Search for H->bb in the associated production in ATLAS

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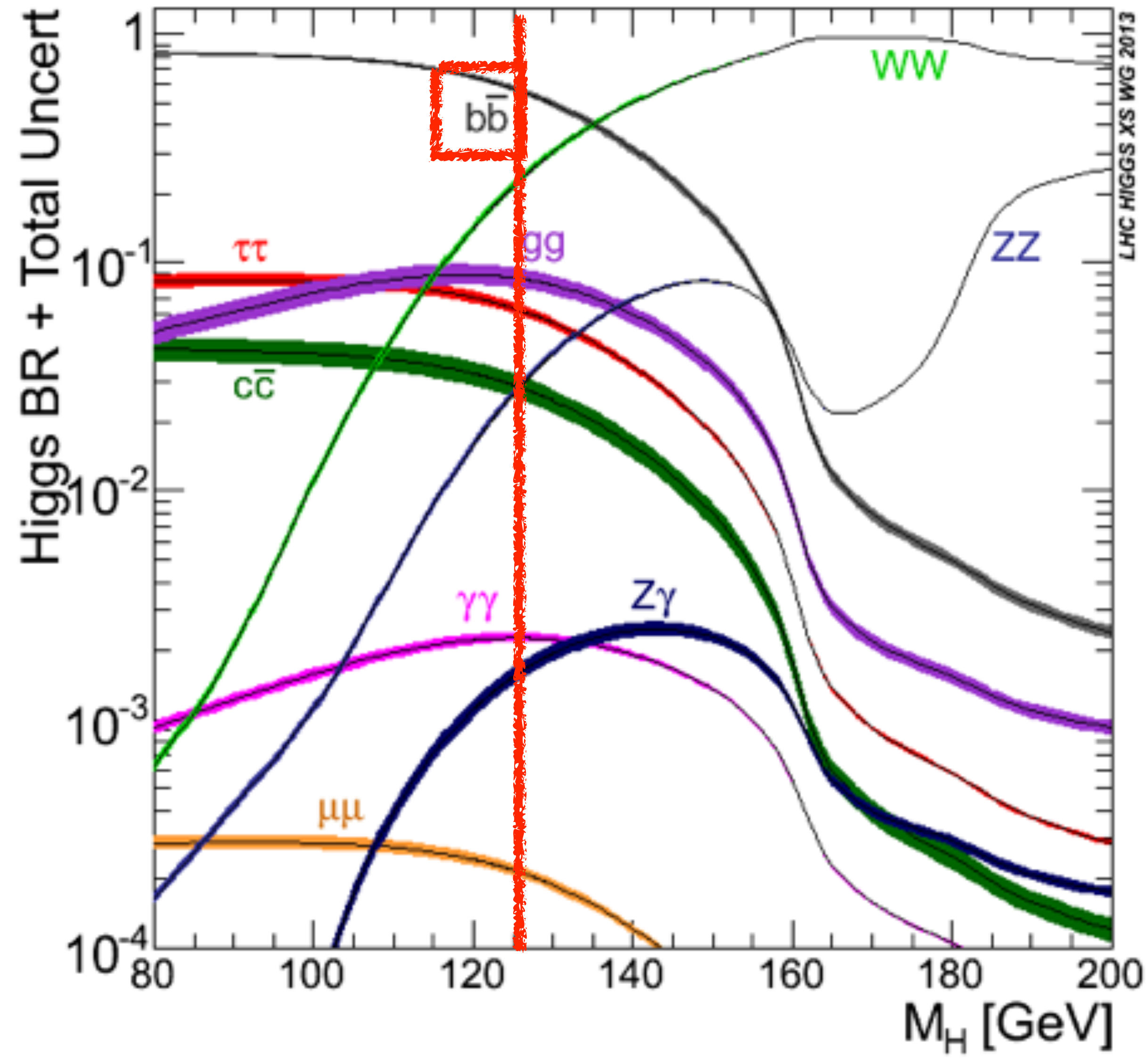
GDR Terascale - Heidelberg 11-13/12/2014

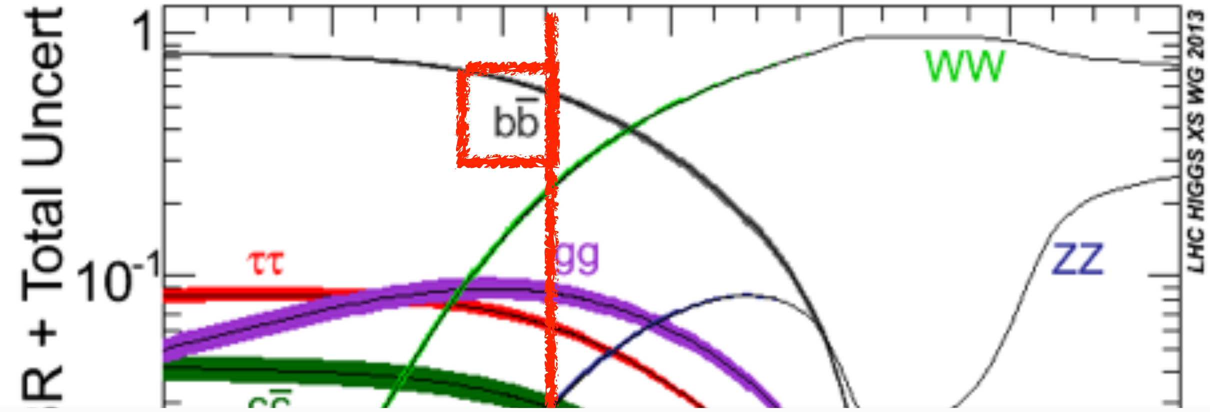
H→bb: Why?

- Since 4 July 2012:
  - Discovery of a new spin J=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 couples to quarks (i.e. in the gluon gluon fusion production)
  - Crucial to get an evidence of the coupling to the quarks
    in particular to down-type quarks.



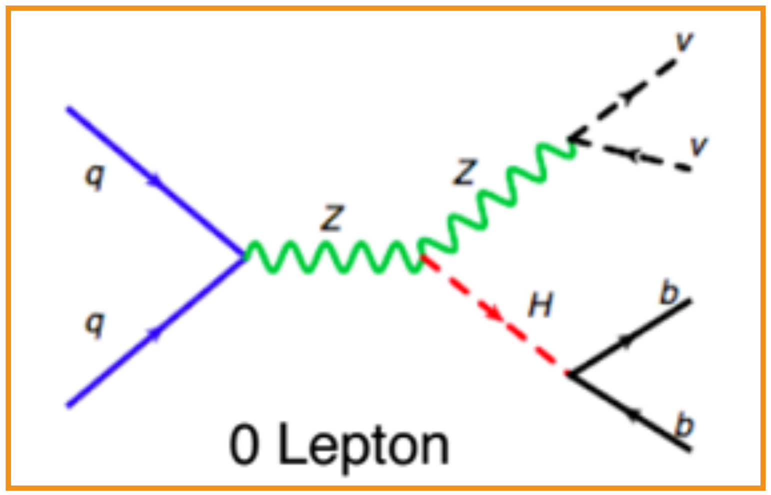
- For mH=125 GeV, BR(H→bb)=0.57
  - Very promising decay mode for new physics involving H
  - For very rare processes involving Higgs (SM or exotics processes), like HH production, H→bb good tool to get some statistics

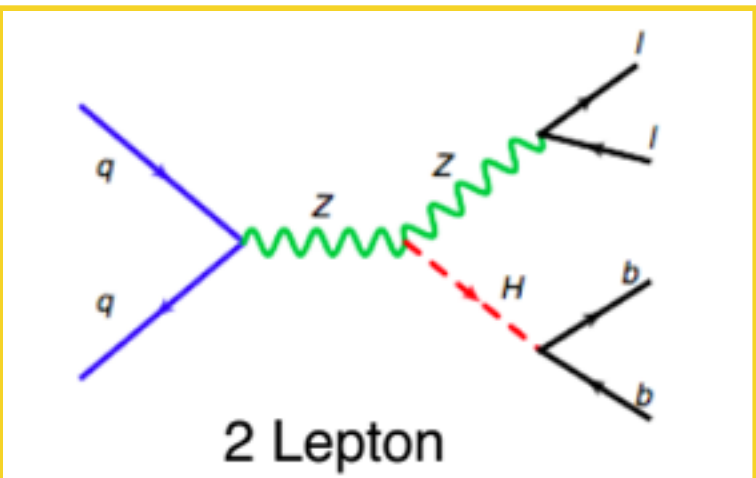
H➞bb: Why?

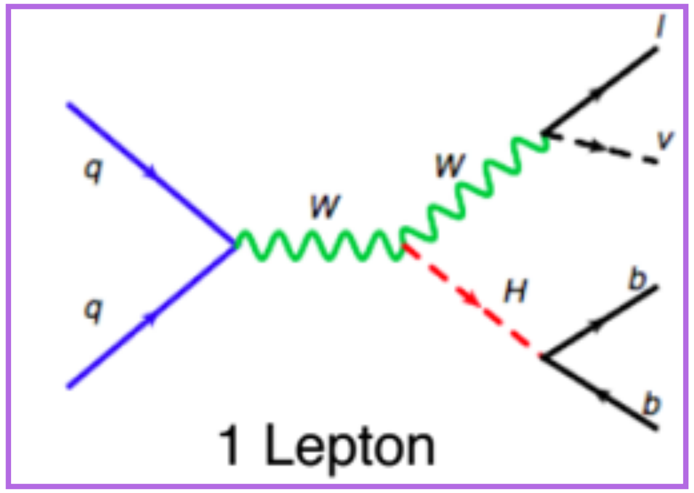


- Since 4 July 2012:

In this talk: H➞bb in the associated production:
3 lepton channels







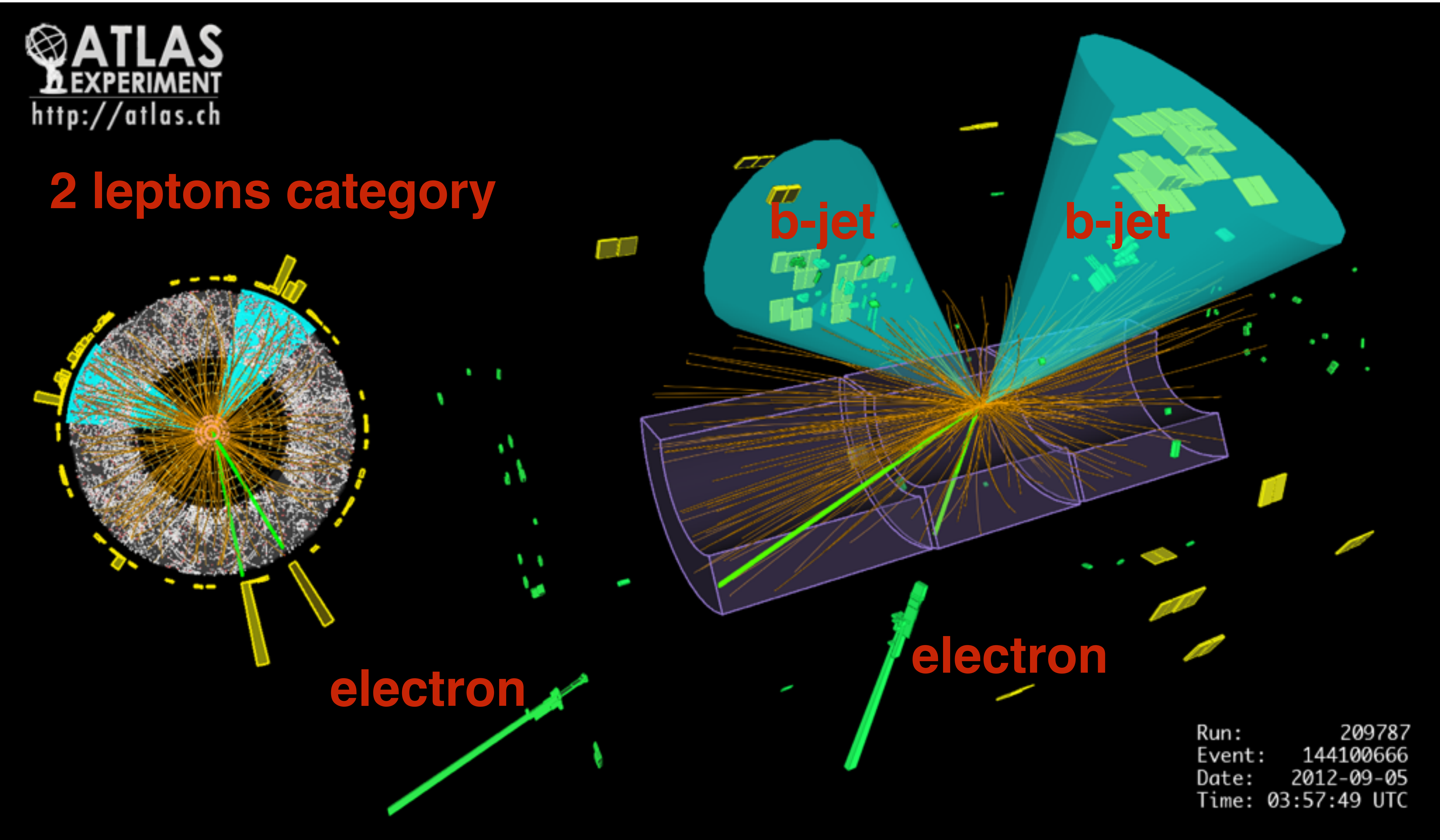
CERN-PH-EP-2014-214
http://arxiv.org/abs/1409.6212, acepted by JHEP

- Crucial to get an evidence of the coupling to the quarks
in particular to down-type quarks.

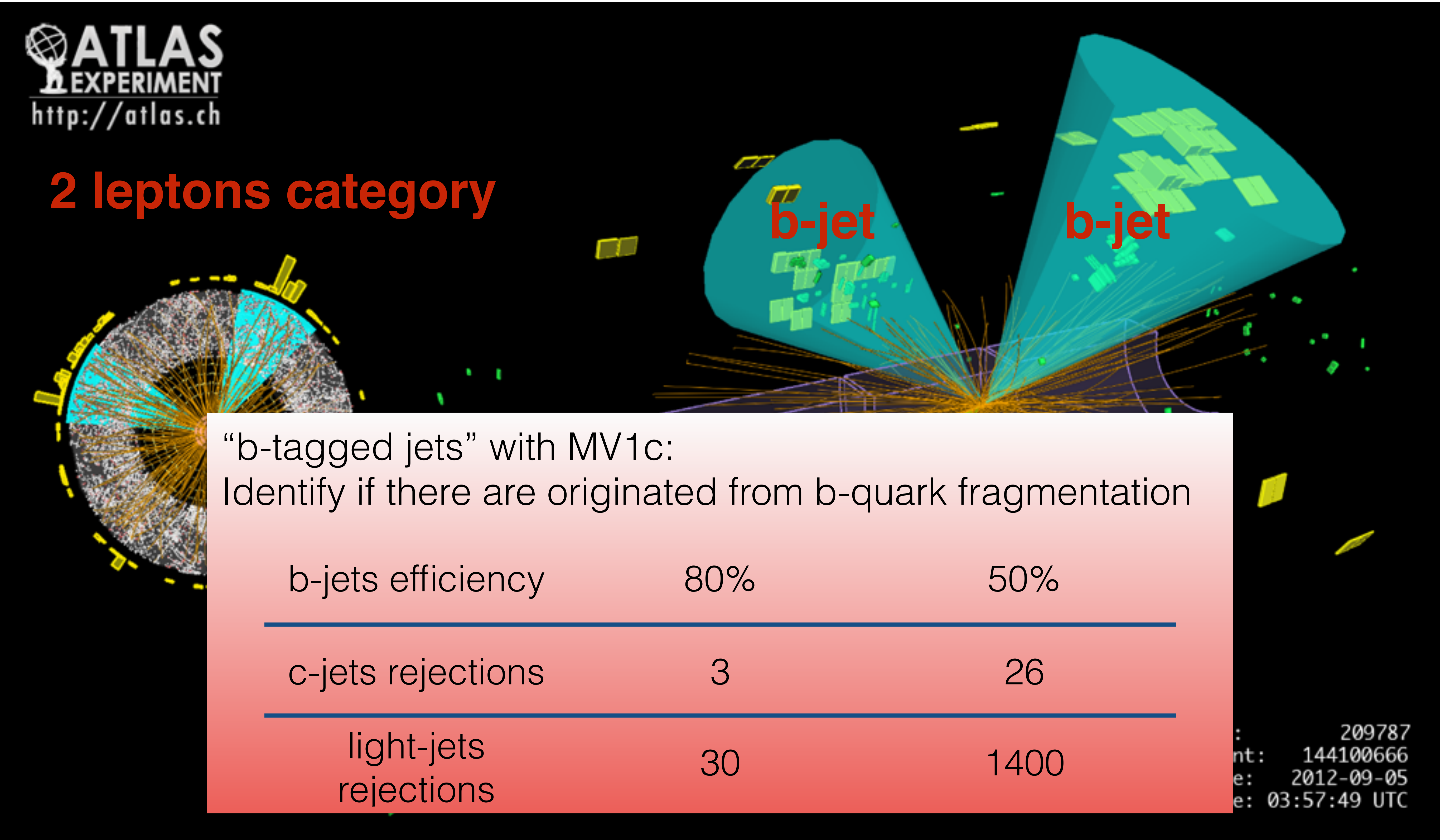
physics involving H

- For very rare processes involving Higgs (SM or exotics processes), like HH production, H➞bb good tool to get some statistics

A bb-ee event in Run 1



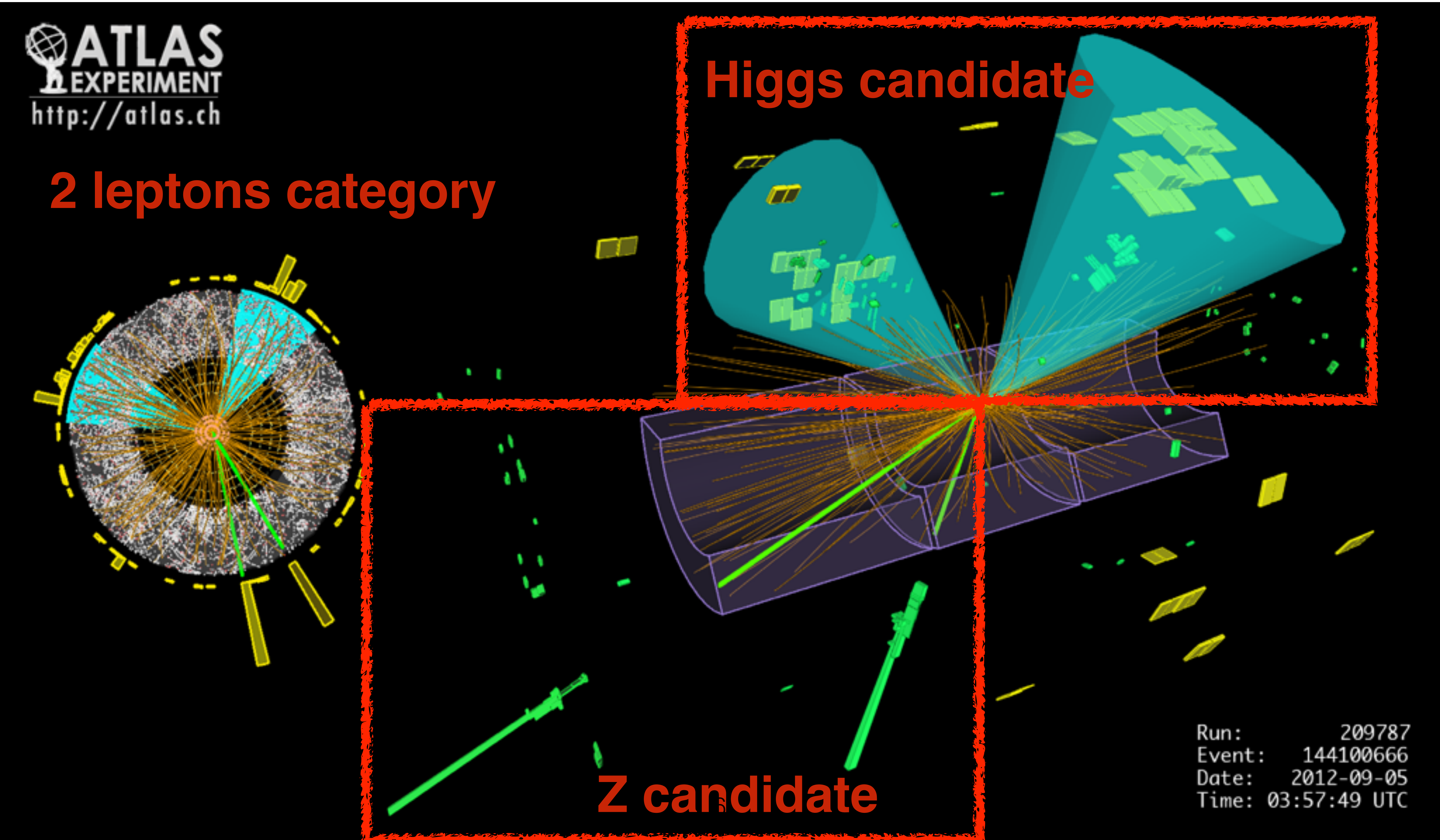
A bb-ee event in Run 1



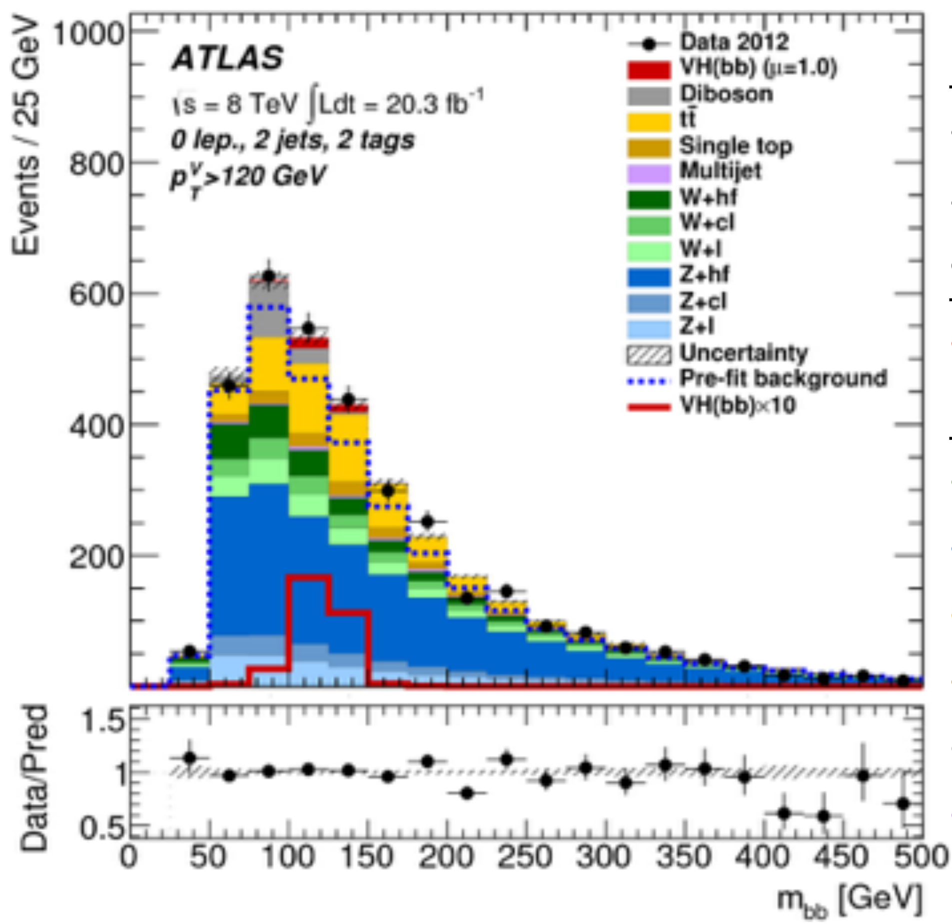
“b-tagged jets” with MV1c:
Identify if there are originated from b-quark fragmentation

b-jets efficiency	80%	50%
c-jets rejections	3	26
light-jets rejections	30	1400

A bb-ee event in Run 1



Backgrounds:



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

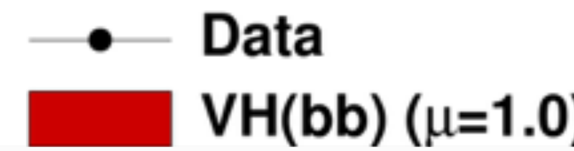
SIGNAL
- WH/ZH PYTHIA8

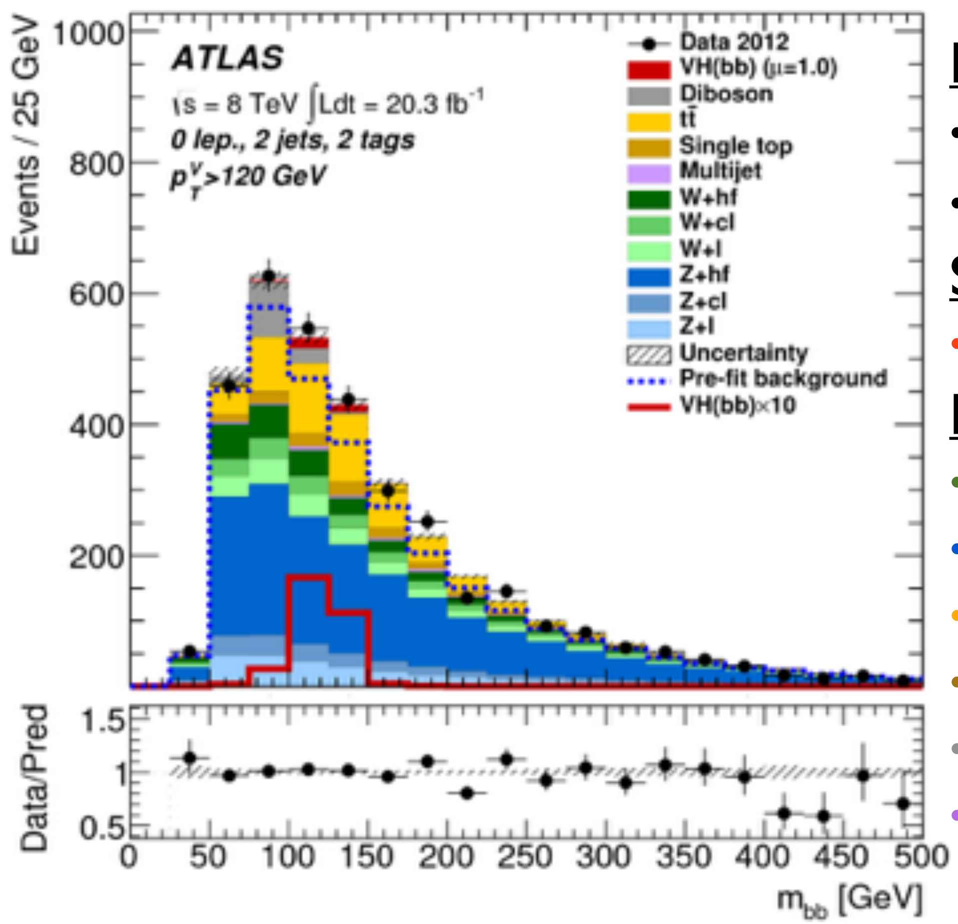
BACKGROUND
- W+jets SHERPA
- Z+jets SHERPA
- Top POWHEG+PYTHIA
- Single Top ACER/POWHEG+PYTHIA
- Diboson (WW,WZ,ZZ) HERWIG
- Multi-jet DATA DRIVEN

Most of the SM processes contribute to the background:

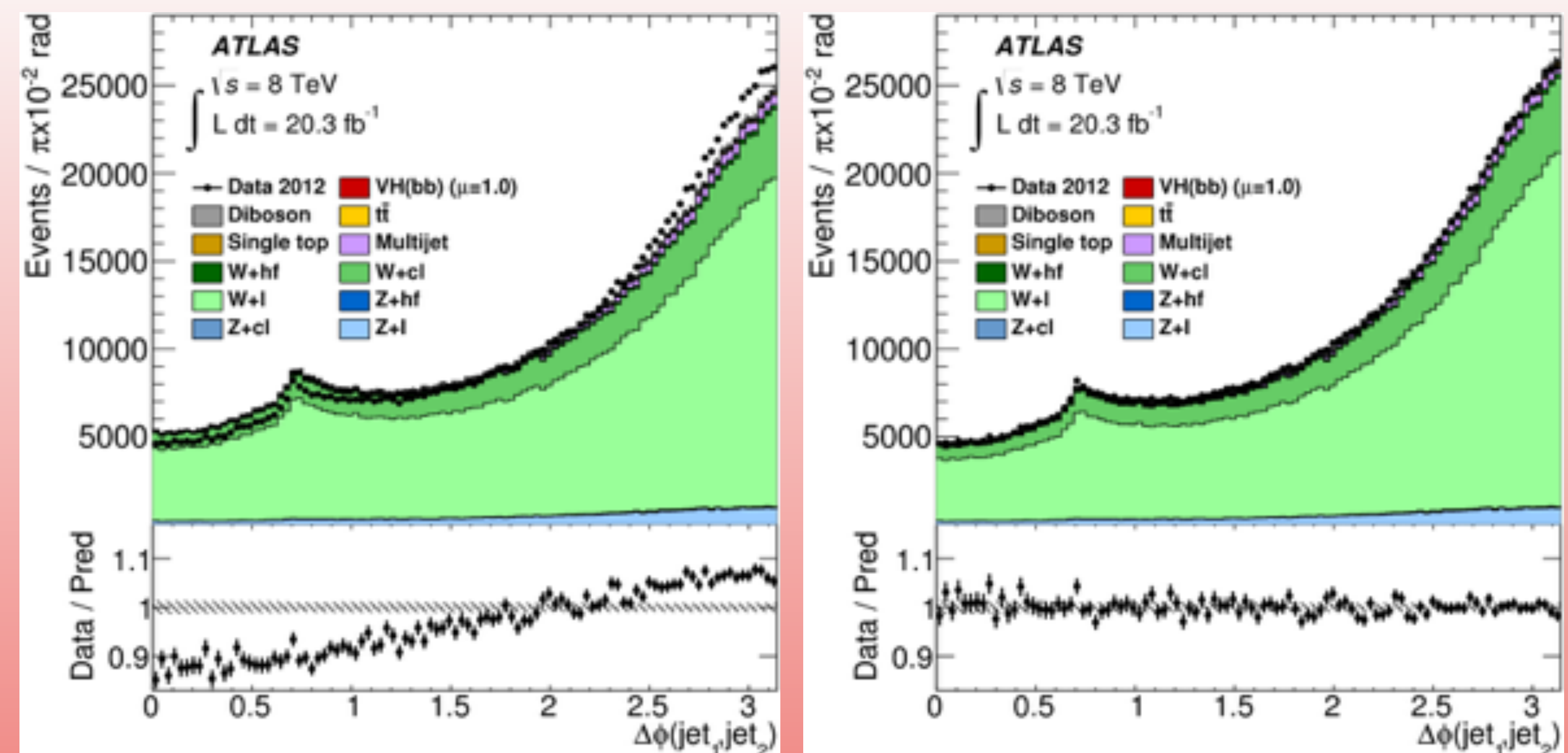
For all of them we use:
-> the status of the art **theoretical predictions;**
-> our best knowledge of the **detector simulation;**
-> modelling studies on **dedicated control regions;**
-> **combined fit** of control regions and signal regions to extract information.

Backgrounds:





How much can we trust the modelling from MC?



Dedicated studies on the modelling, and already some help from Sherpa authors to improve this in Run2.
But it is clear that the modelling of the backgrounds is an important aspect of the analysis

Most of the SM processes c
background:

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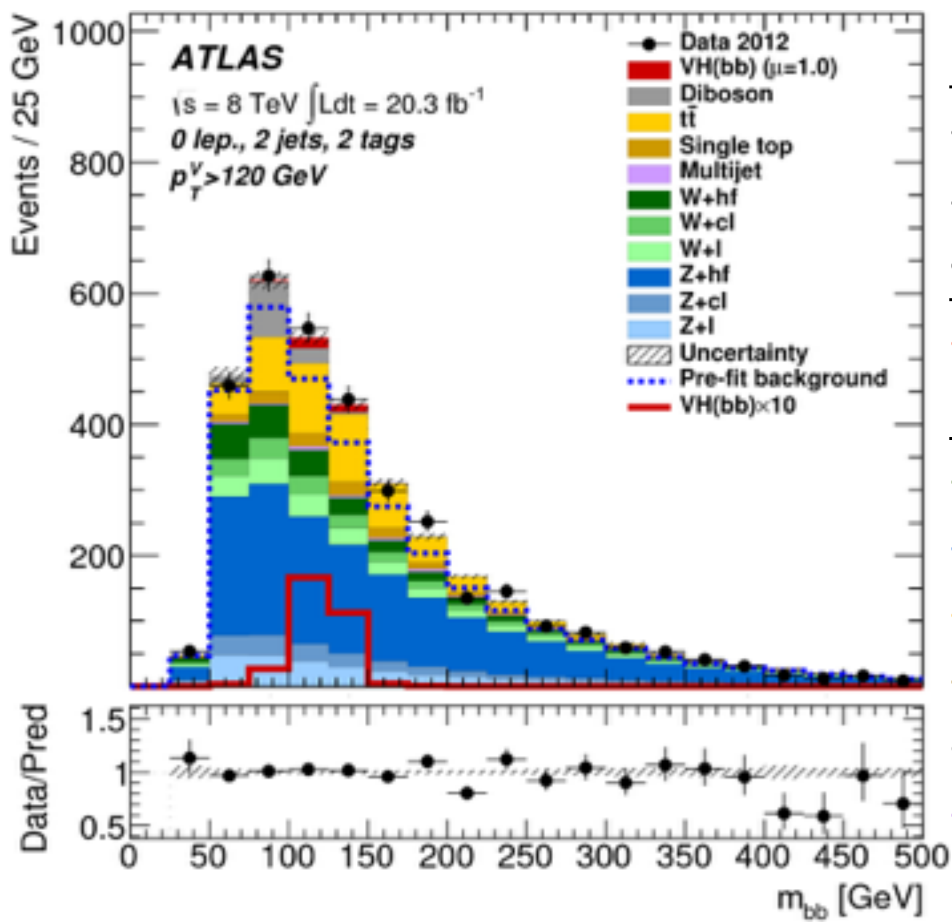

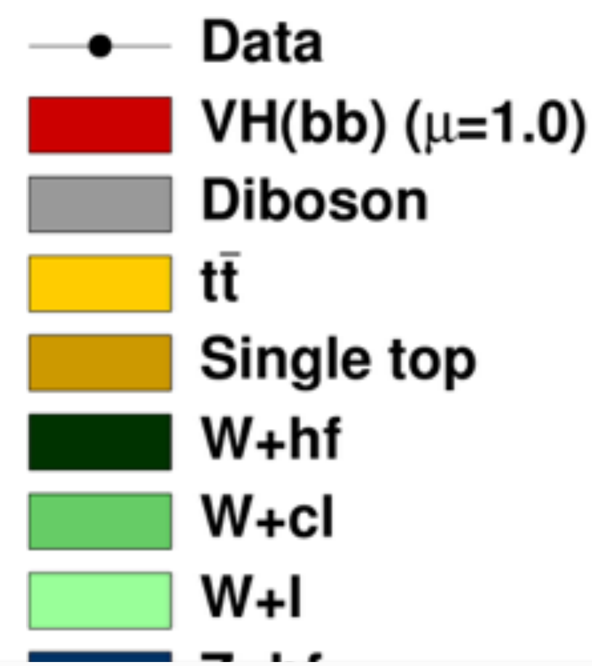

DATA

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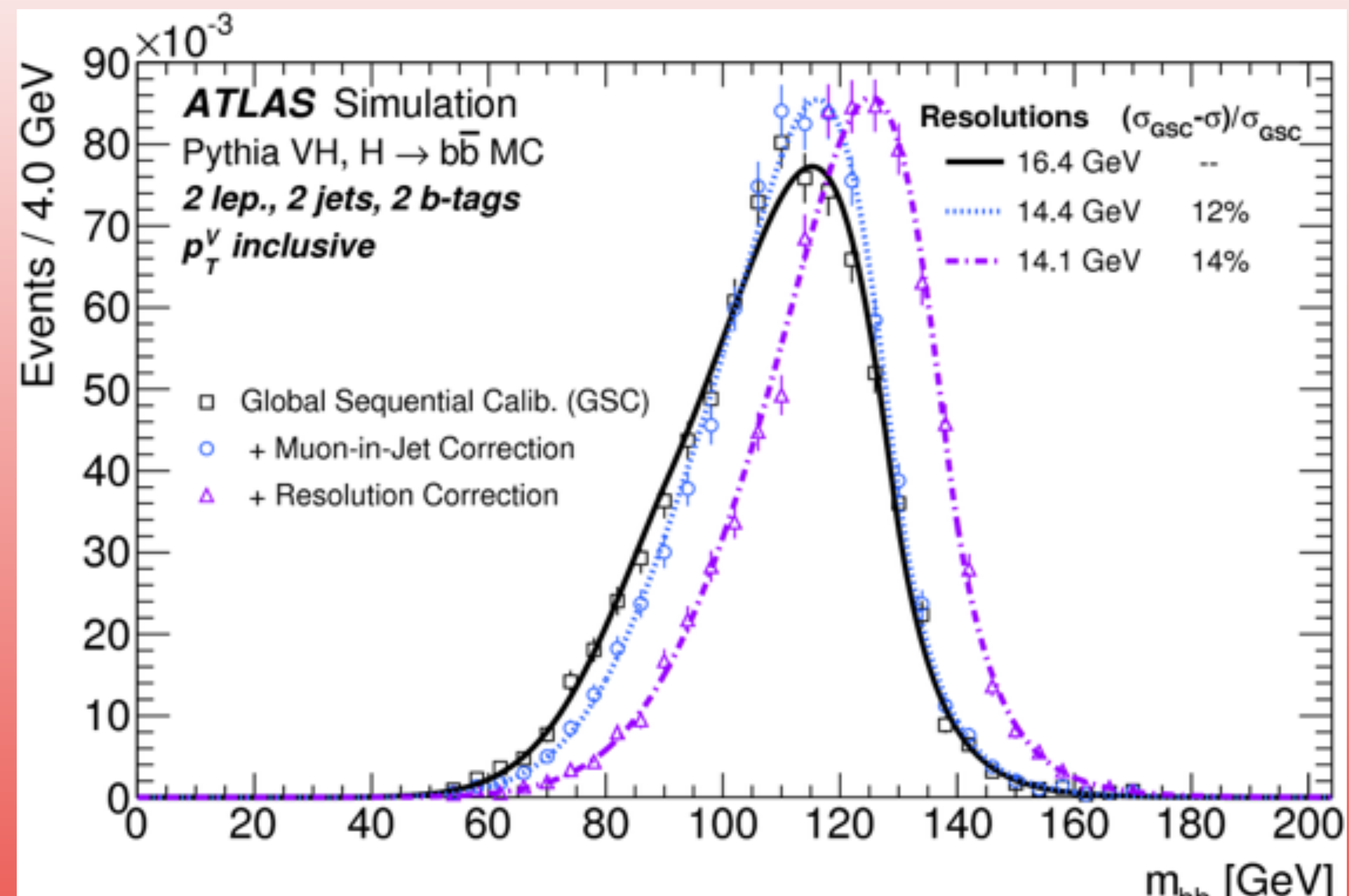
SIGNAL

- WH/ZH PYTHIA8

BACKGROUND

Mbb (i.e. the mass of the higgs candidate)is the best variables to distinguish the signal from backgrounds



Most of the SM processes c
background:

For all of them we use:
-> the status of the art **theor**
-> our best knowledge of the
-> modelling studies on **ded**
-> **combined fit** of control re

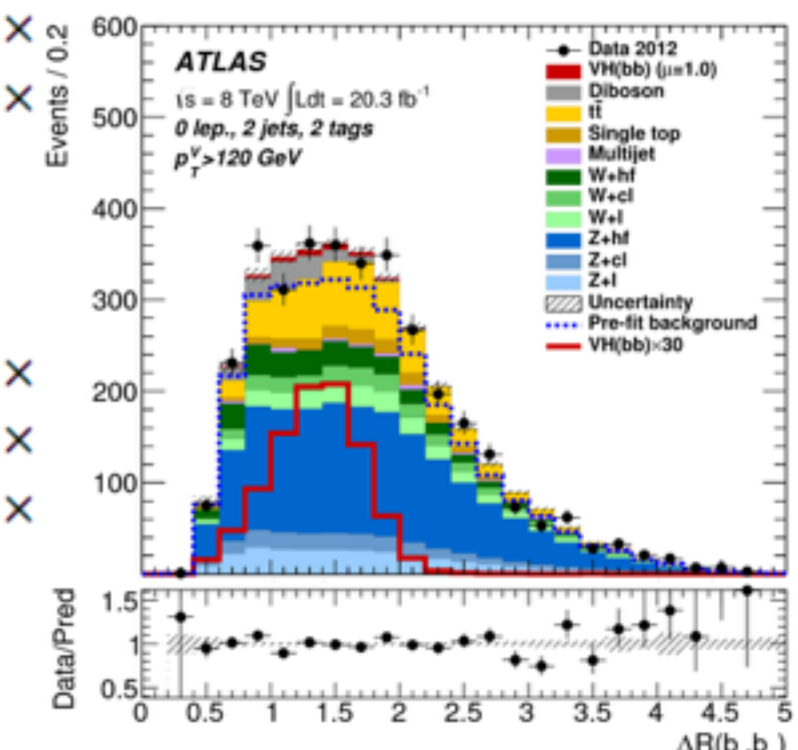
Multivariate analysis

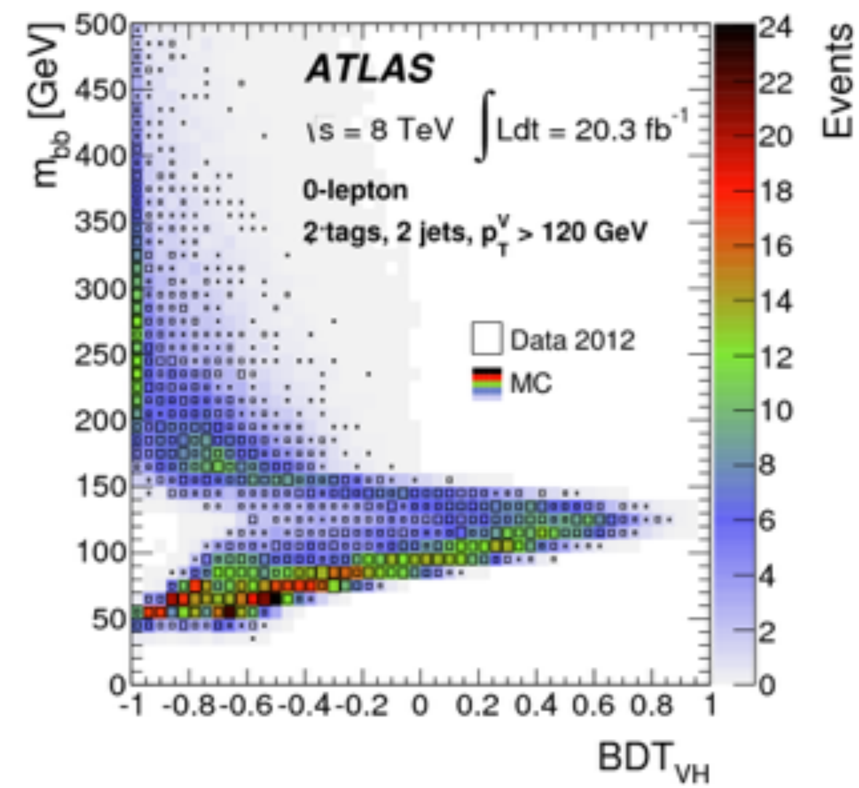
MVA variables

- starting from m_{bb} and $\Delta R(b, b)$, iterative test the additional variables

Variable	0-Lepton	1-Lepton	2-Lepton
p_T^V		×	×
E_T^{miss}	×	×	×
$p_T^{b_1}$	×	×	×
$p_T^{b_2}$	×	×	×
m_{bb}	×	×	×
$\Delta R(b_1, b_2)$	×	×	×
$\lvert\Delta\eta(b_1, b_2)\rvert$	×		×
$\Delta\phi(V, bb)$	×	×	×
$\lvert\Delta\eta(V, bb)\rvert$			×
H_T	×		
$\min[\Delta\phi(\ell, b)]$		×	
m_T^W		×	
$m_{\ell\ell}$			×
$MV1c(b_1)$	×	×	×
$MV1c(b_2)$	×	×	×

To get the best discrimination between signal and background, we used a **multivariate technique** (BDT), and we study several kinematic variables:
The crucial one are:
Mbb,
the distance of the 2 b-jets,
the pT of the vector boson.

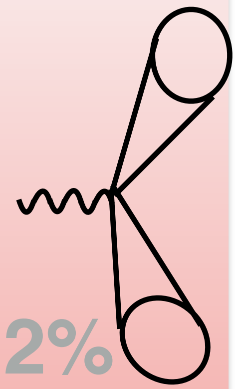




Building the VH analysis

pT of the vector boson

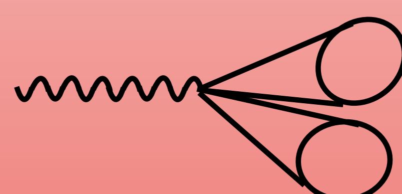
signal/background:



0<pT(V)[GeV]<90 : ~0.1-0.2%

120<pT(V)[GeV]<160 : ~0.3-0.5%

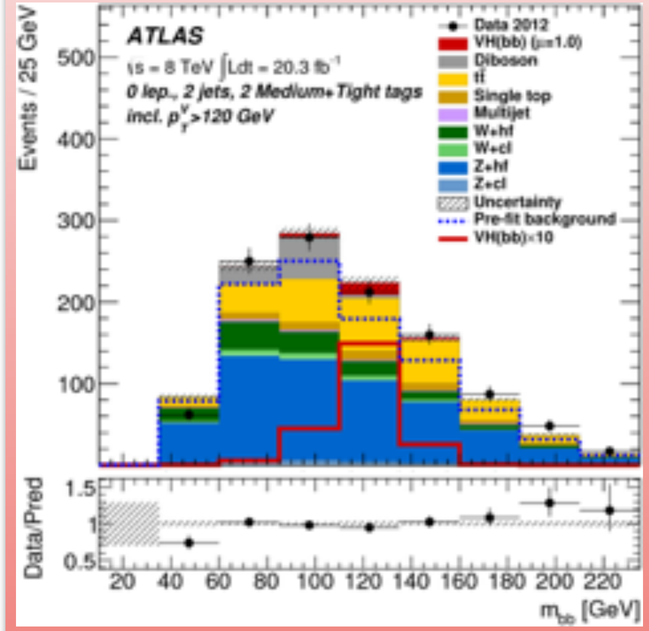
pT(V)[GeV]>200 : ~2%



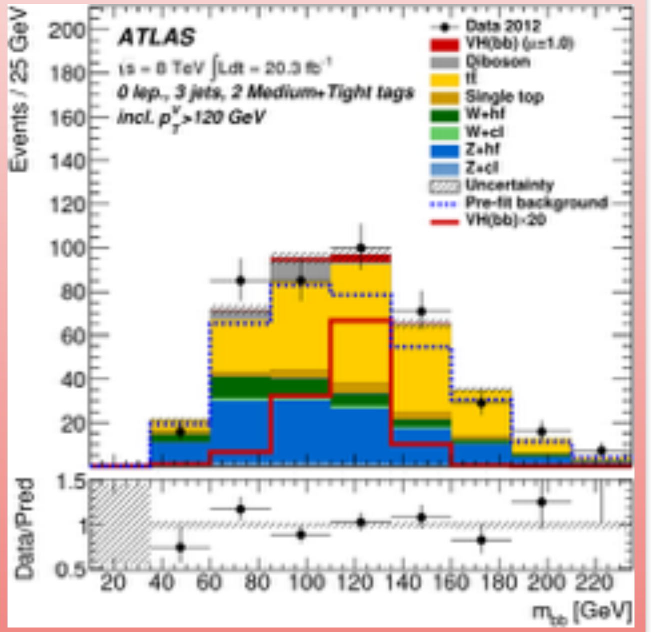
Clear improvement of S/B vs vector boson pT [ATLAS-CONF-2013-079]

Number of jets

2 jets



3 jets

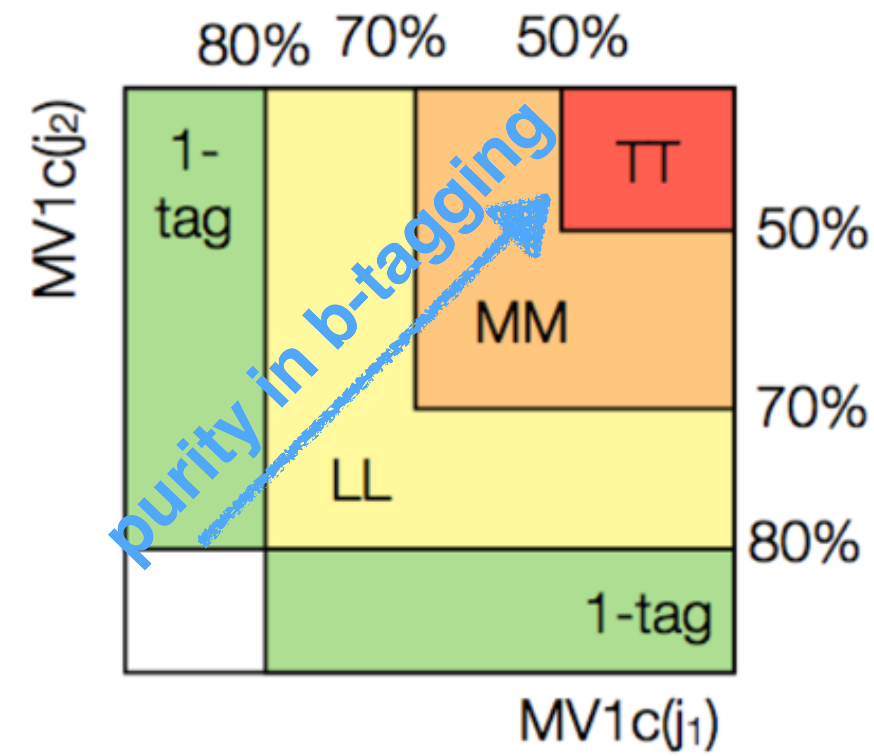


Different background composition for 2 and 3 jets events (i.e. more tt bar events for 0 and 1 leptons ch.)

The idea: split the analysis in bins of jet multiplicity and pT(V)

Analysis strategy

- The analysis has:
  - **3** different **lepton** channels (0, 1 and 2 leptons)
  - **2** regions in **pT of the vector boson (120 GeV)**
  - **2** regions in **jet multiplicity**
    (they have different bkg contributions)
  - **3-4** regions for the **purity of the b-jet** identification



- **Total: 40-50 analysis regions.**

Analysis Phase Space

			Variable
		1 tag (CR)	MV1c
VpT > 120GeV	2 jets	2 tag LL (SR)	MVA BDT
VpT < 120GeV	3 jets	2 tag MM (SR)	
		2 tag TT (SR)	

- In each region, the **shape of the BDT** (or of the b-tagging discriminant) is used to **extract information** on the background and signal.
- All the regions are used in a **simultaneous fit**.

Analysis strategy

- The analysis has:
  - 3
  - 2
  - 2 (
  - 3 i
- **Tota**
- In e (or c **info**
- All t extract information on the signal.

80% 70% 50%

50%

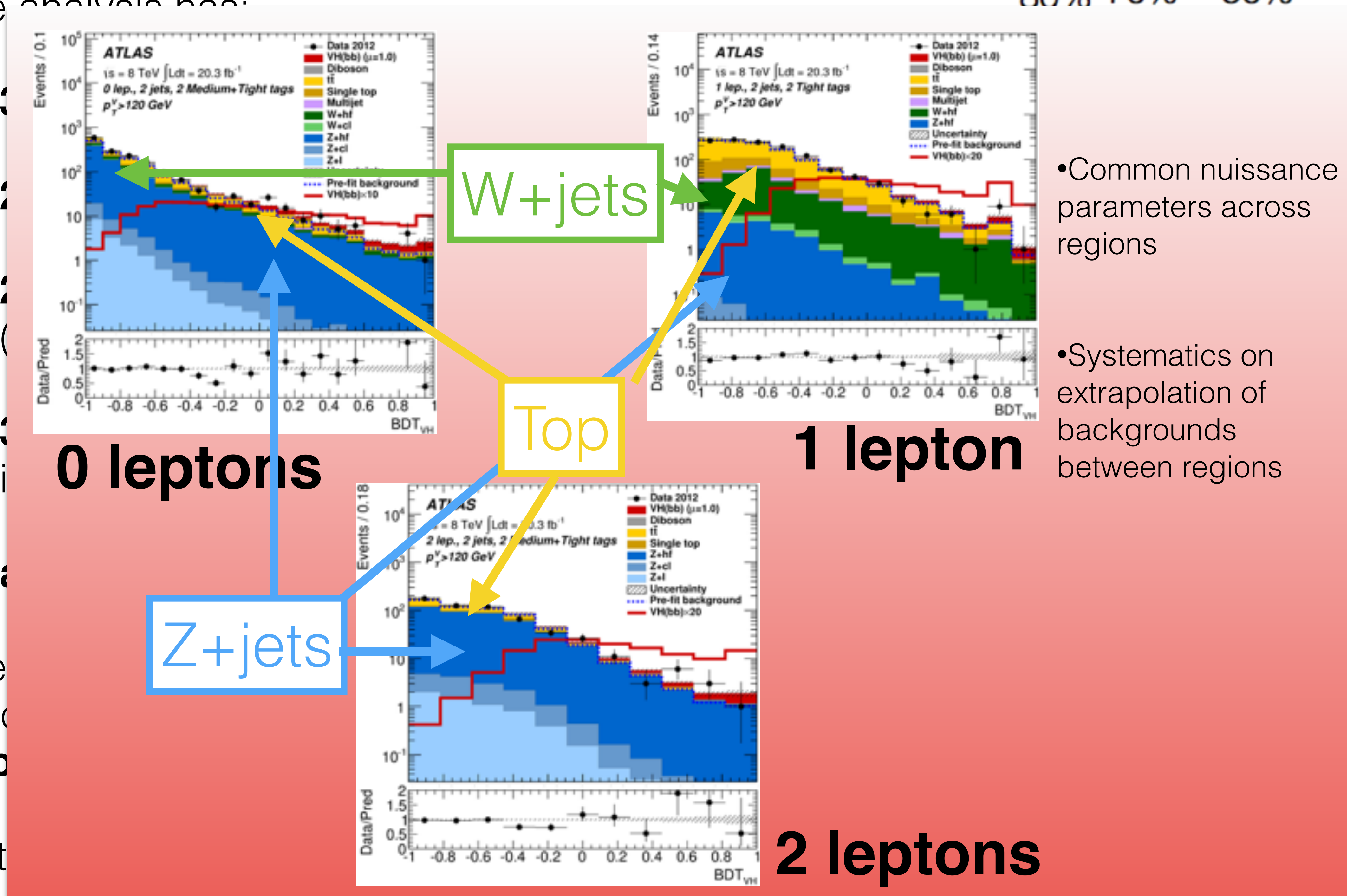
70%

80%

Variable

MV1c

MVA BDT

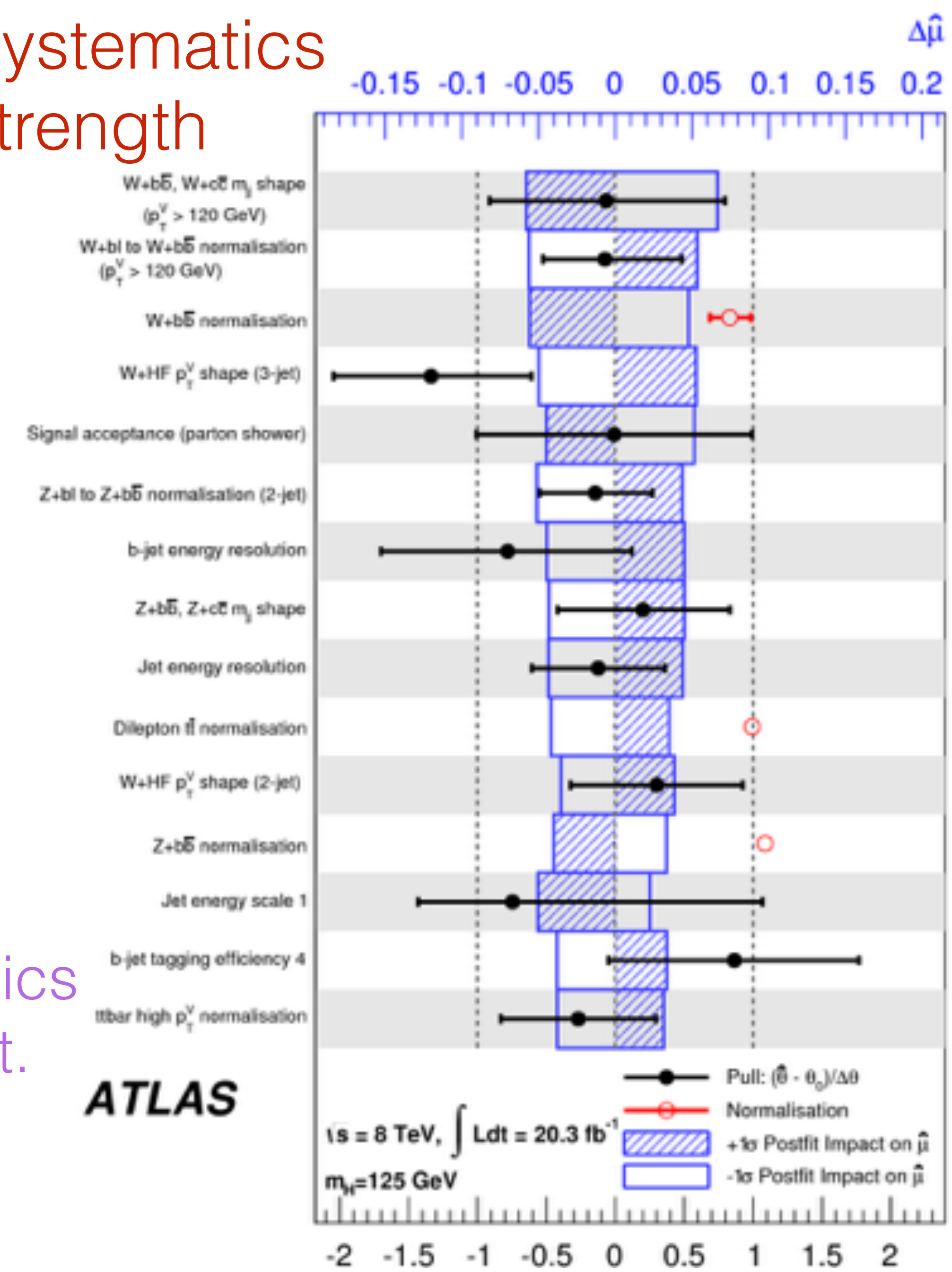


Systematics

Signal	
Cross section (scale)	1% (qq), 50% (gg)
Cross section (PDF)	2.4% (qq), 17% (gg)
Branching Ratio	3.3 %
Acceptance (scale)	1.5–3.3%
3-jet acceptance (scale)	3.3–4.2%
p_T^V shape (scale)	S
Acceptance (PDF)	2–5%
p_T^V shape (NLO EW correction)	S
Acceptance (parton shower)	8–13%
Z+jets	
Zl normalisation, 3/2-jet ratio	5%
Zcl 3/2-jet ratio	26%
Z+hf 3/2-jet ratio	20%
Z+hf/Zbb ratio	12%
$\Delta\phi(\text{jet}_1,\text{jet}_2)$, p_T^V, m_{bb}	S
W+jets	
Wl normalisation, 3/2-jet ratio	10%
Wcl, W+hf 3/2-jet ratio	10%
Wbl/Wbb ratio	35%
Wbc/Wbb, Wcc/Wbb ratio	12%
$\Delta\phi(\text{jet}_1,\text{jet}_2)$, p_T^V, m_{bb}	S
$t\bar{t}$	
3/2-jet ratio	20%
high/low-p_T^V ratio	7.5%
top p_T, m_{bb}, E_T^{miss}	S
Single top	
Cross section	4% (s-,t-channel), 7% (Wt)
Generator	3–52%
m_{bb}, $p_T^{b_2}$	S
Diboson	
Cross section and acceptance (scale)	3–29%
Cross section and acceptance (PDF)	2–4%
m_{bb}	S
Multijet	
0-, 2-lepton channels normalisation	100%
1-lepton channel normalisation	2–60%
Template variations, reweighting	S

Given the complexity of the analysis, and the huge size of the phase space used, good part of the efforts to define robust systematics uncertainties
- for the background and the signal,
- for the detector performance

impact of the systematics on the signal strength $\mu=\sigma/\sigma_{SM}$



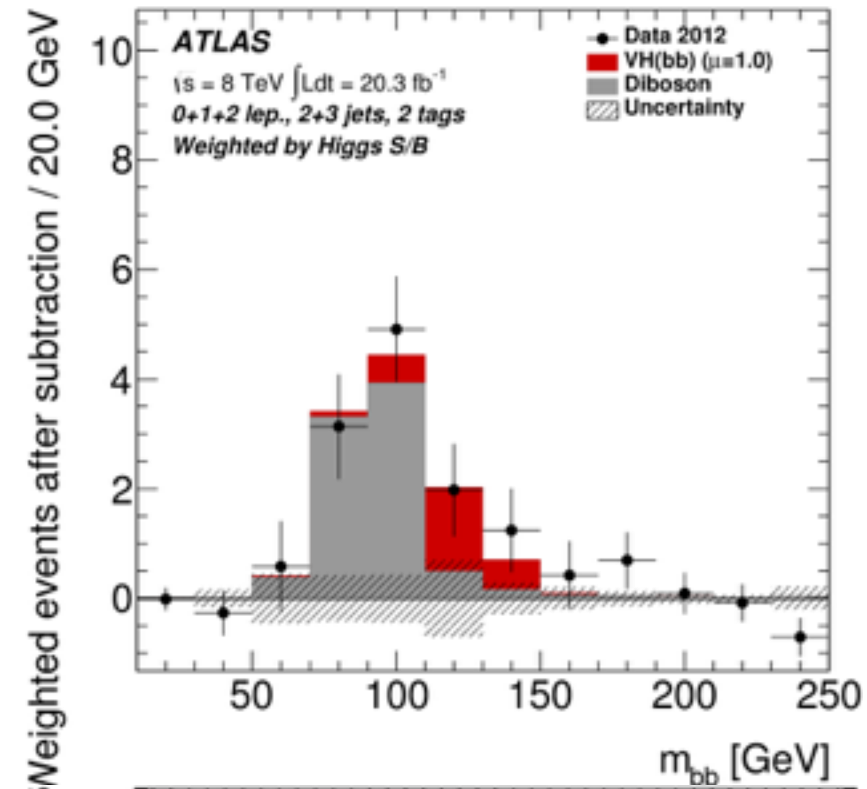
Background modelling systematics are a crucial aspect.

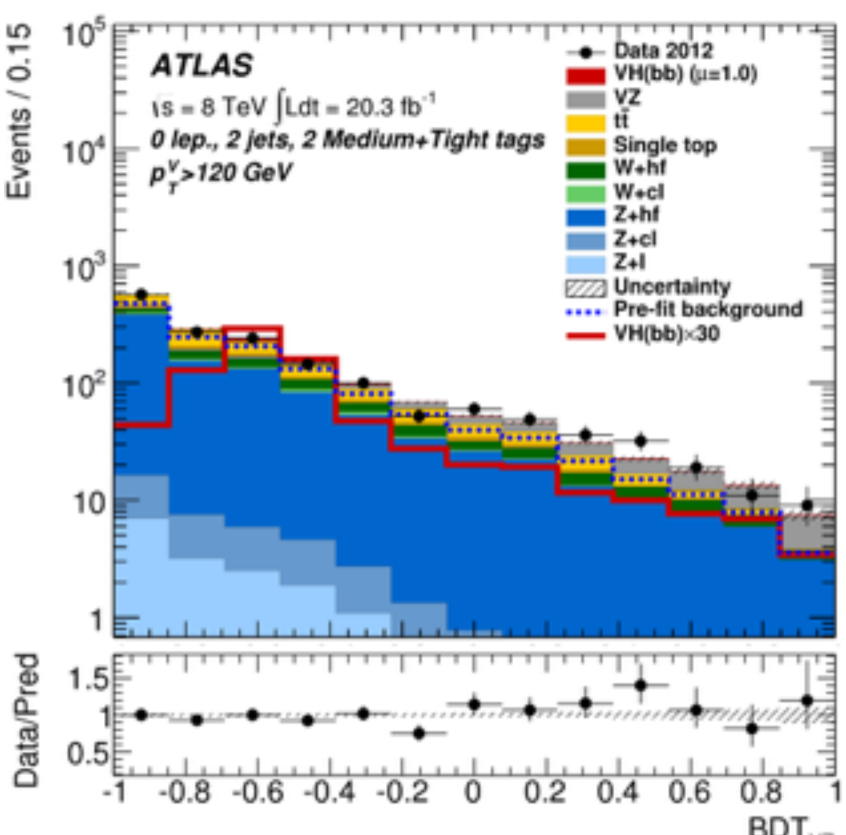
VZ: a Standard Model candle

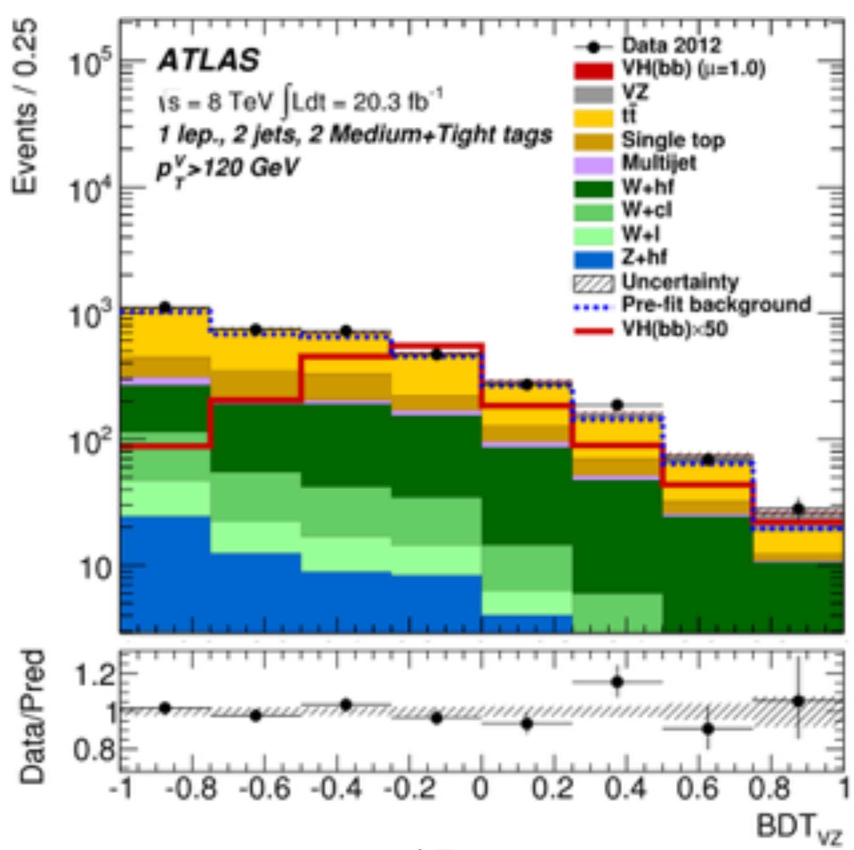
The **VZ->bb** is a SM candle to validate VH analysis:
-> cross section ~5 times larger than VH
-> almost identical final state

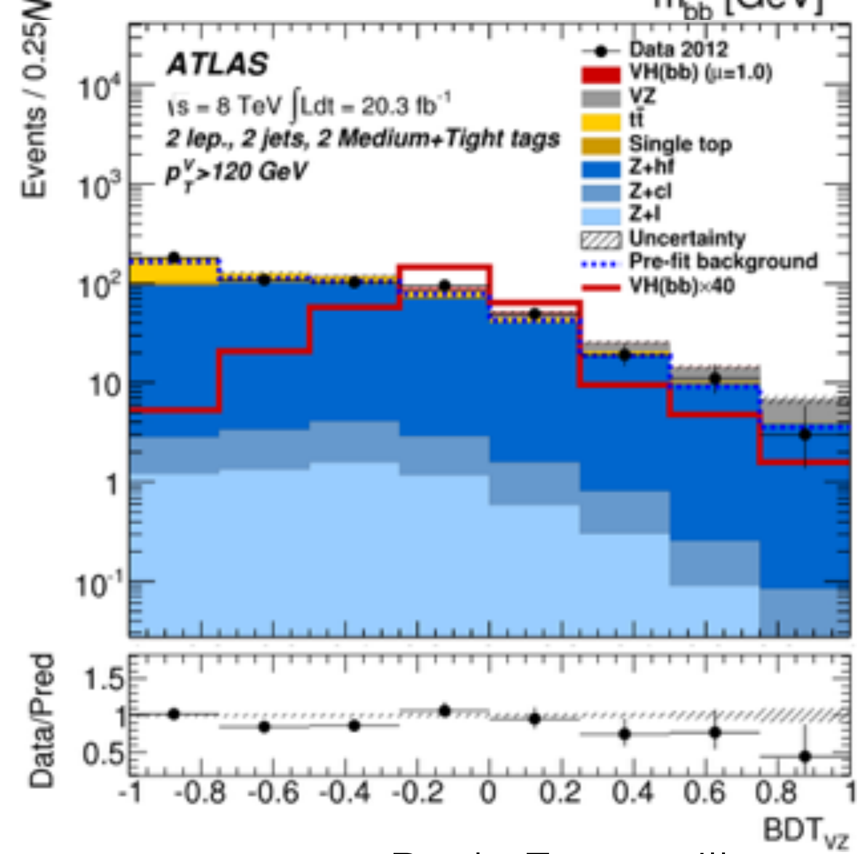
Expected significance: 6.3 σ
Observed significance: 4.9 σ

$\mu=\sigma/\sigma_{SM}=0.74 \pm 0.09(stat) \pm 0.14(syst)$







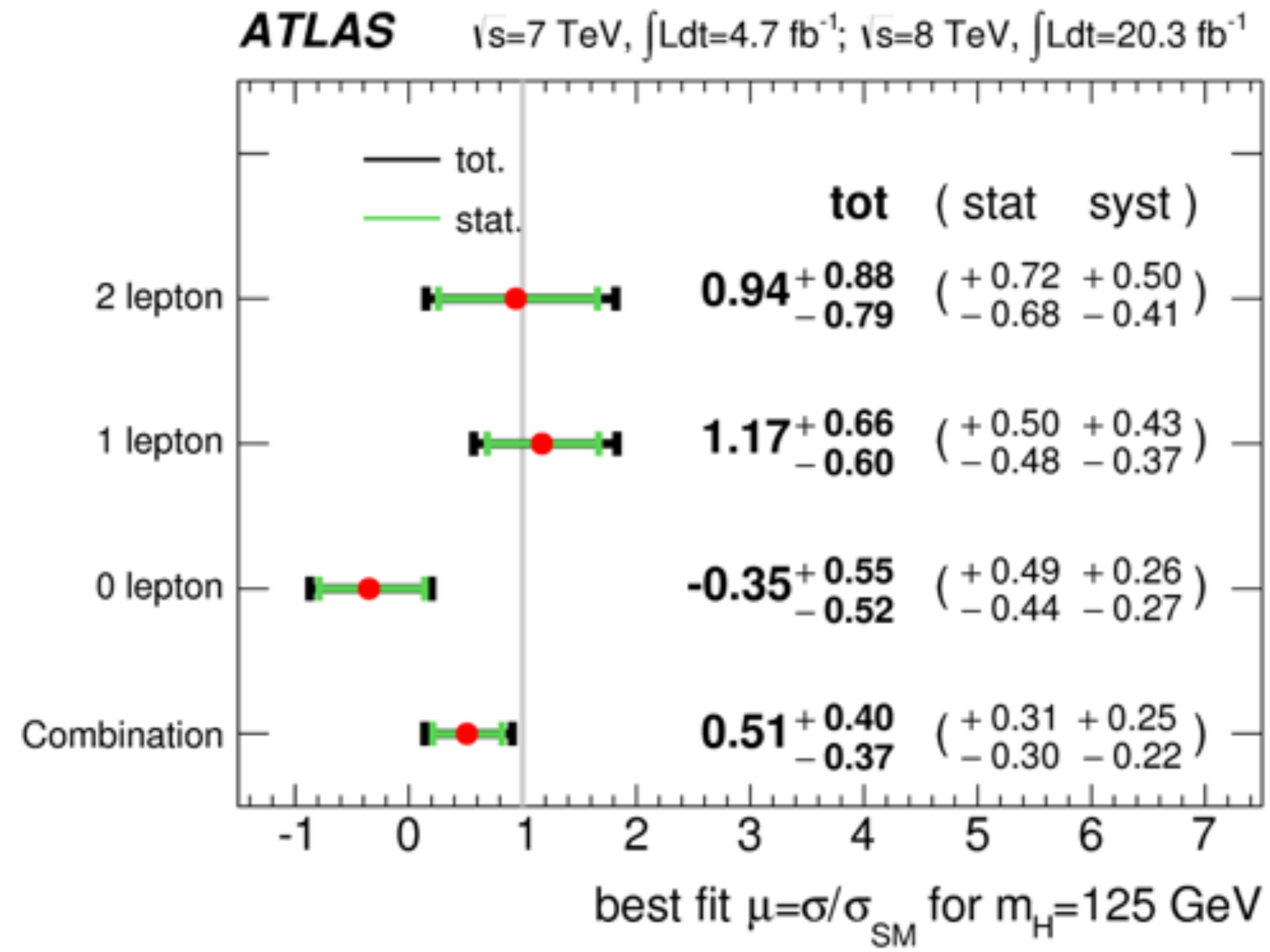


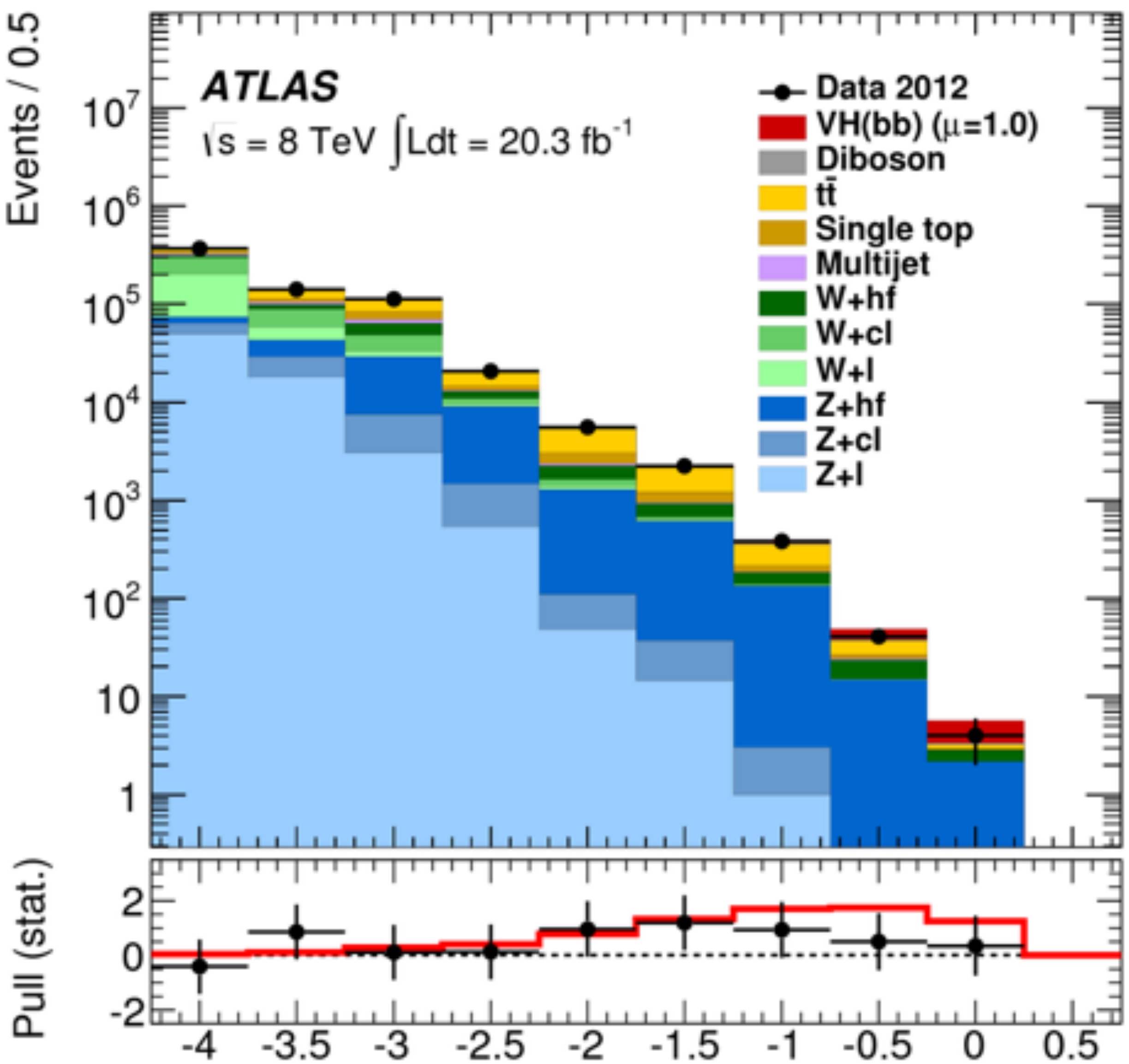
VH Results

VH Run1 results for ATLAS:

Expected significance: 2.6 σ
Observed significance: 1.4 σ

$\mu=\sigma/\sigma_{SM}=0.51 \pm 0.31(\text{stat}) \pm 0.34(\text{syst})$



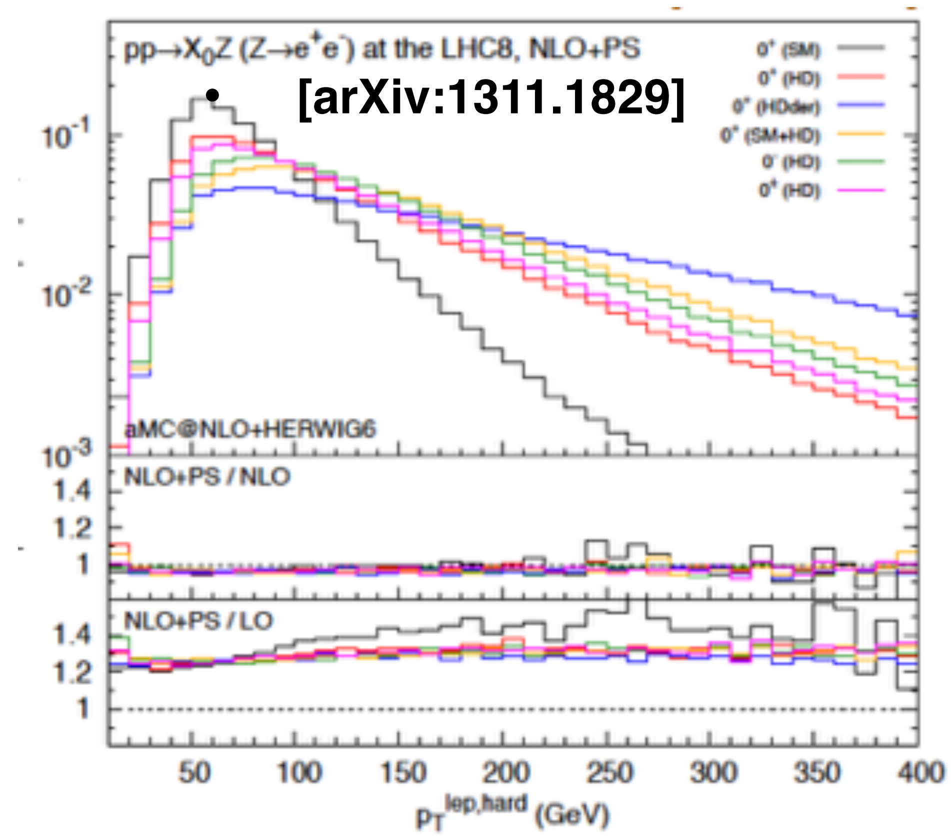


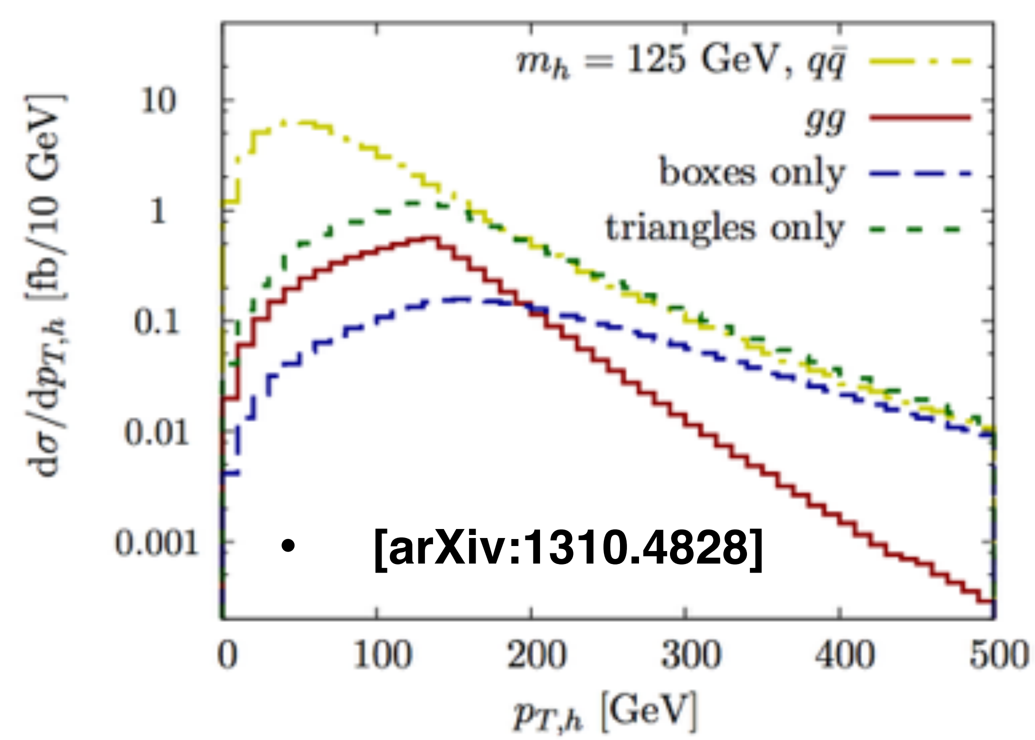
Cross checks done with
a dijet mass analysis:
Expected significance for 8 TeV: 1.9 σ
MVA has a gain of ~30% in exp. significance
Observed significance for 8 TeV: 2.2 σ

$\mu=\sigma/\sigma_{SM}=1.2 \pm 0.44(\text{stat.}) \pm 0.41(\text{syst.})$

VH theory: wish-list for Run2 HEFT, gg->ZH, EW corrections

- **HEFT**
  - For VH, there were already paper using **preliminary results to constrain** parameters on the **Higgs Effective Field Theory. arXiv:[1404.3667v3]**
  - Last October, a **new calculation** able to use effective lagrangians making calculation at the **NLO** was published. **[arXiv:1311.1829]**
  - **NLO reweighing** (or a LO recommendation) would be useful to avoid a proliferation of MC production?
- **gg->ZH:**
  - **the gg->ZH will increase much faster than quark initiated ZH.**
  - **around 150 GeV** it was O(15%) for the Run1, bigger for Run2 **[arXiv:1310.4828]**
  - Seizable systematics, which can start to play a relevant role.
- **EW Corrections:**
  - In Run1, **EW NLO correction** used as weights for the QCD NLO generated events.
  - For Run2 **it would be nice** to have **a framework which incorporate the 2**



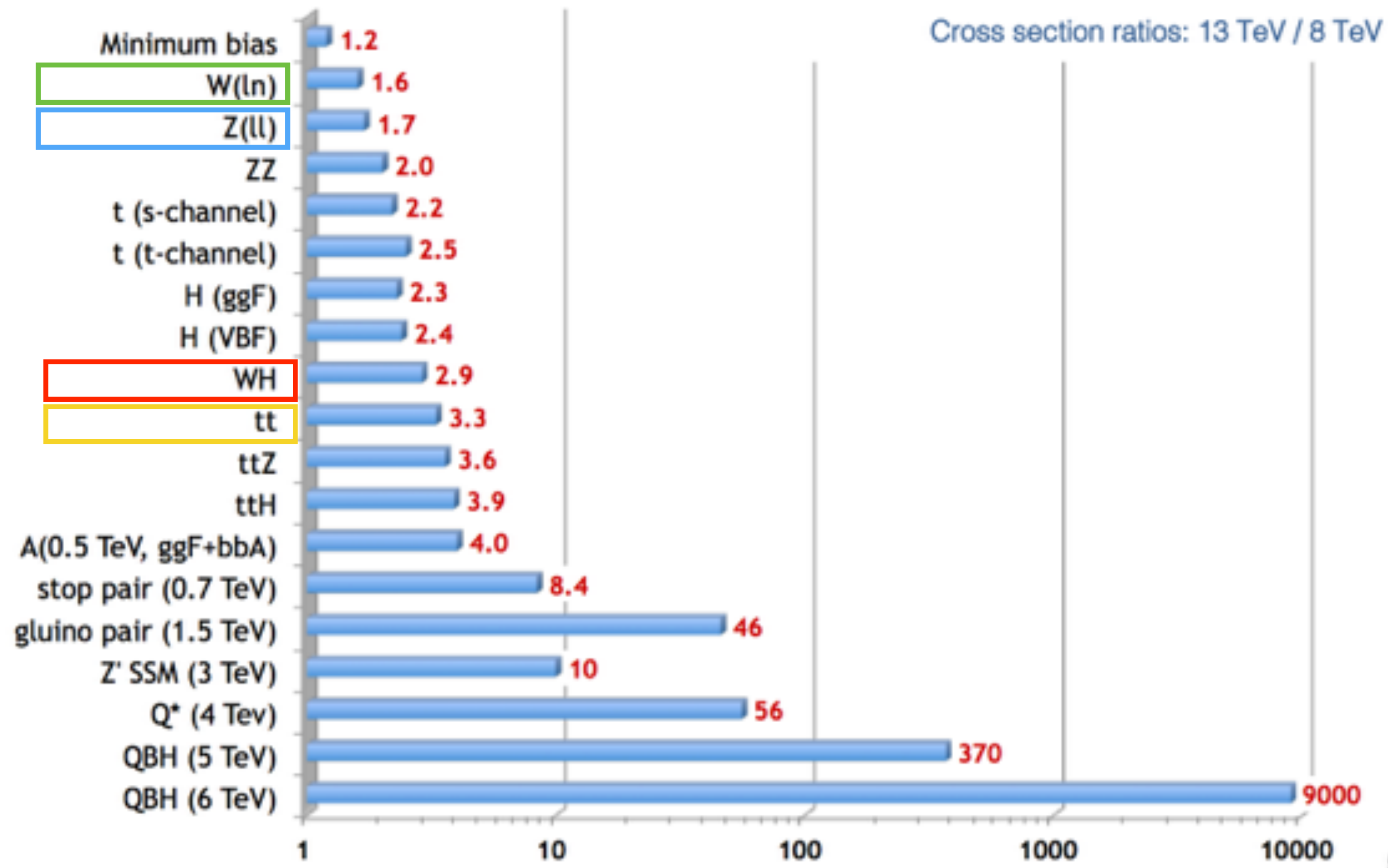


Prospectives for Run2

- We will profit from the experience of Run1 in the Run2.
  But we will have new challenges and new opportunities:

  - Very interesting to improve the performances of the detector given the upgrades/consolidations in the LHC shutdown.

    - i.e. improve the performance of the b-tagging thanks to the extra tracking layer IBL



- **Signal** increase by a factor **~3; EW backgrounds** increase by a factor **~2;**
  t tbar increases by a factor **3.3** (important for 1 lepton channel)

- This means that we expect **~similar conditions of 8 TeV with half of the statistics at 13 TeV**

  - **Ingenuity will improve it!**

Conclusions

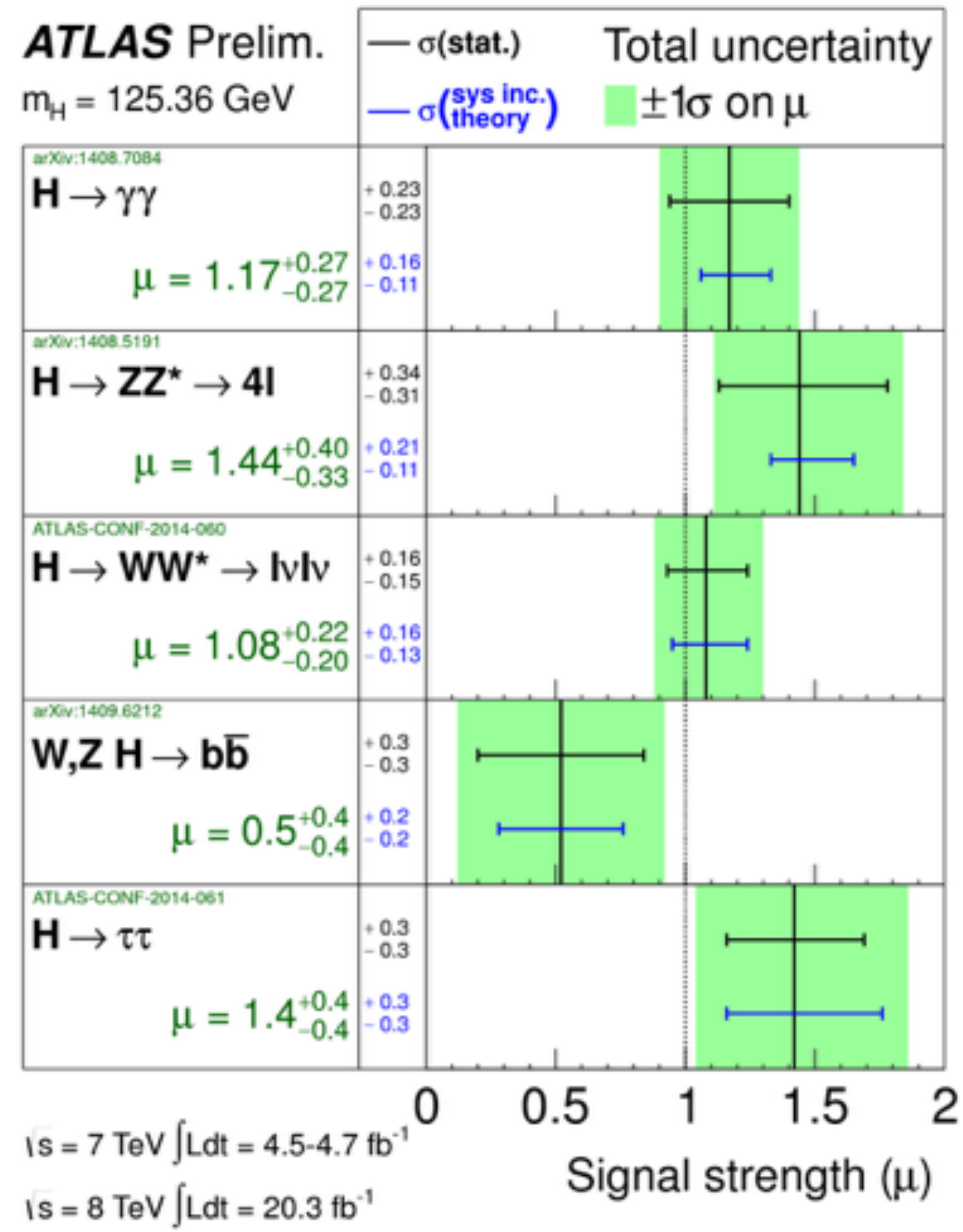
- The Run1 analysis of VH->bb helped a lot in defining solid analysis strategy and to validate very advanced techniques.

  - From summer 2013 to fall 2014:
    1.4 σ exp. -> 2.6 σ exp.

  - **Very competitive expected sensitivity in hadron collider experiment**
    (compared with CMS, CDF and D0)

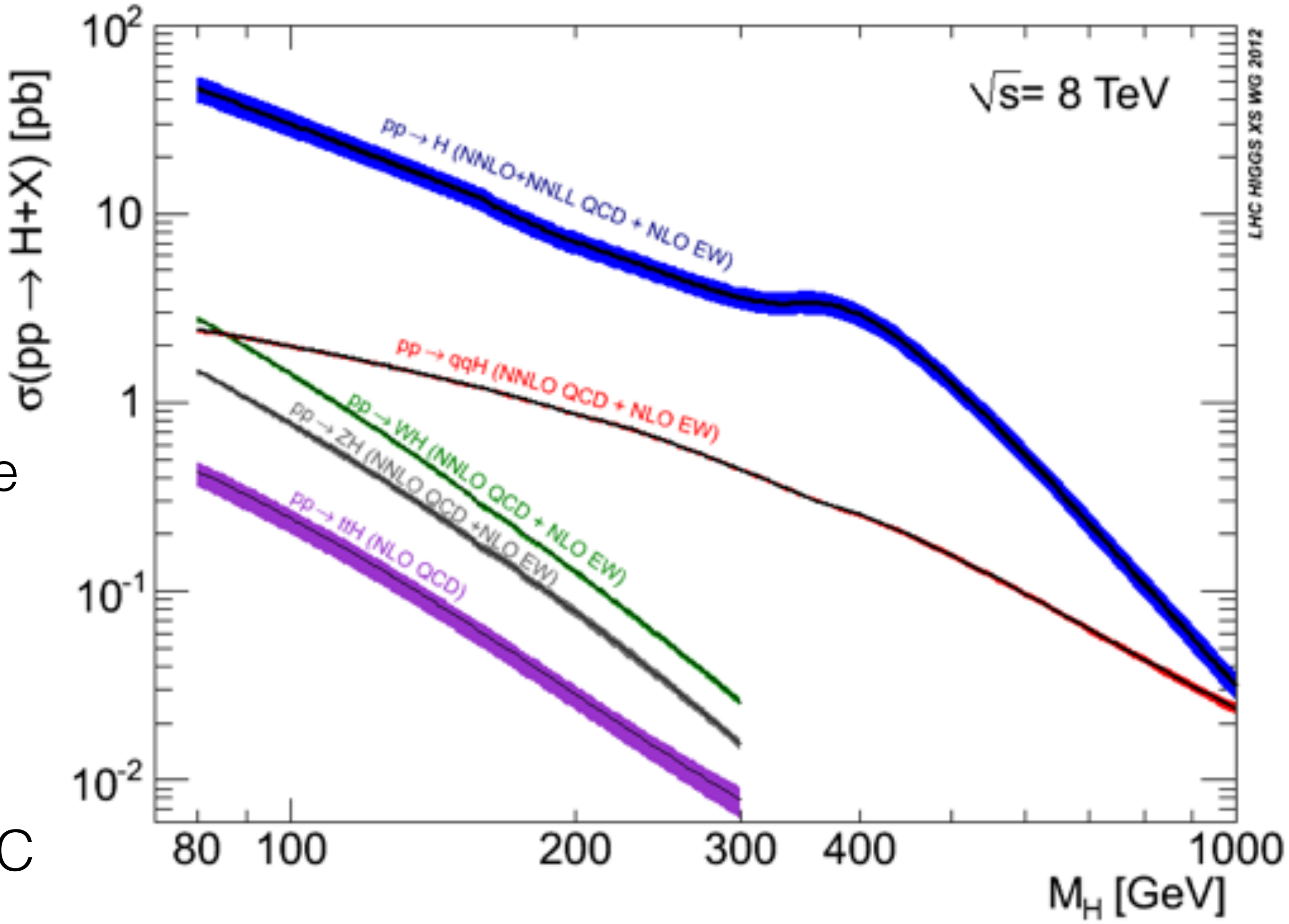
  - Run1 data does **not show a significant excess**, but some first indication is there.

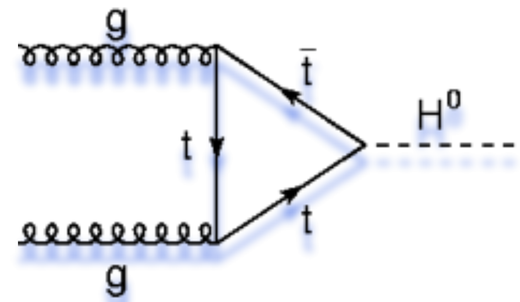
- Challenges and opportunities open for Run2. This make the Run2 very exiting!



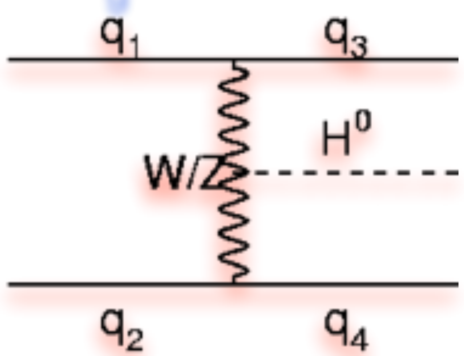
Backup

H→bb:How?

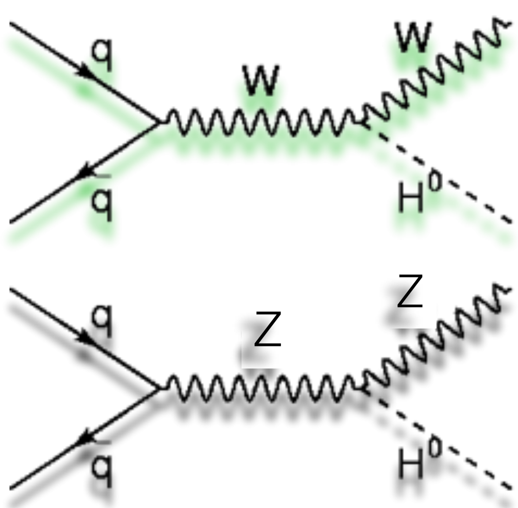




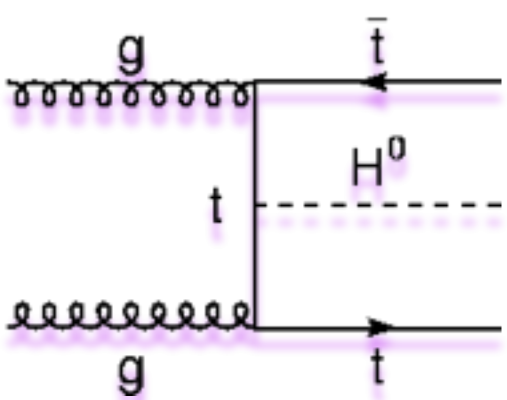
Gluon-Gluon fusion:
s/b for H→bb : $<10^{-4}$ - 10^{-5}
Challenge for brave people



Vector boson fusion:
H→bb: better s/b
if compared with ggF
Already some results at LHC



Associated production:
if W or Z decay leptonically, easier to kill the multi-jet background originated by strong interactions.
Main contributor to the Higgs evidence at Tevatron.
I will focus on this today: VHbb analysis



ttH:
Very interesting and complex final state:
events with 4-8 or more jets at least 4 originated by b
Already some results at LHC

Event selection

Variable	Dijet-mass analysis					Multivariate analysis	
Common selection							
p_Tv [GeV]	0–90	$90^{(*)}$–120	120–160	160–200	> 200	0–120	> 120
$\Delta R(\text{jet}_1, \text{jet}_2)$	0.7–3.4	0.7–3.0	0.7–2.3	0.7–1.8	< 1.4	> 0.7 (p_Tv<200 GeV)	
0-lepton selection							
p_T^{miss} [GeV]	NU	> 30	> 30			NU	> 30
$\Delta\phi(\vec{E}_T^{miss}, p_T^{miss} vec)$		$< \pi/2$	$< \pi/2$				$< \pi/2$
$\min[\Delta\phi(\vec{E}_T^{miss}, \text{jet})]$		–	> 1.5				> 1.5
$\Delta\phi(\vec{E}_T^{miss}, \text{dijet})$		> 2.2	> 2.8				> 2.8
$\sum_{i=1}^{N_{jet}=2(3)} p_T^{jet_i}$ [GeV]		> 120 (NU)	> 120 (150)				> 120 (150)
		See text	–				–
1-lepton selection							
m_T^W [GeV]	< 120					–	
H_T [GeV]	> 180		–			> 180	–
E_T^{miss} [GeV]	–		> 20		> 50	–	> 20
2-lepton selection							
$m_{\ell\ell}$ [GeV]	83-99					71-121	
E_T^{miss} [GeV]	< 60					–	

Event selection

$m_H = 125$ GeV at $\sqrt{s} = 8$TeV				
Process	Cross section $\times$ BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$q\bar{q} \to (Z \to \ell\ell)(H \to b\bar{b})$	14.9	–	1.3 (1.1)	13.4 (10.9)
$gg \to (Z \to \ell\ell)(H \to b\bar{b})$	1.3	–	0.9 (0.7)	10.5 (8.1)
$q\bar{q} \to (W \to \ell\nu)(H \to b\bar{b})$	131.7	0.3 (0.3)	4.2 (3.7)	–
$q\bar{q} \to (Z \to \nu\nu)(H \to b\bar{b})$	44.2	4.0 (3.8)	–	–
$gg \to (Z \to \nu\nu)(H \to b\bar{b})$	3.8	5.5 (5.0)	–	–

Variables in the fit

	Dijet-mass analysis			MVA		
Channel	0-lepton	1-lepton	2-lepton	0-lepton	1-lepton	2-lepton
1-tag	$MV1c$			$MV1c$		
LL	m_{bb}			BDT$^{(*)}$	BDT	
MM 2-tag	m_{bb}			BDT$^{(*)}$	BDT	BDT
TT	m_{bb}				BDT	

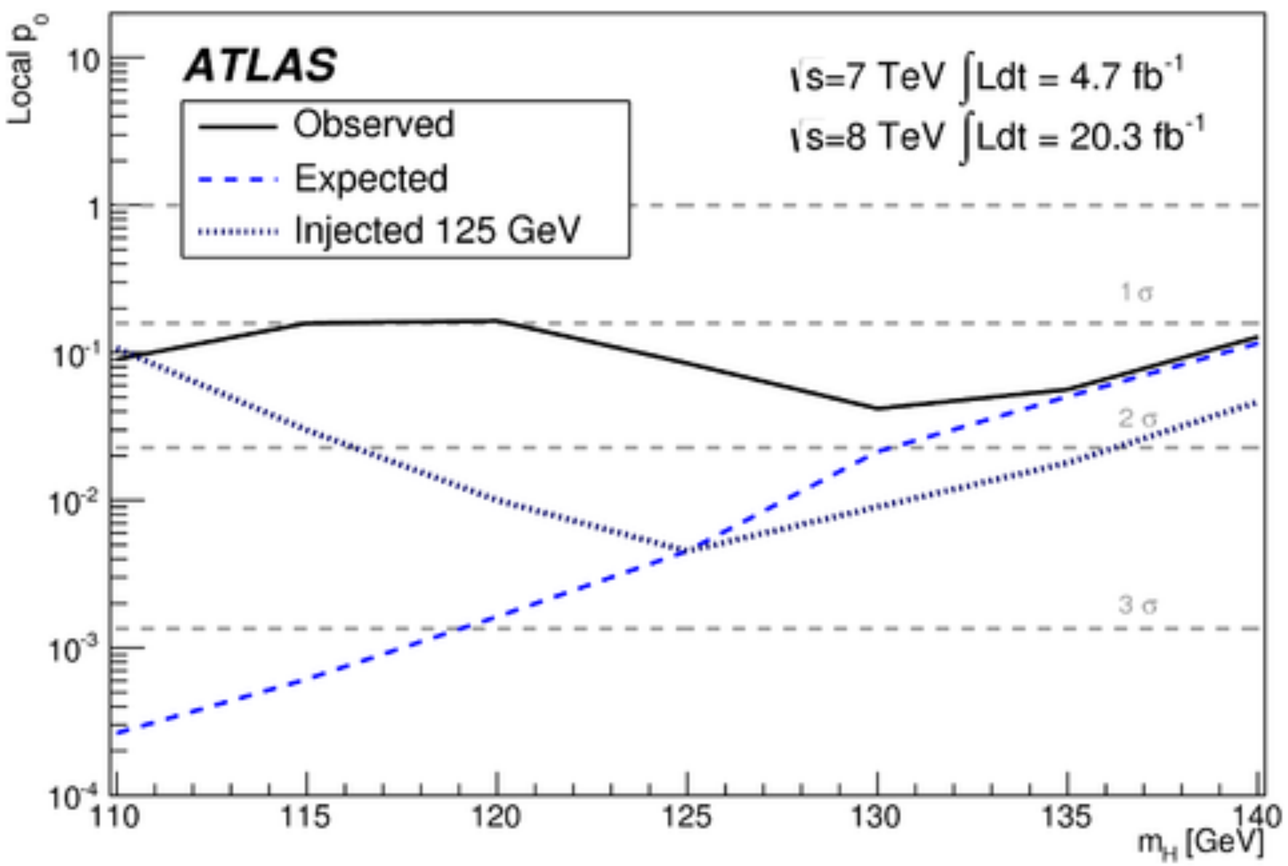
Fit Scale factors

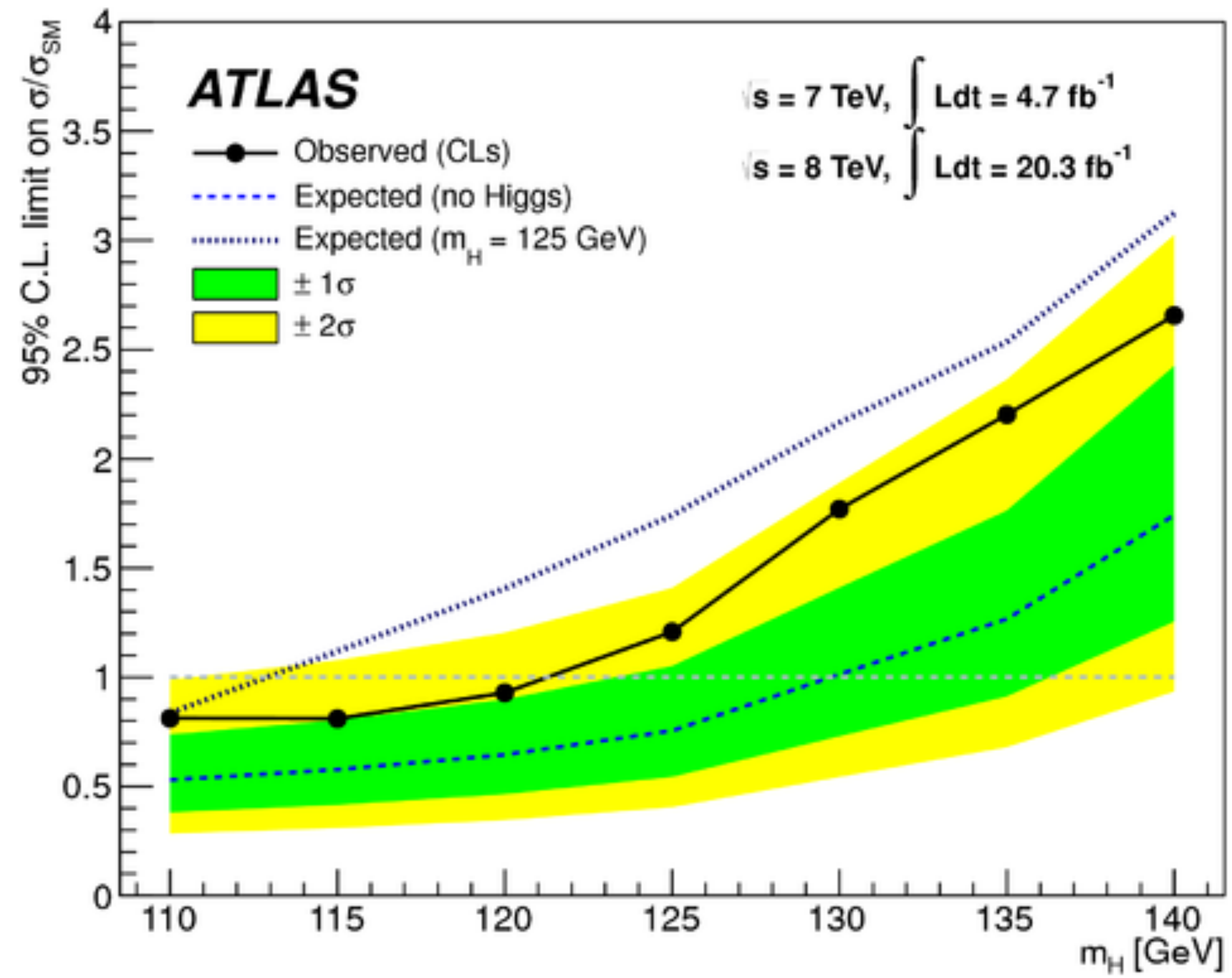
Process	Scale factor
$t\bar{t}$ 0-lepton	1.36 ± 0.14
$t\bar{t}$ 1-lepton	1.12 ± 0.09
$t\bar{t}$ 2-lepton	0.99 ± 0.04
Wbb	0.83 ± 0.15
Wcl	1.14 ± 0.10
Zbb	1.09 ± 0.05
Zcl	0.88 ± 0.12

Systematics

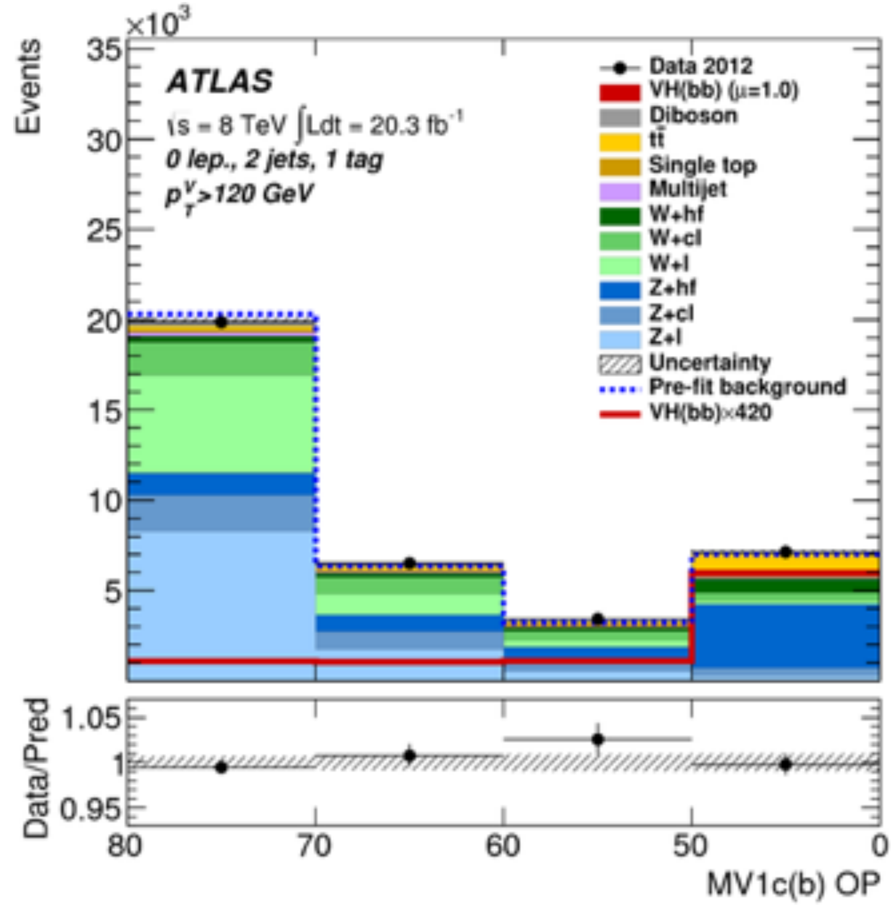
Source of uncertainty		σ_μ
Total		0.41
Statistical		0.32
Systematic		0.26
Experimental uncertainties		
Jets		0.08
E_T^{miss}		0.03
Leptons		0.01
b-tagging$^{(*)}$	b-jets	0.07
	c-jets	0.04
	light jets	0.04
Luminosity		0.03
Theoretical and modelling uncertainties		
Signal		0.07
Floating normalisations	W+jets	0.06
	Z-jets	0.03
	$t\bar{t}$	0.04
Background modelling	W+jets	0.11
	Z-jets	0.08
	$t\bar{t}$	0.05
Single-top		0.04
Diboson		0.02
Multijet		0.06

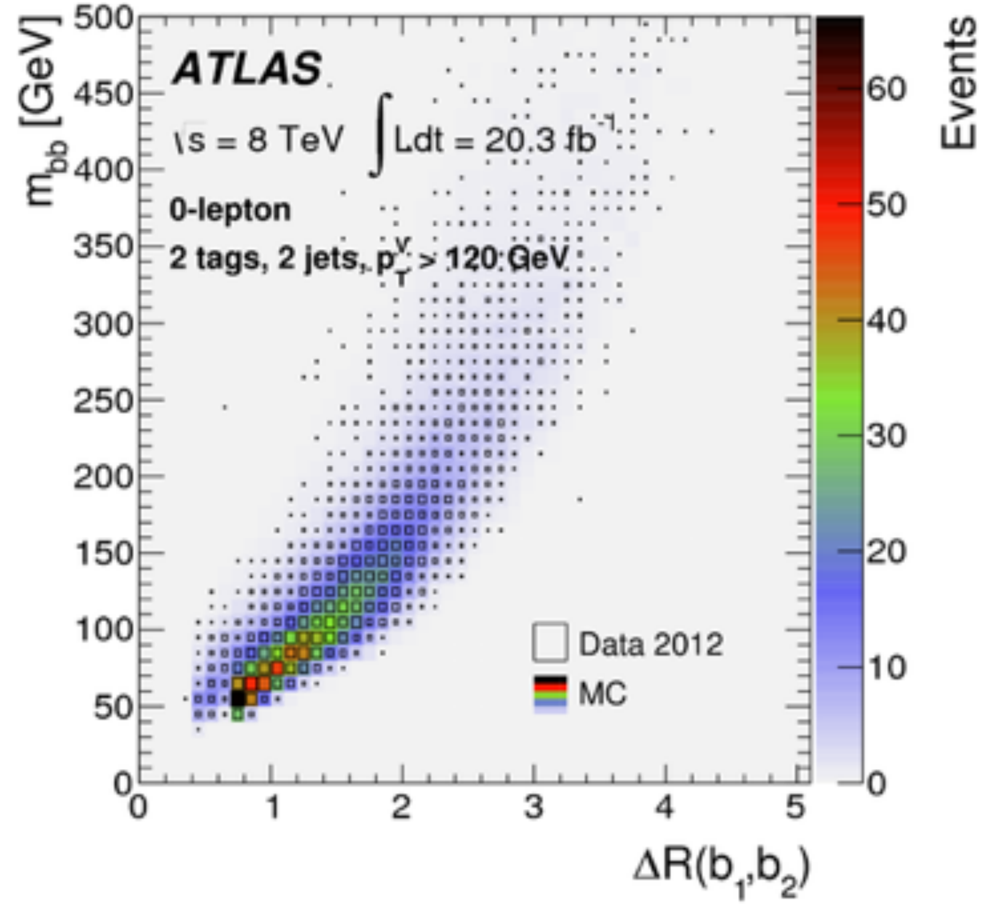
Limits and local p0

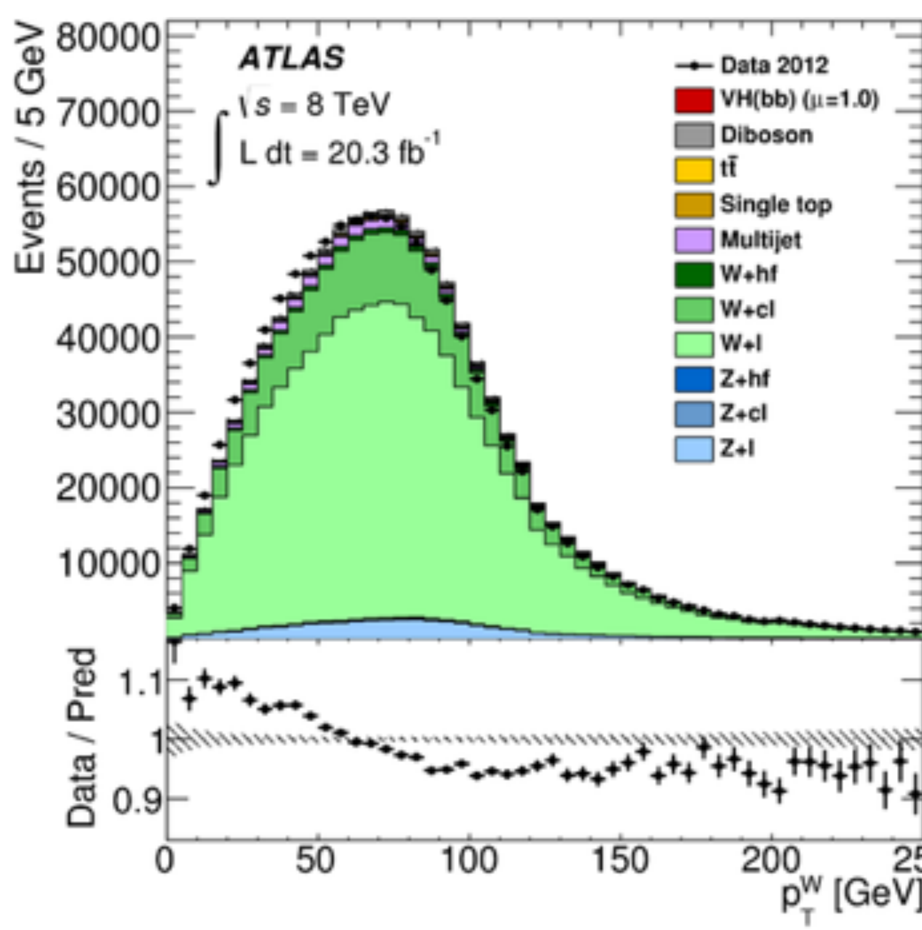


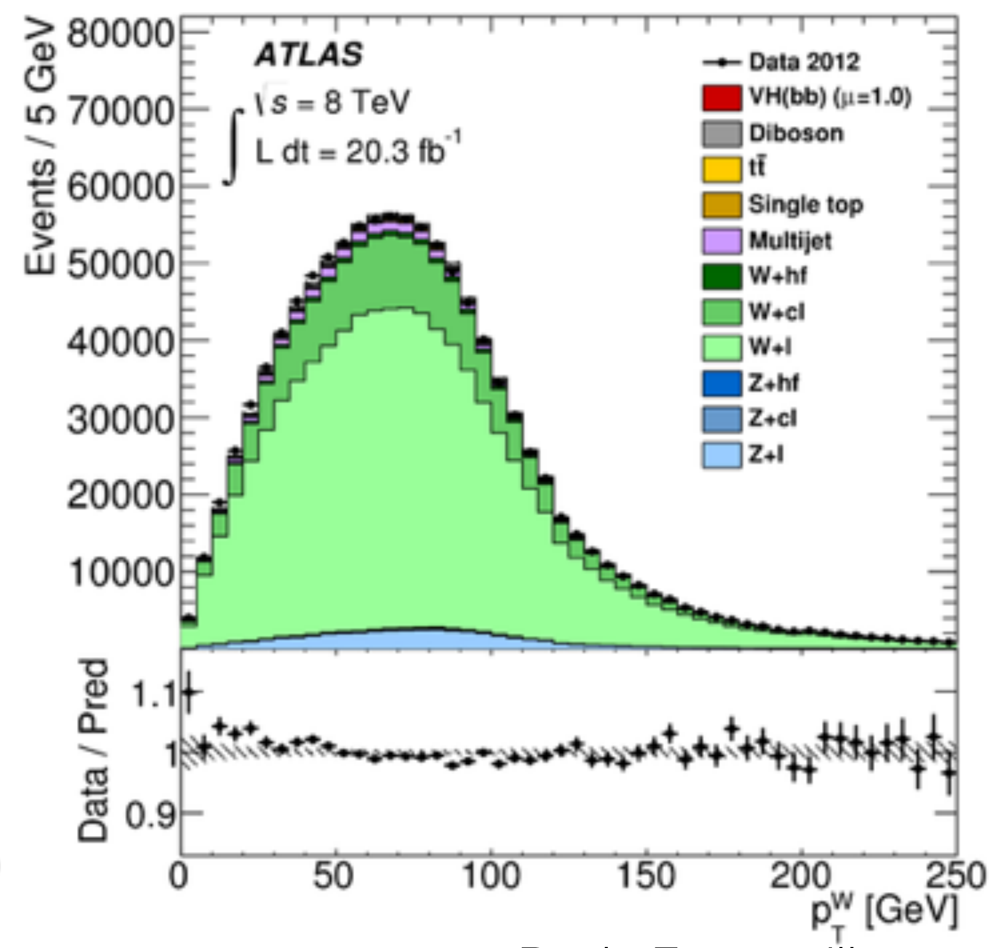


Plots


ATLAS
√s = 8 TeV ∫Ldt = 20.3 fb⁻¹
0 lep., 2 jets, 1 tag
p_T^V>120 GeV
Data 2012
VH(bb) (μ=1.0)
Diboson
tt̄
Single top
Multijet
W+hf
W+cl
W+l
Z+hf
Z+cl
Z+l
Uncertainty
Pre-fit background
VH(bb)×420
Events
×10³
Data/Pred
MV1c(b) OP


ATLAS
√s = 8 TeV ∫Ldt = 20.3 fb⁻¹
0-lepton
2 tags, 2 jets, p_T^V > 120 GeV
Data 2012
MC
m_bb [GeV]
ΔR(b1,b2)
Events


ATLAS
√s = 8 TeV
∫ L dt = 20.3 fb⁻¹
Data 2012
VH(bb) (μ=1.0)
Diboson
tt̄
Single top
Multijet
W+hf
W+cl
W+l
Z+hf
Z+cl
Z+l
Events / 5 GeV
Data / Pred
p_T^W [GeV]


ATLAS
√s = 8 TeV
∫ L dt = 20.3 fb⁻¹
Data 2012
VH(bb) (μ=1.0)
Diboson
tt̄
Single top
Multijet
W+hf
W+cl
W+l
Z+hf
Z+cl
Z+l
Events / 5 GeV
Data / Pred
p_T^W [GeV]