Search for the Standard Model Higgs boson decaying into a *b*-quark pair at ATLAS

Yoshikazu NAGAI

(CPPM, Aix-Marseille Université)

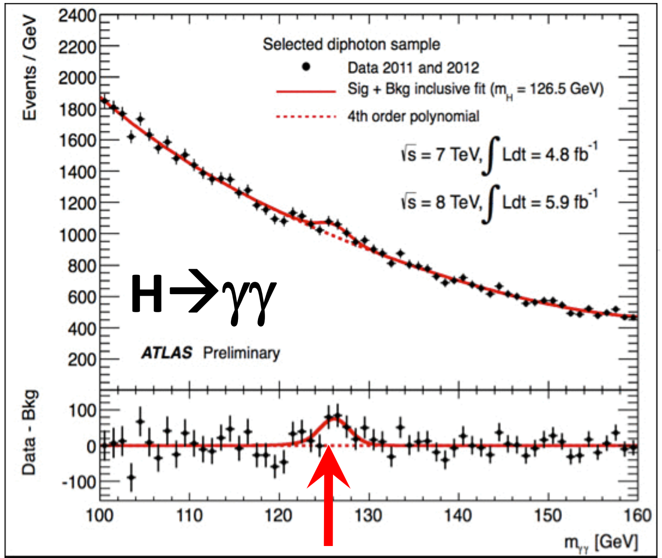
CPPM Seminar
October 20, 2014

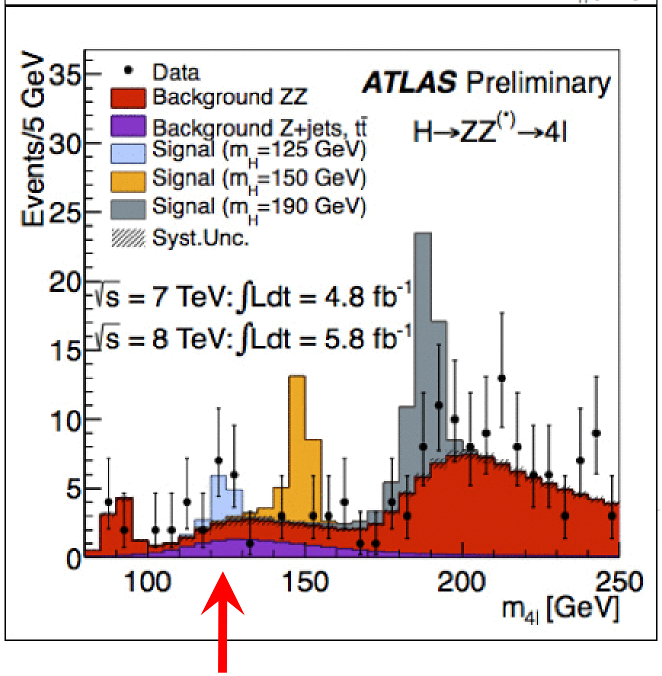
Contents

- Introduction
- Analysis overview
- Result of a search for the H→bb
- Summary & Prospects for the upcoming high-luminosity LHC

Observation of a new boson

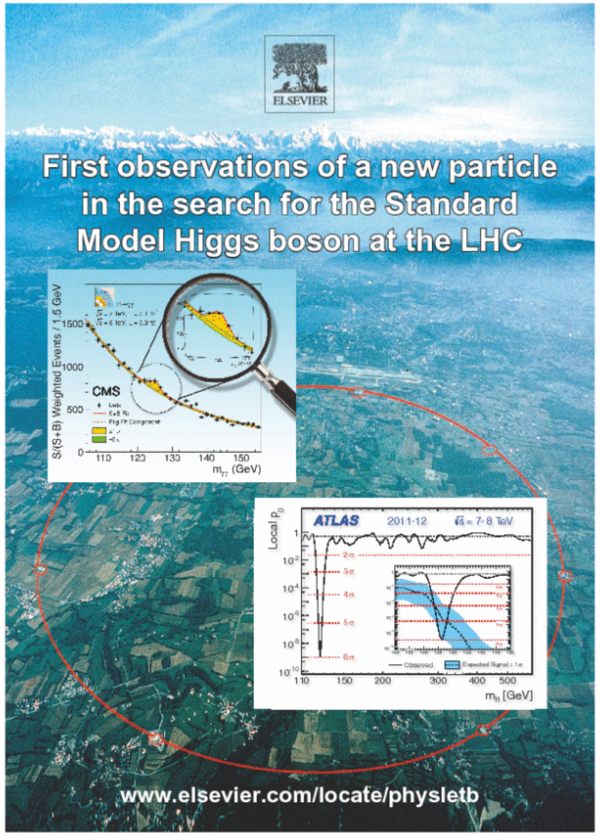
July 4th, 2012





Observation of a new particle at a mass of around 125 GeV by ATLAS (5.1σ) & CMS (5.0σ)

September, 2012



PLB 716(2012) 1-29

October 8th, 2013

The Nobel Prize in Physics 2013
François Englert, Peter Higgs

Nobelprize.org

Share this: 1.9K

The Nobel Prize in Physics 2013

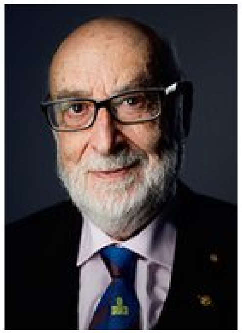


Photo: A. Mahmoud
François Englert
Prize share: 1/2

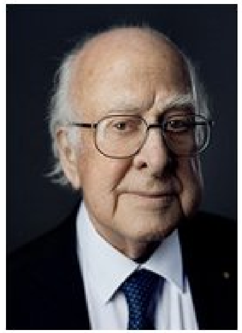


Photo: A. Mahmoud
Peter W. Higgs
Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

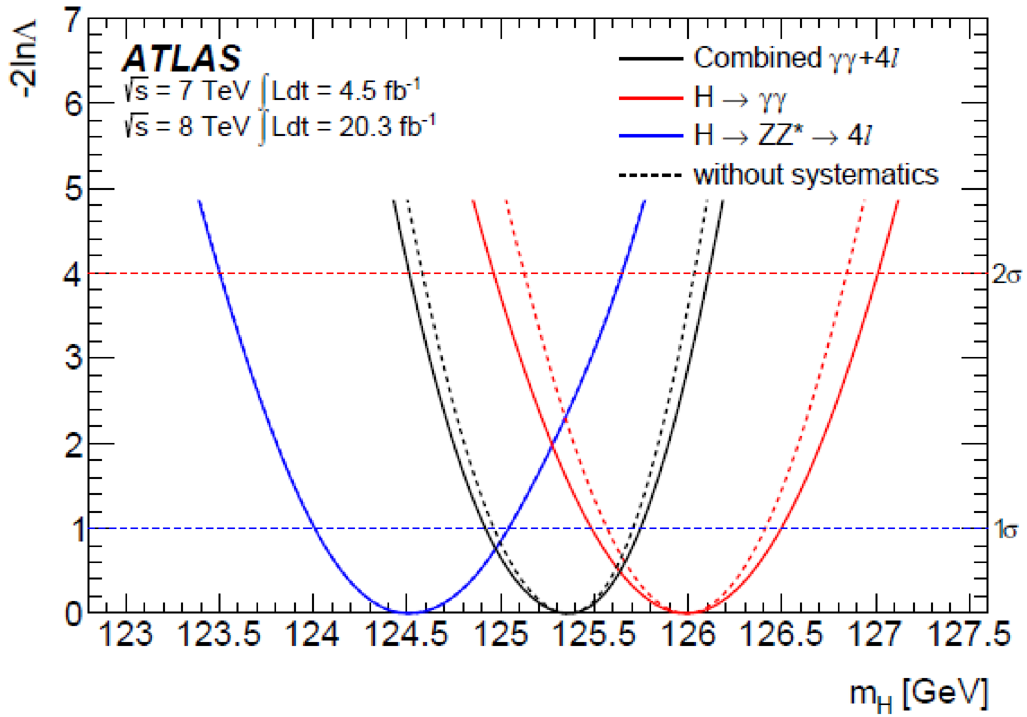
Decay modes of this new boson

	ATLAS	CMS	
$H \rightarrow \gamma\gamma$	**YES !**	**YES !**	
$H \rightarrow ZZ^{(*)}$	**YES !**	**YES !**	Bosonic decay modes
$H \rightarrow WW^{(*)}$	**YES !**	**YES !**	
$H \rightarrow \tau\tau$	Evidence (4.5σ)	Evidence (3.2σ)	Lepton — Fermionic decay modes
$H \rightarrow bb$	??		Quark — Fermionic decay modes

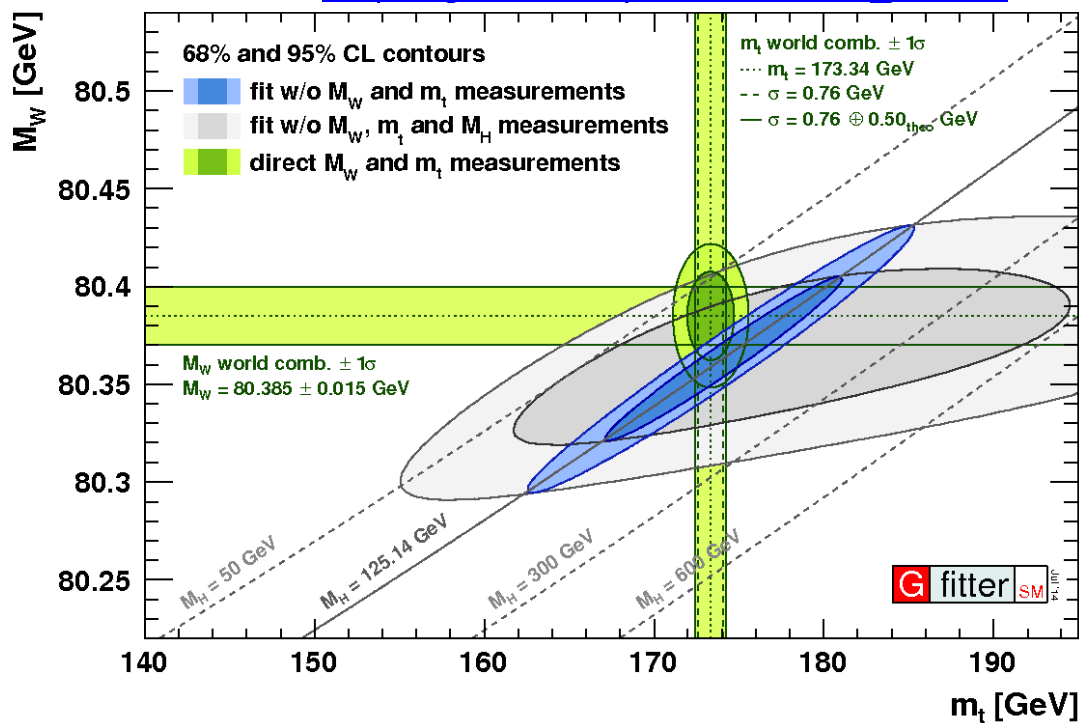
This seminar reviews a search for the *H→bb* decay mode

Is this new boson the SM Higgs boson?
-- property measurements --

Mass ($H \rightarrow \gamma\gamma$, $ZZ \rightarrow 4l$) Phys. Rev. D. 90, 052004 (2014)



G fitter: http://gfitter.desy.de/Standard_Model



Combined (*$H \rightarrow \gamma\gamma$* and *$H \rightarrow ZZ^{(*)} \rightarrow 4l$*):

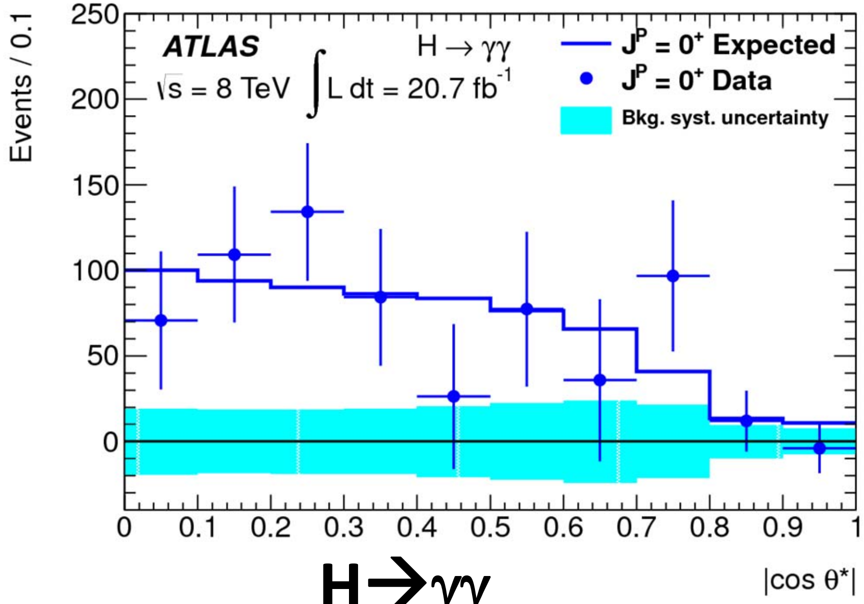
$$m_H = 125.36 \pm 0.37\,(\text{stat}) \pm 0.18\,(\text{syst})\ \text{GeV}$$
$$= 125.36 \pm 0.41\ \text{GeV}$$

Direct measurements of top-quark and W mass are compatible with the EWK global fit including Higgs mass in the fit

Is this new boson the SM Higgs boson?
-- property measurements --

Spin/Parity ($H \to \gamma\gamma$, $ZZ^{(*)} \to 4l$, $WW^{(*)} \to l\nu l\nu$) Phys. Lett. B. 726 (2013)

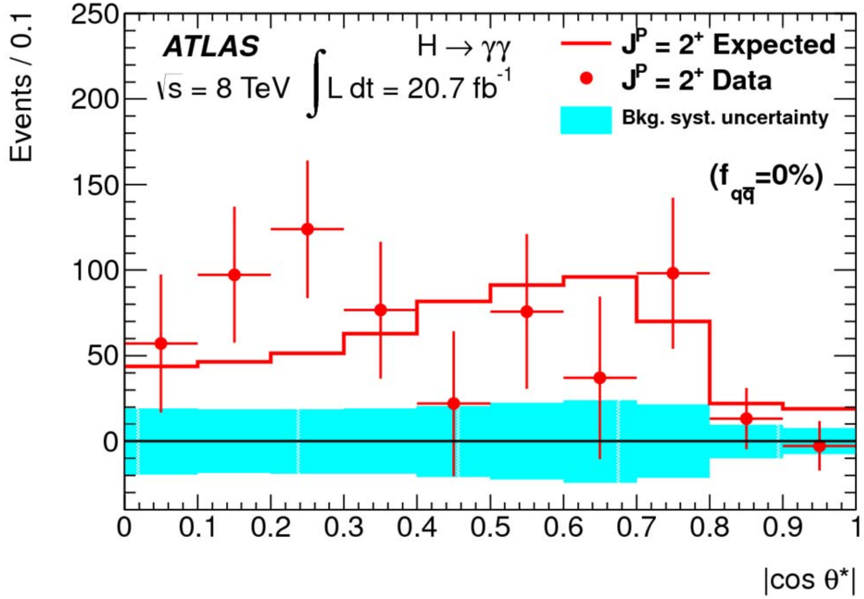
Spin 0^+

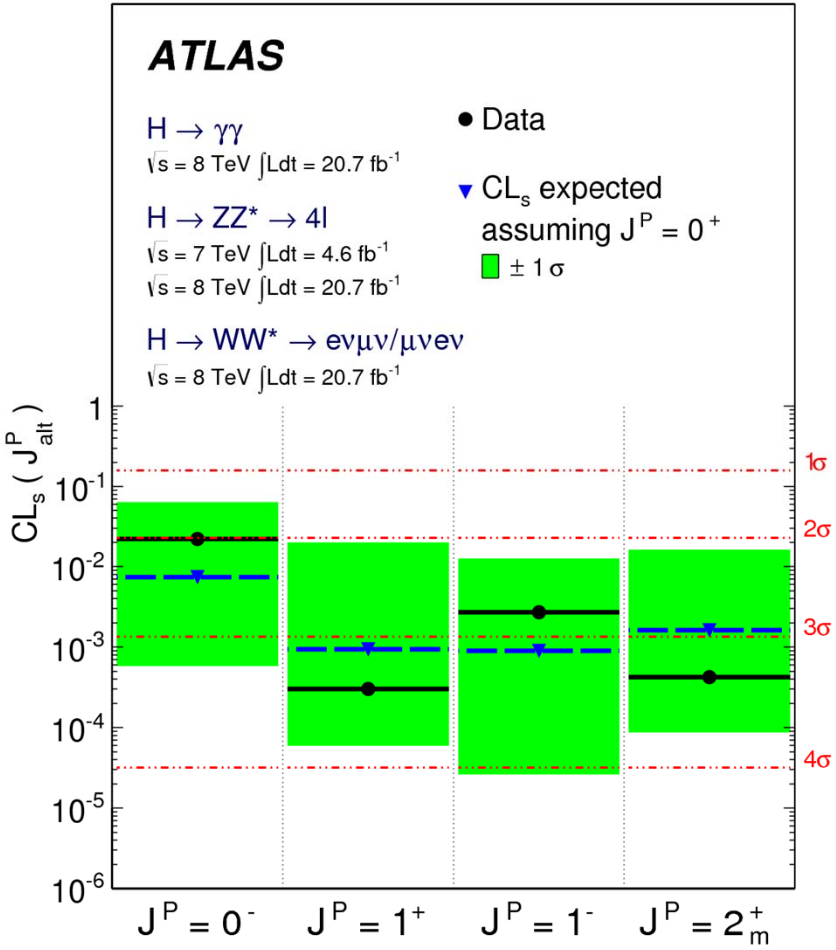


vs

$H \to \gamma\gamma$

Spin 2^+



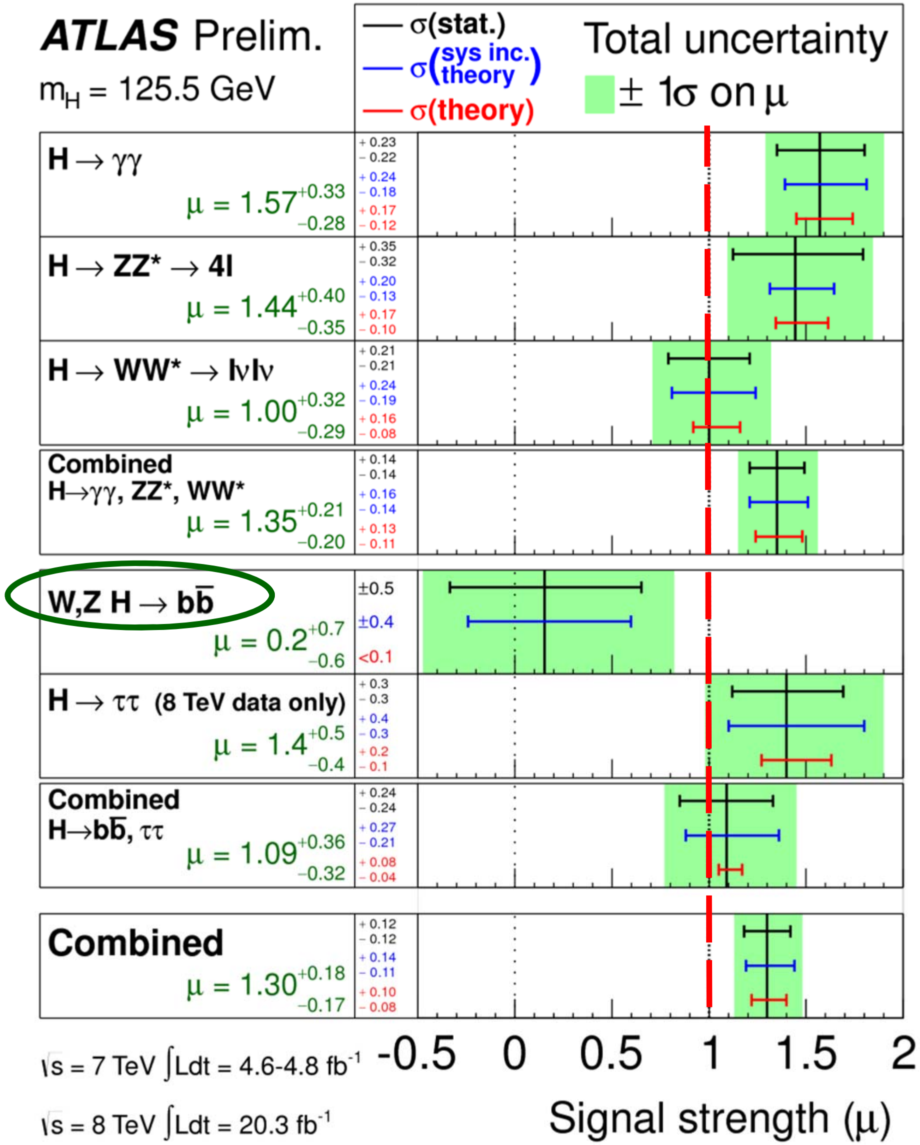


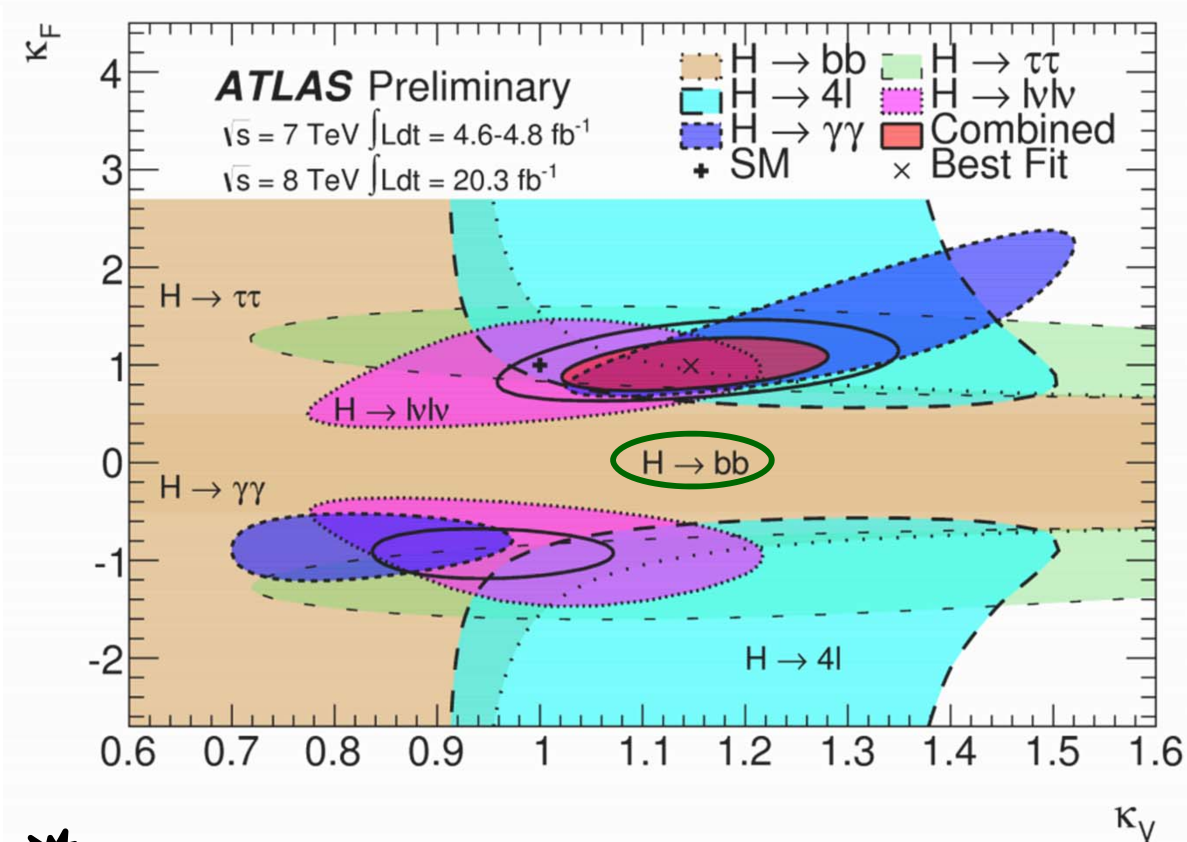
JP = 0^-, 1^+, 1^-, 2^+ hypotheses are excluded > 2σ

(For spin-2 hypothesis, we tested one benchmark scenario)

Is this new boson the SM Higgs boson?
-- property measurements --

Couplings (all production modes, all decay modes) ATLAS-CONF-2014-009 (2014)



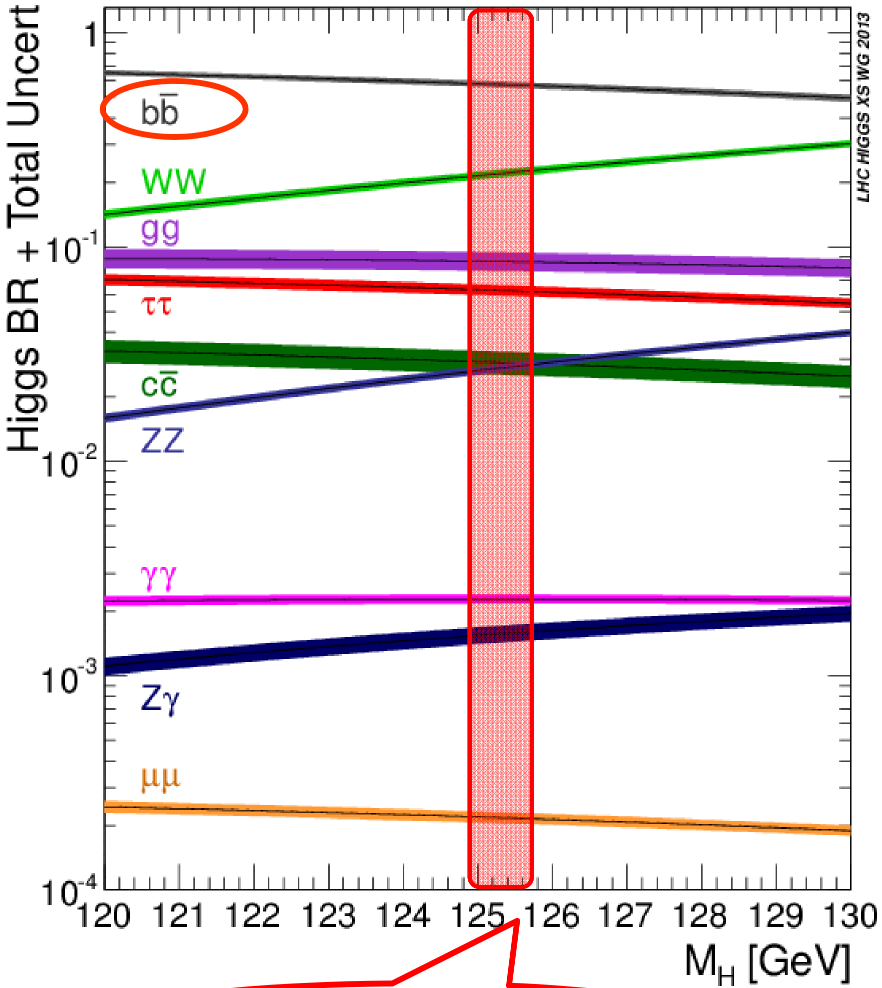


- **No significant deviations from SM prediction**
- **Strong constraint from bosonic decay modes**

Caveat: H→bb does not contain latest results

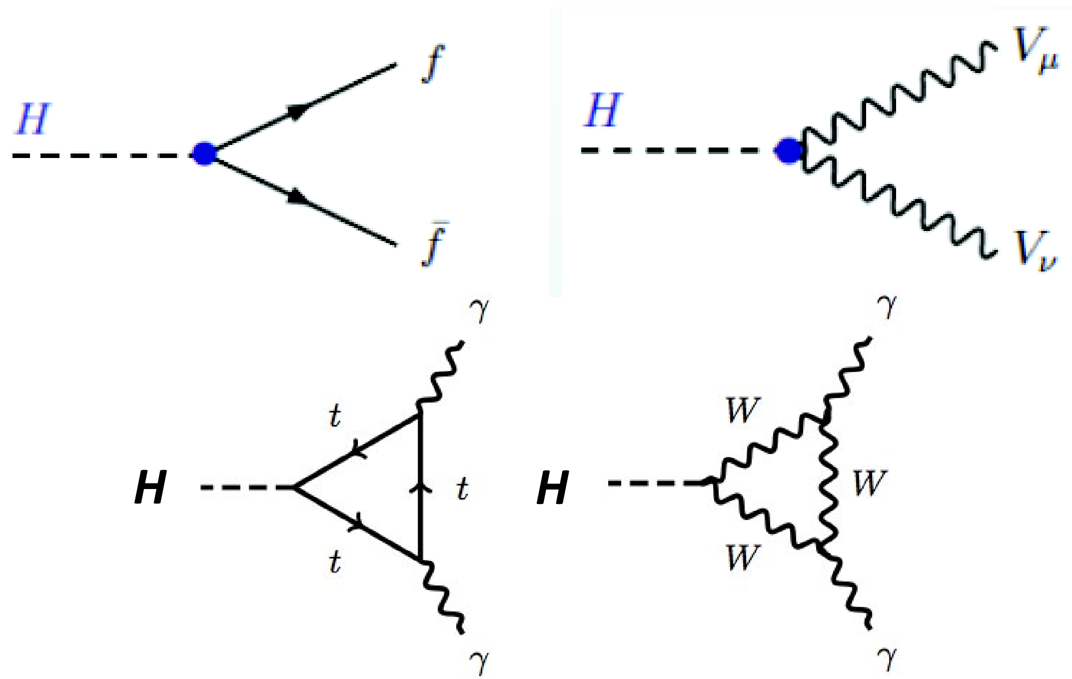
$\mu = (\sigma \times Br)_{measured} / (\sigma \times Br)_{SM}$

Does the new boson decay into a b-quark pair?
-- Branching ratio of the SM Higgs boson --



$m_H = 125.36 \pm 0.41$ GeV

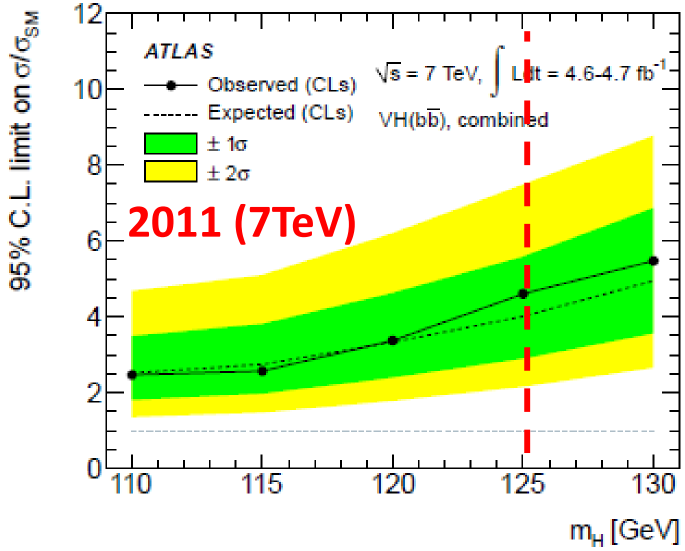
SM Branching ratio at 125.4 GeV						
bb	WW	ττ	ZZ	γγ	Zγ	μμ
57%	22%	6.3%	2.7%	0.23%	0.15%	0.02%



It predominantly decays to a b-quark pair, if the new boson is the SM Higgs boson

Previous studies on VH→Vbb

ATLAS



Upper limit:

< 4.6 x σ_{SM}

Expected limit:

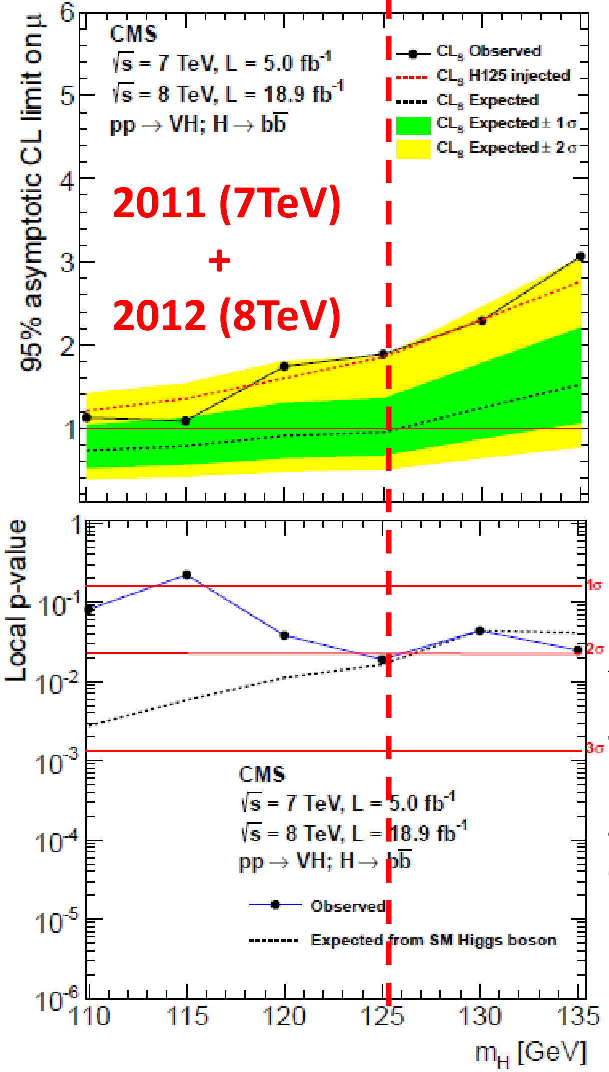
< 4.0 x σ_{SM}

@ m_H = 125 GeV

Some evidence?

but has yet to be confirmed

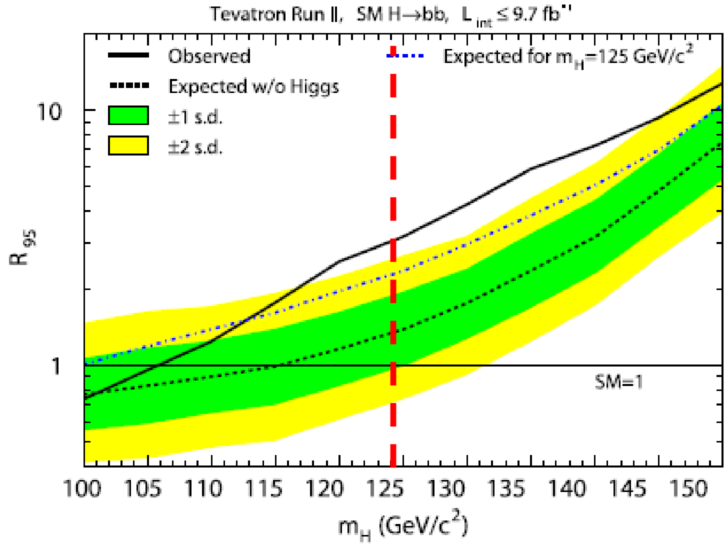
CMS

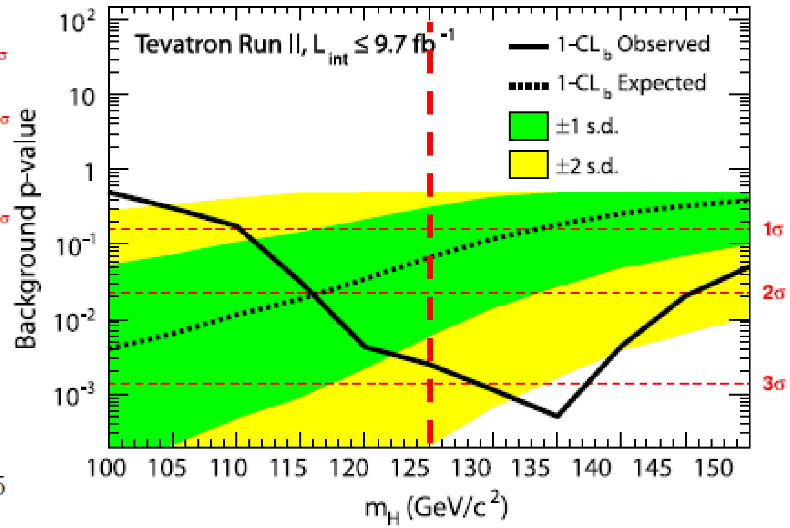


Signal excess @ m_H = 125 GeV

Obs. 2.1σ Exp. 2.1σ

Tevatron





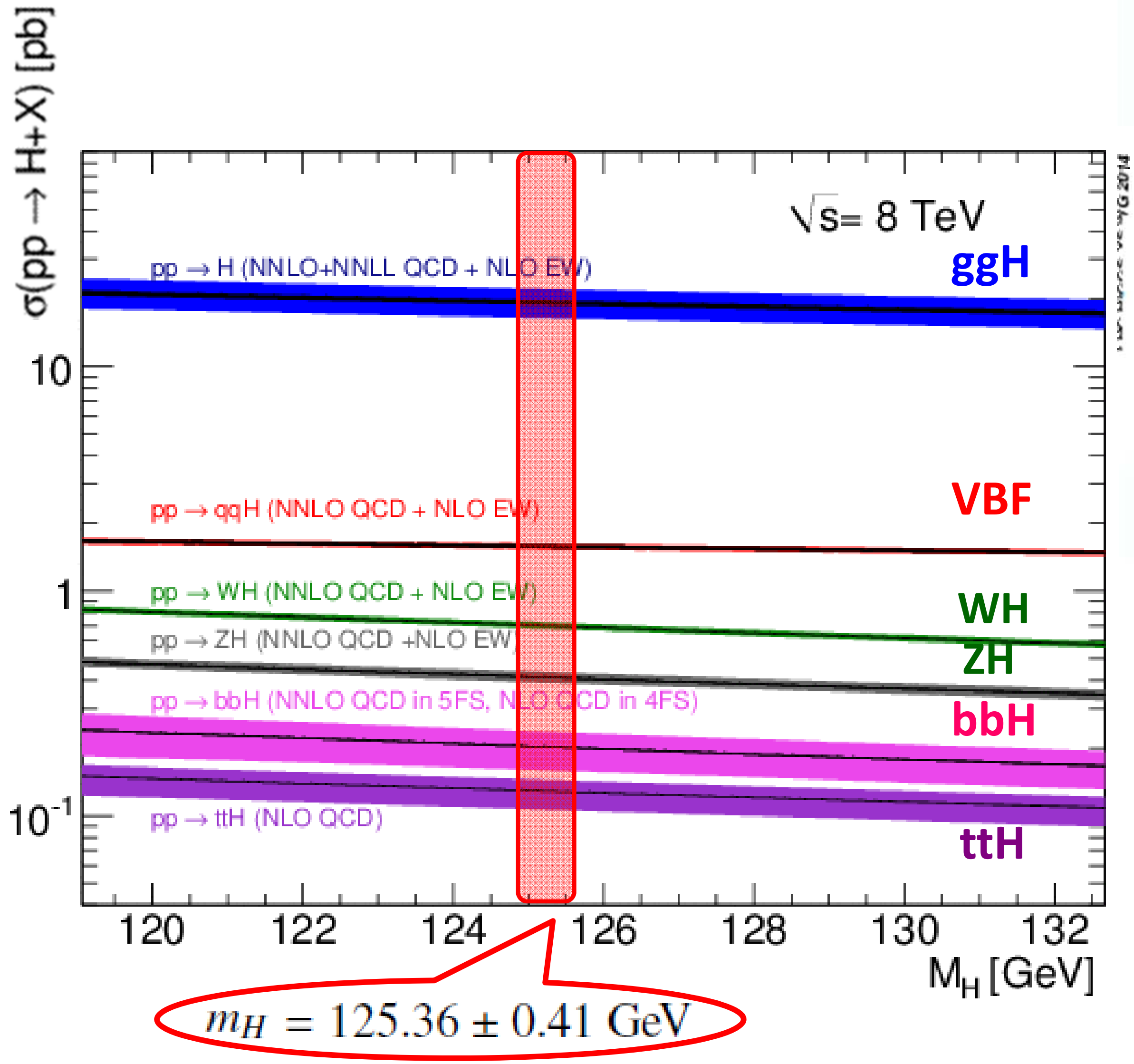
Signal excess @ m_H = 125 GeV

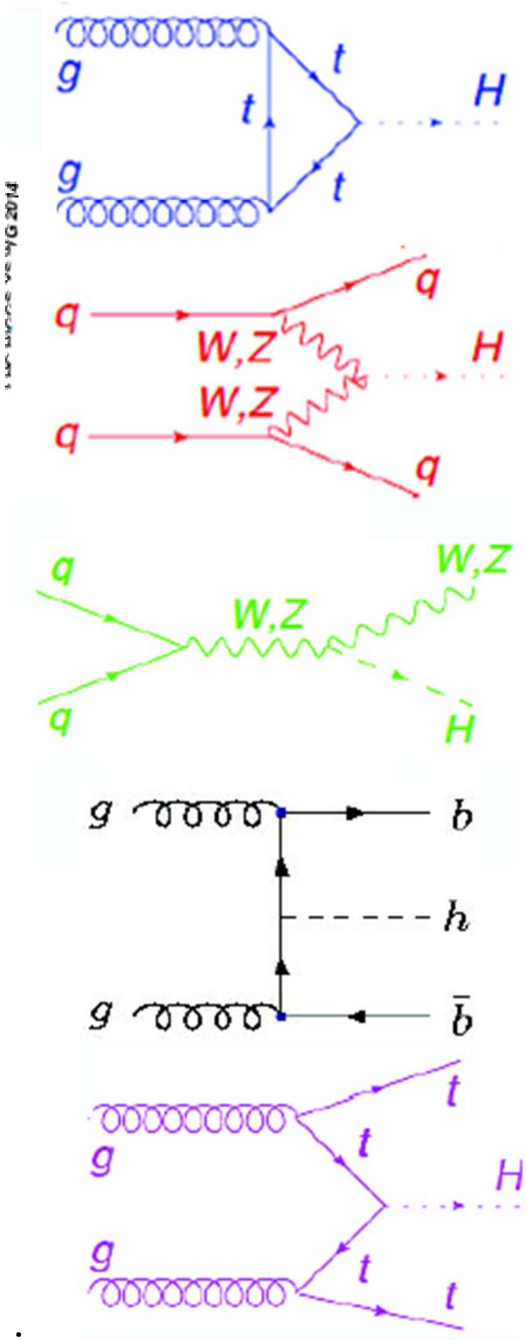
Obs. 2.8σ Exp. 1.6σ

Higgs boson productions at LHC

8 TeV LHC

@m_H = 125 GeV





σ_{ggH} = 19.27 pb

σ_{VBF} = 1.578 pb

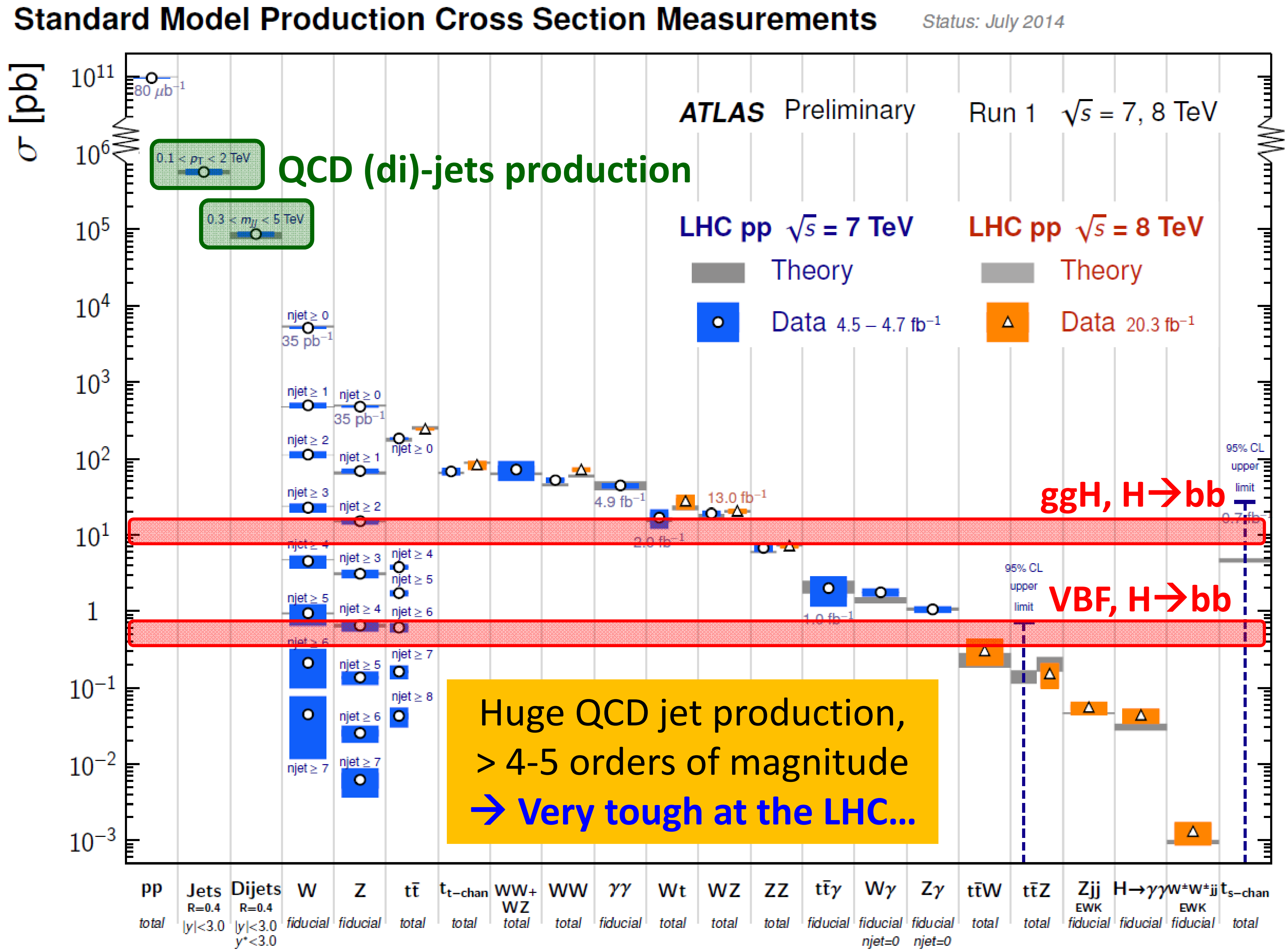
σ_{WH} = 0.705 pb

σ_{ZH} = 0.415 pb

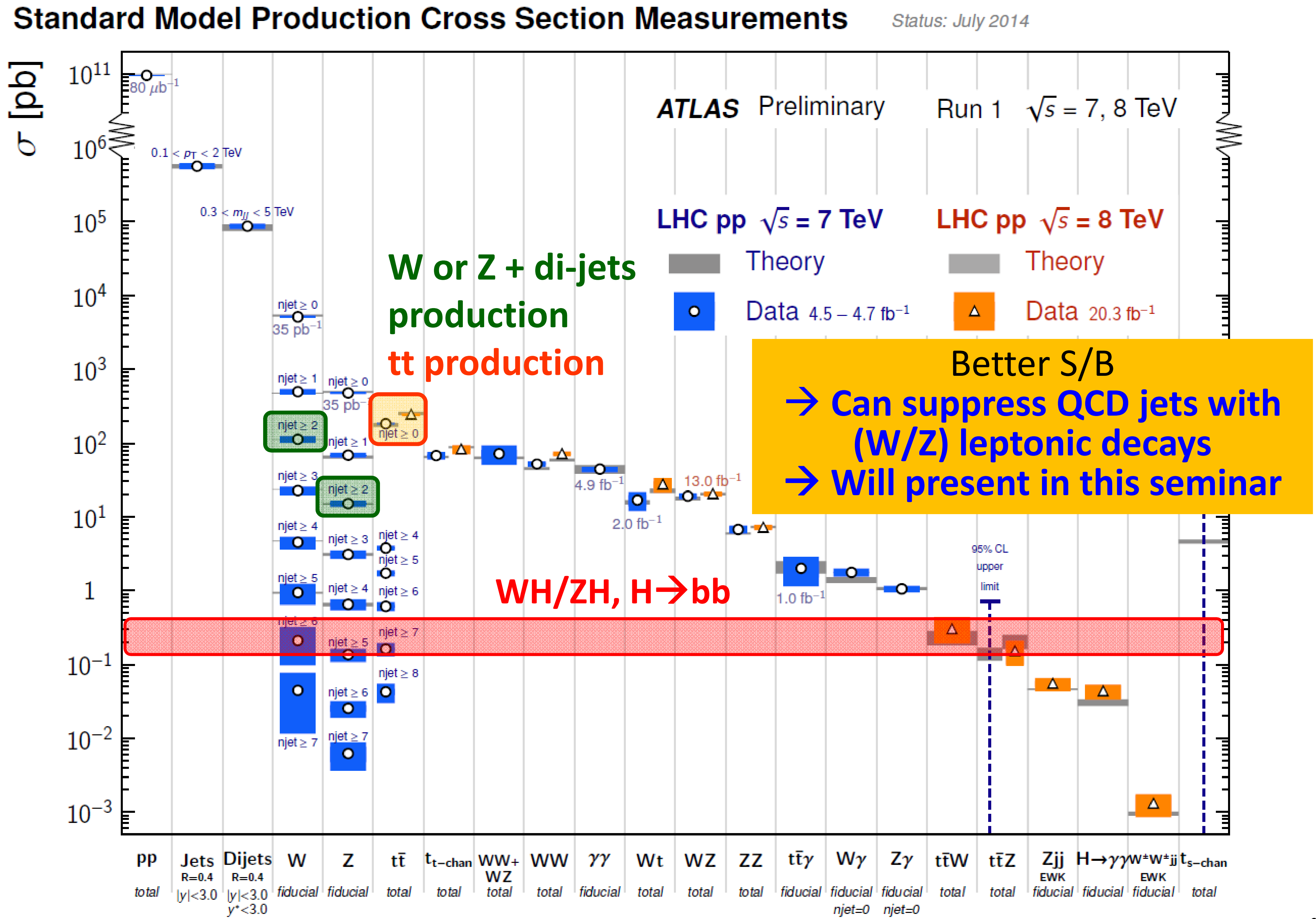
σ_{bbH} = 0.204 pb

σ_{ttH} = 0.129 pb

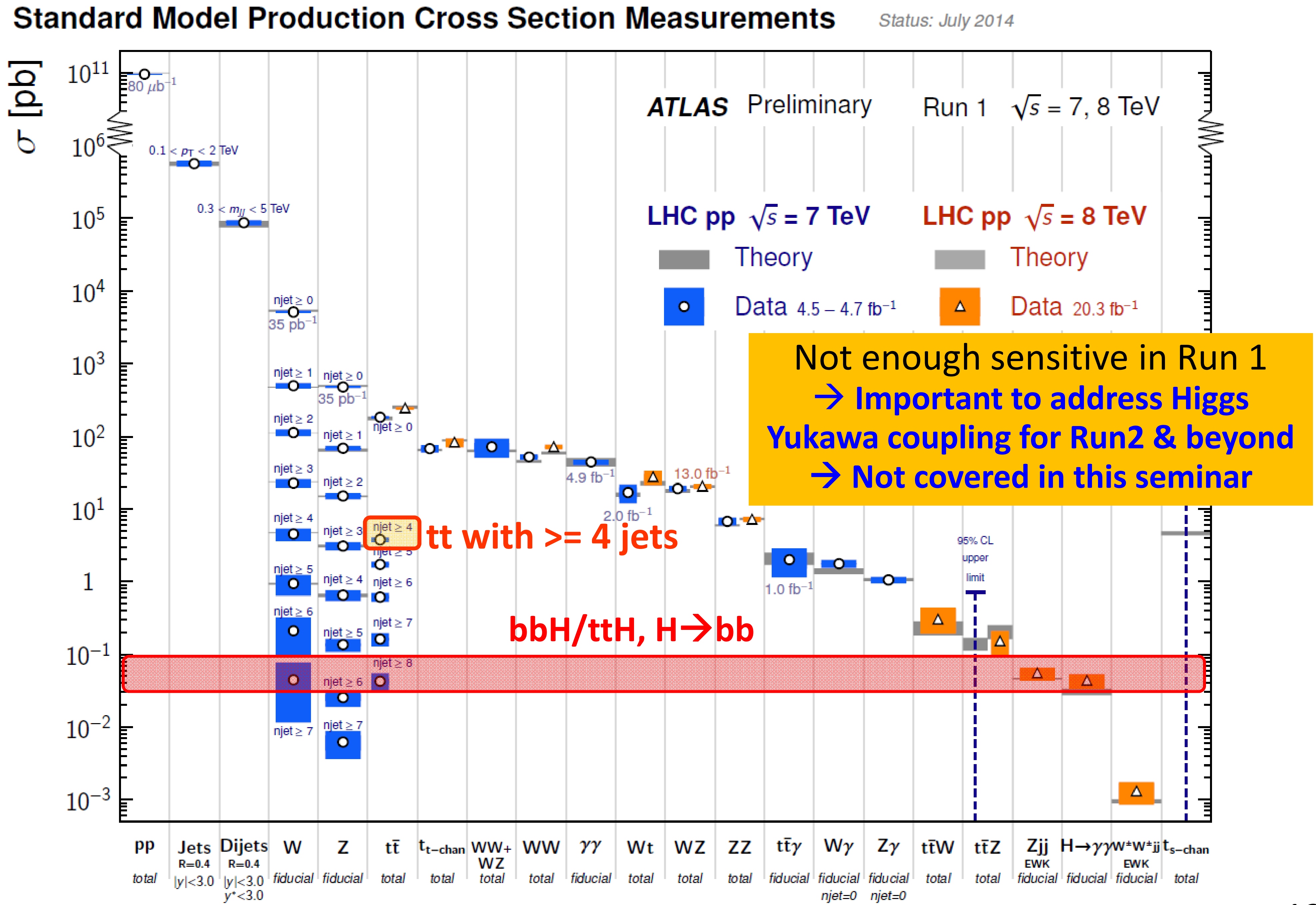
How do we look for H→bb at LHC?



How do we look for H→bb at LHC?

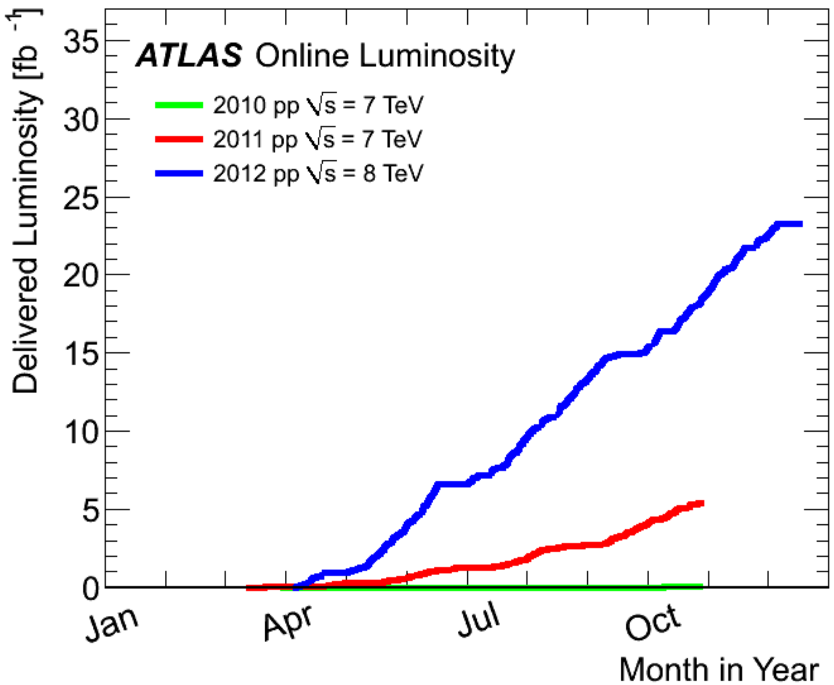


How do we look for H→bb at LHC?



LHC and integrated luminosity

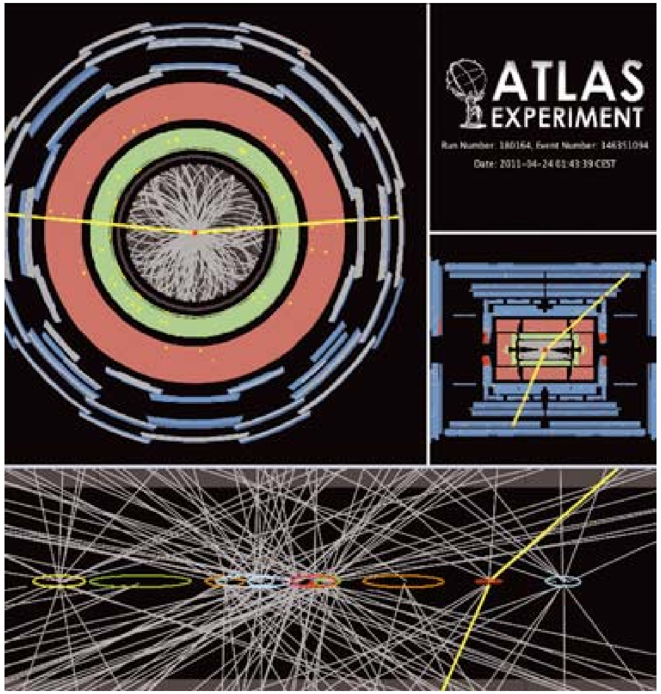
- proton-proton collisions at **7 TeV (2011)** and **8 TeV (2012)**
- The peak instantaneous luminosity at 8 TeV is **7.7 x 10^{33} cm^{-2} s^{-1}**



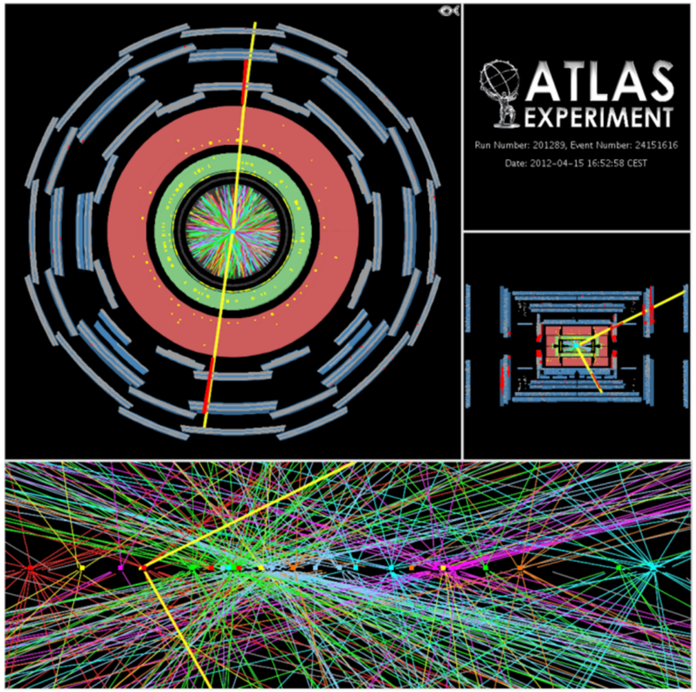
- ATLAS recorded:

  > 5.0 fb^{-1} (2011) and **> 23 fb^{-1} (2012)**
- In this seminar, full data analysis is presented

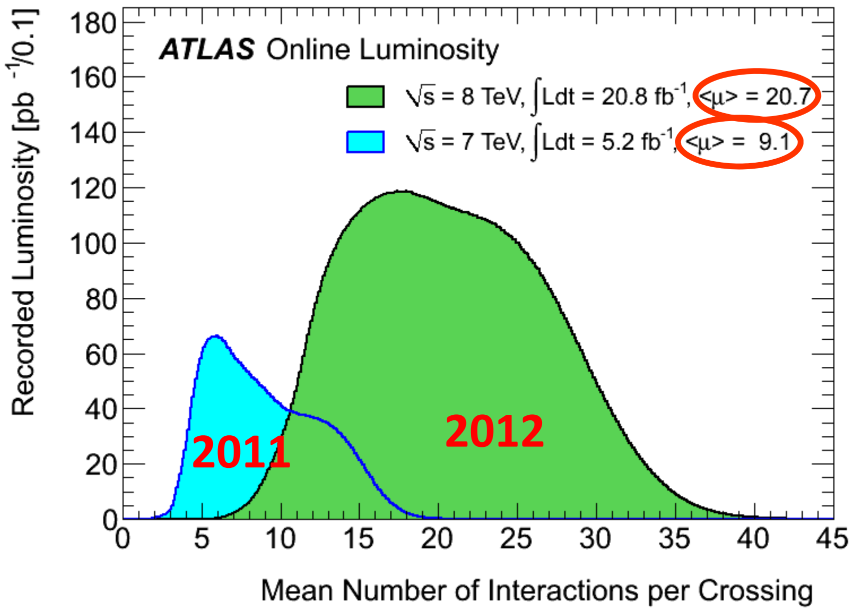
A challenging environment



2011: 11 vertices with Z→μμ



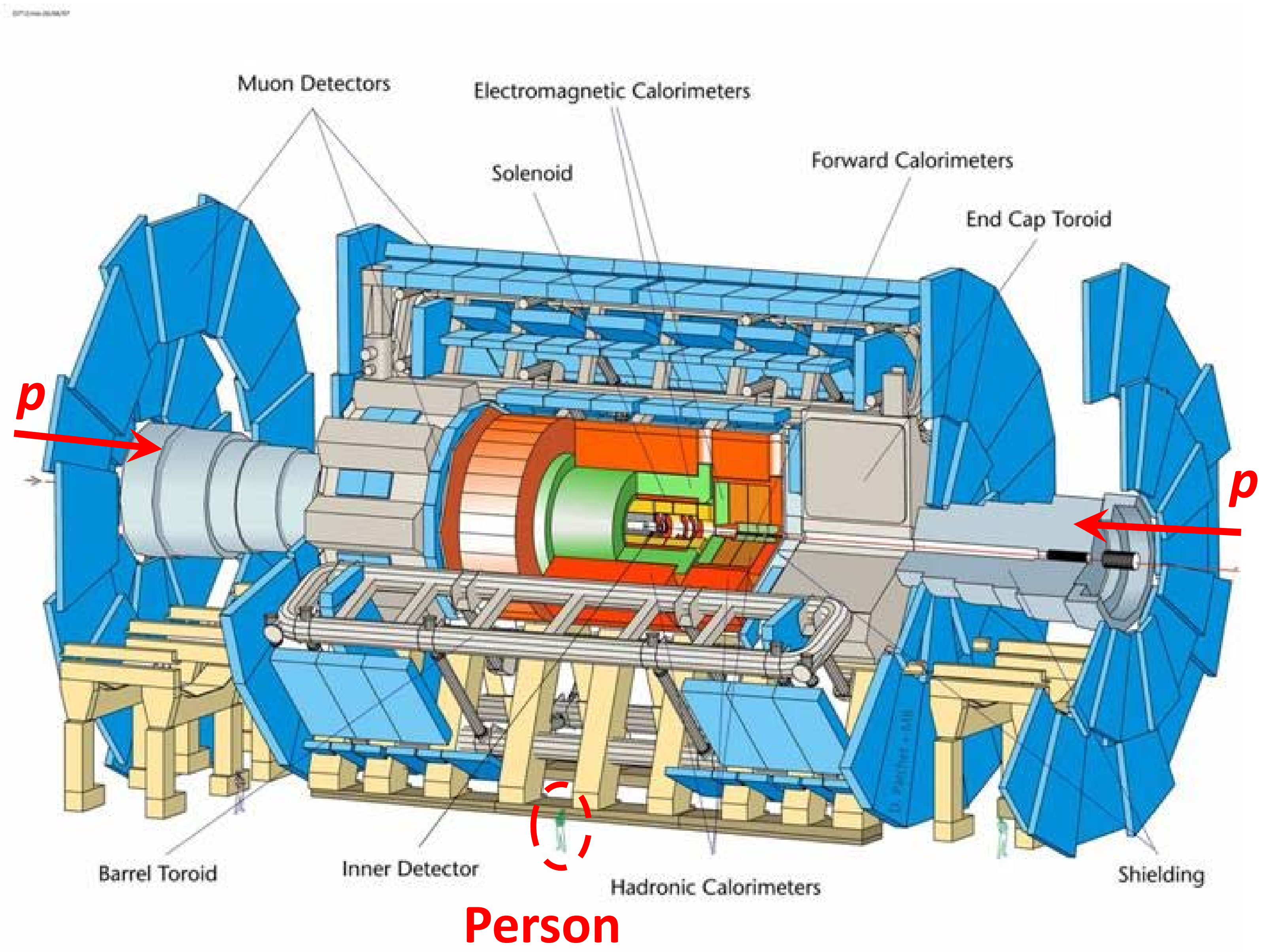
2012: 25 vertices with Z→μμ



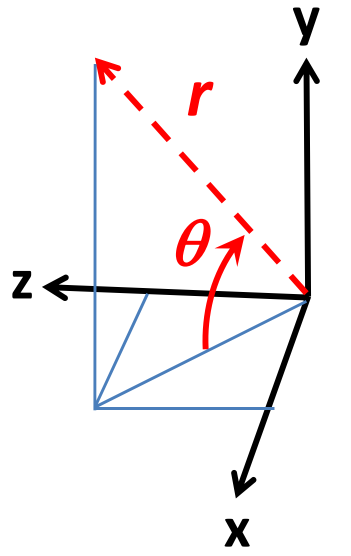
Number of pile-up =
(Cross-section) [cm^2] x
(Luminosity) [$cm^{-2}s^{-1}$] x
(bunch spacing) [s] (50 ns !!)

Need very good resolution to resolve vertices & very fast trigger system to keep interesting events

A Toroidal LHC Apparatus (The ATLAS detector)

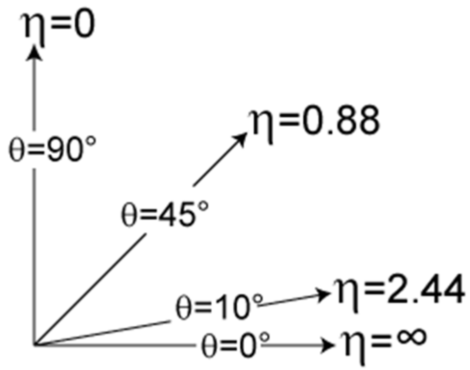


The ATLAS coordinate



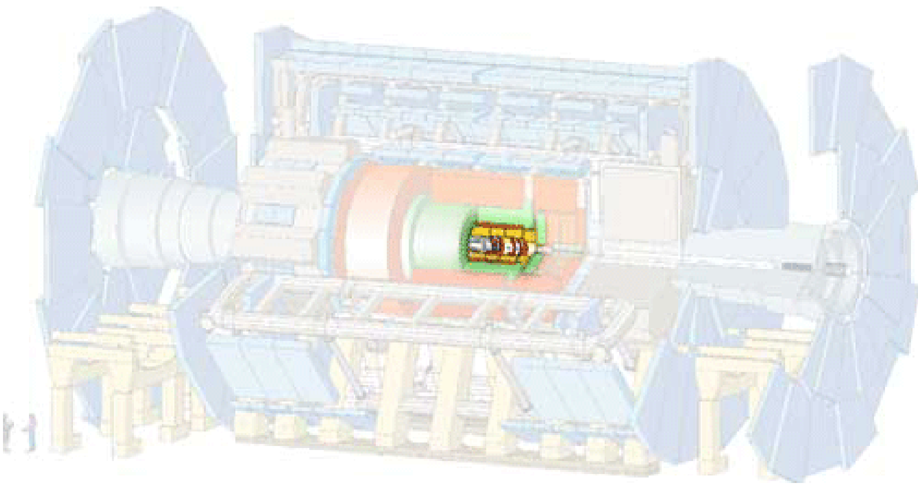
Polar angle is expressed by **pseudorapidity**

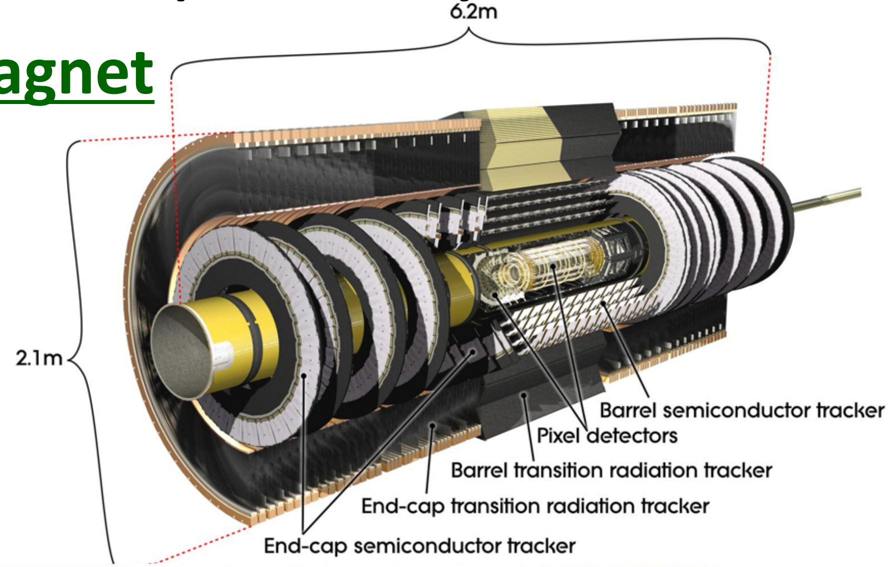
$\eta = -\ln\tan(\theta/2)$

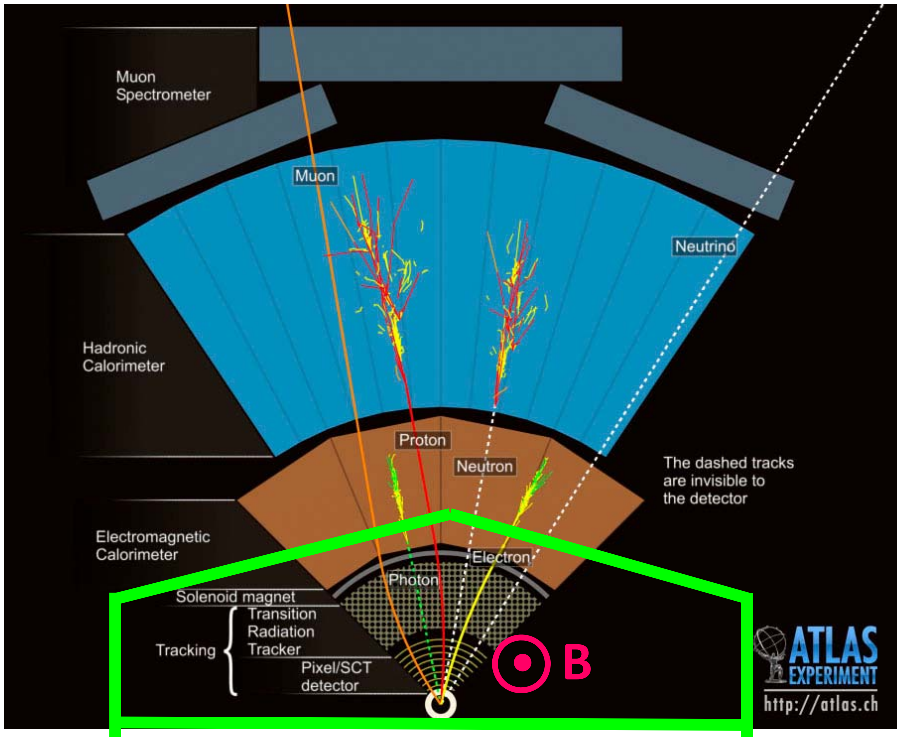


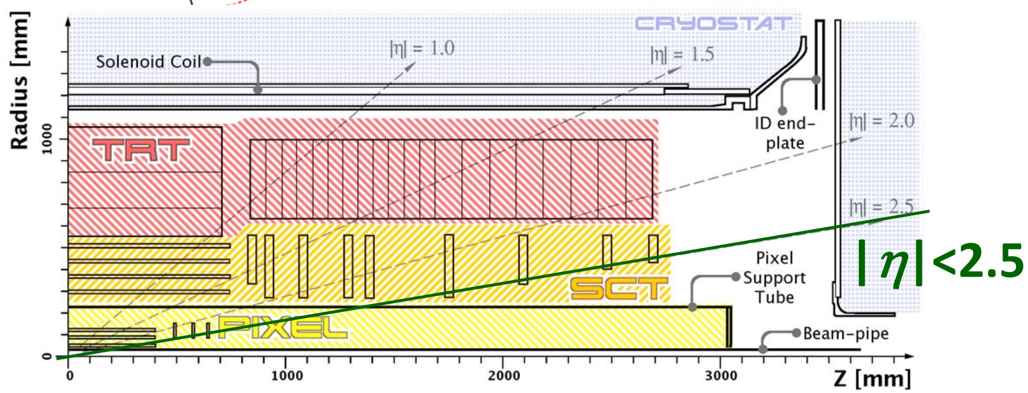
The ATLAS detector (cont'd)

Inner tracking detectors & solenoid magnet







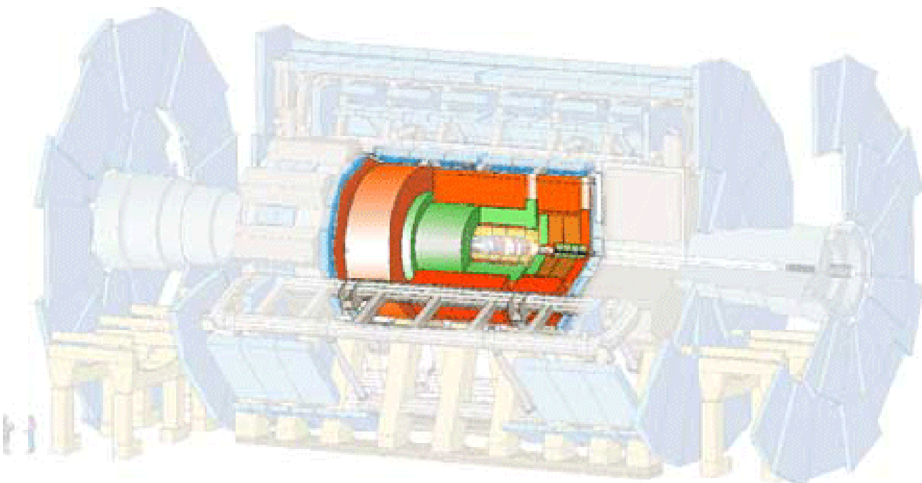


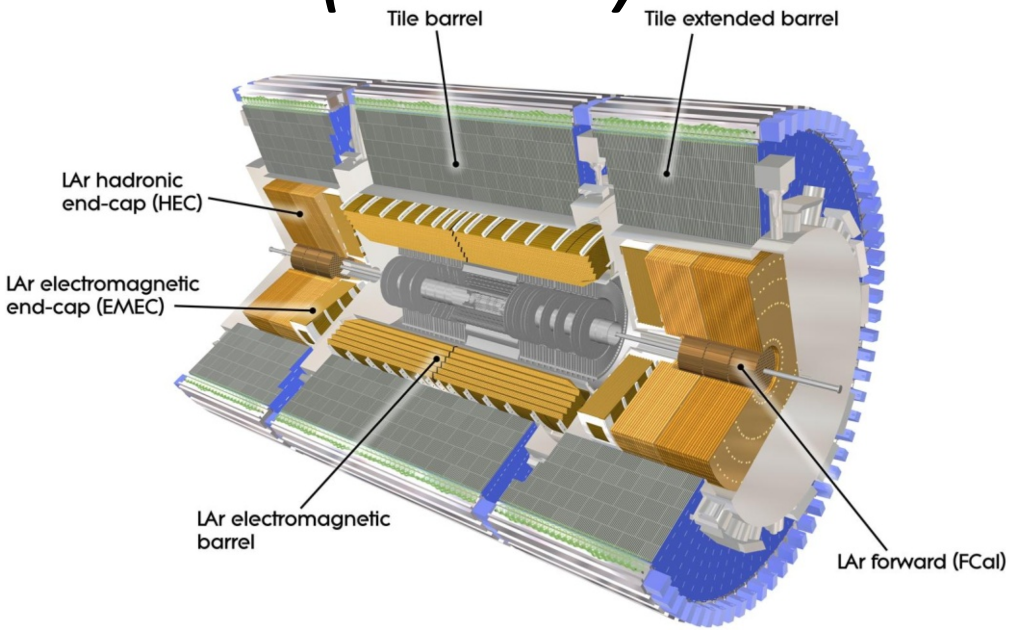
- Silicon (Pixels & strip)
- Transition radiation straw chamber
- Superconducting solenoid magnet

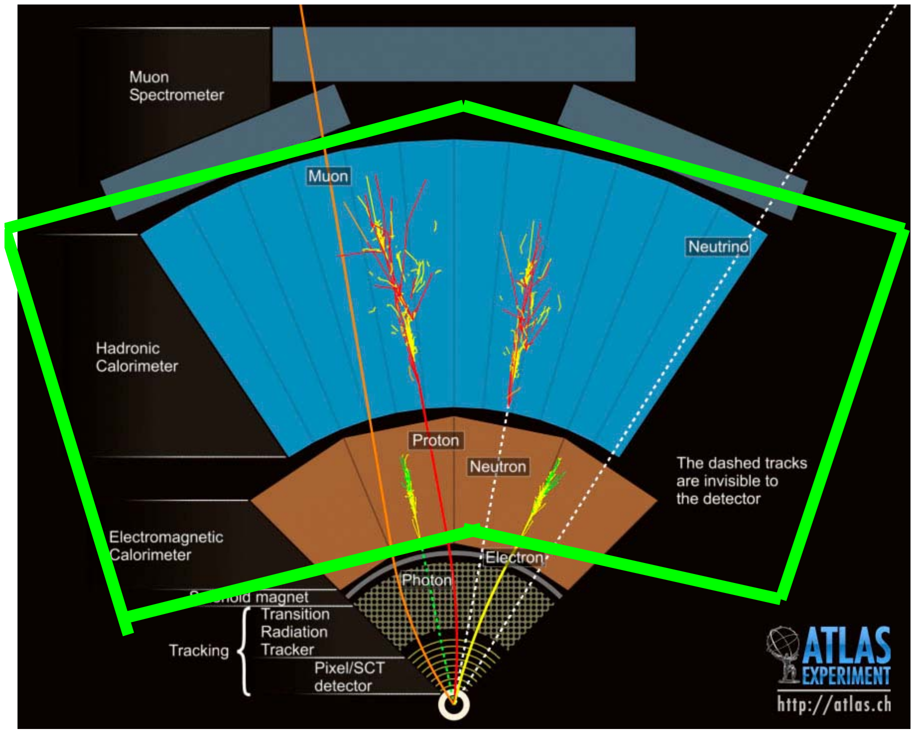
For H→bb analysis, transverse impact parameter resolution is very crucial for b-jets identification $\sigma(d_0) \sim 20\ \mu m$

The ATLAS detector (cont'd)

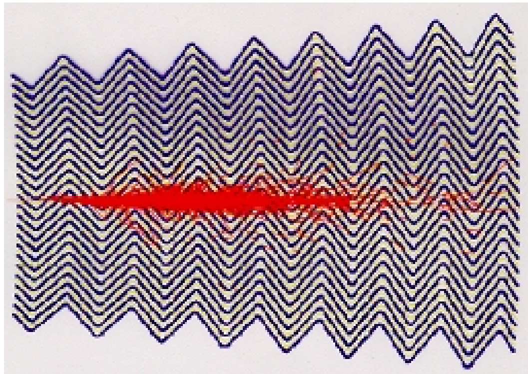
Calorimeters







particles →

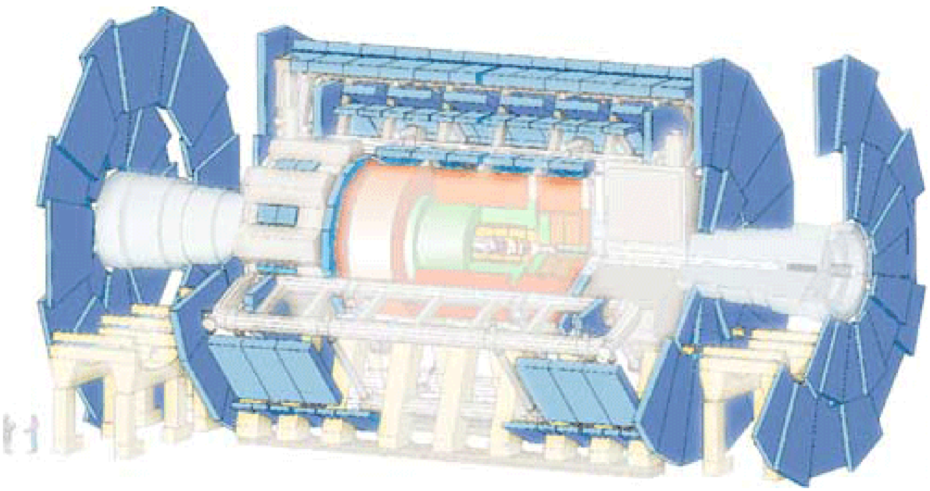


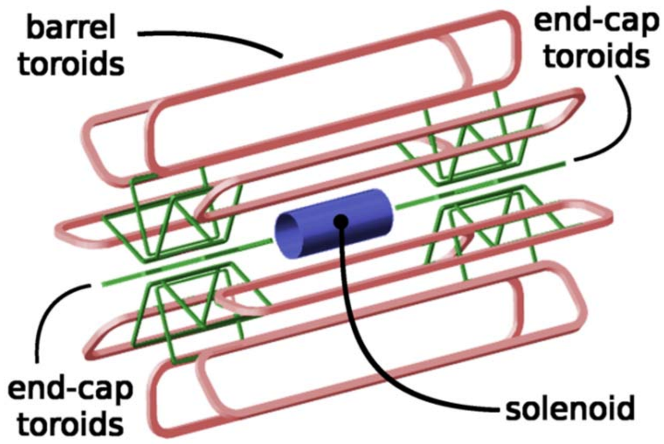
- EM calorimeter (Liq. Ar+Pb)
- Had calorimeter (Fe+scintillator, Liq.Ar+Cu)

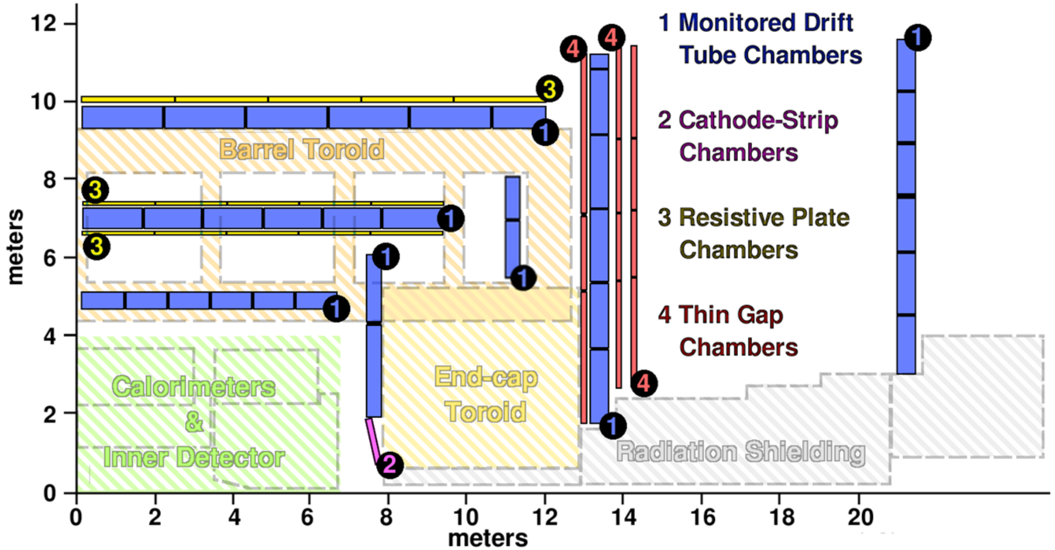
→ Gap-less structure allows good object measurements for jets/electrons and missing transverse energy (E_T^{miss})

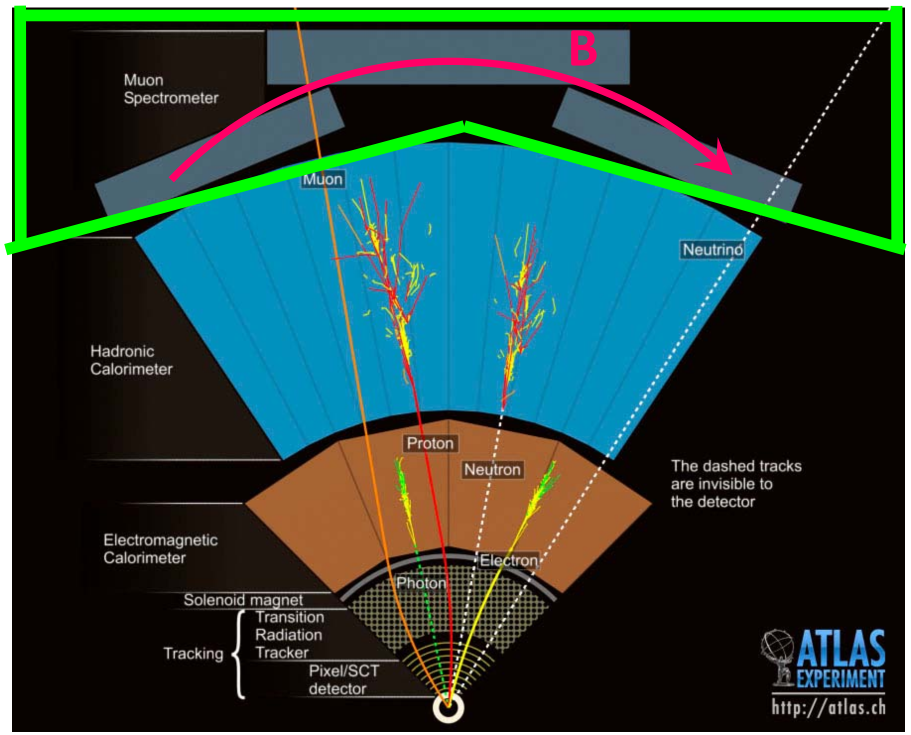
The ATLAS detector (cont'd)

Muon spectrometers and Toroid magnet





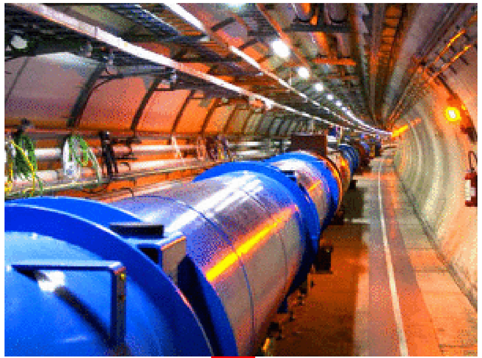




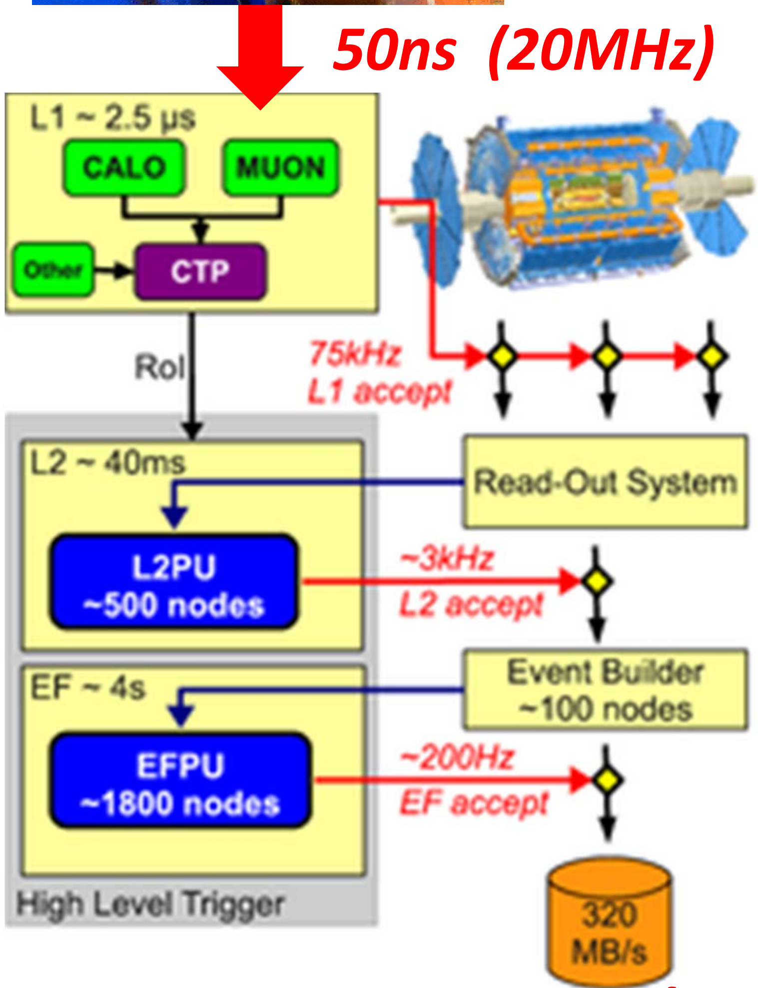
- Consists of fast trigger chambers and position sensitive chambers
- Superconducting coils of toroid magnets

  → **Both independent/combined with ID measurement is possible for muon**

The trigger system

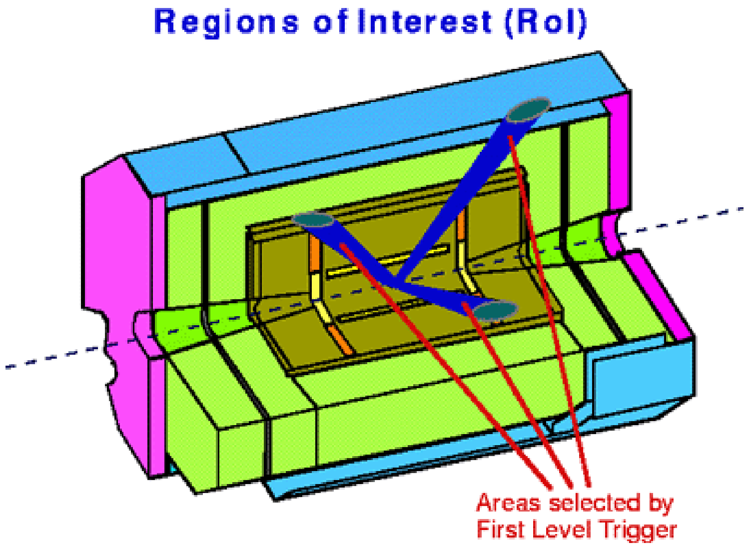


50ns (20MHz)



~1.5 MB/event

- L1: hardware based
  - use calorimeter and muon detector information
  - define “Regions of Interest” (coarse granularity)



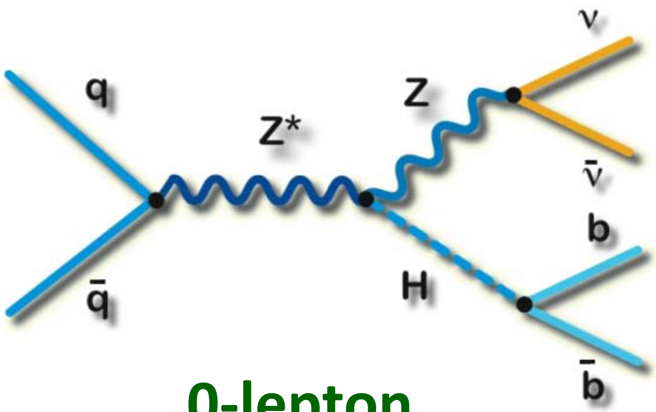
HLT: consists of L2 & EF

- L2: Software based (Special fast algorithms)
  - use full detector granularity inside RoI
  - including tracker information
- EF: Software based (Offline algorithms)
  - use full detector granularity

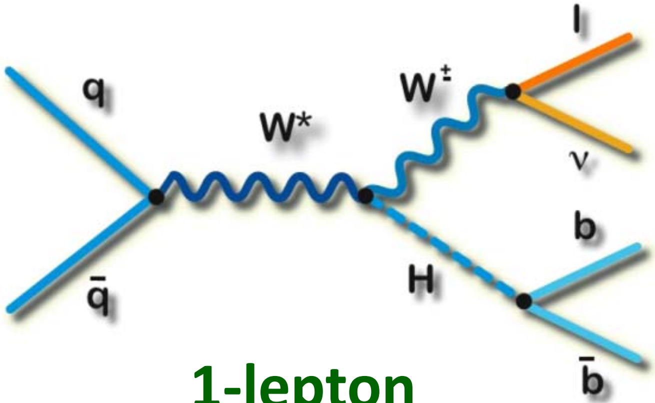
Contents

- Introduction
- Analysis overview
- Result of a search for the $H \rightarrow bb$
- Summary & Prospects for the upcoming high-luminosity LHC

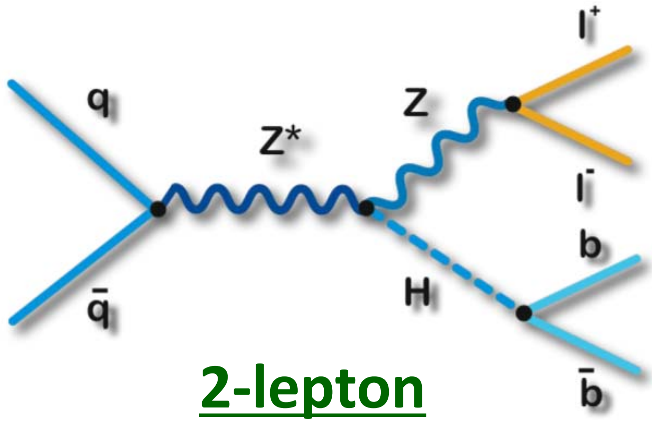
Signal categorization



0-lepton



1-lepton



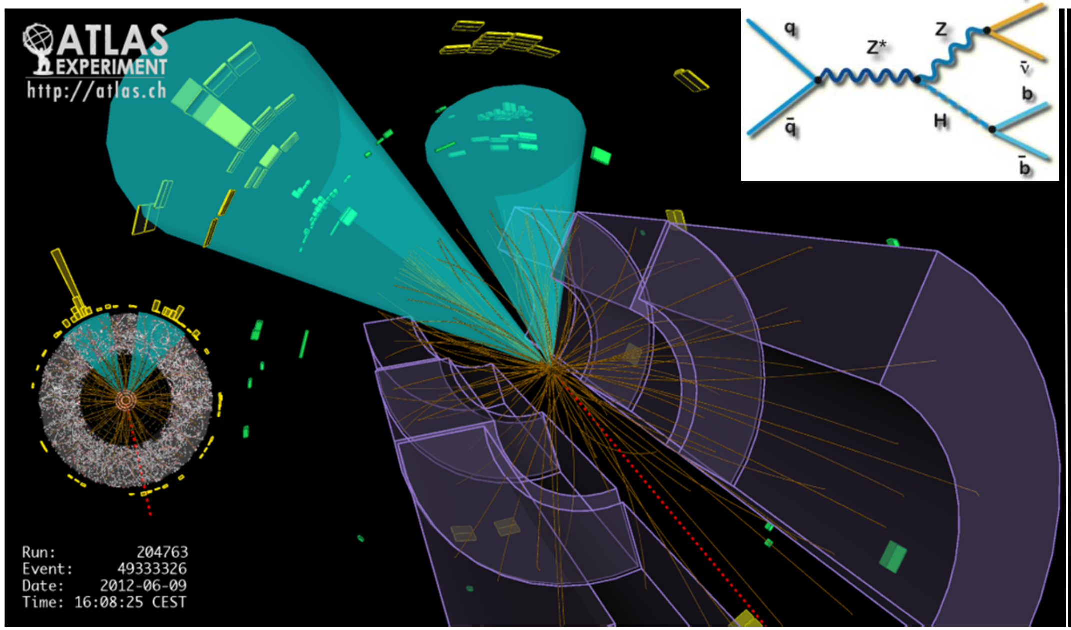
2-lepton

Decay	$Z \to \nu\nu$	$W \to e\nu / W \to \mu\nu$	$Z \to ee / Z \to \mu\mu$
Branching fraction	20%	11% / 11%	3.3% / 3.3%
Number of leptons	0	1	2
Signal yield ($20fb^{-1}$, 8 TeV) **m_H = 125 GeV**	~960	~900 / ~900	~160 / ~160

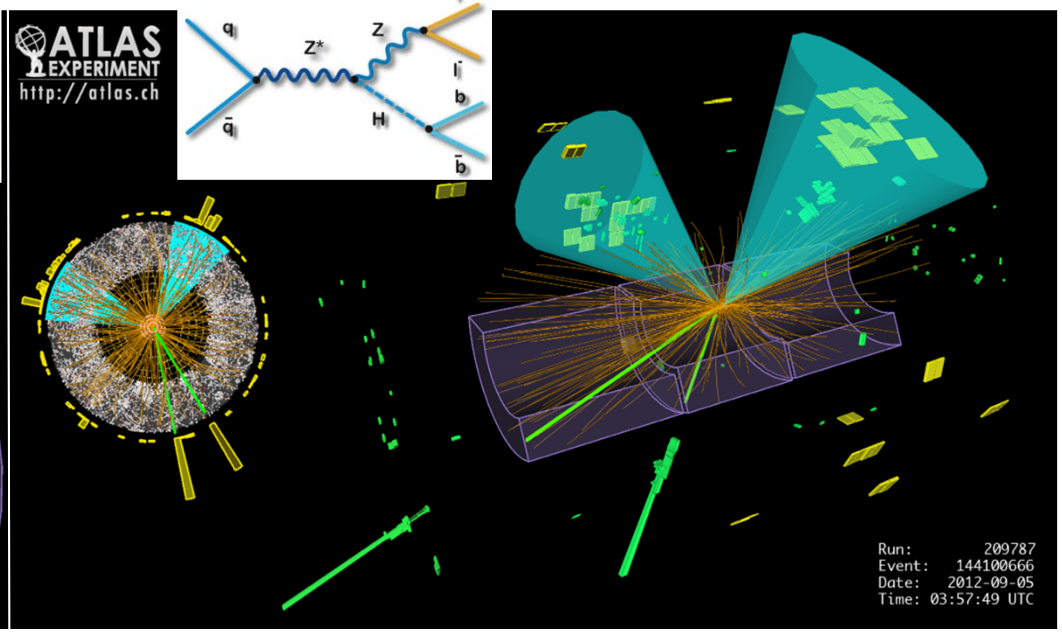
Before any selection applied

How does the event look like?

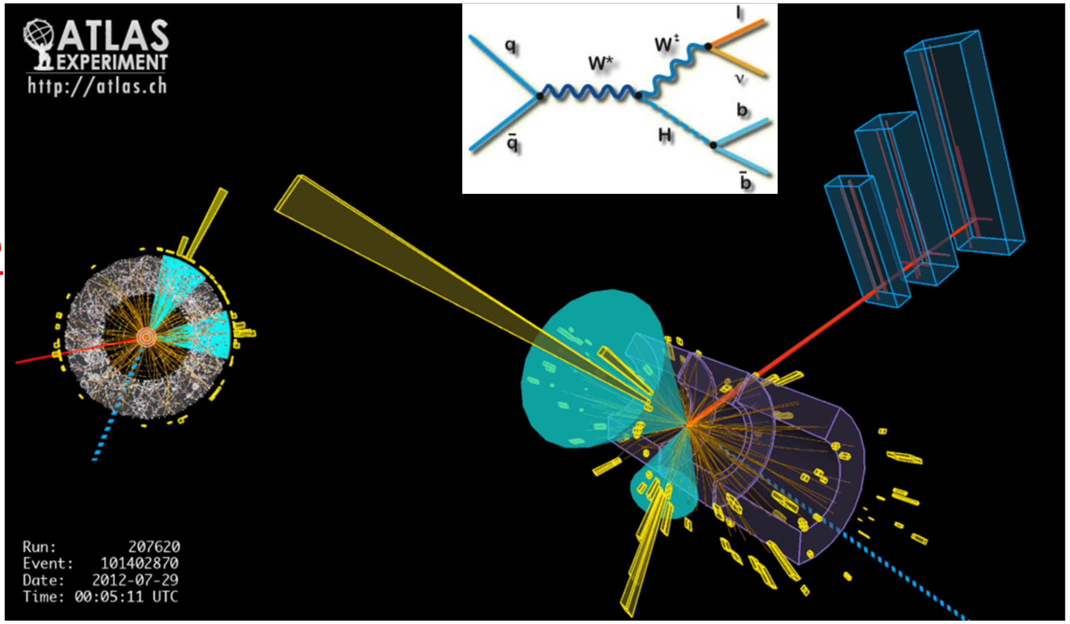
0-lepton candidate



2-lepton candidate



1-lepton candidate



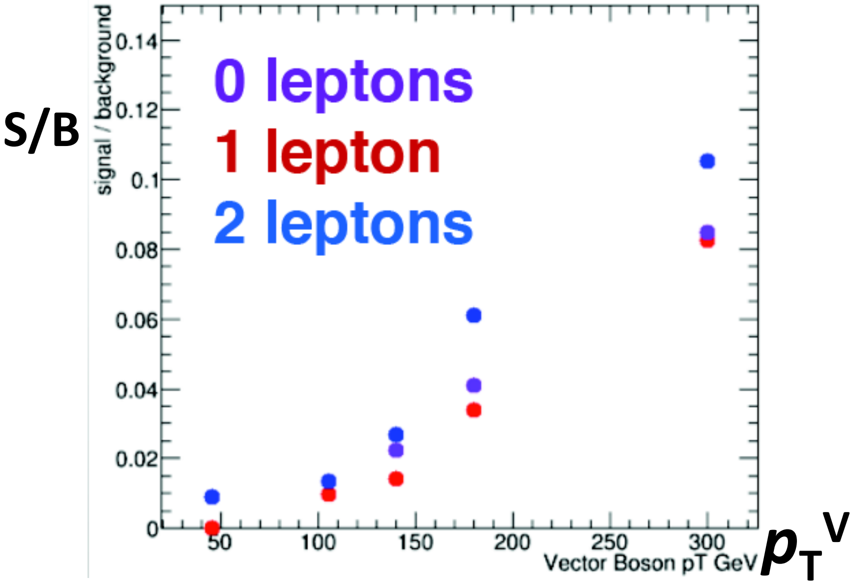
- leptons *(e, μ)*
- jets from *b*-quark
- missing energy *(ν)*

Signal binning

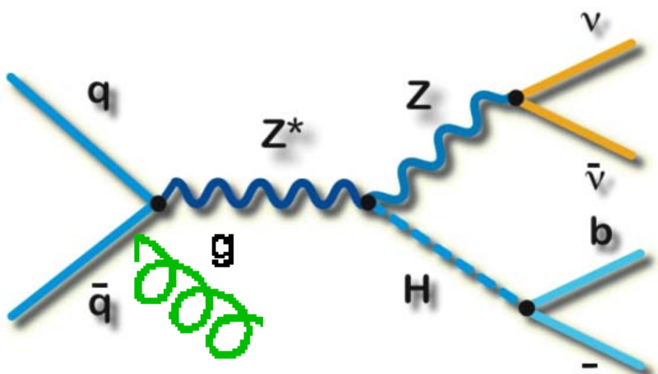
Binning of the signal regions

Separate signal regions based on S/B : maximize analysis sensitivity

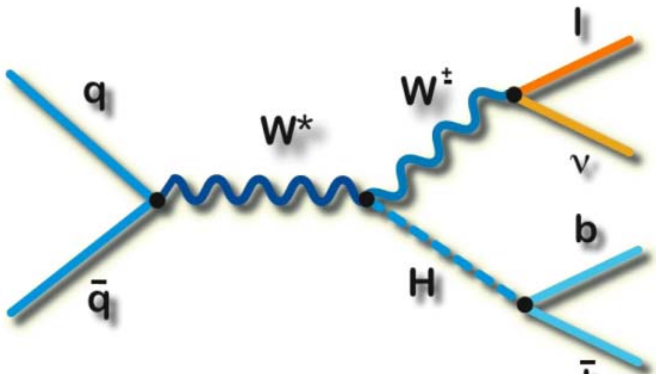
The idea is to split the analysis in bins of jet multiplicity and vector boson p_T



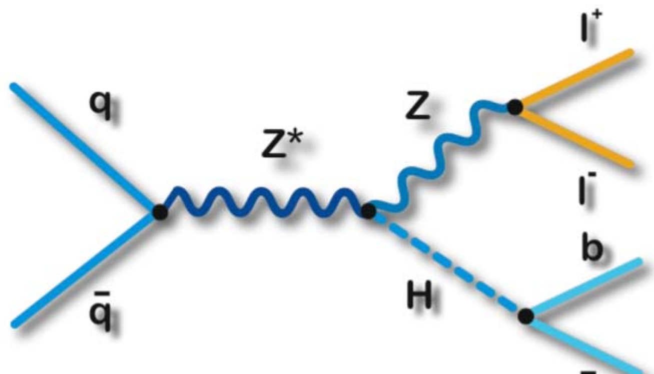
Number of jets	2 jets	3 jets
0-lepton S/B	0.03	0.016
1-lepton S/B	0.009	0.003
2-lepton S/B	0.01	0.009



0-lepton



1-lepton



2-lepton

Event Selections

Two types of analysis

- **Dijet-mass analysis**: the mass of the dijet system of *b*-jets (m_{bb}) as the final discriminating variable **(Cross-check of MVA result)**
- **Multivariate analysis (MVA):** Boosted decision tree (**BDT**) combines various kinematic variables in addition to the m_{bb} **(Nominal result)**

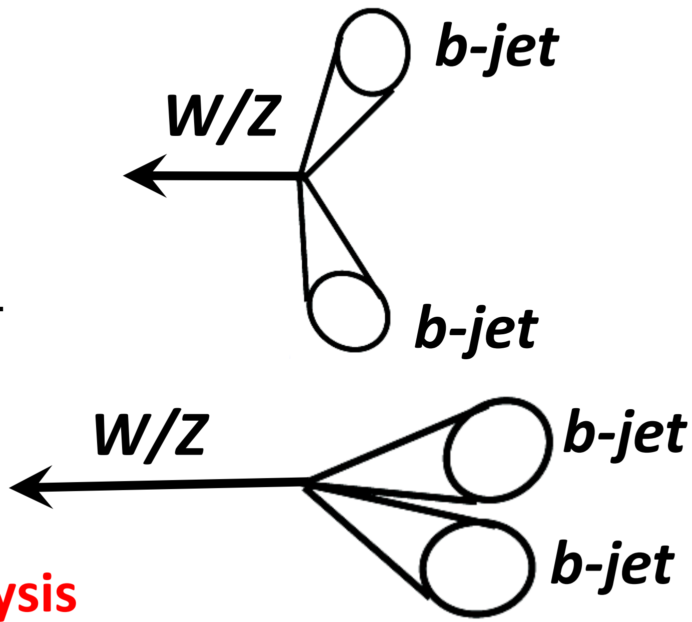
⇨ **Basically focus on MVA analysis in this seminar,**
except new features compared to the previous ATLAS analysis

Common selection

- ***ΔR*** cut values are optimized for the angular separation between two jets, as a function of W/Z p_T

	MVA	
p_T^V (GeV)	0 – 120 (*)	> 120
ΔR(jet1, jet2)	> 0.7	--

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$



(*)0-lepton selection is only 100 – 120 GeV with m_{bb} analysis

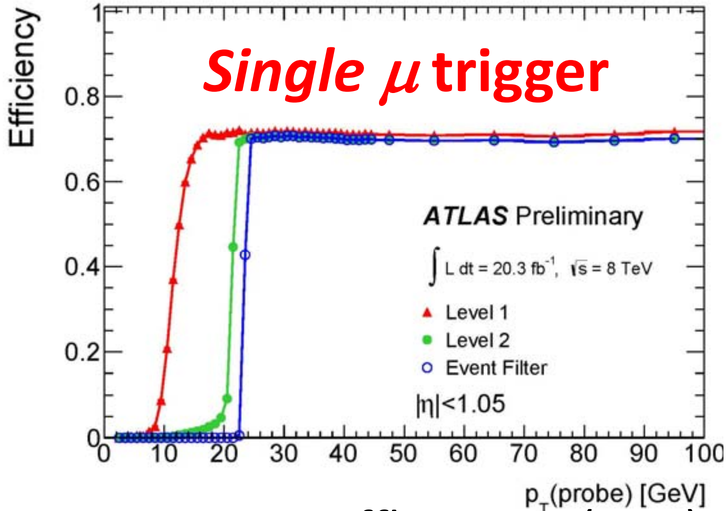
Event Selections (cont'd)

1-lepton selection

H_T and E_T^{miss} cuts to suppress **tt** and **QCD multjet** background

	MVA	
p_T^W (GeV)	0 – 120	> 120
trigger	primary: single e/μ	secondary: E_T^{miss}
m_T^W (GeV)	-- (*)	-- (*)
H_T (GeV)	> 180	--
E_T^{miss} (GeV)	--	> 20

MVA analysis uses m_T^W as an input variable

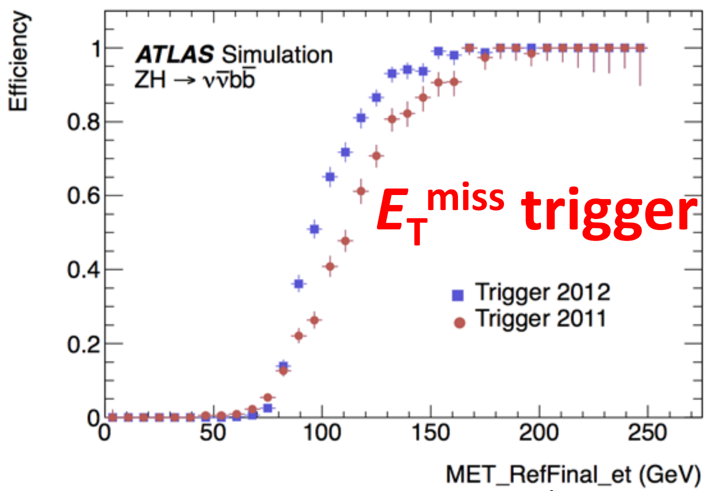


Offline μ p_T (GeV)

2-lepton selection

m_{ll} cut to select on-shell Z boson candidates

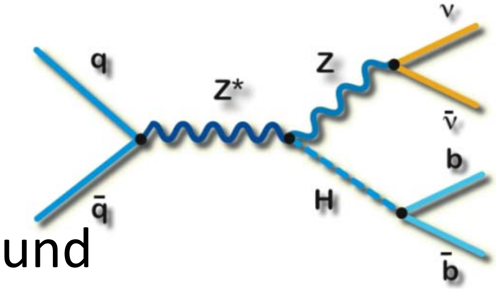
	MVA	
p_T^W (GeV)	0 – 120	> 120
trigger	single e/μ or di-lepton ($ee/\mu\mu$)	
m_{ll} (= m_Z) (GeV)	71—121	71—121



Offline E_T^{miss} (GeV)

New strategy to gain signal → E_T^{miss} trigger

Event Selections (cont'd)



0-lepton selection

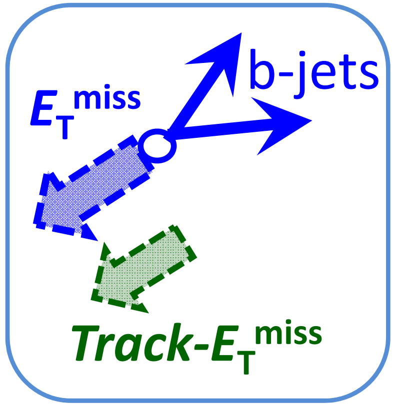
- Several angular cuts applied to suppress **QCD multijet** background

	m_{bb}	MVA
p_T^V (= E_T^{miss}) (GeV)	100 — 120	> 120
trigger	E_T^{miss} trigger	E_T^{miss} trigger
ΔR(jet1, jet2)	0.7 — 3.0	> 0.7 (for p_T^V < 200)
track-E_T^{miss} (GeV)	> 30	> 30
$\Delta\phi$ ($\boldsymbol{E}_T^{miss}$, $\boldsymbol{p}_T^{miss}$)	< π/2	< π/2
min[$\Delta\phi$($\boldsymbol{E}_T^{miss}$, jet)]	> 2.2	> 2.8
Σ(jets p_T) (GeV)	> 120 (2-jets) N/A (3-jets)	> 120 (2-jets) > 150 (3-jets)
Further QCD MJ cuts	applied	--

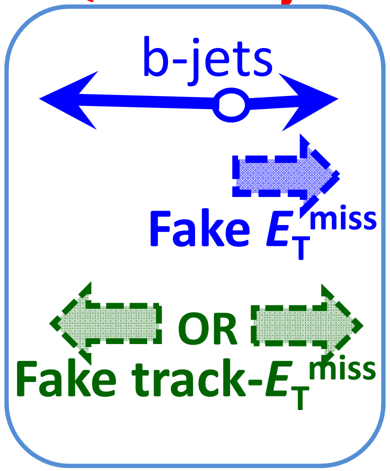
New signal category for the latest analysis

→ Former analysis only for E_T^{miss} > 120 GeV

ZH→ννbb

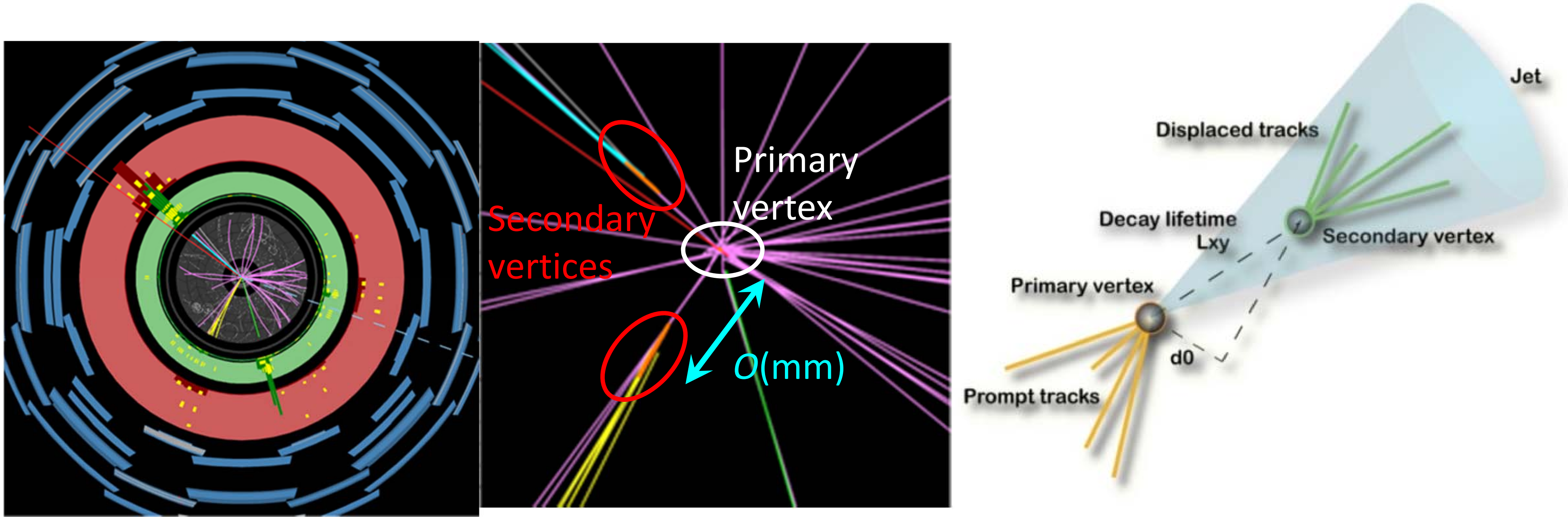


QCD multijet



b-jet identification

- Separate b-quark jet (b-jet) from other flavor jets (light-jet, charm-jet)
- b-quark jet identification (b-tagging) performance is crucial for H→bb analysis



B-hadrons (B^0, B^+, etc…) travels a few mm before it decays with unique topology

→ Displaced vertex

→ Large impact parameter (d_0)

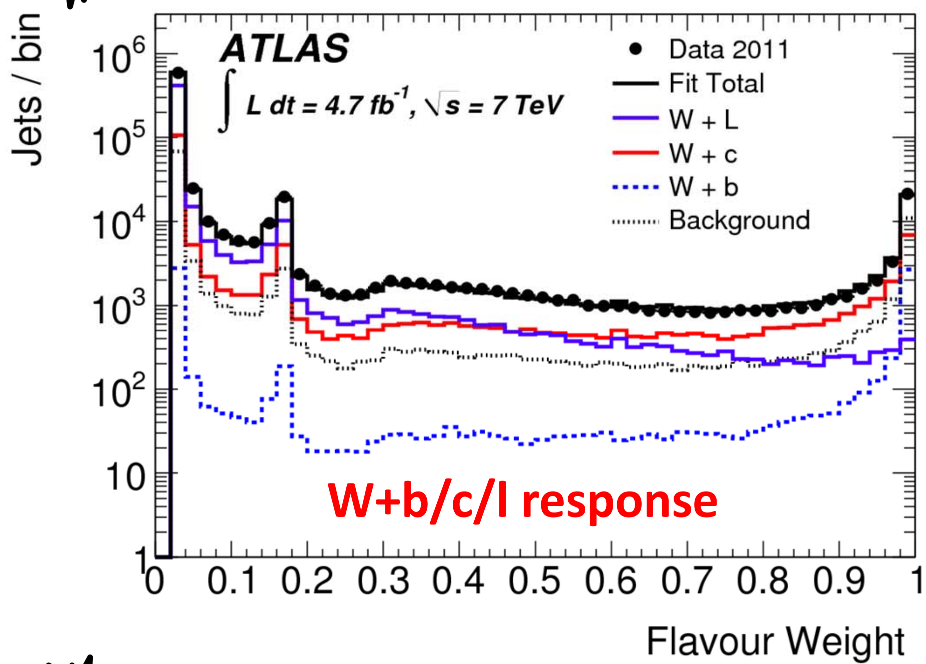
→ Cascade structure (b→c→x primary→secondary→tertiary)

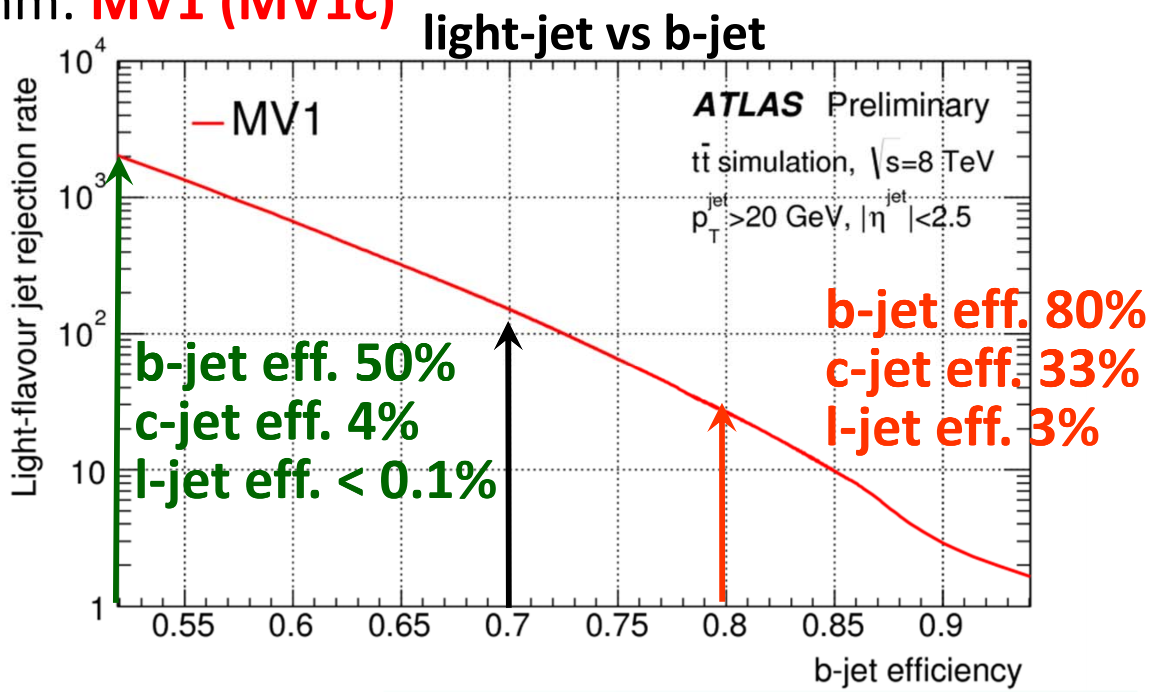
→ soft e/μ from semi-leptonic decay of B-hadrons (~40%)

MVA to combine information all together

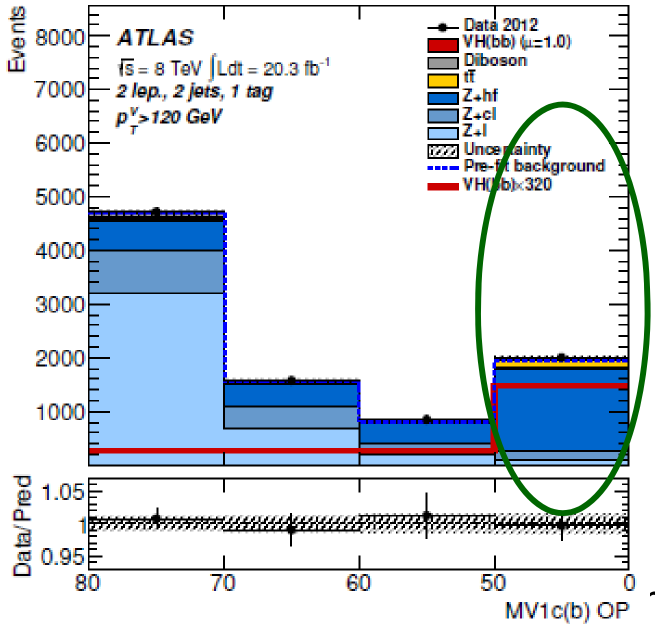
b-jet identification

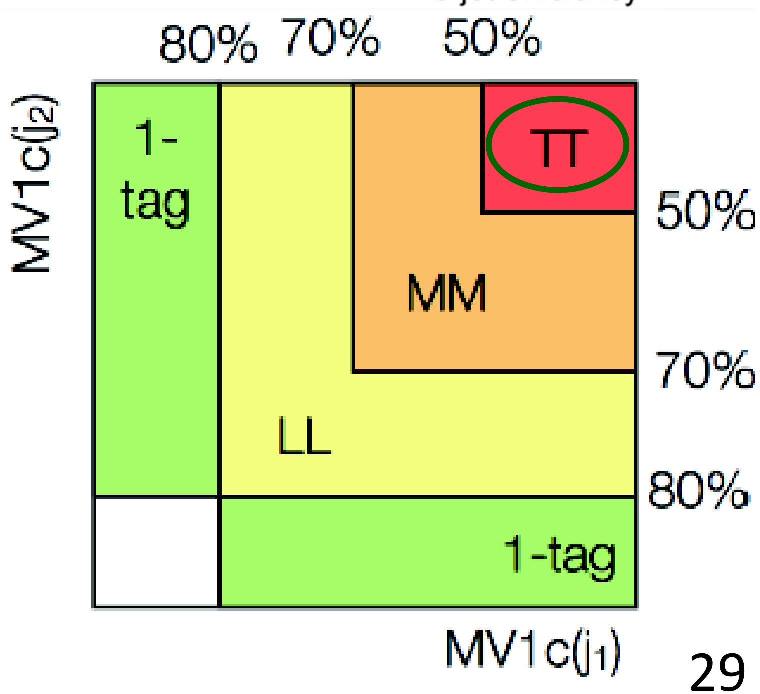
- an artificial neural network algorithm: **MV1 (MV1c)**





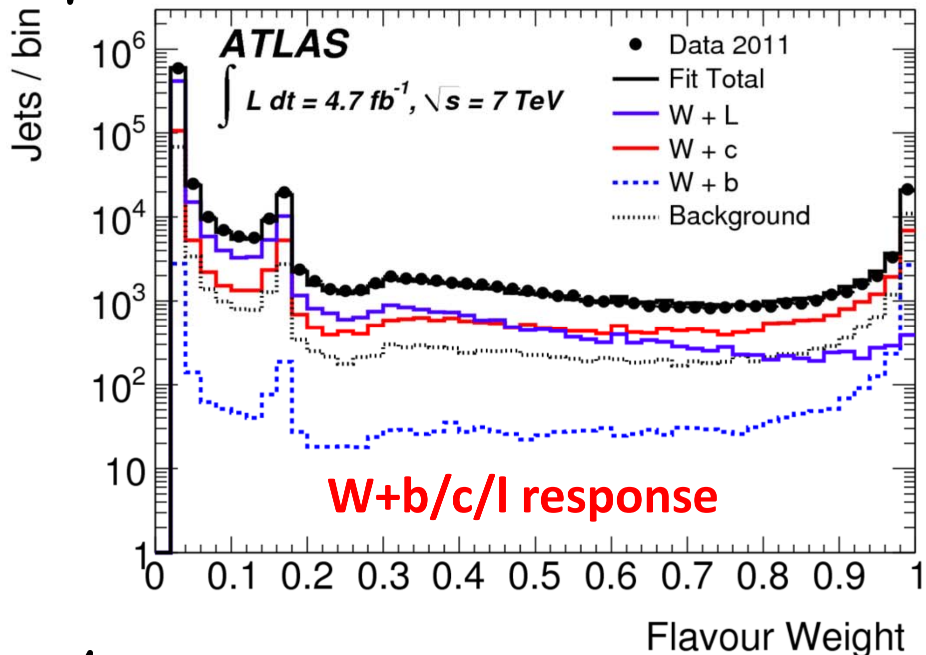
- Separate signal regions based on MV1c

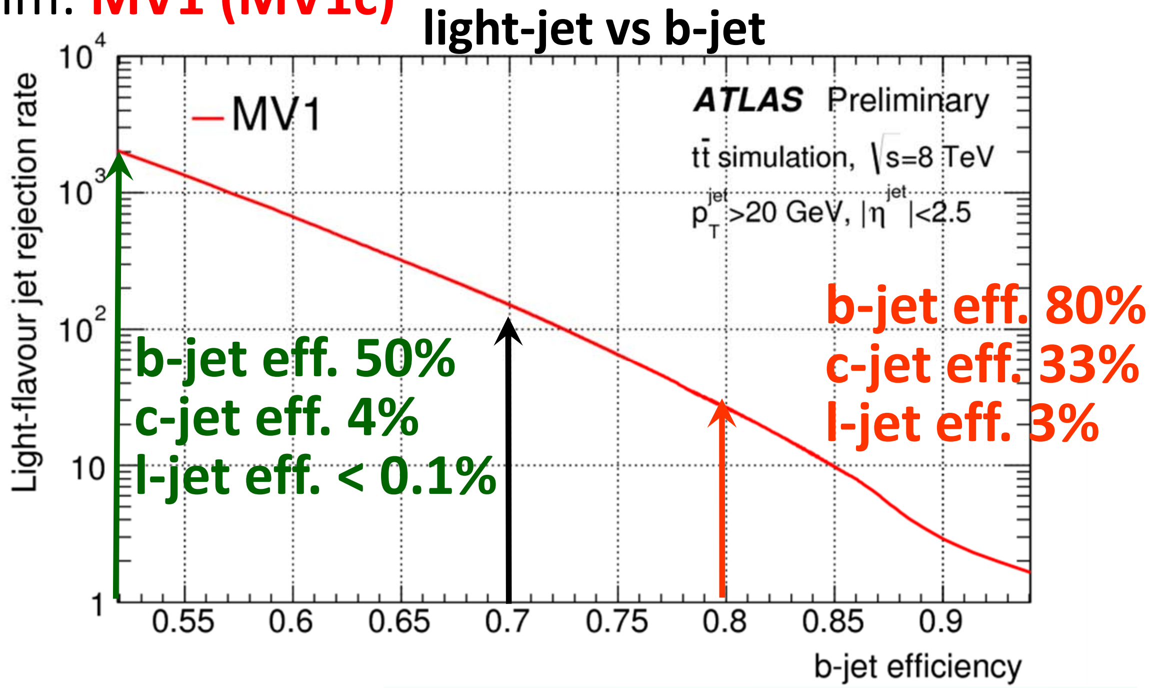




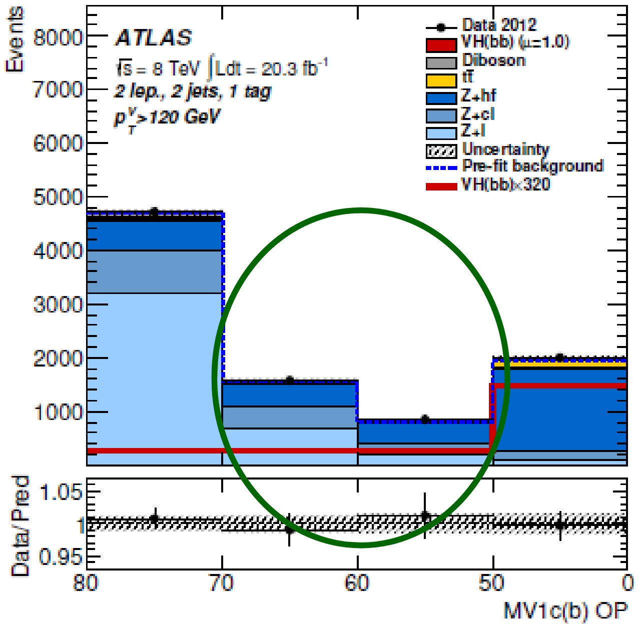
b-jet identification

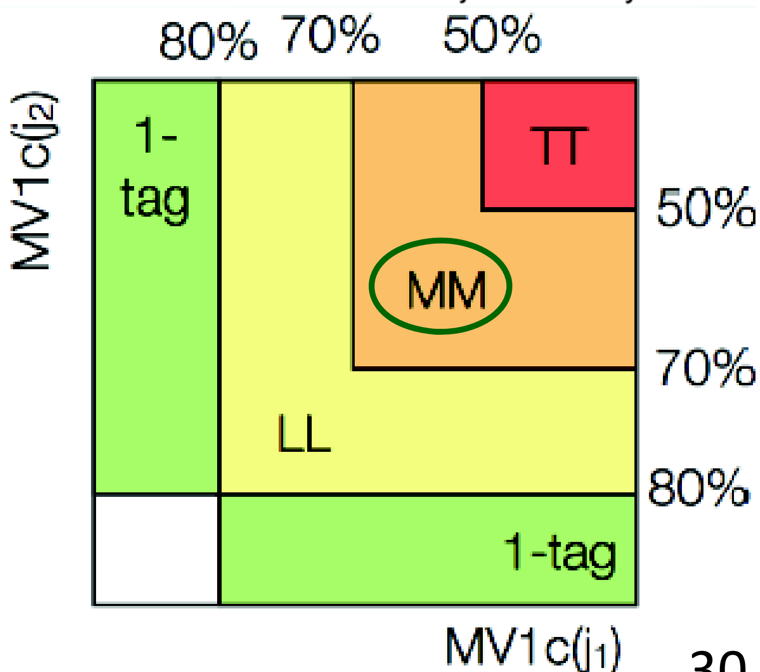
- an artificial neural network algorithm: **MV1 (MV1c)**





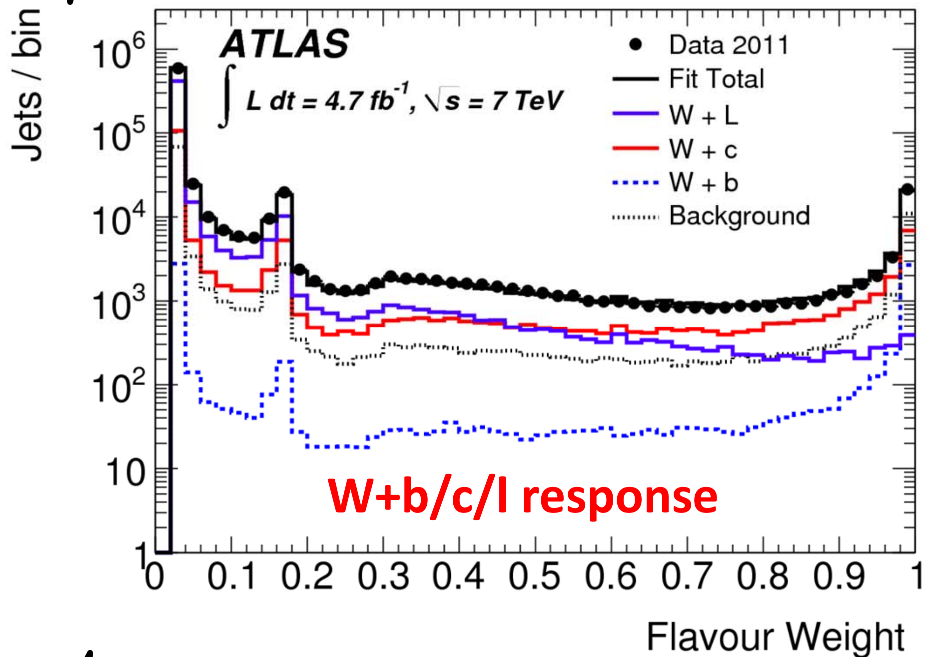
- Separate signal regions based on MV1c

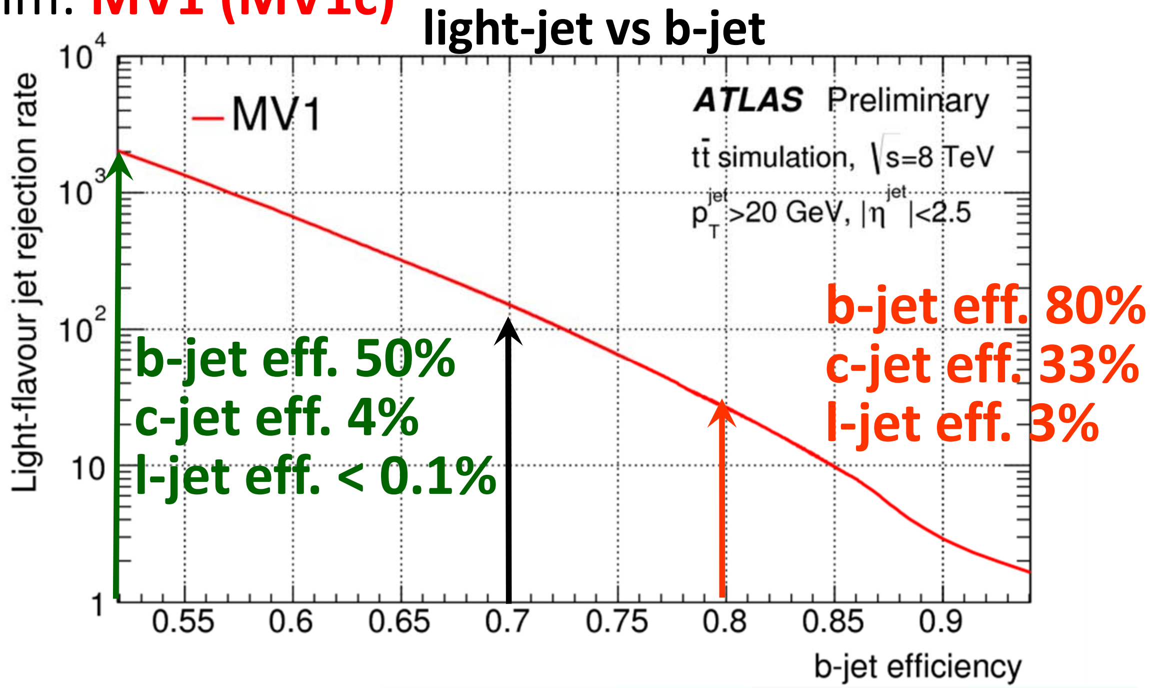




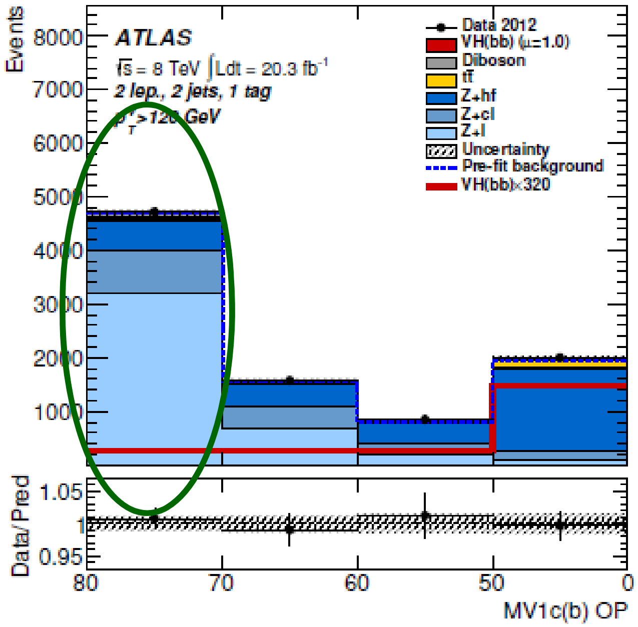
b-jet identification

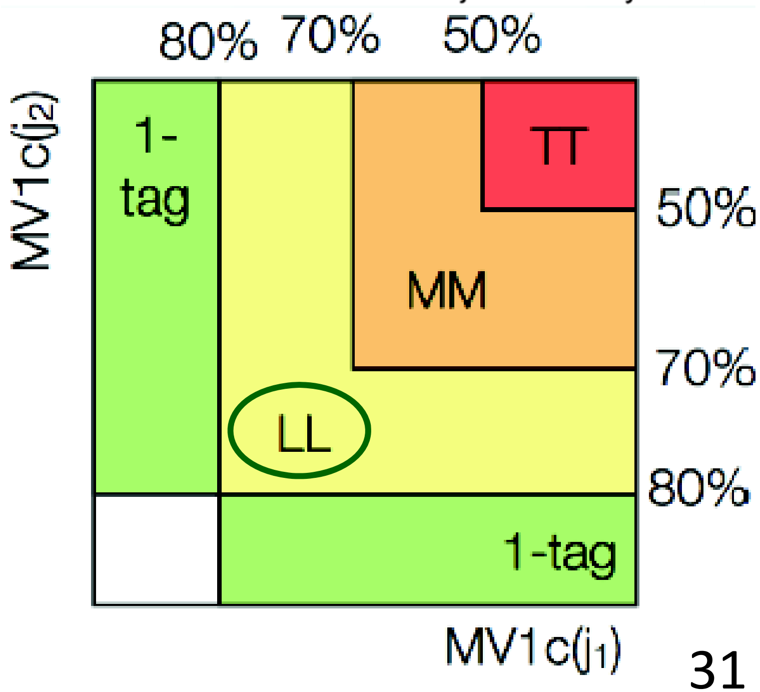
- an artificial neural network algorithm: **MV1 (MV1c)**





- Separate signal regions based on MV1c

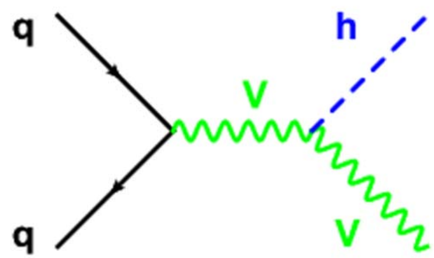


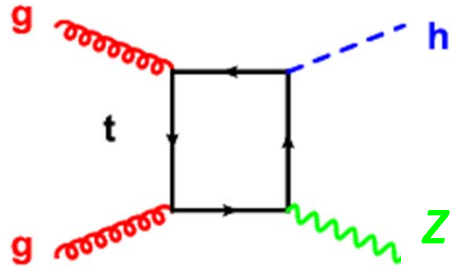


Modeling overview

Shape modeling with MC simulation

Process	Generator
Signal$^{(*)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma* \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(*)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8



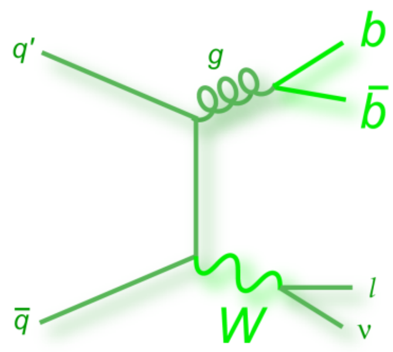


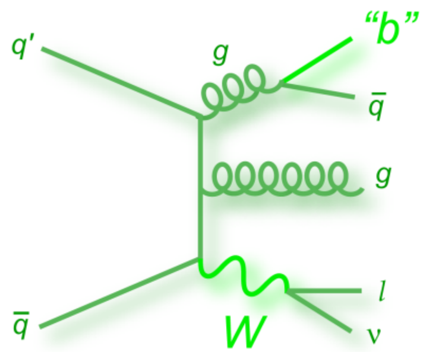
QCD multijets (fake lepton, fake MET) from data

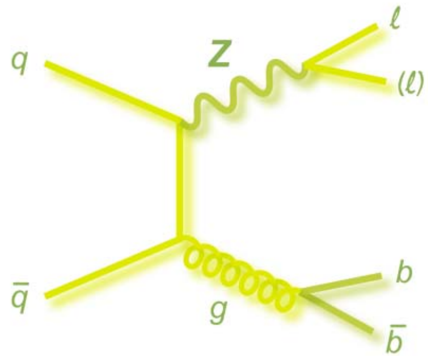
Modeling overview

Shape modeling with MC simulation

Process	Generator
Signal$^{(*)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma* \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(*)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8





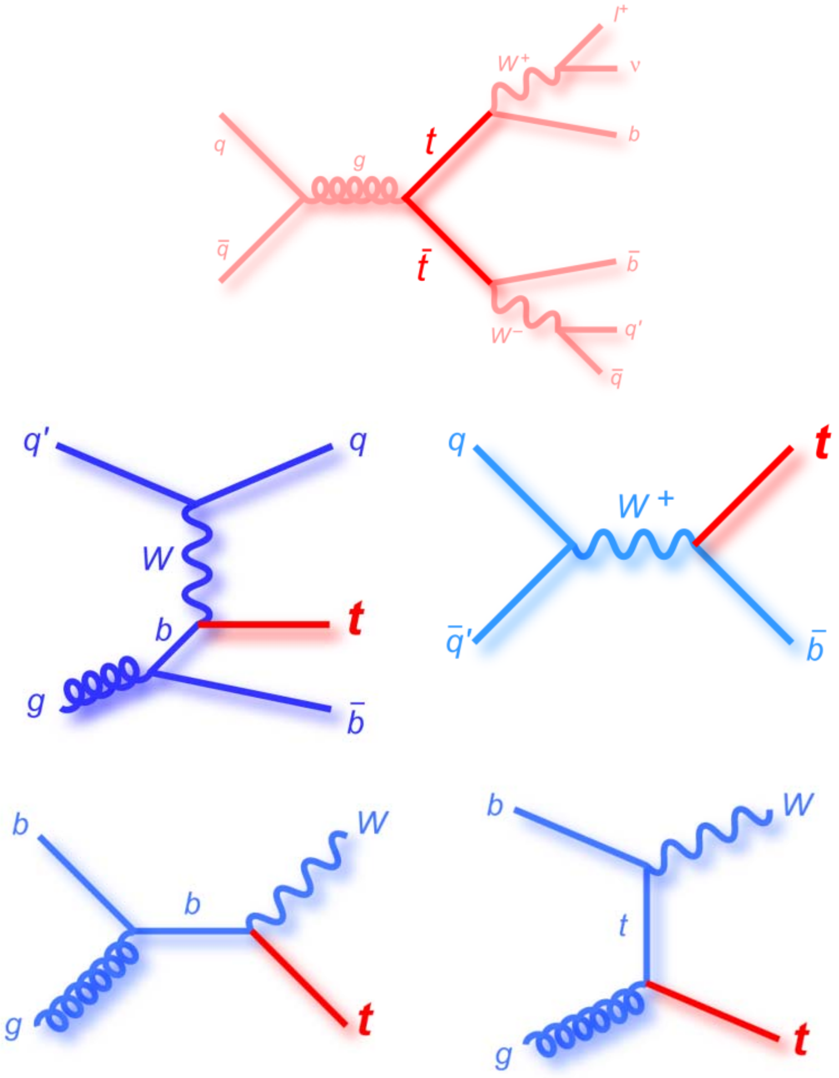


QCD multijets (fake lepton, fake MET) from data

Modeling overview

Shape modeling with MC simulation

Process	Generator
Signal$^{(\star)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma* \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(\star)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8

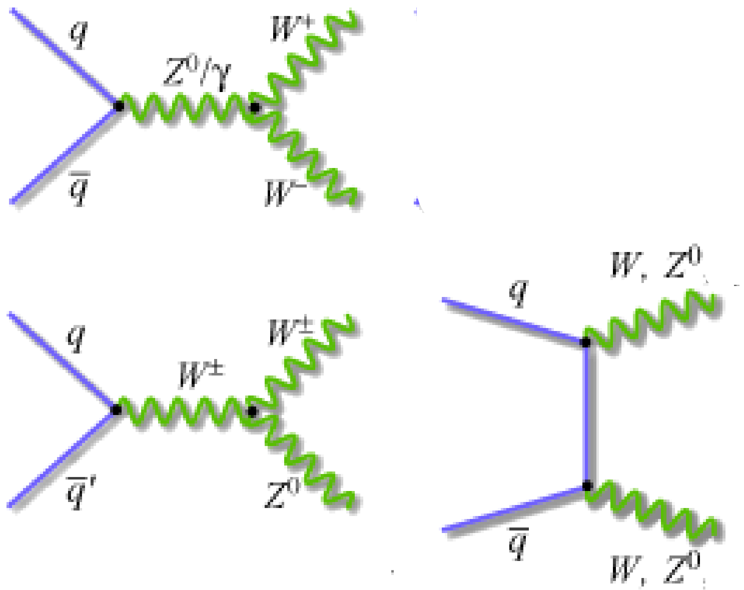


QCD multijets (fake lepton, fake MET) from data

Modeling overview

Shape modeling with MC simulation

Process	Generator
Signal$^{(\star)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma * \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(\star)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8



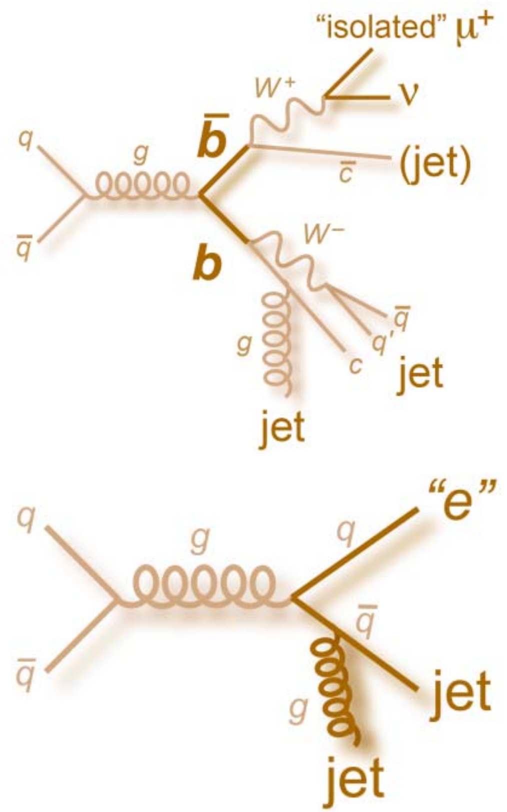
QCD multijets (fake lepton, fake MET) from data

Modeling overview

Shape modeling with MC simulation

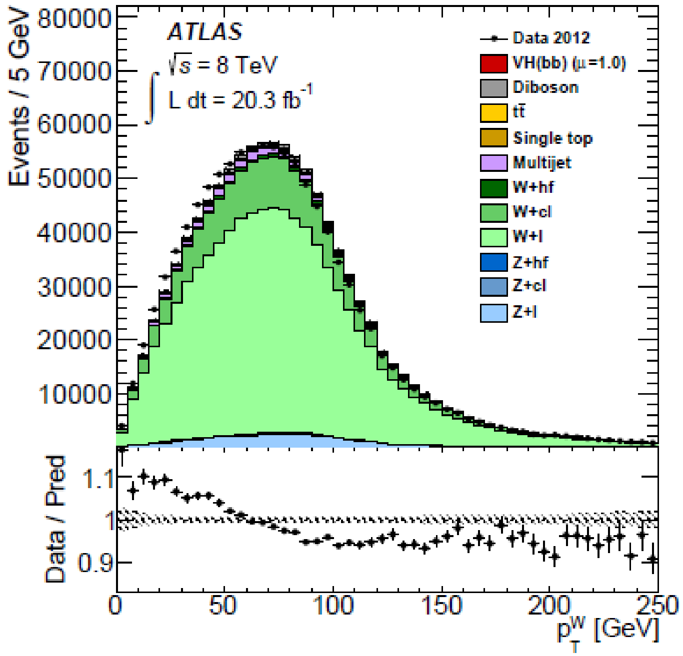
Process	Generator
Signal$^{(*)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma* \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(*)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8

QCD multijets (fake lepton, fake MET) from data

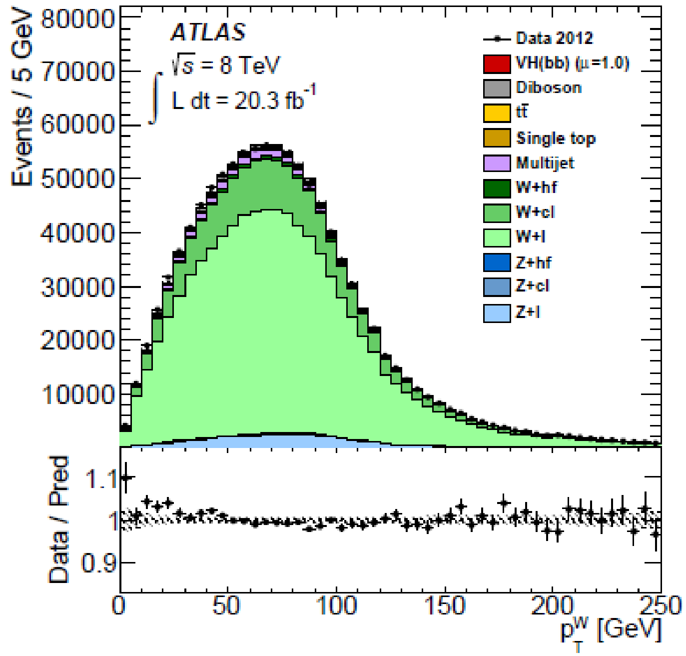


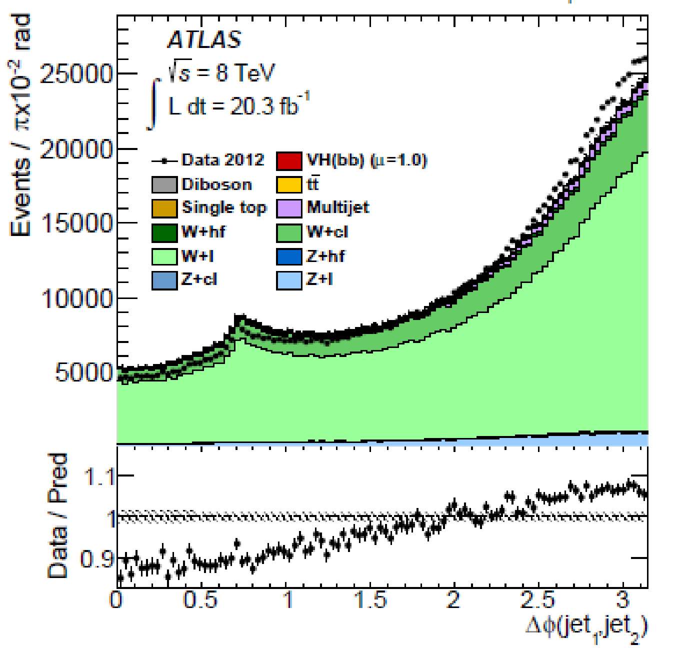
Background modeling

- Modeling of p_T^V is crucial: **sub-divide signal region based on p_T^V**

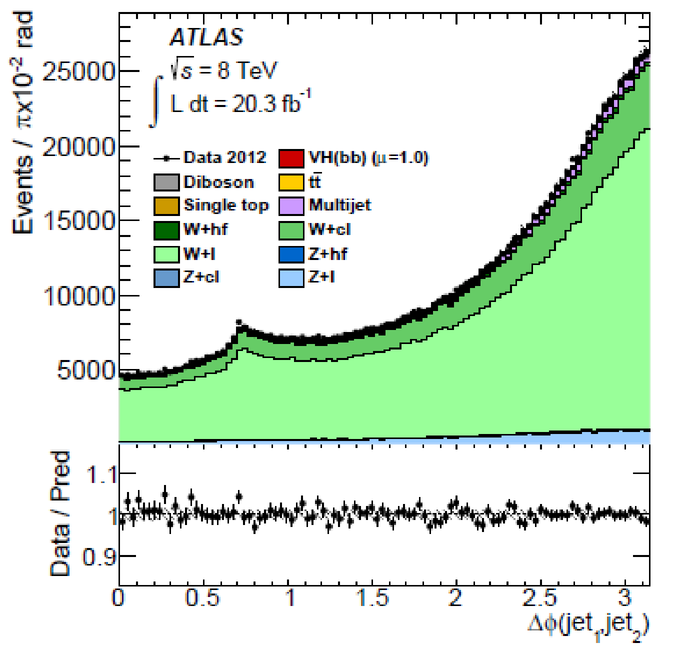


Δϕ correction applied



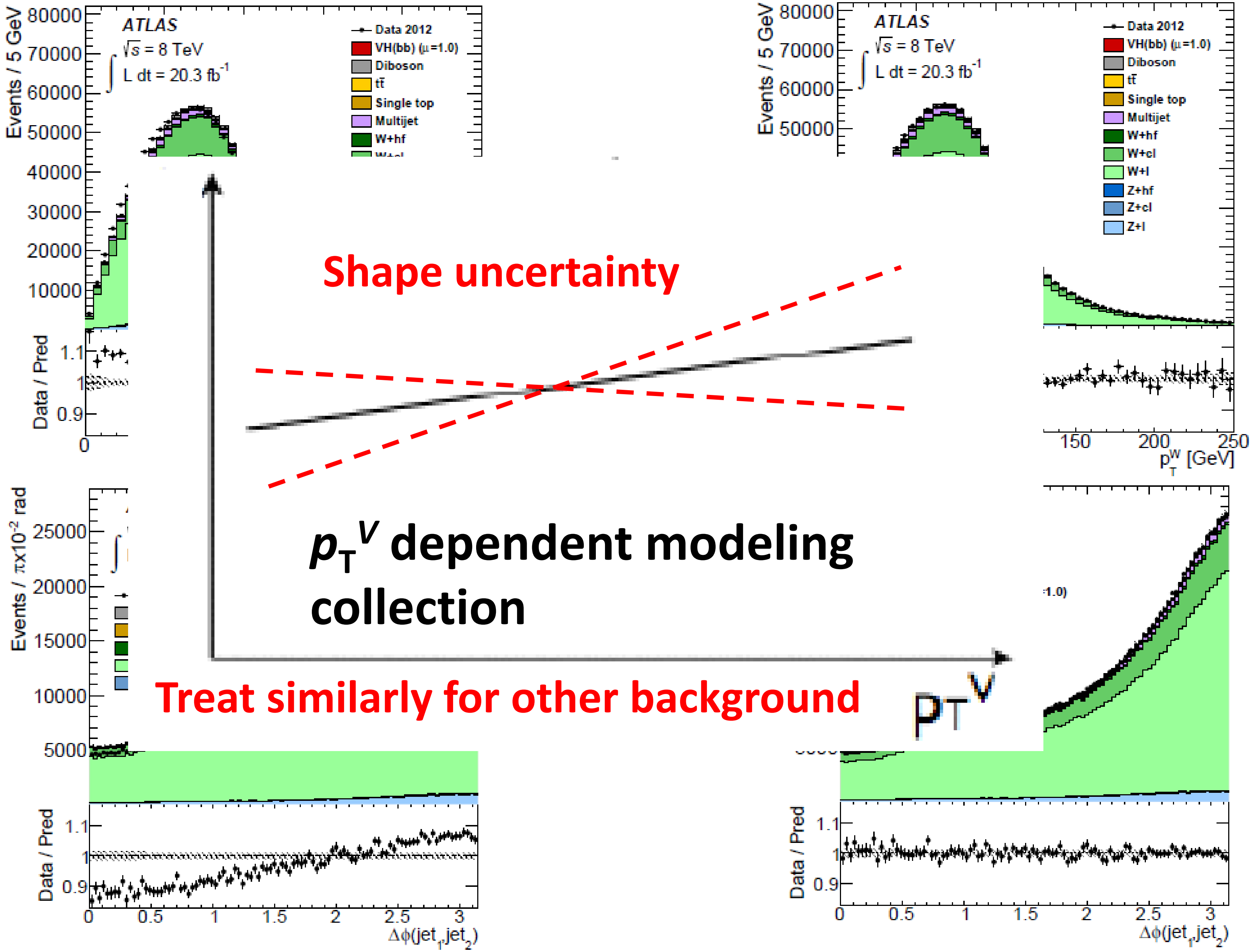


Δϕ correction applied



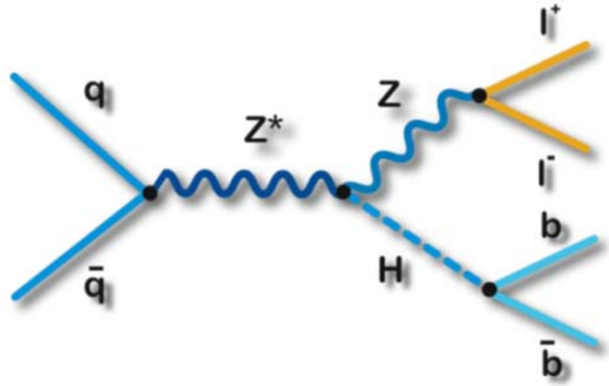
Background modeling

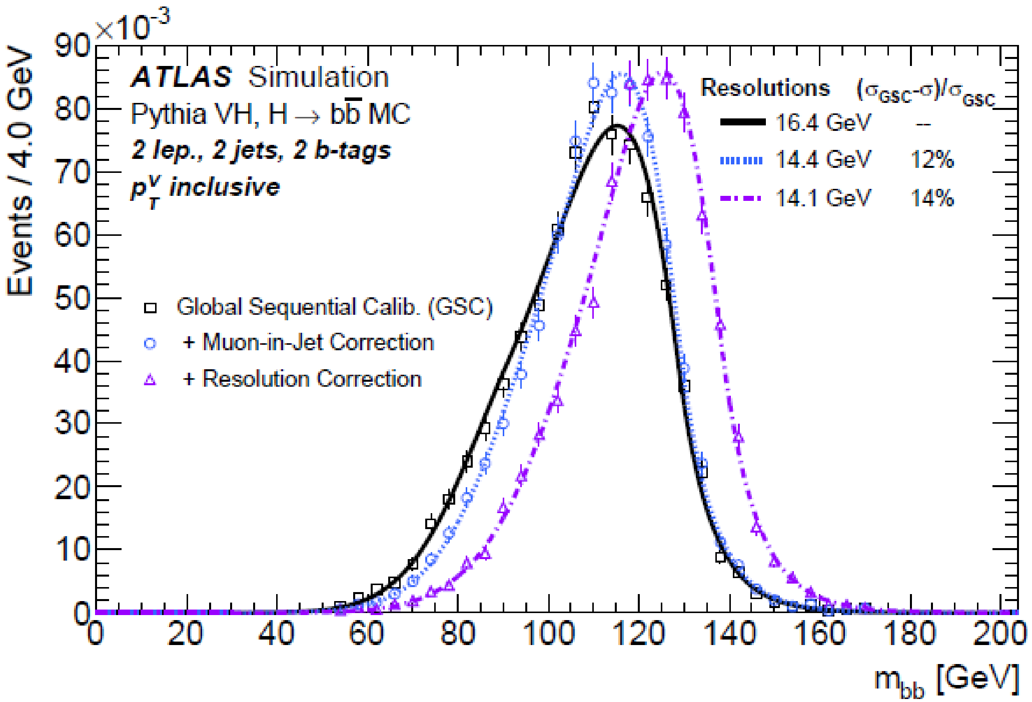
- Modeling of p_T^V is crucial: **sub-divide signal region based on p_T^V**

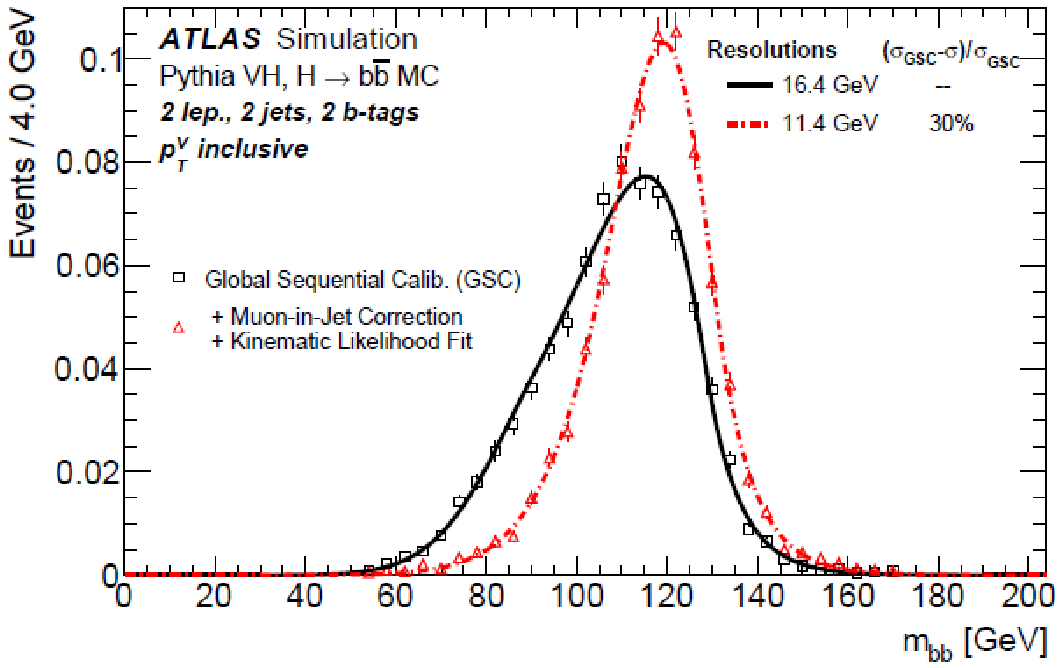


Improve m_{bb} resolution

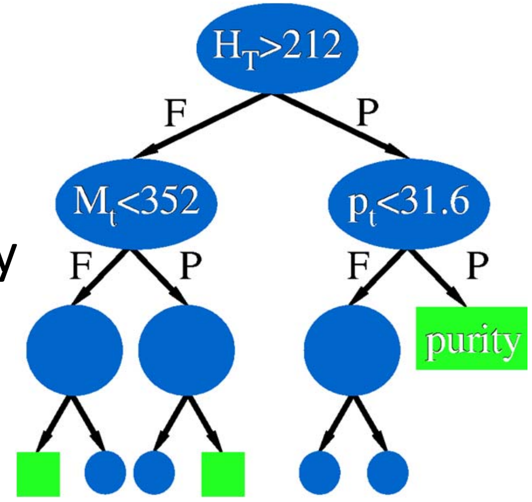
- The most important input for MVA analysis
- Muon-in-jet collection
- Kinematic likelihood fit in 2-lepton channel
  (no intrinsic E_T^{miss} except for b-semileptonic decay)
  → **total resolution improvement ~30%**





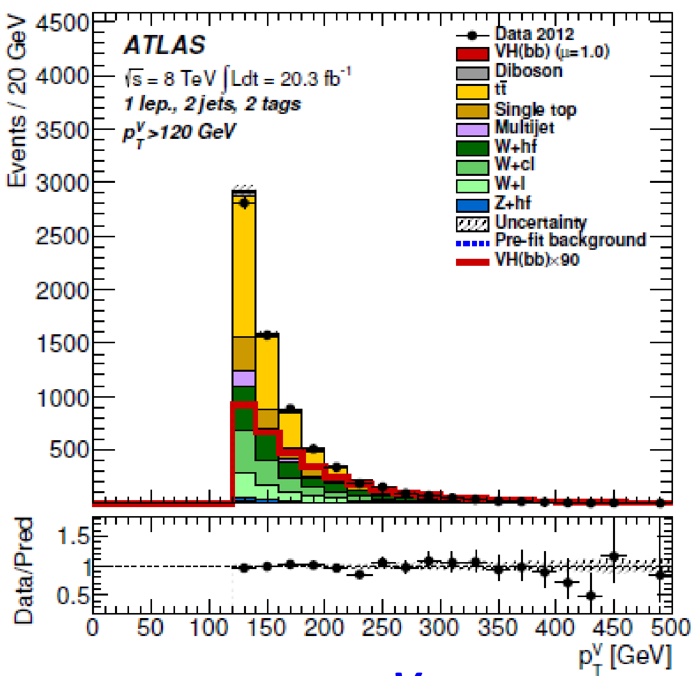


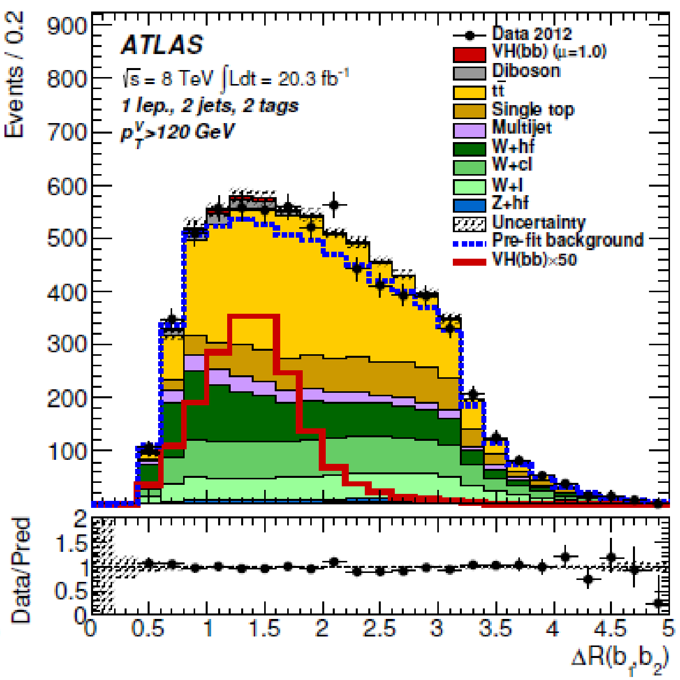
BDT optimization

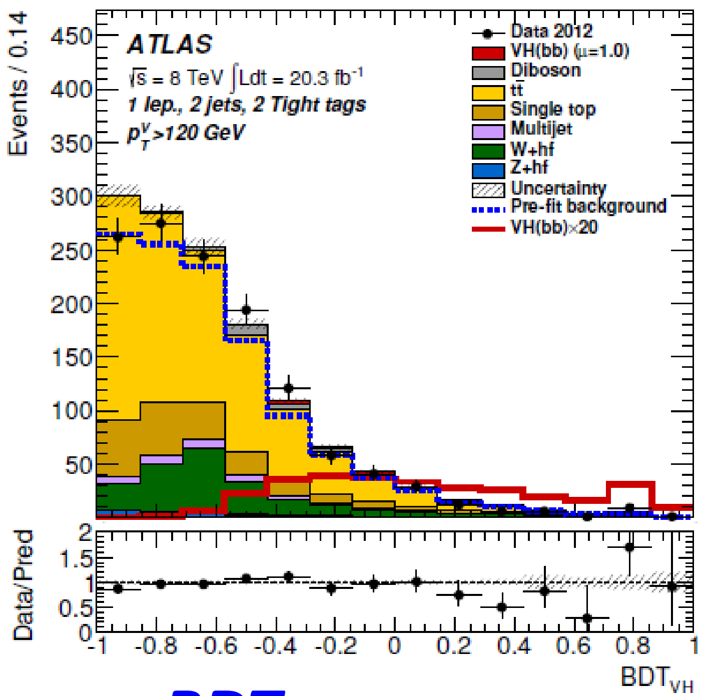


- Input variables are optimized for each signal region separately
  - 0-lepton: 10 (12) variables for 2-jet (3-jet) bin
  - 1-lepton: 11 (13) variables for 2-jet (3-jet) bin
  - 2-lepton: 12 (14) variables for 2-jet (3-jet)bin

Including m_{bb}



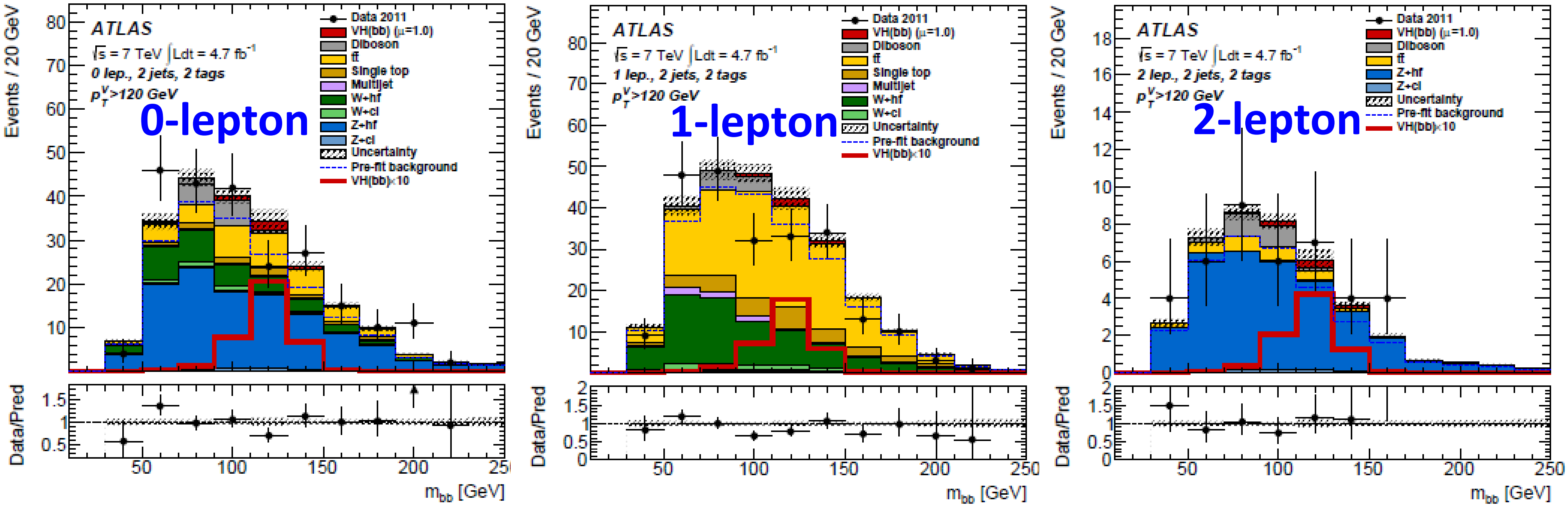


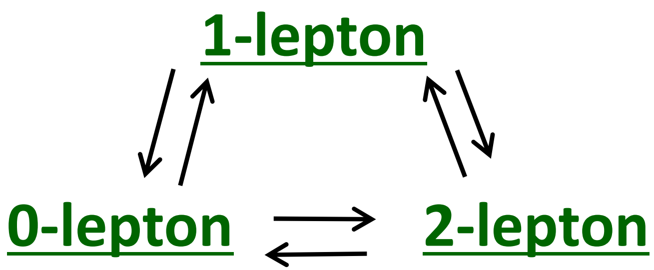


p_T^V $\Delta R(b_1,b_2)$ → **BDT**

Fit model

- Binned maximum likelihood fit performed on the BDT across regions
  → **determine signal yield & background normalization**
- Impact of syst. uncertainties described by nuisance parameters across regions
  → **constrain systematic uncertainties through global fit**



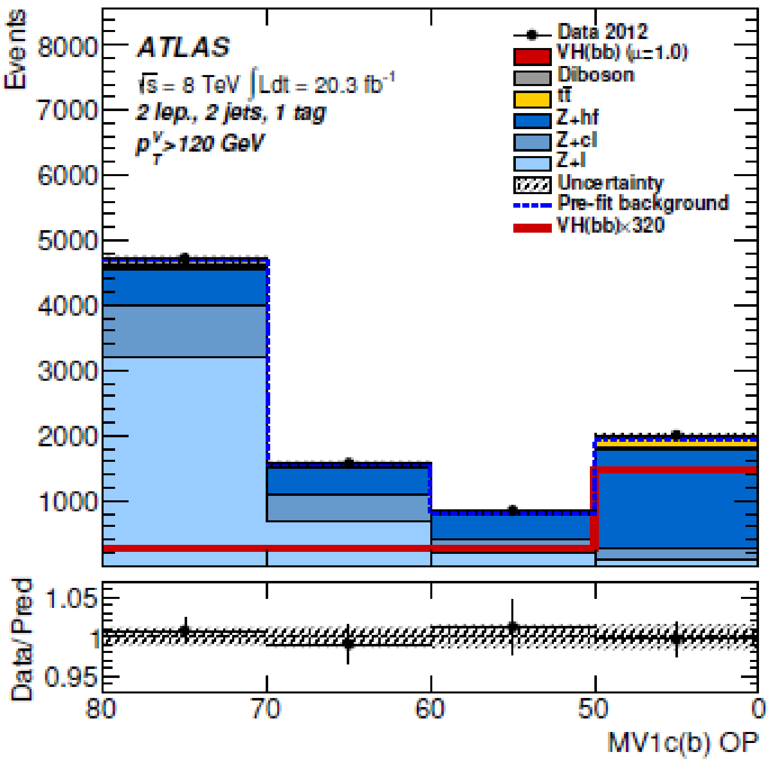


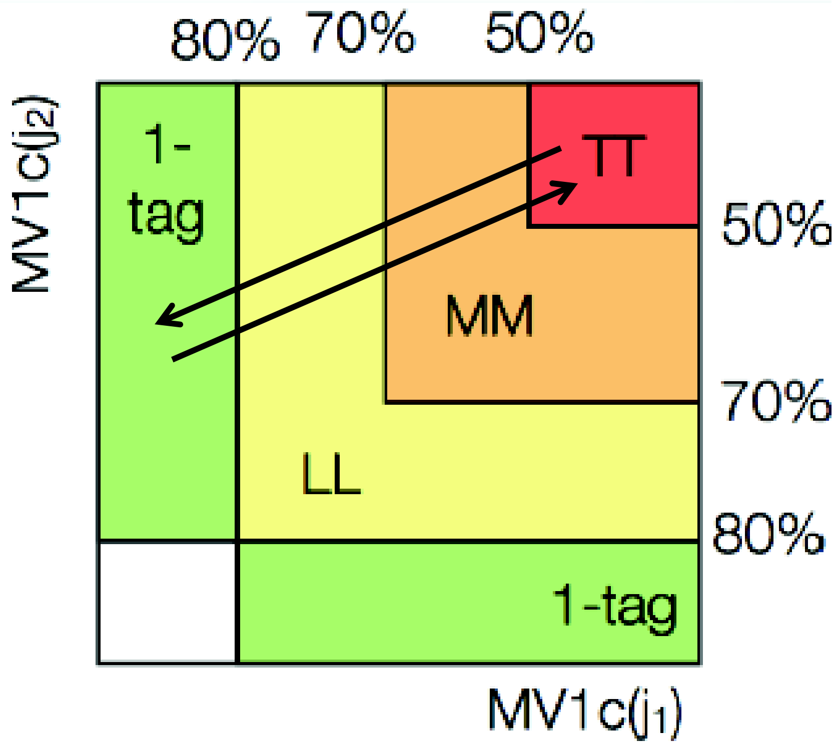
Constrain physics background through lepton categories

(e.g. 0-lepton *Z*+jets constrained from 2-lepton)

Fit model

- Binned maximum likelihood fit performed on the BDT across regions
  → **determine signal yield & background normalization**
- Impact of syst. uncertainties described by nuisance parameters across regions
  → **constrain systematics through global fit**





2 jet
3 jet

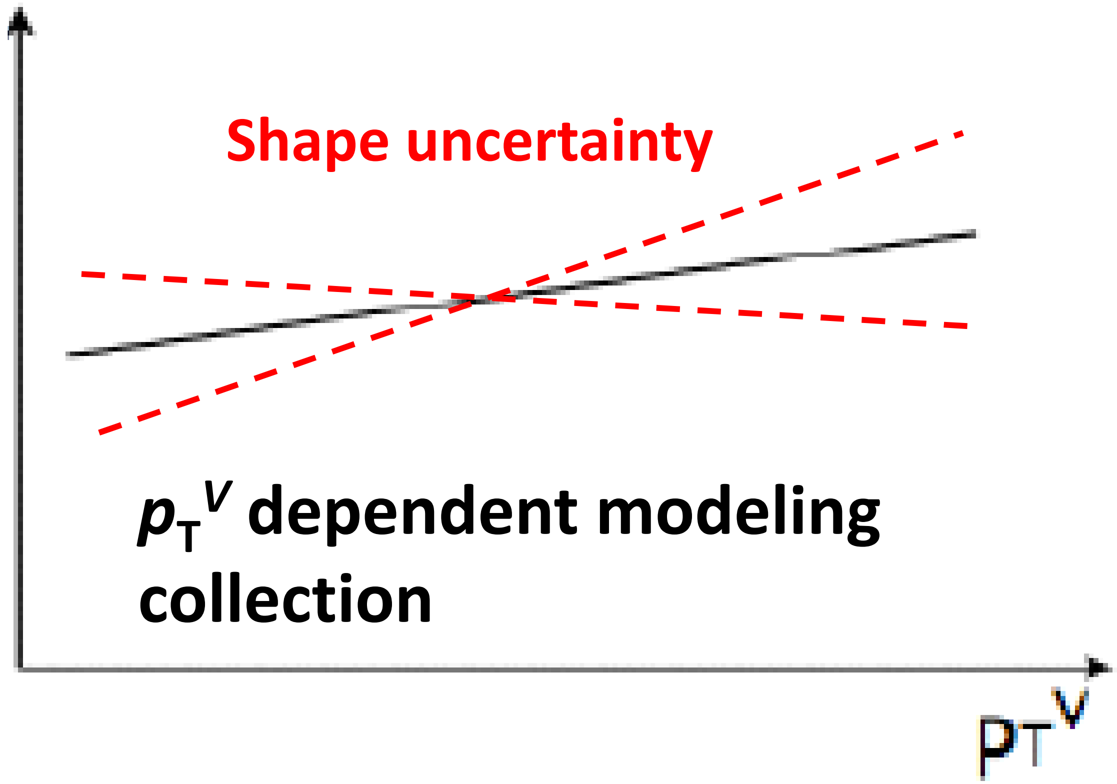
Constrain background flavor composition
(e.g. b-tagging syst. for b/c/light flavor and Z+bb/cc/light normalization)

Constrain 2-jets vs 3-jets difference

Fit model

- Binned maximum likelihood fit performed on the BDT across regions
  → **determine signal yield & background normalization**
- Impact of syst. uncertainties described by nuisance parameters across regions
  → **constrain systematics through global fit**

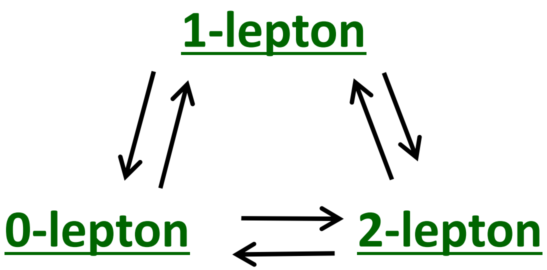
p_T^V	0-120	120-



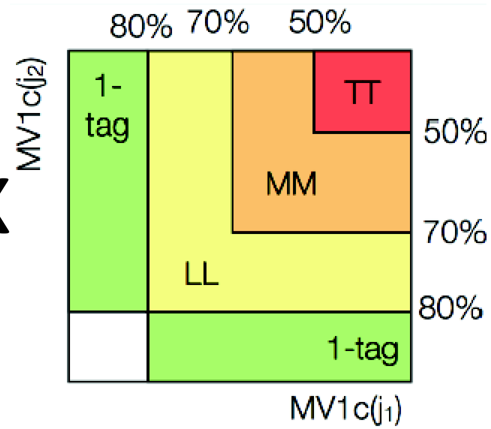
Constrain background modeling of p_T dependence
(e.g. modeling of W+jets ttbar as a function of p_T(V))

Fit model

- Binned maximum likelihood fit performed on the m_{jj}/BDT across regions
  → determine signal yield & background normalization
- Impact of syst. uncertainties described by nuisance parameters across regions
  → constrain systematics through global fit



X



X

2 jet
3 jet

X

p_T^V	*0-120*	*120-*

Fit performed through the BDT bins

Contents

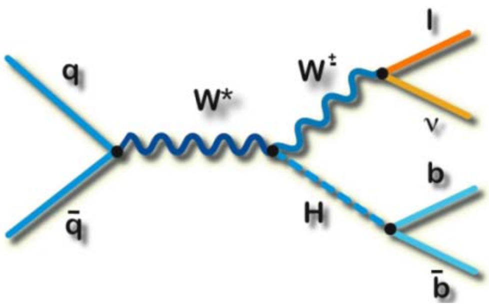
- Introduction
- Analysis overview
- Result of a search for the H→bb
- Summary & Prospects for the upcoming high-luminosity LHC

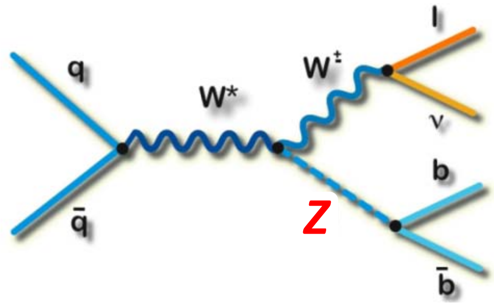
Our analysis techniques are valid for H→bb signals?

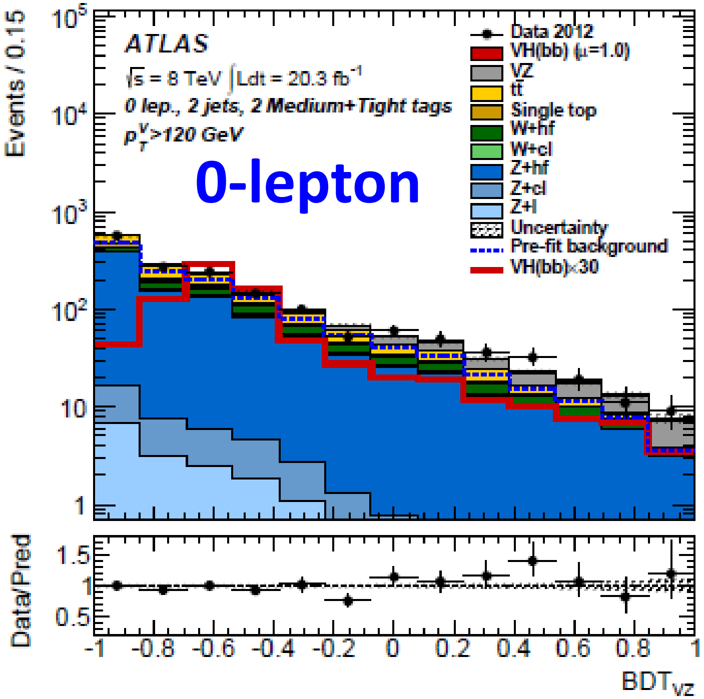
Analysis validation with di-boson signal

Validation of analysis techniques is very important

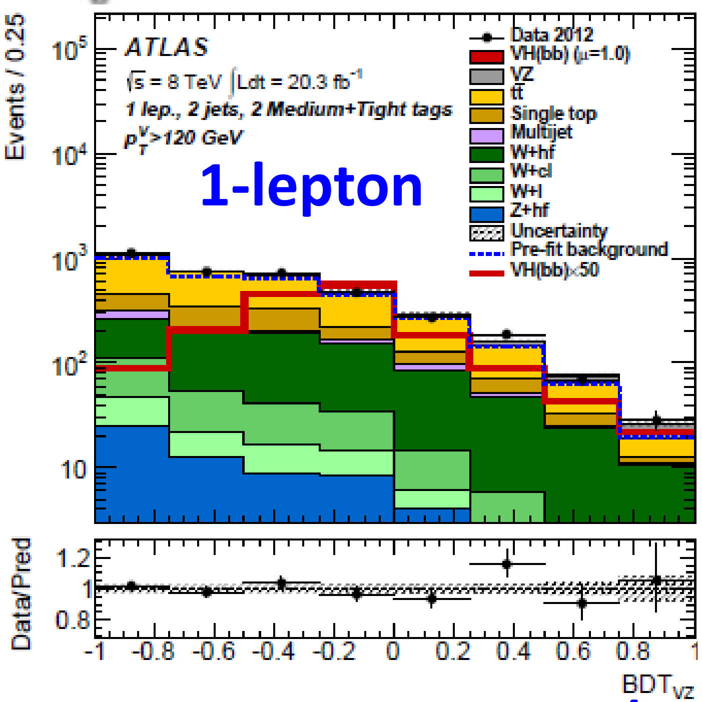
- → **Can use di-boson signals (*WZ, ZZ*), which produces exactly same final states**
- → **Well-established in the SM and can be used as the standard candle**



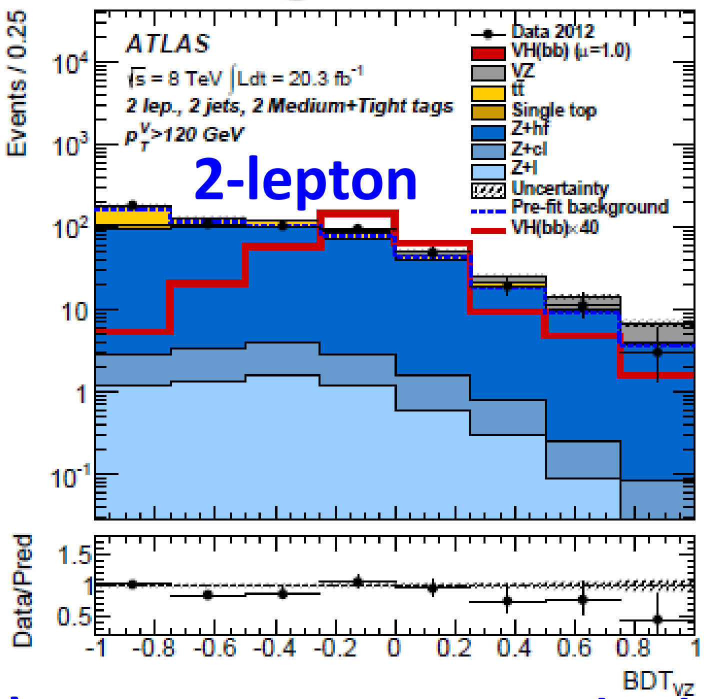




BDT (VZ)



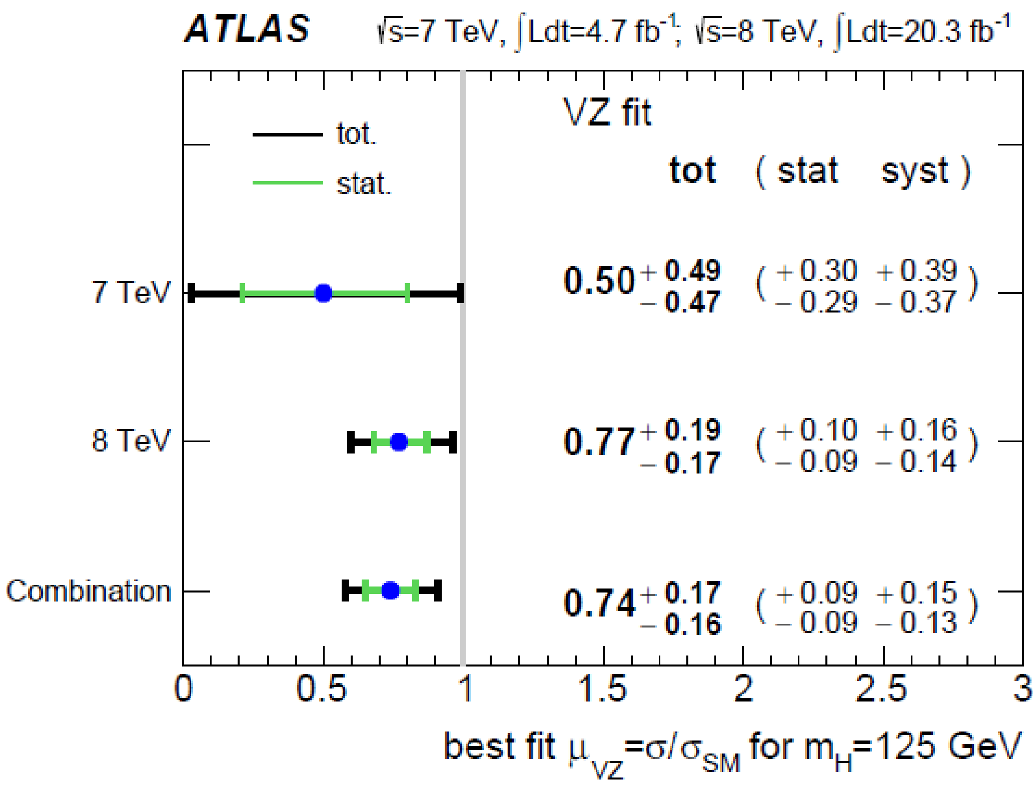
BDT (VZ)

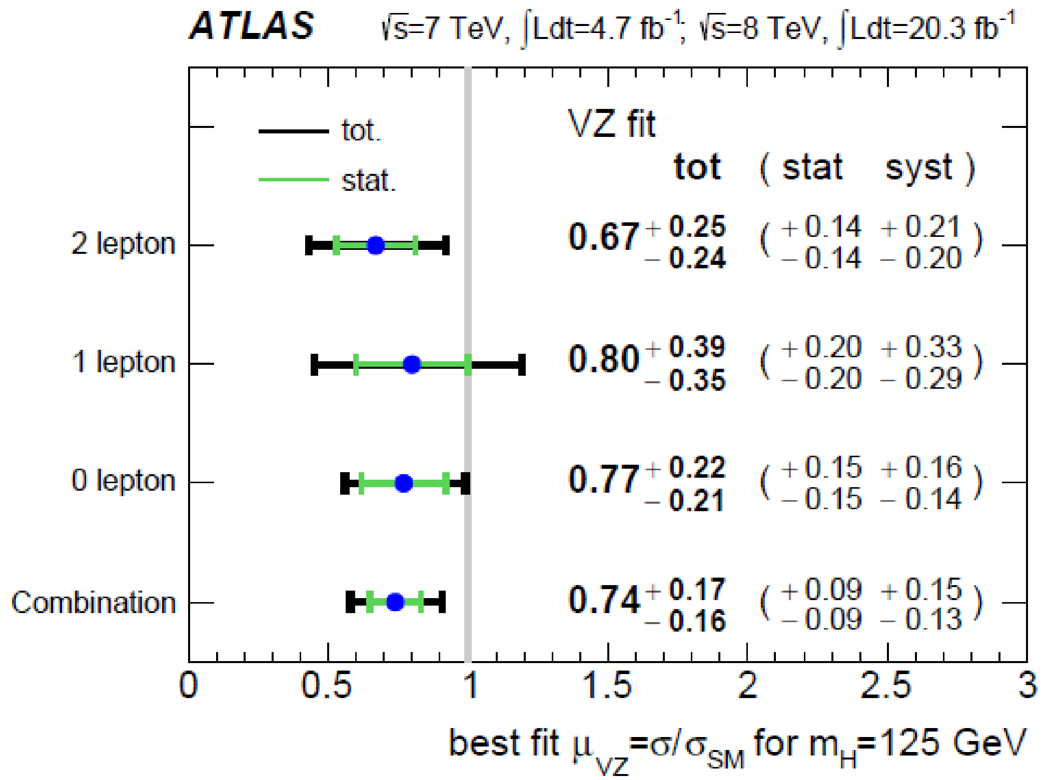


BDT (VZ)

Data and background+signal yield are compatible

Di-boson signal strength





$\mu = (\sigma \times Br)_{measured} / (\sigma \times Br)_{SM}$

$$\mu_{VZ} = 0.74 \pm 0.09(\text{stat.}) \pm 0.14(\text{syst.})$$

Signal excess

Observed: 4.9σ

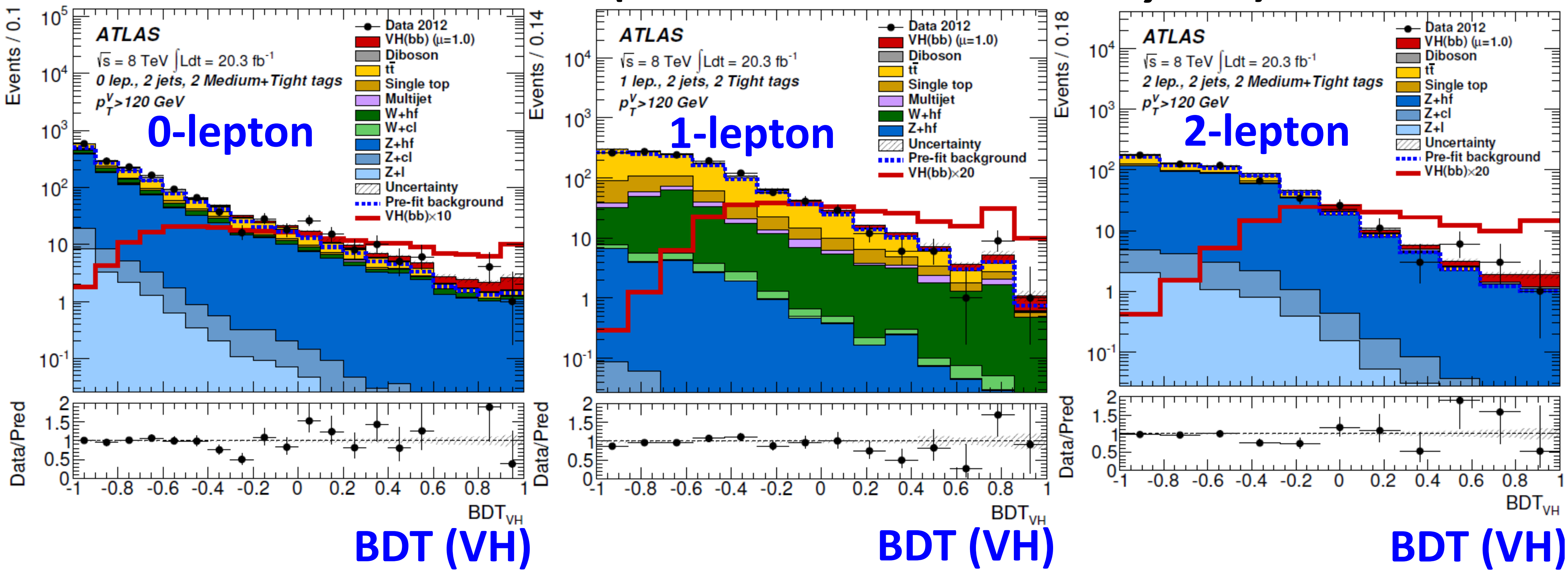
Expected: 6.3σ

Results are compatible with the SM.
Successfully re-observed di-boson process.

Let's go

Good luck !

Fit results (8 TeV, MVA analysis)

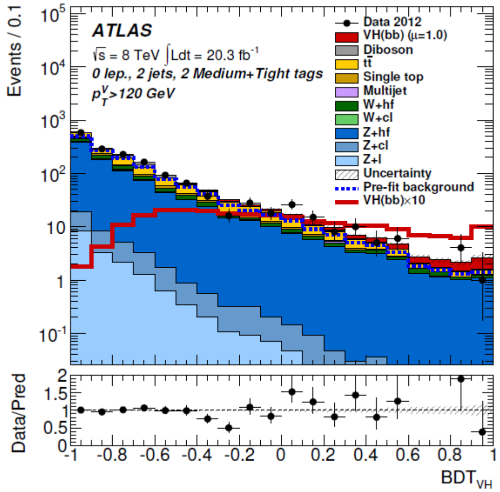


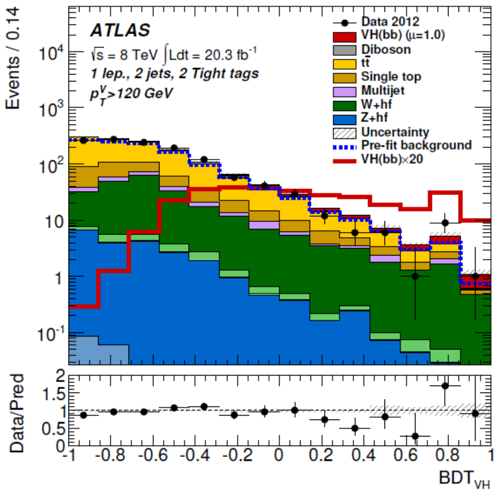
Process	Scale factor
$t\bar{t}$ 0-lepton	1.36 ± 0.14
$t\bar{t}$ 1-lepton	1.12 ± 0.09
$t\bar{t}$ 2-lepton	0.99 ± 0.04
Wbb	0.83 ± 0.15
Wcl	1.14 ± 0.10
Zbb	1.09 ± 0.05
Zcl	0.88 ± 0.12

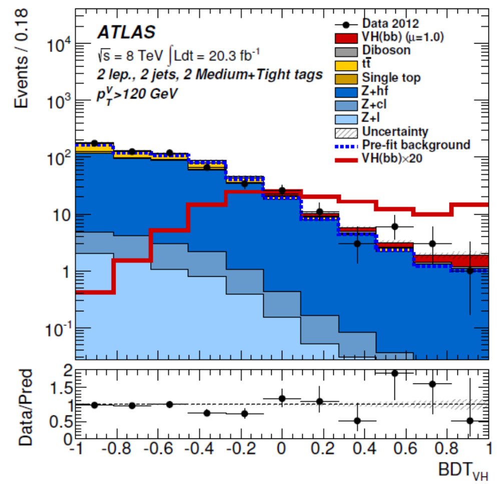
Data and background + signal yields are compatible

Background normalizations are expressed as scale factors to the pre-fit normalization

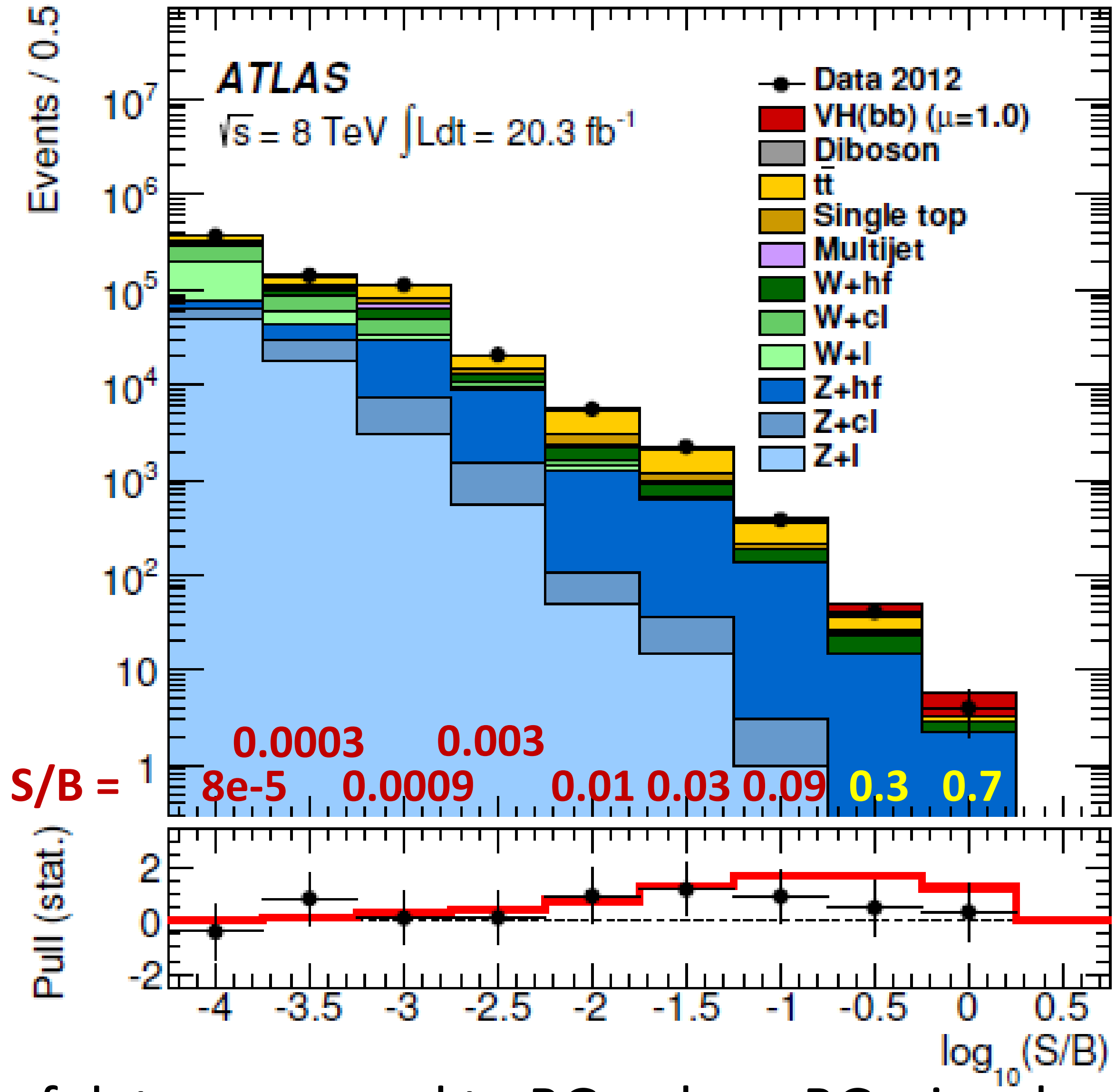
Fit results (8 TeV)







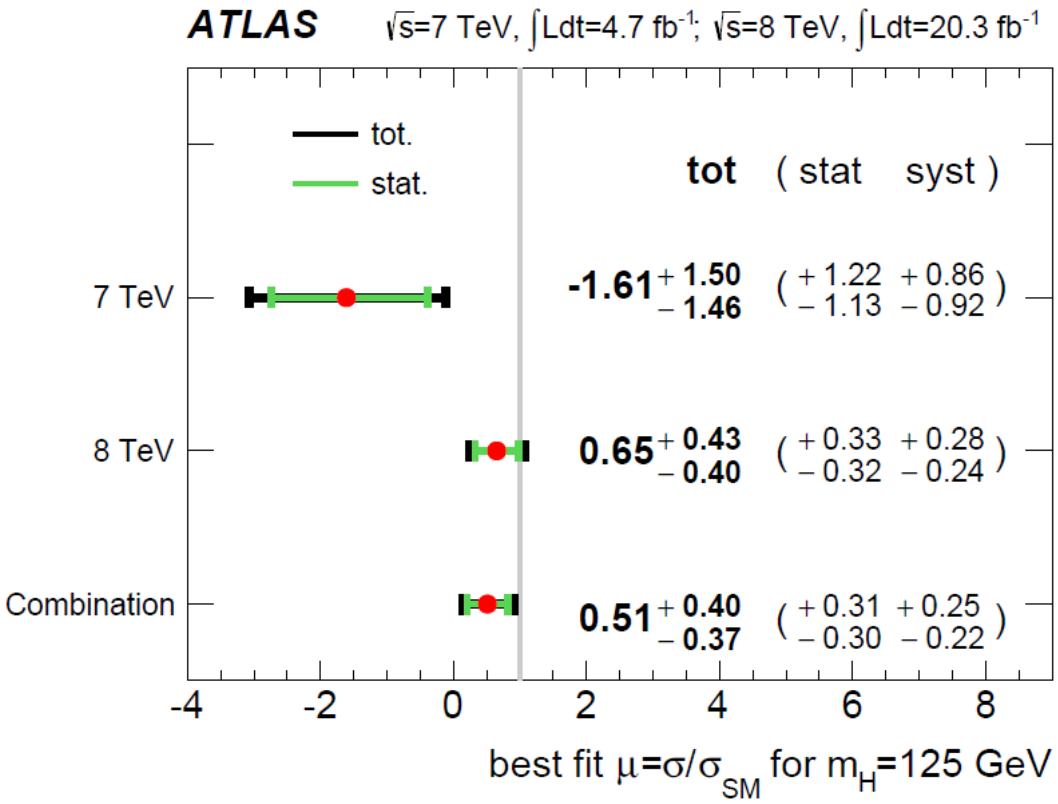
sorted as a function of S/B

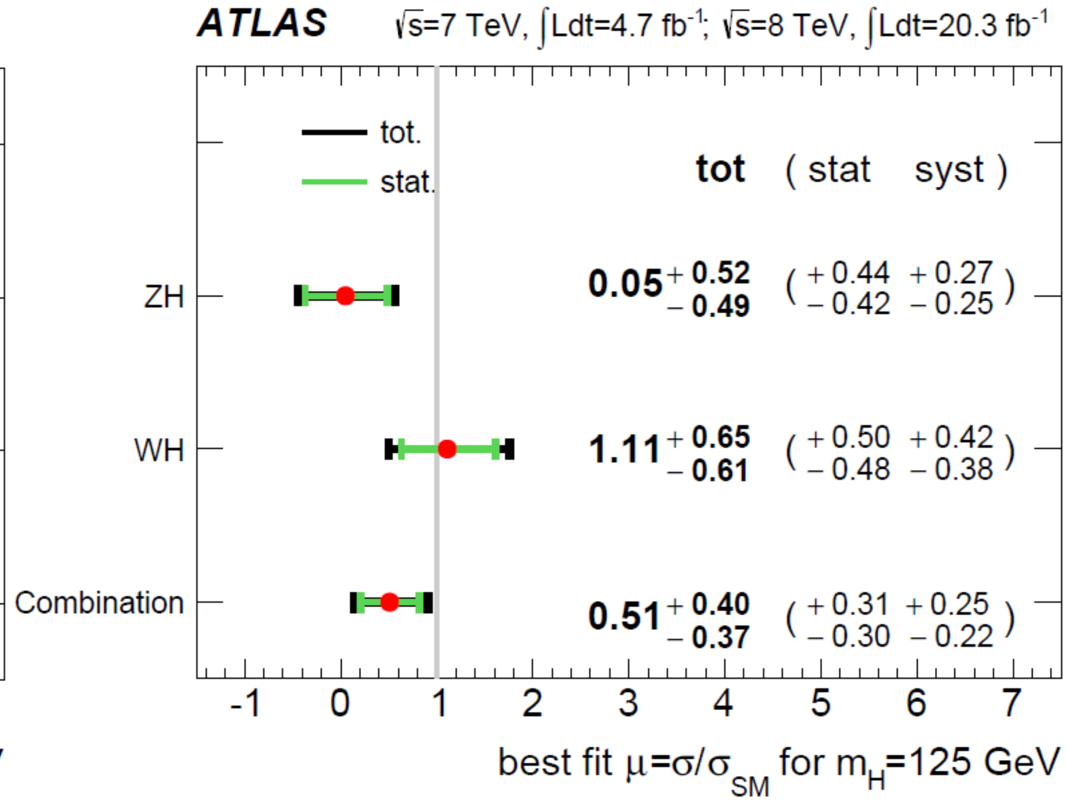


Pull of data compared to BG only or BG+signal

→ **Both hypotheses look compatible with data**

$H \rightarrow bb$ signal strength (7 TeV + 8 TeV)

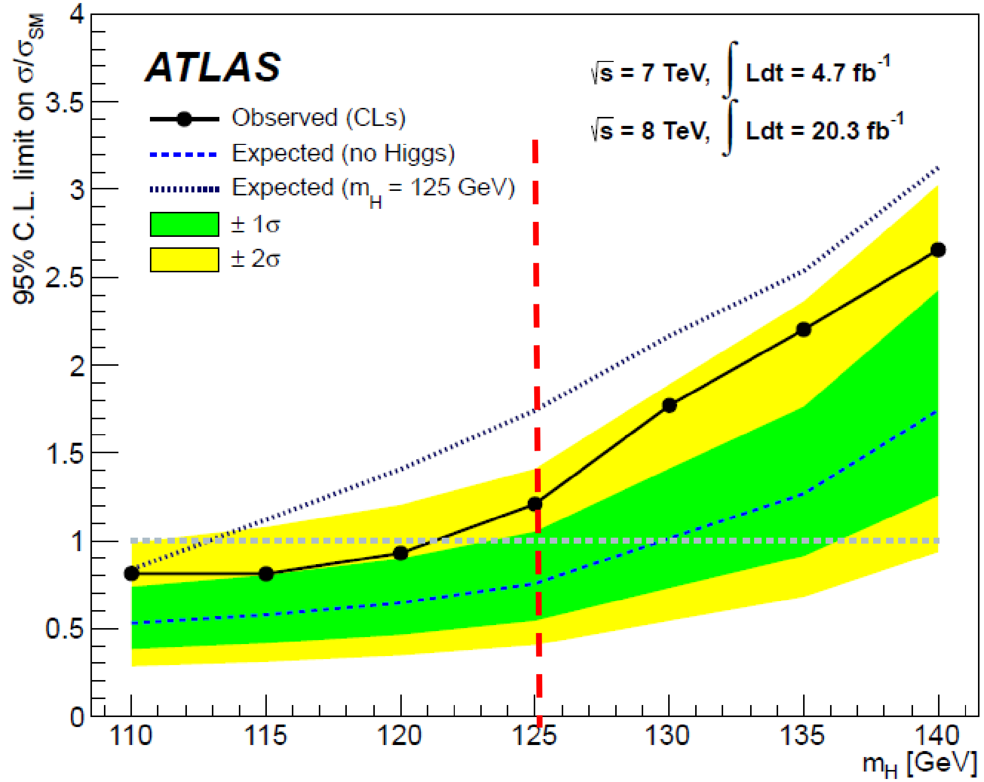


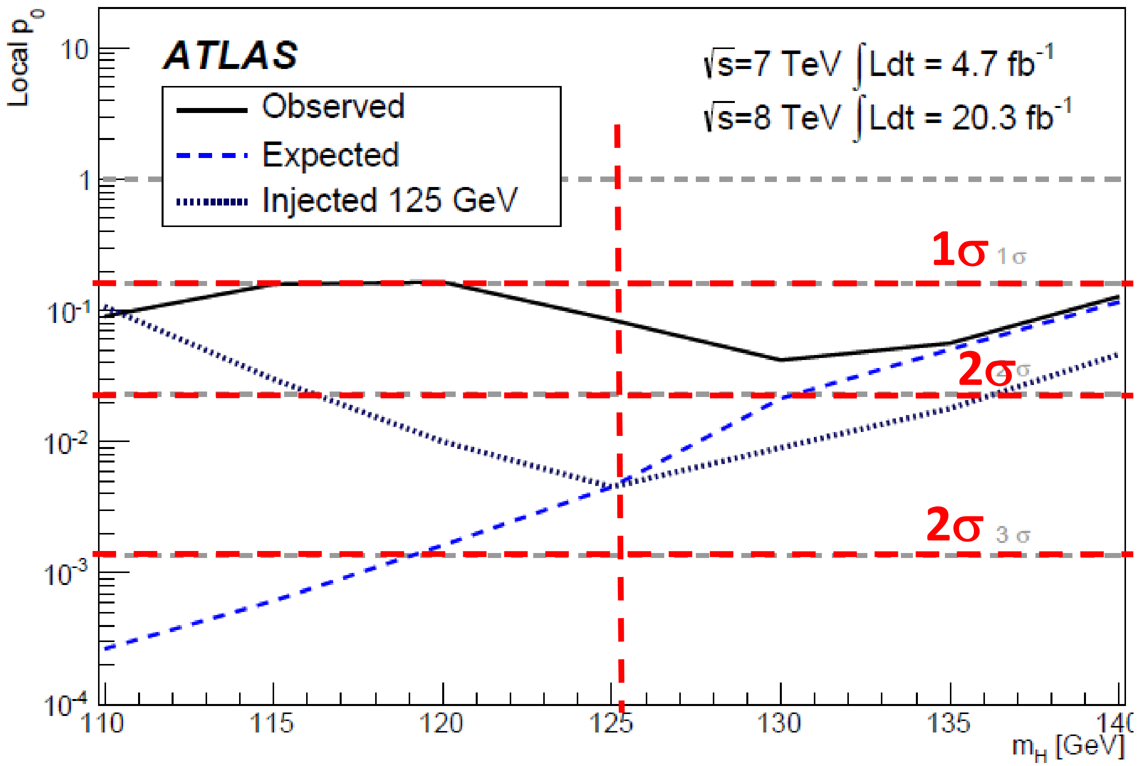


$\mu = (\sigma \times Br)_{measured} / (\sigma \times Br)_{SM}$

$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$ @ m_H = 125.36 GeV

Upper limit & significance (7+8 TeV)





Observed limit: < 1.2 x σ_{SM}
Expected limit: < 0.8 x σ_{SM} @ m_H = 125 GeV

<u>Signal excess</u>

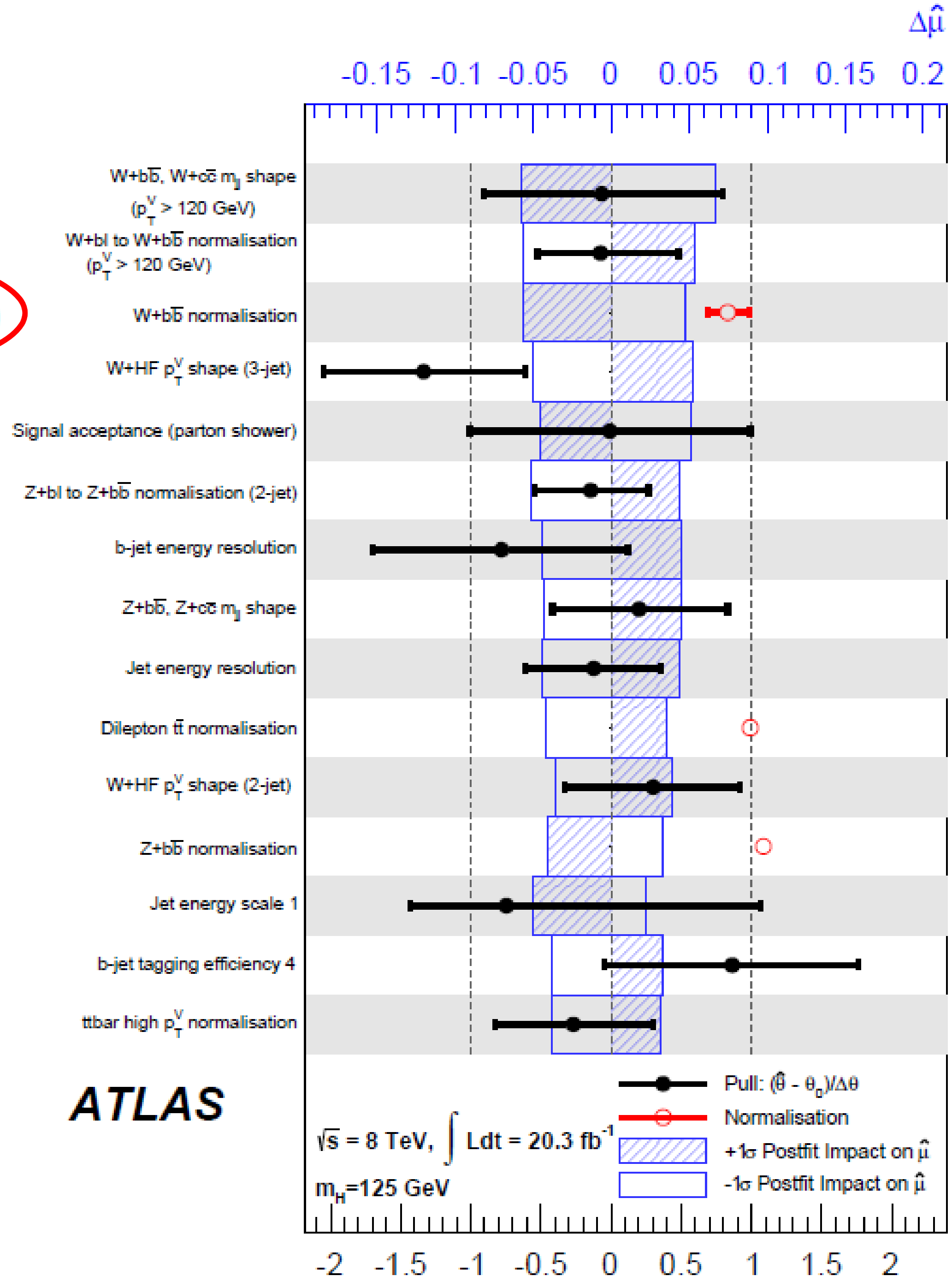
Observed: 1.4σ
Expected: 2.6σ @ m_H = 125 GeV

Close to 3σ sensitivity achieved in Run1

Systematics uncertainties

What is the main source of systematic?

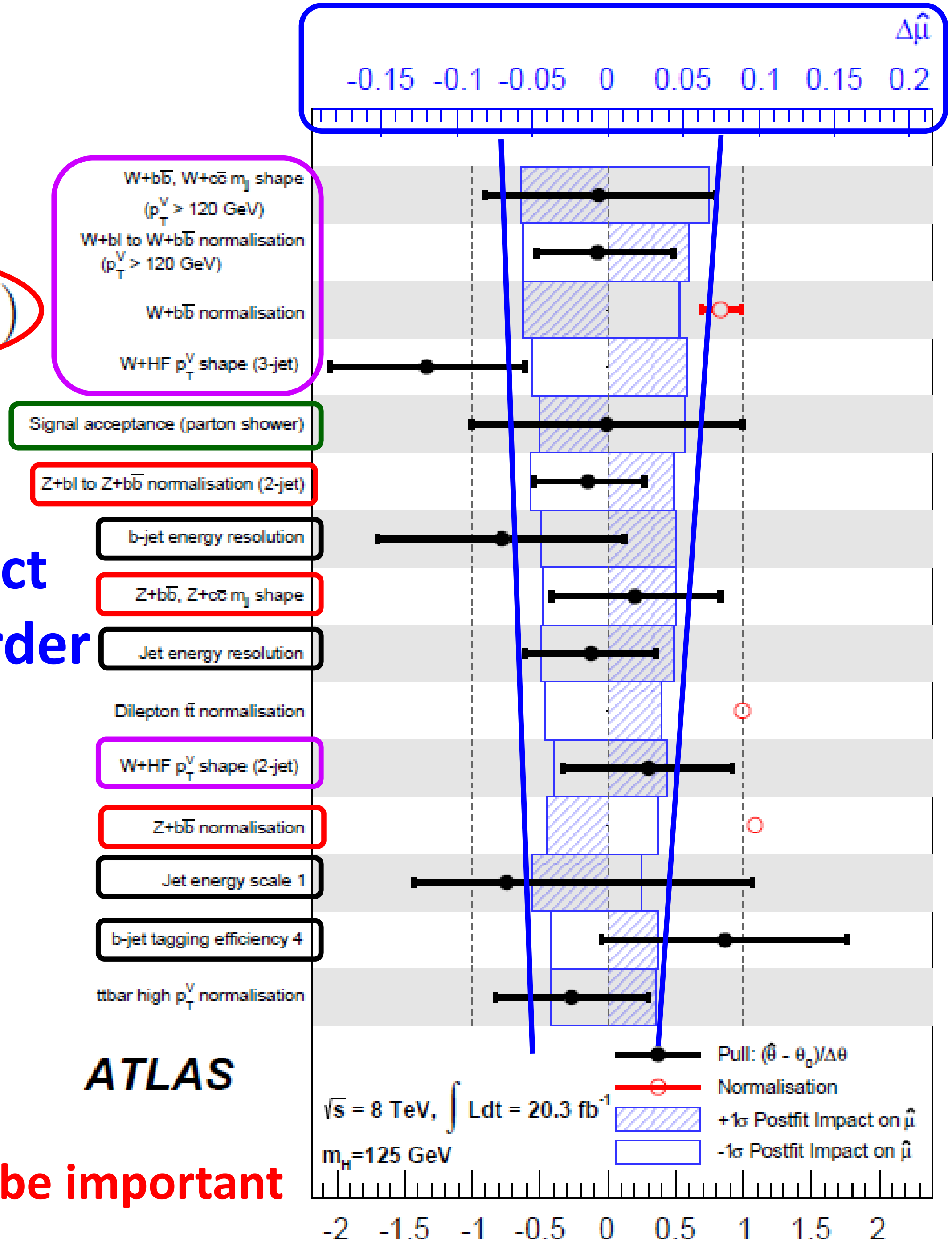
$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$



Systematics uncertainties

What is the main source of systematic?

$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$



Blue box expresses the size of impact on the post-fit μ with decreasing order

Leading systematics are:

W+jets modeling Z+jet modeling

Signal modeling b-jet & jet

For upcoming LHC Run2 & beyond, systematic uncertainty reduction will be important

Results submitted to JHEP

arXiv.org > hep-ex > arXiv:1409.6212

Search or Article-id (Help | Advanced search) All papers Go!

High Energy Physics - Experiment

Search for the $b\bar{b}$ decay of the Standard Model Higgs boson in associated $(W/Z)H$ production with the ATLAS detector

ATLAS Collaboration

(Submitted on 22 Sep 2014)

A search for the $b\bar{b}$ decay of the Standard Model Higgs boson is performed with the ATLAS experiment using the full dataset recorded at the LHC in Run 1. The integrated luminosities used from pp collisions at $\sqrt{s} = 7$ and 8 TeV are 4.7 and 20.3 fb^{-1}, respectively. The processes considered are associated $(W/Z)H$ production, where $W \to e\nu/\mu\nu$, $Z \to ee/\mu\mu$ and $Z \to \nu\nu$. The observed (expected) deviation from the background-only hypothesis corresponds to a significance of 1.4 (2.6) standard deviations and the ratio of the measured signal yield to the Standard Model expectation is found to be $\mu = 0.52 \pm 0.32(\mathrm{stat.}) \pm 0.24(\mathrm{syst.})$ for a Higgs boson mass of 125.36 GeV. The analysis procedure is validated by a measurement of the yield of $(W/Z)Z$ production with $Z \to b\bar{b}$ in the same final states as for the Higgs boson search, from which the ratio of the observed signal yield to the Standard Model expectation is found to be $0.74 \pm 0.09(\mathrm{stat.}) \pm 0.14(\mathrm{syst.})$.

Comments:	69 pages plus author list + cover pages (93 pages total), 25 figures, 11 tables, submitted to JHEP, All figures including auxiliary figures are available at this http URL
Subjects:	**High Energy Physics - Experiment (hep-ex)**
Report number:	CERN-PH-EP-2014-214
Cite as:	arXiv:1409.6212 [hep-ex]
	(or arXiv:1409.6212v1 [hep-ex] for this version)

Submission history

From: Atlas Publications [view email]

[v1] Mon, 22 Sep 2014 15:53:00 GMT (1480kb,D)

Download:

- PDF
- Other formats

Current browse context:

hep-ex

< prev | next >

new | recent | 1409

References & Citations

- INSPIRE HEP (refers to | cited by)
- NASA ADS

Bookmark (what is this?)

Preprint is available **arXiv: 1409.6212**

Contents

- Introduction
- Analysis overview
- Result of a search for the H→bb
- Summary & Prospects for the upcoming high-luminosity LHC

Prospects toward HL-LHC

Global Effort → Global Success

Results today only possible due to extraordinary performance of accelerators – experiments – Grid computing

Observation of a new particle consistent with a Higgs Boson (but which one…?)

Historic Milestone but only the beginning

Global Implications for the future

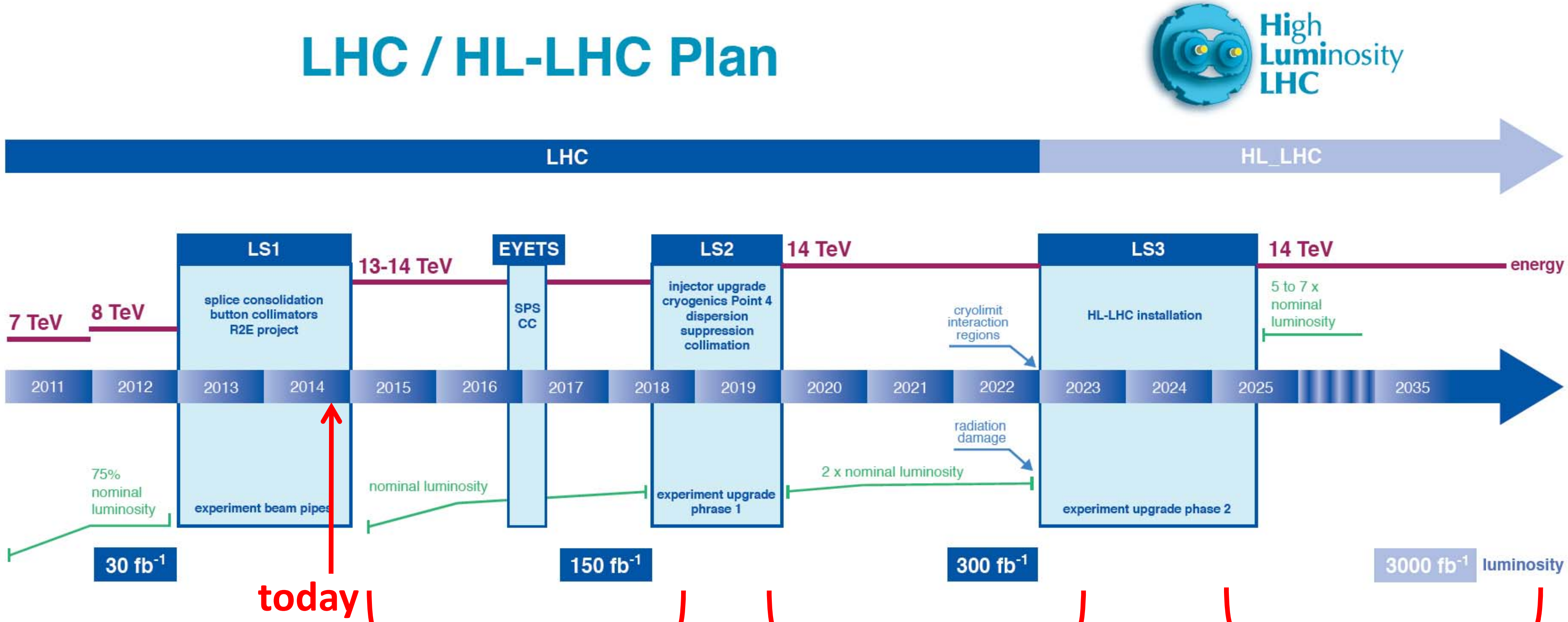
R-D Heuer

CERN

2 years after 4th July 2012 seminar,
we are still on a journey toward the nature of this Higgs boson

A more challenging environment

http://hilumilhc.web.cern.ch/about/hl-lhc-project



$\mathscr{L} \sim 1.6 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

Pile Up ~ 40

$\sqrt{s} = 13$ TeV

bunch spacing 25 ns

$\mathscr{L} \sim 2 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

Pile Up ~ 60

$\sqrt{s} = 14$ TeV

LHC injector upgrade

$\mathscr{L} \sim 5 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

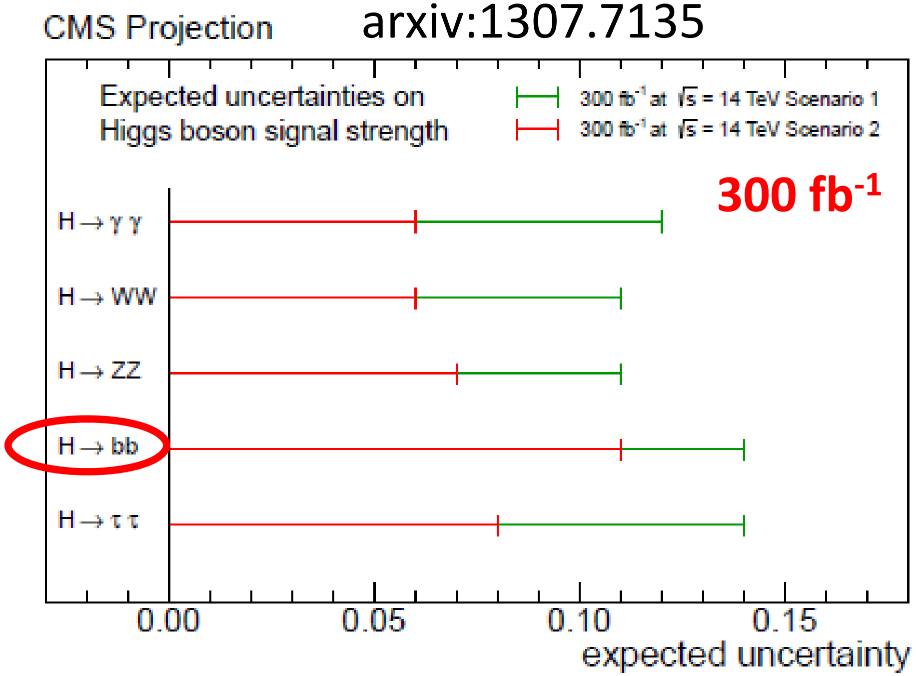
Pile Up ~ 140

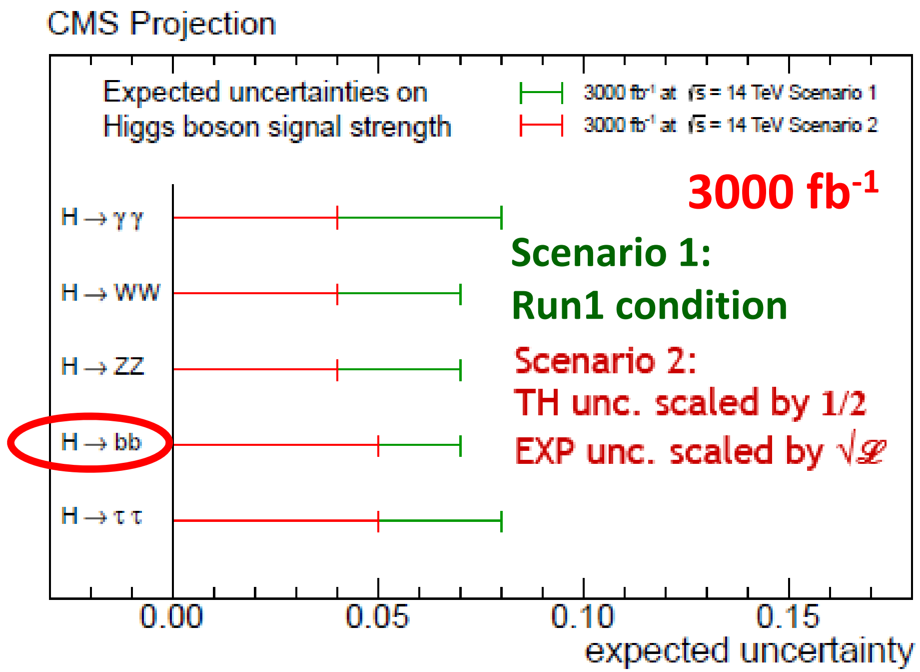
New interaction region layout

Crab cavity

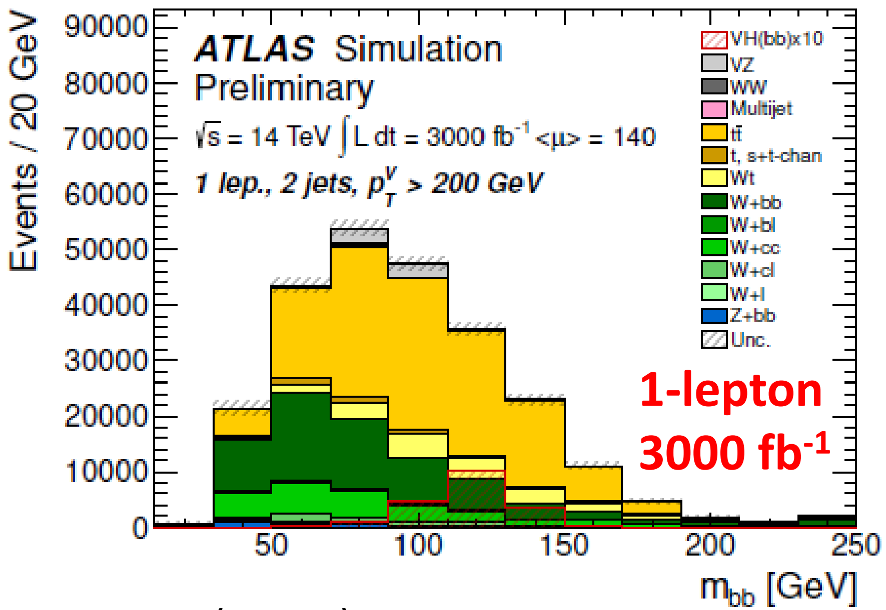
VH →Vbb at 300 fb^{-1} / 3000 fb^{-1}

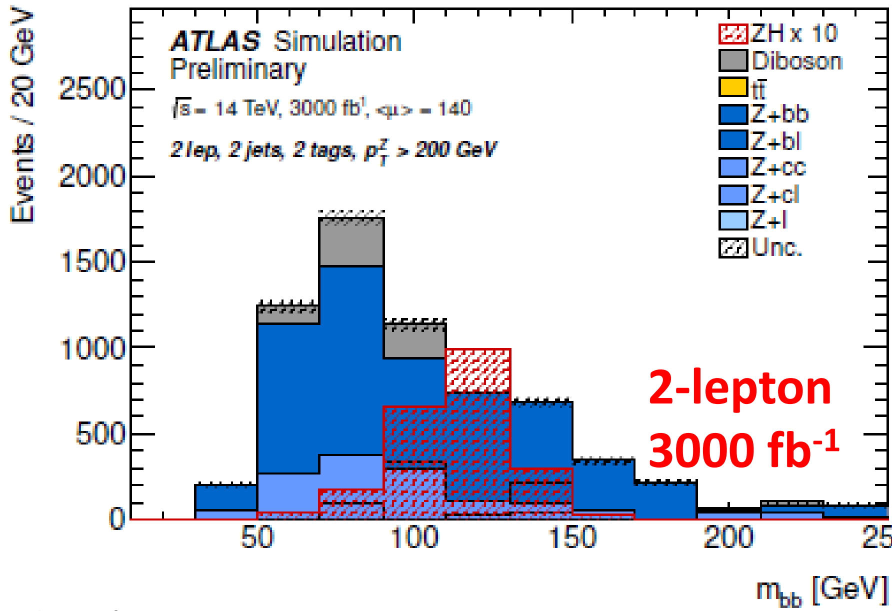
arxiv:1307.7135





ATL-PHYS-PUB-2014-011





VH → Vbb at 300 fb^{-1} / 3000 fb^{-1}

ATL-PHYS-PUB-2014-011

300 fb^{-1} , < μ> = 60

	1-lepton	2-lepton	1 + 2 lepton
Significance (σ)	2.1	3.5	4.1

3000 fb^{-1} , < μ> = 140

	1-lepton	2-lepton	1 + 2 lepton
Significance (σ)	4.7	8.4	9.6

These results assume jet energy scale uncertainty reduction

H→bb observation can be expected in upcoming LHC run
0-lepton is not included in this prospect

Summary

- Analysis validated using di-boson process

$$\mu_{VZ} = 0.74 \pm 0.09(\text{stat.}) \pm 0.14(\text{syst.})$$

For di-boson (WZ, ZZ)
Observed: 4.9σ
Expected: 6.3σ

Successfully re-observed di-boson process

- (W/Z)H→(W/Z)bb analysis using full ATLAS Run1 data presented

$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$

$\mu = (\sigma \times Br)_{measured} / (\sigma \times Br)_{SM}$

For m_H = 125 GeV
Observed: 1.4σ
Expected: 2.6σ

Close to 3σ evidence sensitivity
and we had a bit of bad luck (or real deficit from new physics? ☺)

- LHC will restart soon with higher energy and luminosity

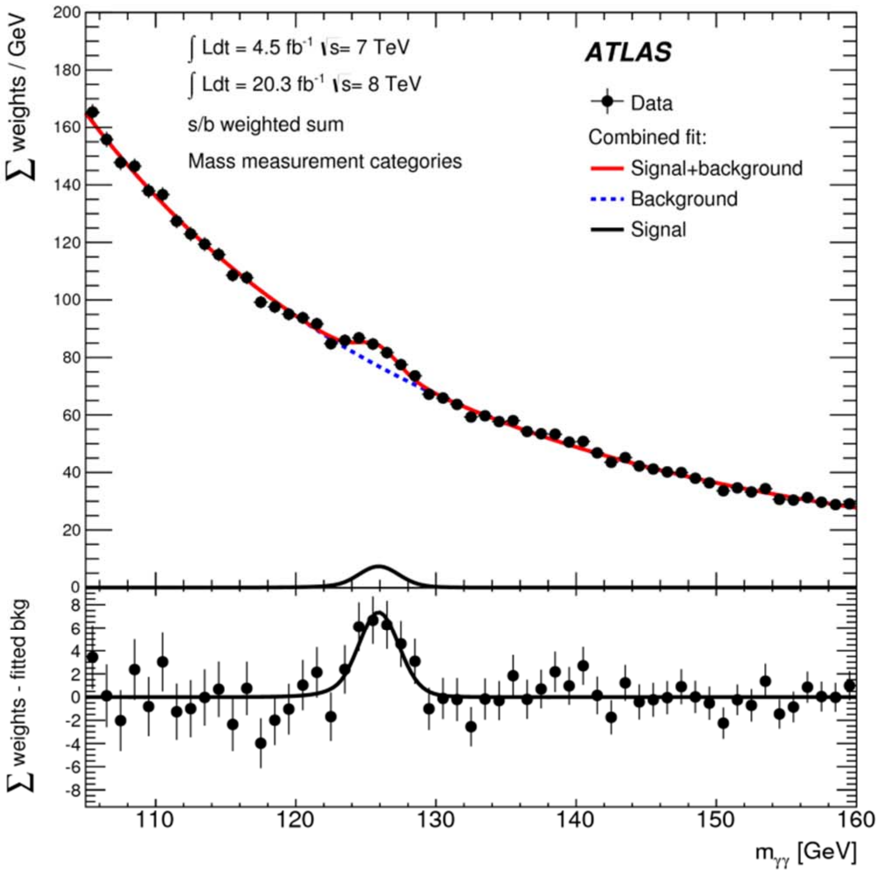
H→bb observation can be expected soon if it exists !
Improving background understanding is crucial for analysis Run2 and beyond

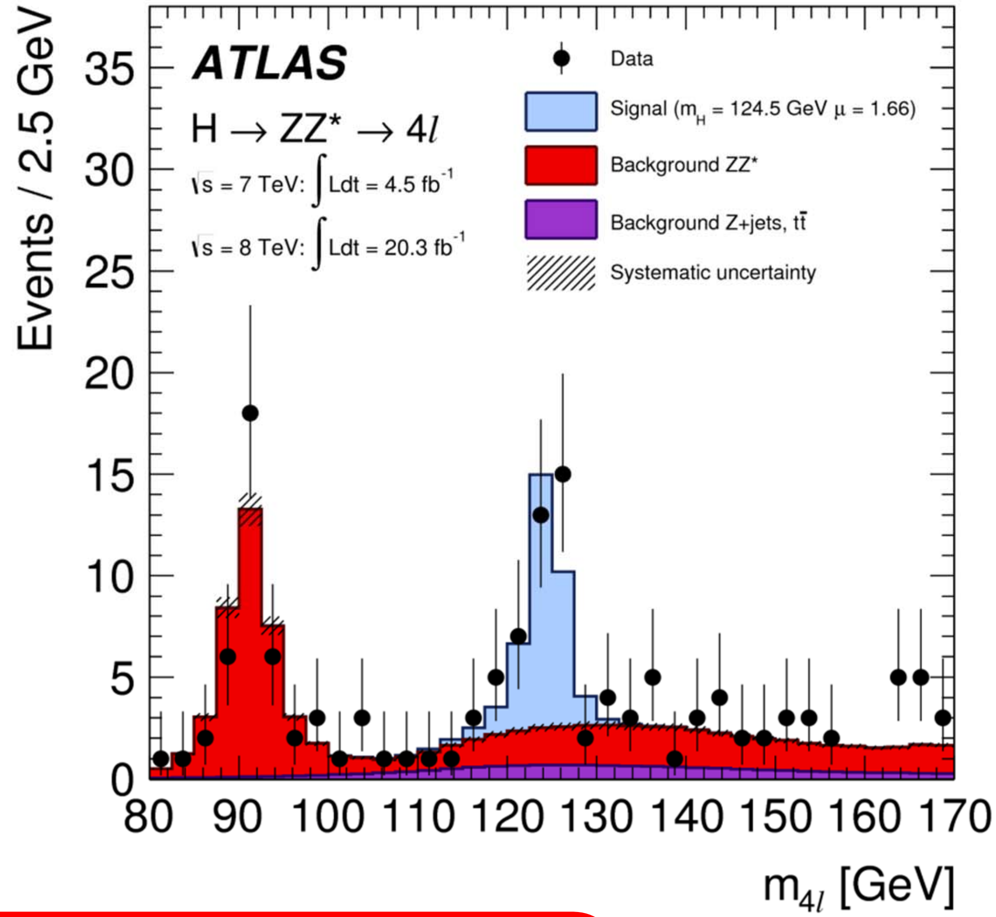
Stay tuned!!

Backup

Latest mass measurements

Mass (H→γγ, ZZ→4l) Phys. Rev. D. 90, 052004 (2014)





H→γγ:

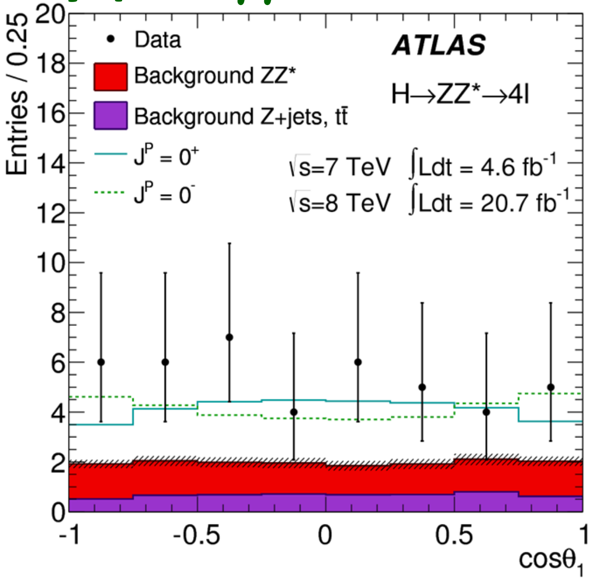
$$m_H = 125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{syst})\ \text{GeV}$$

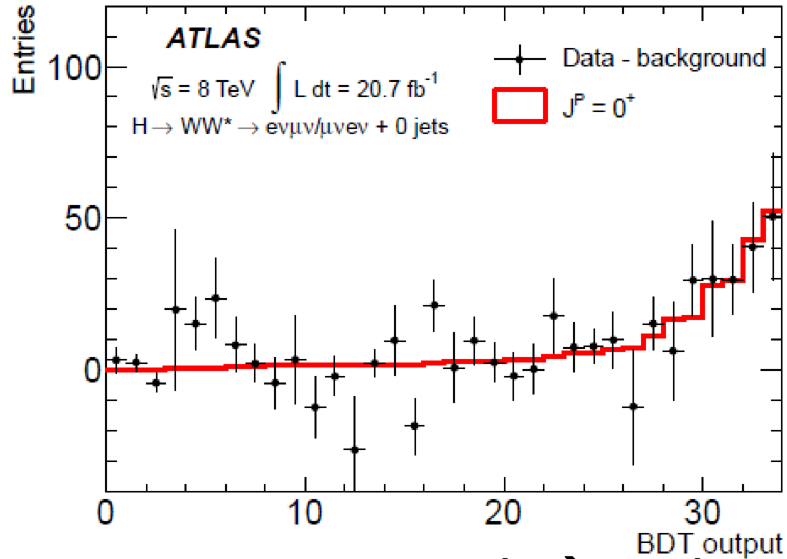
H→ZZ→4l:

$$m_H = 124.51 \pm 0.52\ (\text{stat}) \pm 0.06\ (\text{syst})\ \text{GeV}$$

Latest spin/parity measurements

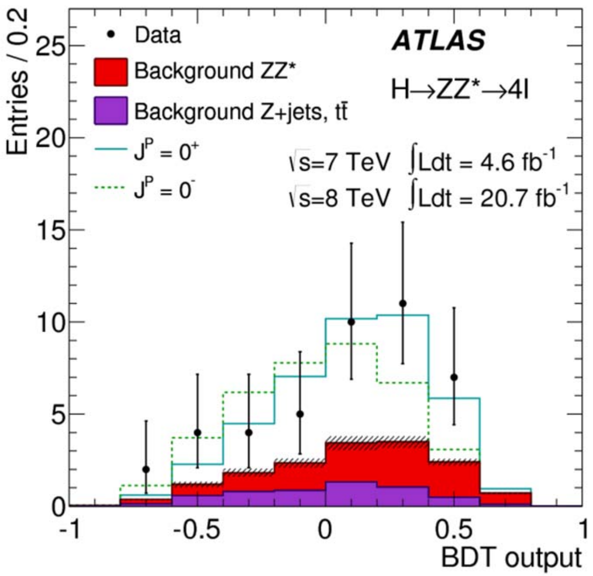
Spin/Parity ($H \rightarrow \gamma\gamma$, $ZZ \rightarrow 4l$, $WW \rightarrow l\nu l\nu$) Phys. Lett. B. 726 (2013)

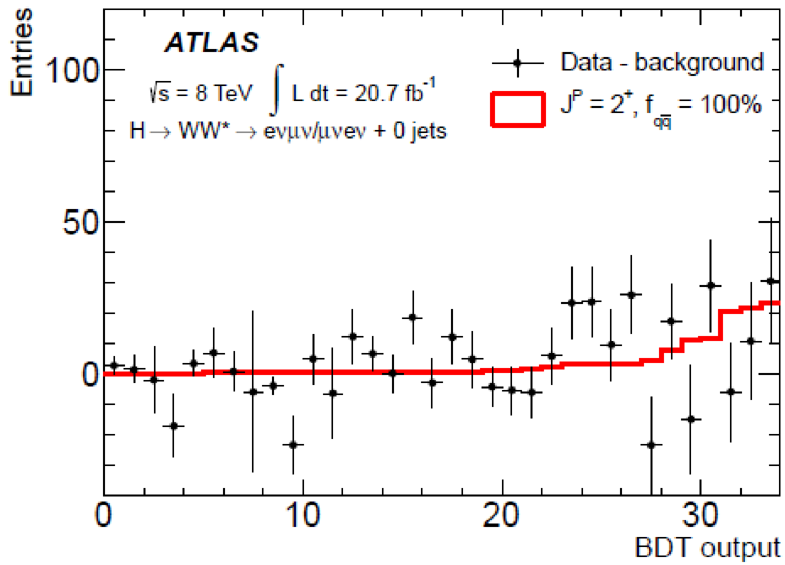




Spin 0^+ vs Spin 0^- ($H \rightarrow ZZ$)

Spin 0^+ vs Spin 2^+ ($H \rightarrow WW$)





H → $\gamma\gamma$ spin/parity observable

Collins-Soper frame

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_{\mathrm{T}}^{\gamma\gamma}/m_{\gamma\gamma})^2}}\frac{2p_{\mathrm{T}}^{\gamma 1}p_{\mathrm{T}}^{\gamma 2}}{m_{\gamma\gamma}^2}$$

Spin 2 models

arXiv: 1001:3396

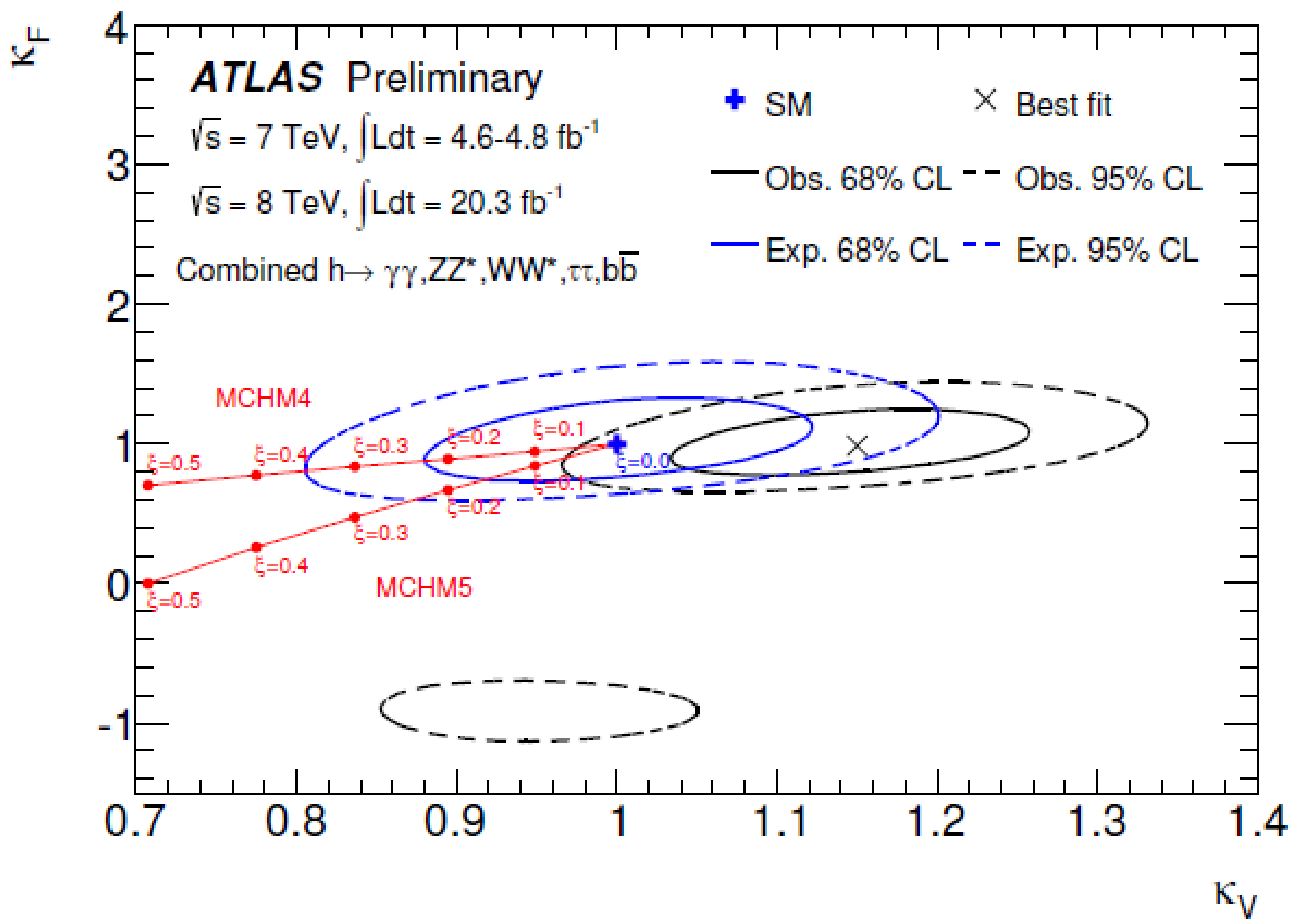
We choose 2_m^+ model among possible models for spin-2 hypothesis

TABLE I: The list of scenarios chosen for the analysis of the production and decay of an exotic X particle with quantum numbers J^P. For the two 2^+ cases, the superscripts m (minimal) and L (longitudinal) distinguish two scenarios, as discussed in the last column. When relevant, the relative fraction of gg and $q\bar{q}$ production is taken to be 1:0 at $m_X = 250$ GeV and 3:1 at $m_X = 1$ TeV. The spin-zero X production mechanism does not affect the angular distributions and therefore is not specified.

scenario (J^P)	$X \to ZZ$ decay parameters	X production parameters	comments
0^+	$a_1 \neq 0$ in Eq. (2)	$gg \to X$	SM Higgs-like scalar
0^-	$a_3 \neq 0$ in Eq. (2)	$gg \to X$	pseudo-scalar
1^+	$g_{12} \neq 0$ in Eq. (4)	$q\bar{q} \to X$: $\rho_{11}, \rho_{12} \neq 0$ in Eq. (9)	exotic pseudo-vector
1^-	$g_{11} \neq 0$ in Eq. (4)	$q\bar{q} \to X$: $\rho_{11}, \rho_{12} \neq 0$ in Eq. (9)	exotic vector
2_m^+	$g_1^{(2)} = g_5^{(2)} \neq 0$ in Eq. (5)	$gg \to X$: $g_1^{(2)} \neq 0$ in Eq. (5) $q\bar{q} \to X$: $\rho_{21} \neq 0$ in Eq. (10)	Graviton-like tensor with minimal couplings
2_L^+	$c_2 \neq 0$ in Eq. (6)	$gg \to X$: $g_2^{(2)} = g_3^{(2)} \neq 0$ in Eq. (5) $q\bar{q} \to X$: $\rho_{21}, \rho_{22} \neq 0$ in Eq. (10)	Graviton-like tensor longitudinally polarized and with $J_z = 0$ contribution
2^-	$g_8^{(2)} = g_9^{(2)} \neq 0$ in Eq. (5)	$gg \to X$: $g_1^{(2)} \neq 0$ in Eq. (5) $q\bar{q} \to X$: $\rho_{21}, \rho_{22} \neq 0$ in Eq. (10)	"pseudo-tensor"

Constraint on the new physics

ATLAS-CONF-2014-010



MCHM4 model: $\kappa = \kappa_V = \kappa_F = \sqrt{1-\xi}$

MCHM5 model:

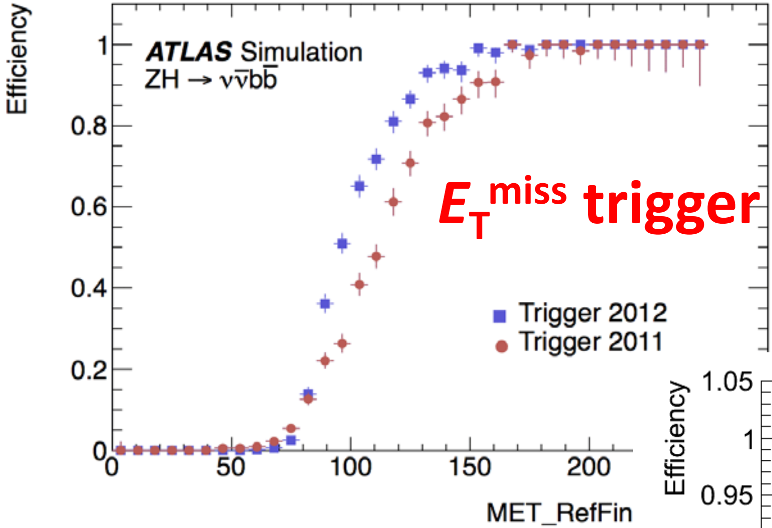
$$\kappa_V = \sqrt{1-\xi}$$

$$\kappa_F = \frac{1-2\xi}{\sqrt{1-\xi}}.$$

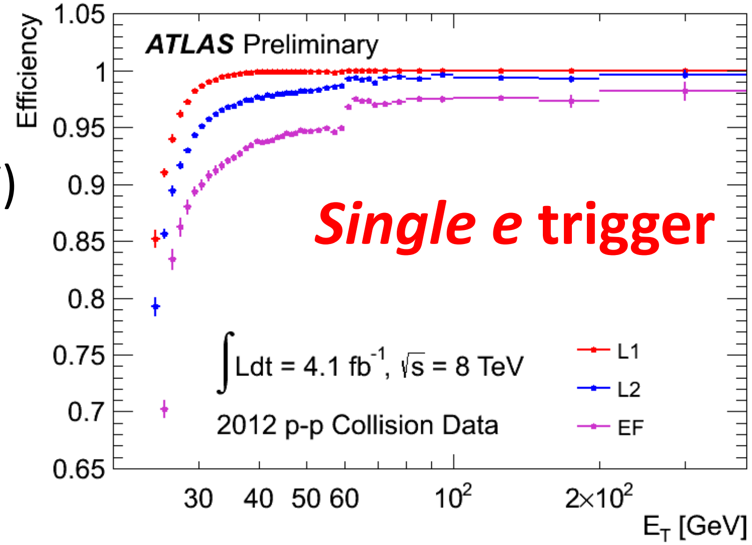
Trigger selection

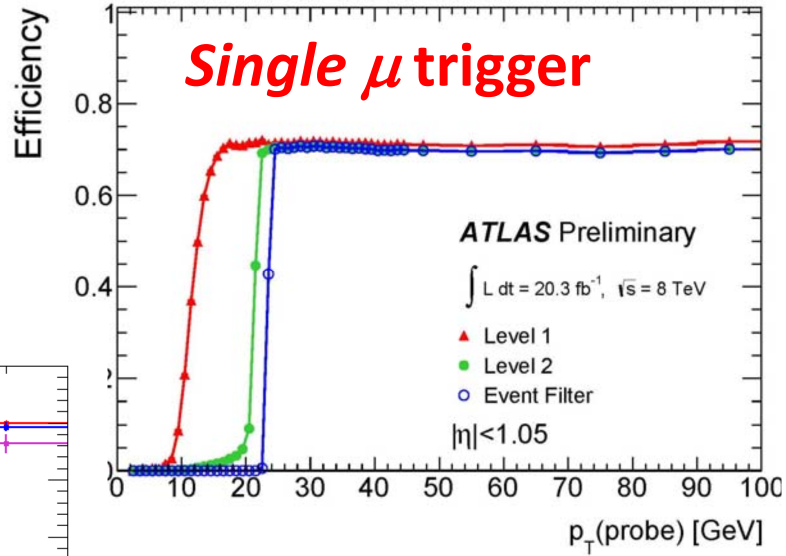
Triggers for analysis

- 0-lepton: trigger by **missing transverse energy (E_T^{miss})** threshold: 80 GeV
- 1-lepton: Primary trigger by **single-lepton trigger (e/μ)** threshold: 18~24 GeV
  Secondary trigger by E_T^{miss} to compensate μ inefficiency
- 2-lepton: trigger by **single-lepton trigger (e/μ)** or **di-lepton trigger (ee/μμ)**
  threshold: 18~24 (12~13) GeV for single (di-lepton) trigger

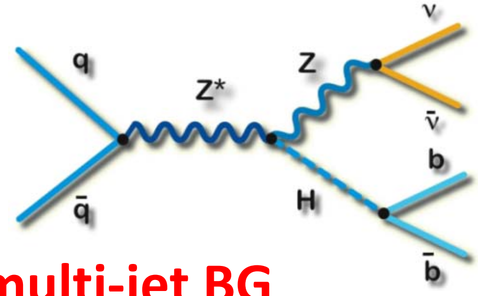


Offline MET (GeV)



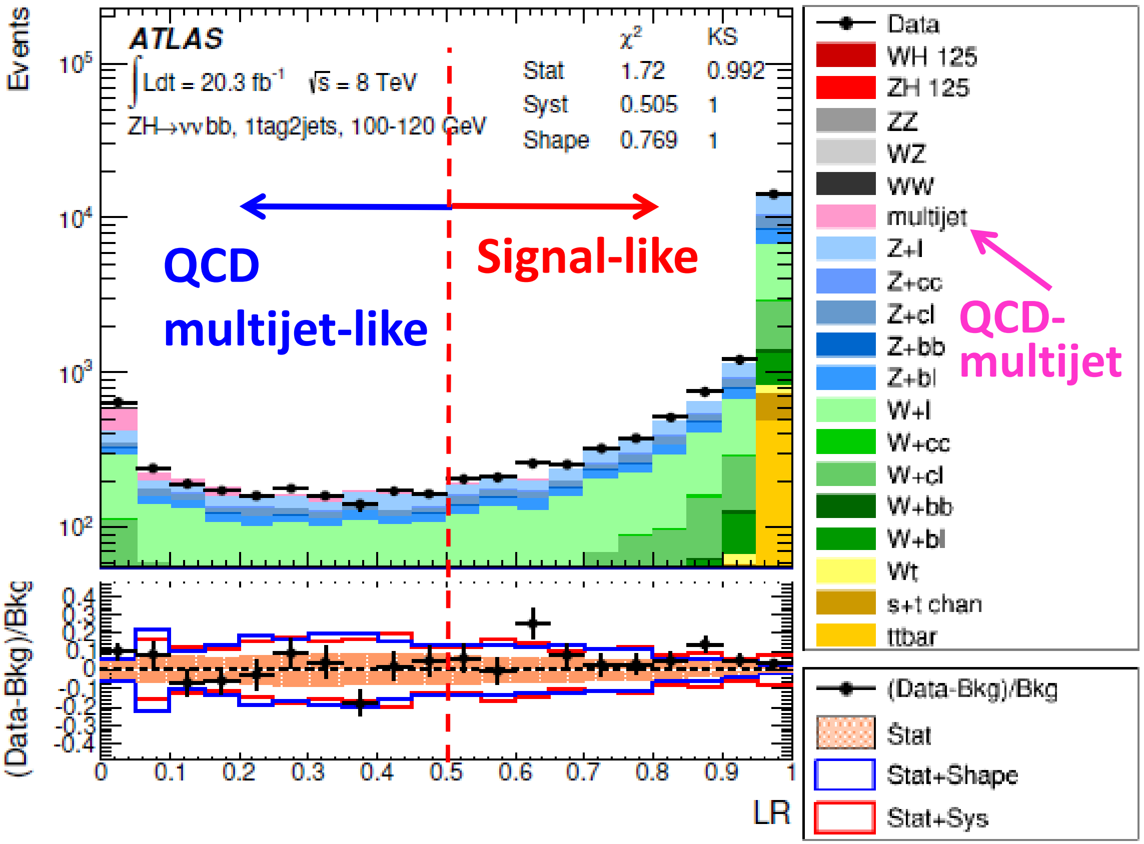


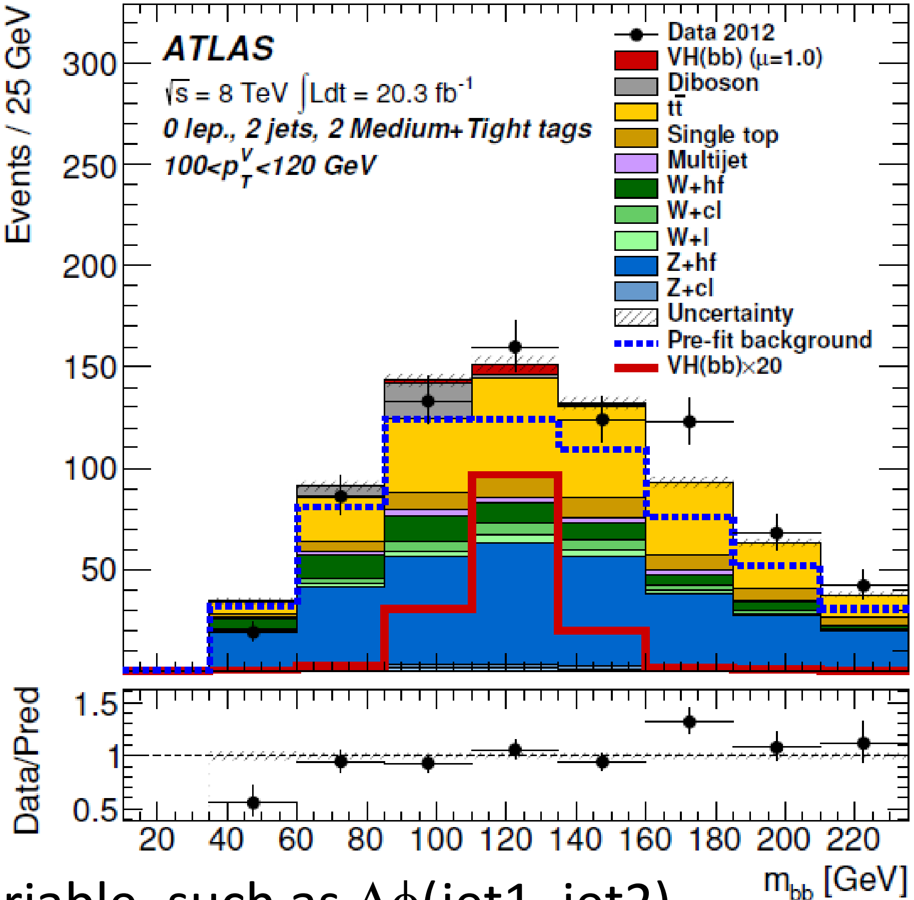
0-lepton new signal region



E_T^{miss} 100—120 GeV (low E_T^{miss} bin)

- Difficulty: **analysis using trigger turn-on region and huge QCD multi-jet BG**
- Developed special QCD multi-jet rejection technique: **Likelihood ratio method**



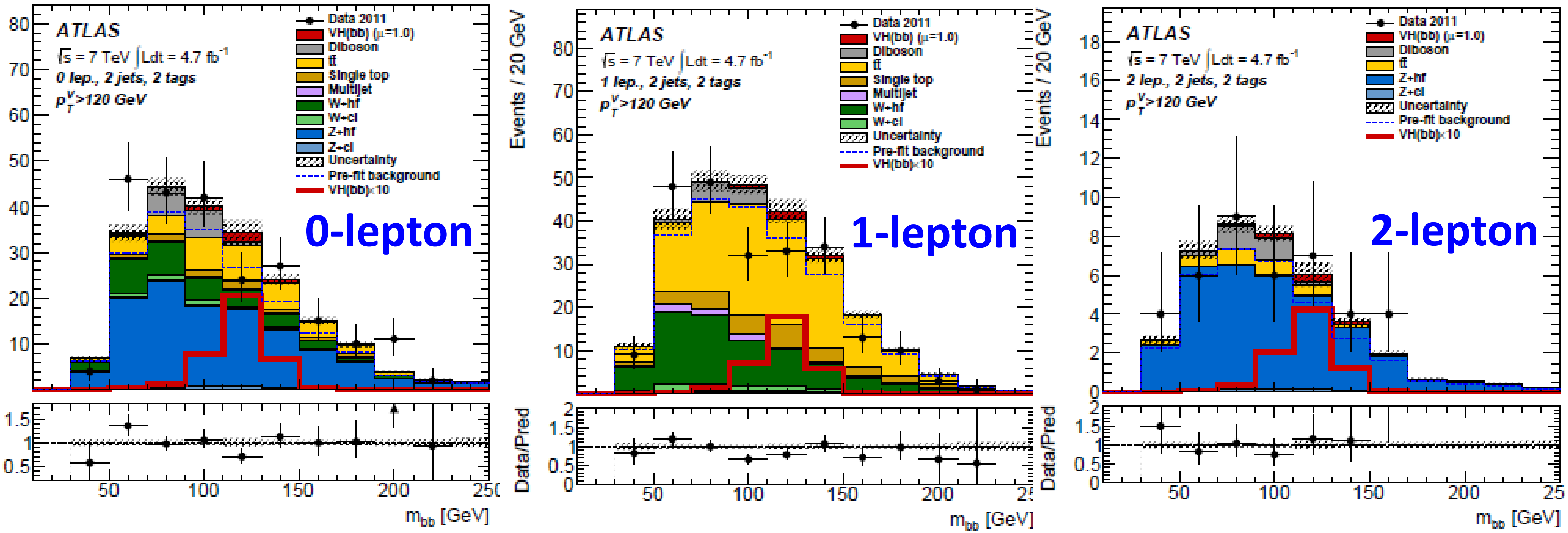


Likelihood ratio constructed from kinematics variable, such as $\Delta\phi$(jet1, jet2)

→ **QCD multijet background is negligible after cut**

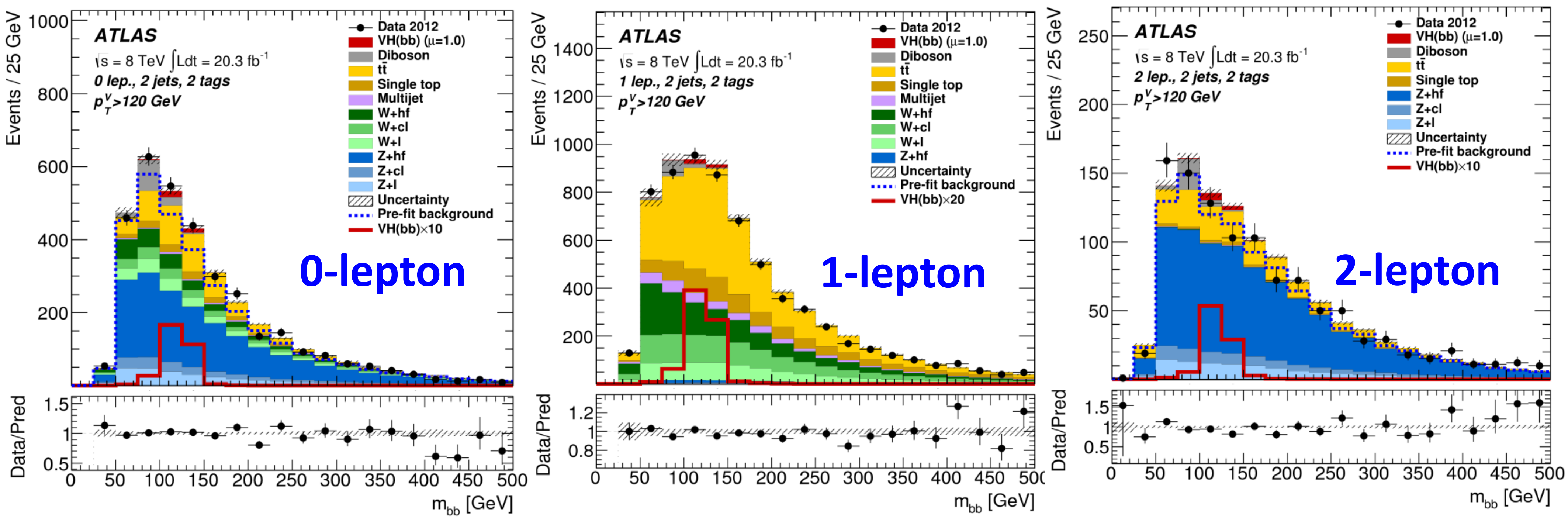
→ **m_{bb} of low E_T^{miss} bin is used for nominal analysis**

Fit results (7 TeV, m_{jj} analysis)



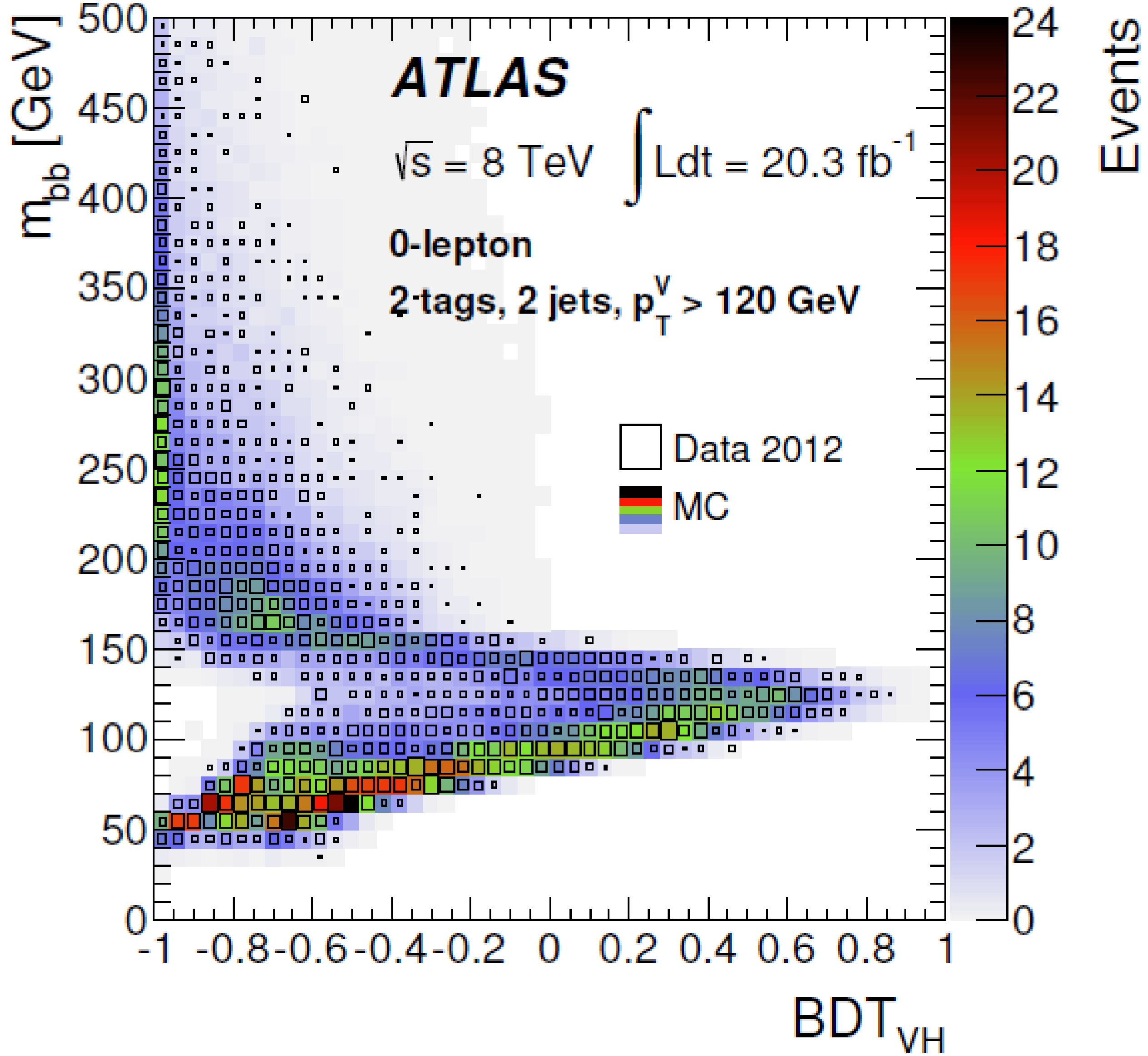
Data and background + signal yields are compatible

Fit results (8 TeV, m_{jj} analysis)



Data and background + signal yields are compatible

Correlation b/w BDT & m_{jj}



BDT input kinematics

Variable	0-Lepton	1-Lepton	2-Lepton
p_T^V		$\times$	$\times$
E_T^{miss}	$\times$	$\times$	$\times$
$p_T^{b_1}$	$\times$	$\times$	$\times$
$p_T^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(b_1, b_2)$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(b_1, b_2)\rvert$	$\times$		$\times$
$\Delta\phi(V, bb)$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(V, bb)\rvert$			$\times$
H_T	$\times$		
$\min[\Delta\phi(\ell, b)]$		$\times$	
m_T^W		$\times$	
$m_{\ell\ell}$			$\times$
$MV1c(b_1)$	$\times$	$\times$	$\times$
$MV1c(b_2)$	$\times$	$\times$	$\times$
	Only in 3-jet events		
$p_T^{jet_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

Kinematics fitter

- **Likelihood fit:**
  - llbb system constrained to e balanced in the transverse plane
  - m_{ll} constrained to a Breit-Wigner
  - Lepton parameters follow Gaussian distributions
  - Jet parameters follow a dedicated asymmetric transfer function

Lep. resolution

Jet transfer function

$$\mathscr{L} = \prod_i f(y_i^{obs}, y_i^{pred}) = G\left(\Omega_\ell^n; \Omega_\ell^0, \sigma_\Omega\right) L^j\left(P_T^n; P_T^0, \eta_j^0\right) L^j_{truth}\left(P_T^n; \eta_j^0\right)$$

$$\prod_{i=j} G\left(\phi_i^n; \phi_i^0, \sigma_\phi\right) \prod_{i=x,y} G\left(\sum p_i^n; \sum P_i, \sigma_{\sum p_i}\right)$$

Transverse balance

$$\mathcal{B}(m_{\ell\ell}^n; M_Z, \Gamma_Z).$$

Z mass: Breit-Wigner

Systematics

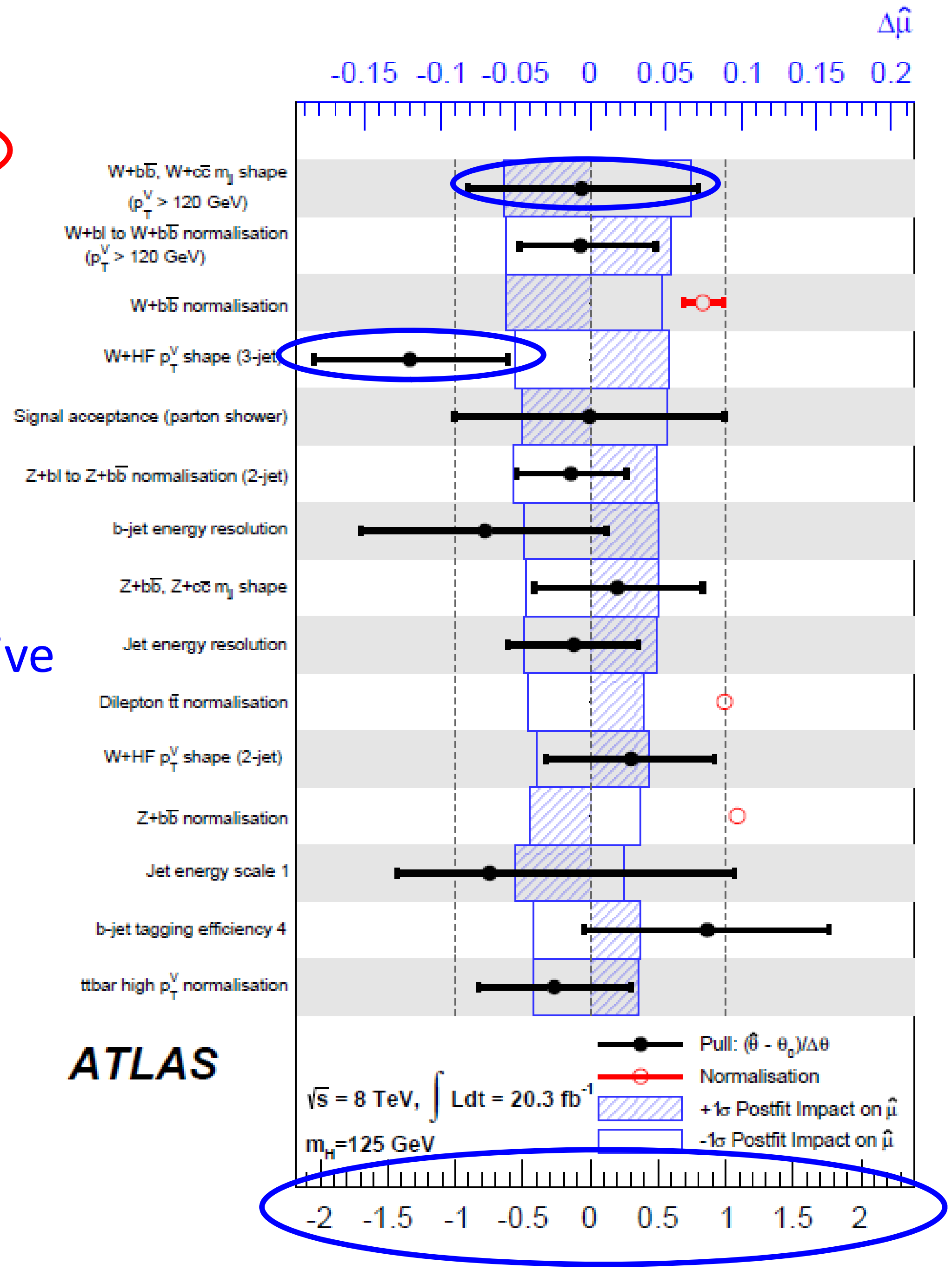
What is the main source of systematic?

$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$

The systematic uncertainties are listed in decreasing order of their impact on the postfit impact on μ

The deviations of the fitted nuisance parameters from its nominal value .

error bars express postfit uncertainties relative to their nominal uncertainties



Systematics

What is the main source of systematic?

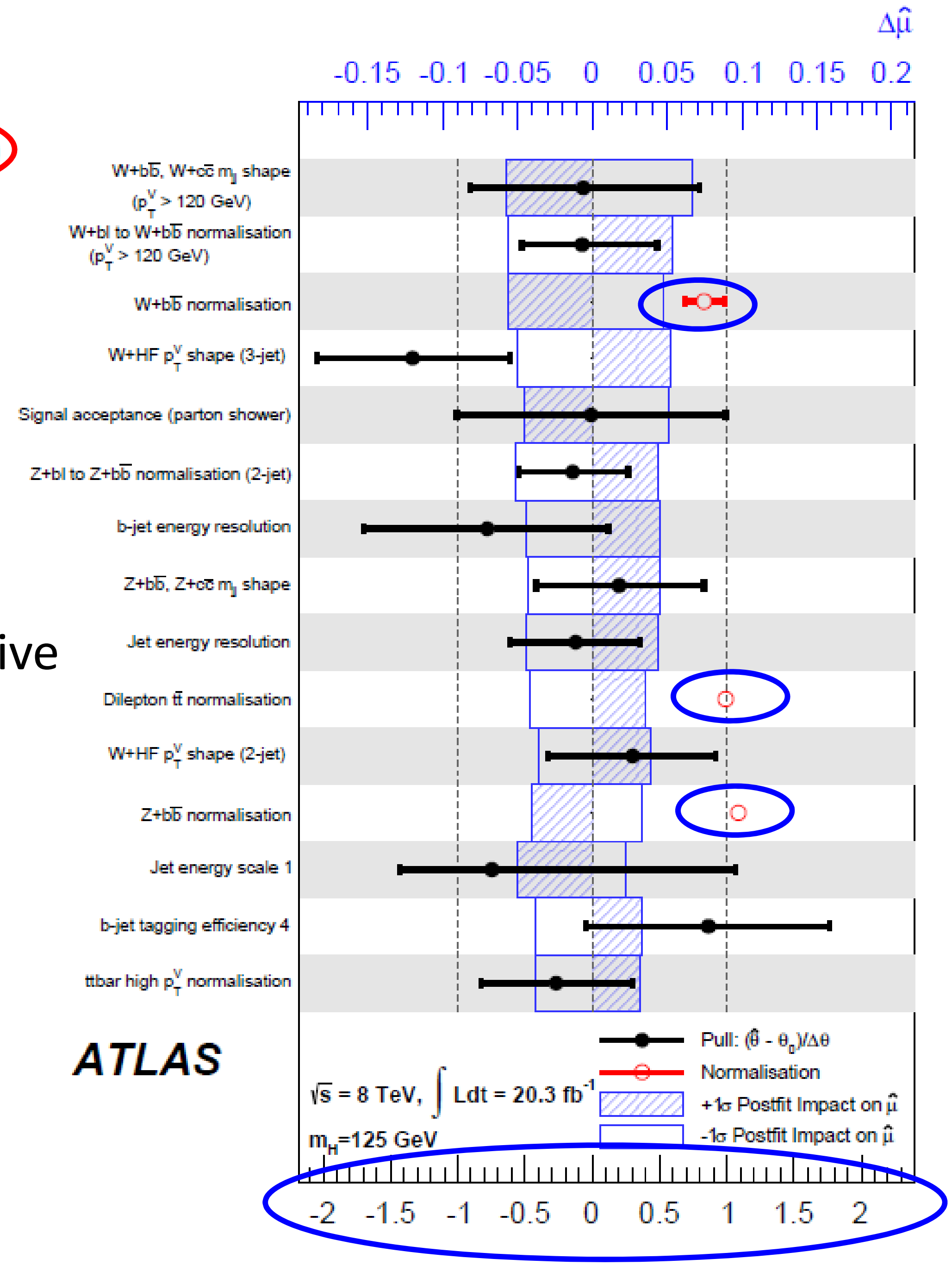
$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$

The systematic uncertainties are listed in decreasing order of their impact on the postfit impact on μ

The deviations of the fitted nuisance parameters from its nominal value .

error bars express postfit uncertainties relative to their nominal uncertainties

The normalization parameters which are freely floating in the fit



Systematics

What is the main source of systematic?

$$\mu = 0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$$

The systematic uncertainties are listed in decreasing order of their impact on the postfit impact on μ

The deviations of the fitted nuisance parameters from its nominal value .

error bars express postfit uncertainties relative to their nominal uncertainties

The normalization parameters which are freely floating in the fit

Leading systematics are:

W+jets modeling **Z+jet modeling**

Signal modeling **b-jet & jet**