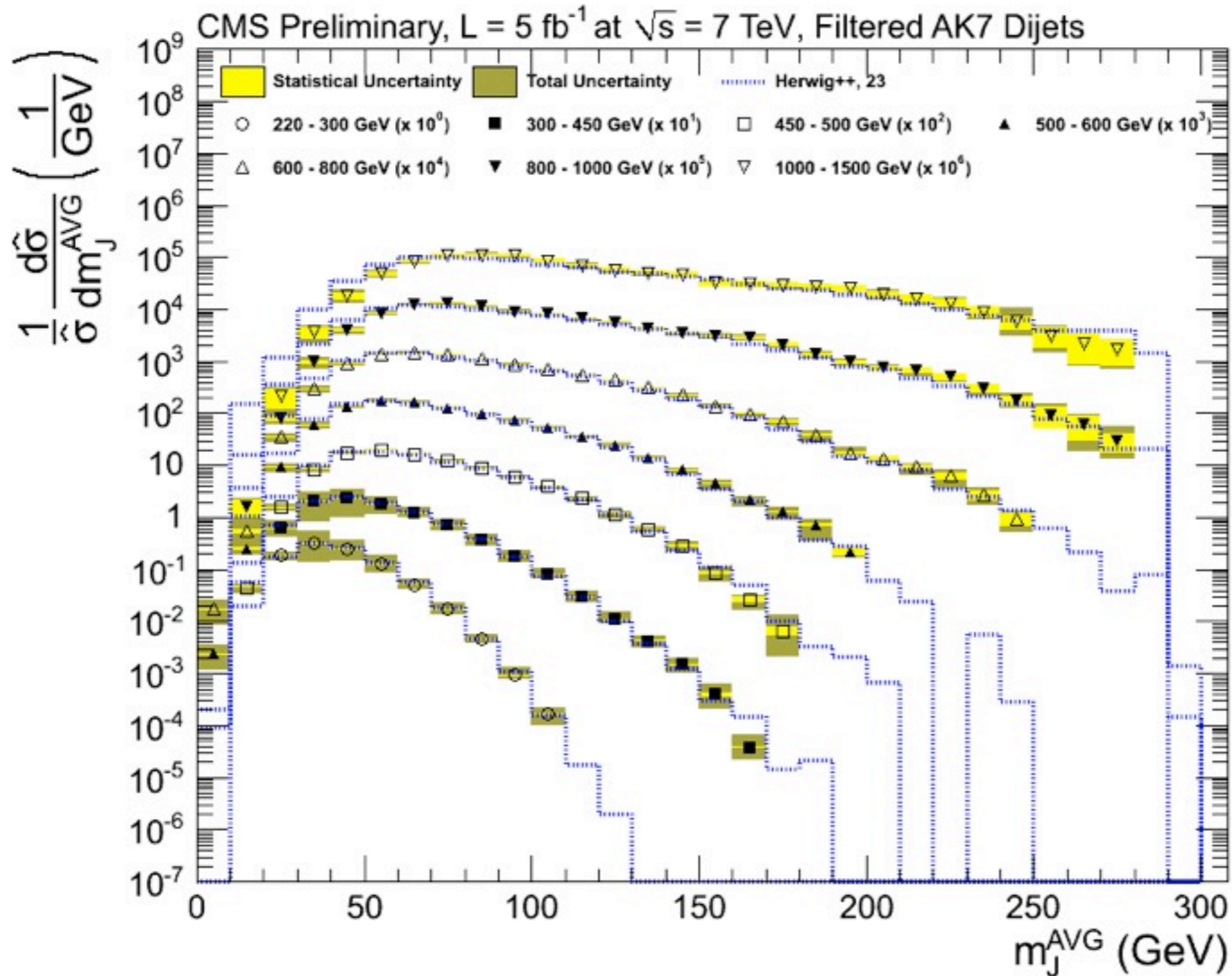
Nhan Tran





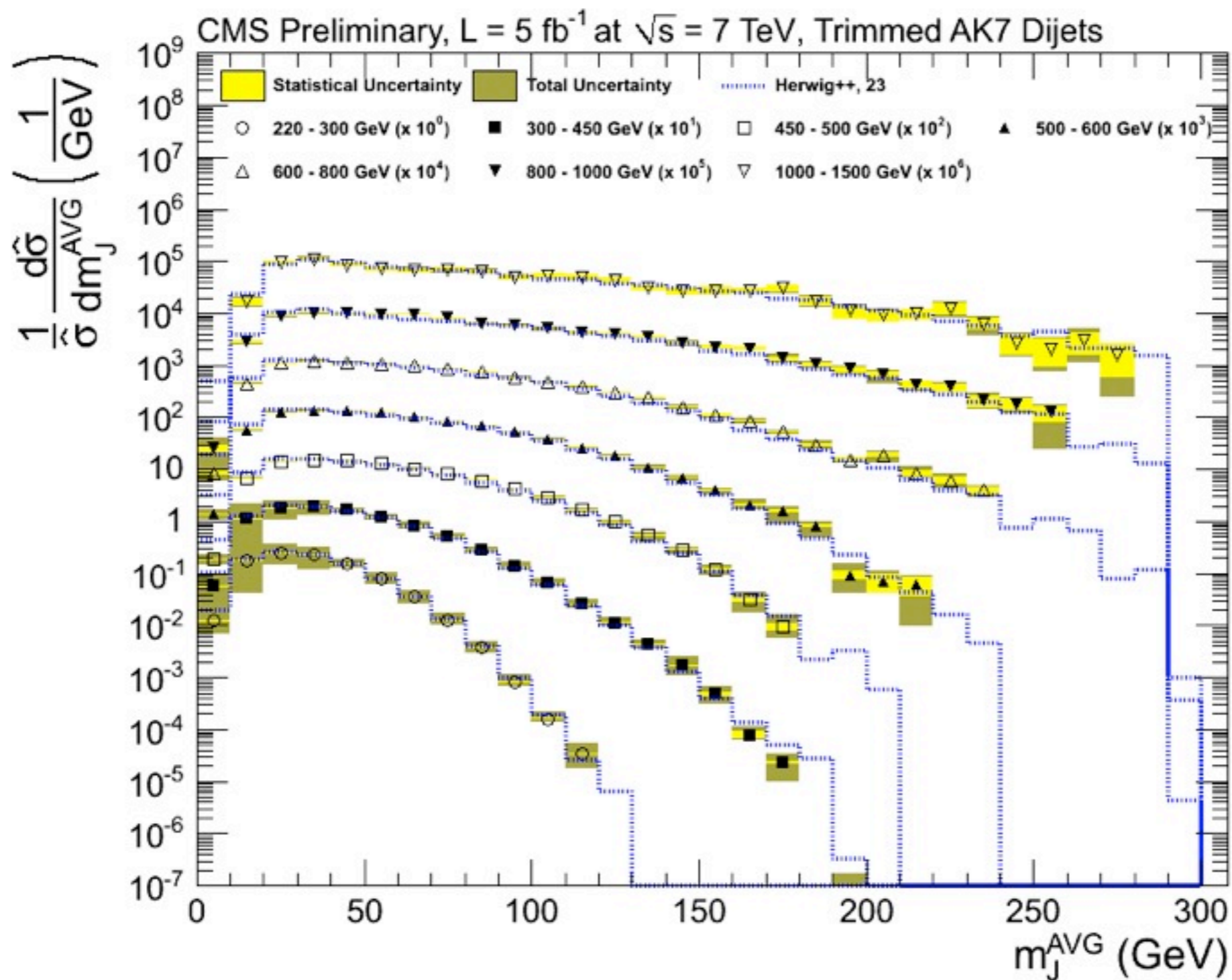
# CMS : Jet substructure

Nhan Tran



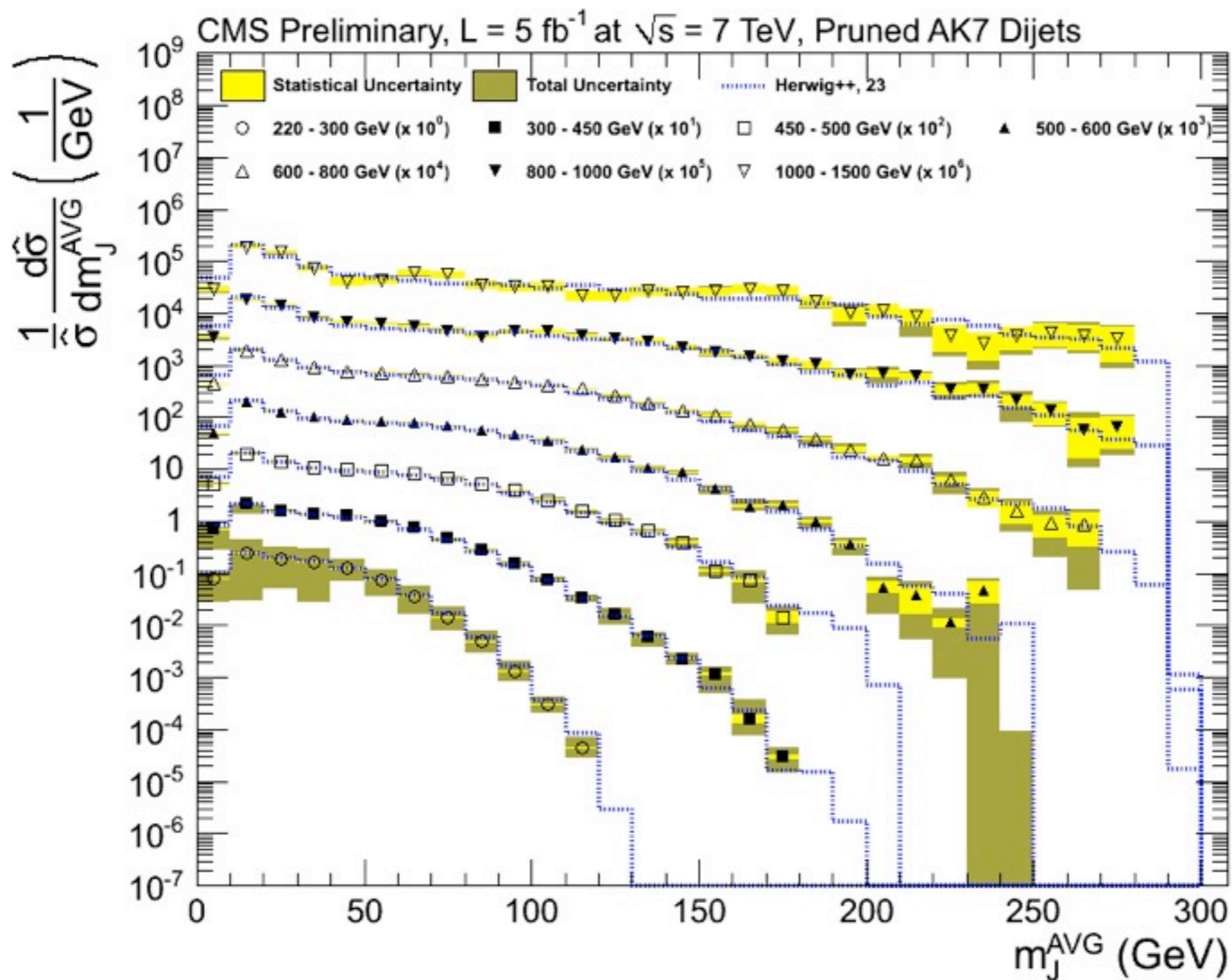
# CMS : Jet substructure

Nhan Tran



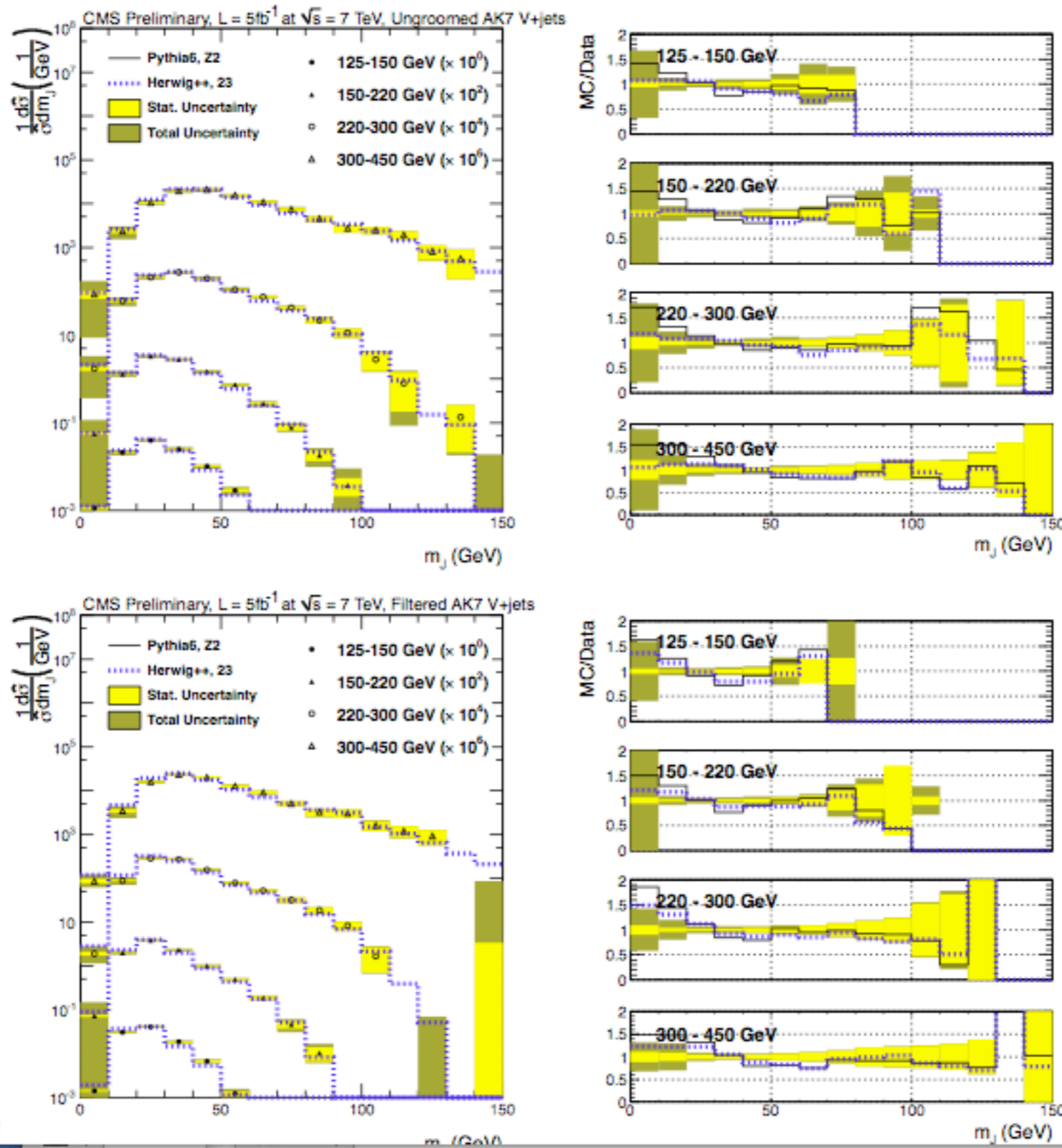
# CMS : Jet substructure

Nhan Tran



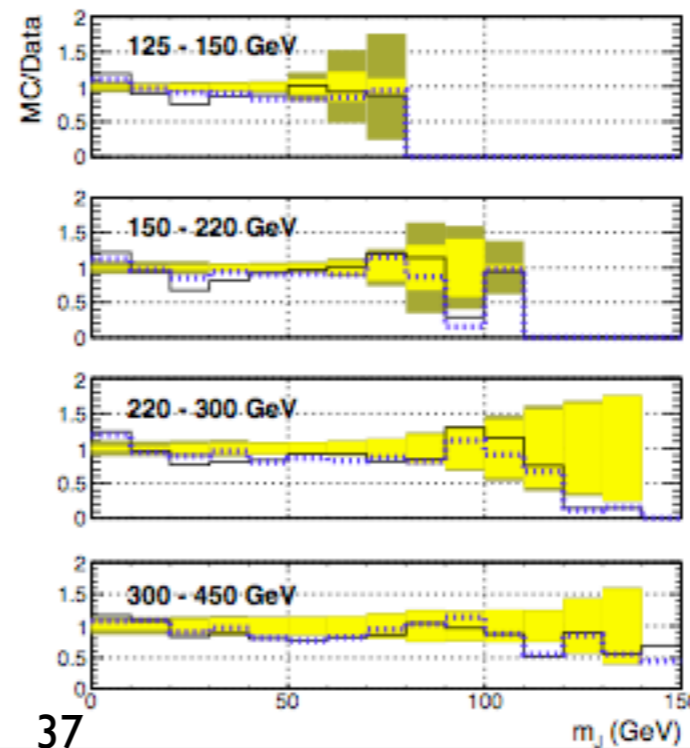
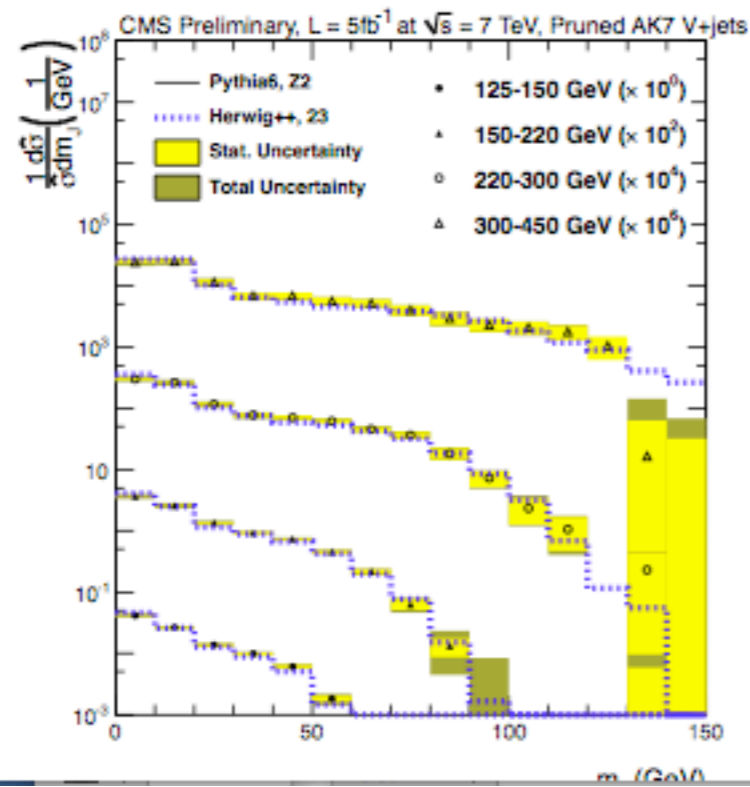
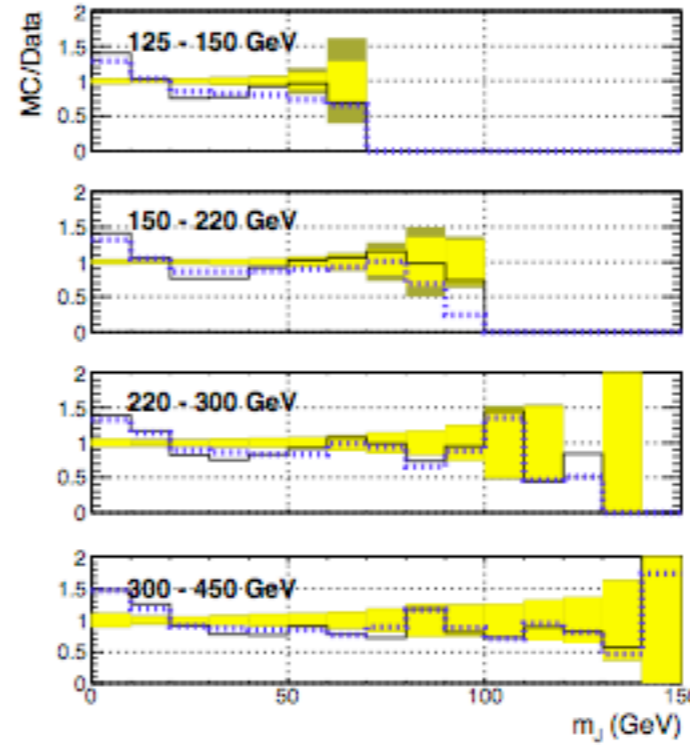
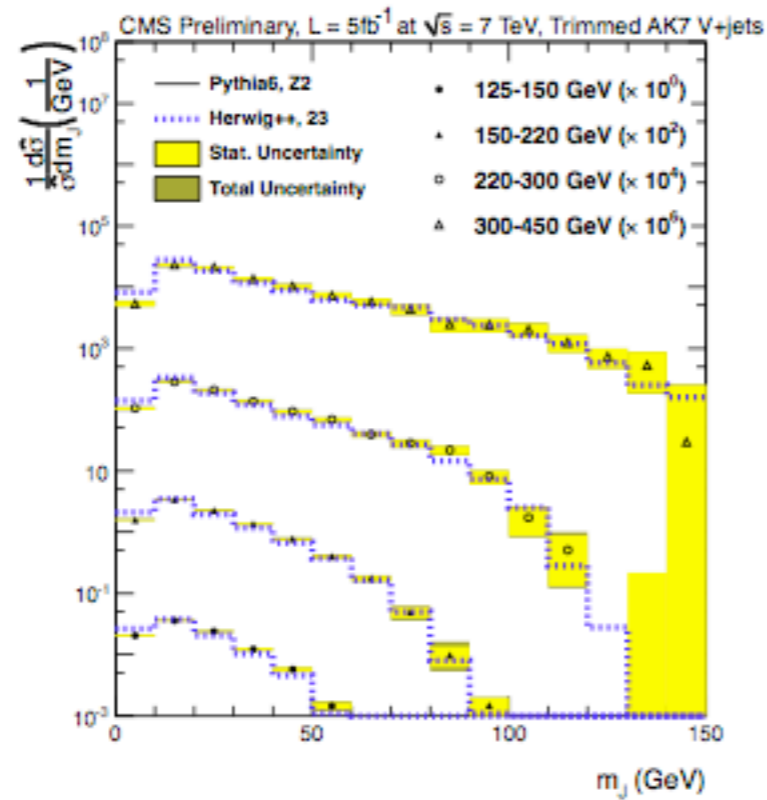
# CMS : Jet substructure

Nhan Tran



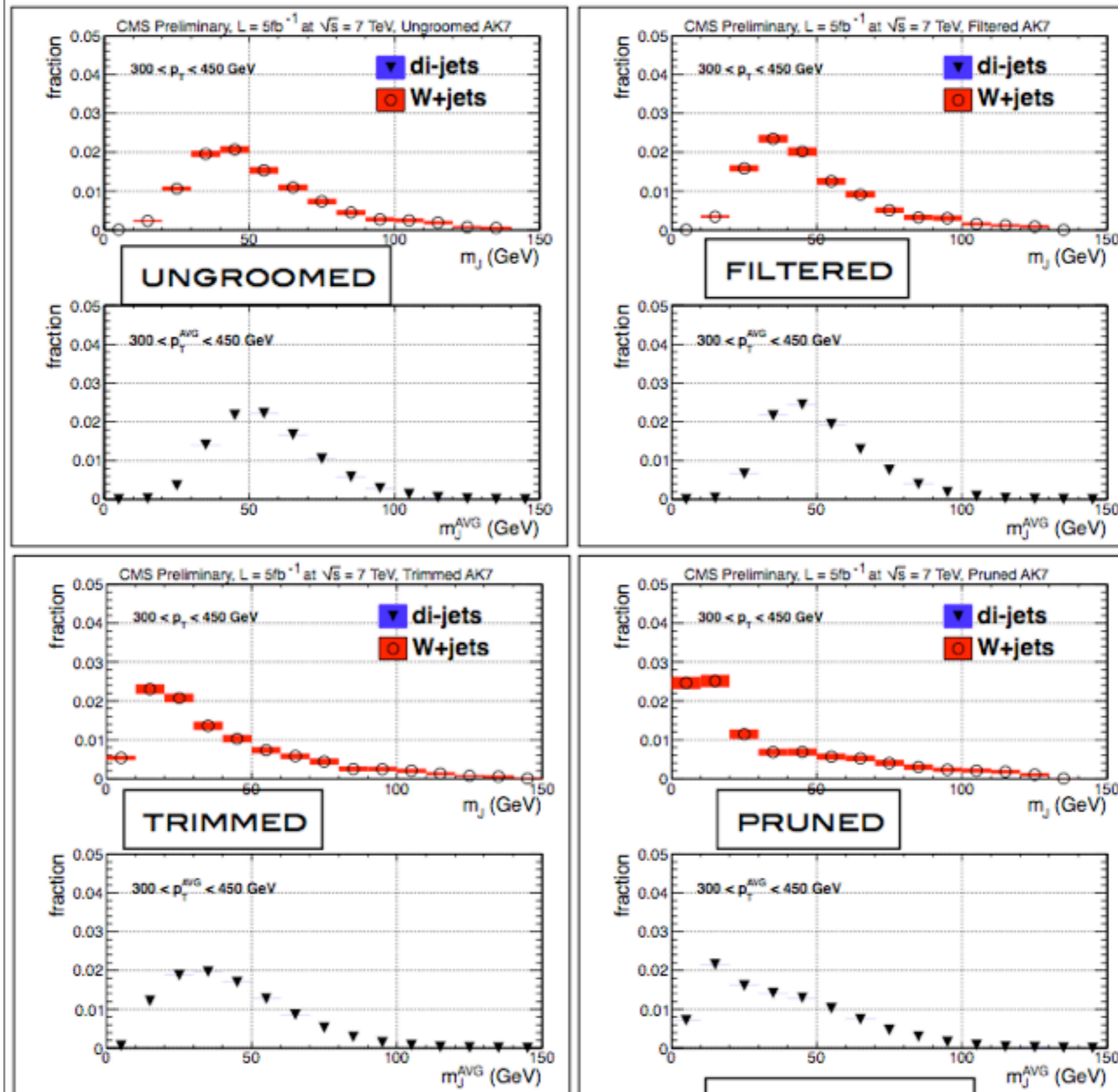
# CMS : Jet substructure

Nhan Tran



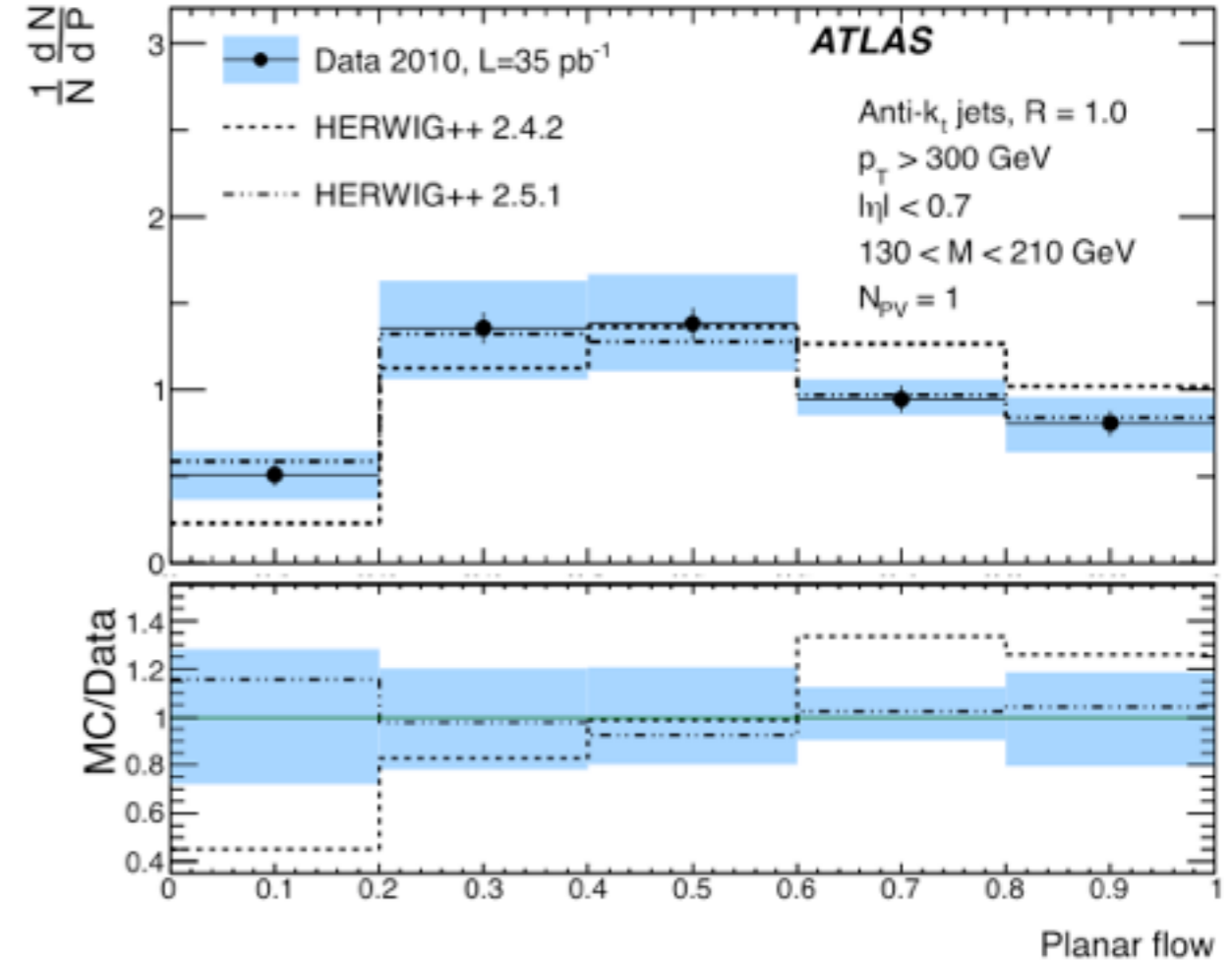
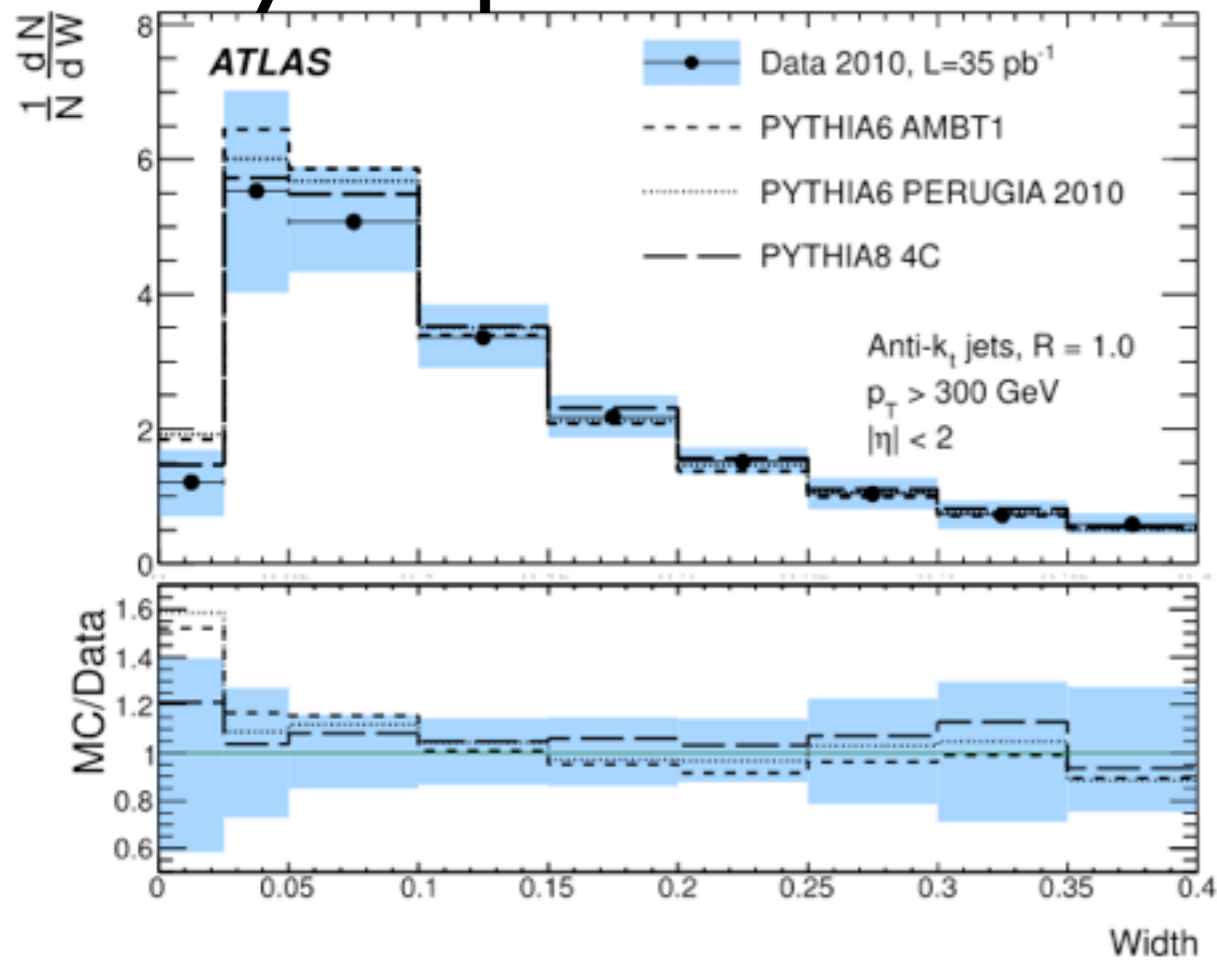
# CMS : Jet substructure

Nhan Tran



# ATLAS : Jet shapes

Lily Asquith

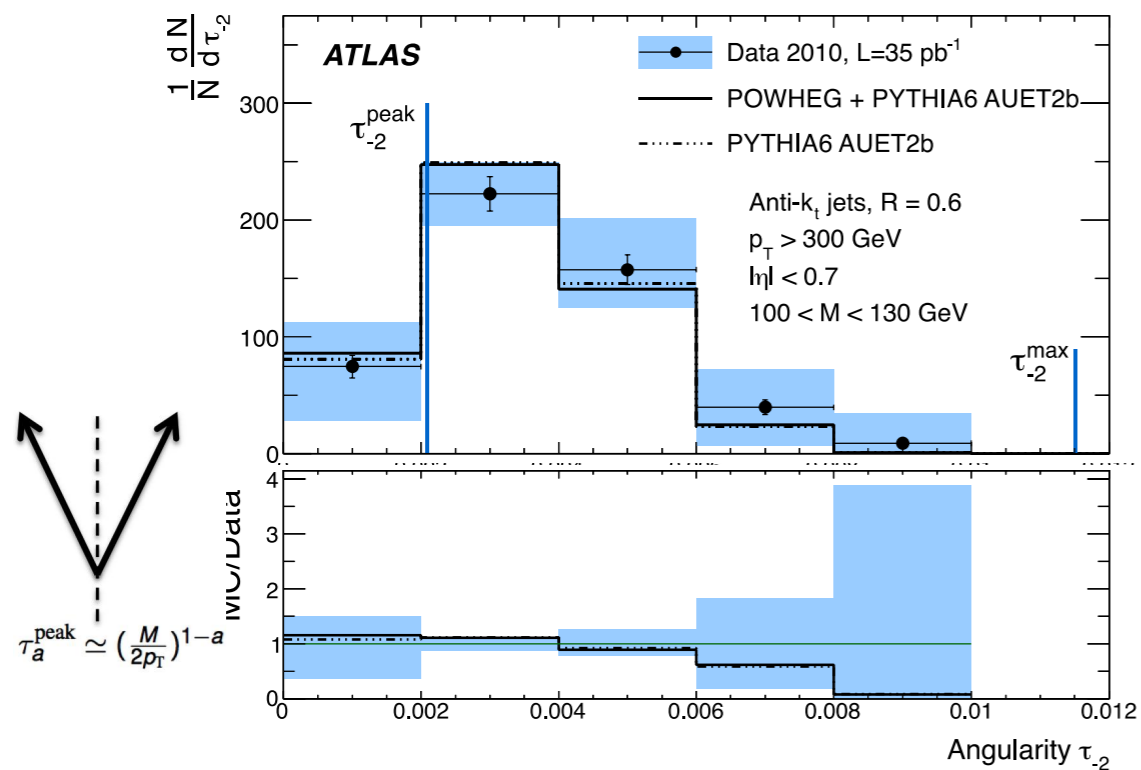


# ATLAS : Jet shapes

Lily Asquith

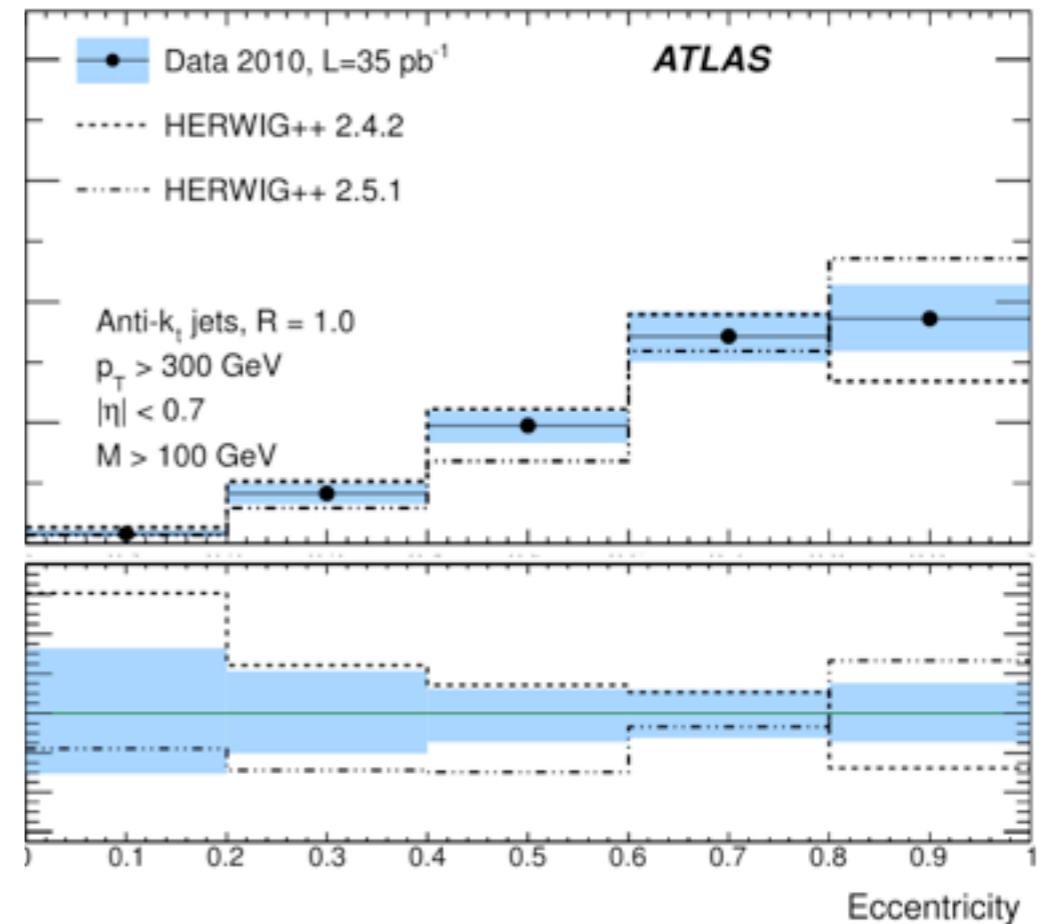
## Angularity

Nice agreement between data and MC and with QCD small angle approx.



$\tau_a^{\text{max}} \simeq \left(\frac{2}{R}\right)^a \left(\frac{M}{2p_T}\right)$

37



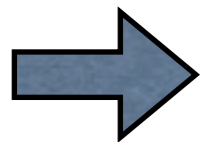


# Substructure Measurements

- ✦ Take-home message :
  - Even LO + PS tools working pretty well against data
  - Experiments providing lots of information
  - Still work to do, so help out!

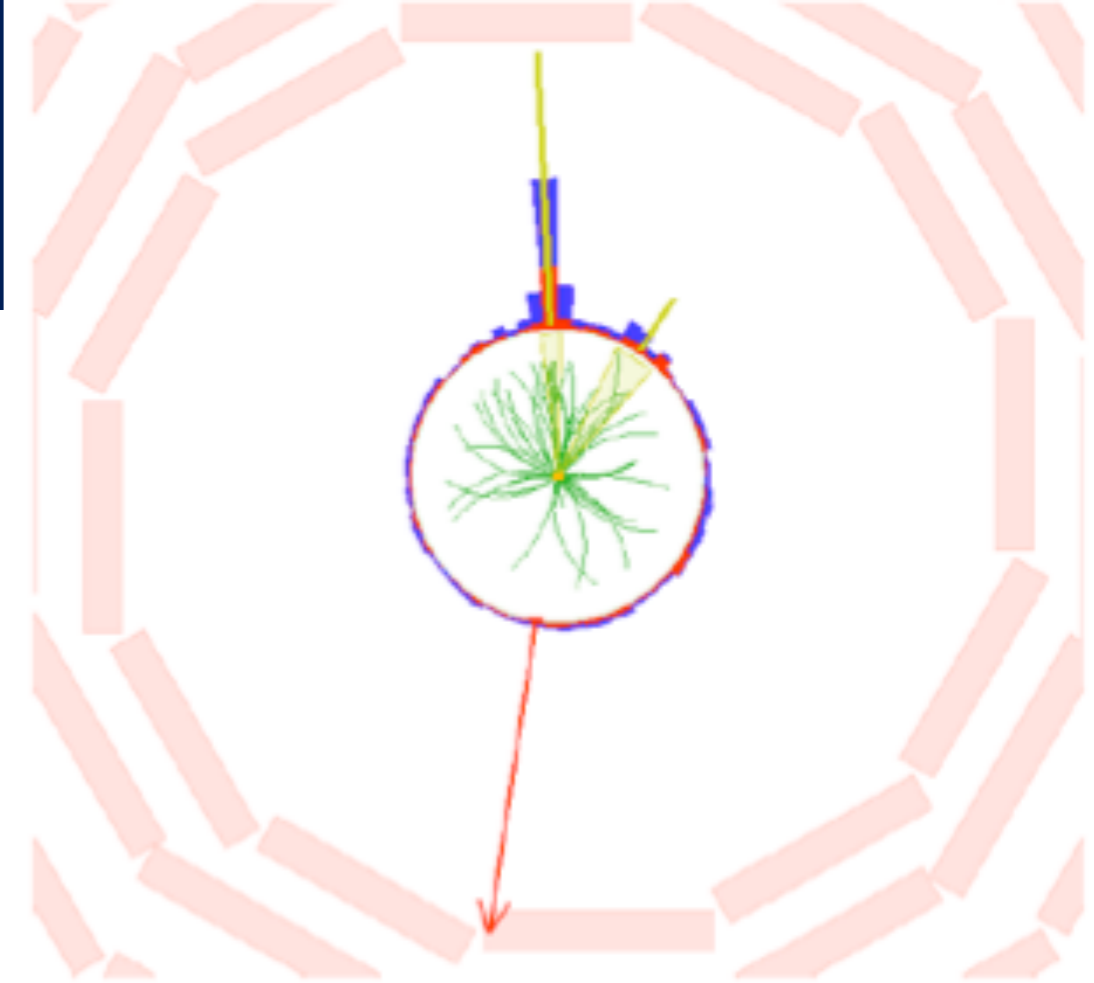
# Outline

- ✦ A new context
- ✦ Merged jets in data
- ✦ Pileup
- ✦ Studies on tools
- ✦ Substructure measurements
- ✦ Applications to searches
- ✦ Future colliders
- ✦ Conclusion



# Application : CMS $H \rightarrow bb$

- Booster regime helps here, using grooming on the list of improvements



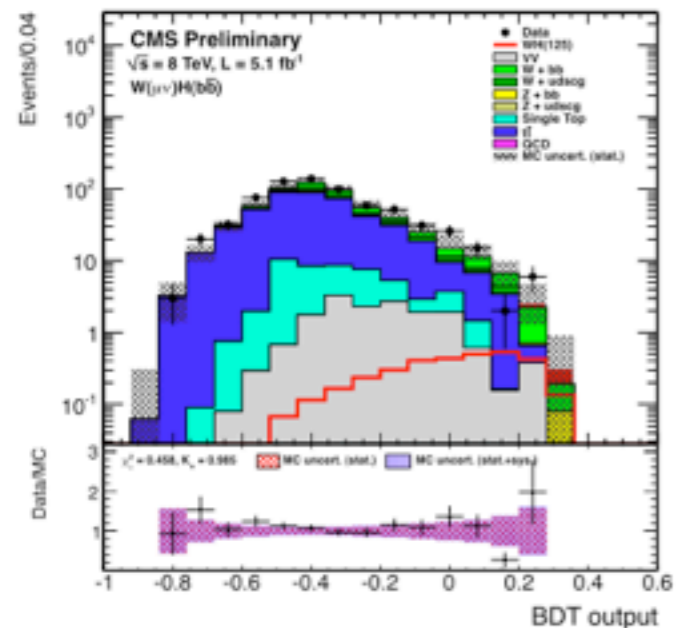
*ZvvHbb candidate*

$W_{\mu\nu}H_{bb}$

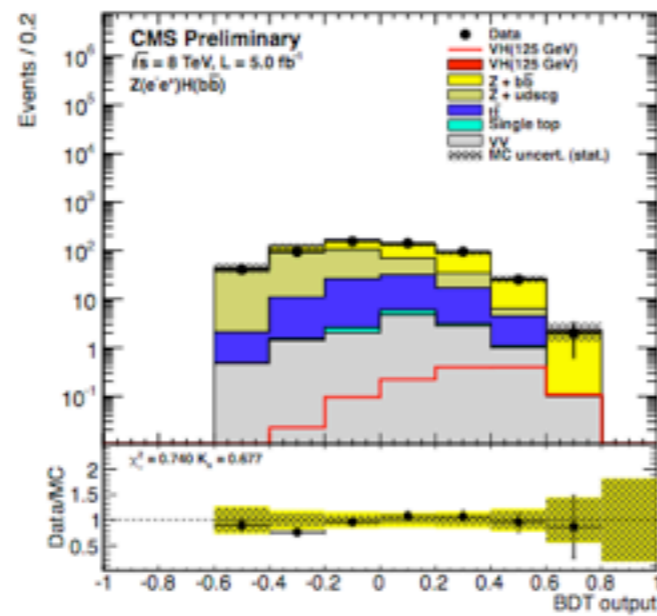
$Z_{ee}H_{bb}$

8 TeV

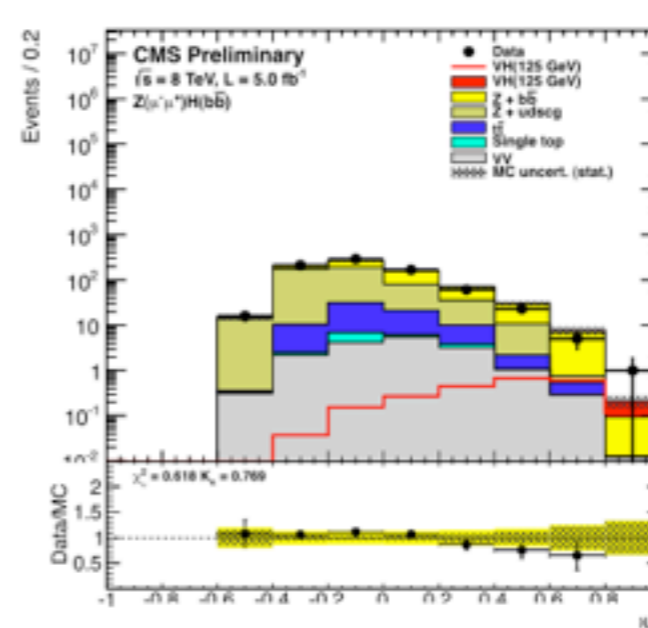
$Z_{\nu\nu}t_{bb}$



highBoost bin



mediumBoost bin



highBoost bin

Annapaola de Cosa

# Application : ATLAS $H \rightarrow bb$



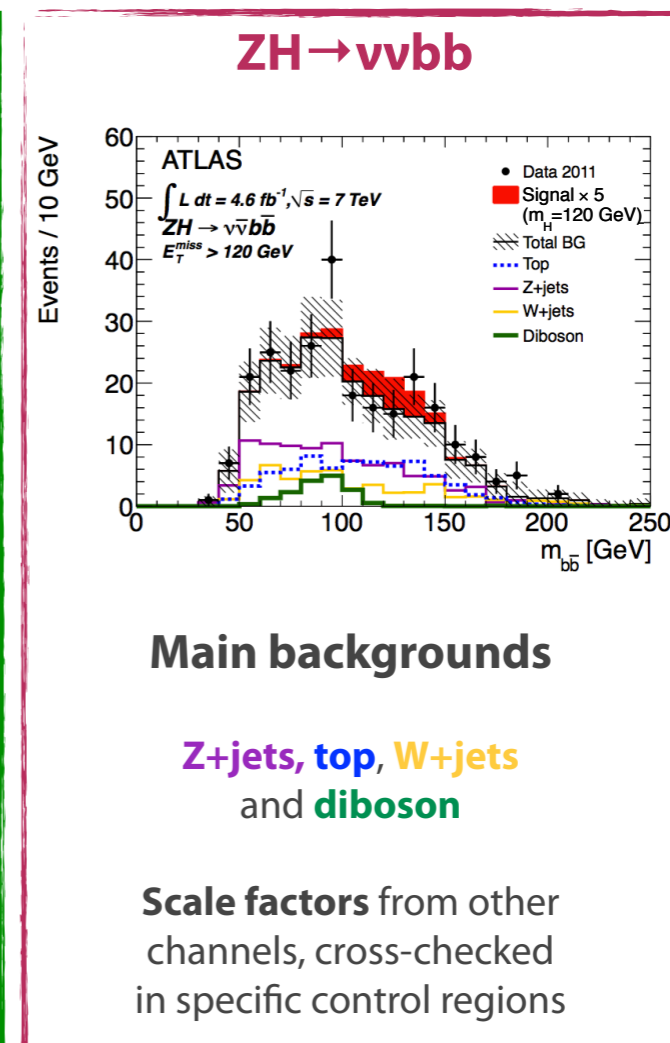
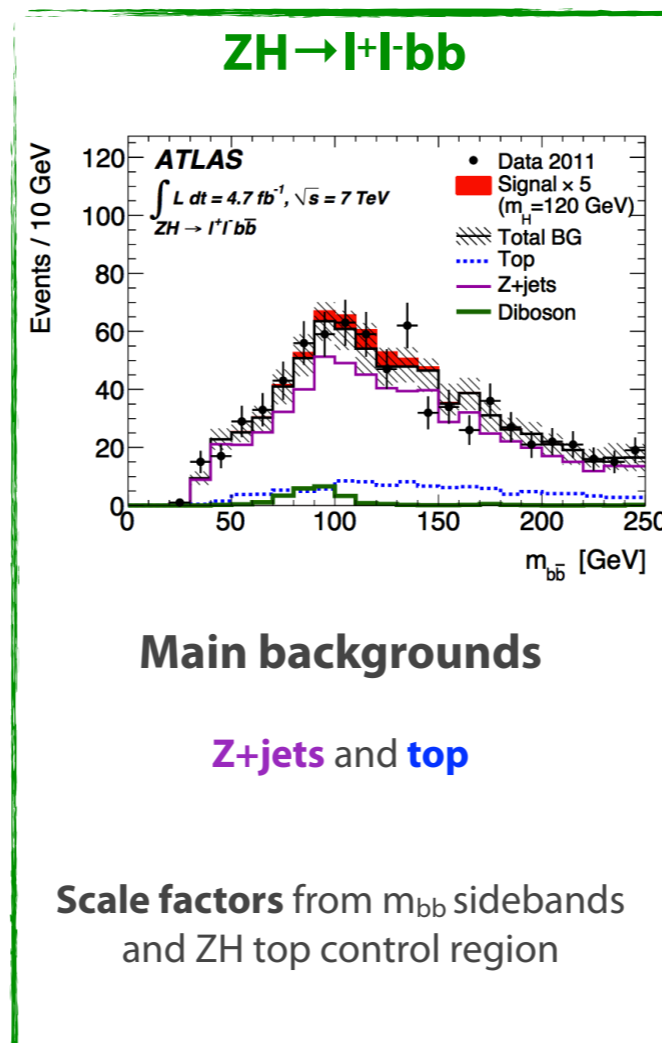
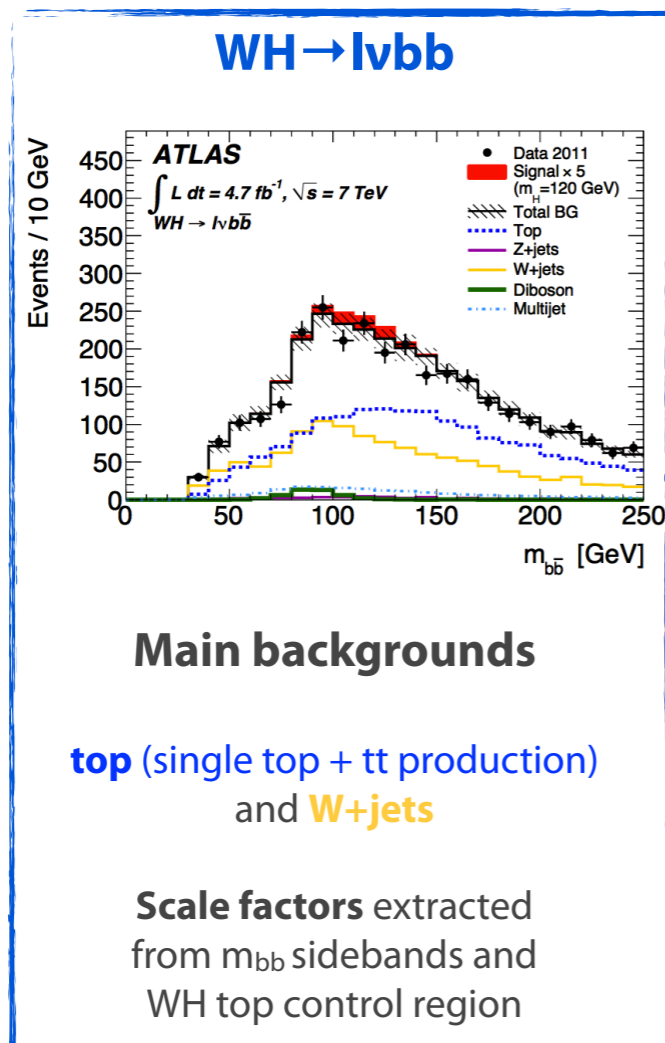
## $m_{bb}$ and background contributions



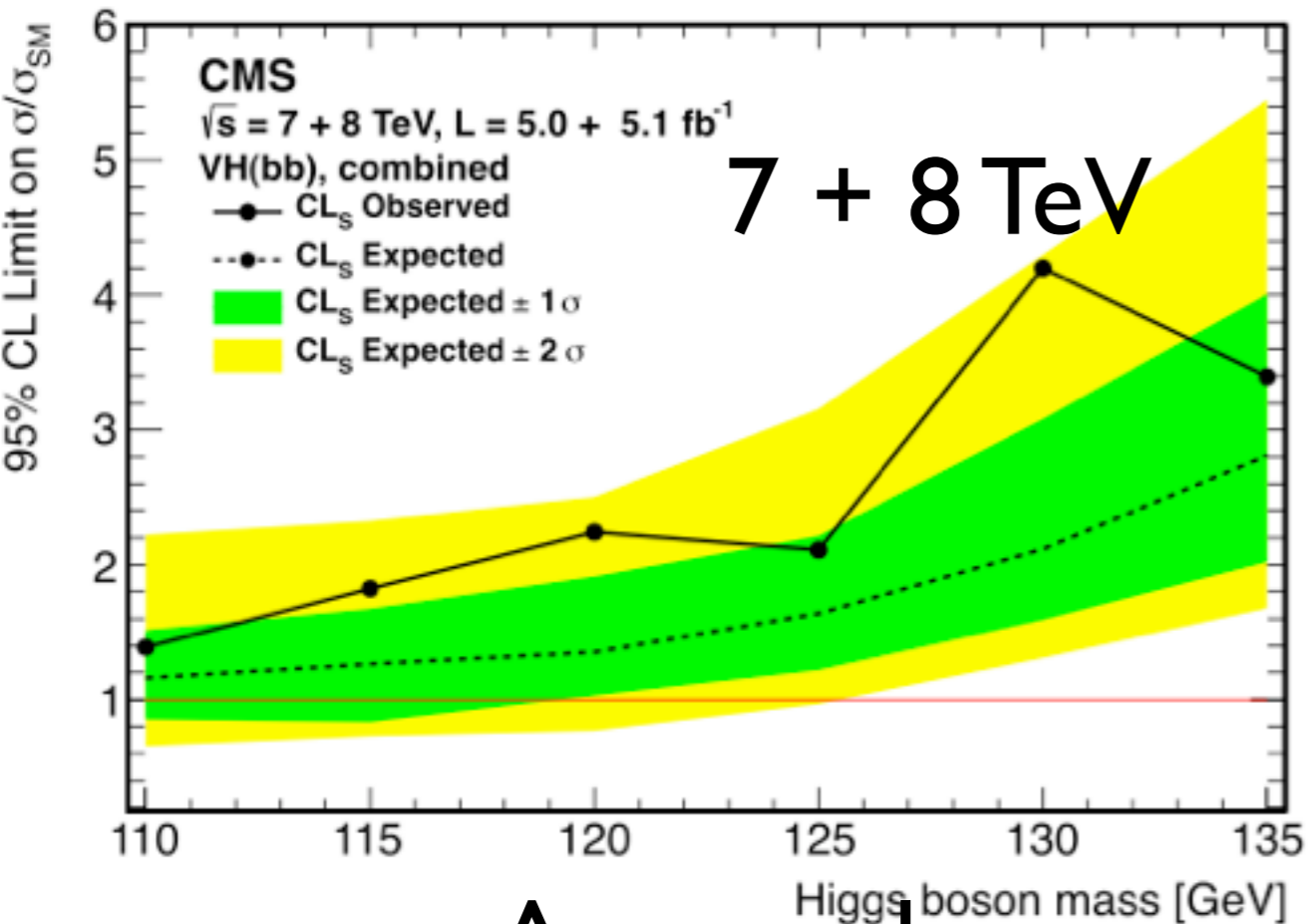
Chiara Debenedetti

$m_{bb}$  shape evaluated from MC and normalisation of leading backgrounds from data, **outside Signal Region:  $80 < m_{bb}/\text{GeV} < 150$**  and in dedicated top control regions

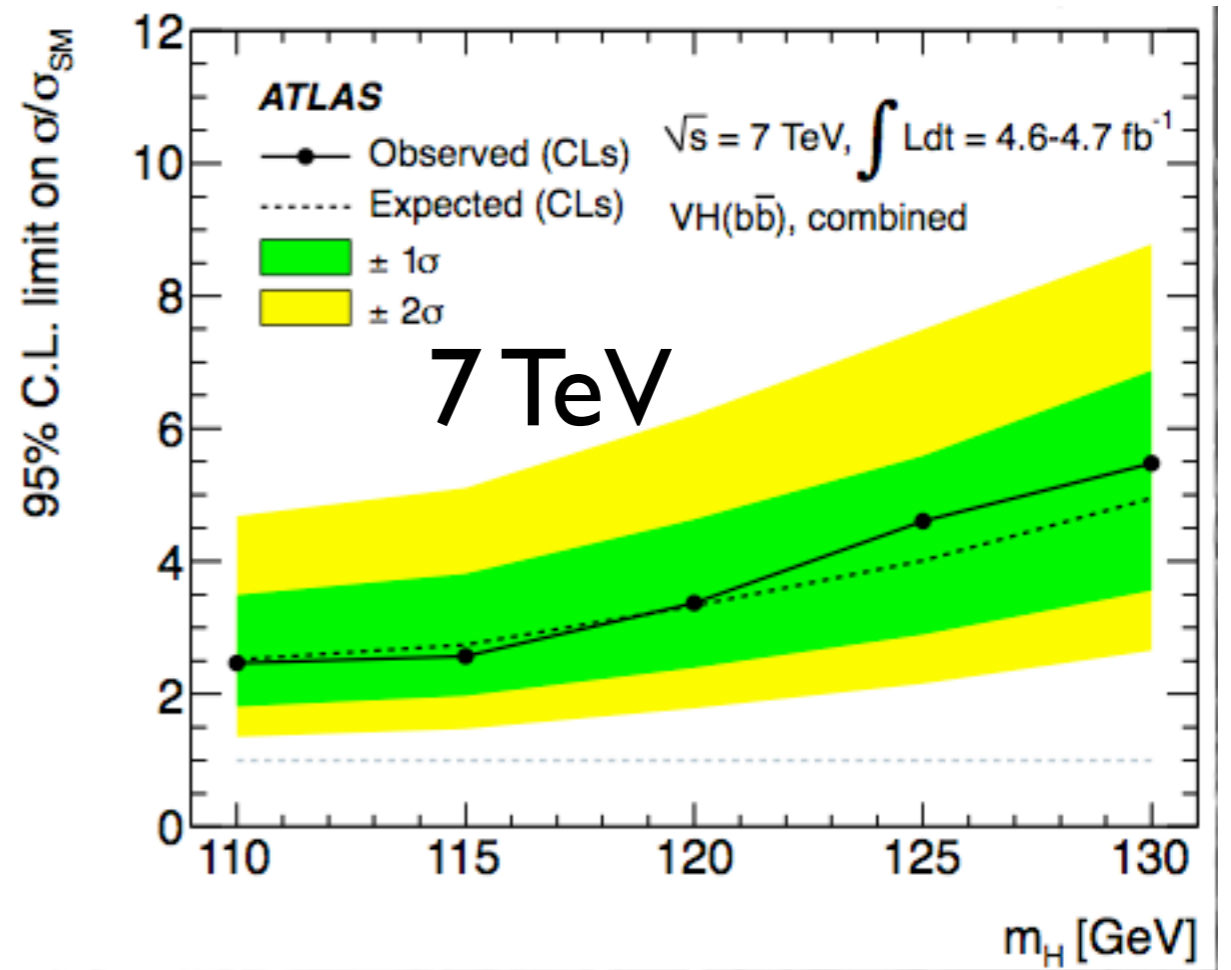
7 TeV



# Application : $H \rightarrow b\bar{b}$



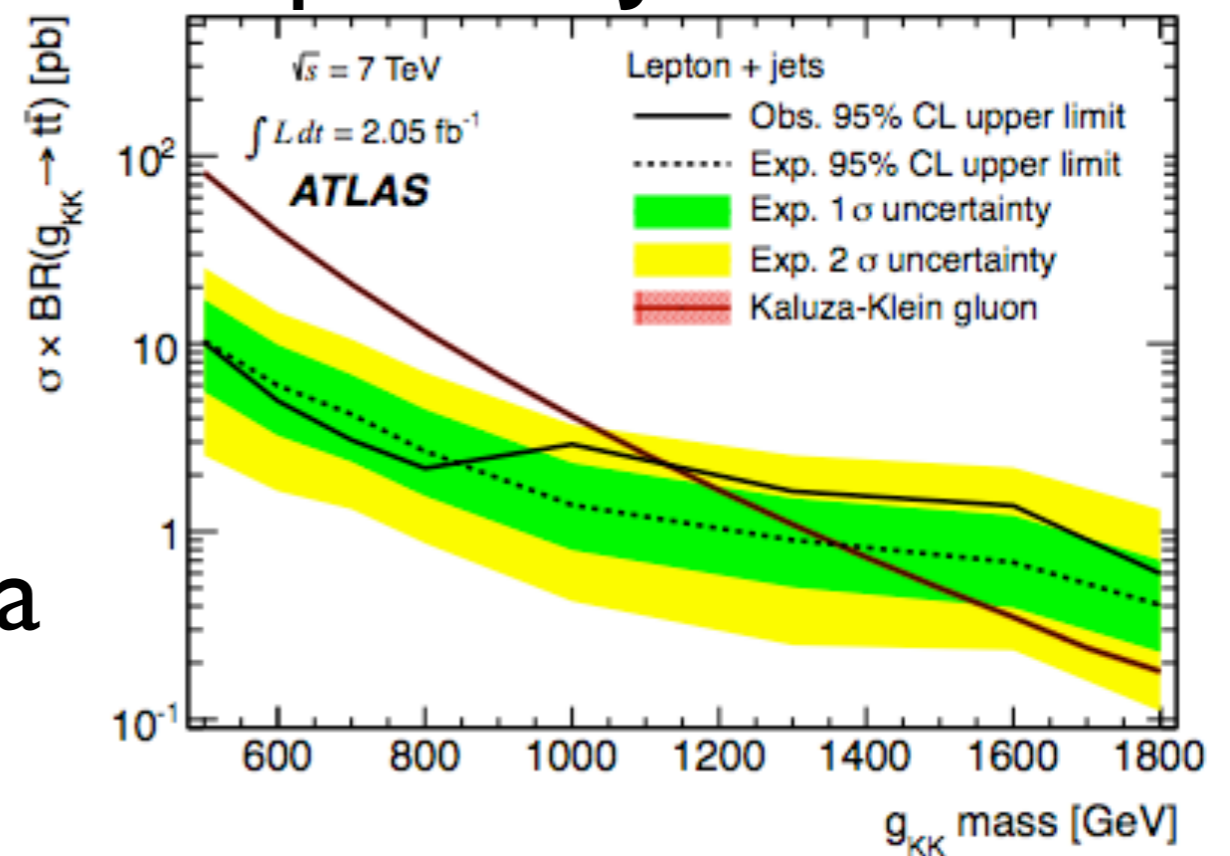
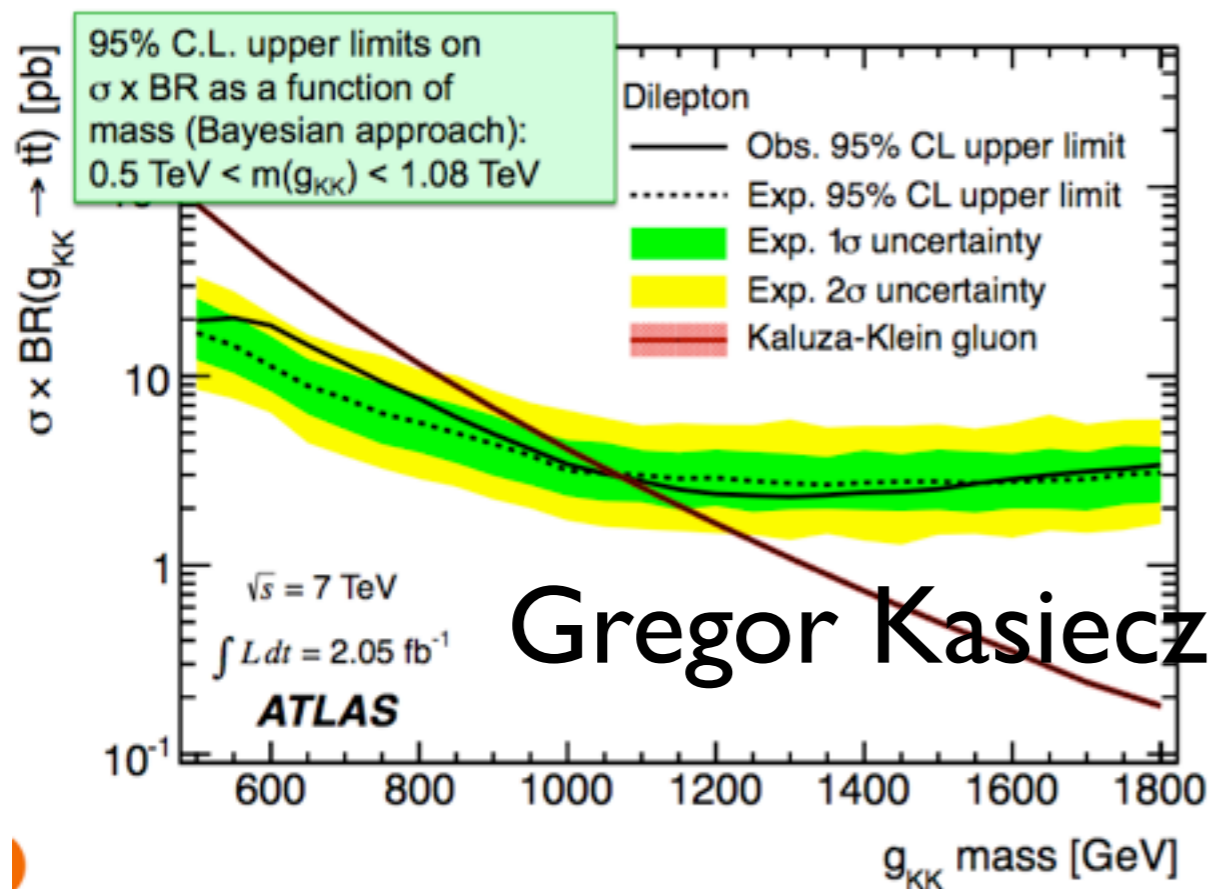
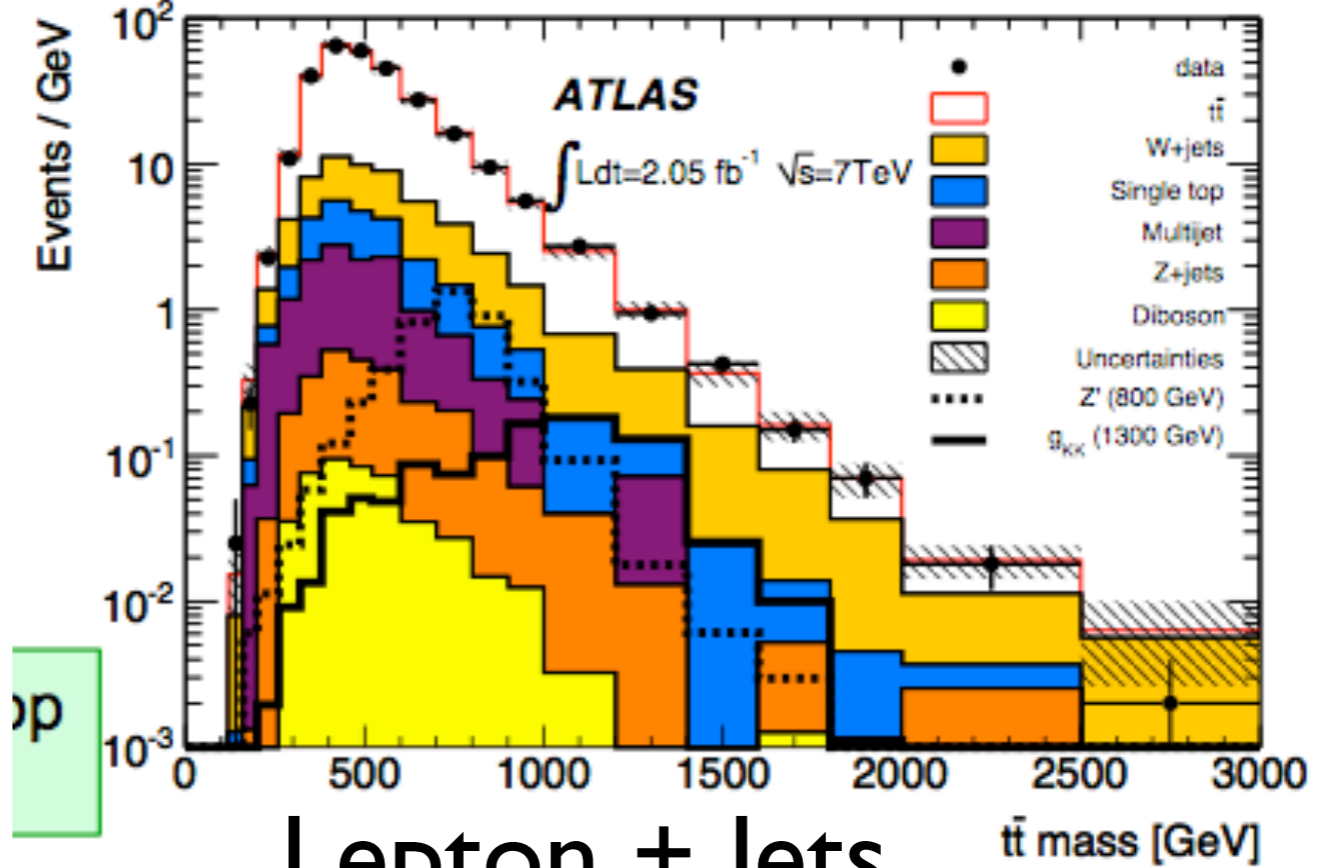
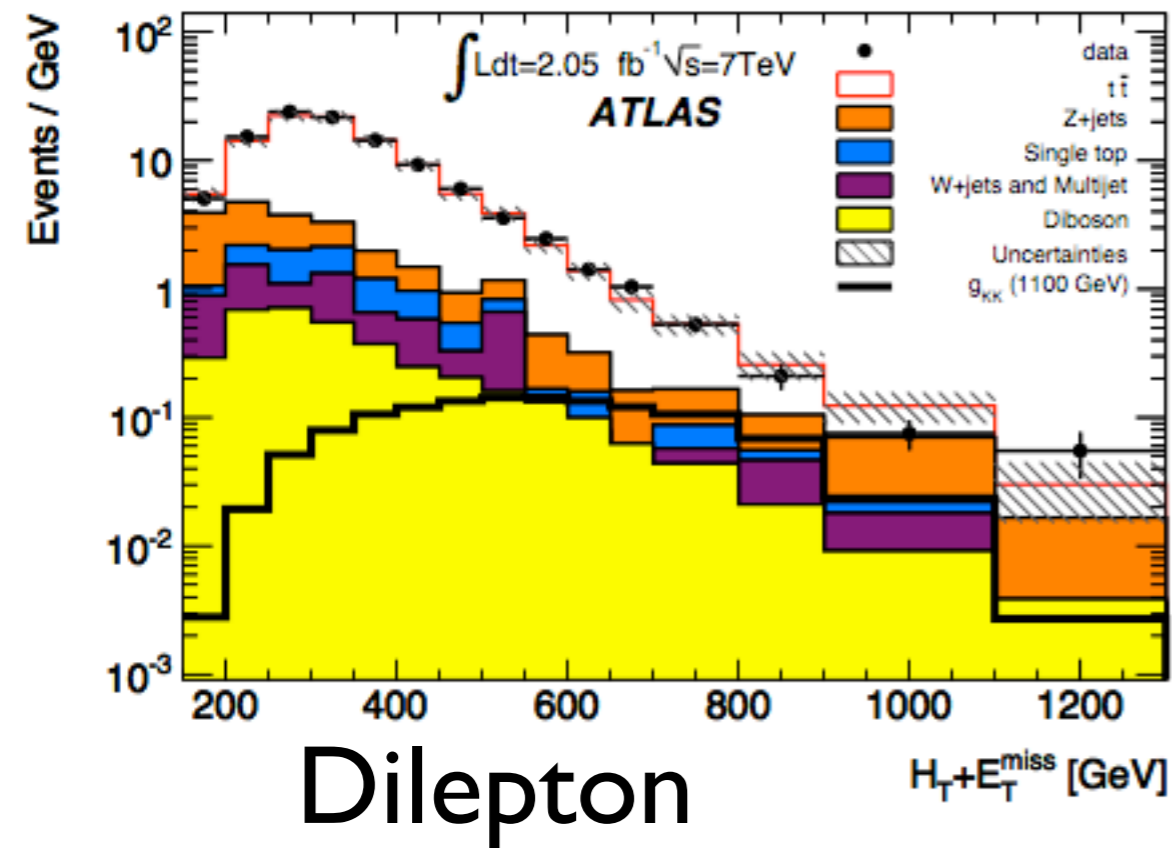
Annapaola  
de Cosa



Chiara Debenedetti

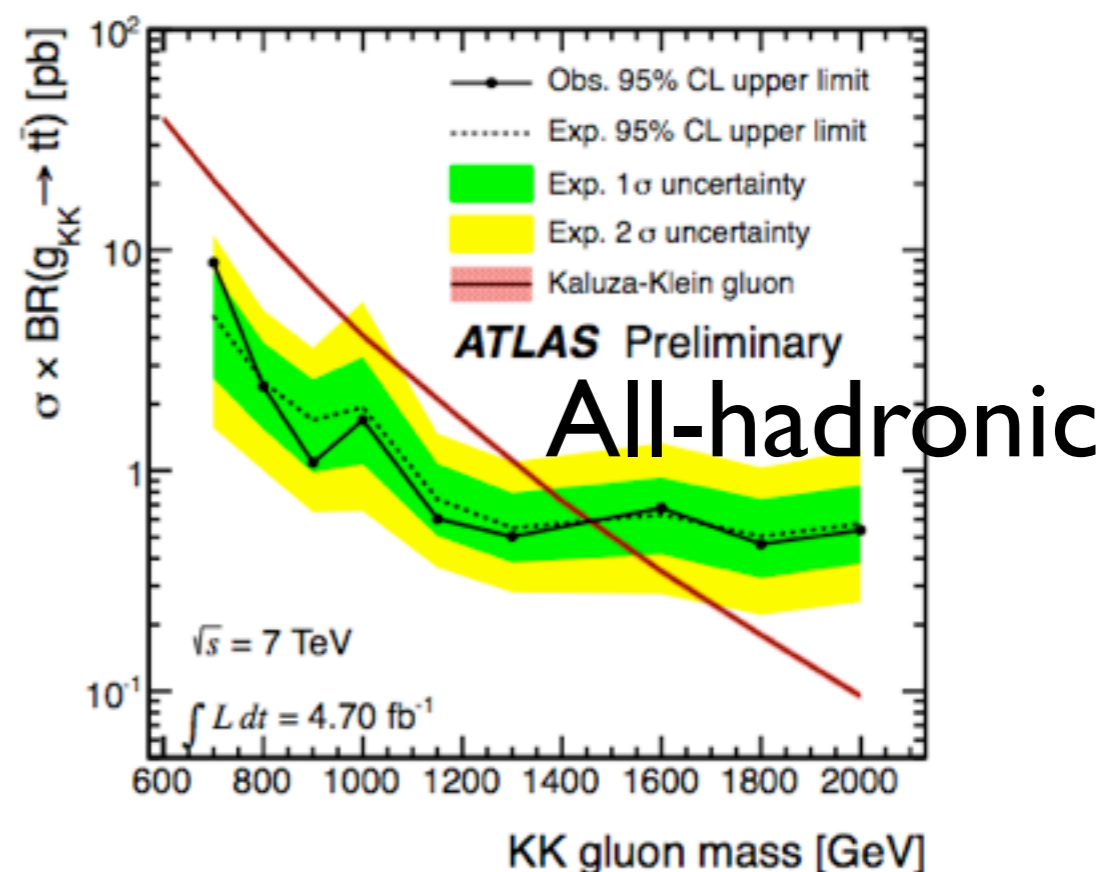
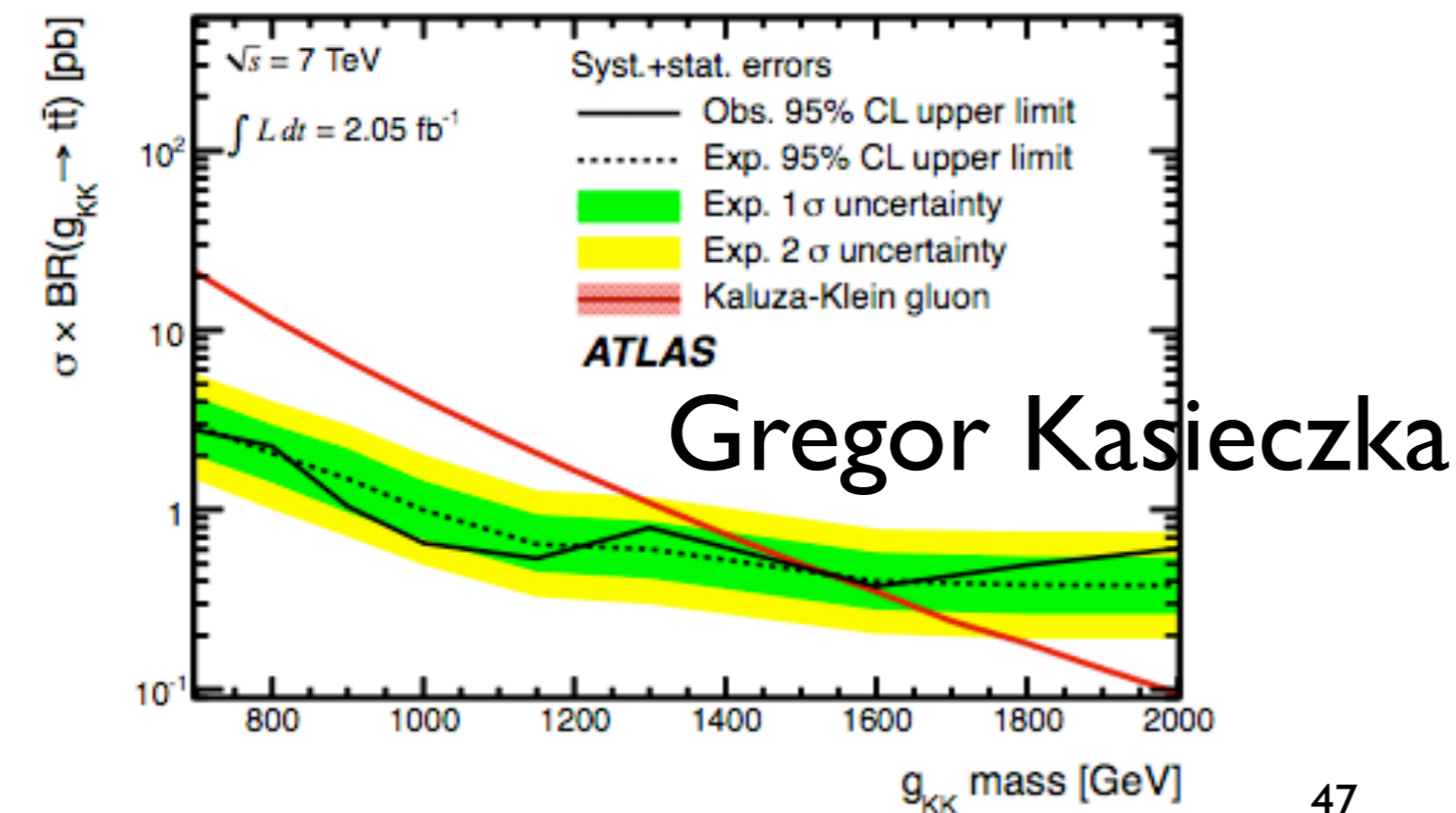
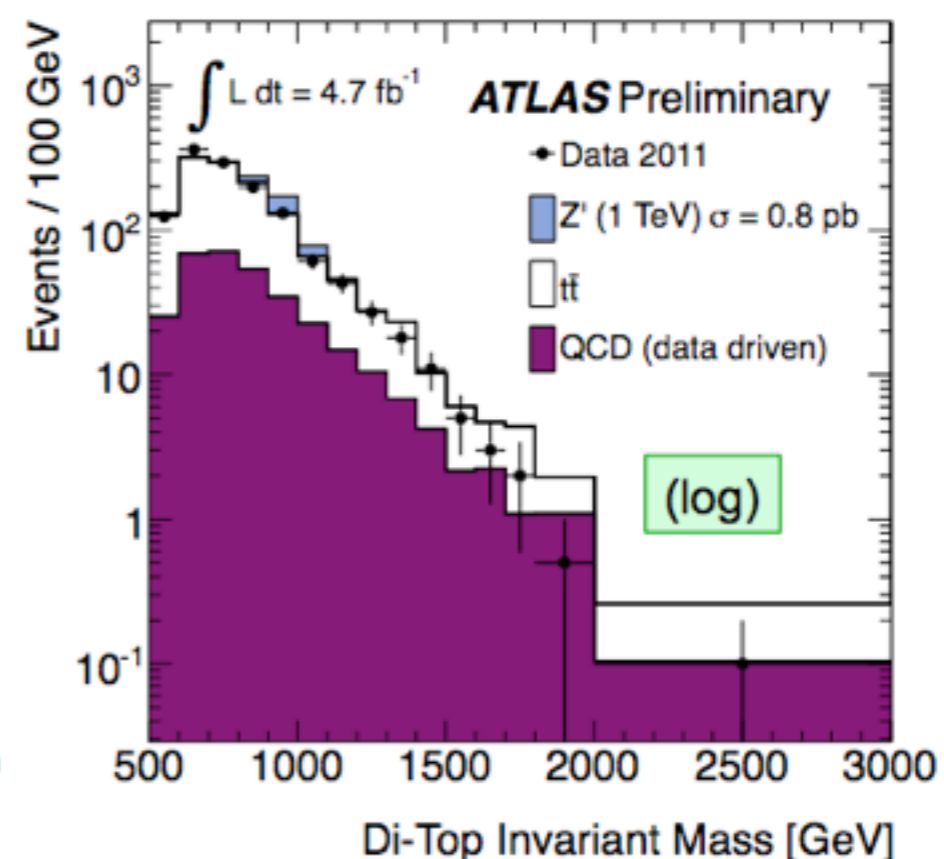
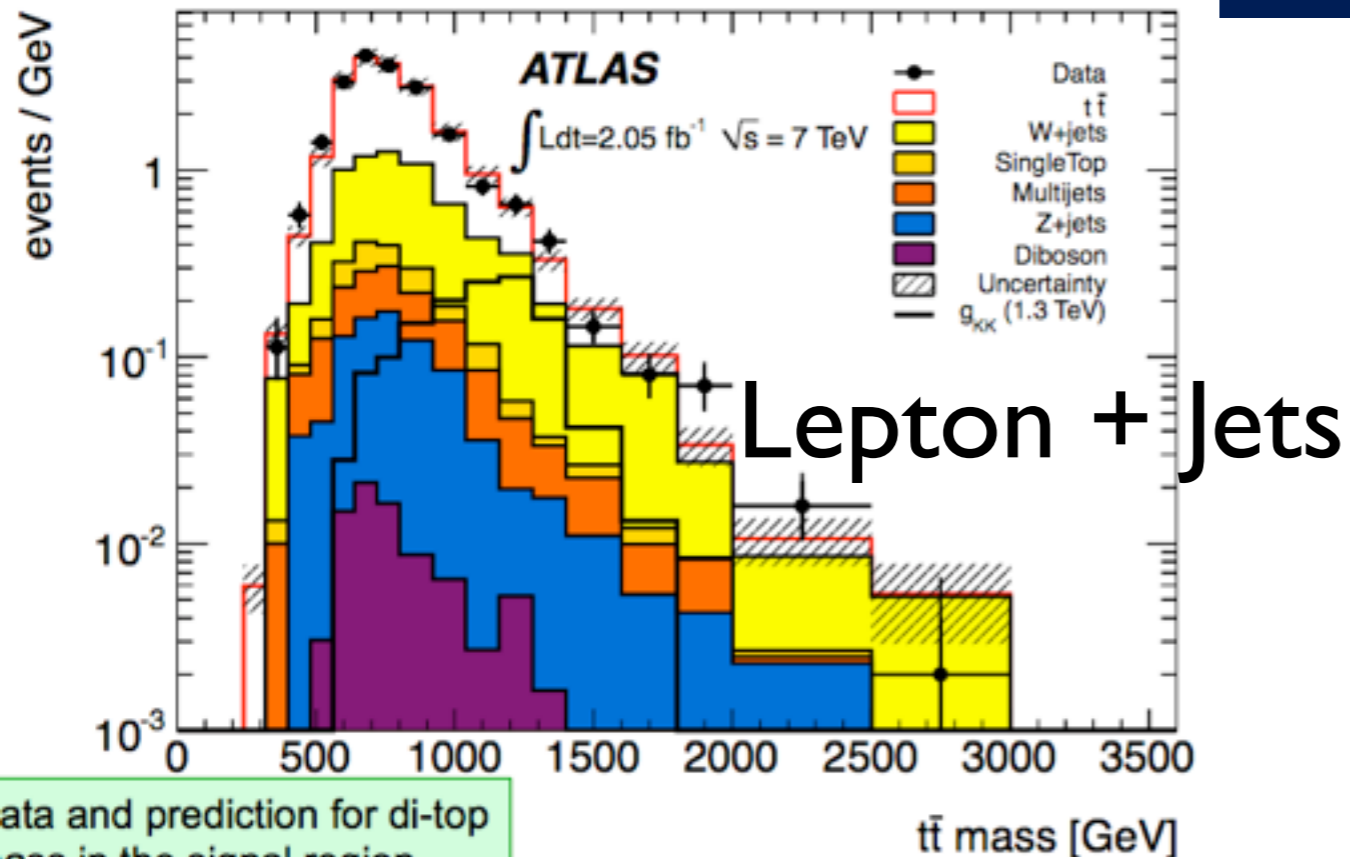
Diligent work being done in this difficult channel  
Absolutely critical for the understanding of the Higgs

# Application : ATLAS $t\bar{t}$ unboosted



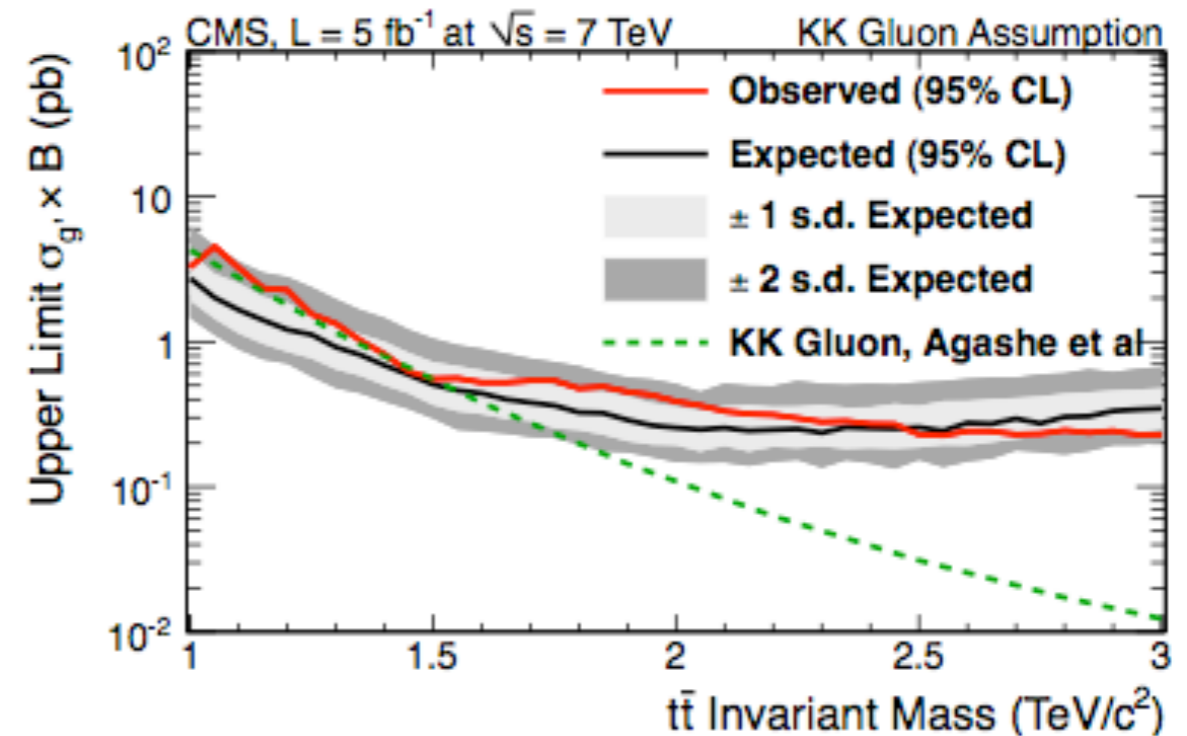
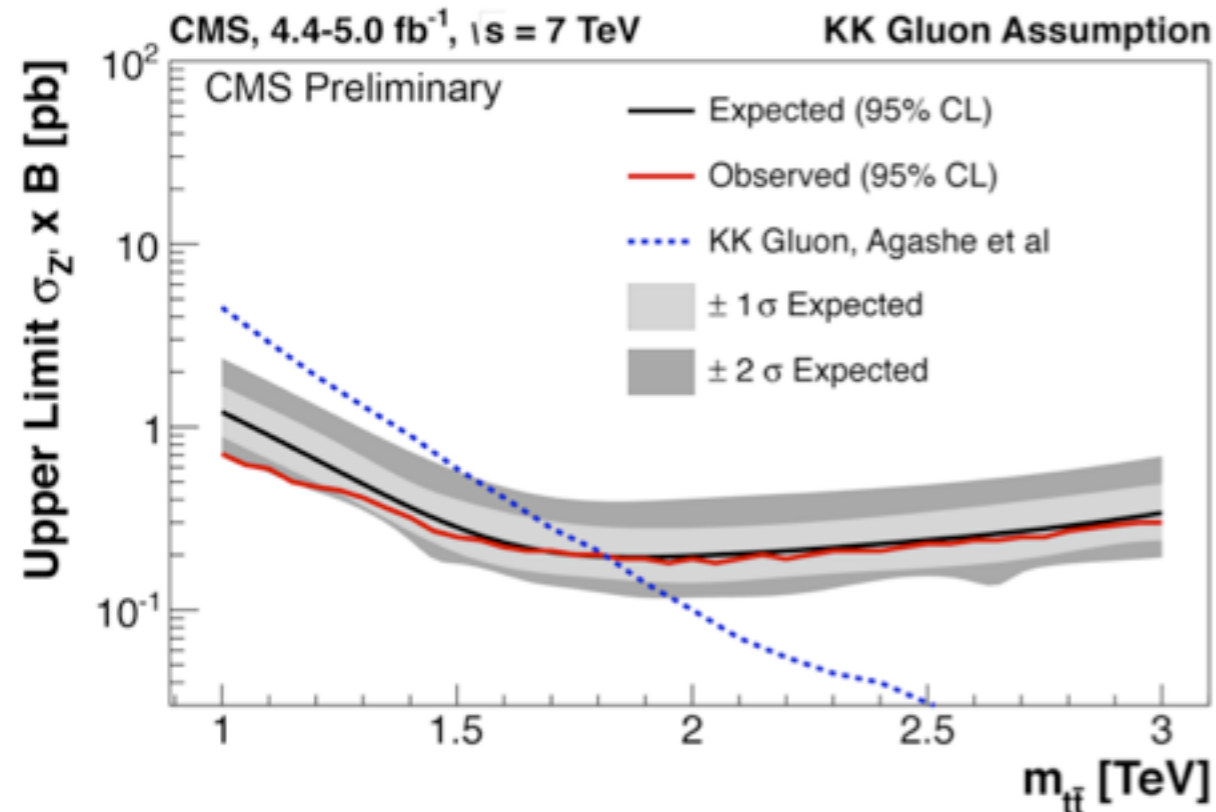
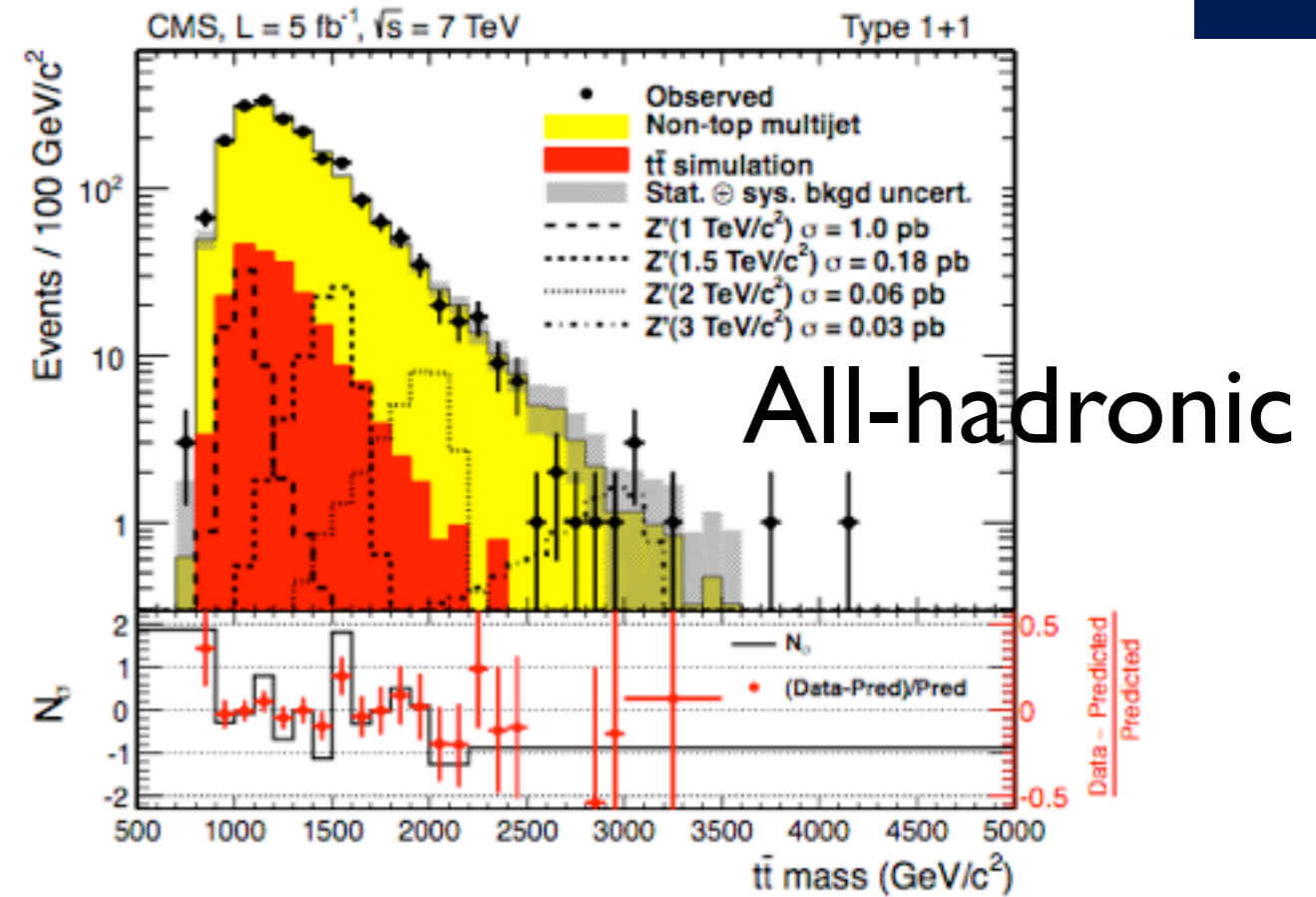
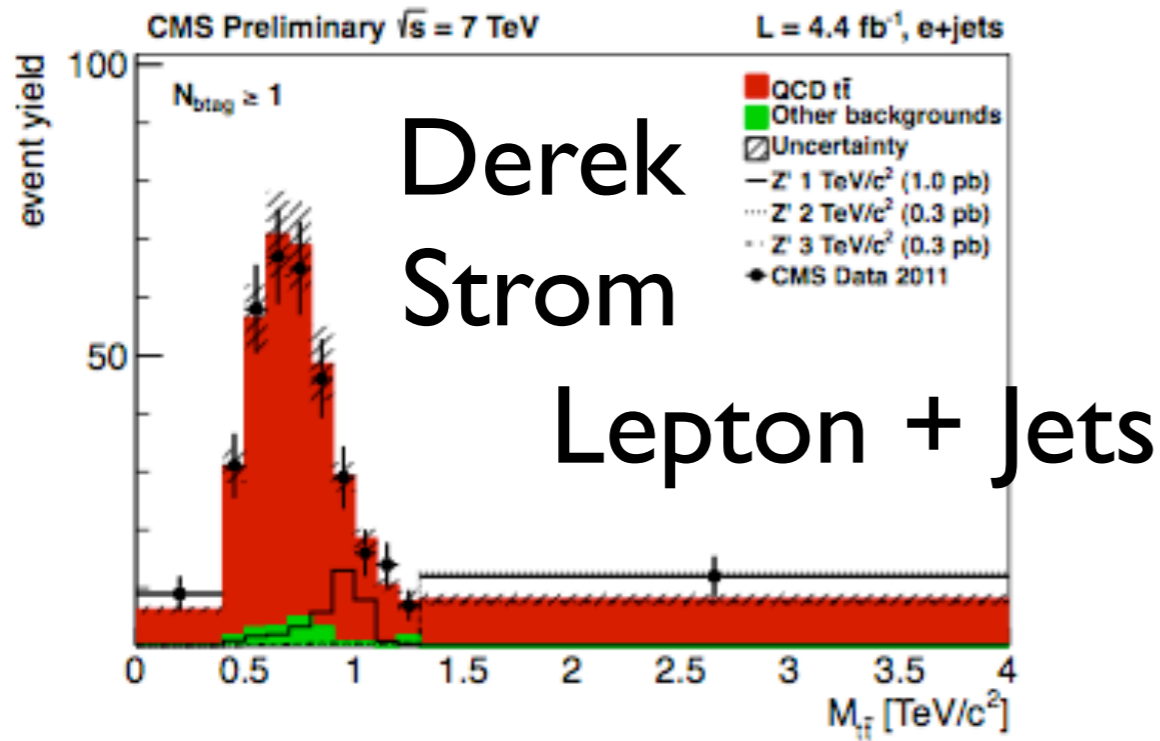
Gregor Kasieczka

# Application : ATLAS $t\bar{t}$ boosted



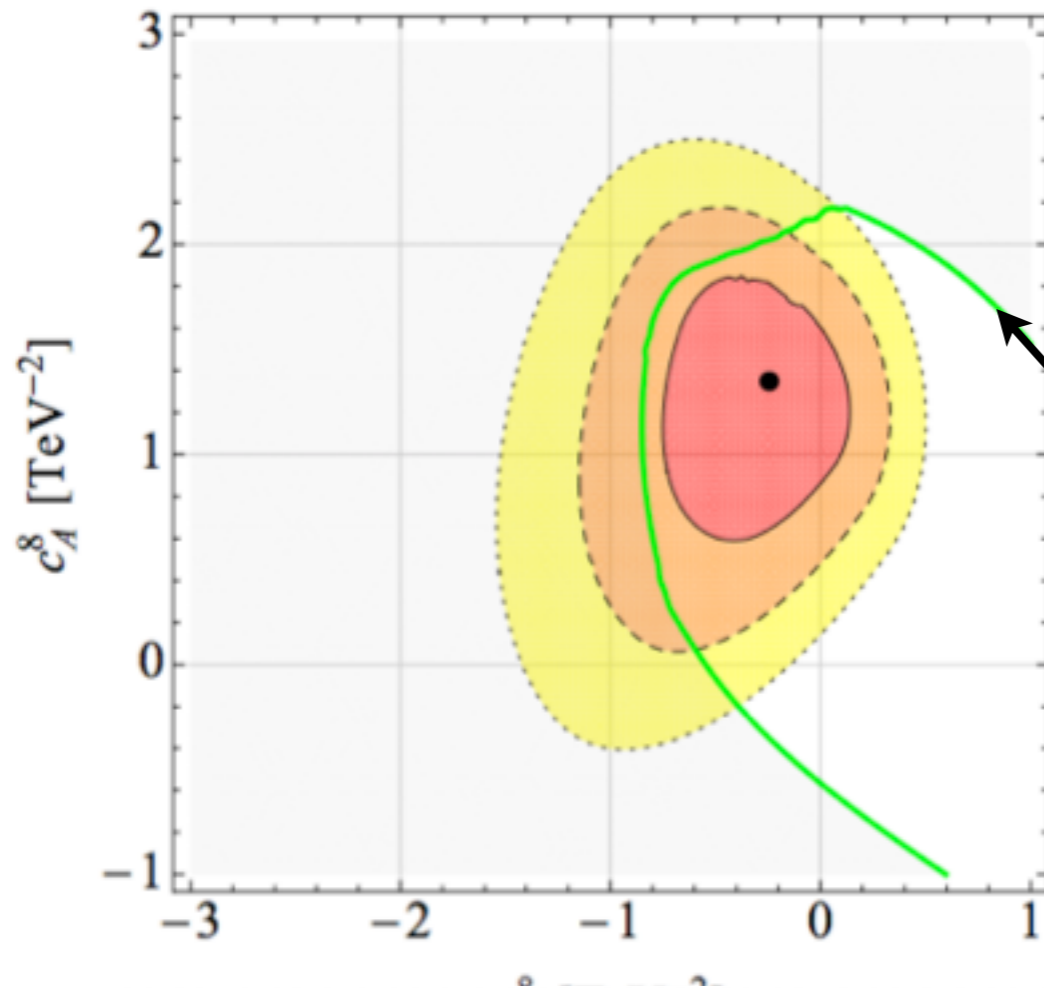
# Application : CMS $t\bar{t}b\bar{a}r$ boosted

Electron + Jets,  $\geq 1$  b tag





# Application : CMS boosted non-resonant



- EFT phase space available for Afb anomaly
- Boosted techniques providing information here!

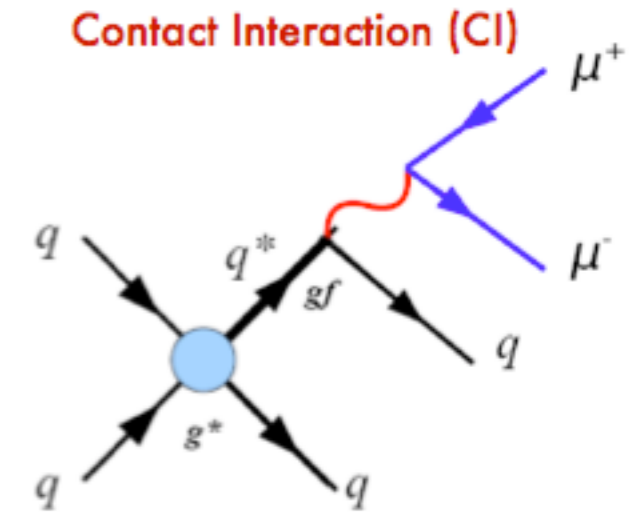
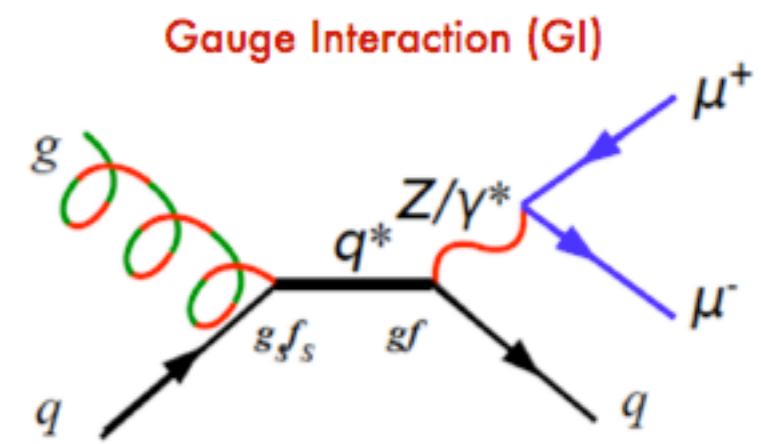
$S < 2.6$  at 95% C.L.

	1+1	1+2
Expected SM $t\bar{t}$ events	$194 \pm 106$	$129 \pm 80$
Expected non-top multijet events	$1546 \pm 45$	$2271 \pm 130$
Total expected events	$1740 \pm 115$	$2400 \pm 153$
Observed events	1738	2423
$t\bar{t}$ efficiency	$(2.5 \pm 1.3) \times 10^{-4}$	$(1.6 \pm 1.0) \times 10^{-4}$

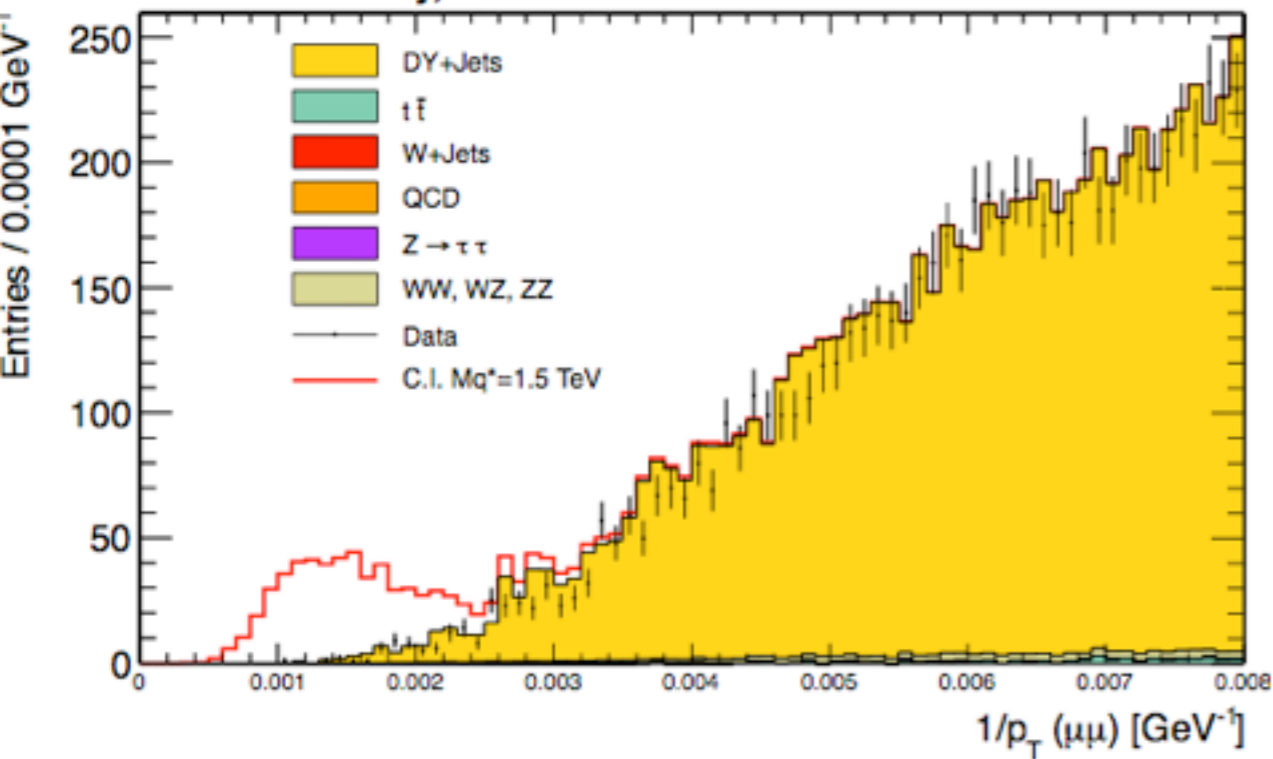
# Application : Boosted Z

Flavia Dias

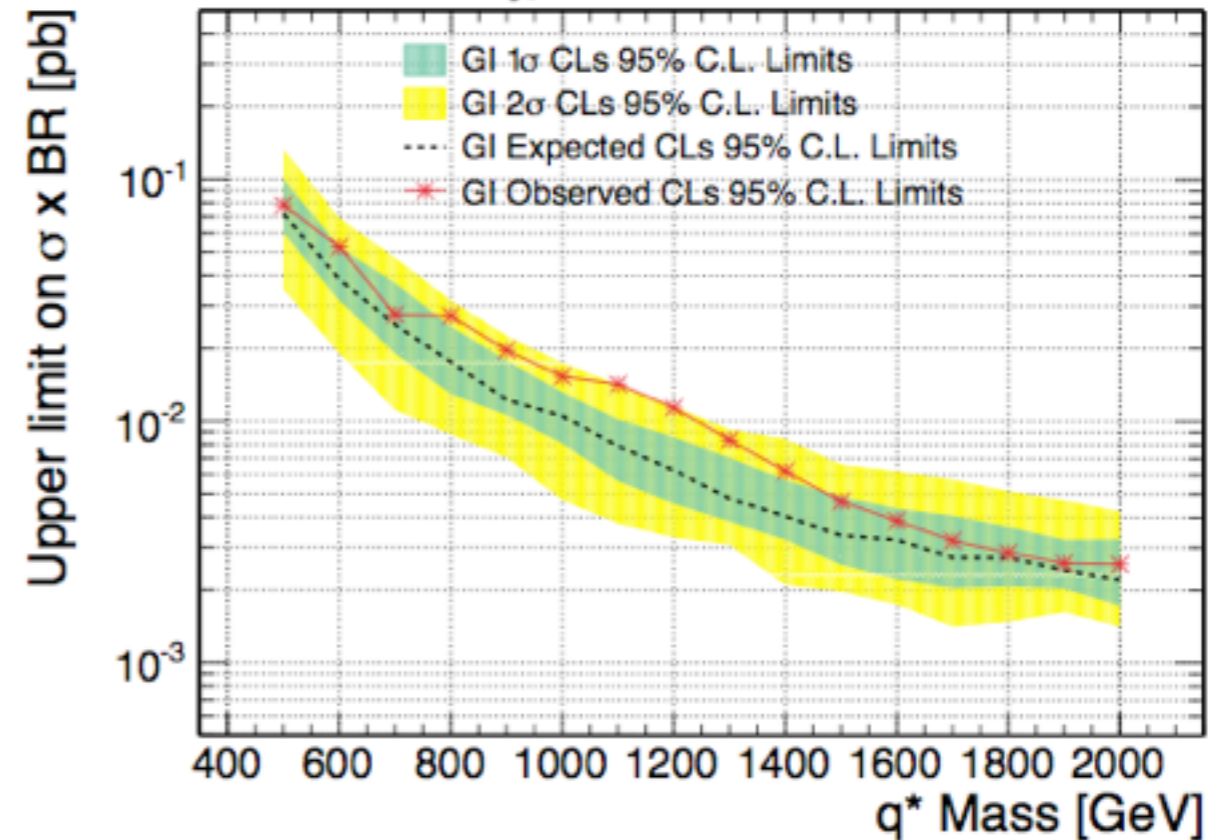
## ✦ Boosted Z's



CMS Preliminary, 5.0 fb<sup>-1</sup> at  $\sqrt{s}=7$  TeV

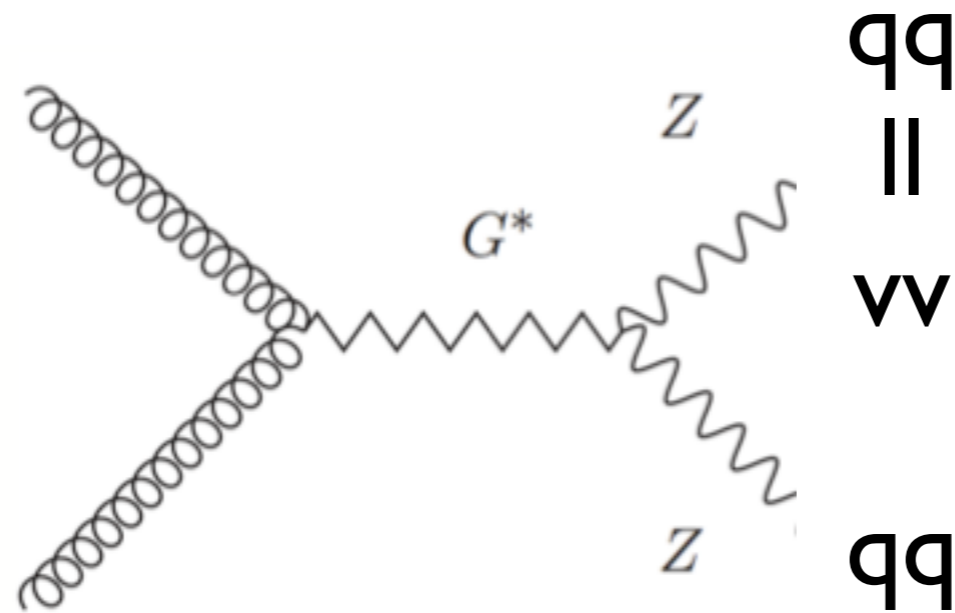


CMS Preliminary, 5.0 fb<sup>-1</sup> at  $\sqrt{s}=7$  TeV



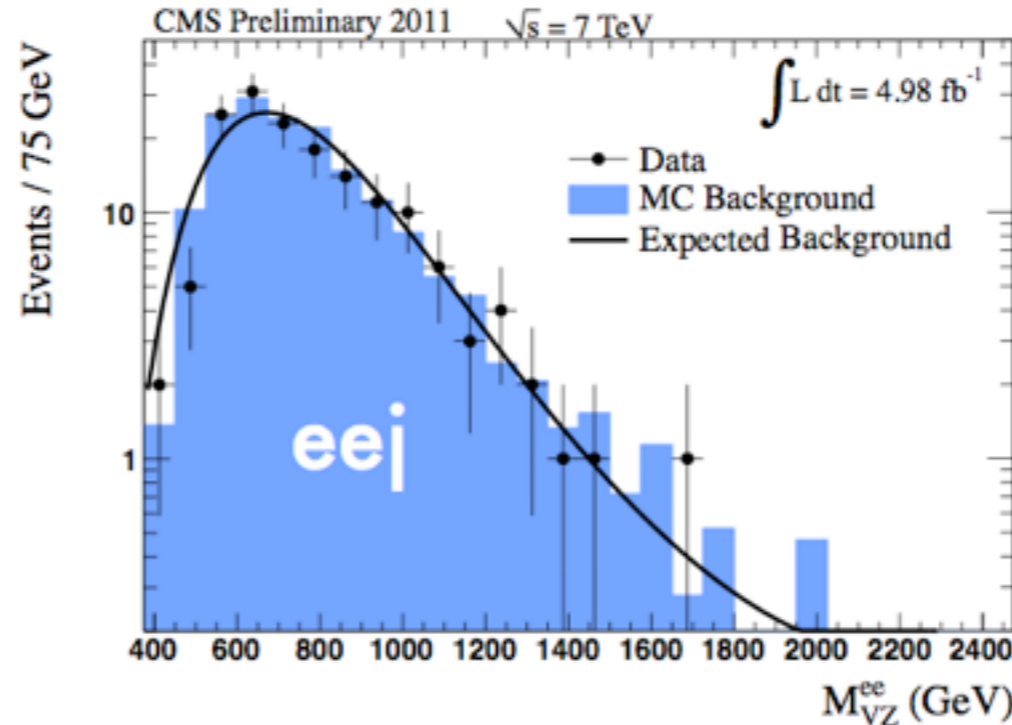
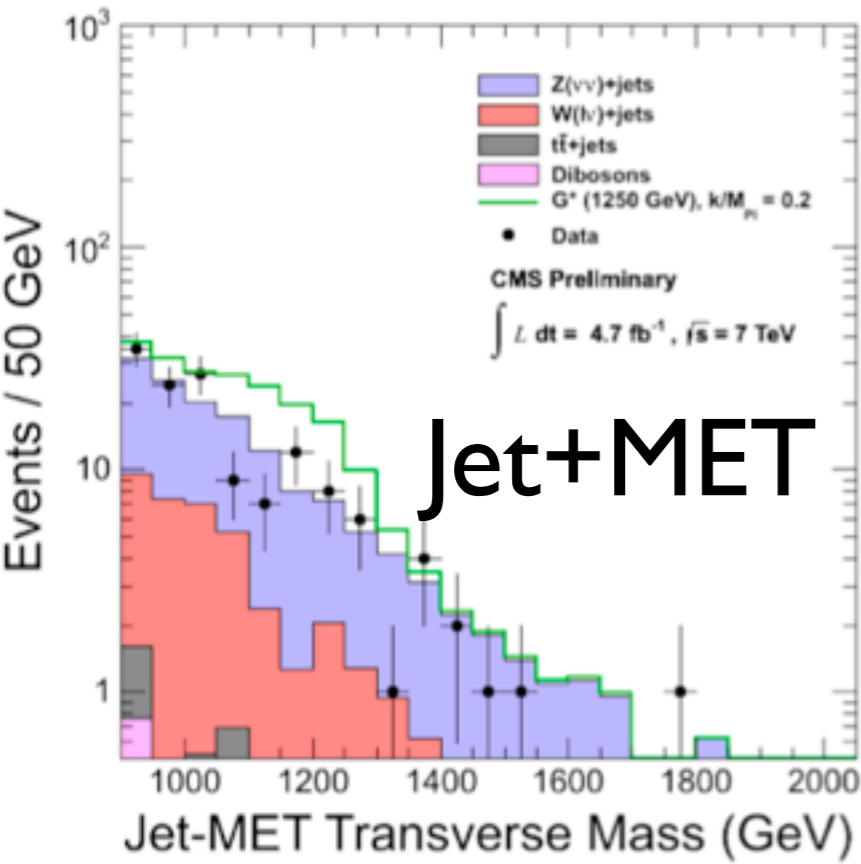
# Application : Boosted $VV$

Flavia Dias

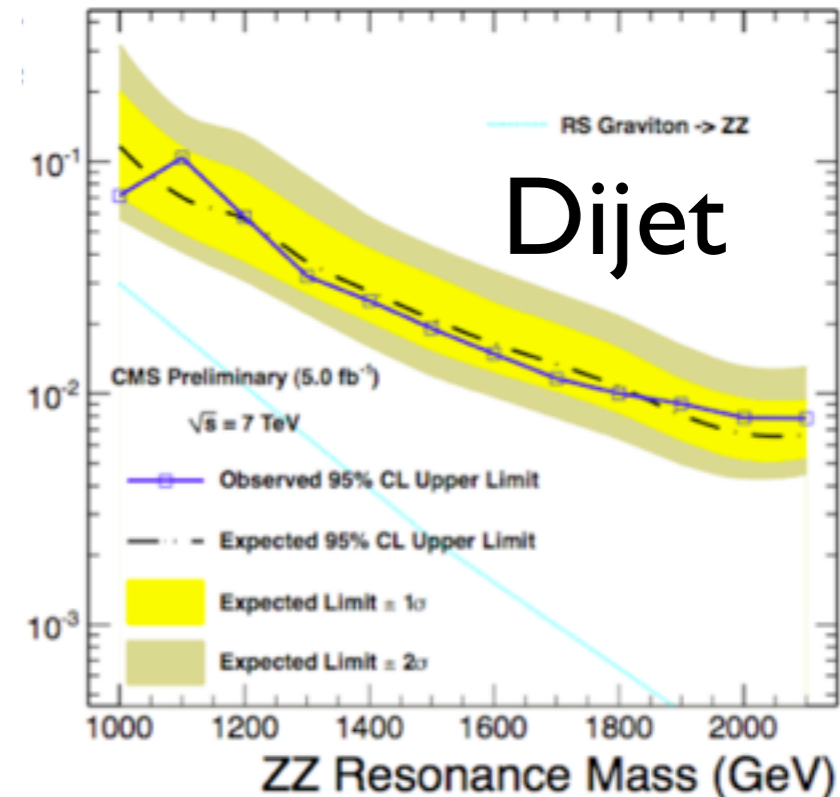
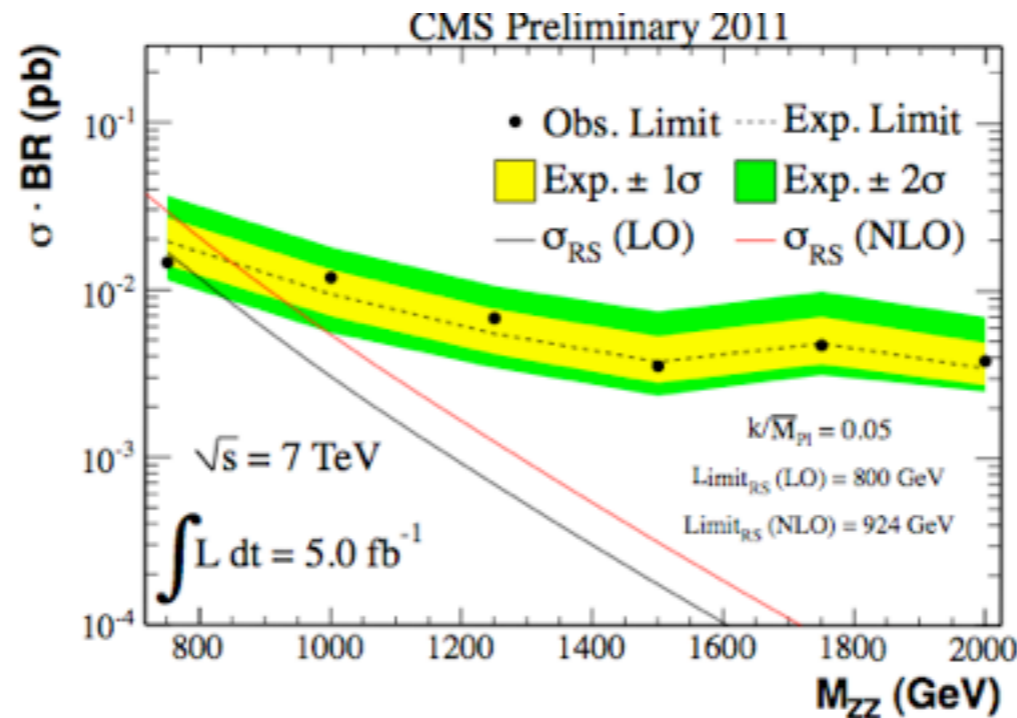
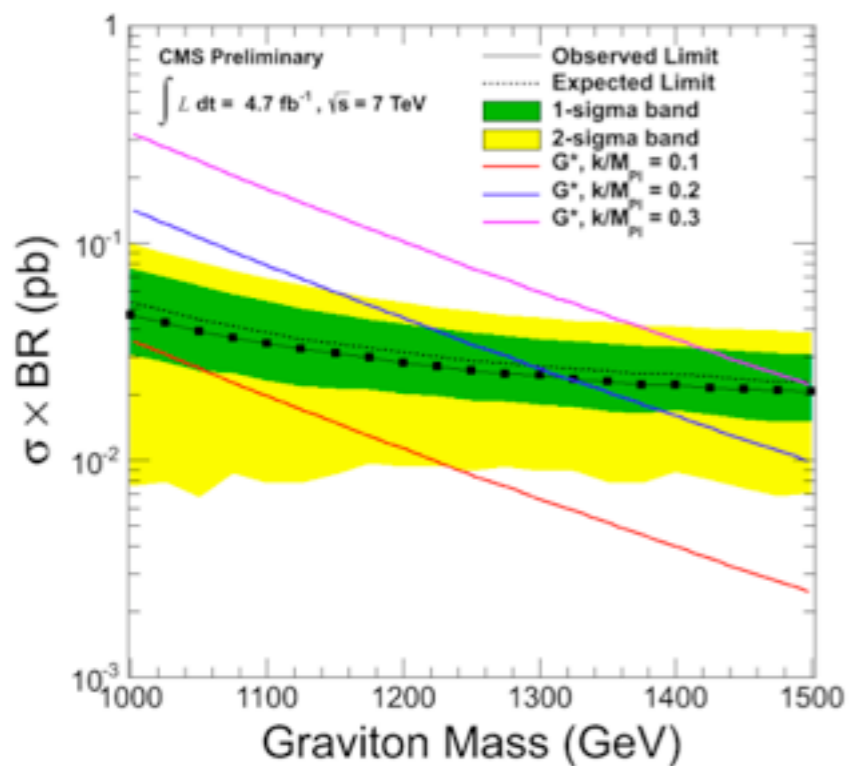
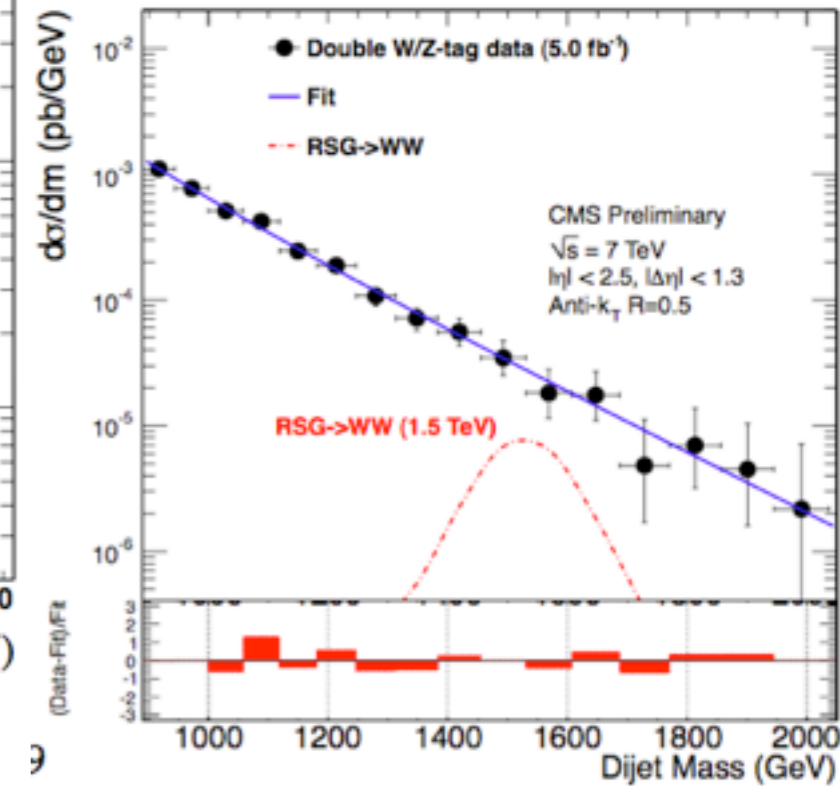


All in the boosted regime!

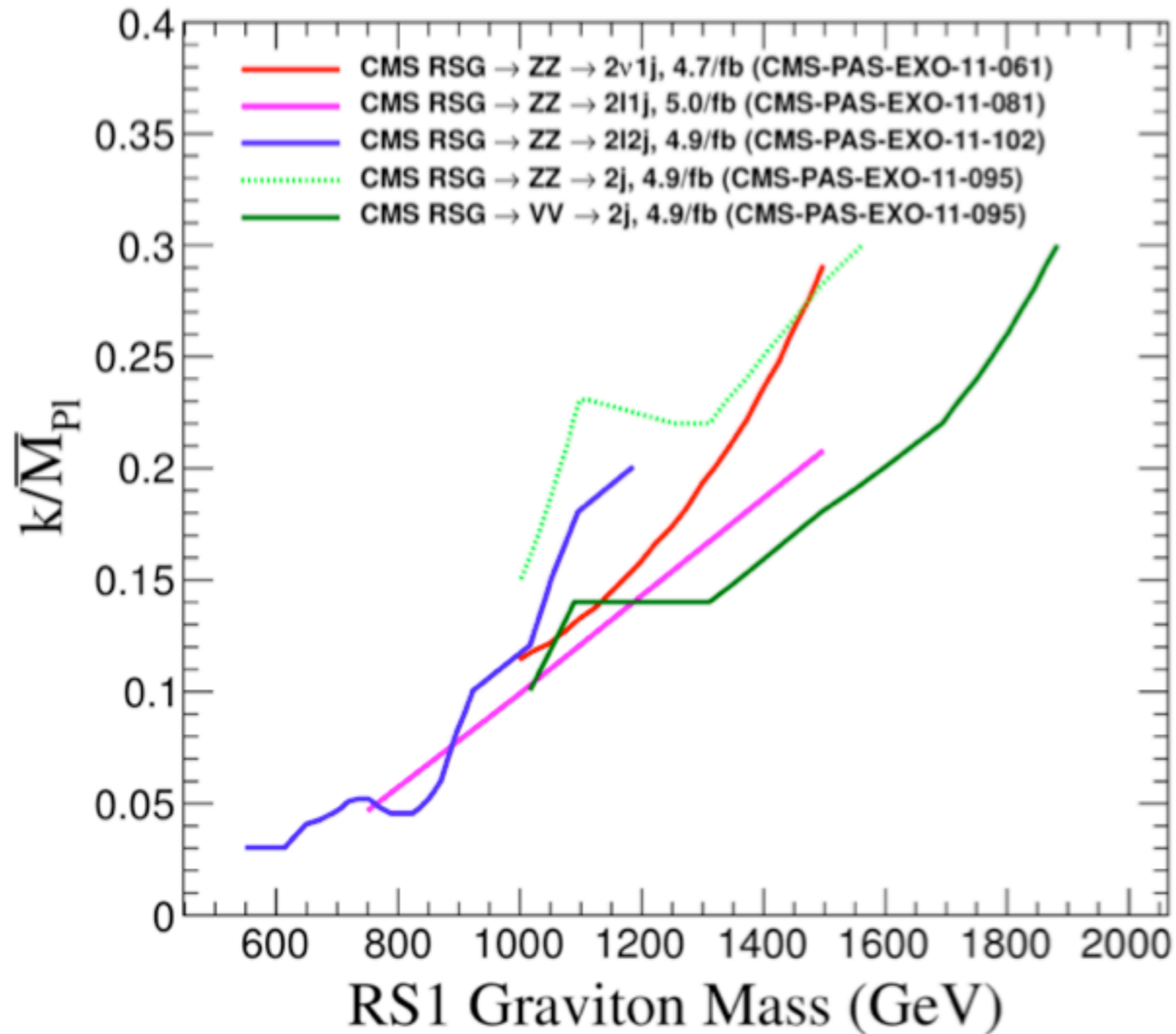
# Application : Boosted VV



**Jet+Z->ll**



# Application : Boosted VV

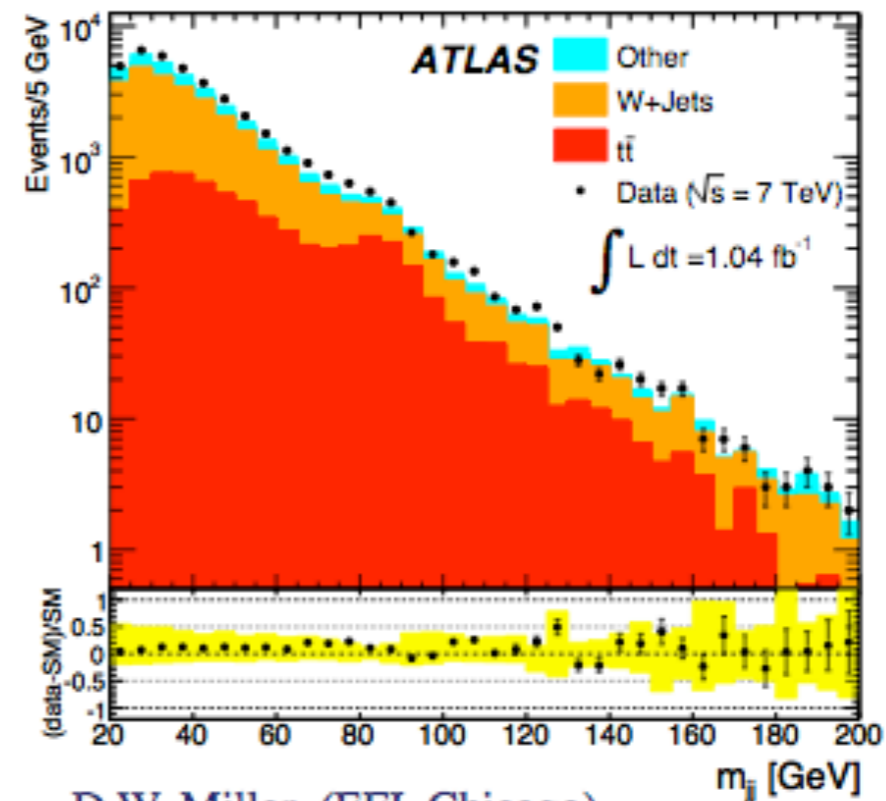


# Application : 4th gen

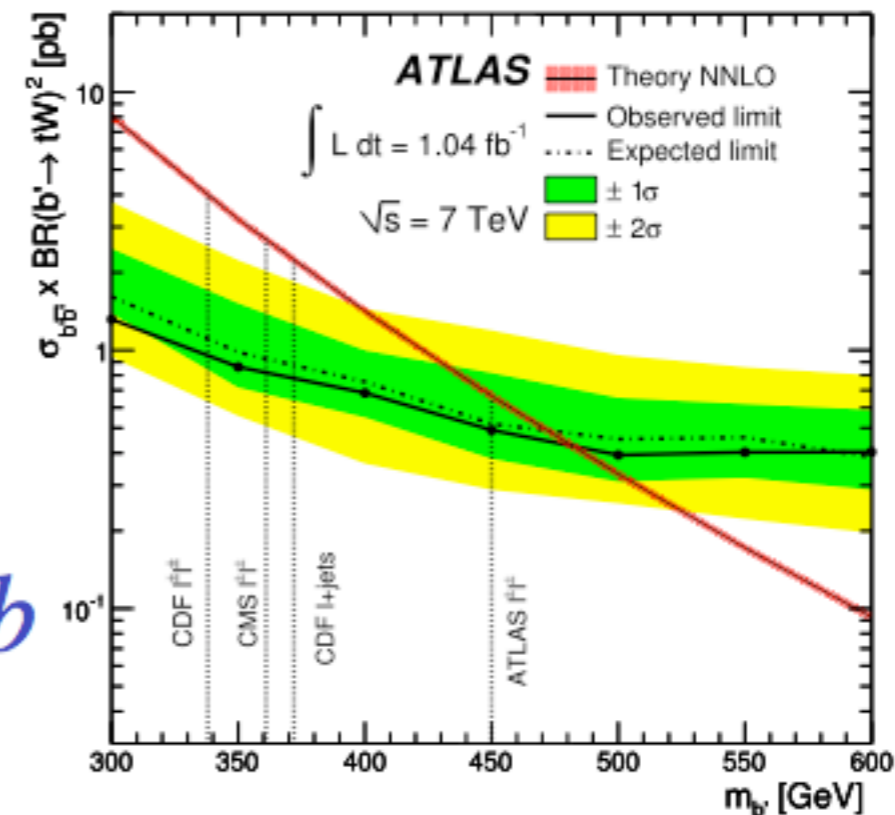
- ✘ See talk by David Miller
- ✘ Survey of analyses
  - ▬ I can't do a survey of a survey. Results are not quite as sharp:



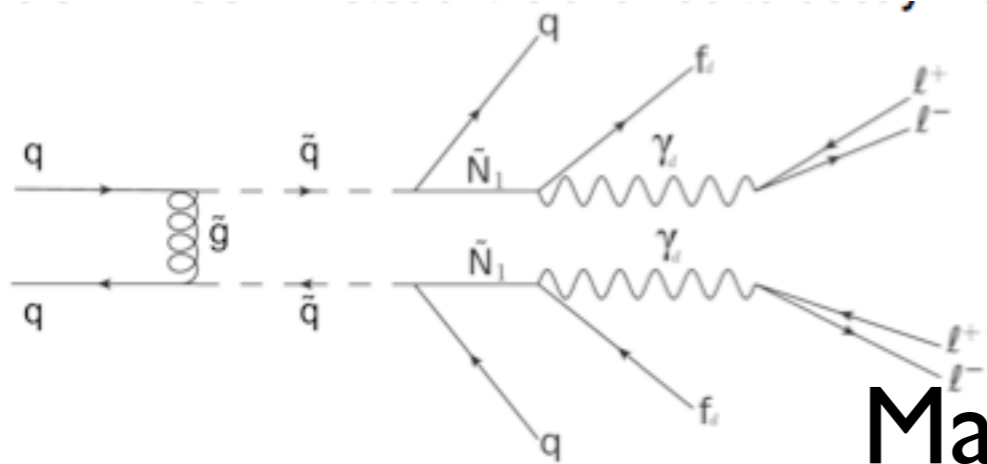
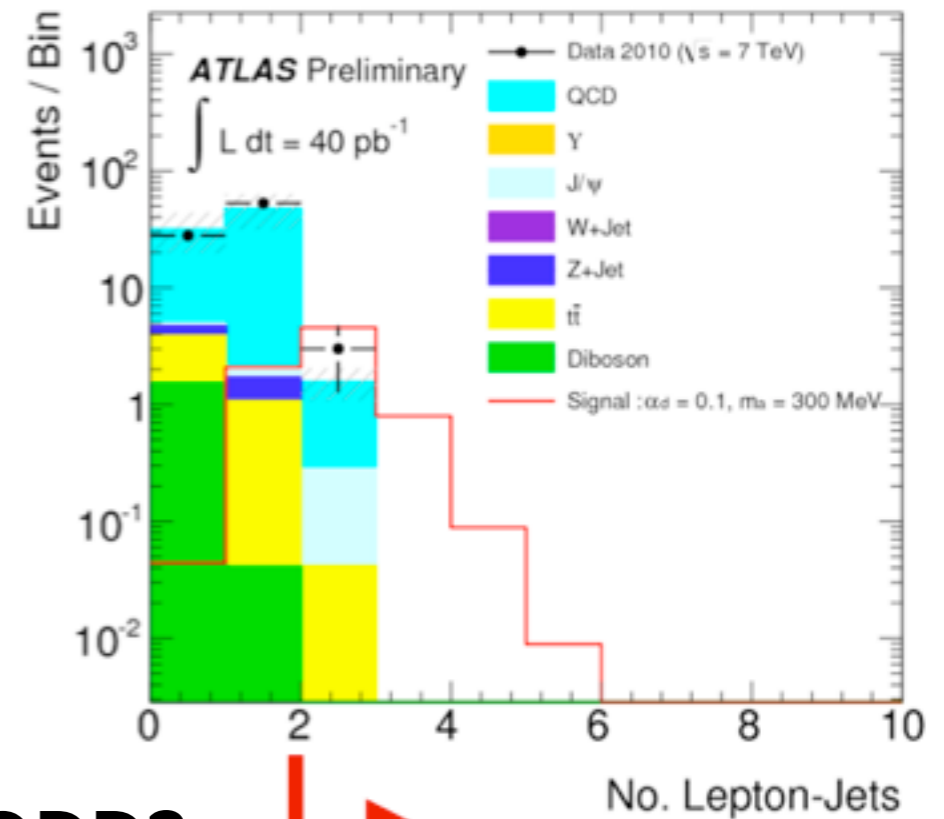
- ✘ One boosted analysis : 4th generation



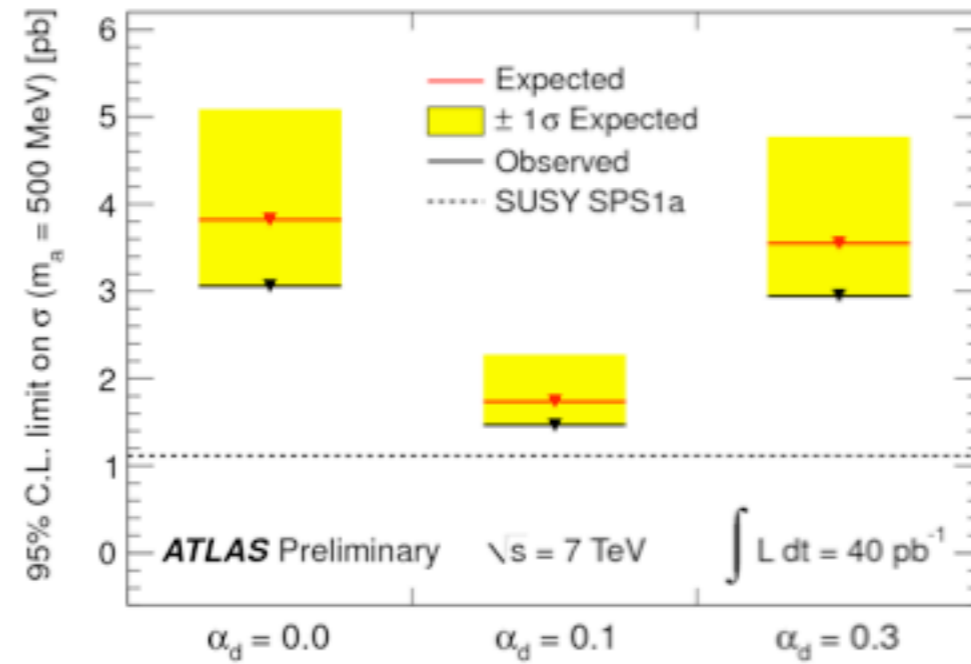
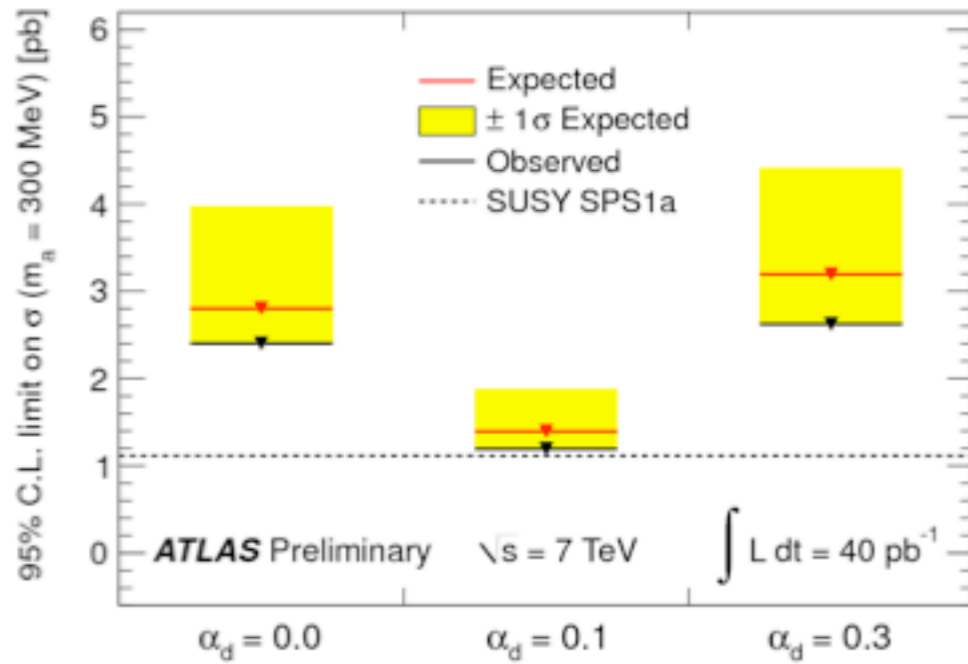
D.W. Miller (EFI, Chicago)



# Application : ATLAS, Non-hadronic jets



Marco Schioppa

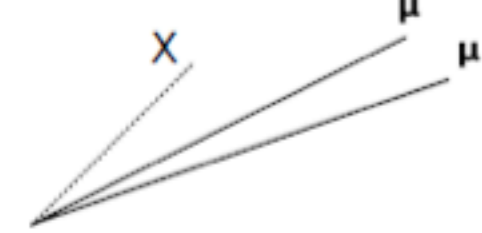


Muon channel provides a unique and almost background-free signal

# Application : CMS Non-hadronic jets

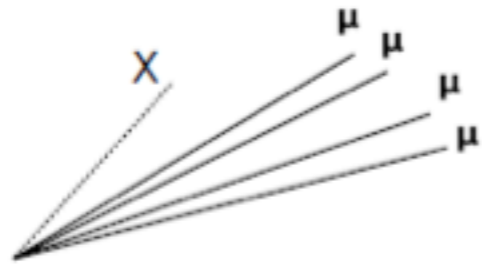
- Assume new bosons produced on-shell:

1 muon jet,  $p_T > 80$  GeV/c,  
2 muons



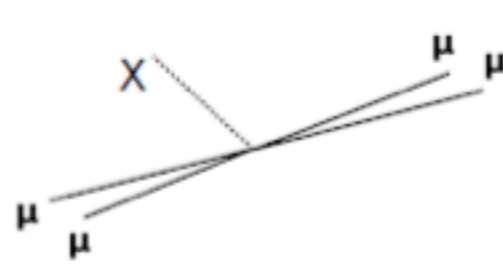
dimuon + X

1 muon jet, 4 muons

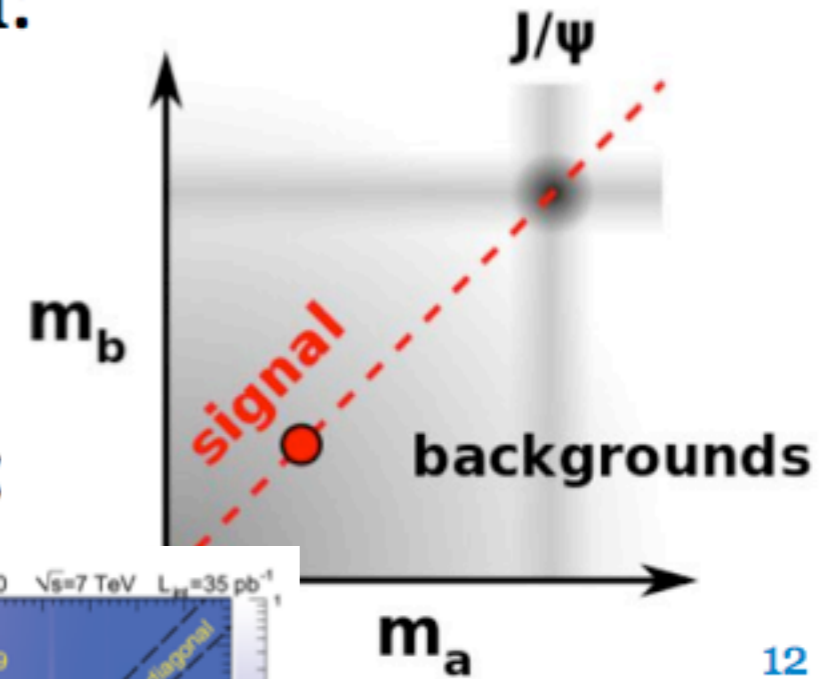


quadmuon + X

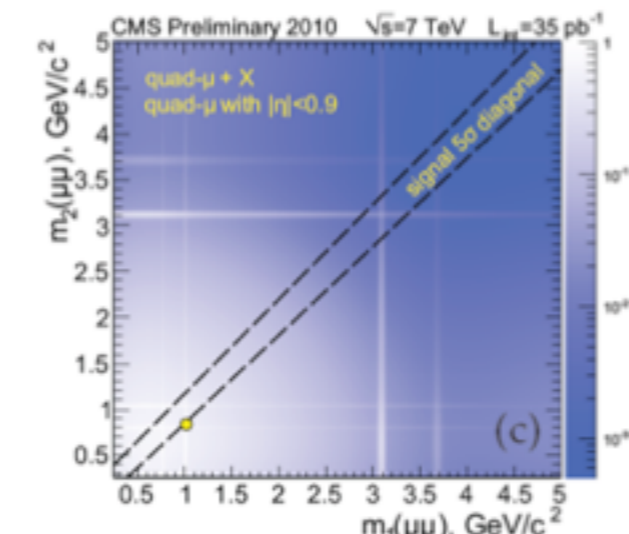
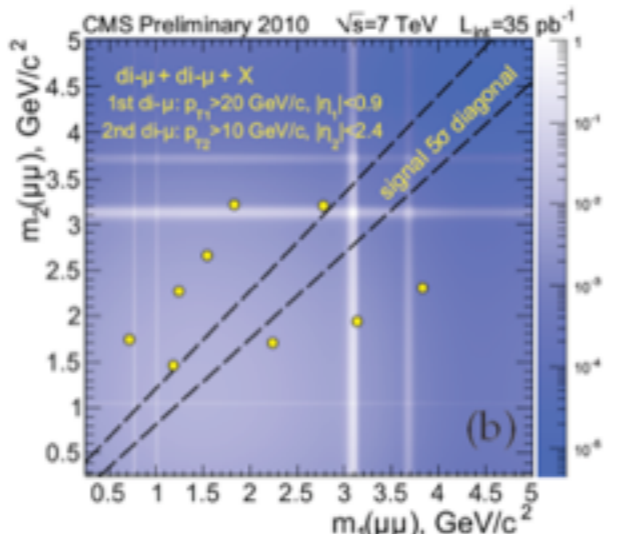
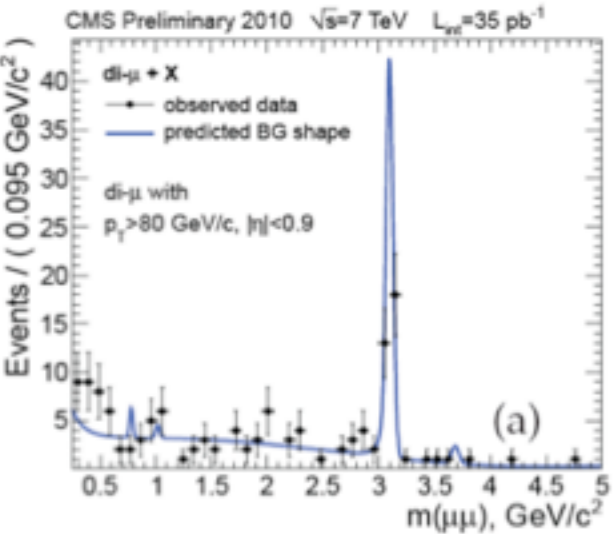
2 muon jets, 2+2 muons



two dimuons + X



12



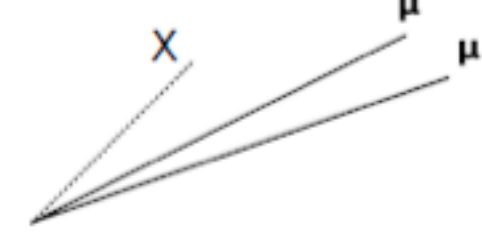
- No events with consistent masses of dimuons in higher order categories



# Application : CMS Non-hadronic jets

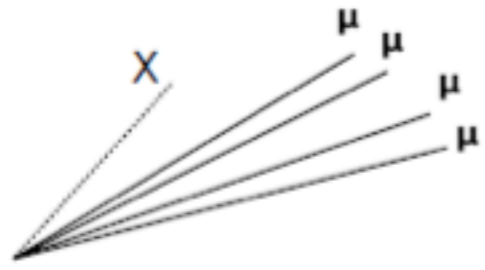
- Assume new bosons produced on-shell:

1 muon jet,  $p_T > 80$  GeV/c,  
2 muons



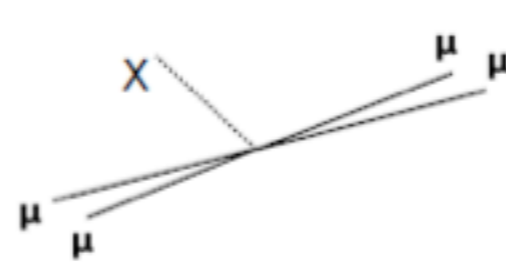
dimuon + X

1 muon jet, 4 muons

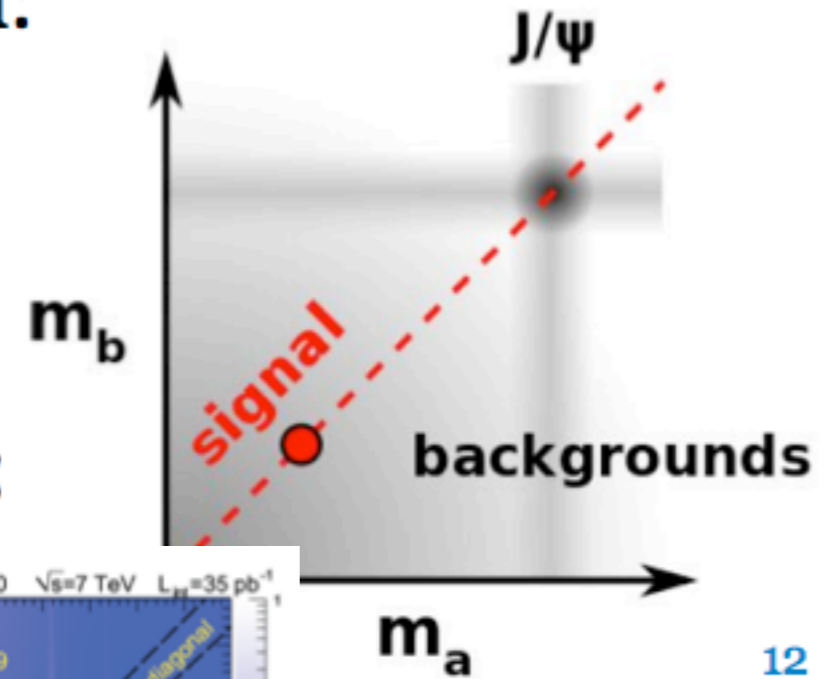


quadmuon + X

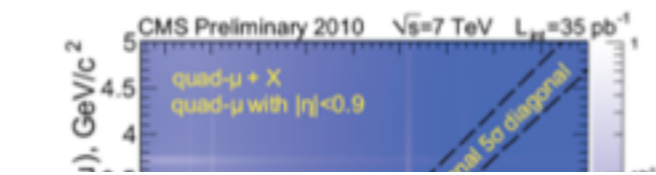
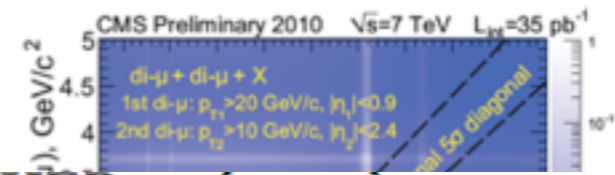
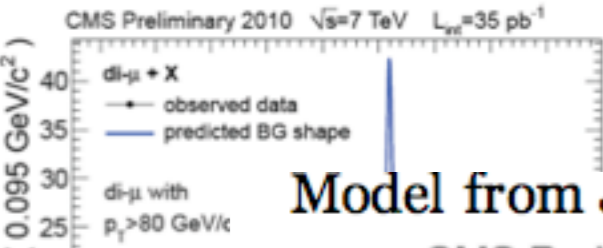
2 muon jets, 2+2 muons



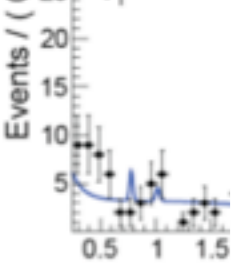
two dimuons + X



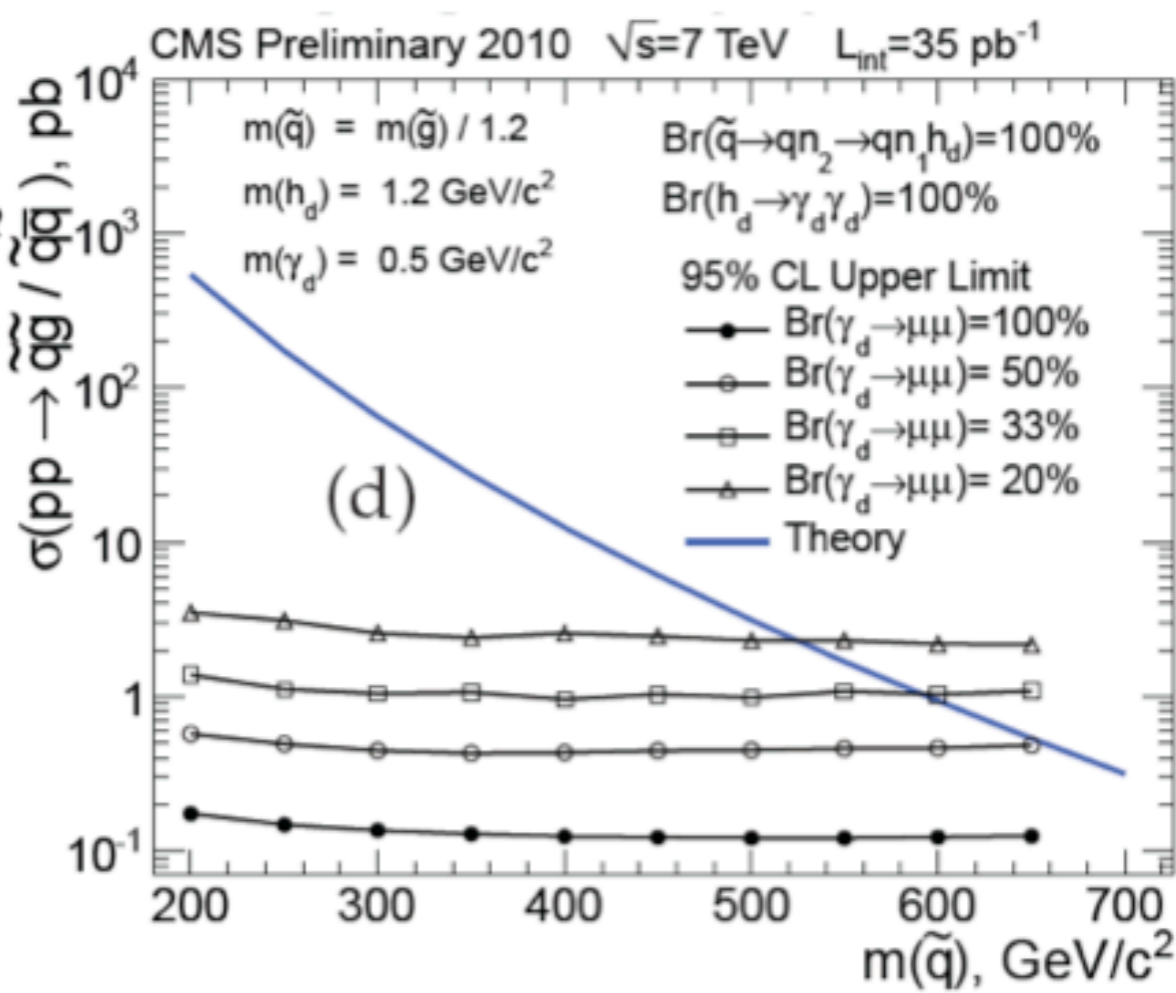
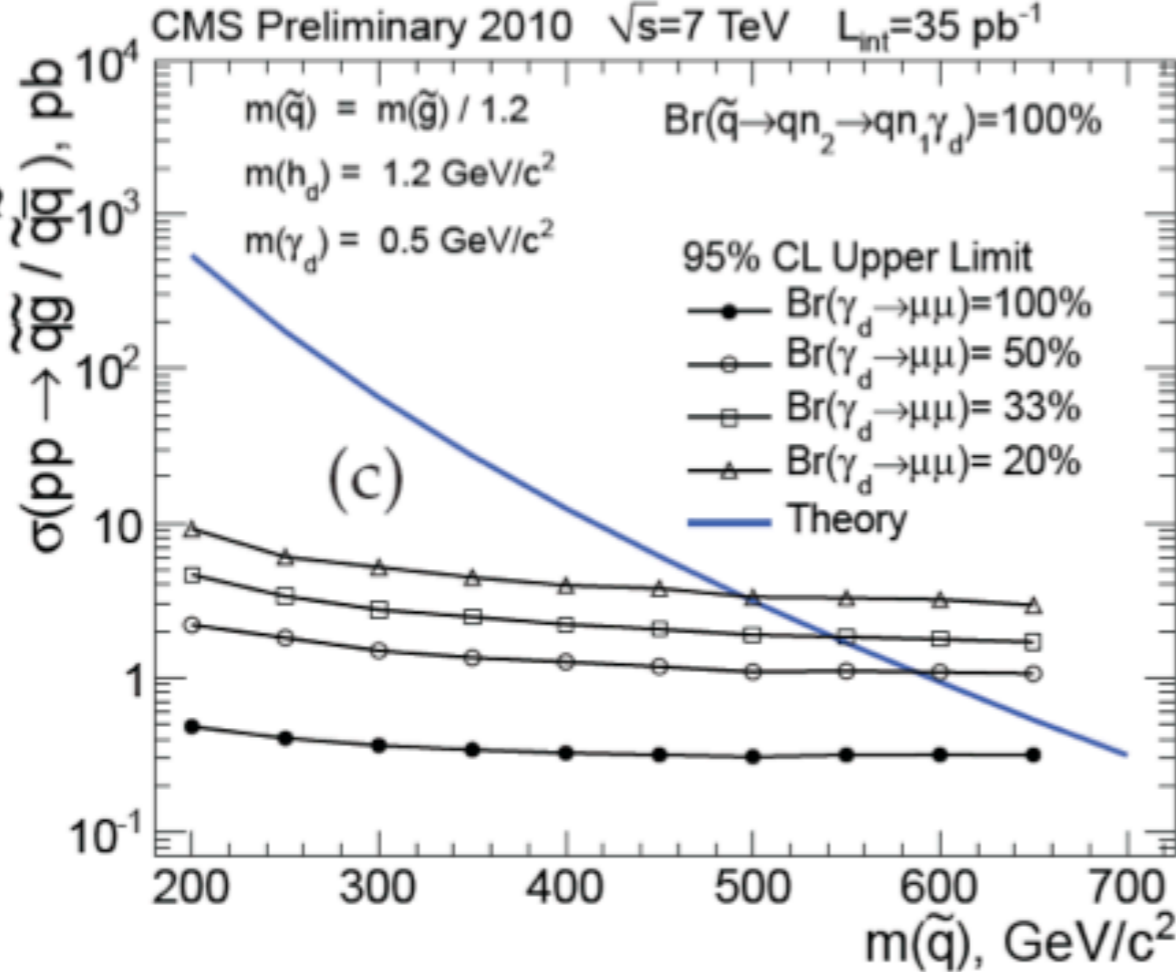
12



Model from JHEP 04 (2009) 014.



•  $N_c$

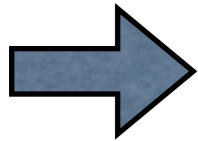


# Applications

- ✦ Take-home message :
  - Already widely deployed in searches
  - Providing physics input to the community
  - And yet, still in infancy! Get the word out!

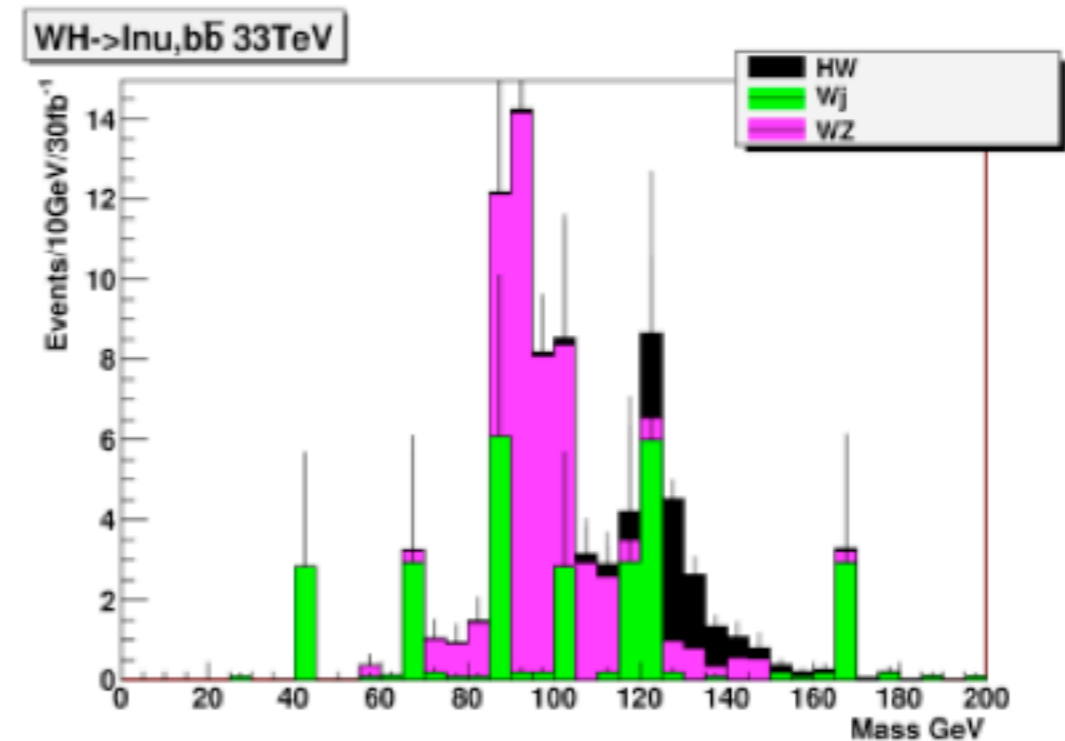
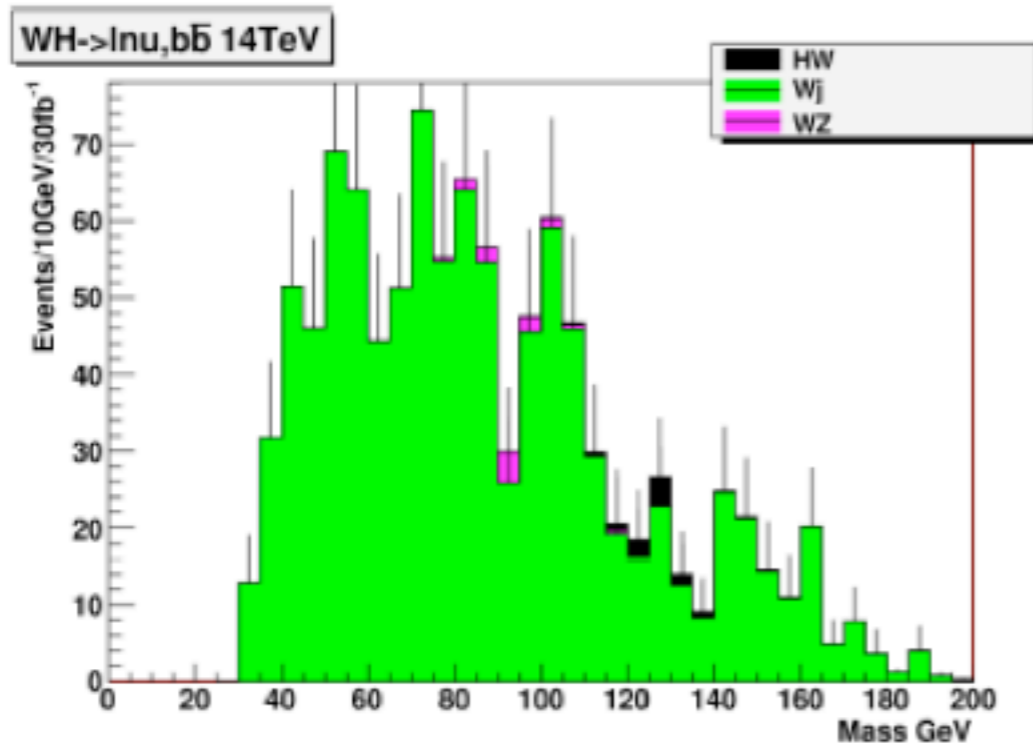
# Outline

- ✦ A new context
- ✦ Merged jets in data
- ✦ Pileup
- ✦ Studies on tools
- ✦ Substructure measurements
- ✦ Applications to searches
- ✦ Future colliders
- ✦ Conclusion



# Future colliders

Mario Campanelli



- ✦ Good news: even more boosted!
  - (And I'm almost done)
- ✦ Bad news : Pileup may be disastrous!

# Summary



# Summary



(yes, I actually own this T-shirt) :  
<http://store.xkcd.com/>

# Thank you!

- ✦ BOOST2012 was an enormously successful workshop (in my view)
- ✦ Many thanks to the organizers for putting on a fantastic show on a very reasonable budget!
- ✦ Only problem: we'll all spend a few weeks shedding the extra kilos from the great food ;)