37th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
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Search for the Higgs boson in VH(bb) channel using the ATLAS detector

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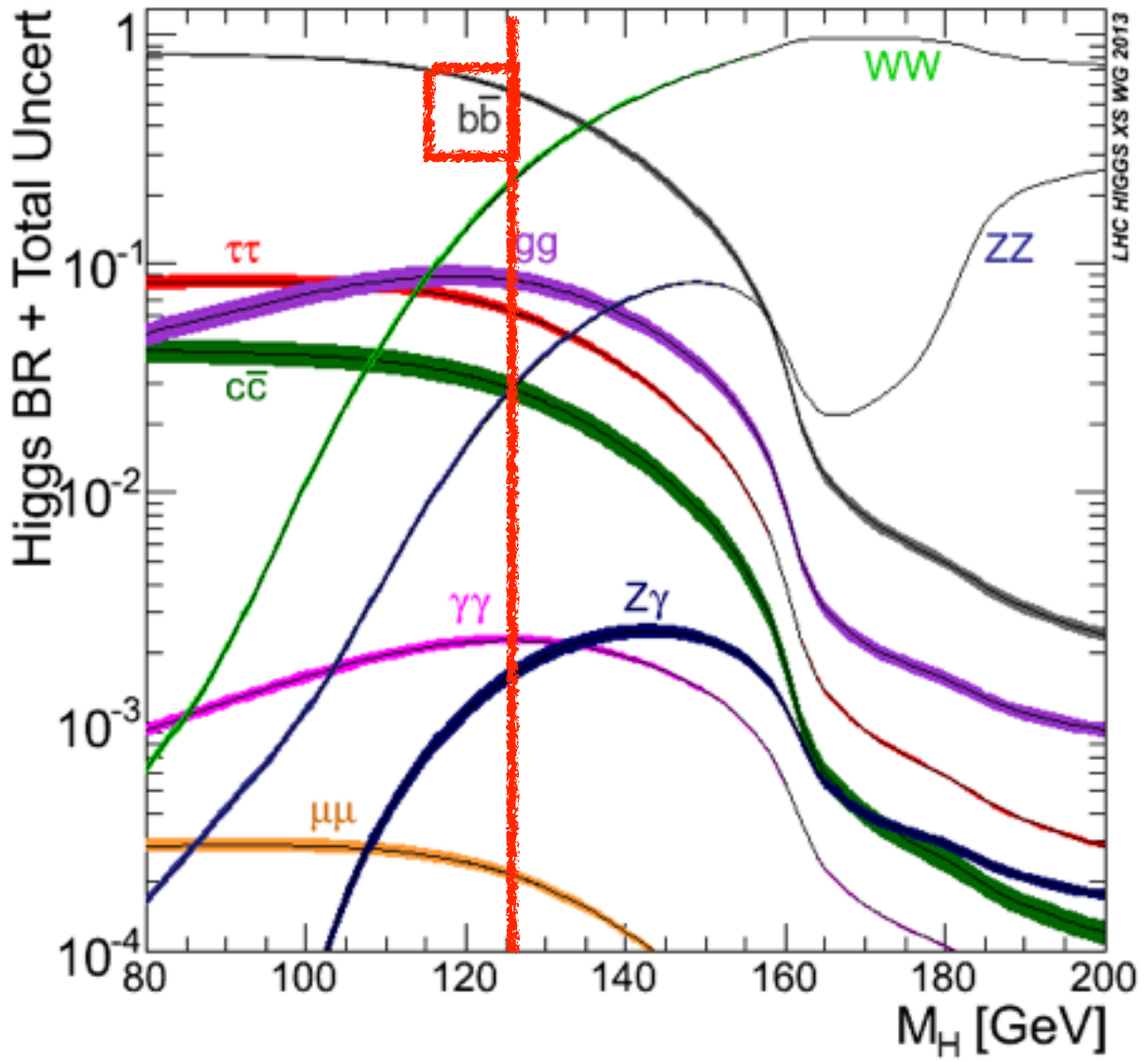
H→bb: Why?

- Since 4 July 2012:
  - Discovery of a new spin $J^P=0^+$ particle. H→γγ H→ZZ H→WW.
  - No strong deviations from SM BEH boson properties.
  - Observed m_H =125.36 ± 0.41 GeV.
- Evidence for fermionic decay modes:
  ATLAS: H→ττ (4.1σ)
  CMS: combination H→ττ H→bb (3.8σ)
- Indirect indication of couplings to quarks (i.e. in ggH production)
- Crucial to get an evidence of the coupling to the quarks
  in particular to down-type quarks.



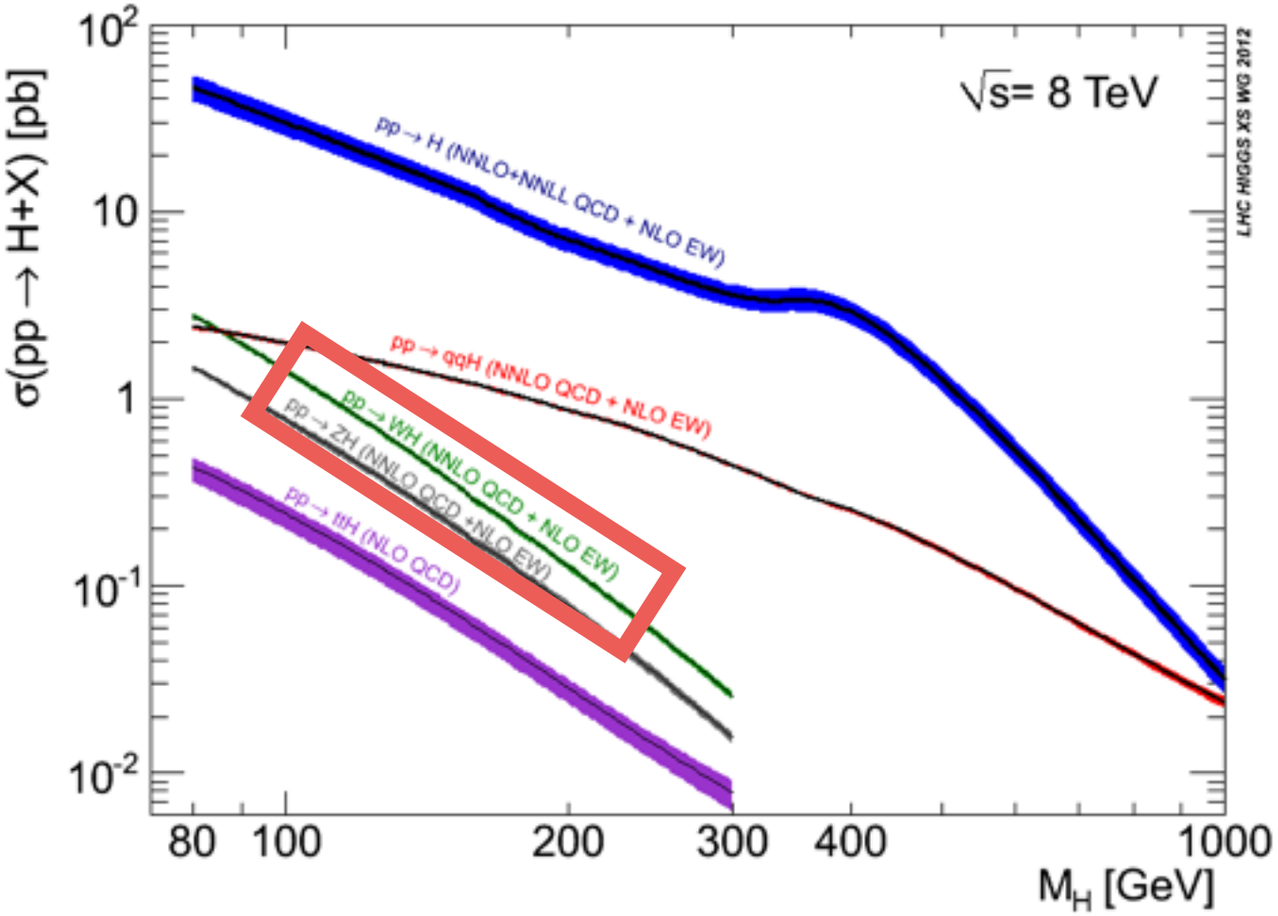
- For m_H=125.4 GeV, BR(H→bb)=0.57
- H→bb good tool for very rare processes involving BEH boson (SM or exotics processes), like HH production!

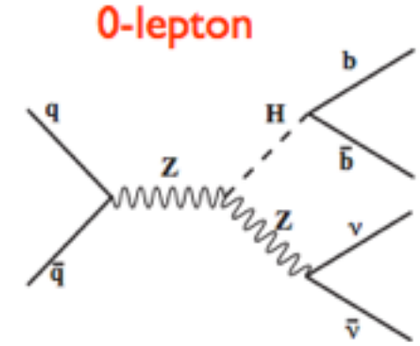
ATLAS-CONF-2013-079

H→bb:How?

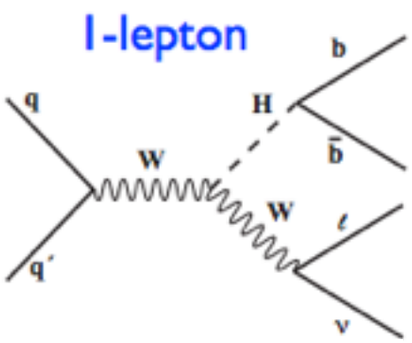
Associated production:
if W or Z decay **leptonically,** easier to kill the multi-jet background originated by strong interactions. (in the next slides V=W,Z)

Categorise events depending on the number of charge leptons:

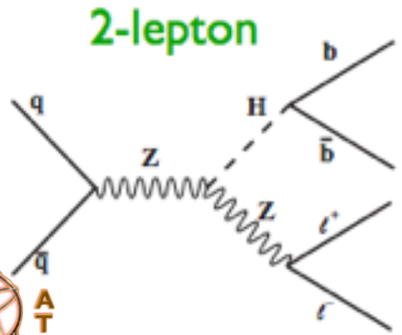




0-lepton category: 0 electrons, 0 muons
→ to cover Z→νν H→bb

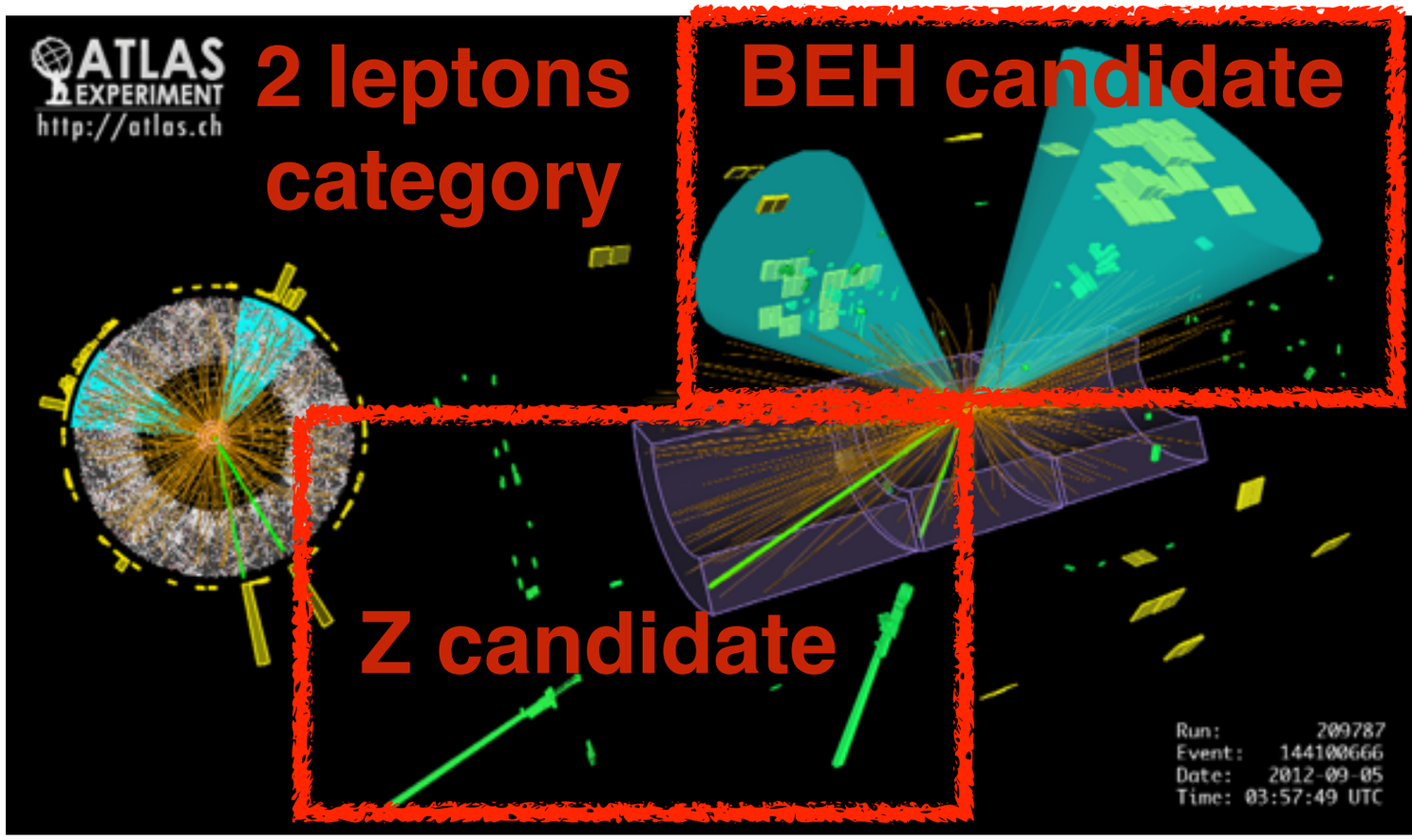


1-lepton category: only 1 electron or only 1 muon
→ to cover W→lν H→bb



2-leptons category: 2 electrons or 2 muons
→ to cover Z→ll H→bb

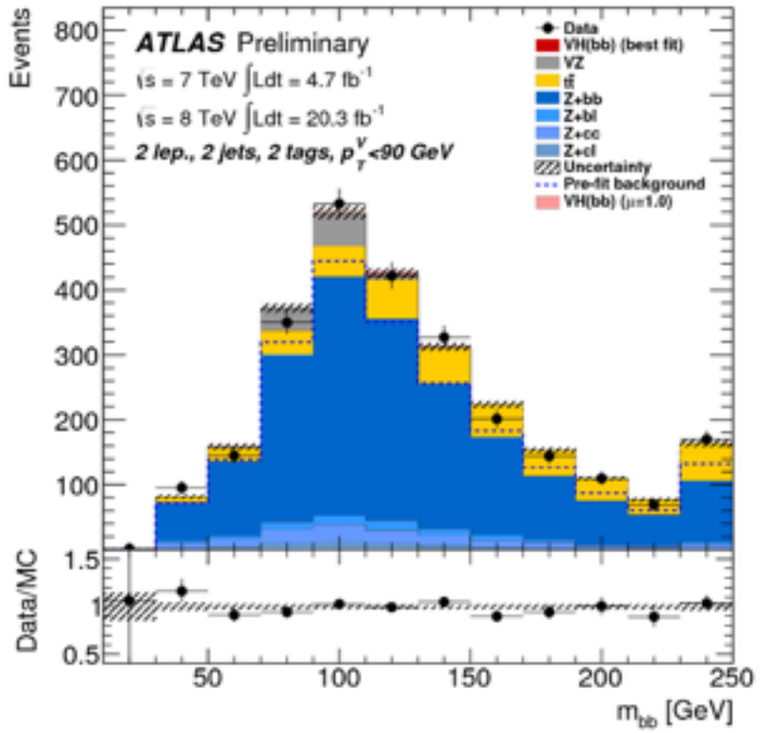
Event Selection

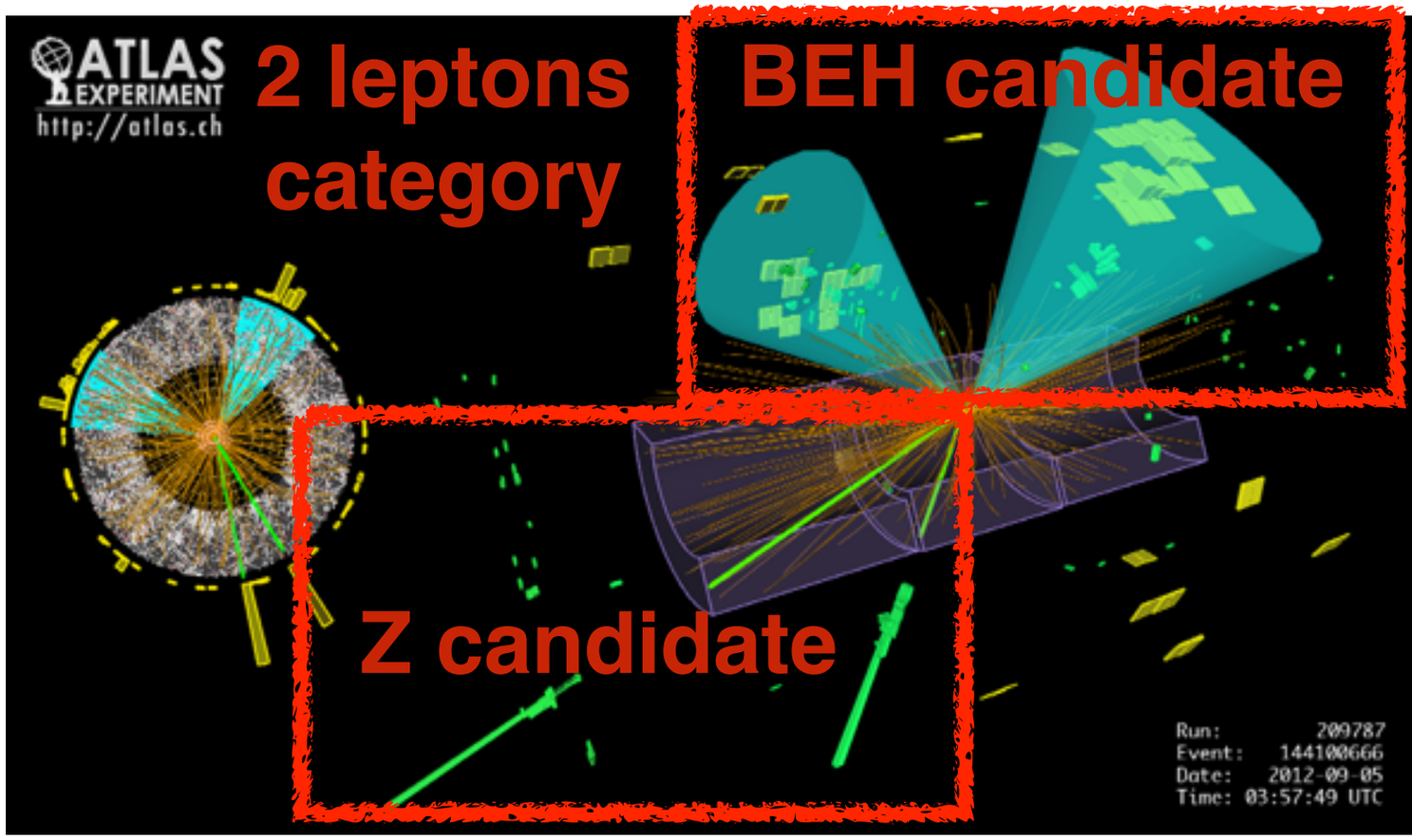


Common selection:

At least 2 jets with p_T>45 GeV, p_T>20 GeV and $|\eta|$<2.5
Leading (subleading) lepton (e,μ) p_T> 25 (10) GeV
Leptons (e,μ) required to be isolated

Event Selection





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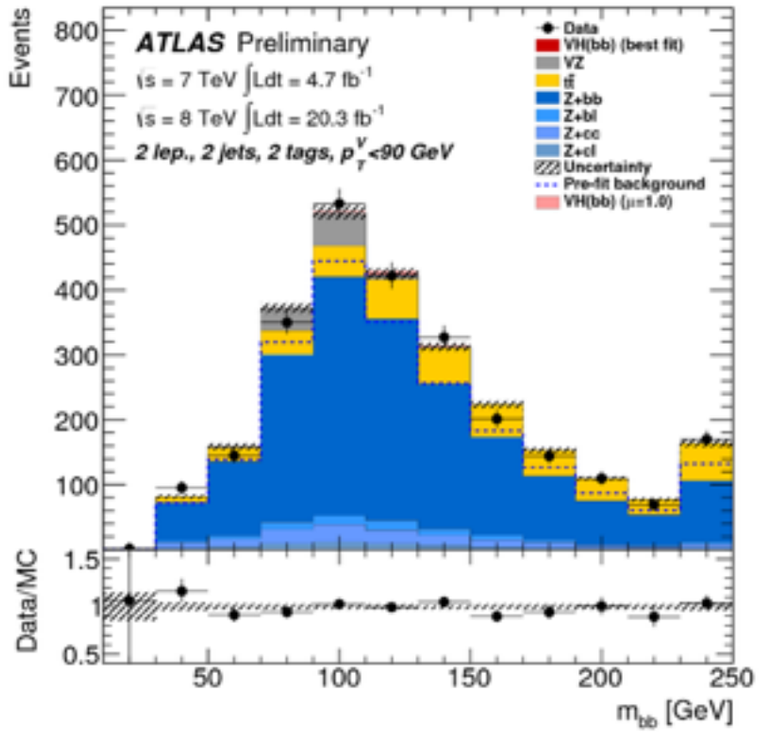
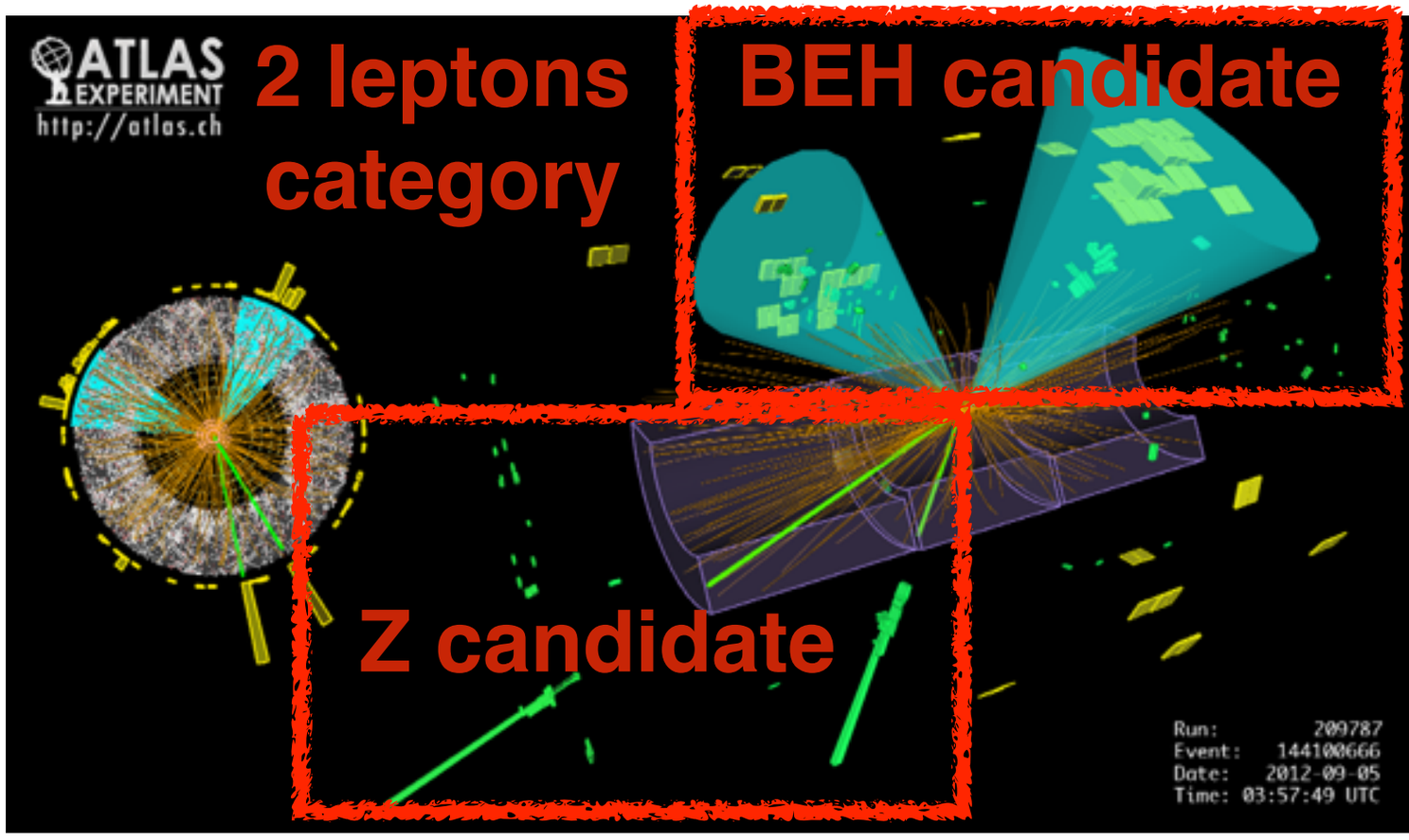
Analysis of the di-jet mass shape of the BEH boson candidate,
to search for an excess around 125 GeV (di-jet mass resolution ~10-12%)

Event Selection





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Analysis of the di-jet mass shape of the BEH boson candidate,
to search for an excess around 125 GeV (di-jet mass resolution ~10-12%)

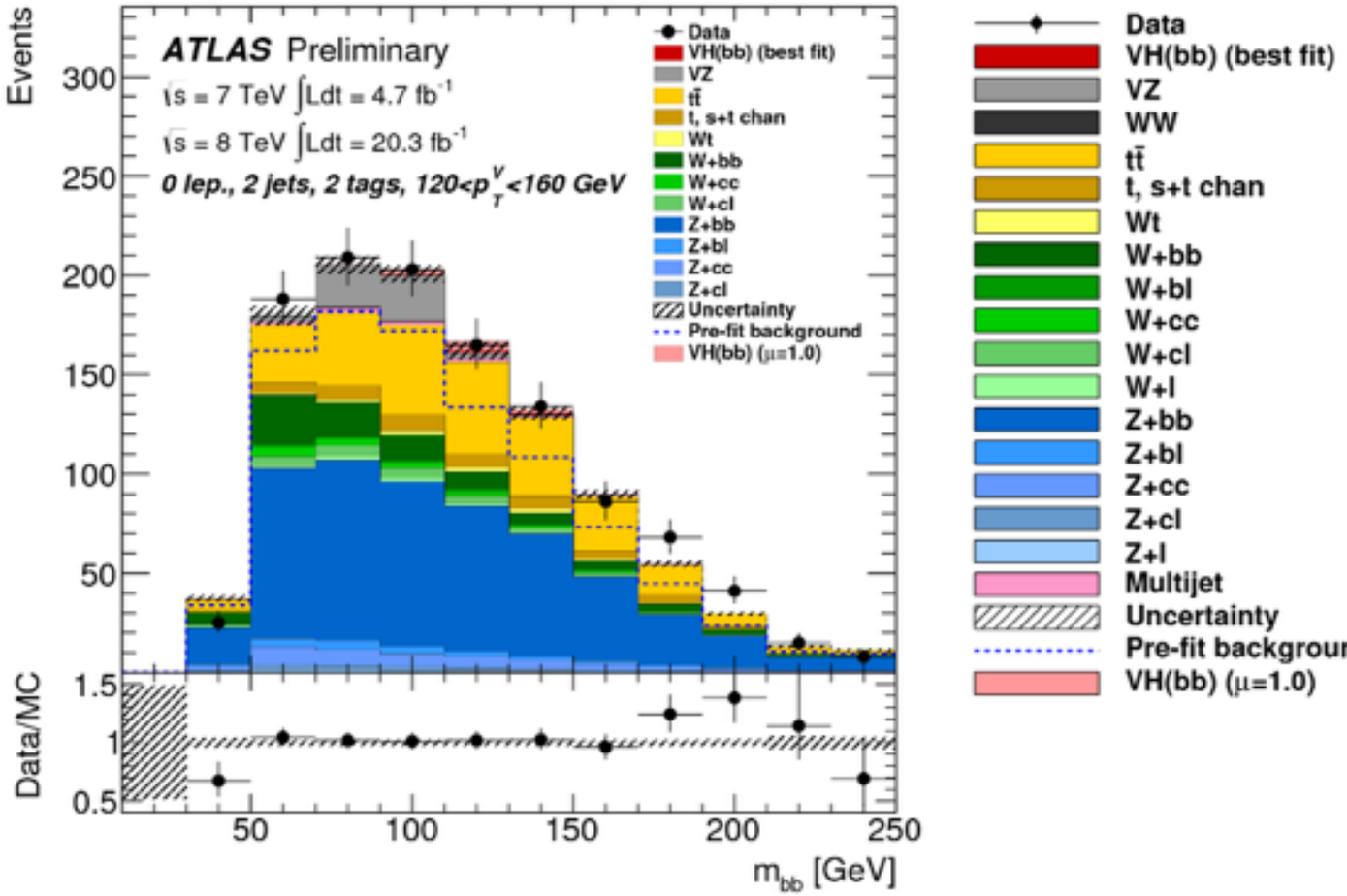
Exploiting the different signal/background ratios
VS. p_T^V;
VS. number of jets:

—> Binning the analysis in p_T^V ranges for events with 2 and 3 jets
—> Require 2 b-tagged jets (70% eff.)
=> **the BEH boson candidate**

		2jets, 2-tags	3jets, 2-tags
3 p_T^V bins x	0-lepton	Shape	Shape
5 p_T^V bins x	1-lepton	Shape	Shape
5 p_T^V bins x	2-leptons	Shape	Shape

p_T	0-90 1-lept, 2-lept	90-120 1-lept, 2-lept	120-160 all channels	160-200 all channels	> 200 all channels
ΔR(j,j)	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	< 1.4

Signal and Background modelling



DATA

- 2011: 4.7 fb^{-1} @ $\sqrt{s}$=7 TeV
- 2012: 20.3 fb^{-1} @ $\sqrt{s}$=8 TeV

SIGNAL

- WH/ZH PYTHIA8

BACKGROUND

- W+jets SHERPA
- Z+jets SHERPA
- Top POWHEG+PYTHIA
- Single Top ACER/POWHEG+PYTHIA
- Diboson (WW,WZ,ZZ) HERWIG
- Multi-jet DATA DRIVEN

The Challenge: Control with high precision the backgrounds.

1) Detailed study of each background;
2) Extract from data as much information as possible;

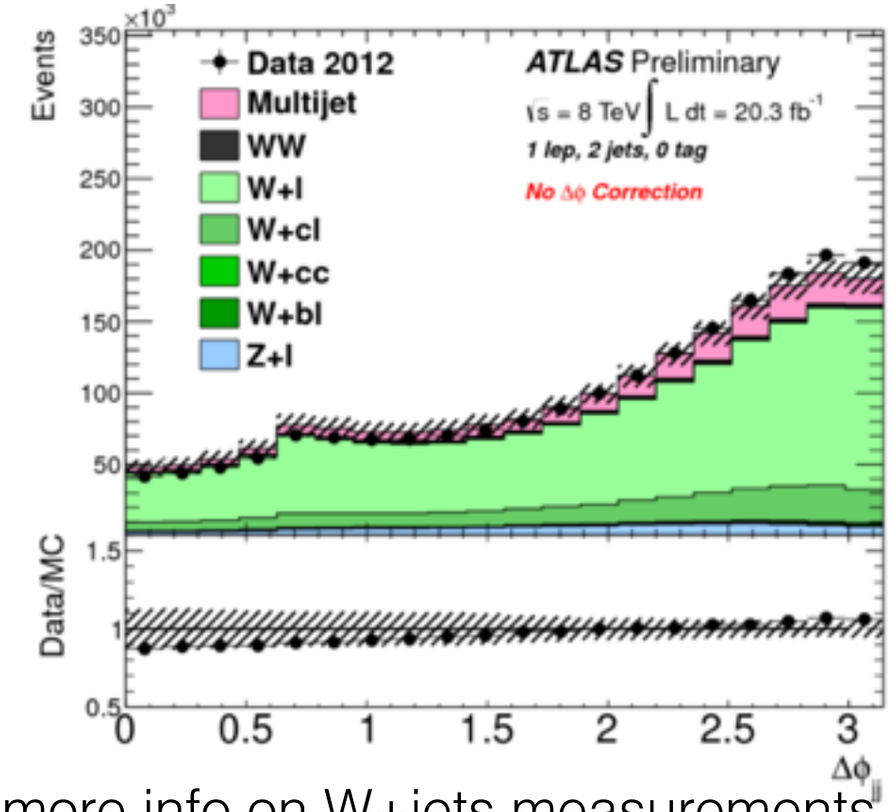
Building the VH analysis in ATLAS

Modelling systematics

	m_{bb}	$\Delta\phi_{jj}$	$p_T^{V,top}$	3-to-2 jet ratio
tt	MC	-	data	MC
W	MC	data	data	MC
Z	data	data	-	MC
single top	MC	-	MC	MC
diboson	MC	-	MC	MC

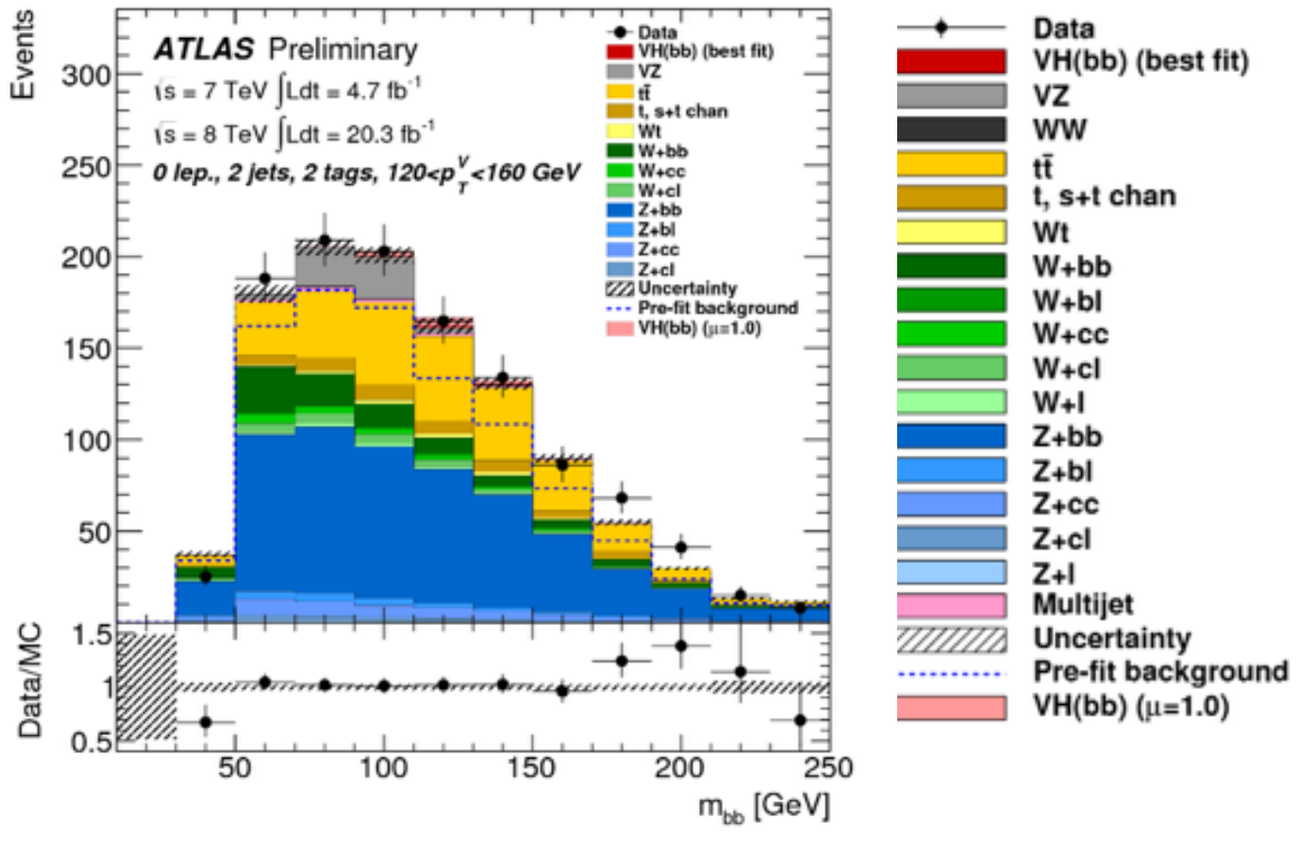
p_T	0-90	90-120	120-160	160-200	> 200
ΔR(j,j)	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	< 1.4

		2jets, 2-tags	3jets, 2-tags
3 p_T^V bins x	0-lepton	**Shape**	Shape
5 p_T^V bins x	1-lepton	**Shape**	Shape
5 p_T^V bins x	2-lepton	**Shape**	Shape



more info on W+jets measurements on G. Hesketh talk
ATLAS-CONF-2014-035

Example of 2jets2tag signal regions



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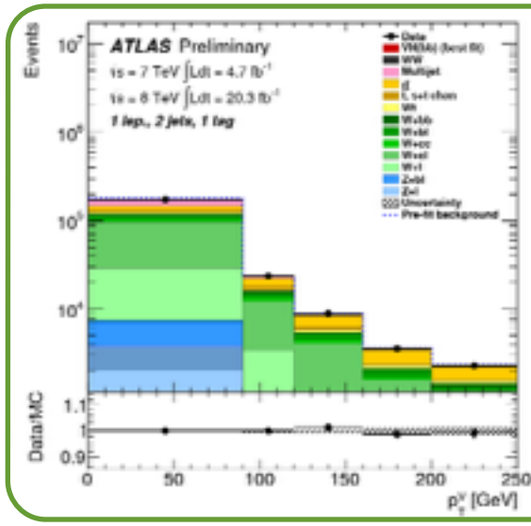
tt	MC	-	data	MC
W	MC	data	data	MC
Z	data	data	-	MC
single top	MC	-	MC	MC
diboson	MC	-	MC	MC

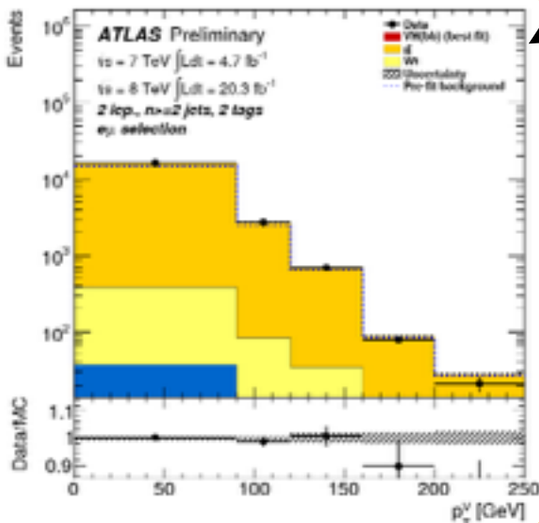
p_T	0-90	90-120	120-160	160-200	> 200
ΔR(j,j)	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	< 1.4

	2jets, 1-tags	3jets, 1-tags	2jets, 2-tags	3jets, 2-tags	Top emu CR
3 p_T^V bins x 0-lepton	Norm	Norm	**Shape**	Shape	-
5 p_T^V bins x 1-lepton	Norm	Norm	**Shape**	Shape	-
5 p_T^V bins x 2-lepton	Norm	Norm	**Shape**	Shape	**Norm**

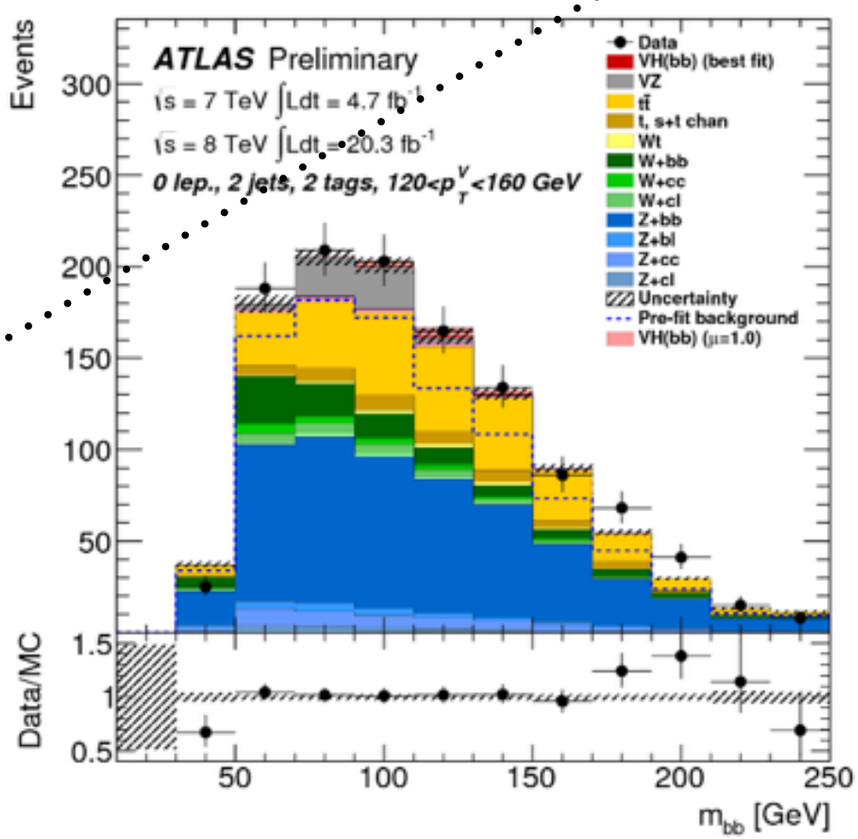


Example of control region
2jet 1tag
1 lepton

Cut applied:
- 2jets 2tag.
- e and μ with $m_{e\mu}$>40 GeV.

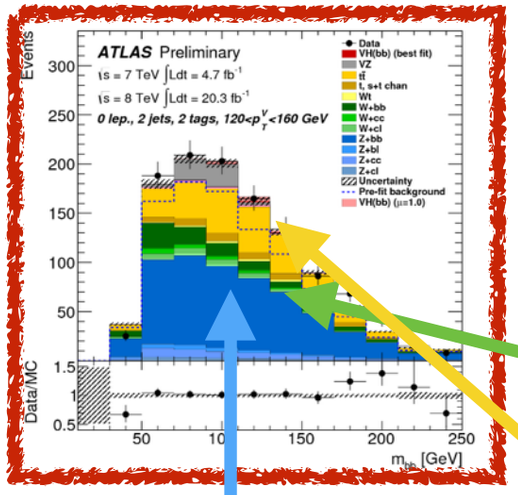


Example of 2jets2tag signal regions

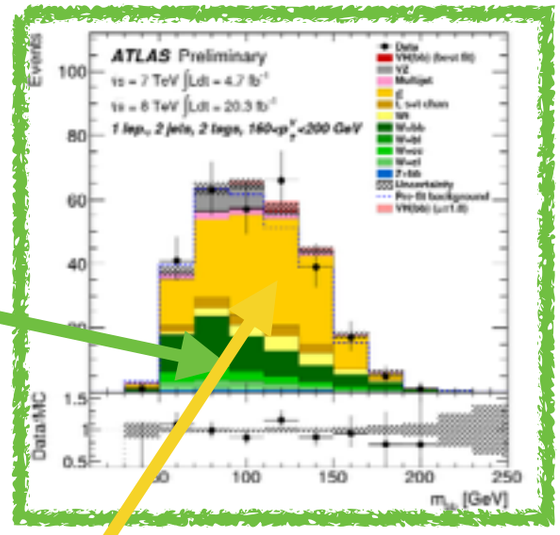


Building the VH analysis in ATLAS

One fit to rule them all

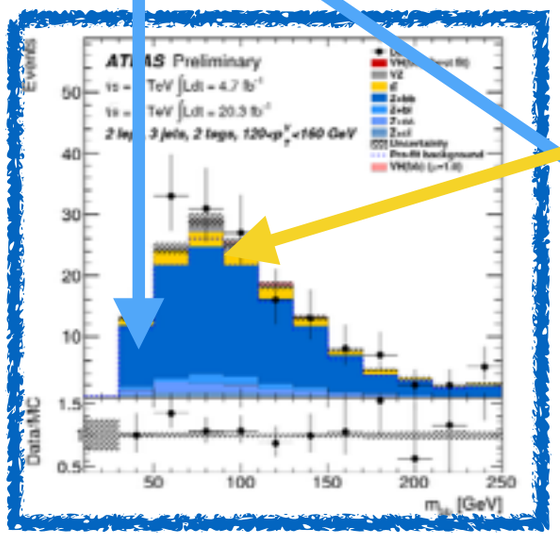


W+jets

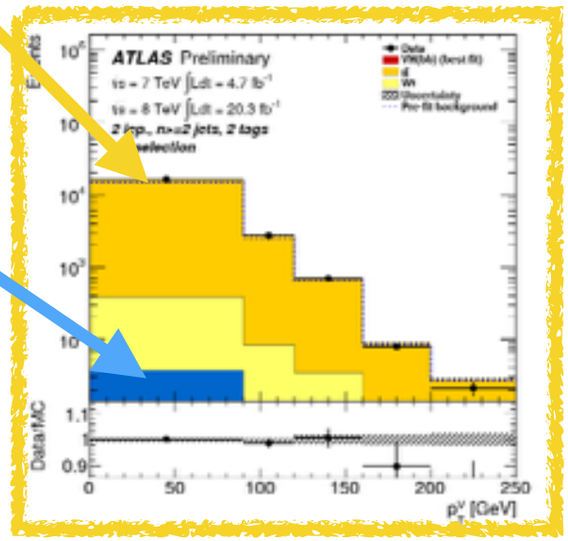


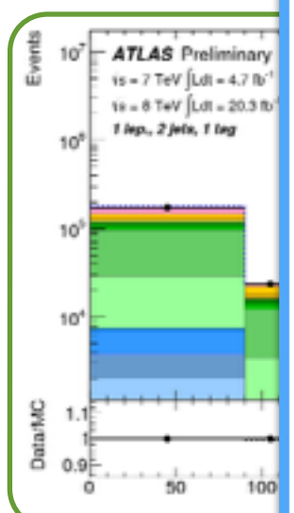
- Common nuissance parameters across regions
- Systematics on extrapolation of backgrounds between regions

Z+jets



Top





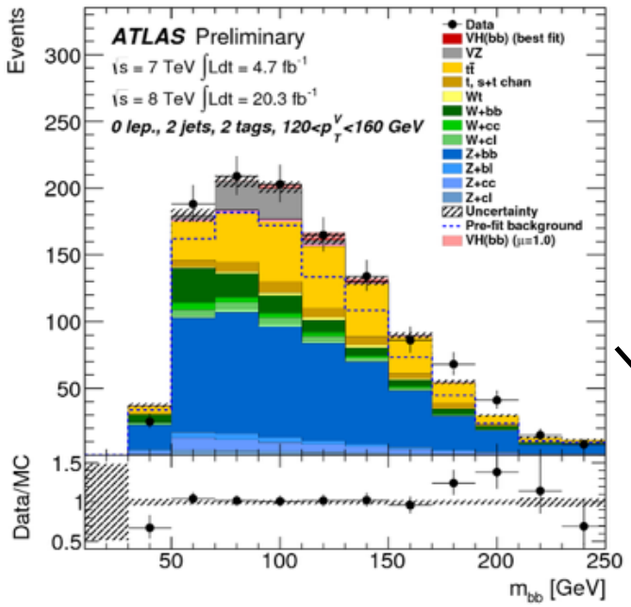
Cut applie
- 2tag2jets
- Signal e
mll>40 Ge
- No mll ar

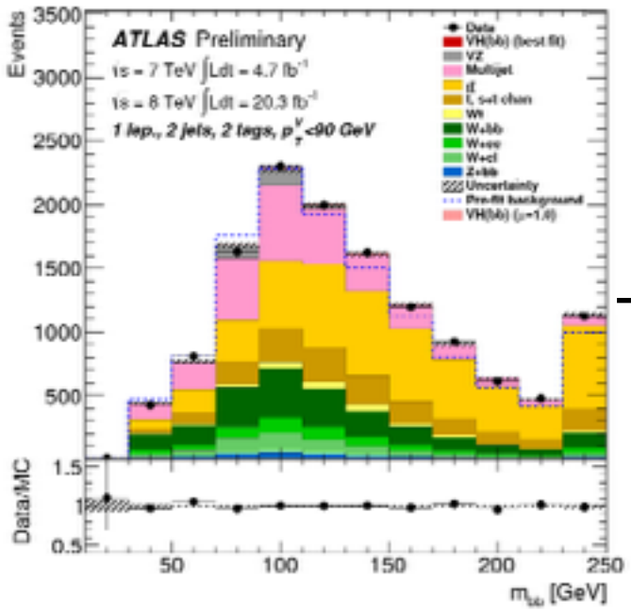
	Top emu CR
e	-
e	-
e	Norm

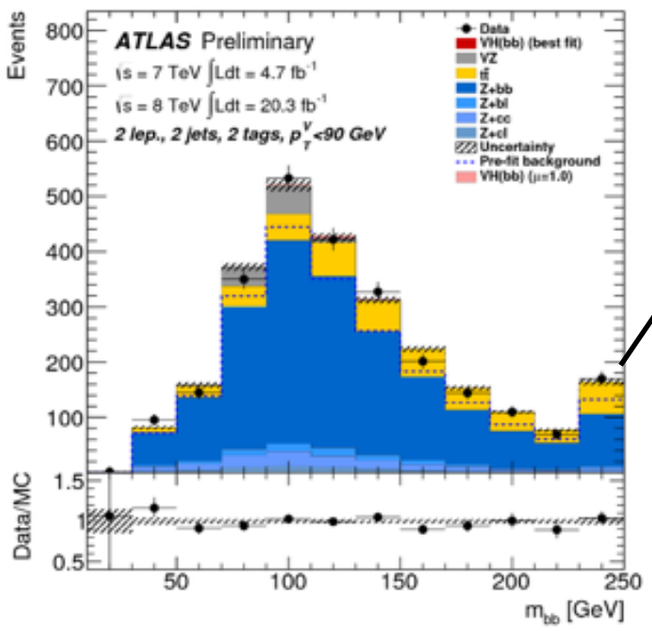
Data
VH(bb) (best fit)
VZ
WW
tt̄
t, s+t chan
Wt
W+bb
W+bl
W+cc
W+cl
W+l
Z+bb
Z+bl
Z+cc
Z+cl
Z+l
Multijet
Uncertainty
Pre-fit background
VH(bb) (μ=1.0)

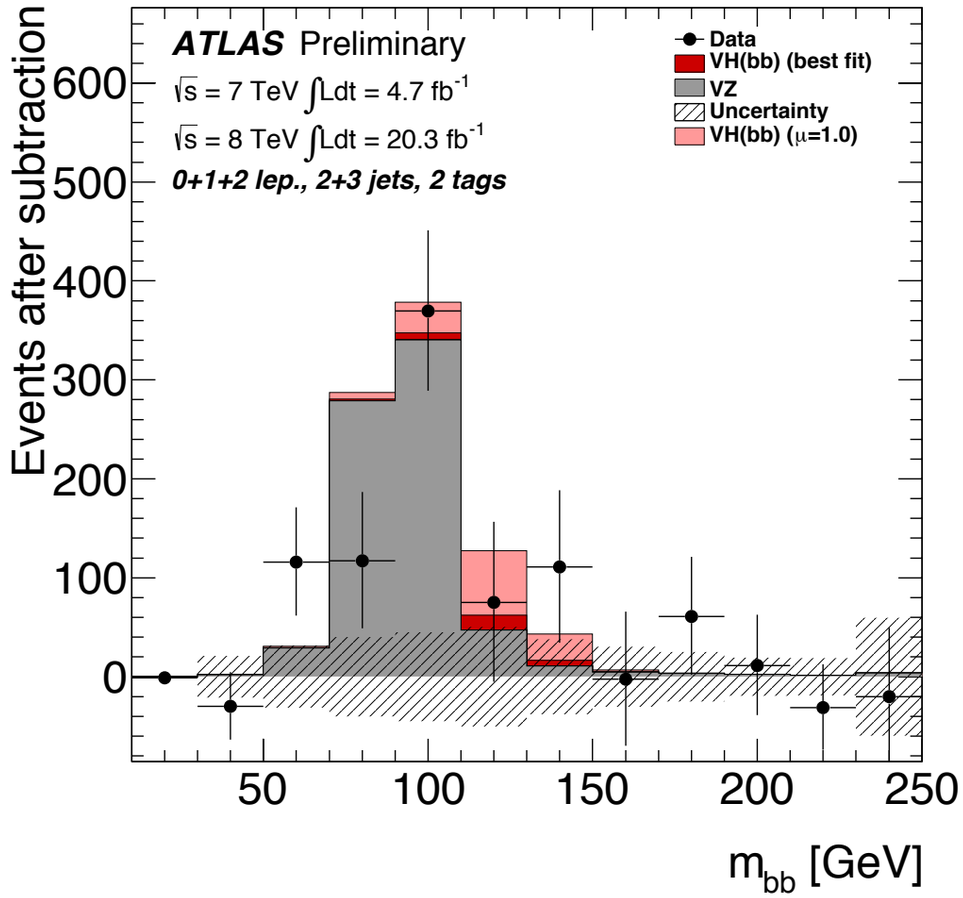
VZ(bb) results

SM candle to validate the analysis chain: VZ(bb)







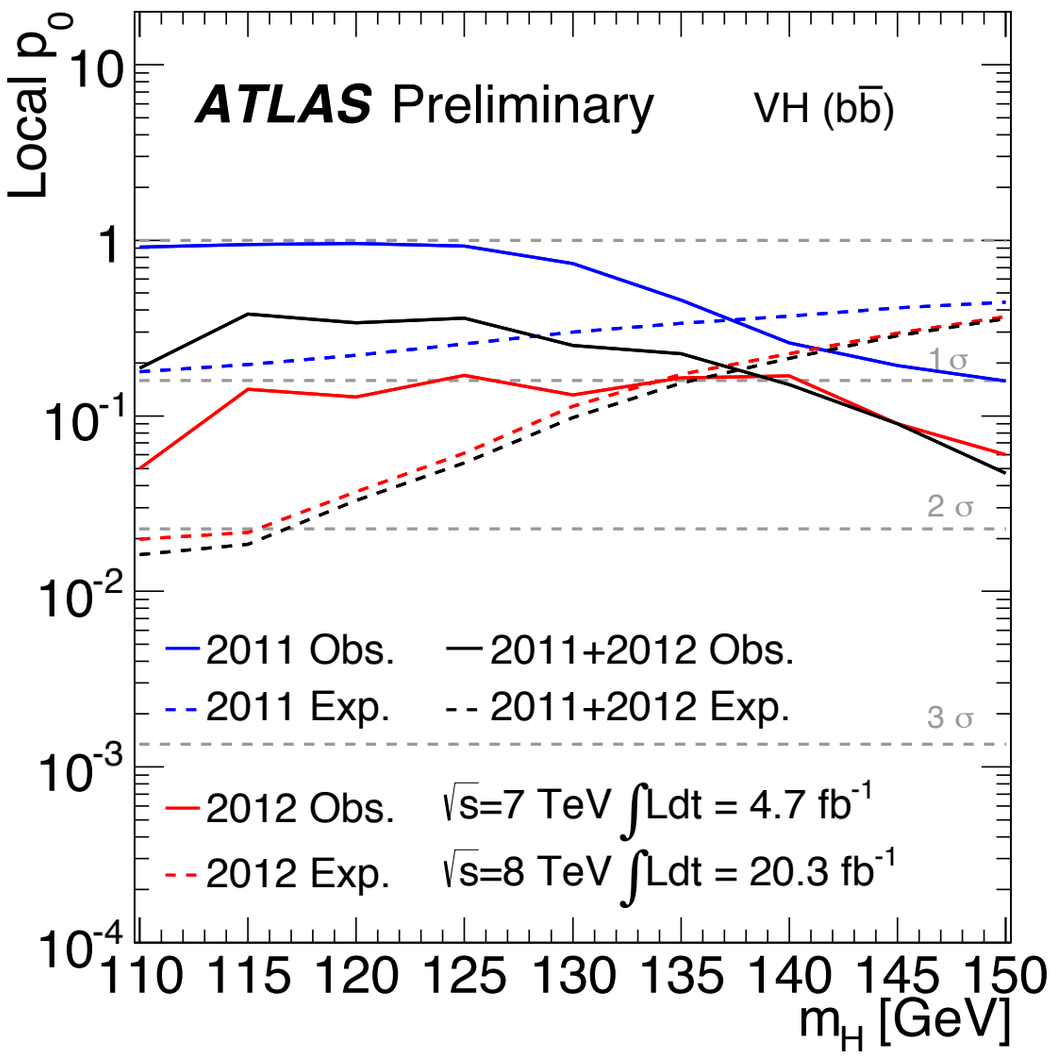


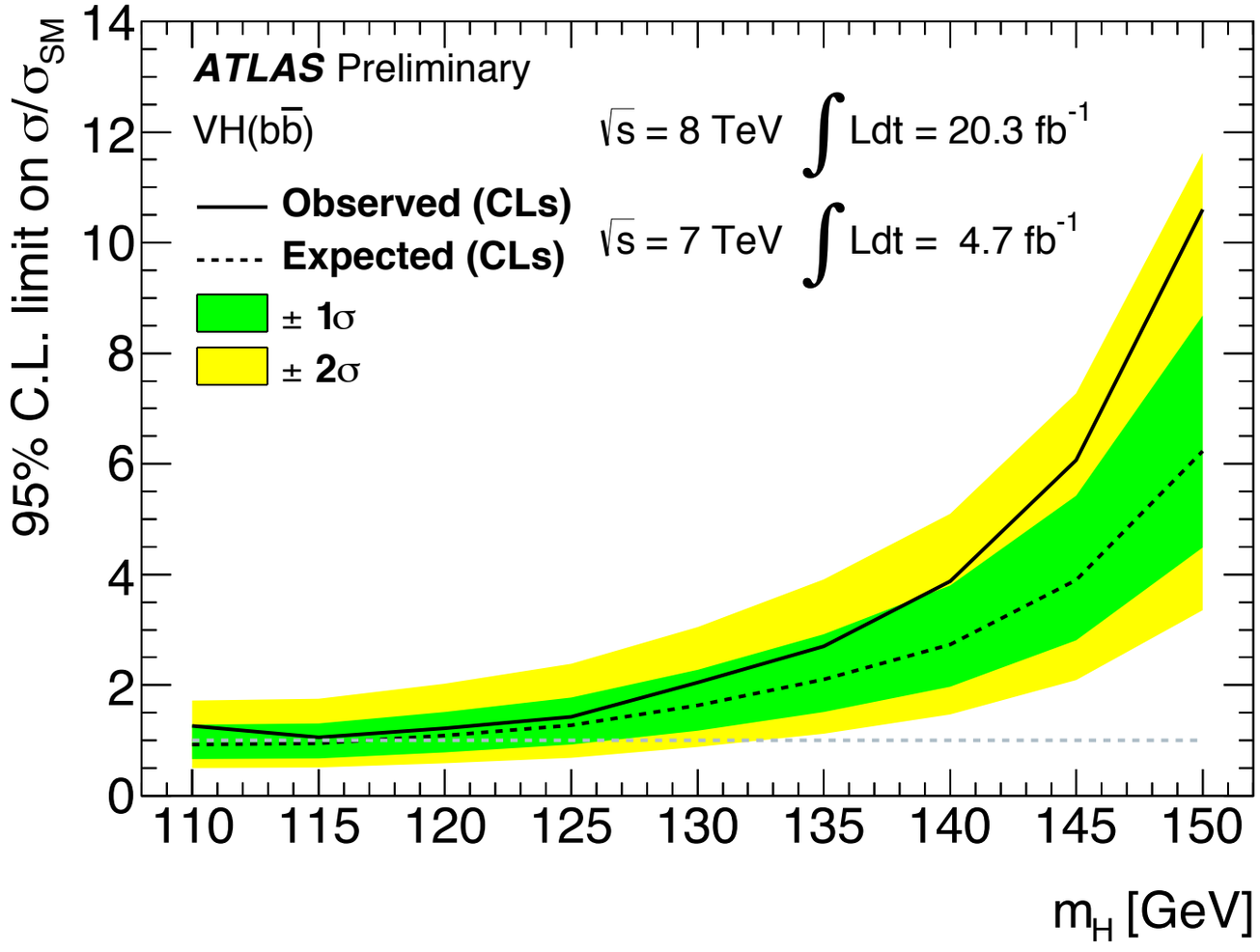
μ= best fit value for $\sigma_{meas.}/\sigma_{SM}$

Significance of the VZ: 4.8 sigma(5.1 expected)

$$\mu_{VZ} = 0.9 \pm 0.2$$

VH(bb) results





- 1σ excess in 2012 data at m_H=125 GeV (as expected).
- Deficit in 2011 data leads to a small excess (0.4σ) in combined result at m_H=125 GeV

VH(bb) results

VH(bb) for each year and channel

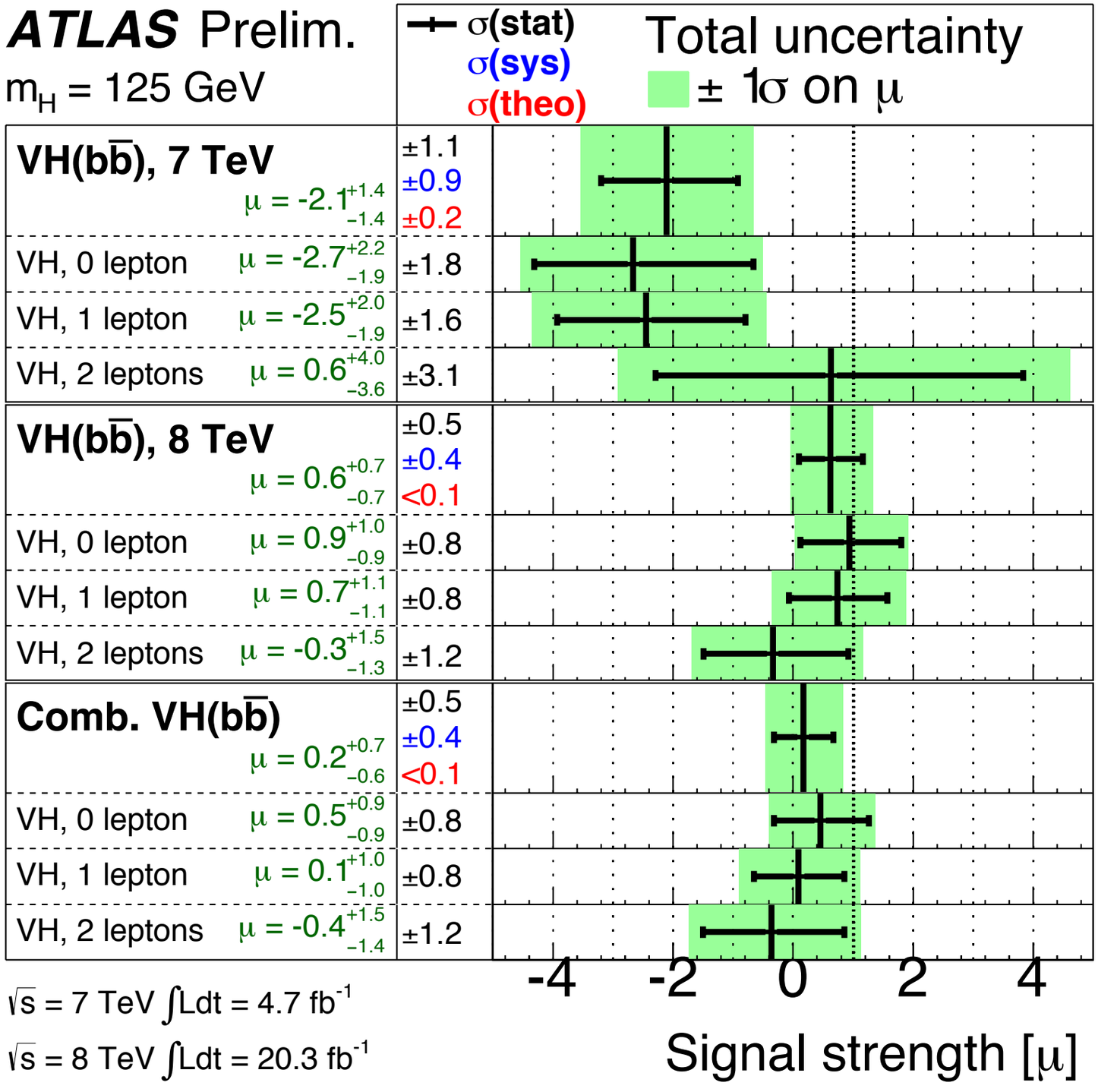
- Combined result consistent with μ=0:
1.3σ away from μ=1
0.3σ away from μ=0

- 8 TeV result has some excess:
0.5σ away from μ=1
1.1σ away from μ=0

- 2σ deficit in 7 TeV result with respect to SM expectation

- Results dominated by statistical uncertainties

Dominant systematics:
Uncertainty on the b-tagging
Uncertainty on the jet measurement
Uncertainty on the modelling of V+jets



Conclusions

- Search for the VH(bb) using the Run 1 data collected by the ATLAS detector.
- Fit to diboson (VZ) peak consistent with Standard Model expectation, corresponds to a 4.8σ excess over the background-only hypothesis
- Fit to m_{bb} peak is consistent with both a SM BEH boson and no SM BEH boson
  Advanced analysis techniques for Run 1 data (i.e. MVA)
  can help in distinguish more the 2 hypothesis.
  Run 2 will play a crucial role in this.
- Combined fit to the cross section results in $\mu = 0.2 \pm 0.5(\text{stat.}) \pm 0.4(\text{syst.})$ for $m_H = 125\text{GeV}$

Backup

Tables - event selection and SF

Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 b-tags $p_{\mathrm{T}}^{\mathrm{jet}_1} > 45$ GeV $p_{\mathrm{T}}^{\mathrm{jet}_2} > 20$ GeV + ≤ 1 extra jets		
Missing E_T	$E_{\mathrm{T}}^{\mathrm{miss}} > 120$ GeV $p_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV $\Delta\phi(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}) < \pi/2$ $\min[\Delta\phi(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet})] > 1.5$ $\Delta\phi(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}, b\bar{b}) > 2.8$	$E_{\mathrm{T}}^{\mathrm{miss}} > 25$ Gev	$E_{\mathrm{T}}^{\mathrm{miss}} < 60$ GeV
Vector Boson	-	$m_{\mathrm{T}}^{W} < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

	p_{T}^{V} [GeV]	0-90	90-120	120-160	160-200	>200
All Channels	$\Delta R(b, \bar{b})$	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	<1.4
1-lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>25				>50
	m_{T}^{W} [GeV]	40-120			<120	

Process	Scale factor
$t\bar{t}$	1.13 ± 0.05
Wb	0.89 ± 0.15
Wcl	1.05 ± 0.14
Zb	1.30 ± 0.07
Zcl	0.89 ± 0.48

$m_H = 125$ GeV at 7 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	12.3	0.0	0.7	8.2
$W \to \ell\nu$	107.1	0.2	3.5	-
$Z \to \nu\nu$	36.4	2.2	-	-
$m_H = 125$ GeV at 8 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	15.3	0.0	0.9	8.4
$W \to \ell\nu$	130.2	0.2	3.3	-
$Z \to \nu\nu$	45.5	2.5	-	-

Tables: yields

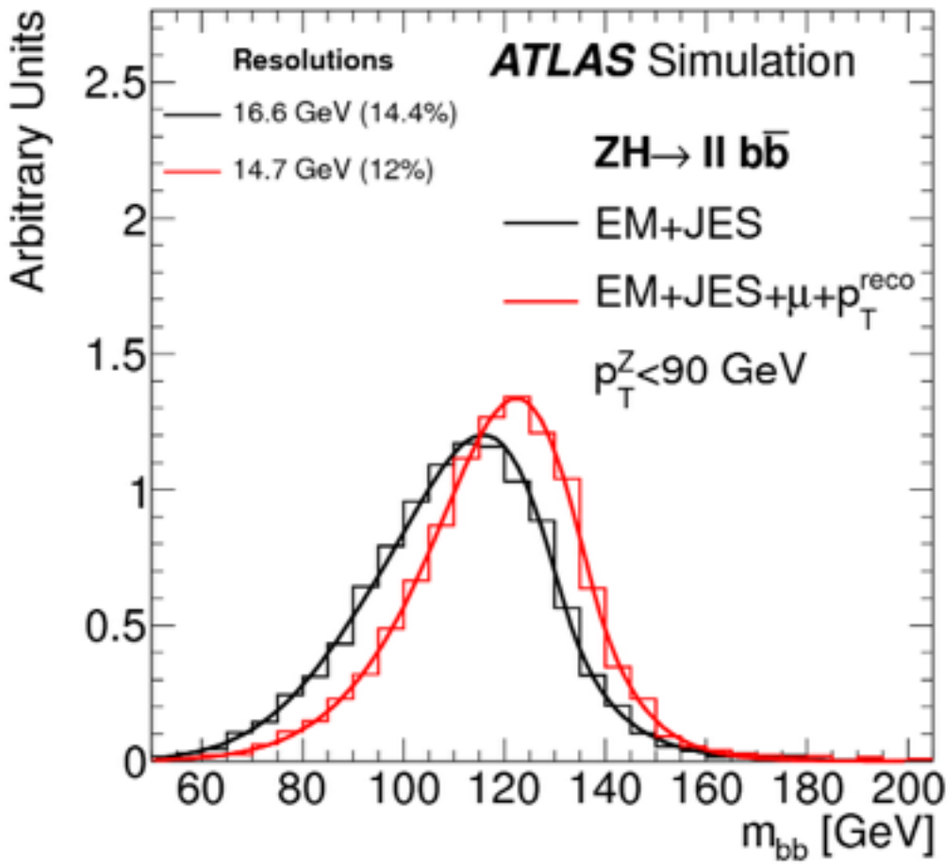
2-jet, 2-tag sample

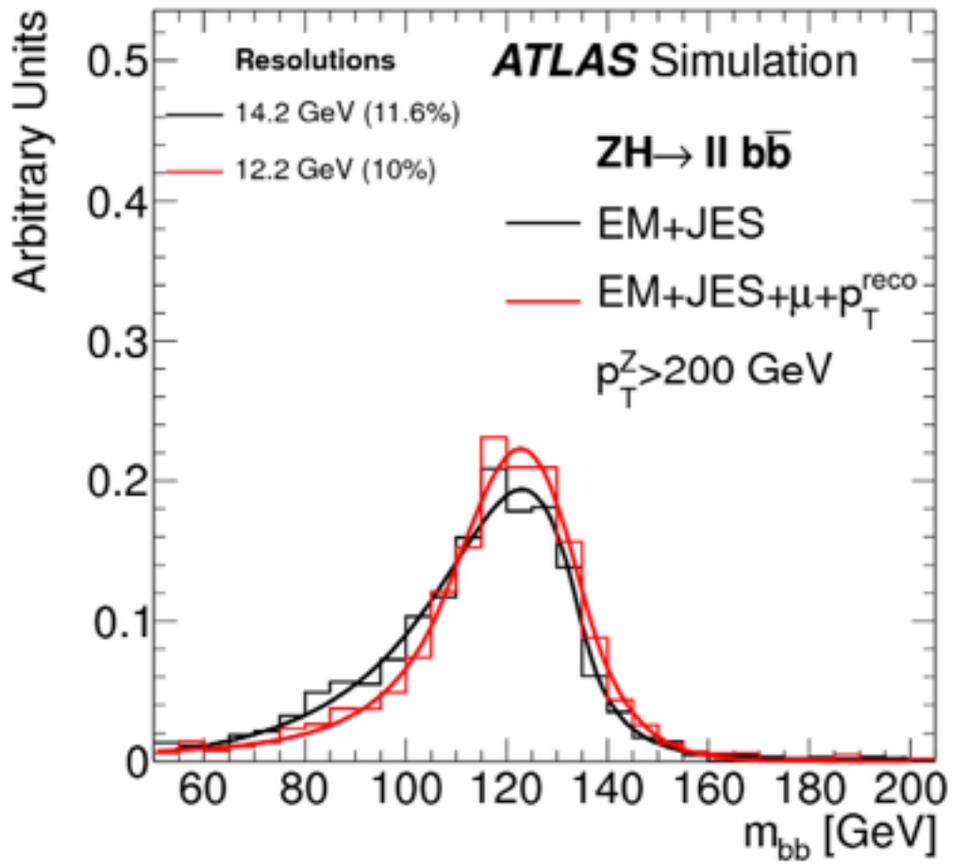
Process	0-lepton E_T^{miss} [GeV]			1-lepton p_T^W [GeV]					2-lepton p_T^Z [GeV]				
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \to \nu\nu$	1.6	0.9	1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Z \to \ell\ell$	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	2.1	0.5	0.4	0.2	0.2
$W \to \ell\nu$	0.4	0.2	0.2	7.6	1.7	1.2	1.0	1.1	<0.1	<0.1	<0.1	<0.1	<0.1
VH total	2.0	1.1	1.1	7.8	1.8	1.2	1.1	1.1	2.1	0.5	0.4	0.2	0.2
VH expected	11	5.8	6.1	42	9.5	6.6	5.6	6.1	11	2.7	2.2	1.1	1.2
Top	159	33	8	2763	729	359	113	40	166	32	8.0	0.5	<0.1
W+c, light	21	5.3	2.7	616	65	27	12	7.8	<0.1	<0.1	<0.1	<0.1	<0.1
W+b	30	10	6.1	909	106	49	25	19	<0.1	<0.1	<0.1	<0.1	<0.1
Z+c, light	23	8.1	5.2	22	2.1	0.5	0.3	0.1	91	12	5.6	1.6	1.0
Z+b	226	71	39	97	13	3.9	1.8	0.5	938	146	64	14	8.3
WW	0.5	0.1	0.1	11	1.0	0.7	0.3	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
VZ	26	11	10	145	20	12	7.6	6.5	60	8.6	4.5	2.2	2.1
Multijet	4.8	1.1	0.7	1306	45.6	8.7	4.8	0.4	<0.1	<0.1	<0.1	<0.1	<0.1
Total Bkg.	491 ± 10	141 ± 3	72 ± 2	5869 ± 64	981 ± 16	460 ± 9	165 ± 4	74 ± 3	1255 ± 24	199 ± 4	82 ± 2	18 ± 1	11.4 ± 0.5
Data	502	143	90	5916	990	458	162	79	1282	204	70	22	6
S/B	0.004	0.008	0.02	0.001	0.002	0.003	0.006	0.02	0.002	0.003	0.005	0.01	0.02

3-jet, 2-tag sample

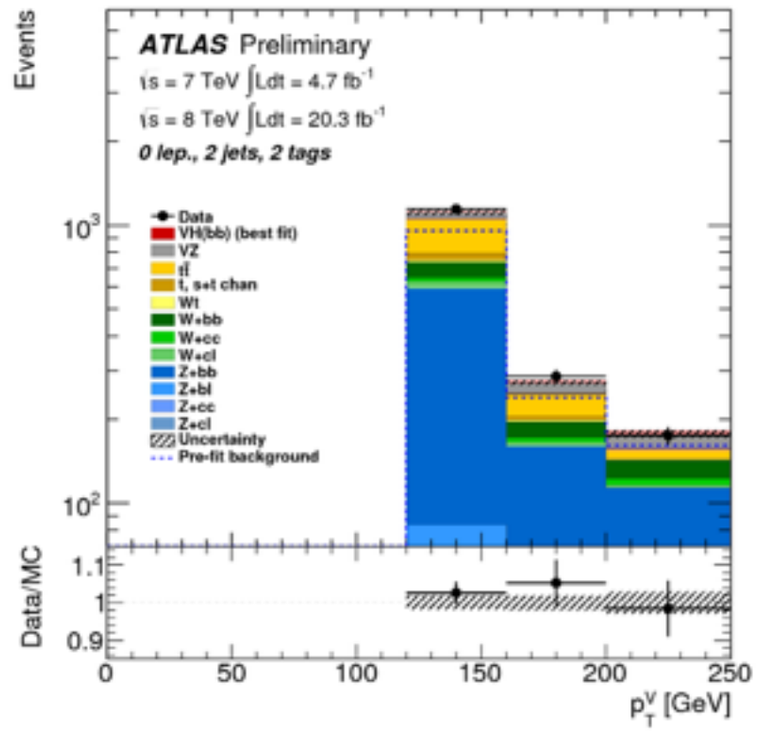
Process	0-lepton E_T^{miss} [GeV]			1-lepton p_T^W [GeV]					2-lepton p_T^Z [GeV]				
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \to \nu\nu$	0.4	0.2	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
$Z \to \ell\ell$	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.9	0.3	0.2	0.1	0.1
$W \to \ell\nu$	0.1	0.1	<0.1	2.1	0.6	0.5	0.5	0.6	<0.1	<0.1	<0.1	<0.1	<0.1
VH total	0.5	0.3	0.4	2.2	0.6	0.5	0.5	0.6	0.9	0.3	0.2	0.1	0.1
VH expected	2.7	1.6	1.9	12	3.2	2.6	2.8	3.4	4.9	1.4	1.1	0.6	0.7
Top	169	44	13	4444	1171	592	238	121	114	22	5.5	0.3	<0.1
W+c, light	7.1	2.1	1.2	189	23	11.7	6.8	5.4	<0.1	<0.1	<0.1	<0.1	<0.1
W+b	12	4.7	3.3	318	36	21	14	12	<0.1	<0.1	<0.1	<0.1	<0.1
Z+c, light	6.3	2.8	2.5	8.8	0.9	0.4	0.2	0.1	53	9.6	4.5	1.4	1.2
Z+b	59	26	17	56	6.9	2.5	1.4	0.7	509	91	45	12	7.6
WW	0.2	0.1	0.1	4.0	0.5	0.3	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
VZ	3.7	1.8	2.3	31	4.7	3.1	2.5	3.7	20.1	3.1	1.6	0.9	1.2
Multijet	3.1	0.6	0.4	425	17	5.5	3.0	0.8	<0.1	<0.1	<0.1	<0.1	<0.1
Total Bkg.	260 ± 6	82 ± 2	40 ± 1	5476 ± 57	1260 ± 17	637 ± 11	266 ± 7	143 ± 5	696 ± 16	125 ± 3	57 ± 2	15 ± 1	10 ± 1
Data	287	59	40	5523	1233	639	249	154	734	119	56	13	9
S/B	0.002	0.004	0.009	0.0004	0.0005	0.0008	0.002	0.004	0.001	0.002	0.004	0.008	0.01

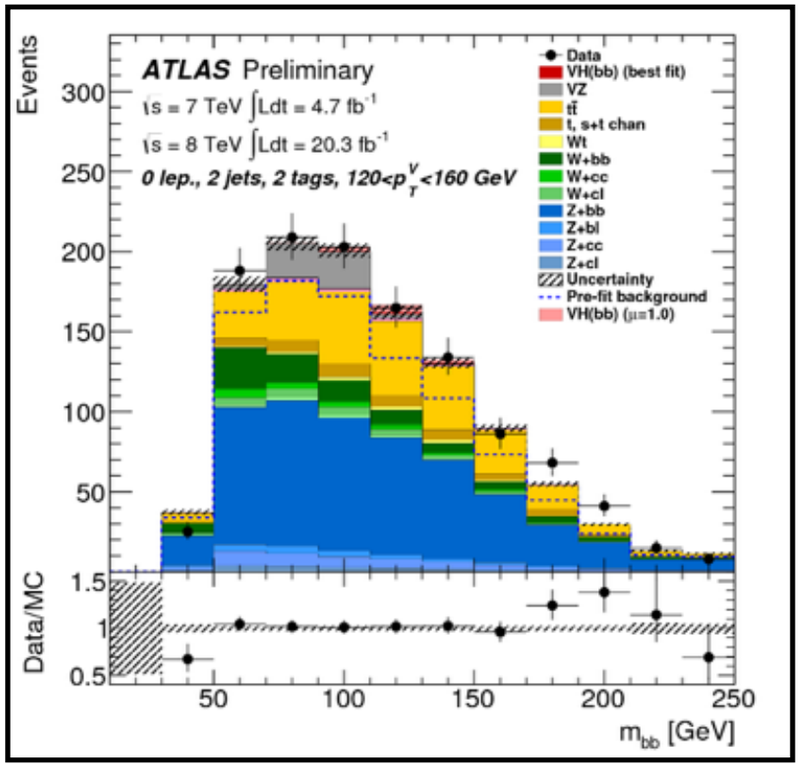
m_{bb} Resolution

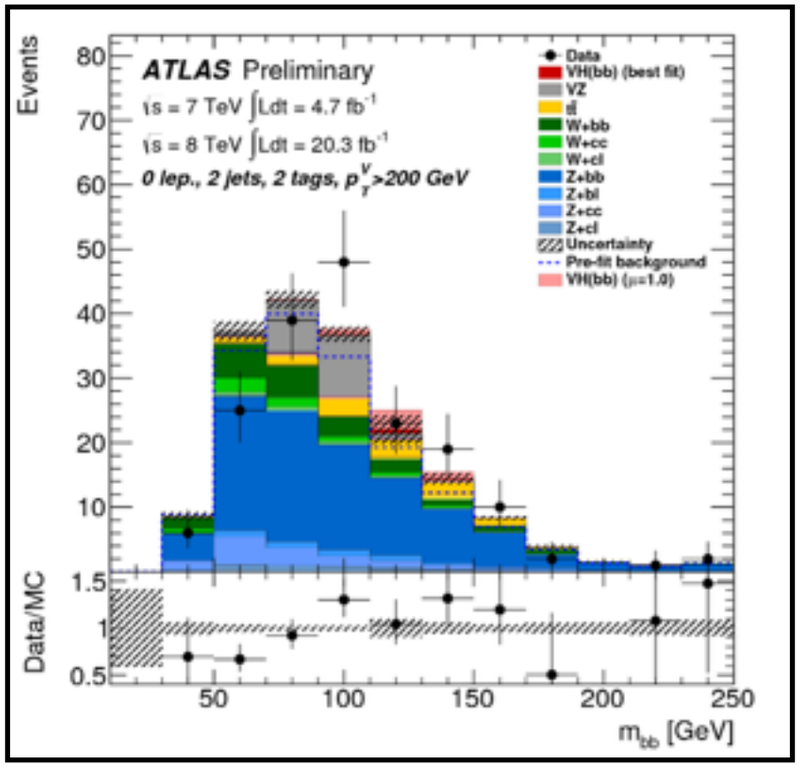


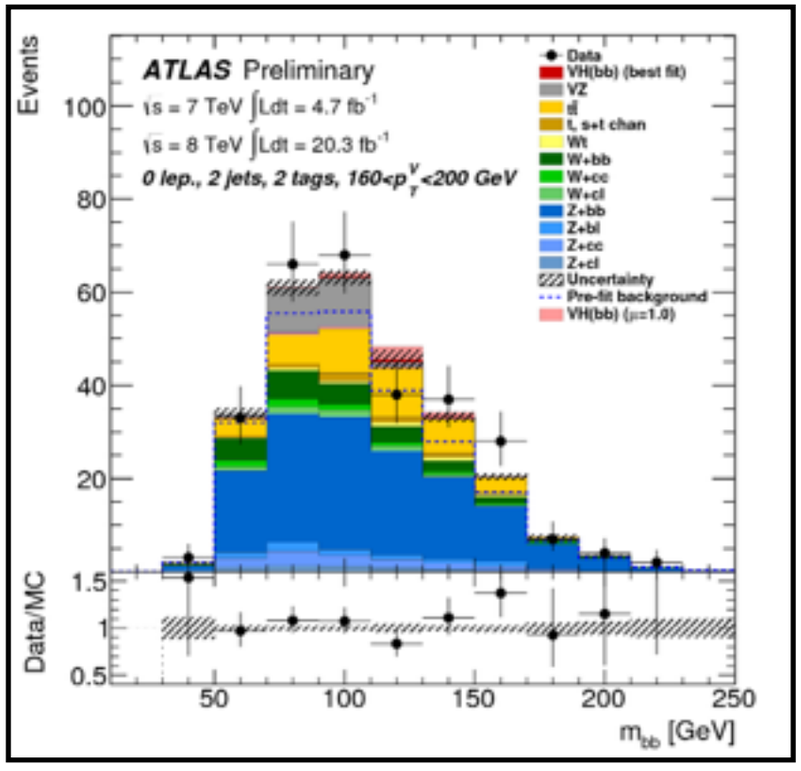


0 Lepton region - 2 jets

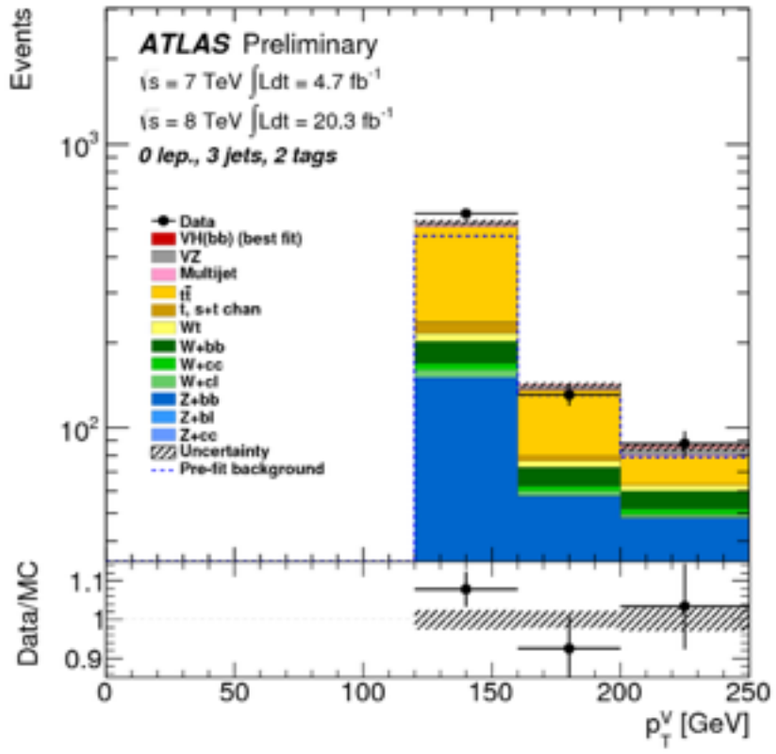


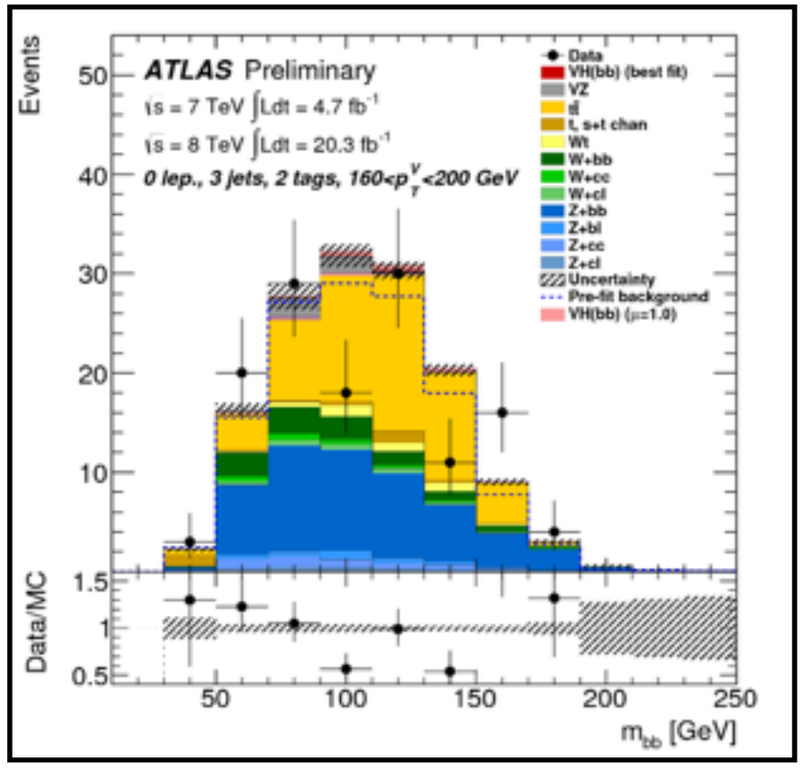


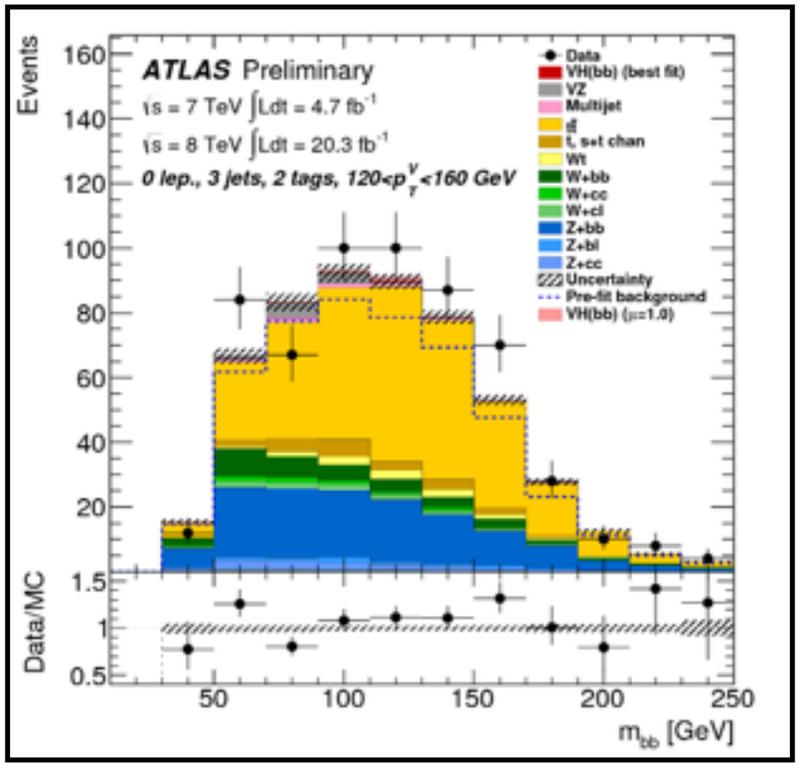


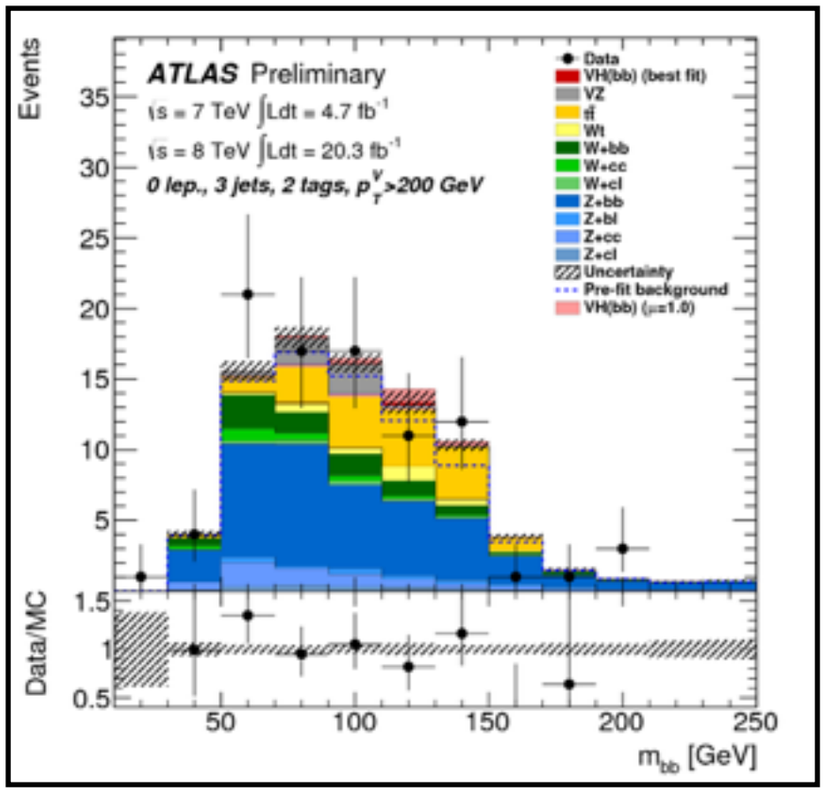


0 Lepton region - 3 jets

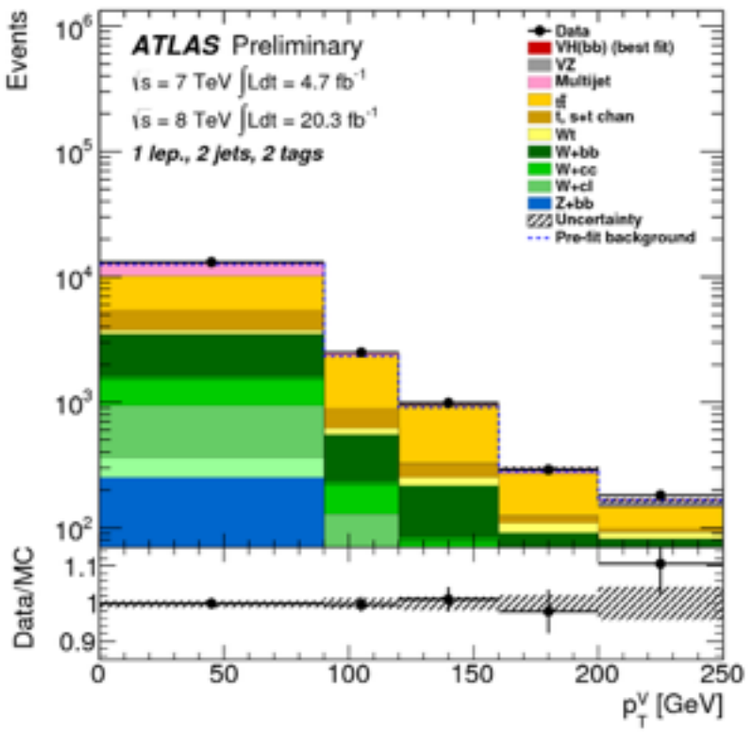


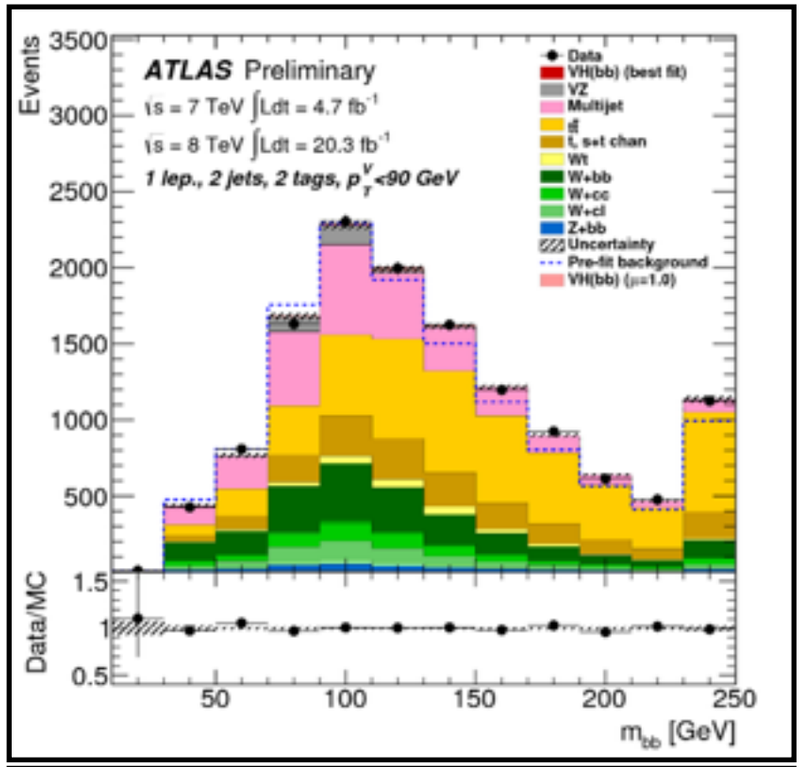


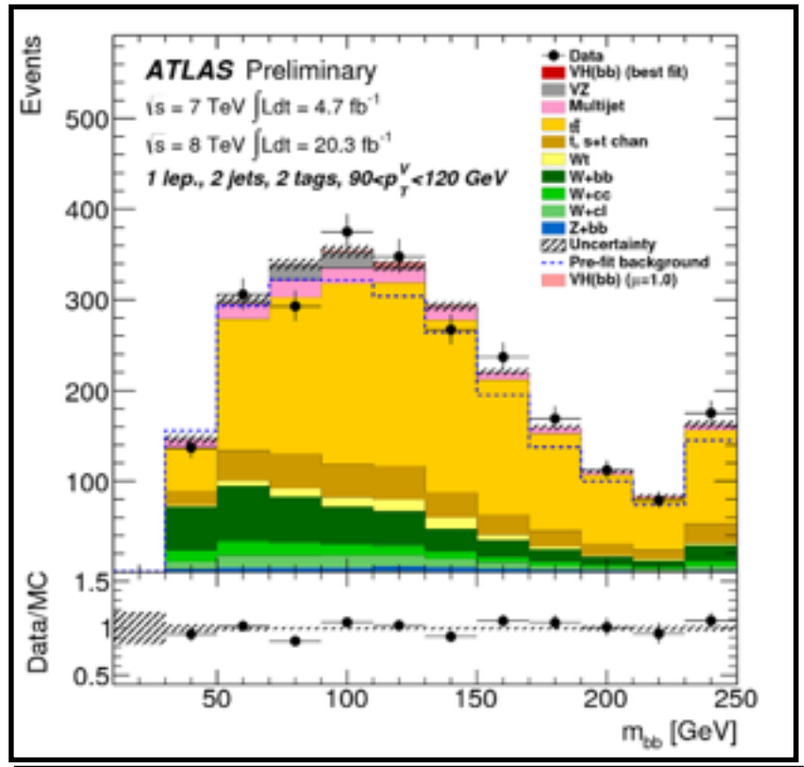


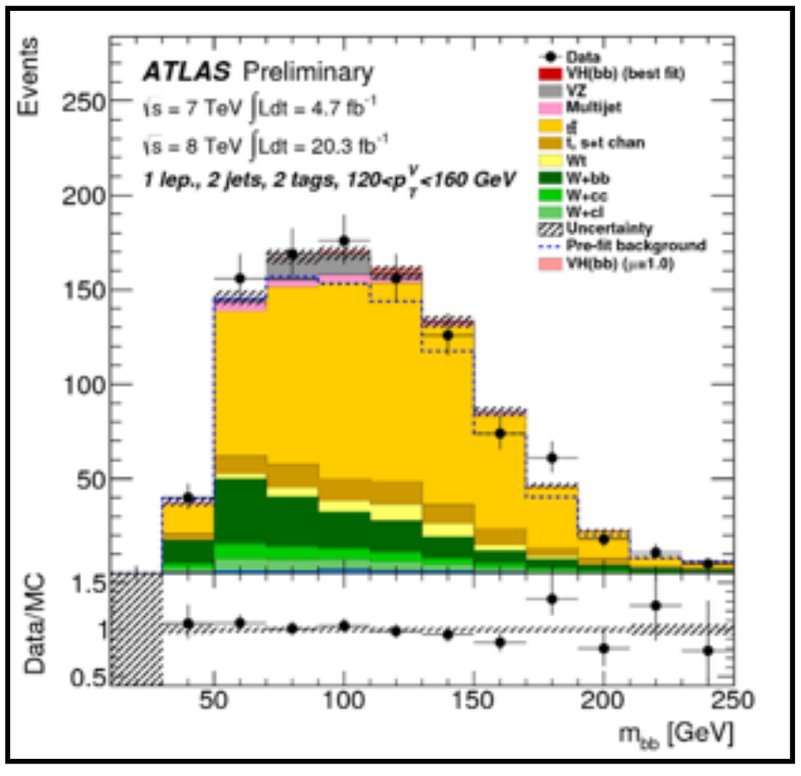


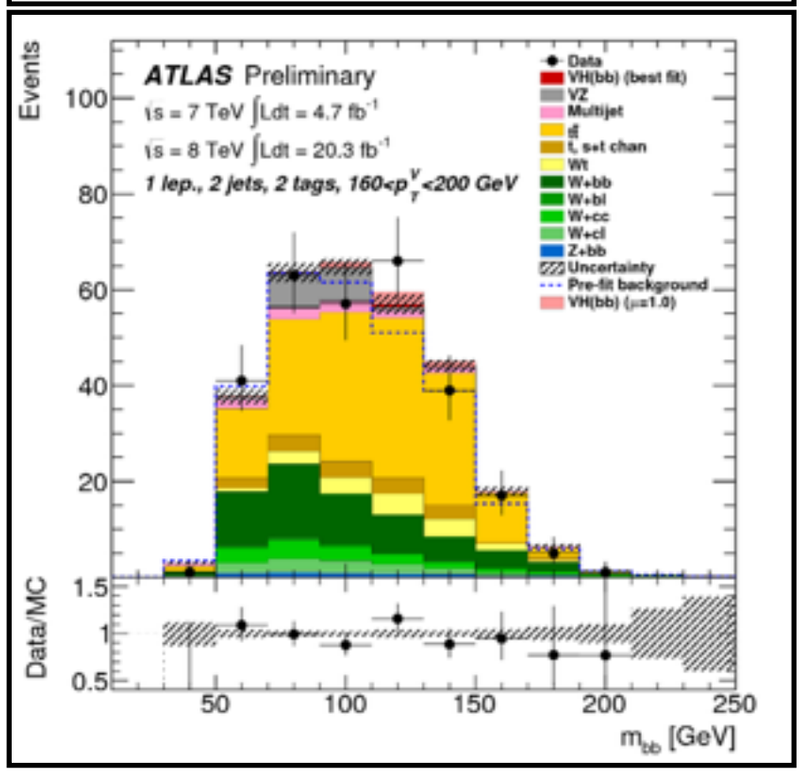
1 Lepton region - 2 jets

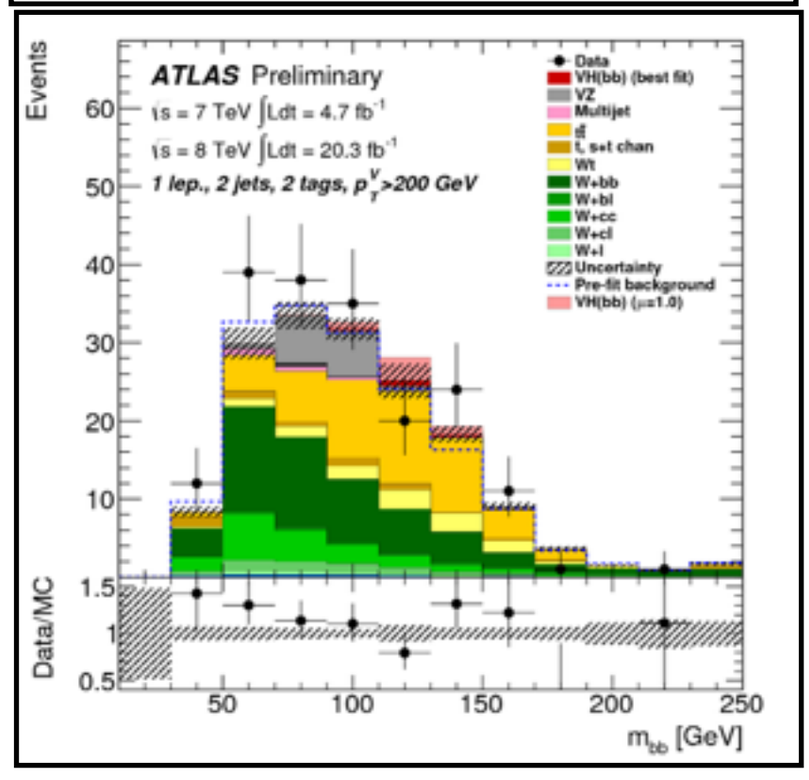




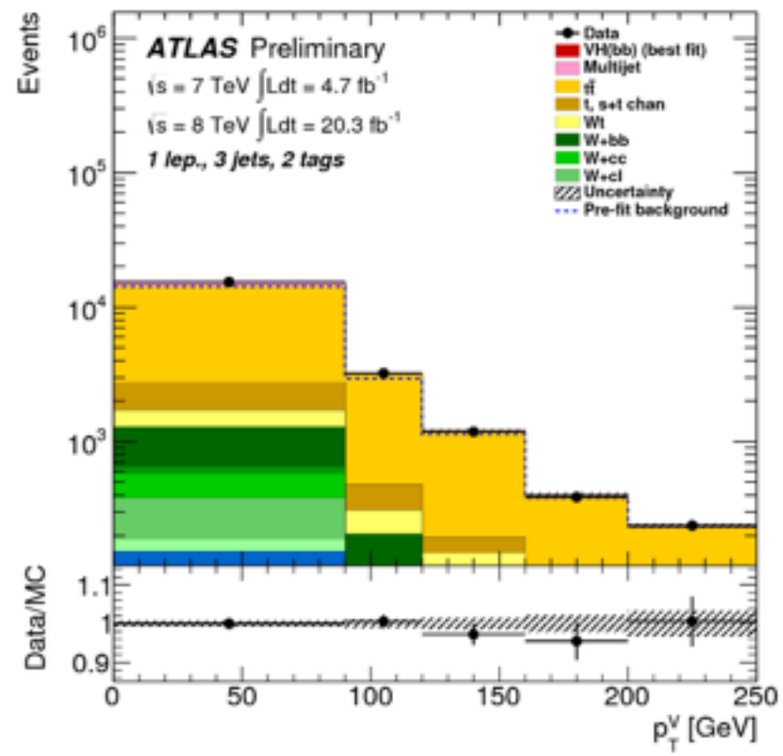


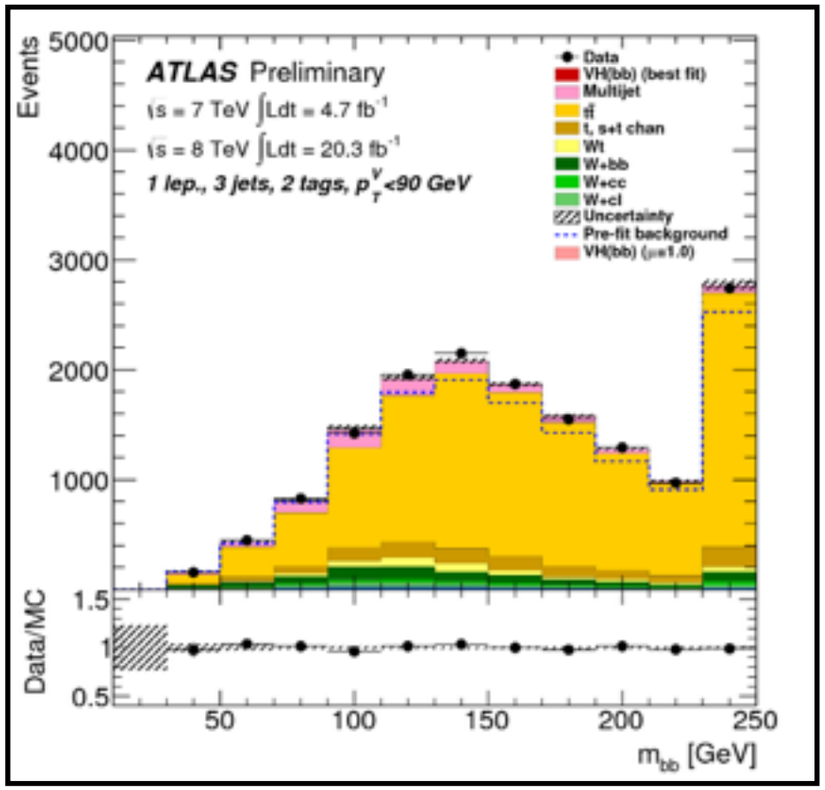


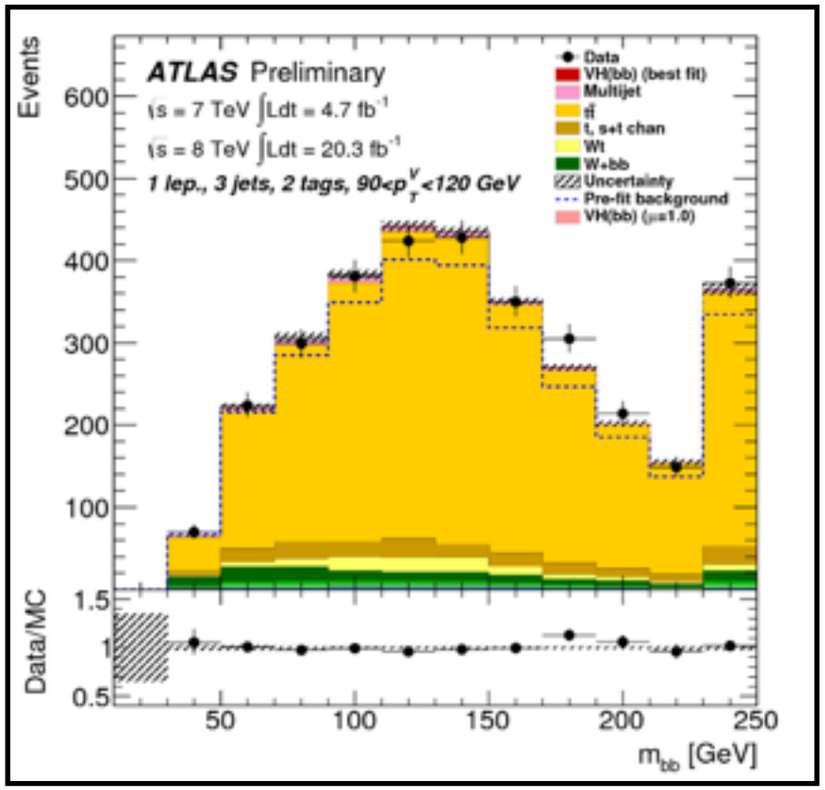


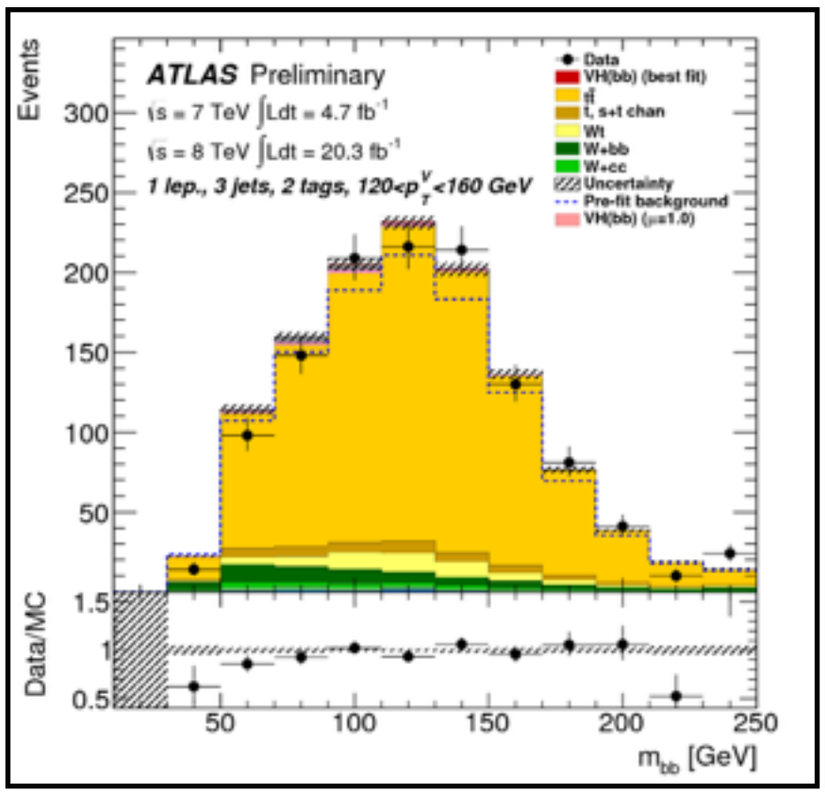


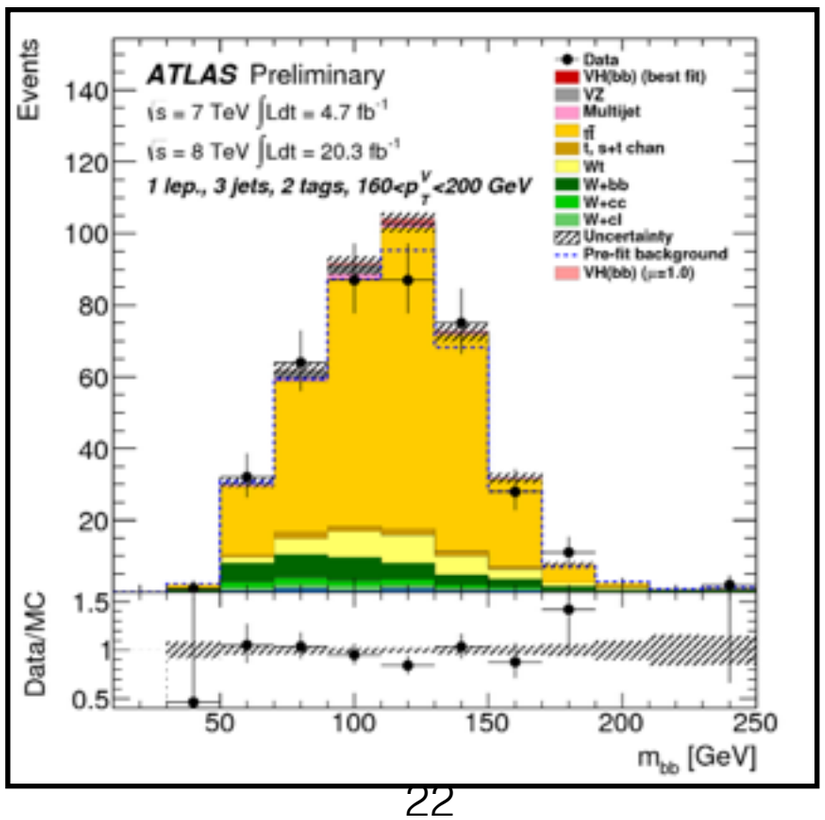
1 Lepton region - 3 jets

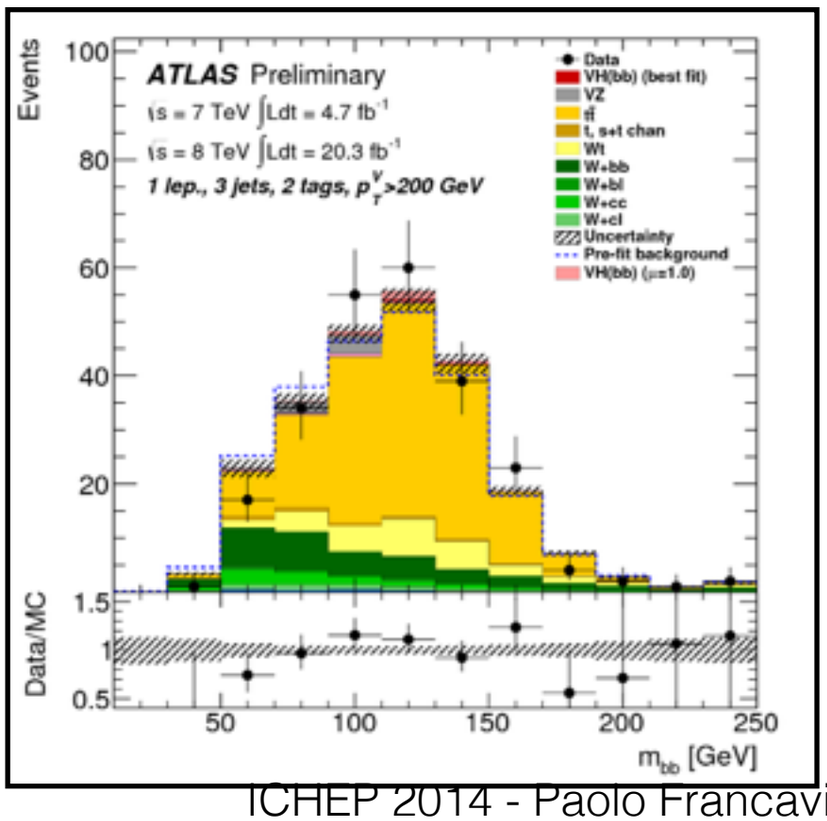




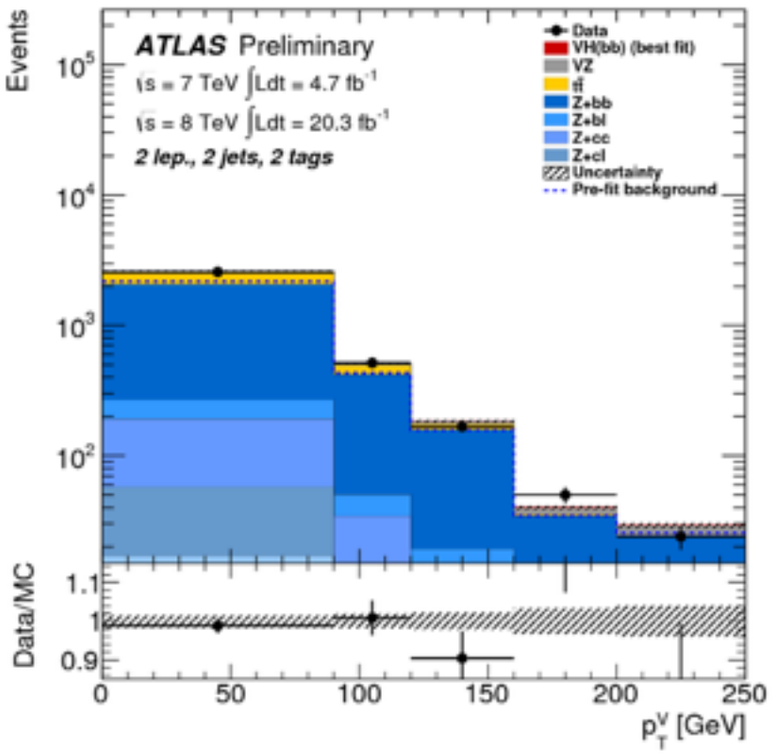


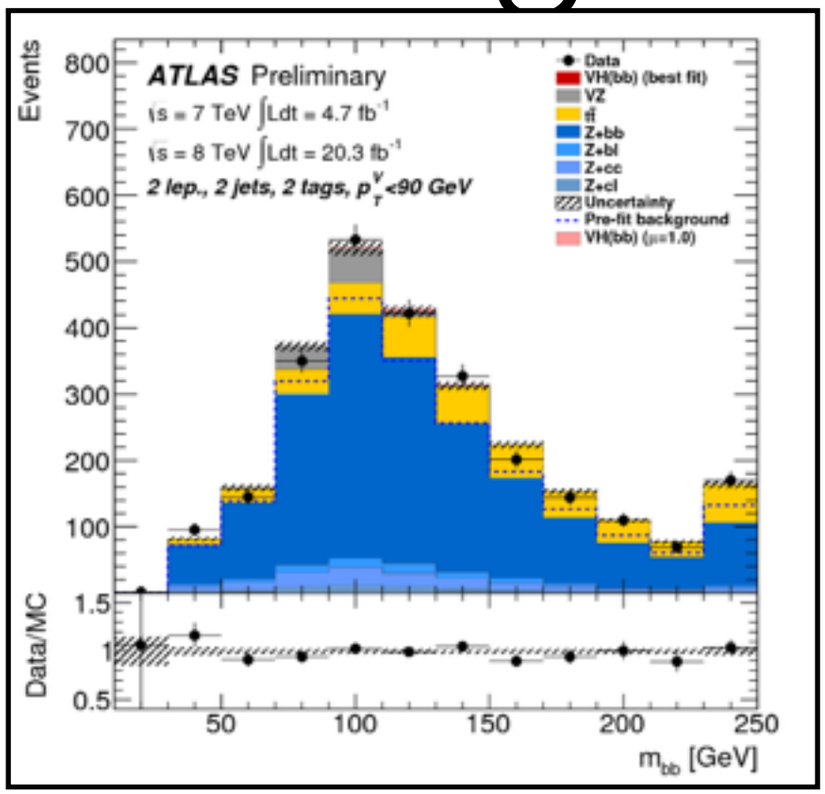


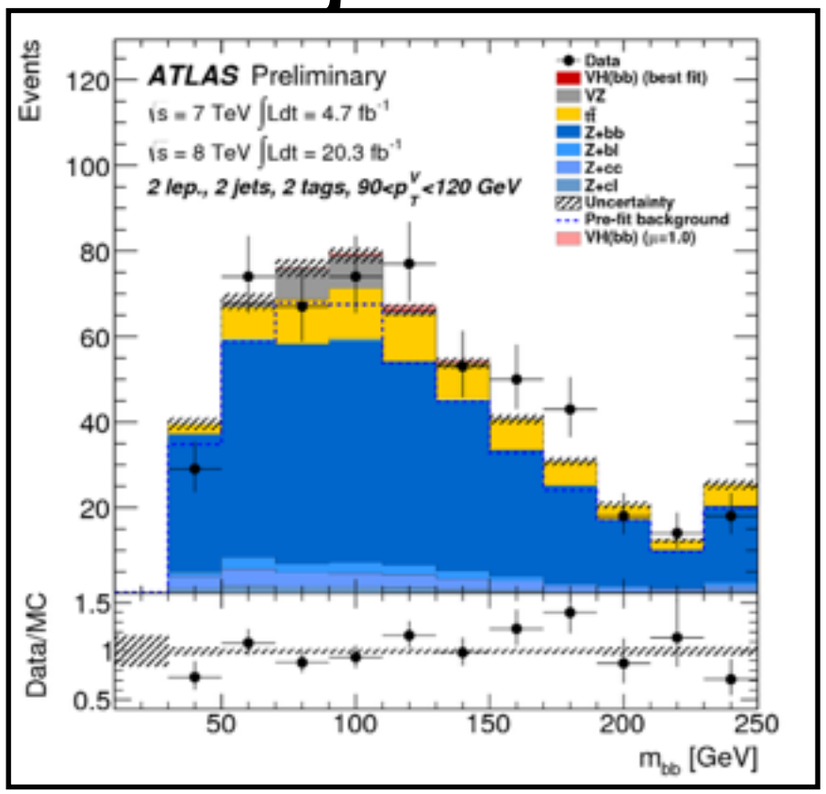


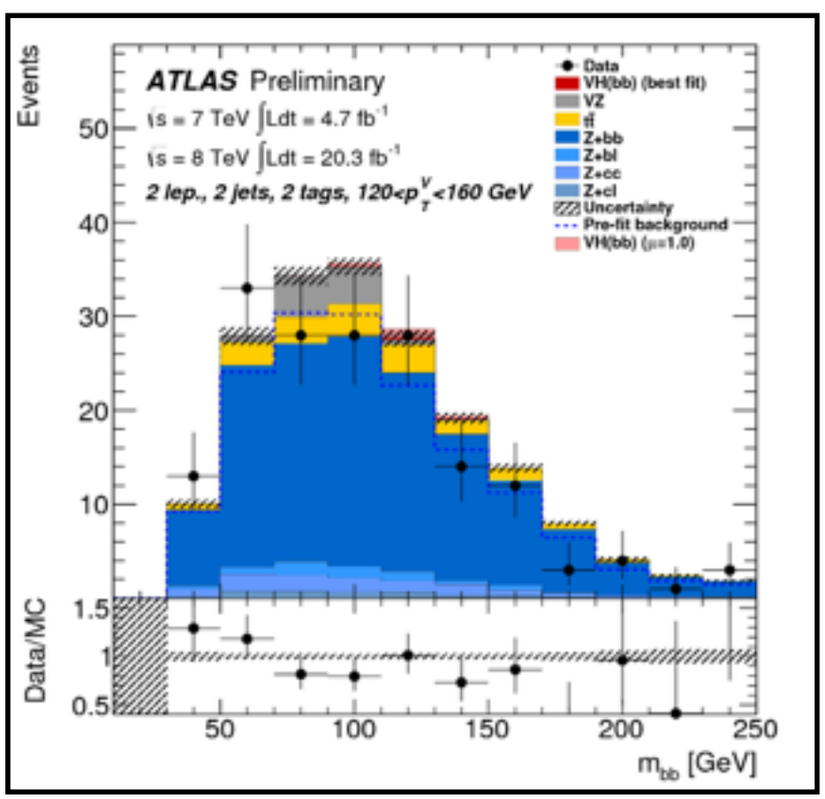


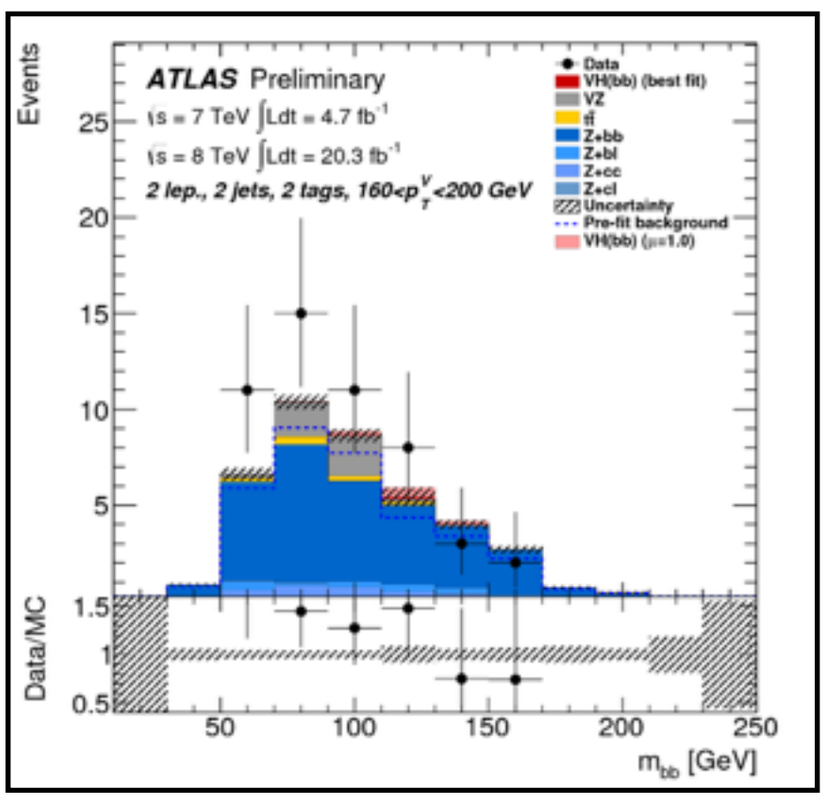
2 Leptons region - 2 jets

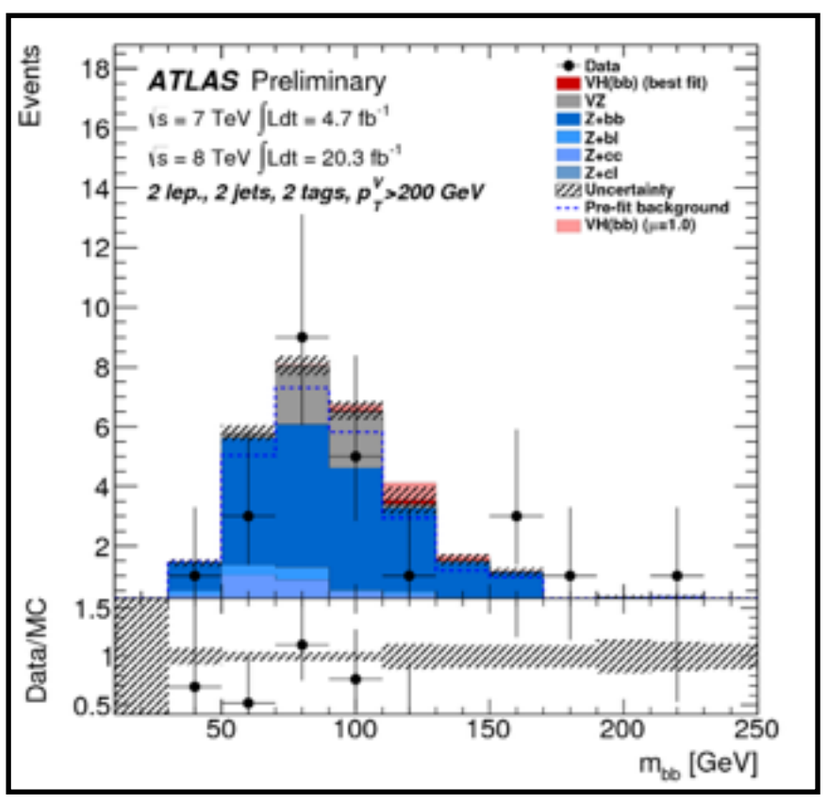




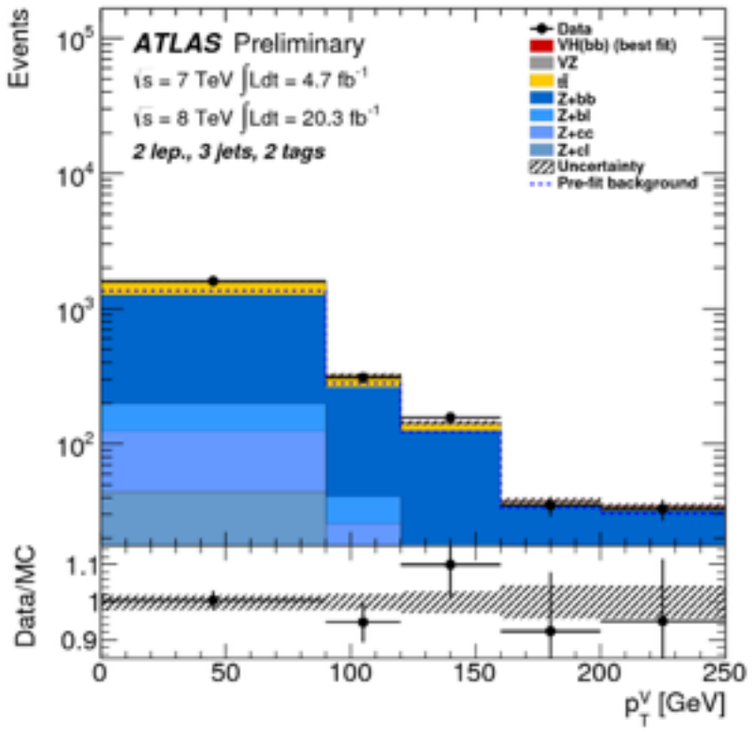


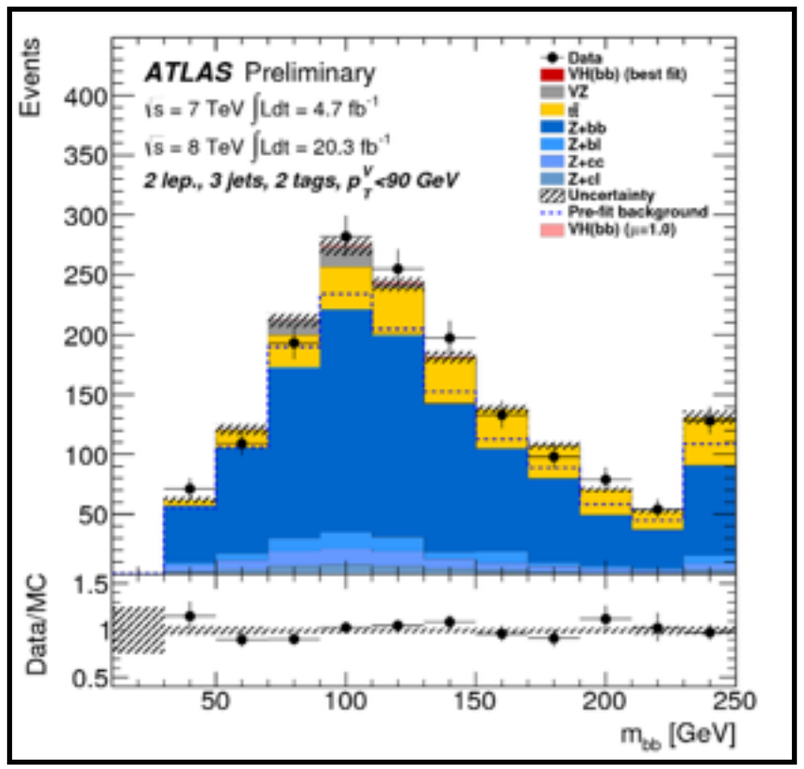


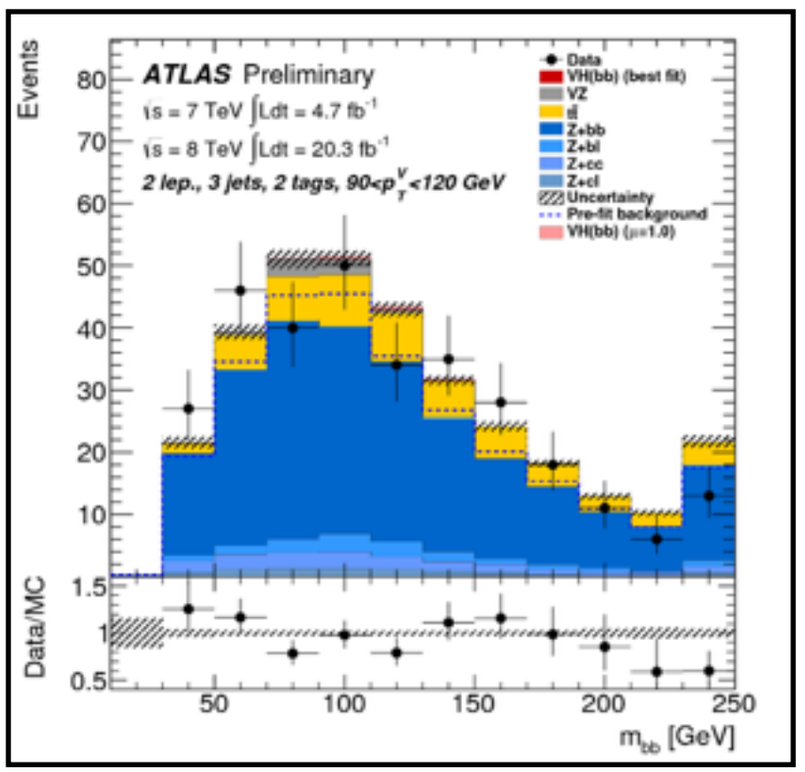


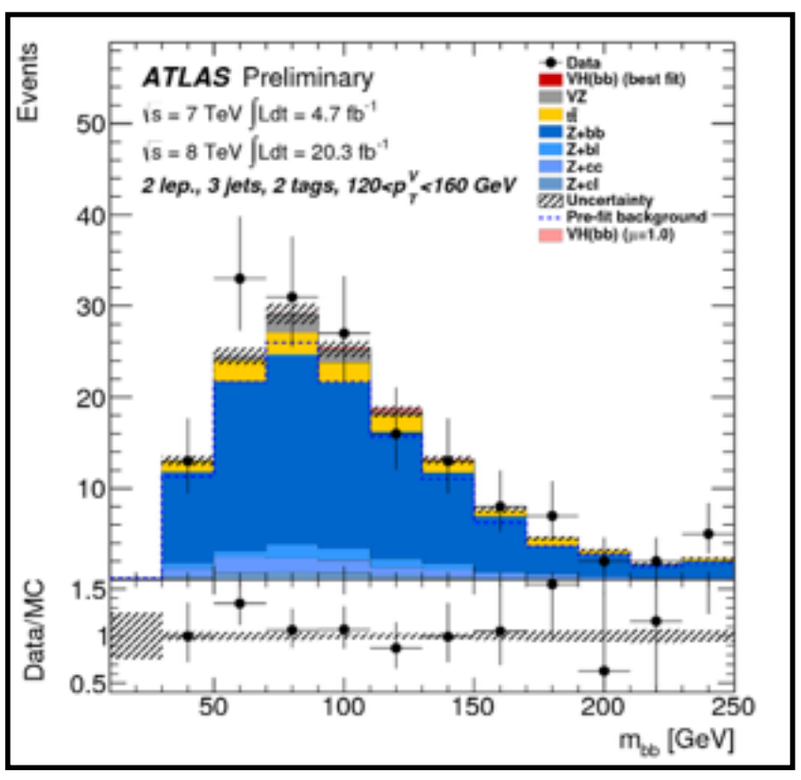


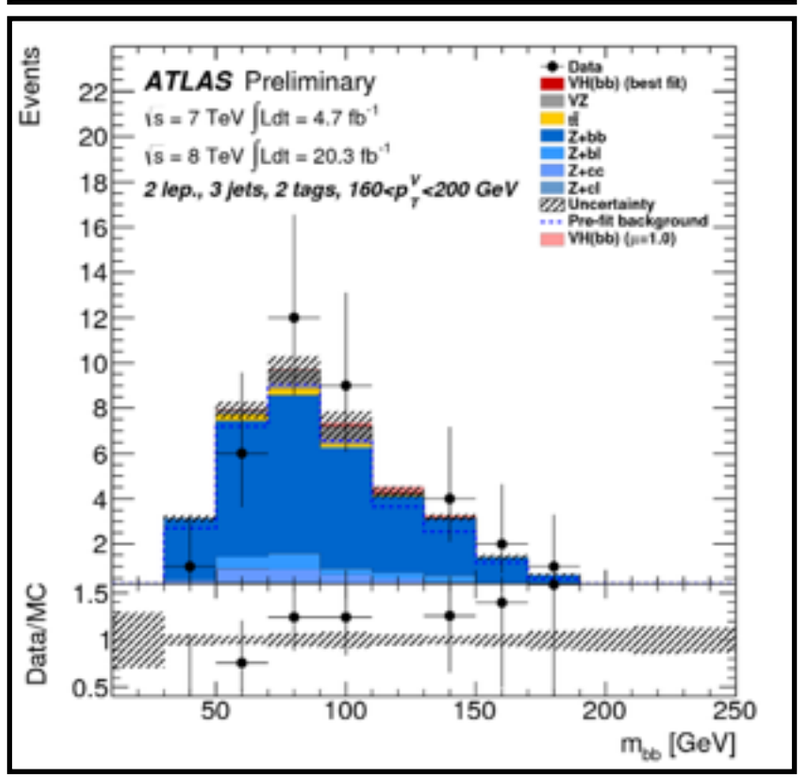
2 Leptons region - 3 jets

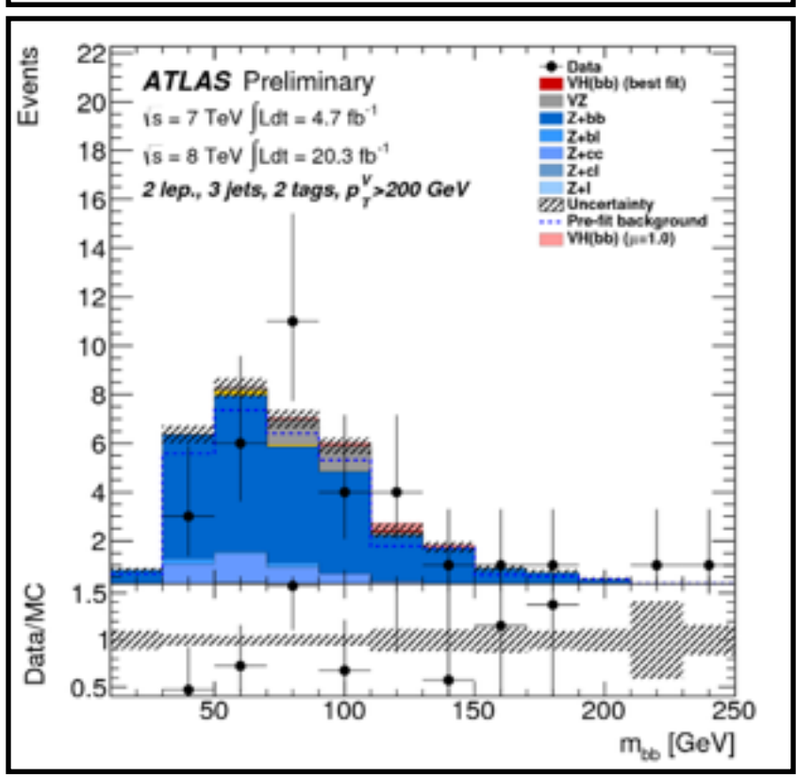




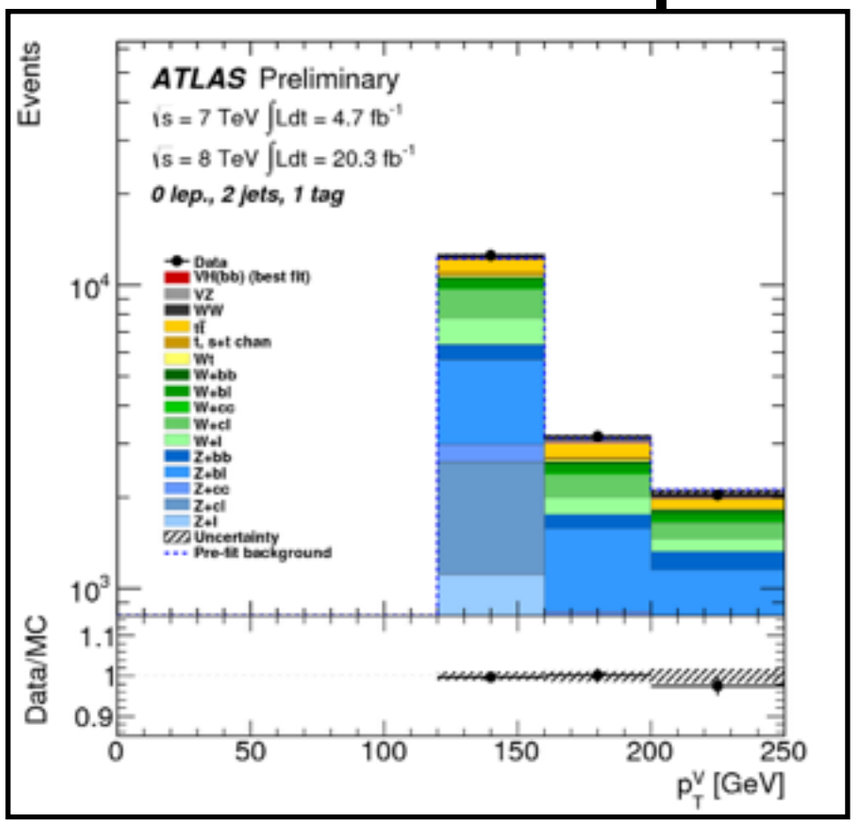


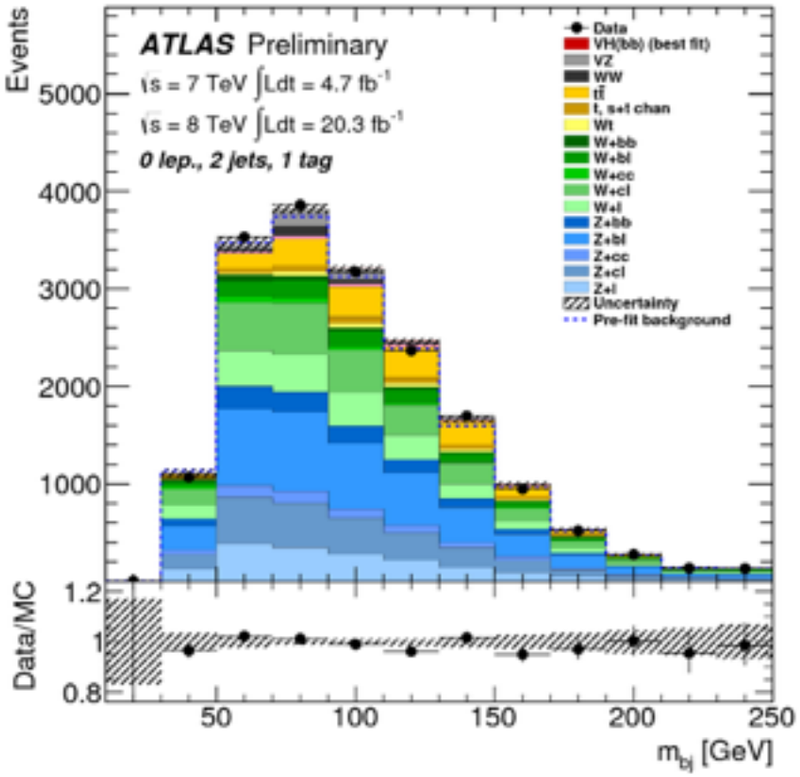


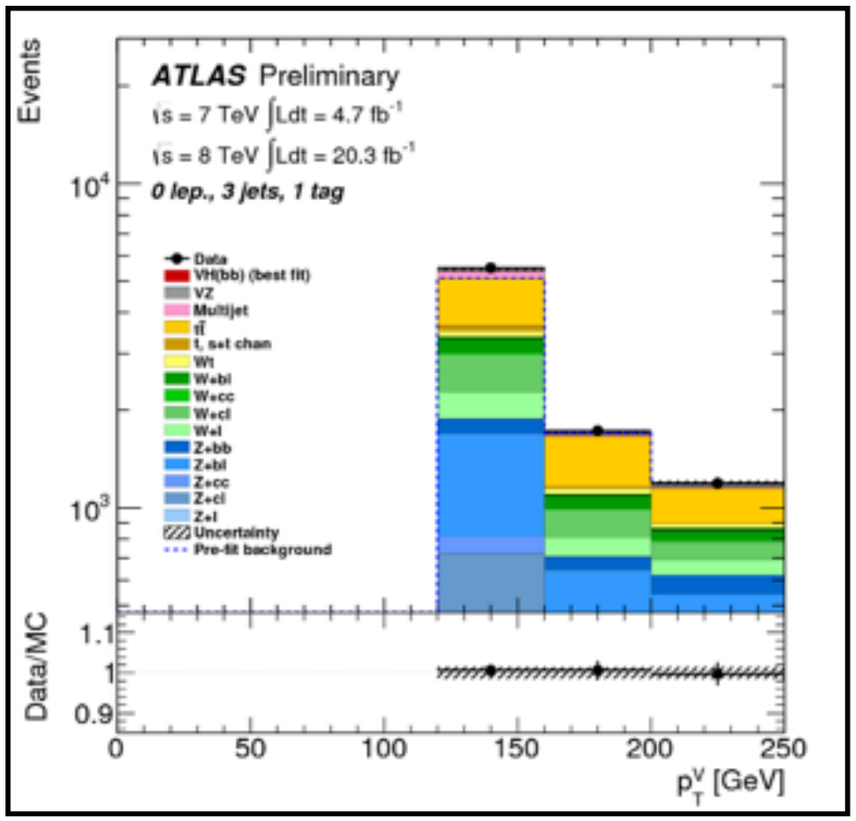


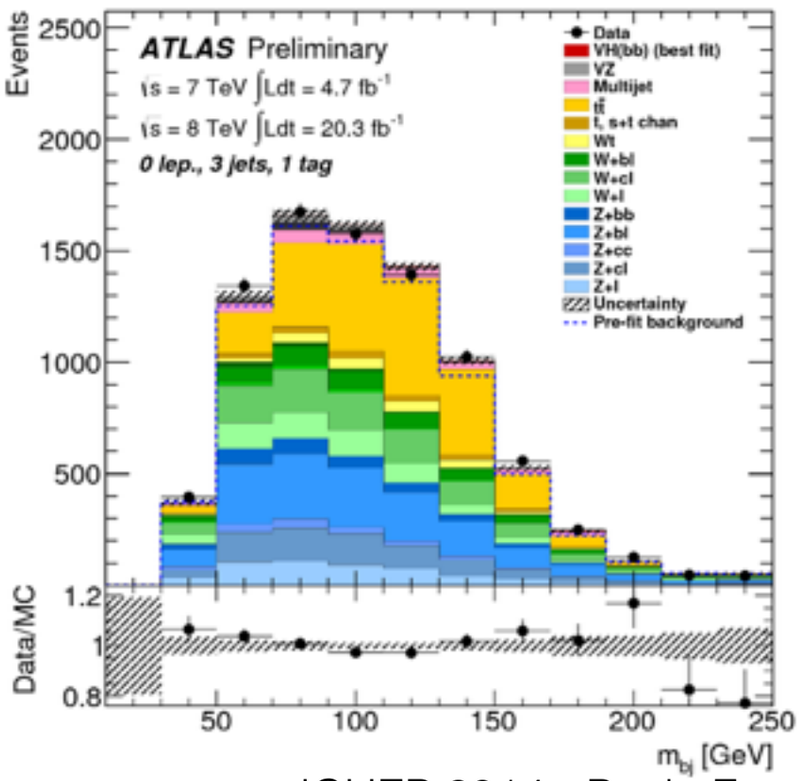


0 Lepton region - 1 tag

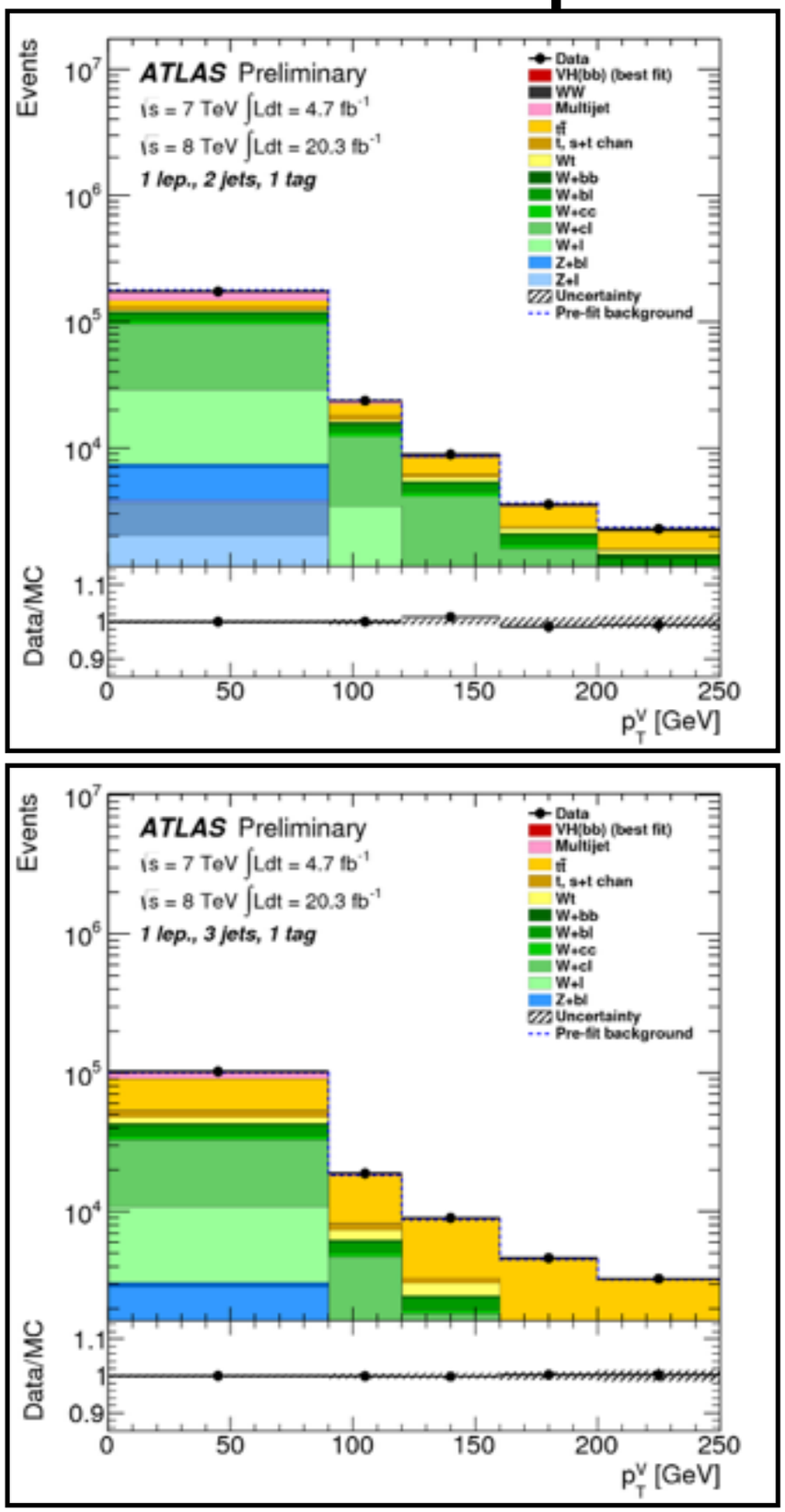


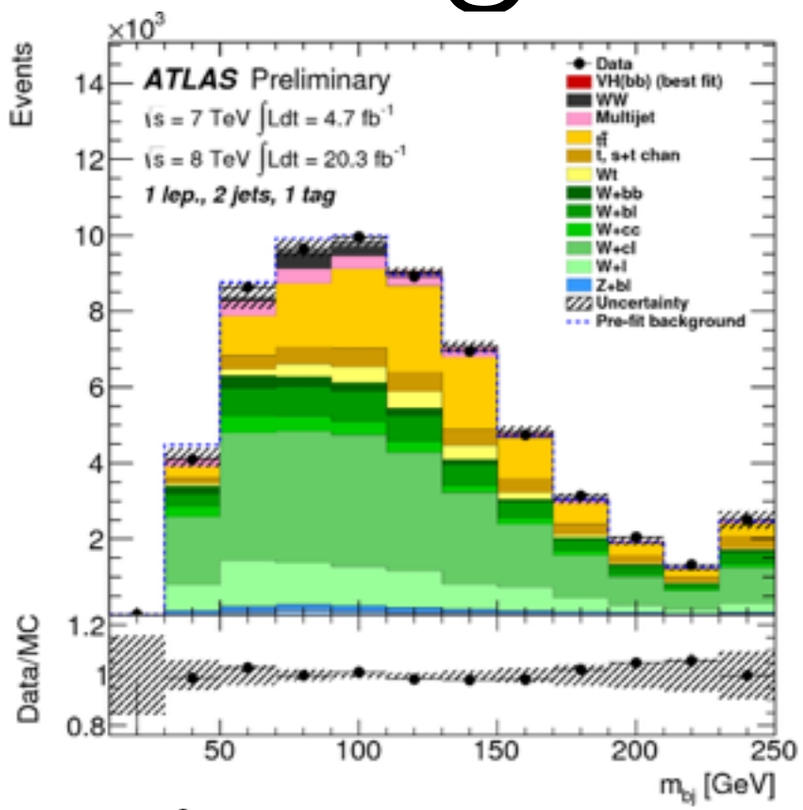


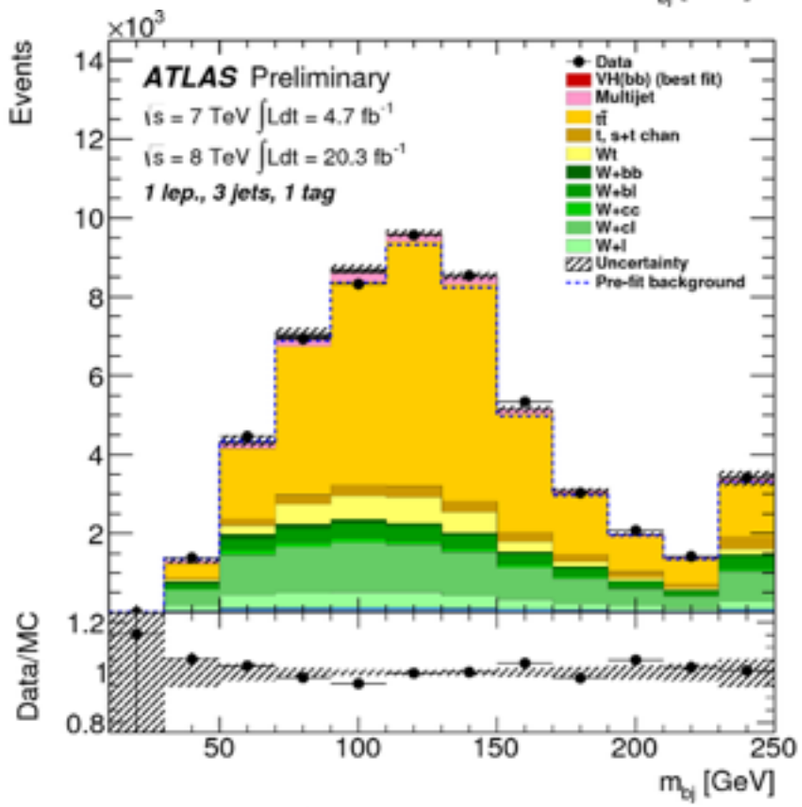




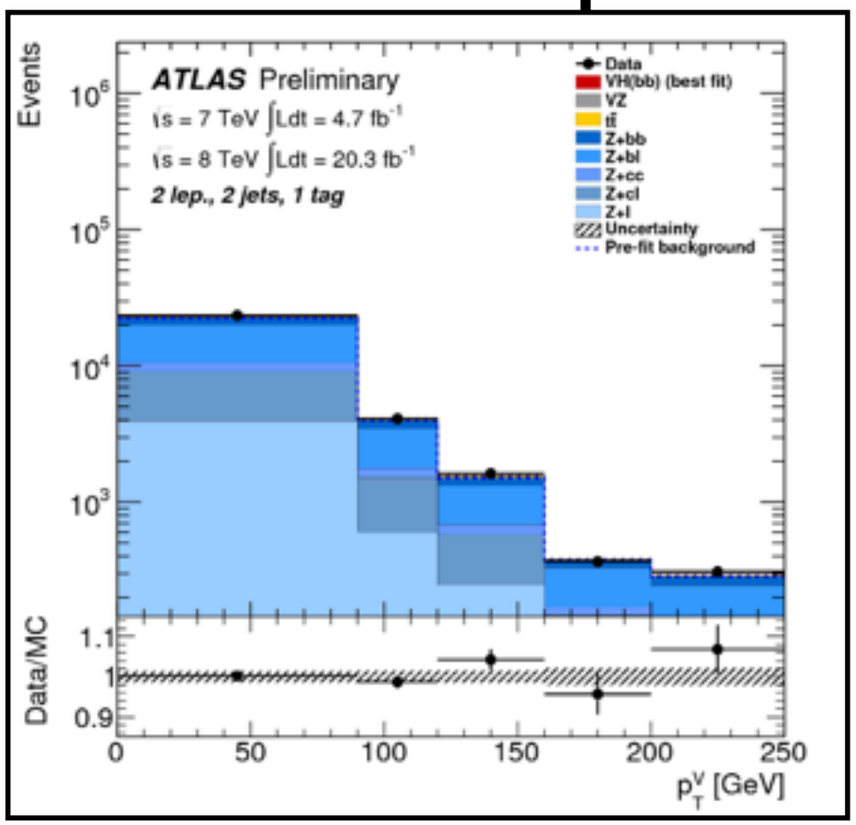
1 Lepton region - 1 tag

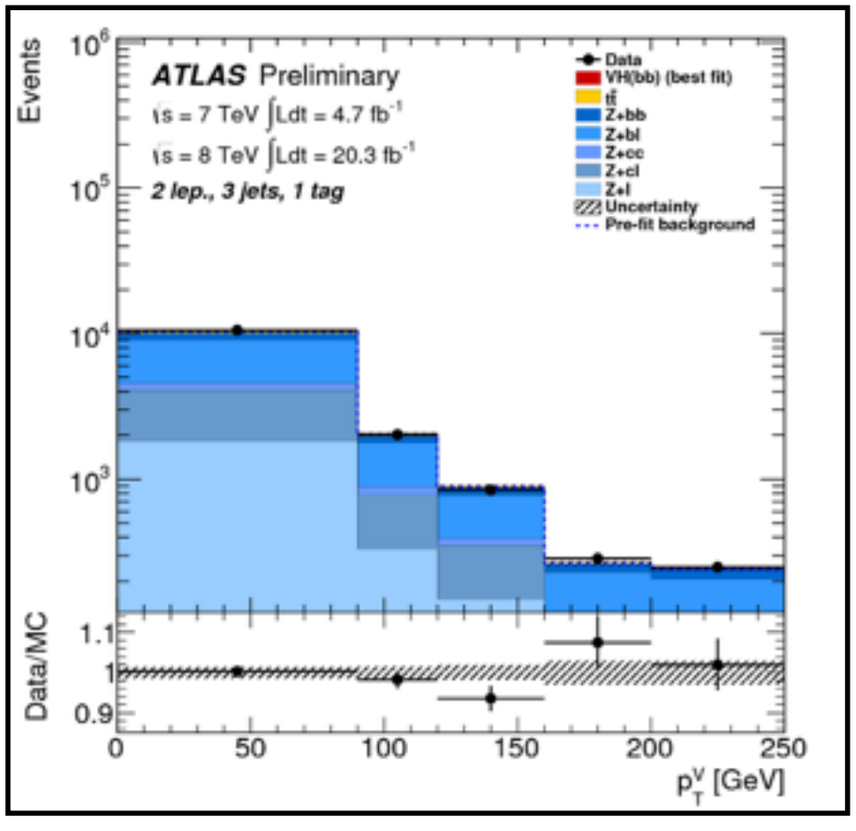


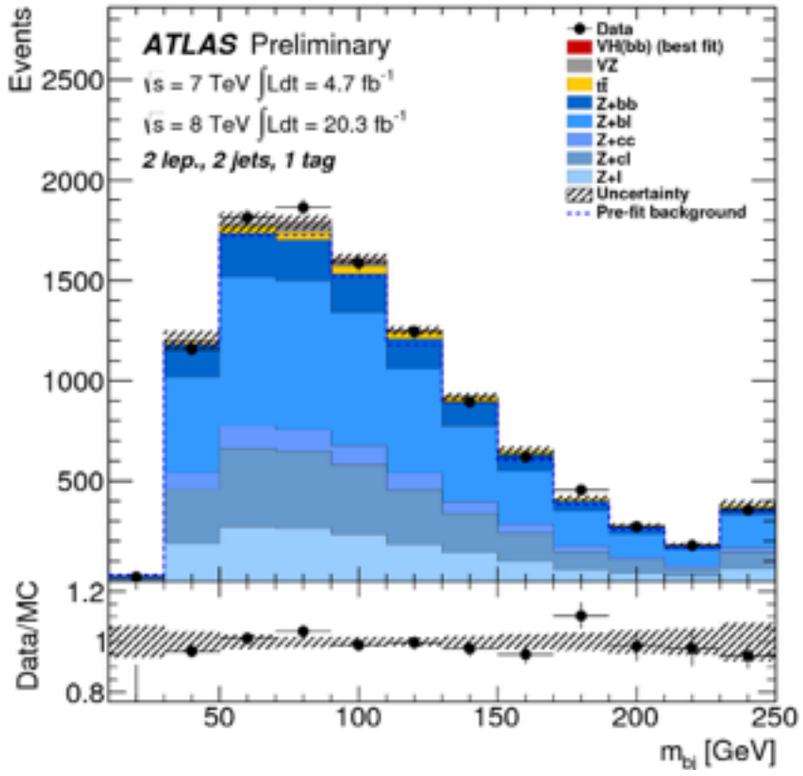


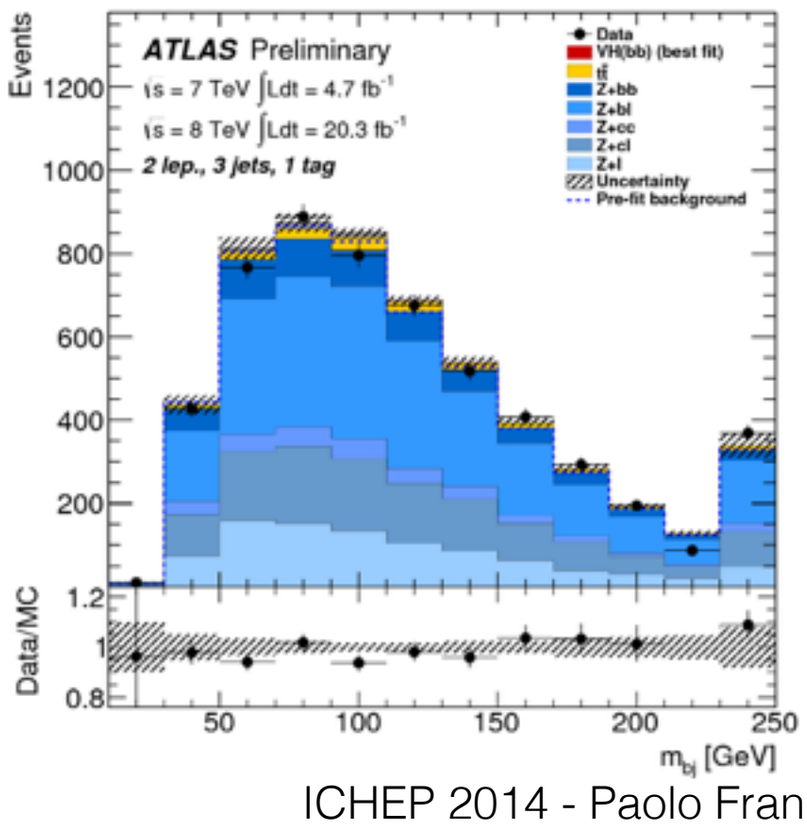


2 Leptons region - 1 tag

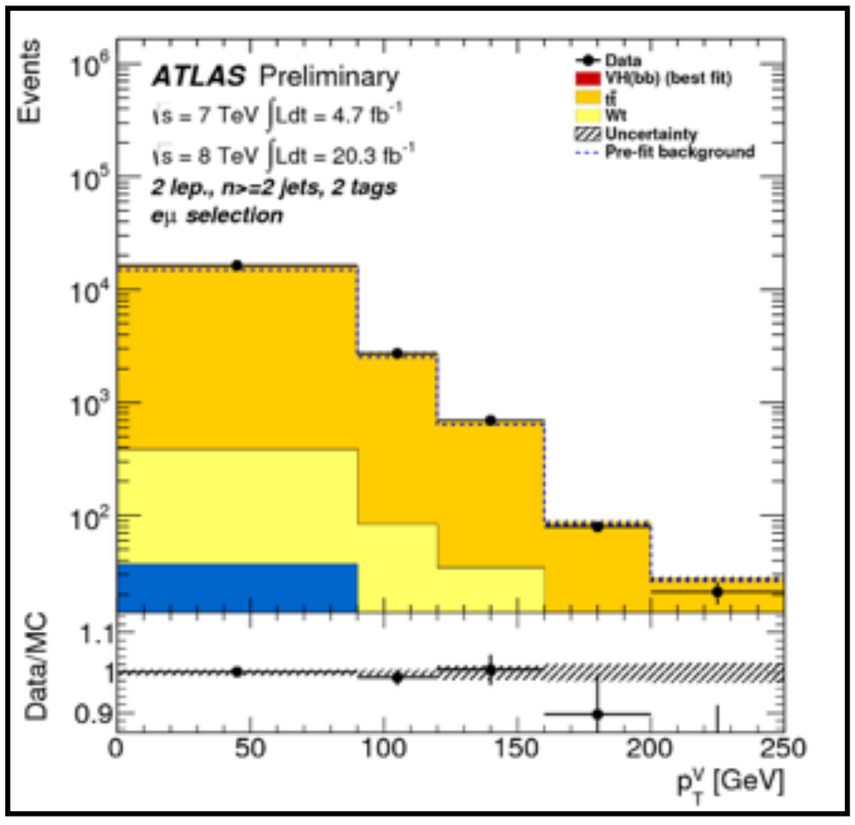


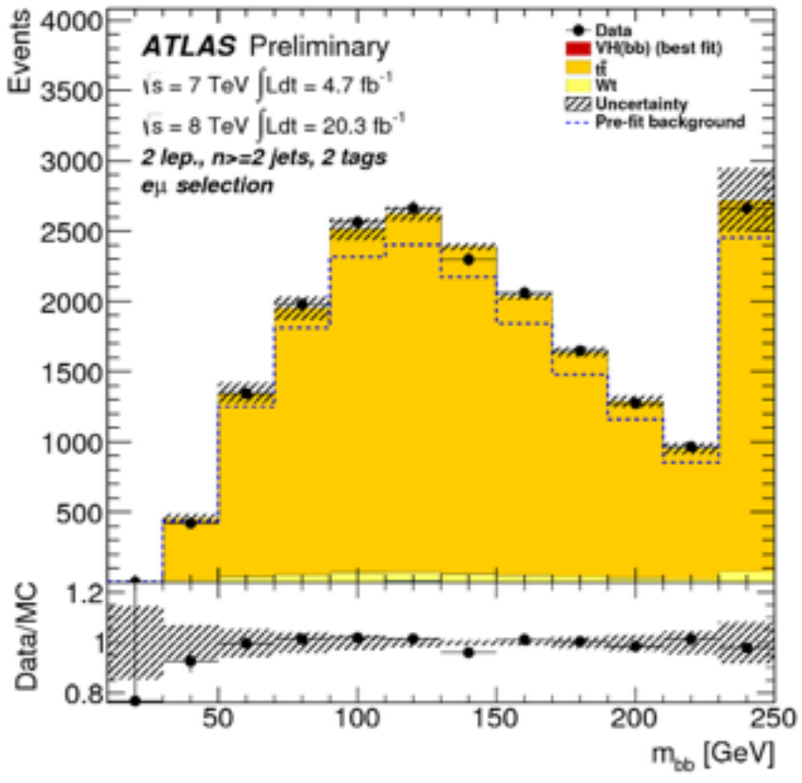




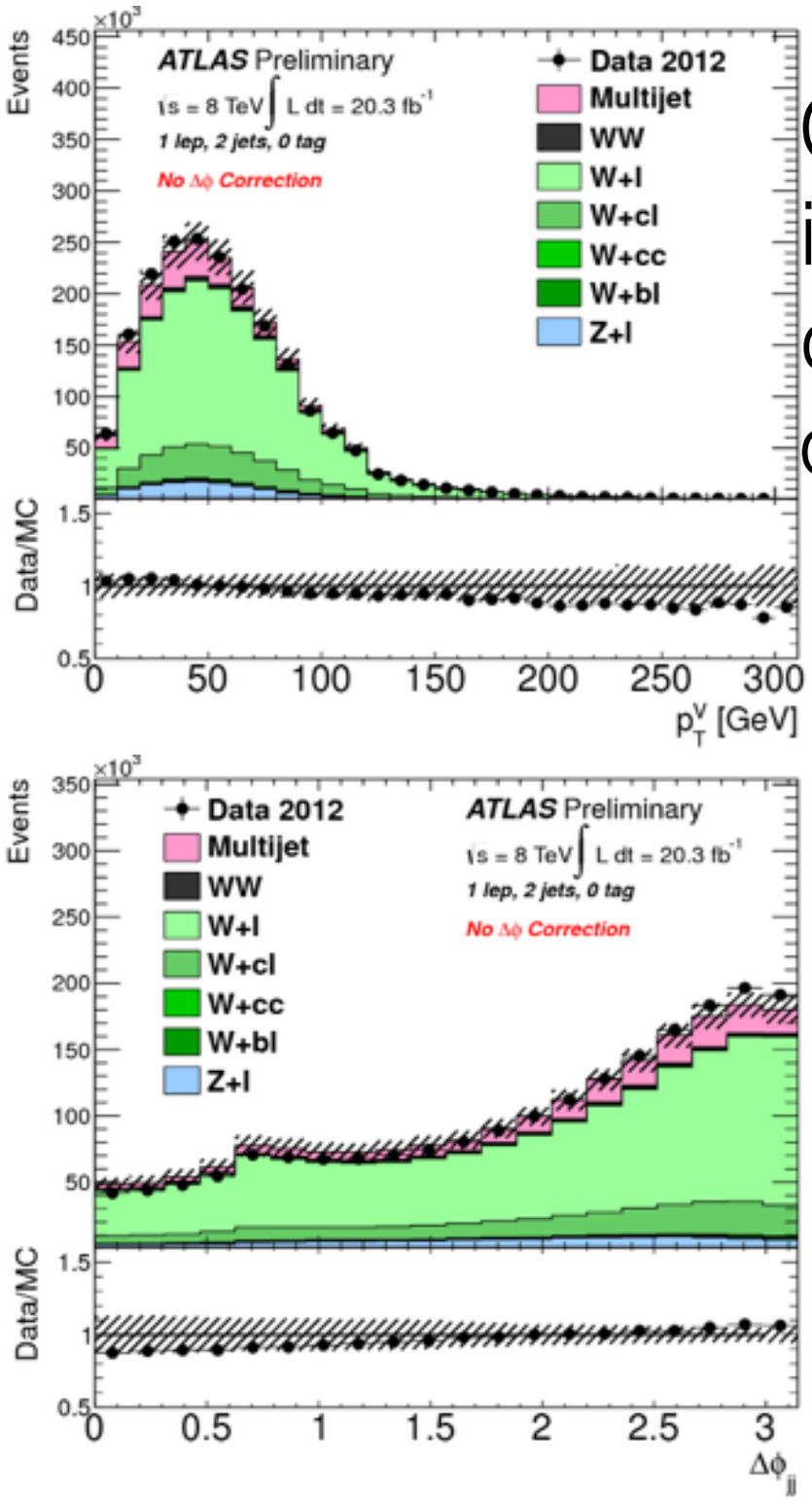


ttbar eμ control regions

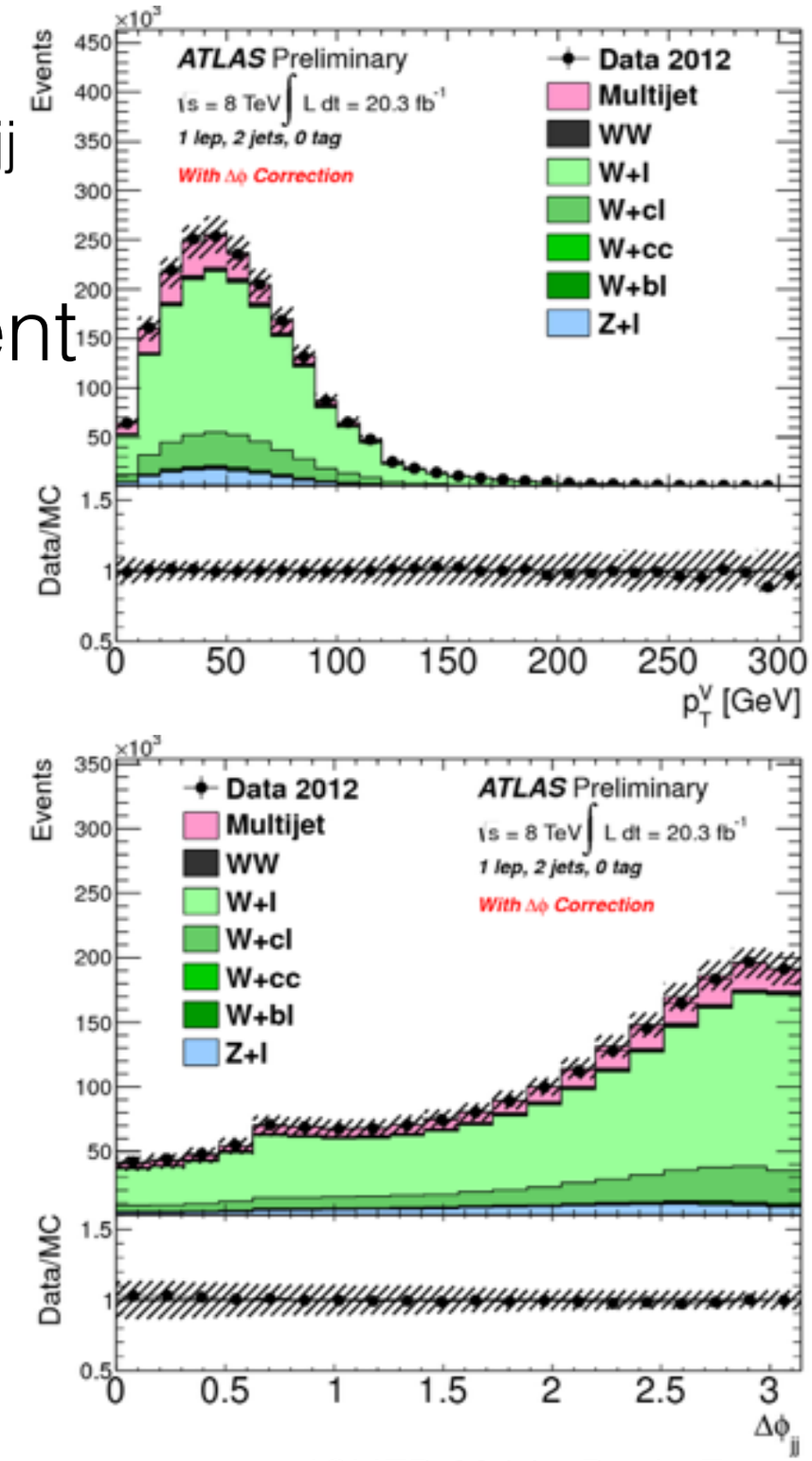




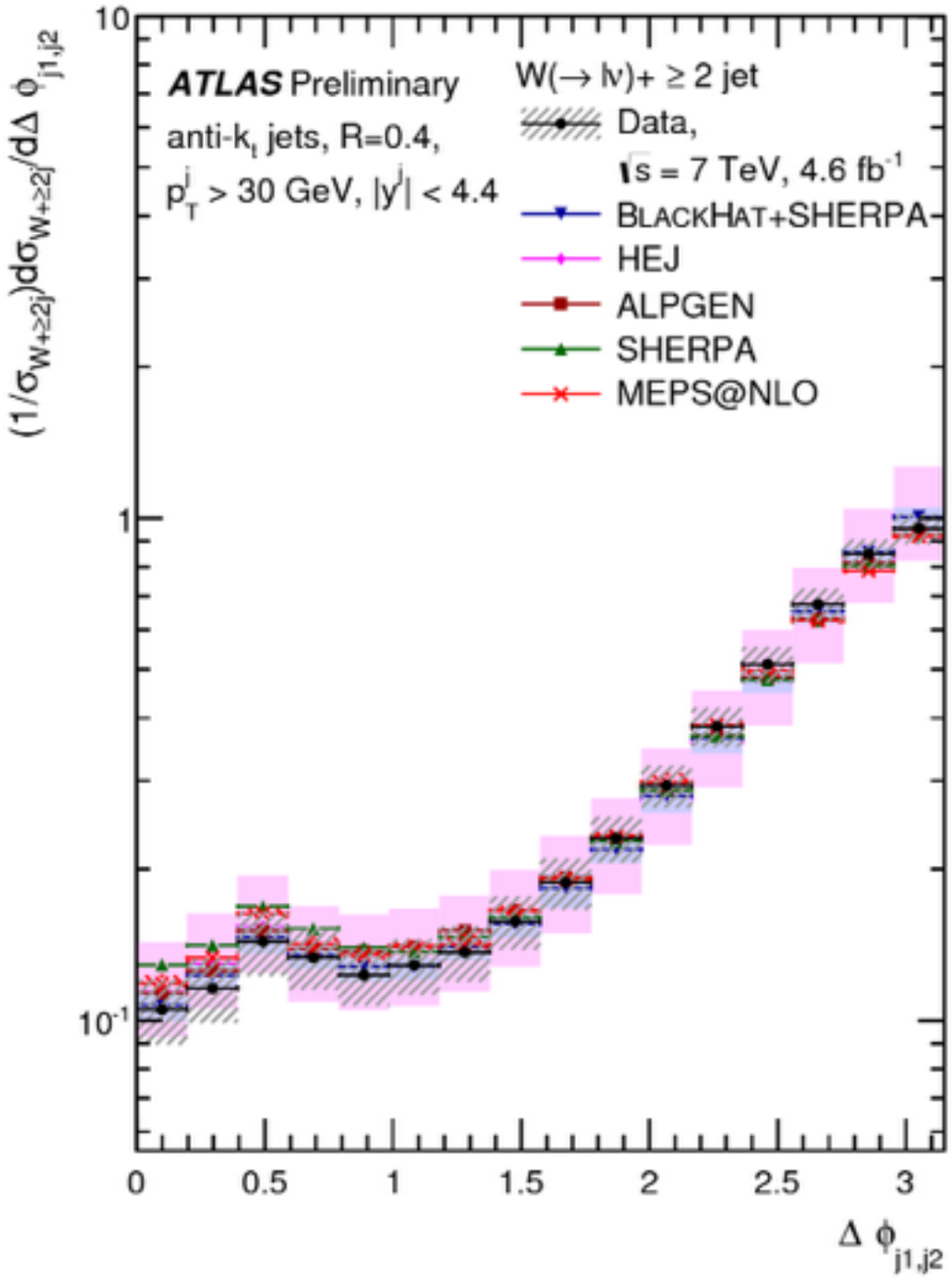
V+jets modelling

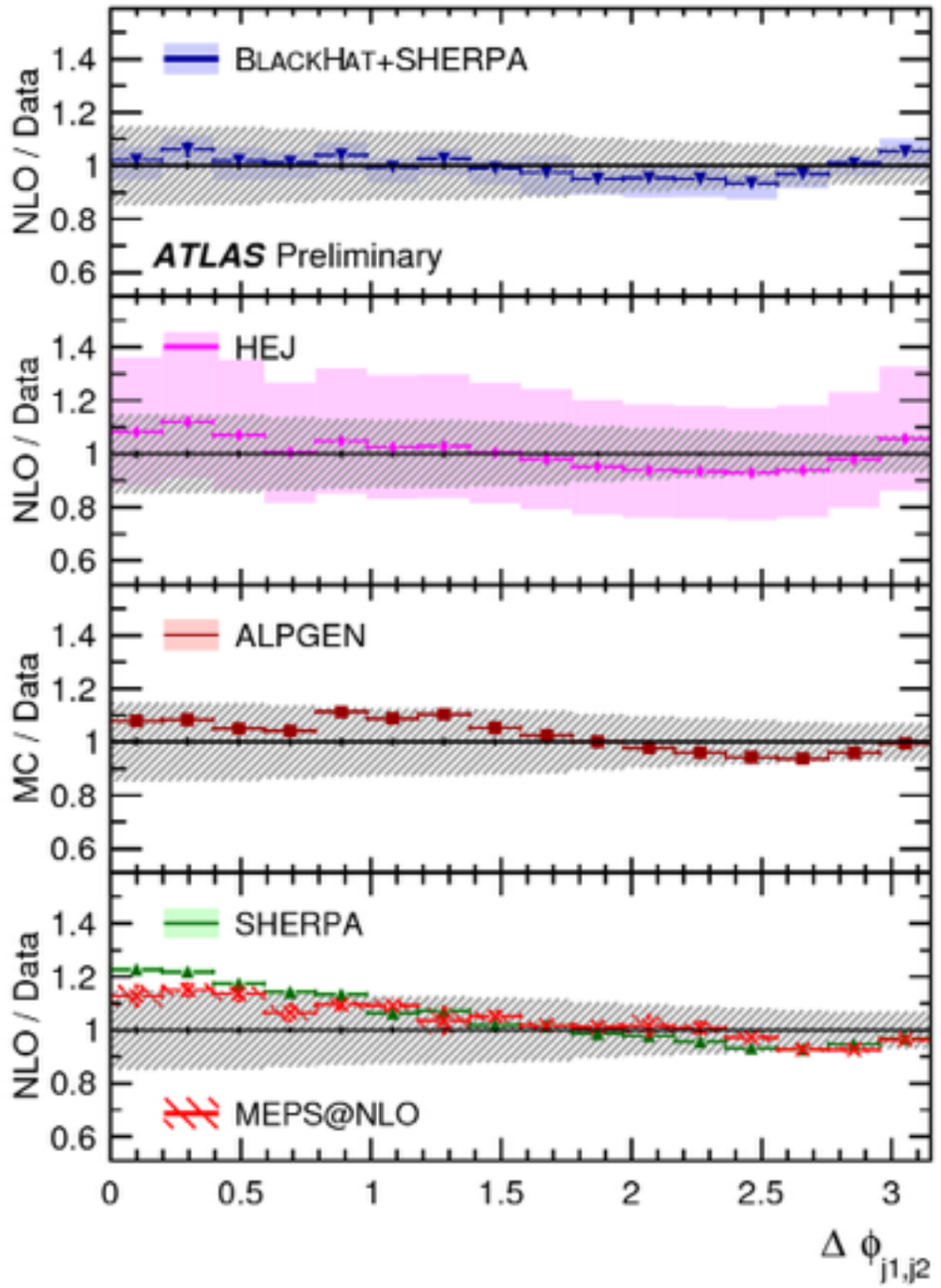


Correcting the $\Delta\phi_{jj}$ improve the data-MC agreement of the pTV



V+jets modelling



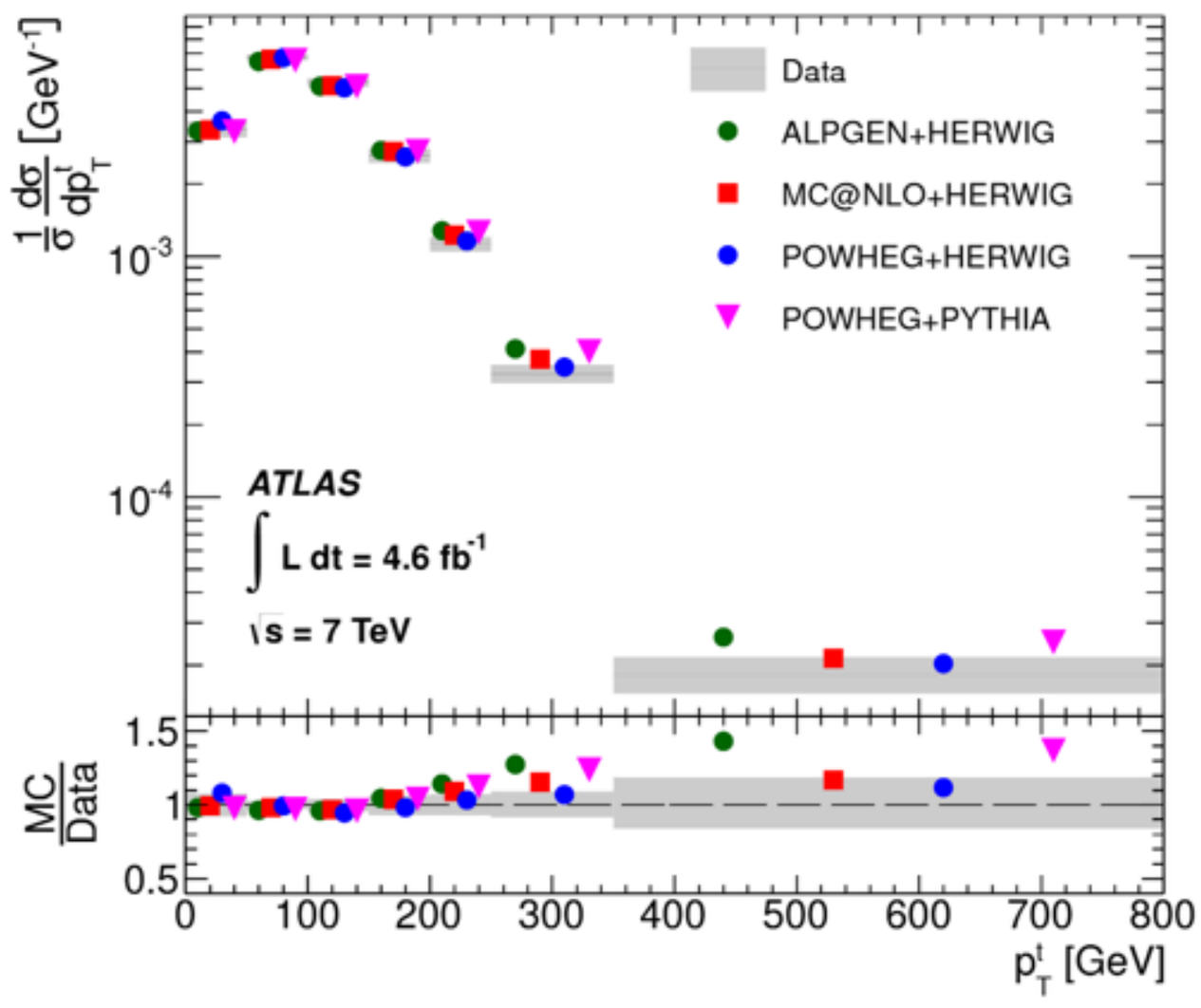


more info on W+jets measurements
on G. Hesketh talk
ATLAS-CONF-2014-035

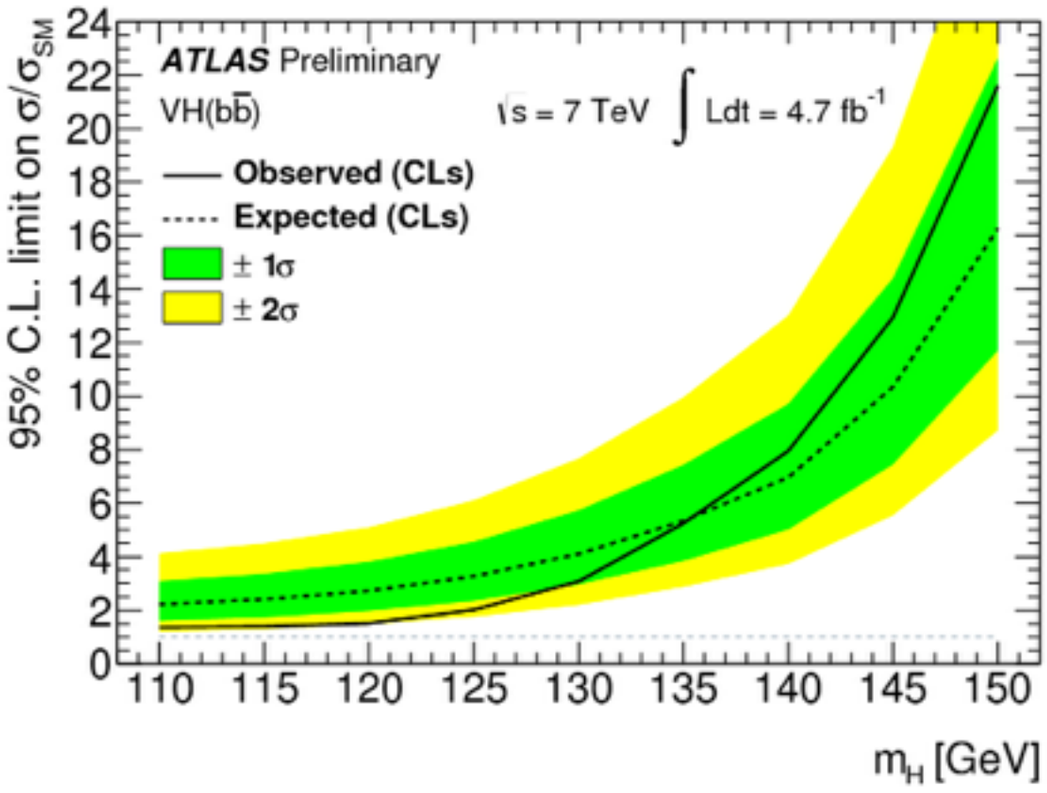
Top modelling

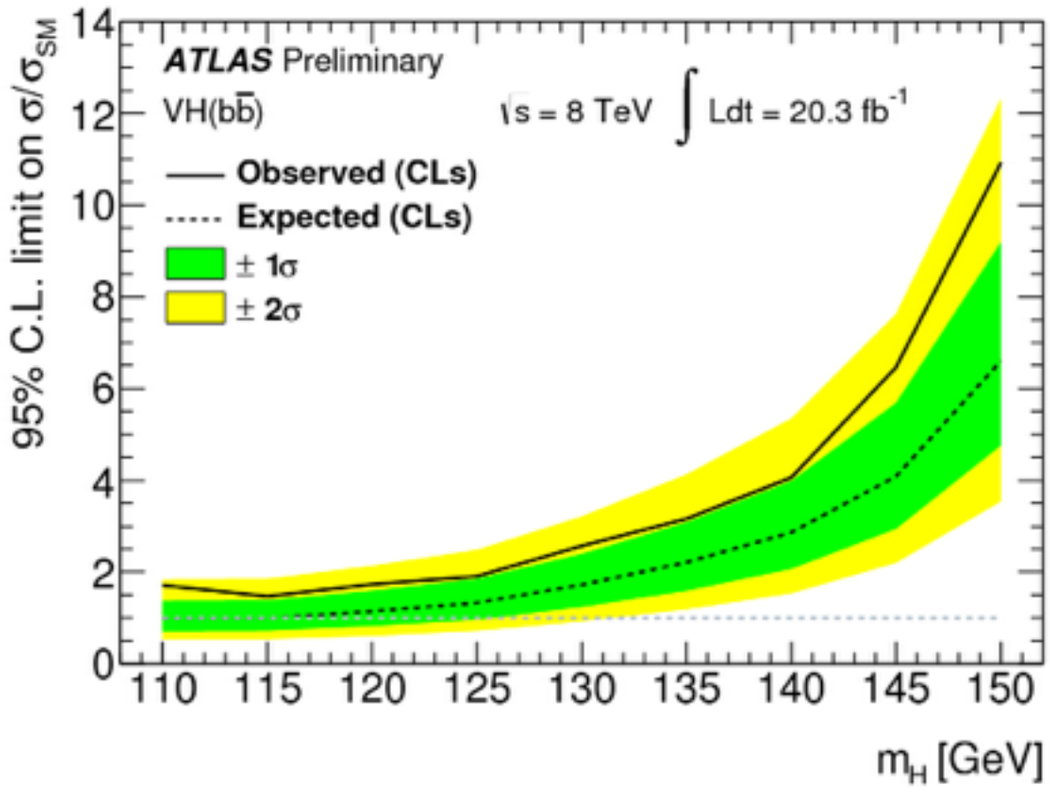
Top p_T
corrected to the ATLAS
measured spectrum.

CERN-PH-EP-2014-099

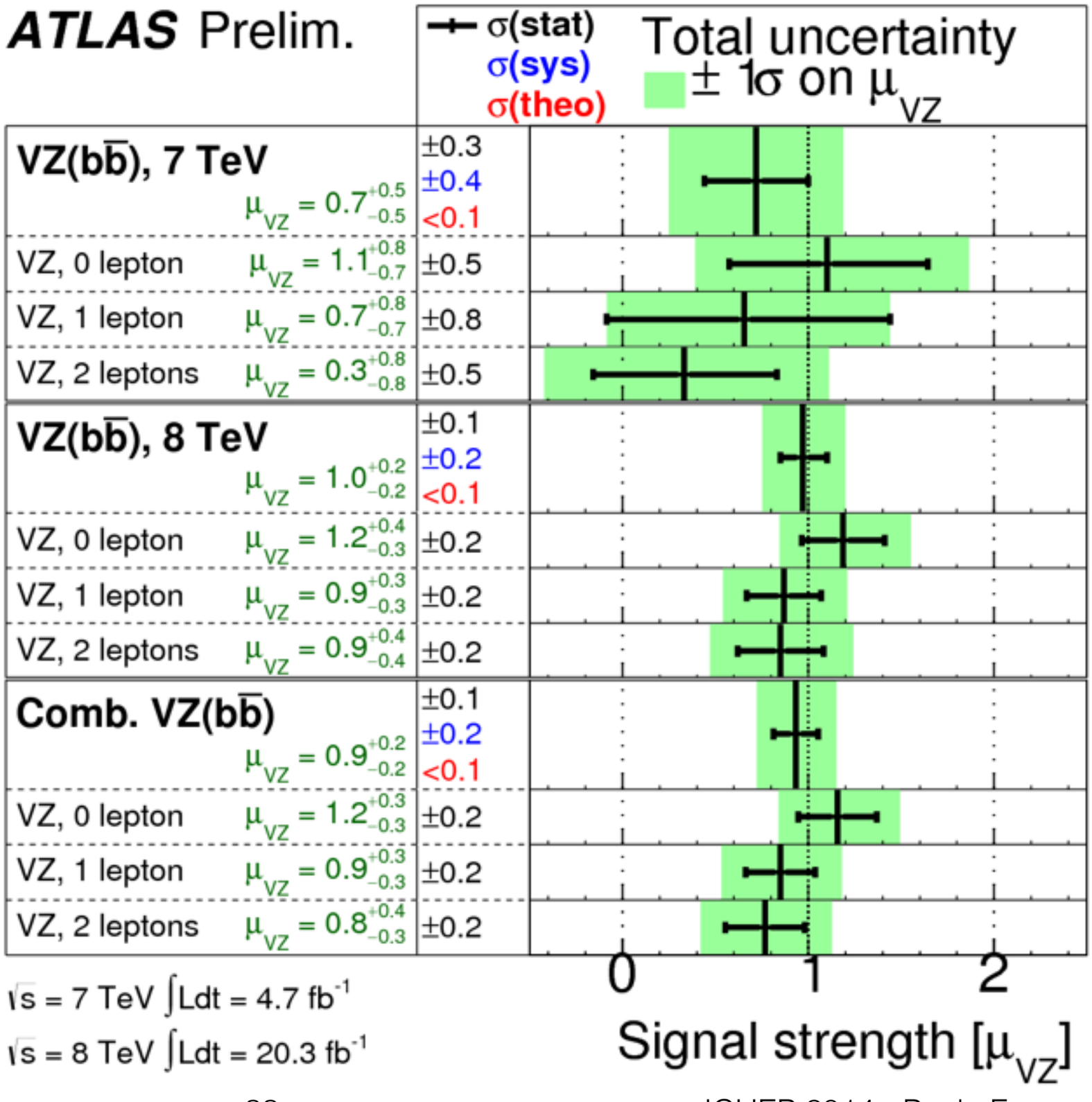


7 TeV and 8 TeV Limits



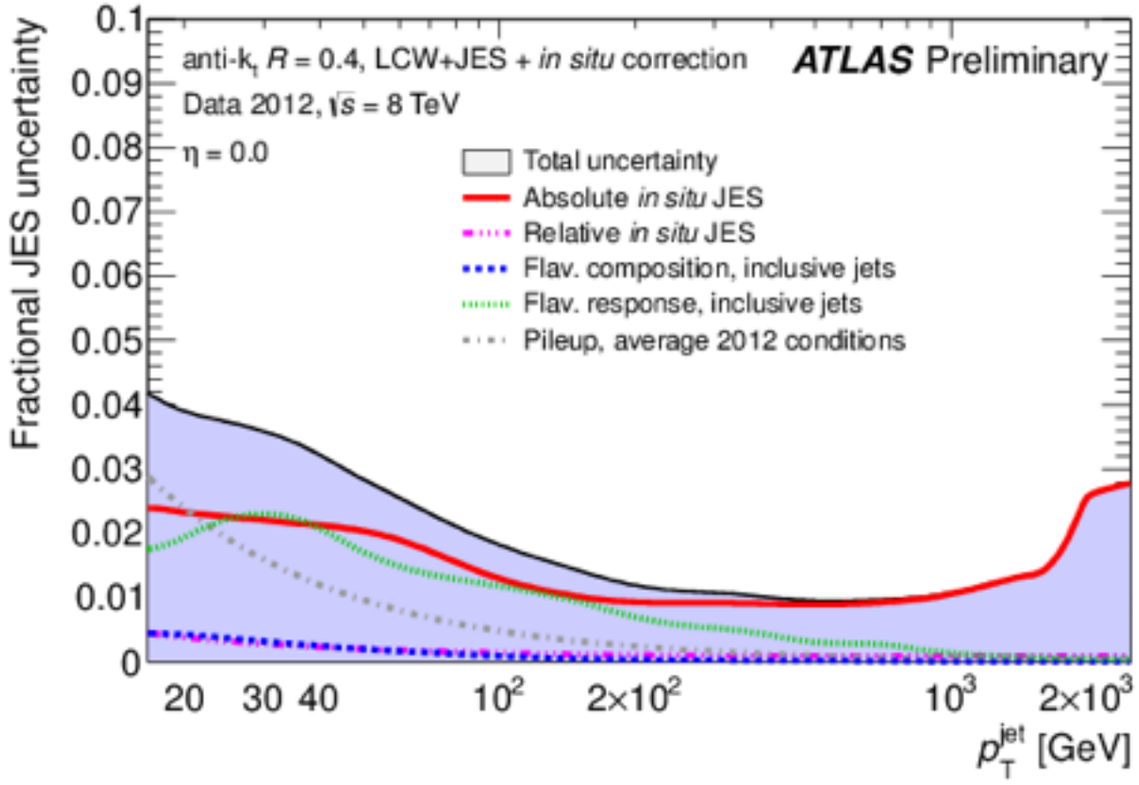


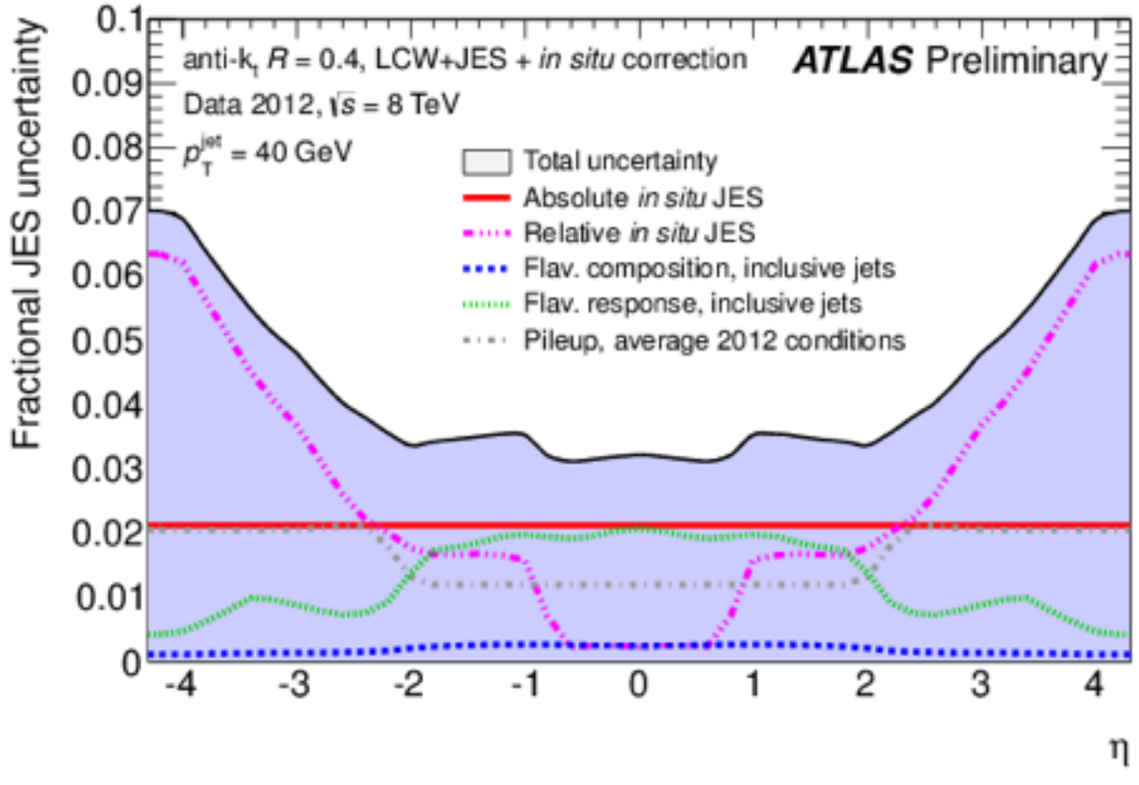
Diboson results



Jets

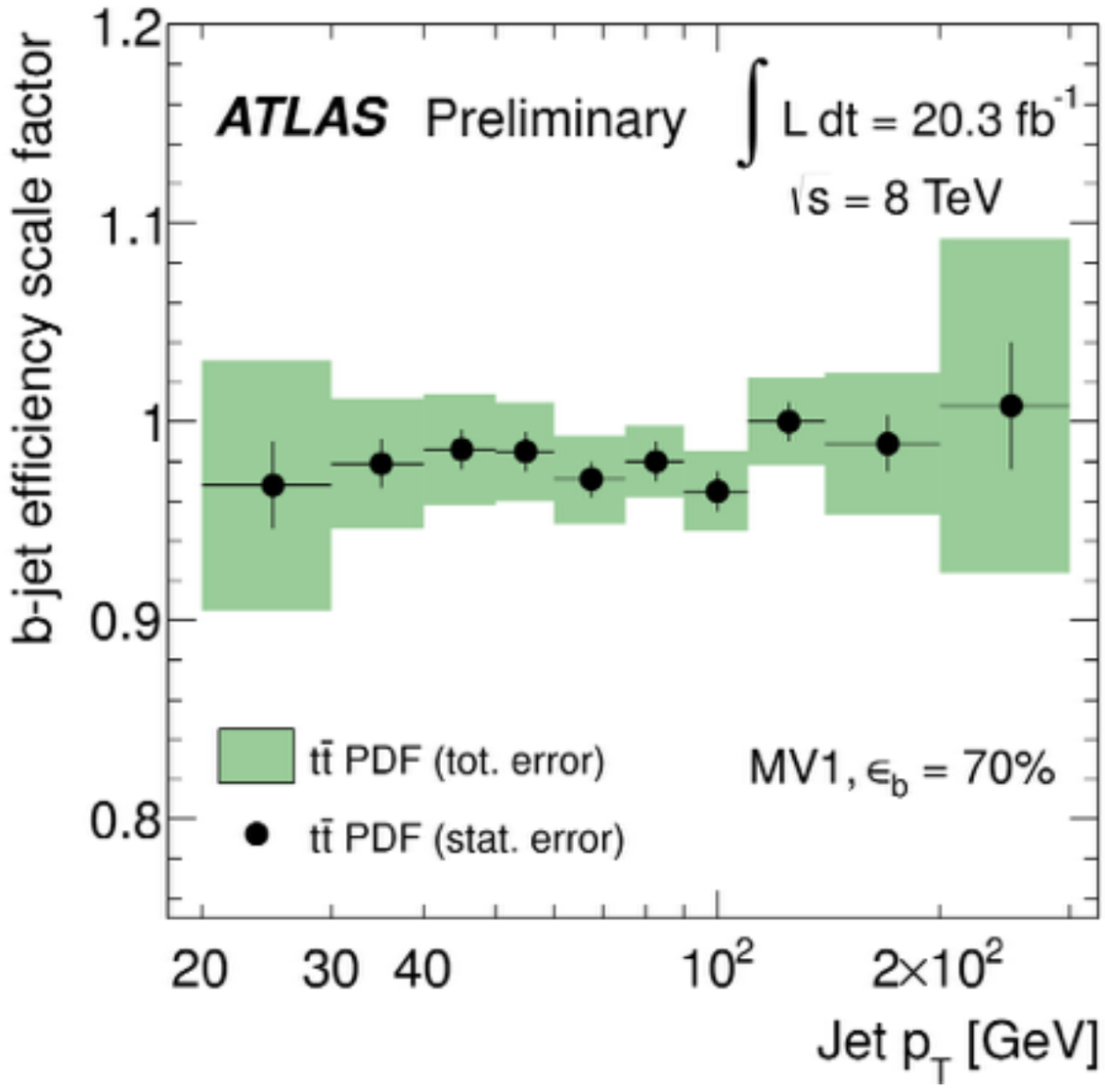
AntiKt with R=0.4 have been used in the analysis



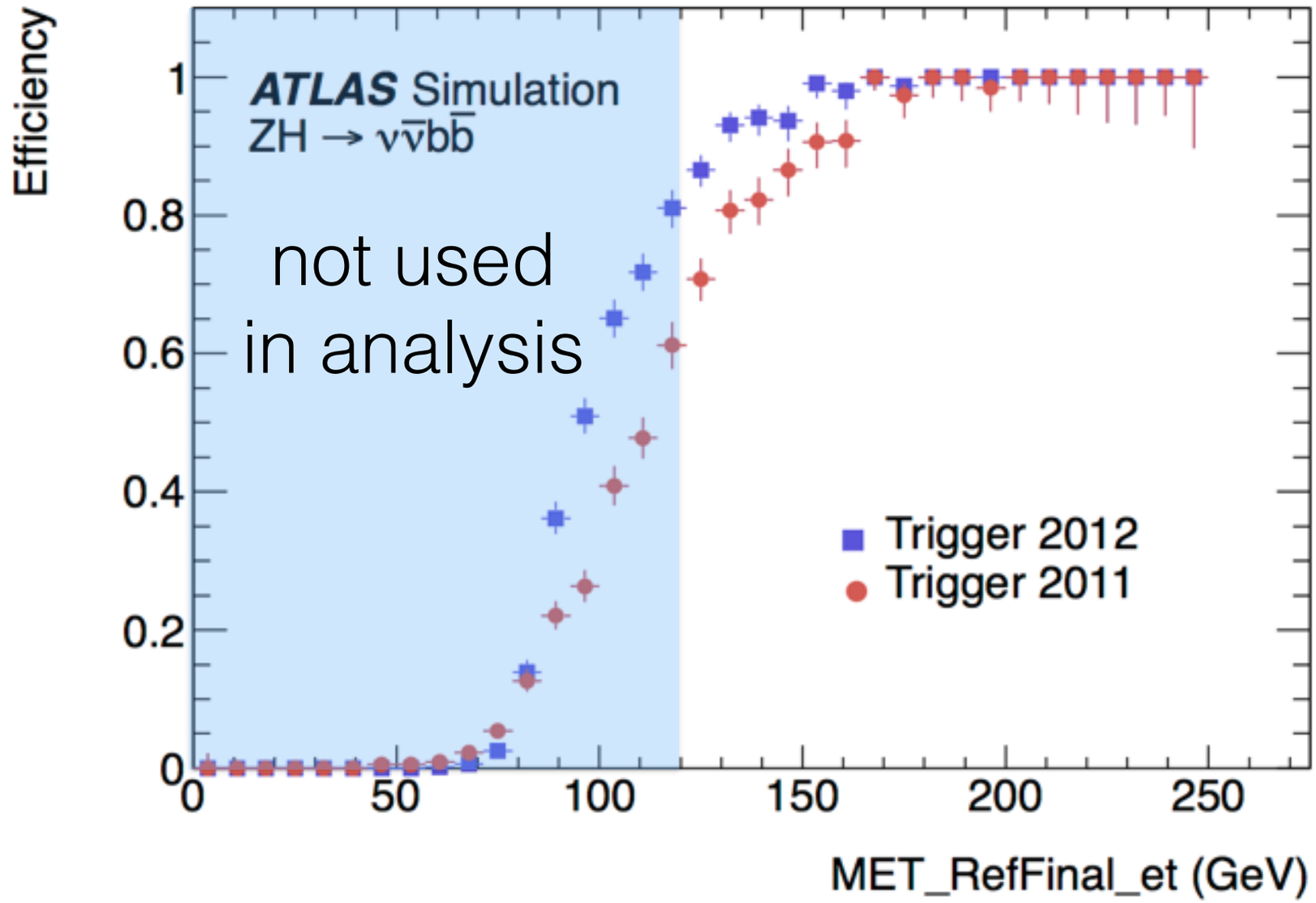


B-tagging

b-jets efficiency 70%
c-jets rejection factor: 5
light jets rejection factor: 150



MET Trigger


Efficiency
ATLAS Simulation
ZH → νν̄bb̄
not used
in analysis
Trigger 2012
Trigger 2011
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250
MET_RefFinal_et (GeV)