H → bb:

Searching for the dominant Higgs decay mode at the LHC

Paolo Francavilla, ILP - LPNHE
ILP Day 2014
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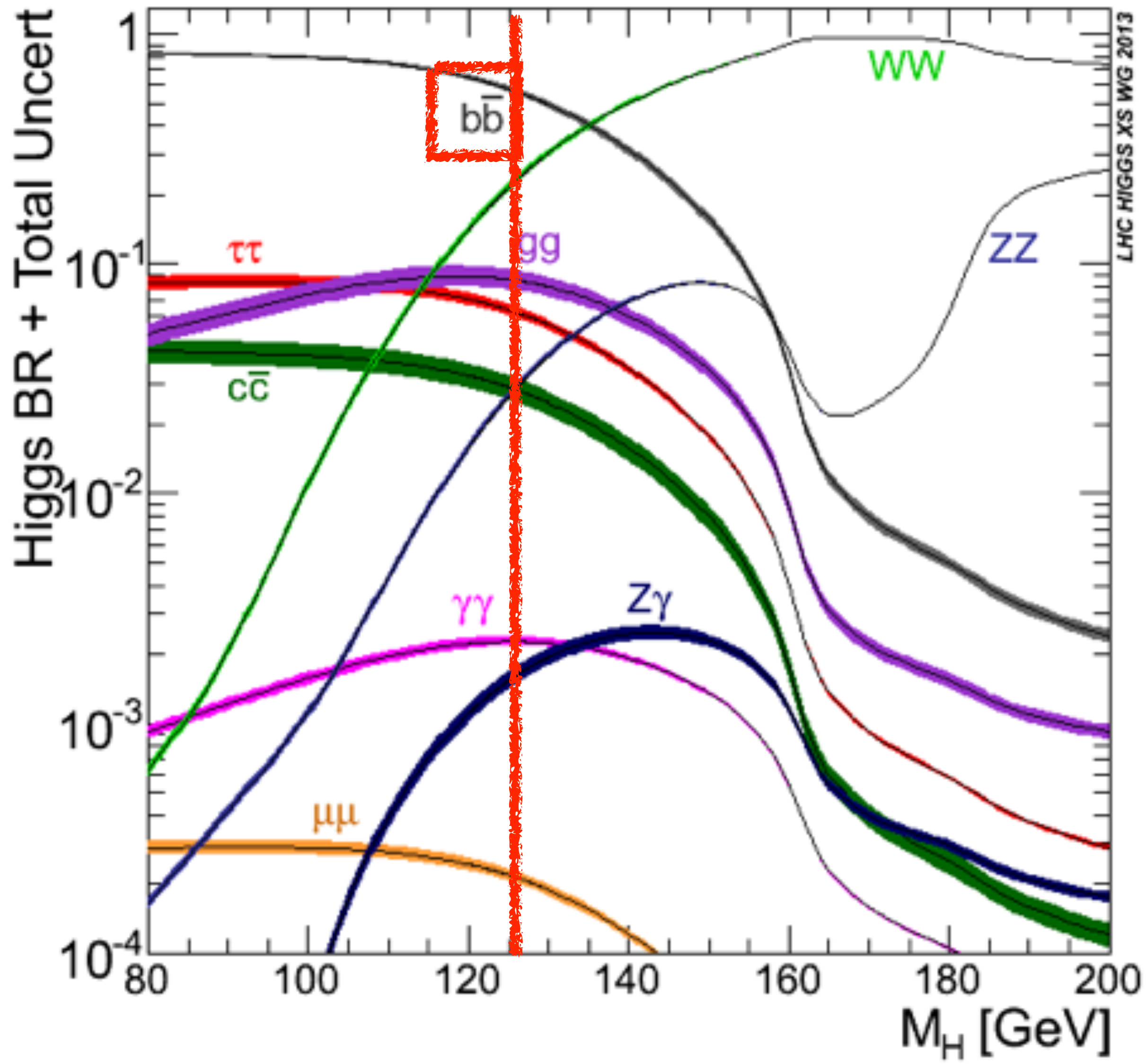
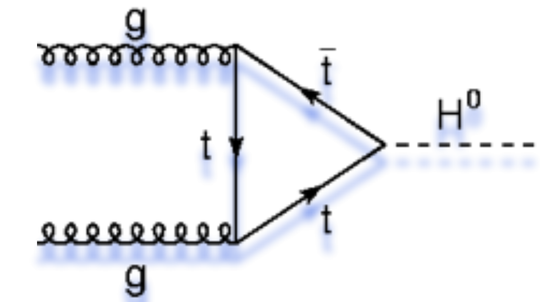
H→bb: Why?

- Since 4 July 2012:
  - Discovery of a new spin 0 particle H→γγ H→ZZ H→WW.
  - No strong deviations from SM Higgs properties.
  - Observed mH ~125 GeV.
  - Some direct evidence of coupling to fermions (H→ττ)
  - 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.

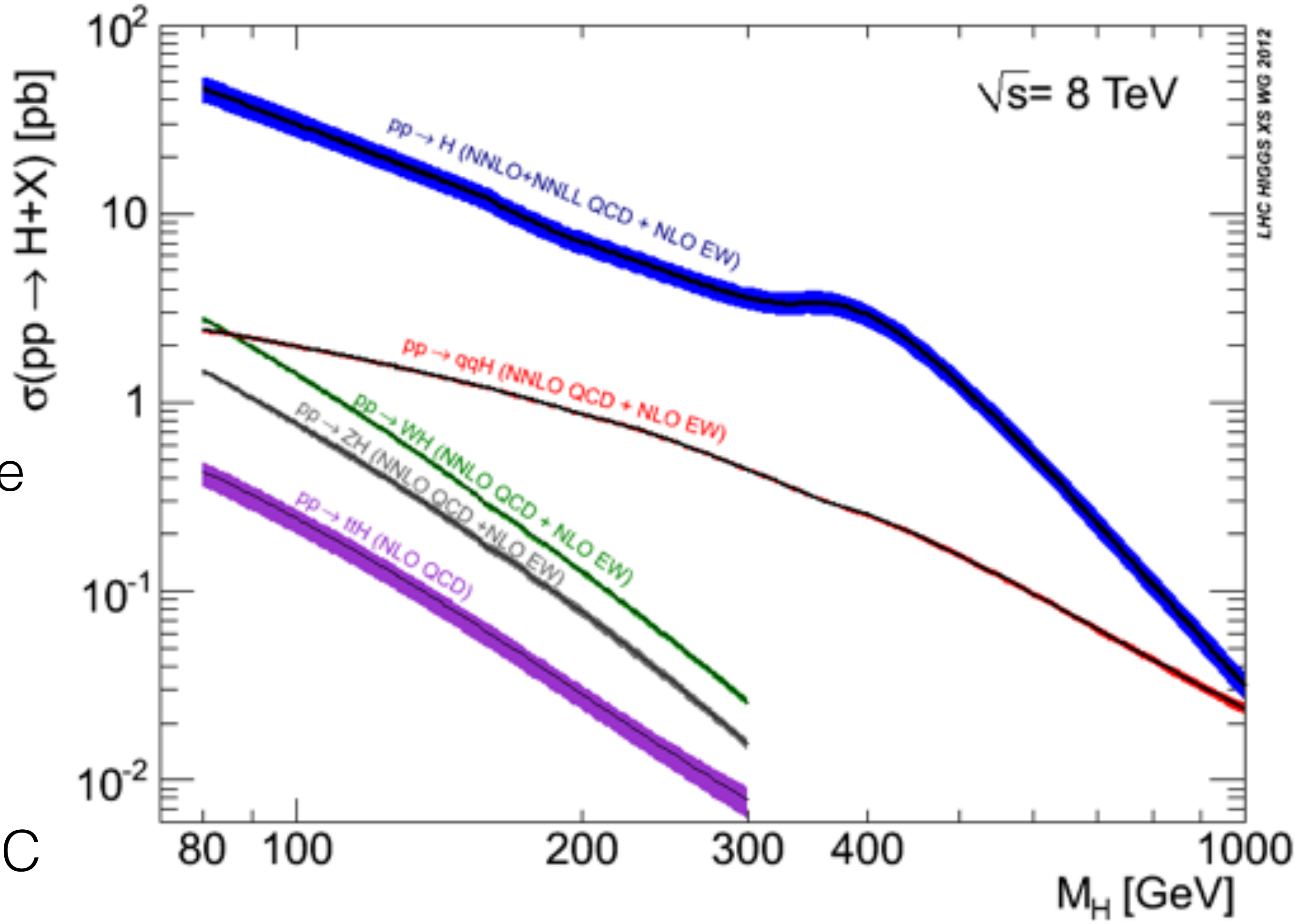


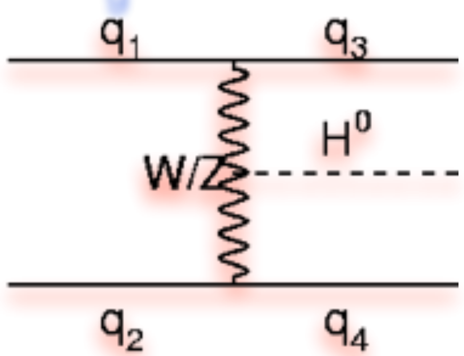
- For mH=125 GeV, BR(H→bb)=0.57
  - For very rare processes involving Higgs (SM or exotics processes), like HH production, H→bb good tool to get some statistics

H→bb:How?

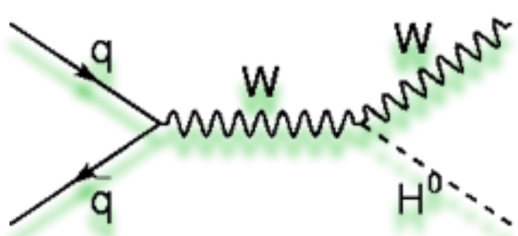


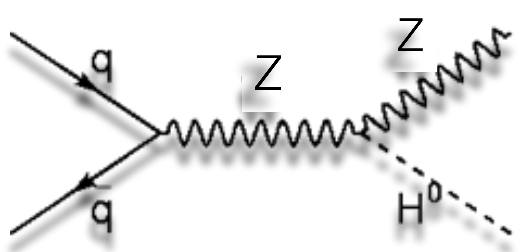
Gluon-Gluon fusion:
s/b for H→bb : <10^{-4} - 10^{-5}
Challenge for brave people



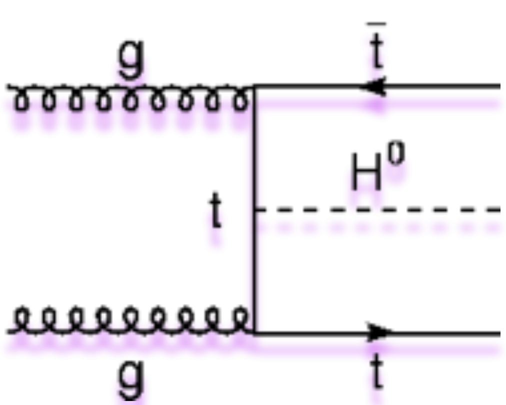


Vector boson fusion:
H→bb: better s/b
if compared with ggF
Already some results at LHC





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

The VH analysis strategy: some numbers

Decay	$Z\to\nu\nu$	$Z\to ee$, $Z\to\mu\mu$	$Z\to\tau\tau$	$Z\to$had	$W\to e\nu$ $W\to\mu\nu$	$W\to\tau\nu$	$W\to$had
BR	20%	3.3% 3.3%	3.3%	70%	11% 11%	11%	67%
N. recon. lepton cat.	0	2	/	/	1	(1) lept. decay	/
SM Higgs mH=125 VH $\to$bb events (20 fb-1, 8 TeV)	~950	~155 ~155	~155	~3300	~890 ~890	~890	~5400

NOTE: Being one of the leading forces for 0 lepton analysis, Editor of the supporting documentation for the results shown here, and editor of the supporting note of the paper in preparation

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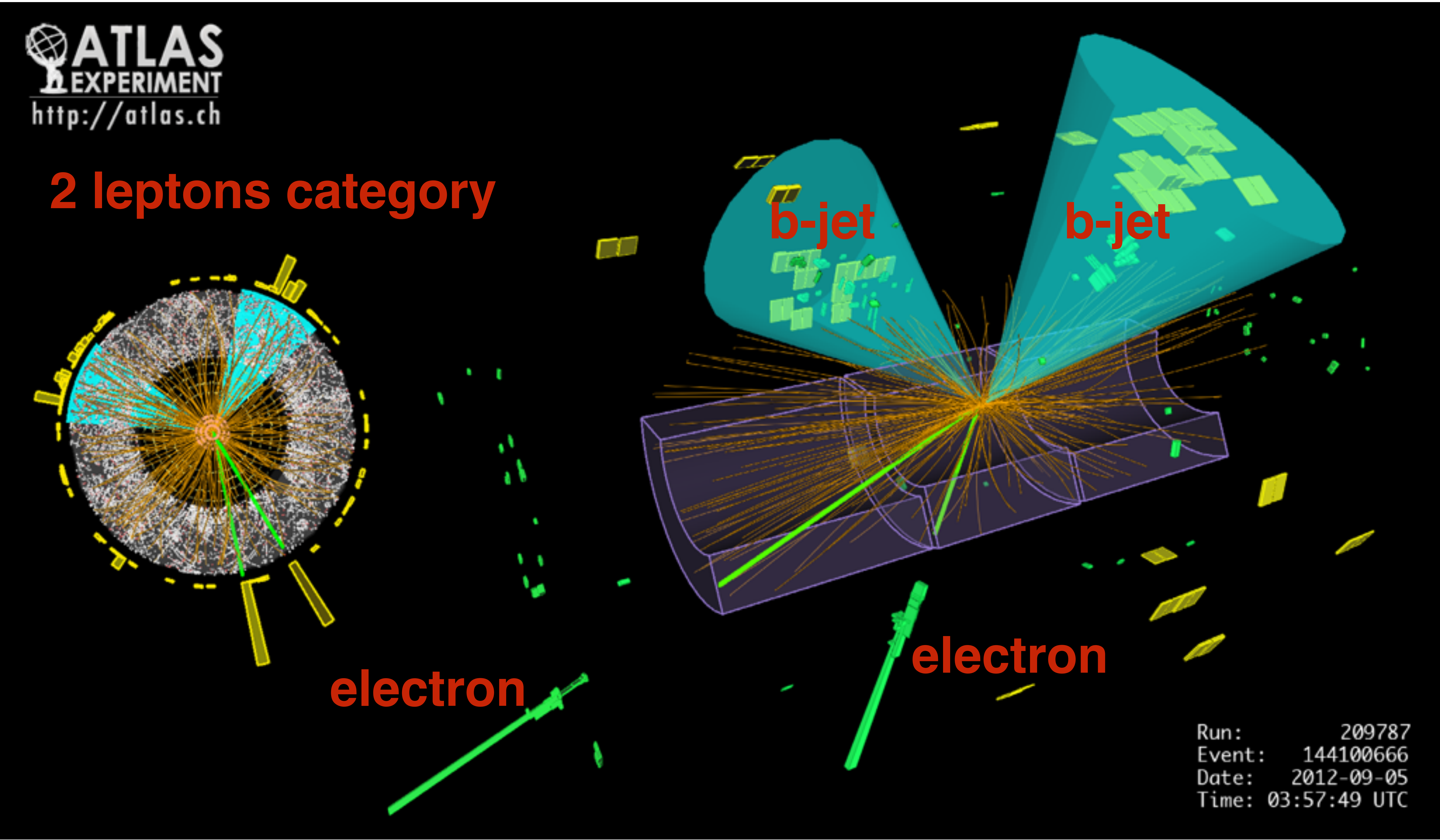
From these events to the analysis selections:
Trigger,
Lepton reconstruction acceptance and efficiency,
Jet reconstruction acceptance and efficiency,
b-tagging efficiency,
Cut optimisation to suppress the background (i.e. $90<m_{bb}<150$)

NOTE: Thanks to some of the people in ILP, we adopted in 2009 a revolutionary jet definition (anti-k_T), and a series of tools which helped us a lot. THANKS!

How an event would look like



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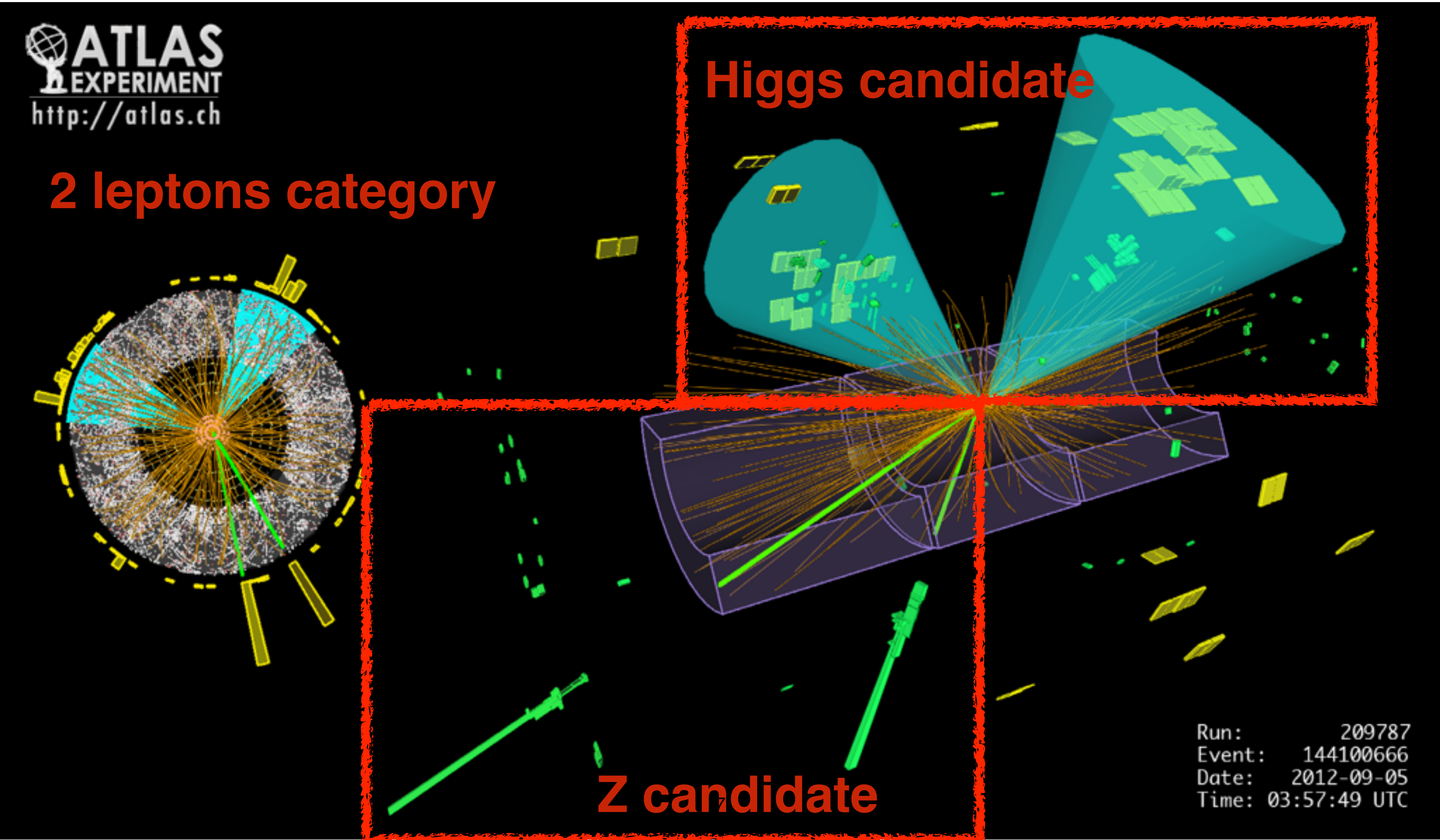
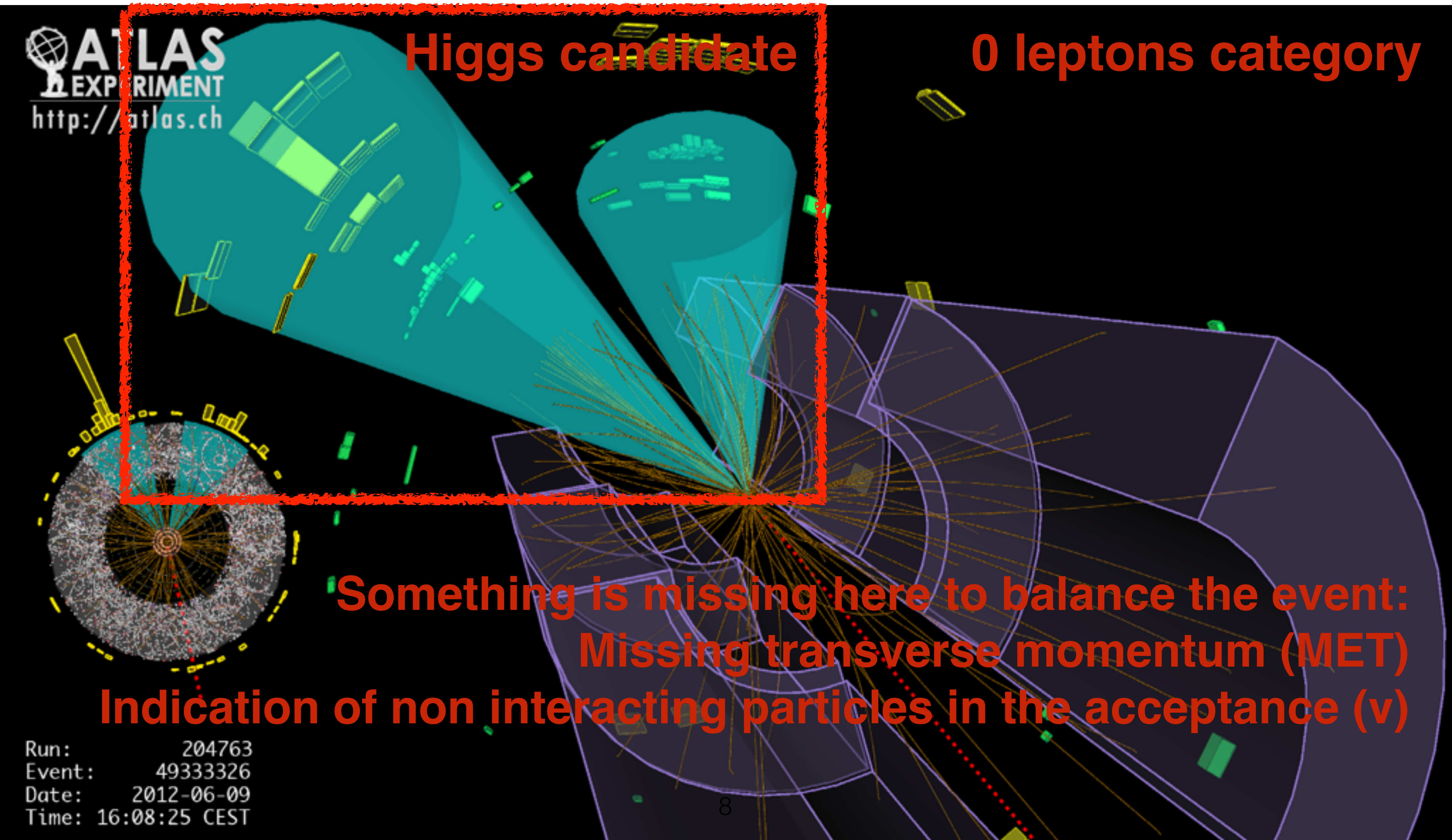


NOTE: Calorimeter plays a relevant role here
(glad to make it working while being Run Coordinator for the Tile Calorimeter in 2011)

How an event would look like



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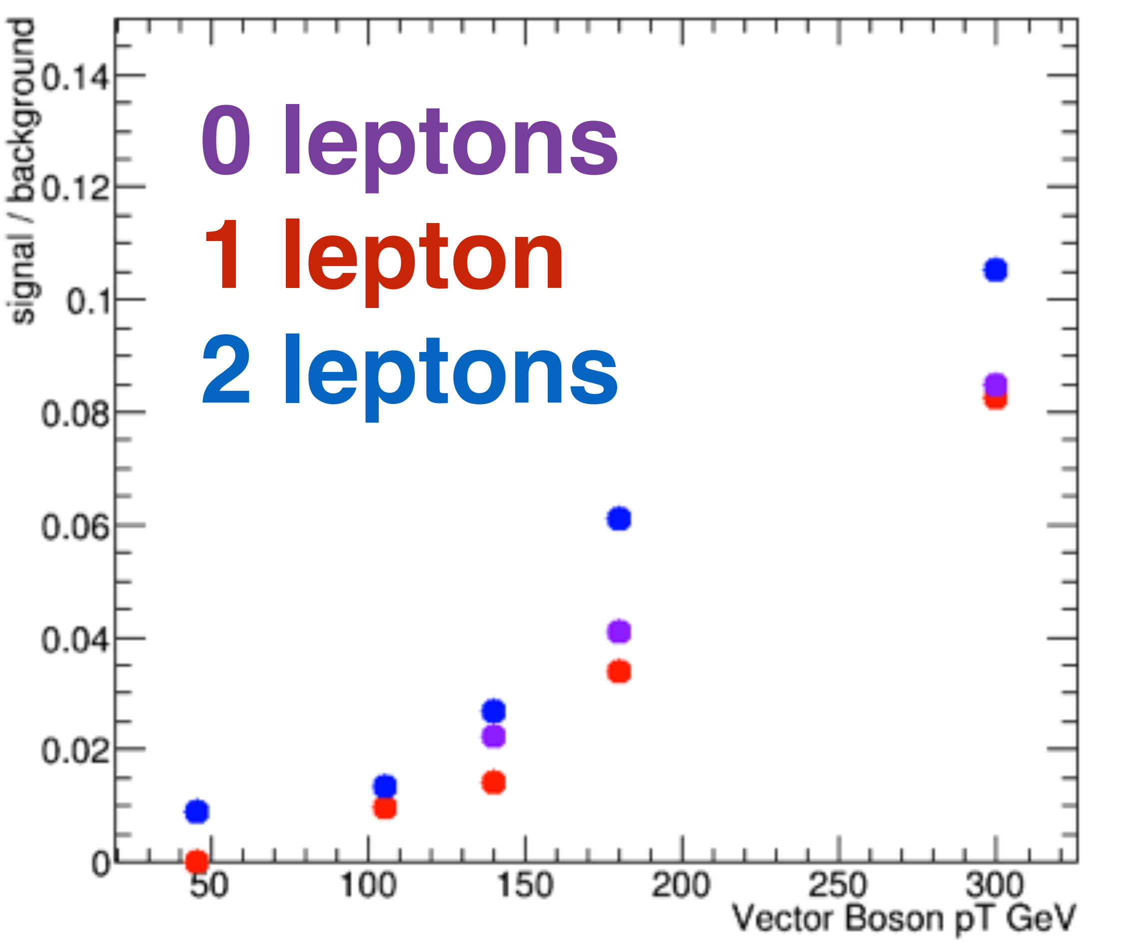
After selections	30	27	/	/	93		/
Background after selections	1100	2500	/	/	15400		/
s/sqrt(b)	0.9	0.5	/	/	0.7		/

Can we do something more to get more sensitivity?

Building the VH analysis



Clear improvement of S/B vs vector boson pT

NJets	2 jets	3 jets
0 leptons s/b	3%	1.6%
1 lepton s/b	0.9%	0.3%
2 leptons s/b	1%	0.9%

Different S/B for 2 and 3 jets events. (ttbar in 1 lepton analysis)

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

Building the VH analysis in ATLAS

DATA
2011: 4.7 fb-1 @ sqrt(s)=7 TeV
2012: ~21 fb-1 @ sqrt(s)=8 TeV

MC
WH/ZH PYTHIA8
Top POWHEG+PYTHIA
Single Top ACER/POWHEG+PYTHIA
W+jets SHERPA
Z+jets SHERPA
Diboson (WW,WZ,ZZ) HERWIG

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

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		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

Reconstructed lepton categories

Split 2 jets VS 3 jets

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3 p_T^V bins x	0-lepton	Norm	Norm	**Shape**	Shape	-
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Regions used to control the backgrounds

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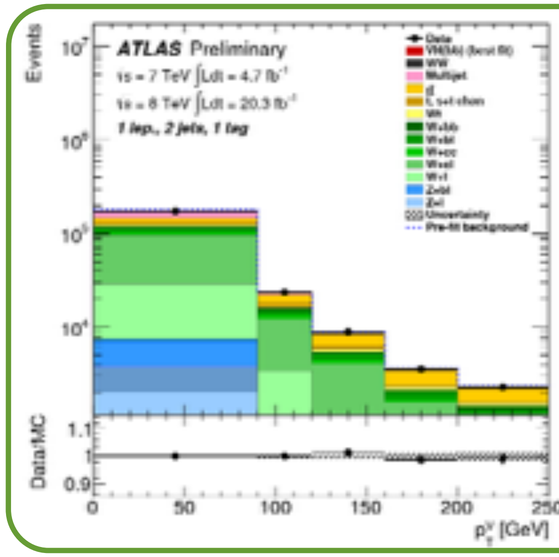


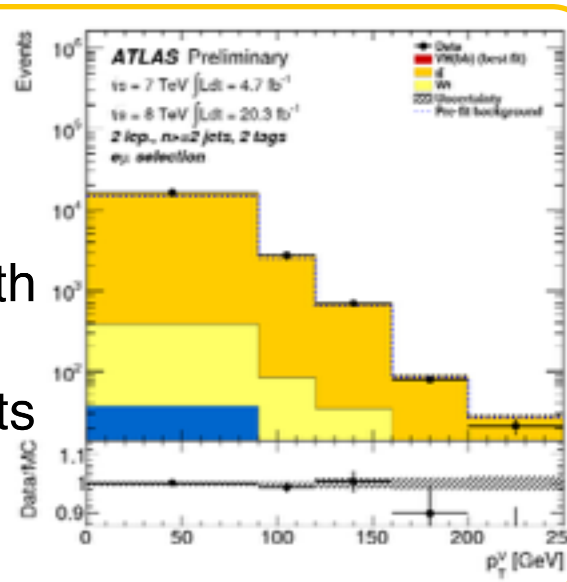
Example of control region

2jet 1tag

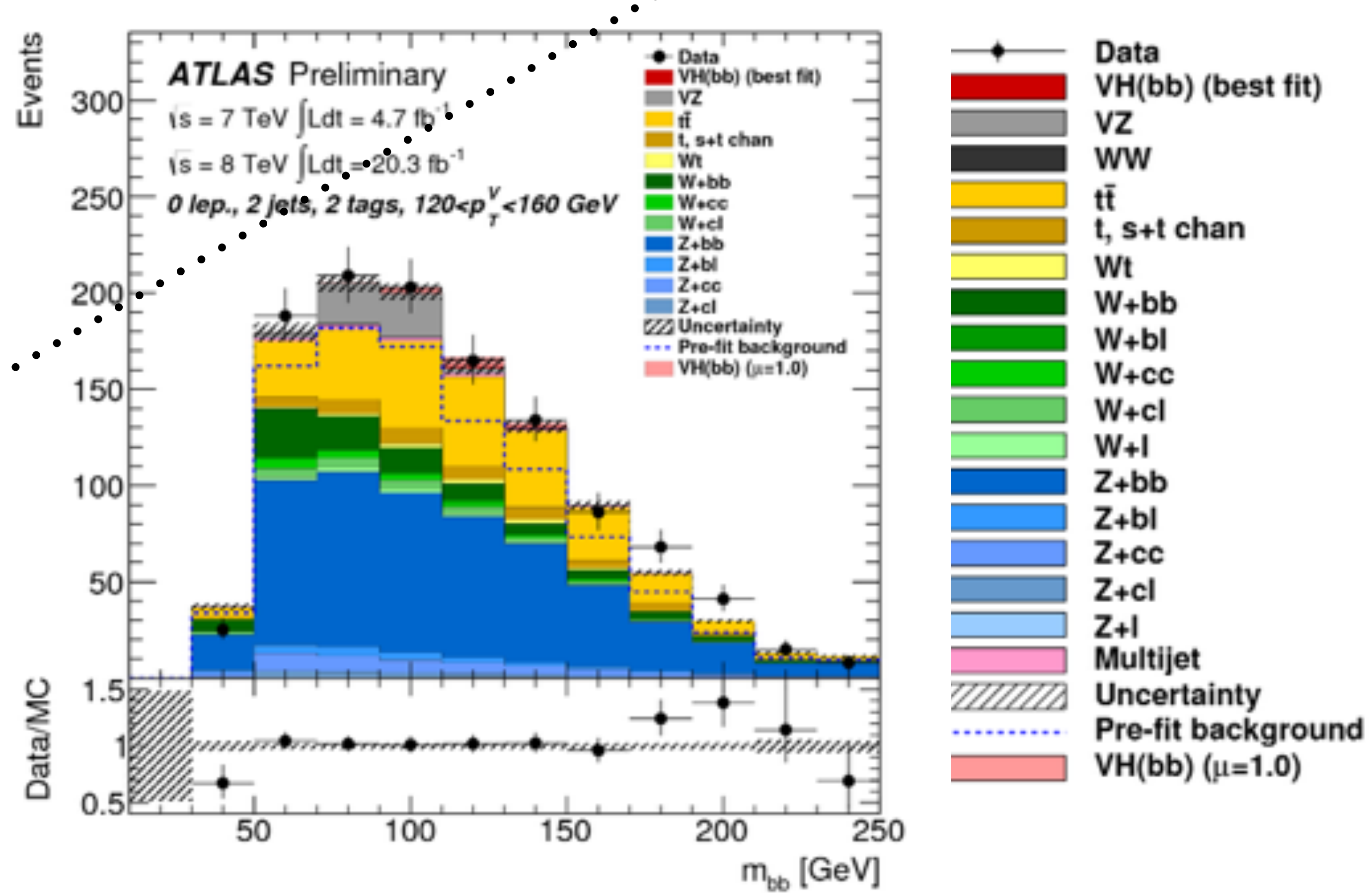
1 lepton

Cut applied:

- 2tag2jets.
- Signal e and mu with mll>40 GeV.
- No mll and MET cuts



Example of 2jets2tag signal regions



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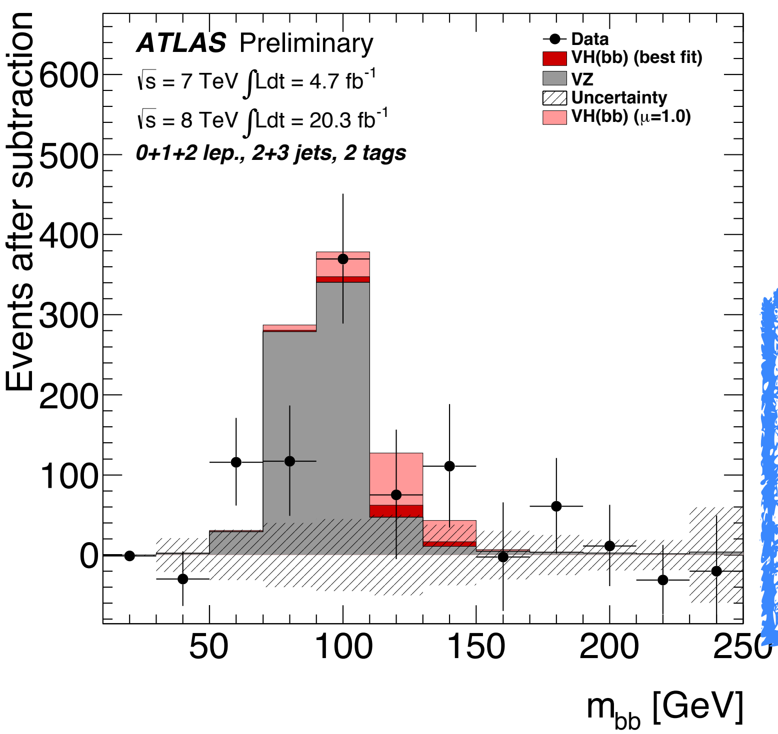
VH→bb Results



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

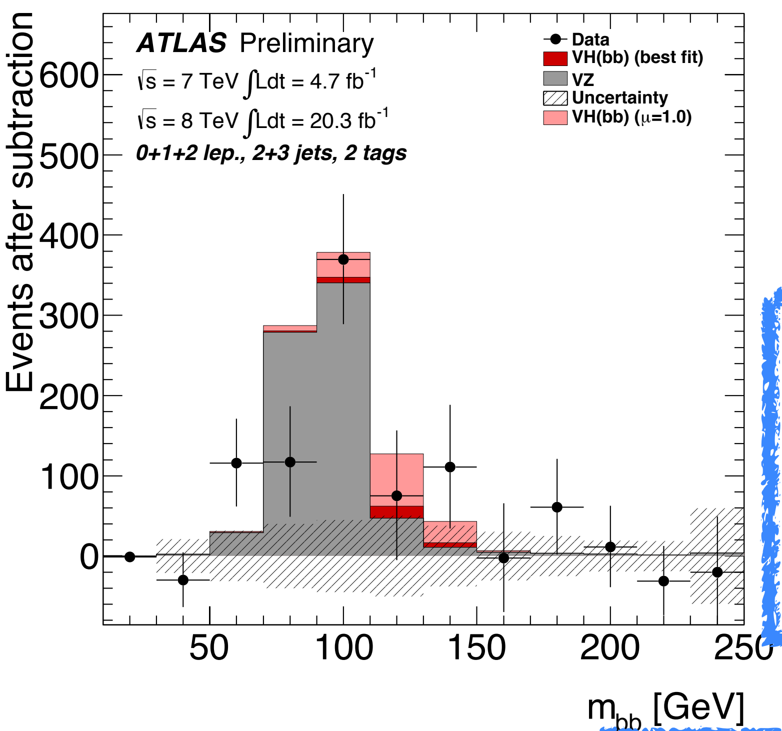
Significance of the VZ: 4.8 sigma(5.1 expected)

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

The analysis is complex, but fortunately we have a candle to validate it: VZ→bb

ATLAS-CONF-2013-079

VH→bb Results



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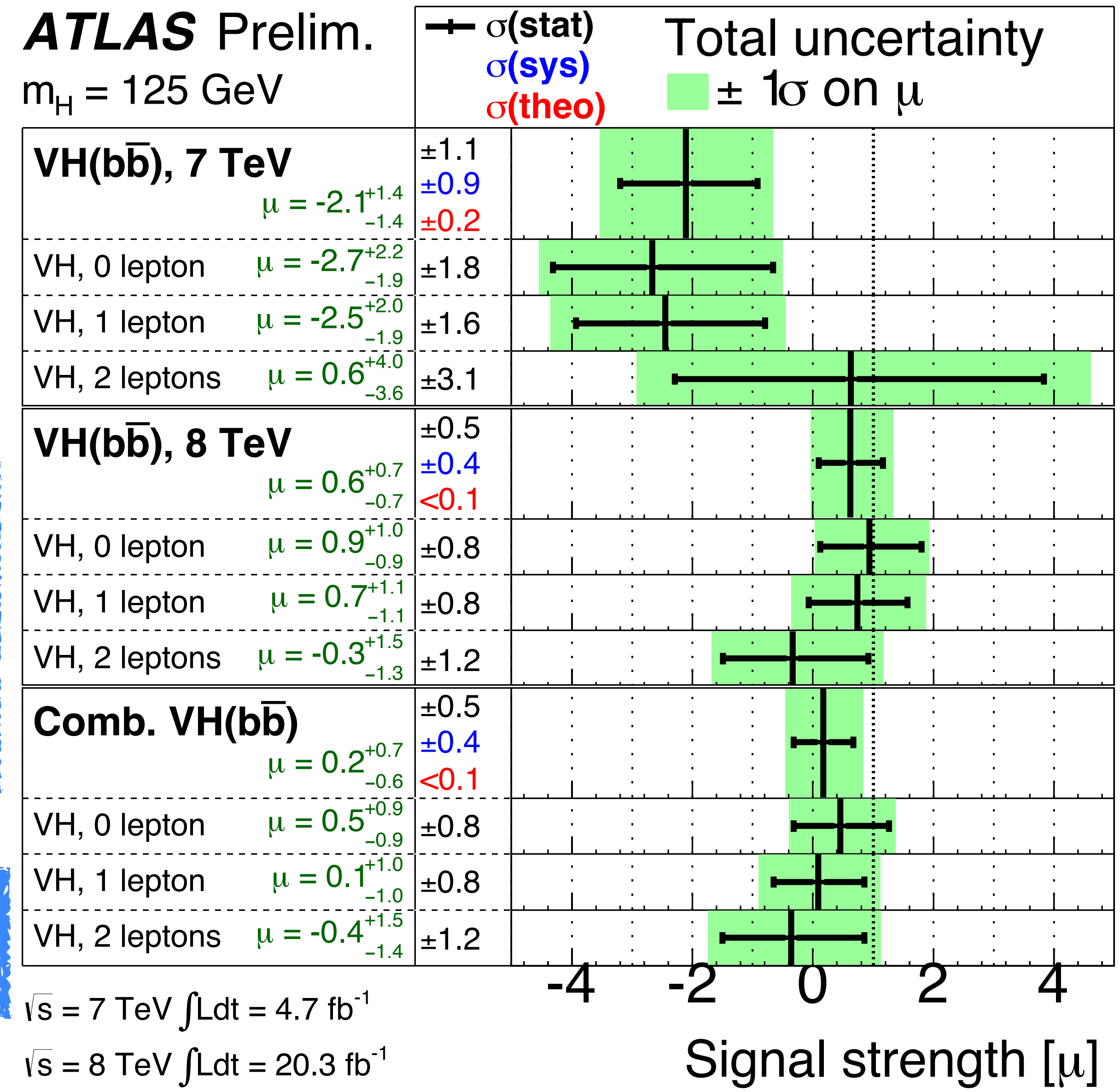
$$\mu = 0.2 \pm 0.5(\text{stat.}) \pm 0.4(\text{syst.})$$

$$m_H = 125\text{GeV}$$

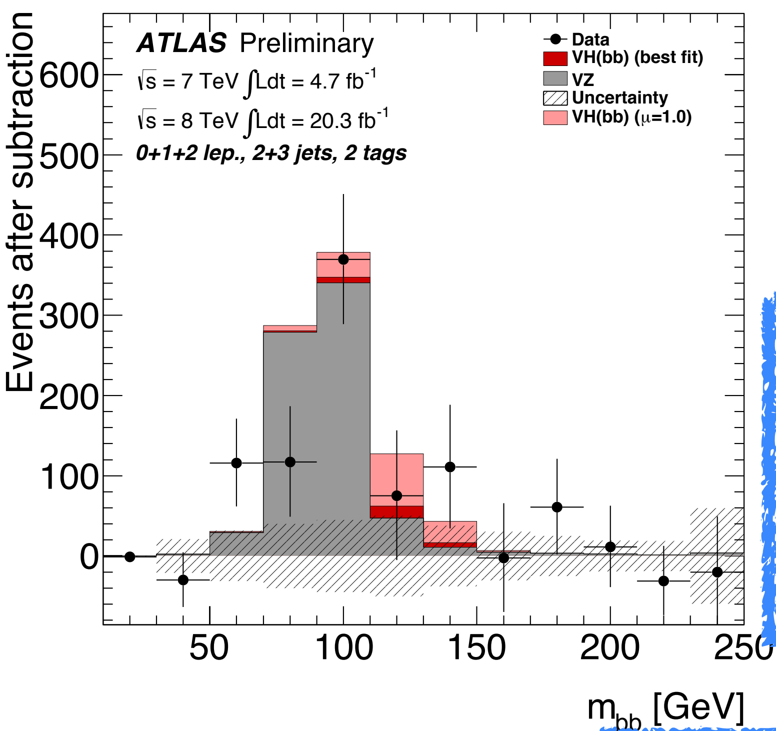
CMS BDT: μ=1.0±0.5 local significance 2.1σ

CMS mjj: μ=0.76±0.7 local significance 1.1σ



ATLAS-CONF-2013-079

VH→bb Results



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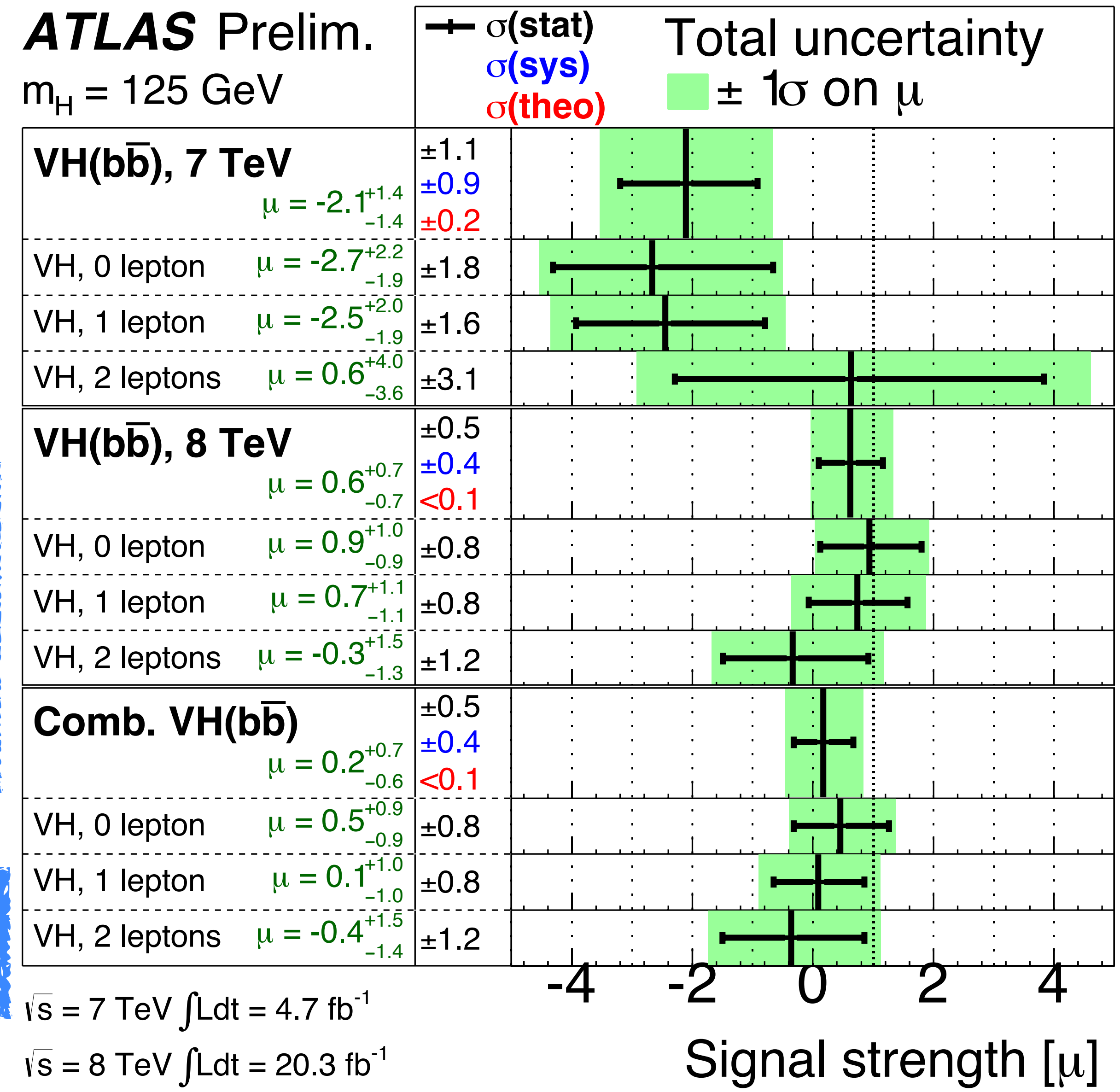
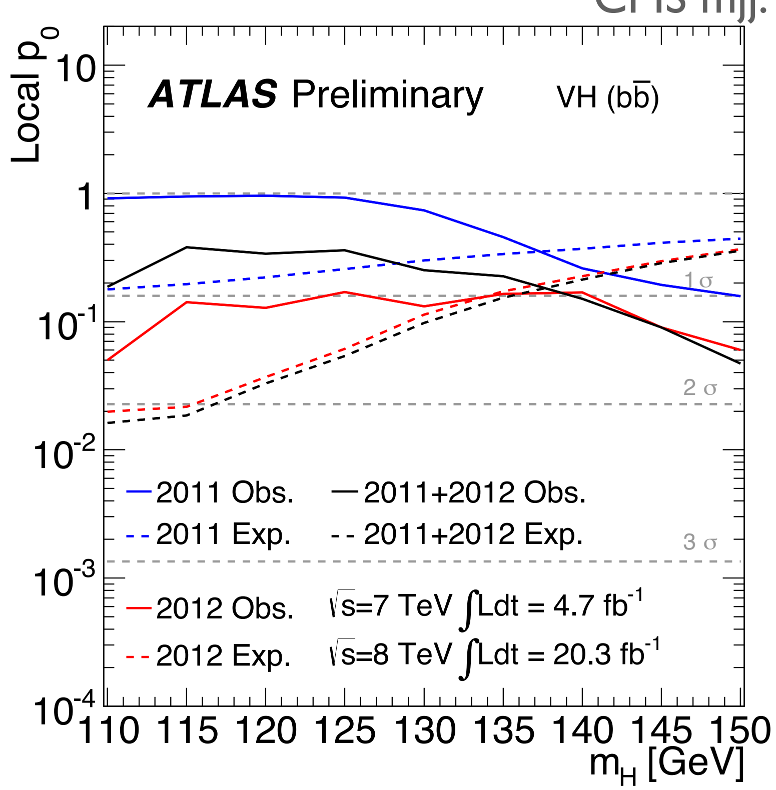
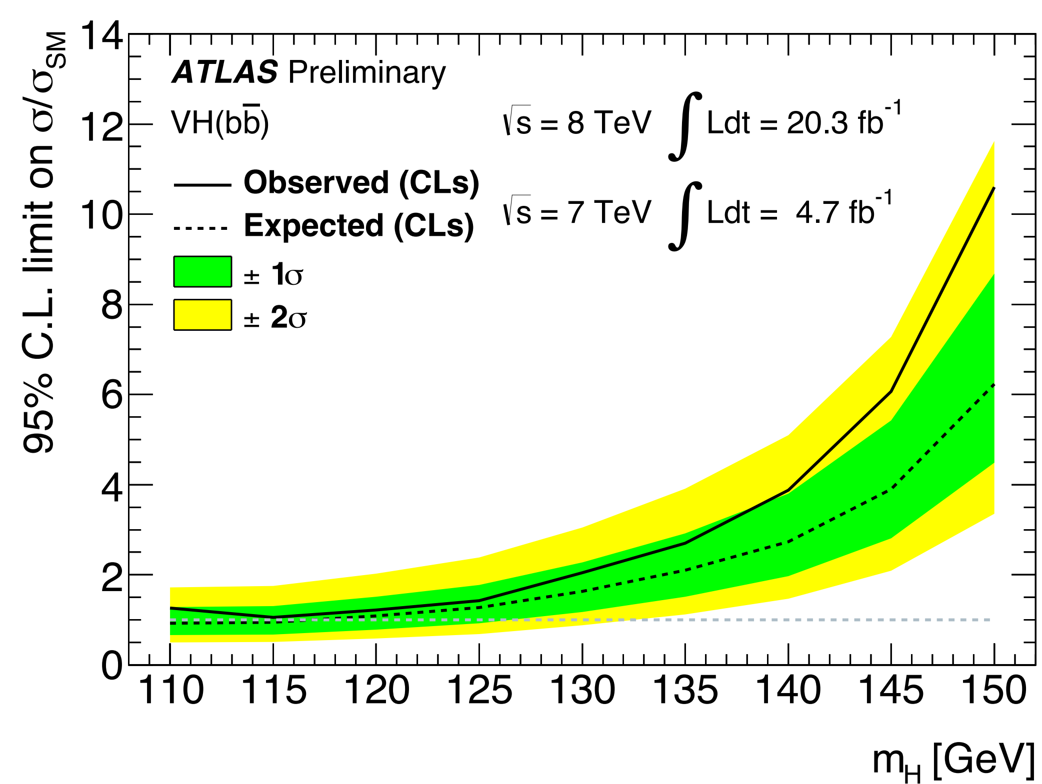




VH:
obs. (exp.) limits at 125 GeV:
1.4 (1.3) xSM
CMS BDT: 1.89 (0.95)
CMS mjj: 2.0 (1.4)
obs. (exp.) probability of obtaining a result at least as signal-like in the absence of signal:
0.36 (0.05)



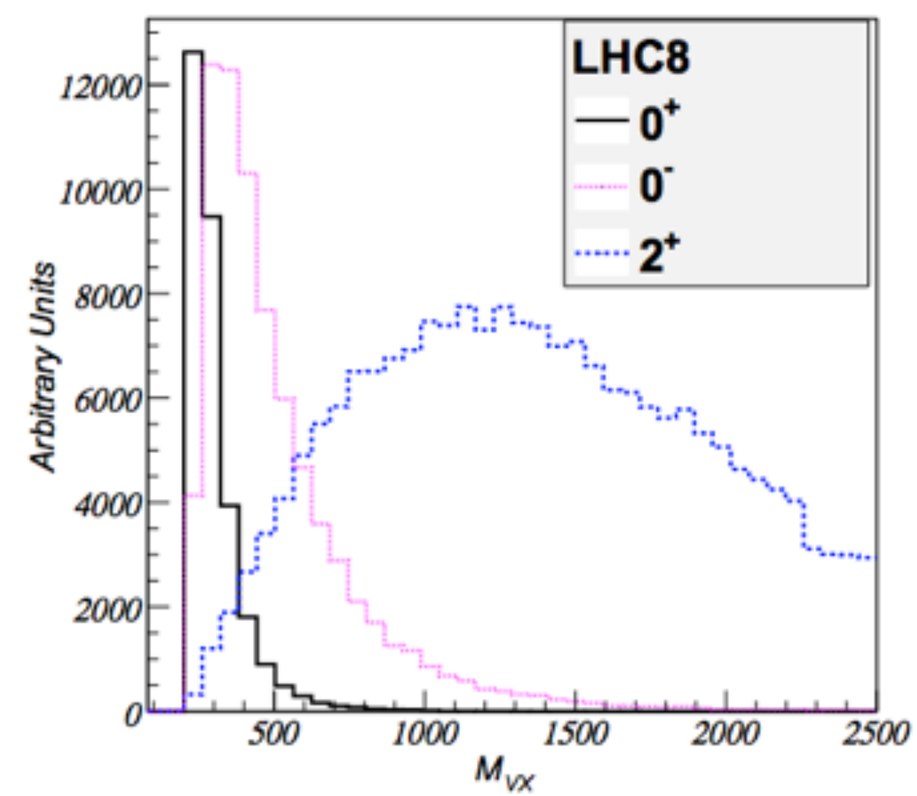
Foreseen improvements for the final Run 1 results

Deacay	Z→νν	Z→ee, Z→μμ	Z→ττ	Z→had	W→eν W→μν	W→τν	W→had
After selections	30	27	/	/	93		/
Background after selections	1100	2500	/	/	15400		/

We hope to arrive soon to a new VH result in ATLAS.
ttH and VBF ongoing

- Given the table: possible improvements:
  - Increase the signal acceptance
  - Improve the background rejection (i.e. multi variate analysis)
- Two big constrains:
  - Several backgrounds need to be dominated,
  - A better understanding of the detector performance (i.e. B-tagging, jets, MET)

And the spin?
JHEP 1211, 134 (2012)
Using M(VH) to discriminate.
Clear hope with more statistics.
Nice challenge for the current statistics



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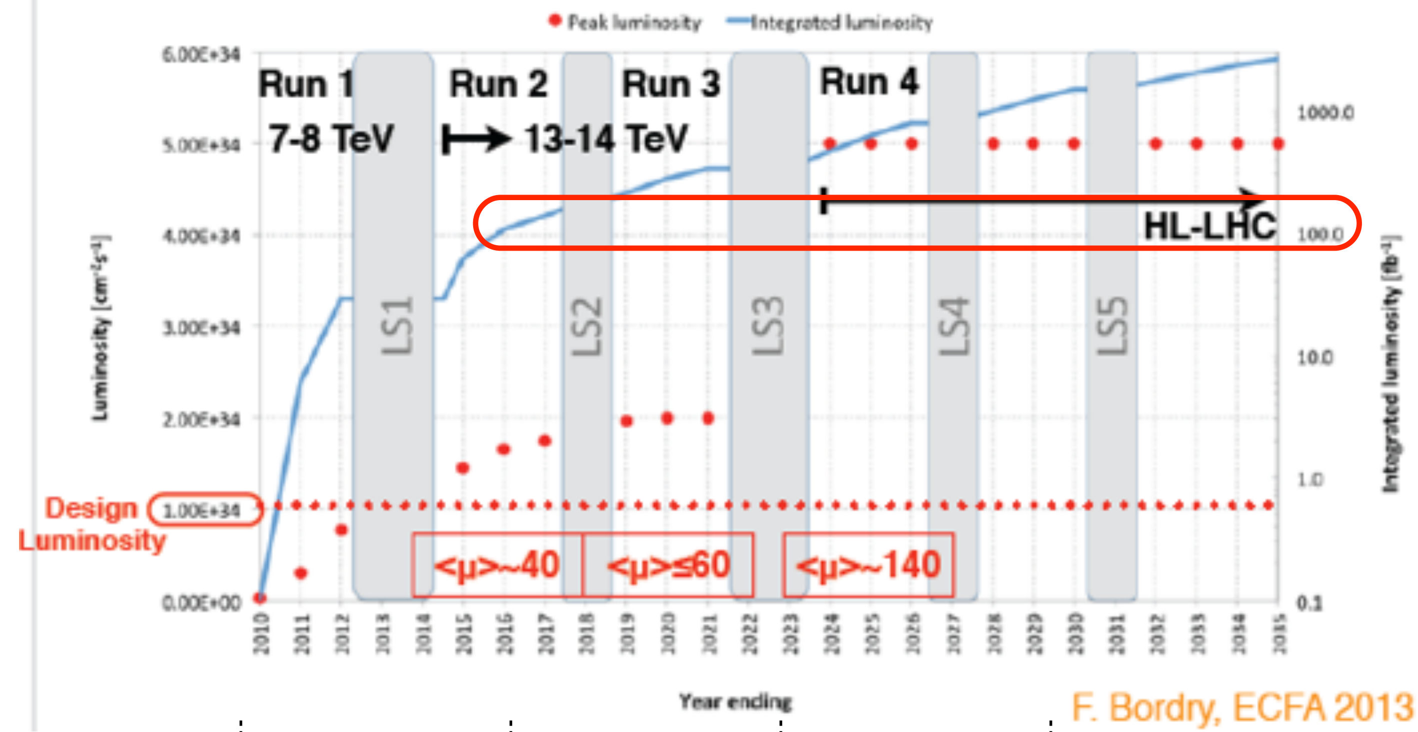
Perspectives

Assuming just luminosity and cross section scaling:
- **tt(14 TeV)/tt(8 TeV) :3.9**
- **EW(14 TeV)/EW(8 TeV):1.9**

No other analysis improvement assumed
No deterioration of performance due to operation condition
- **i.e. trigger, pile-up**

No performance improvements assumed
No limitation due to systematic uncertainty assumed

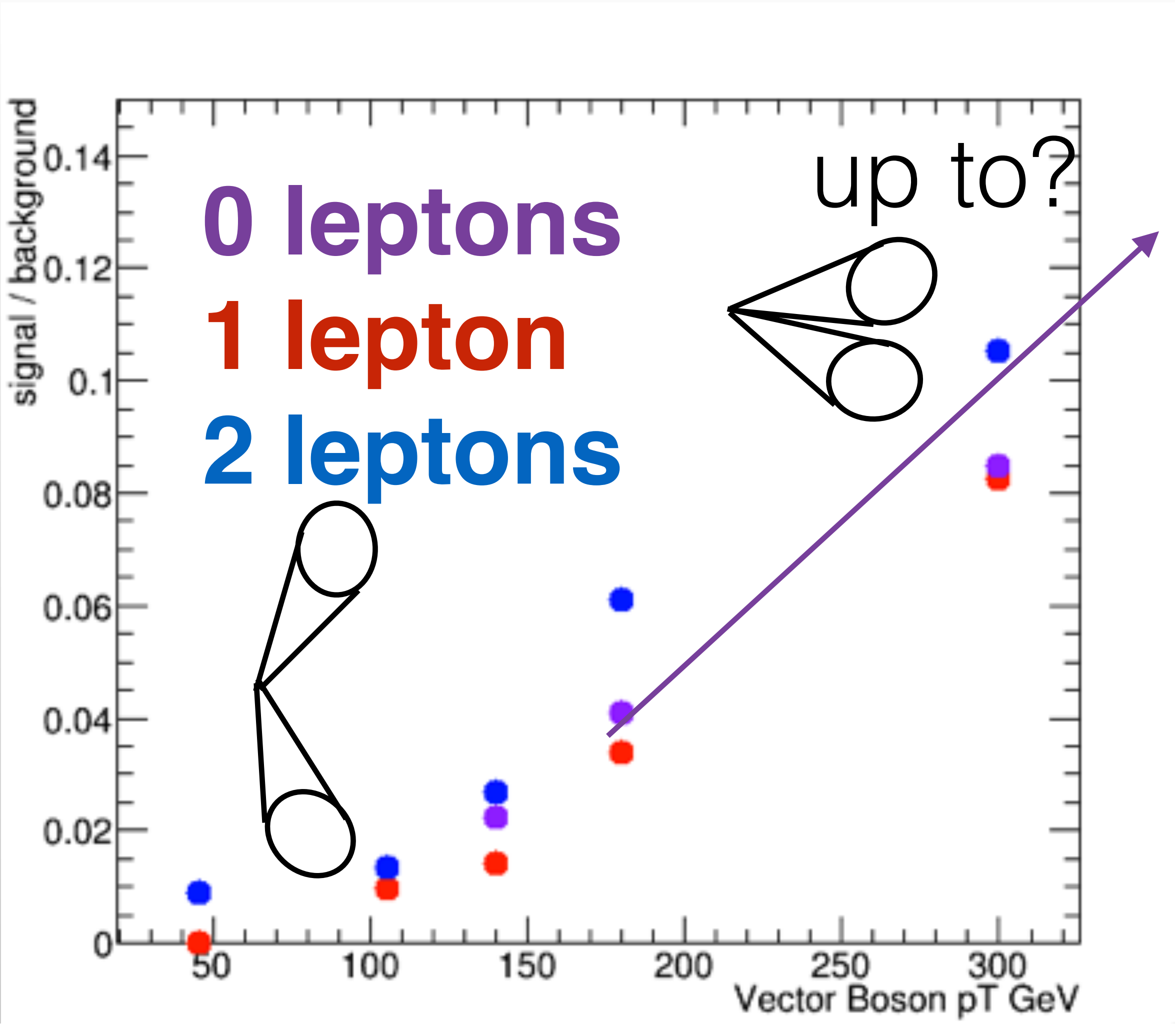


F. Bordry, ECFA 2013

Decay	Z→νν	Z→ee, Z→μμ	Z→ττ	Z→had	W→eν W→μν	W→τν	W→had
VH →bb events (100 fb	11000	1800 1800	1800	39000	9500 9500	9500	58000
After selections*	350	340	/	/	992		/
Background after selections*	13500	26000			246000		
s/sqrt(b)	3	2			1.3		

Note: ingenuity will improve these numbers!!

Performances:Jet substructures



Clear improvement of S/B vs vector boson pT

In the current analysis, we require at least 2 jets. If pT(H)> 300-400 GeV non negligible fraction of events will have the Higgs decay products reconstructed in a jet with R =1 or 1.2.

So, if we want to get more and more sensitivity from the boosted regime,

1) we have to make sure we are not loosing events because they do not pass the 2 jet selection
2) we need to use the best technology to reconstruct the Higgs candidate.
    1) small R sizes?
    2) jet substructure techniques?

Very active community in HEP developing jet substructure techniques.
Possible option to deeply investigate for VH→bb for Run 2
and in searches of new physics with H→bb

NOTE: glad to help on this being MET sub- convener 2013-2014

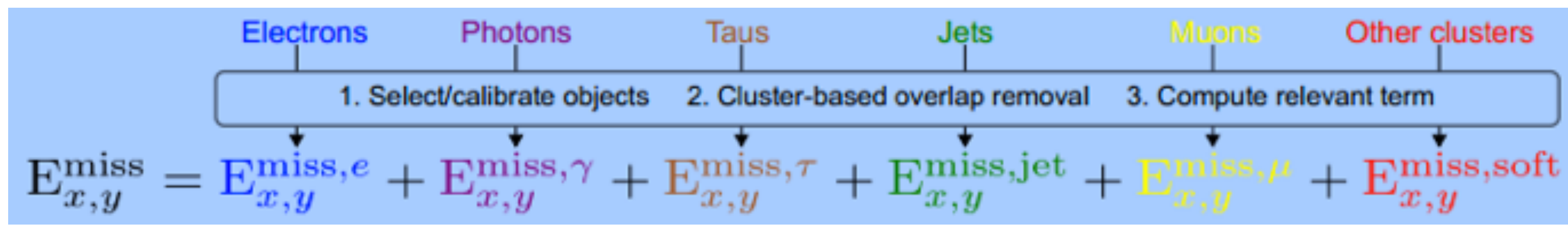
Performances : MET

Used in VH to estimate the Z→νν p_T, the reconstruct the W p_T, to suppress the top background in Z→ll

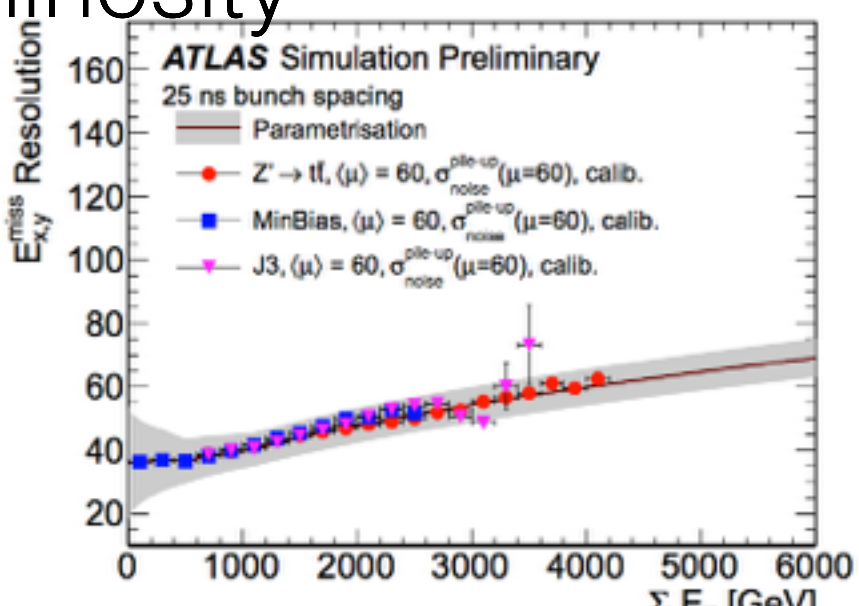
Widely used in ATLAS, in standard model measurement, and particularly interesting in new physics (SUSY, Dark Matter,…) searches

naive definition: measurement of what is missing in the transverse plane to balance the event

more accurate description: keep correlations with all the other objects in the event

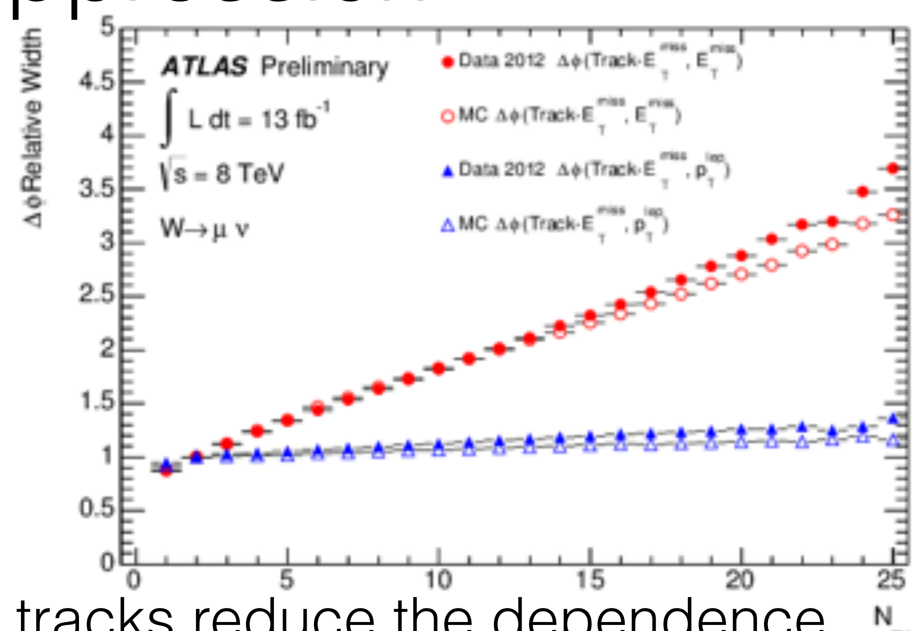


High luminosity



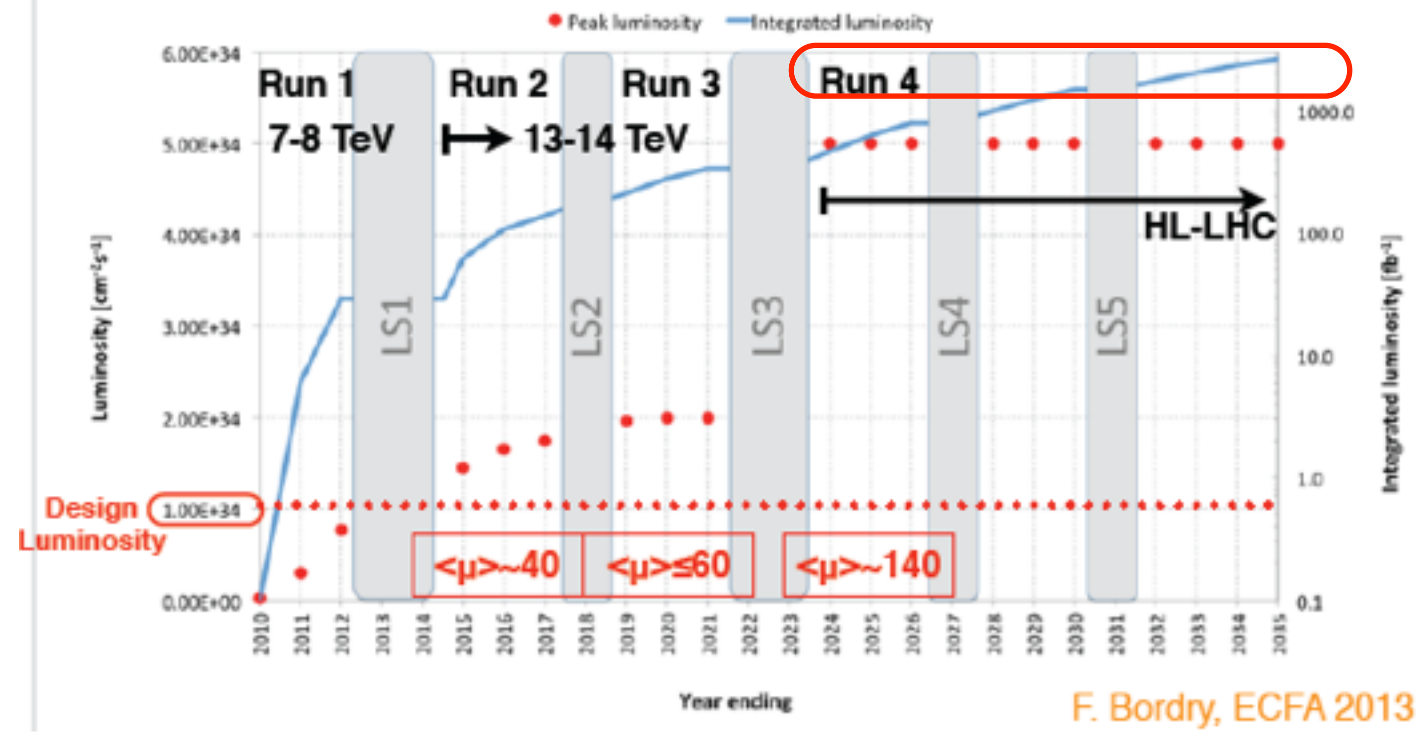
First simulation to get the prospective for MET performance already done (used for all the prospective studies in ATLAS).
Optimisation ongoing

PU suppression



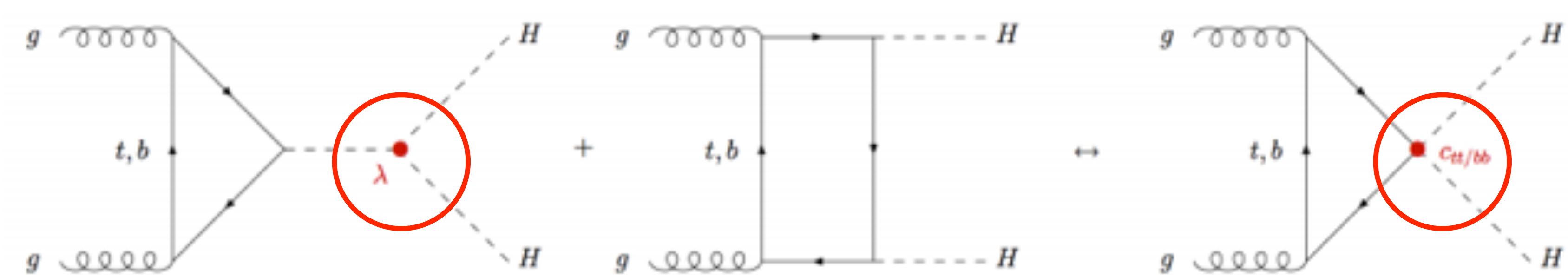
Use of the tracks reduce the dependence on Npv (pileup).
Working to complete the definition for Run 1 and to get the systematics

Perspectives: H→bb long term



If 2015-2020 will be a crucial period for physics at the LHC, 2035 is not that far… First very preliminary performance studies already done, with incredible high level of pile-up on average 140 interactions per bunch crossing, and just one of this could be the interesting one. If 40 is already a challenge, 140 will be for brave people.

But, among the other possible studies, with 3000 fb -1 of data we can start to approach the door of the double Higgs production.



ESTIMATED YIELDS FOR 3000/fb

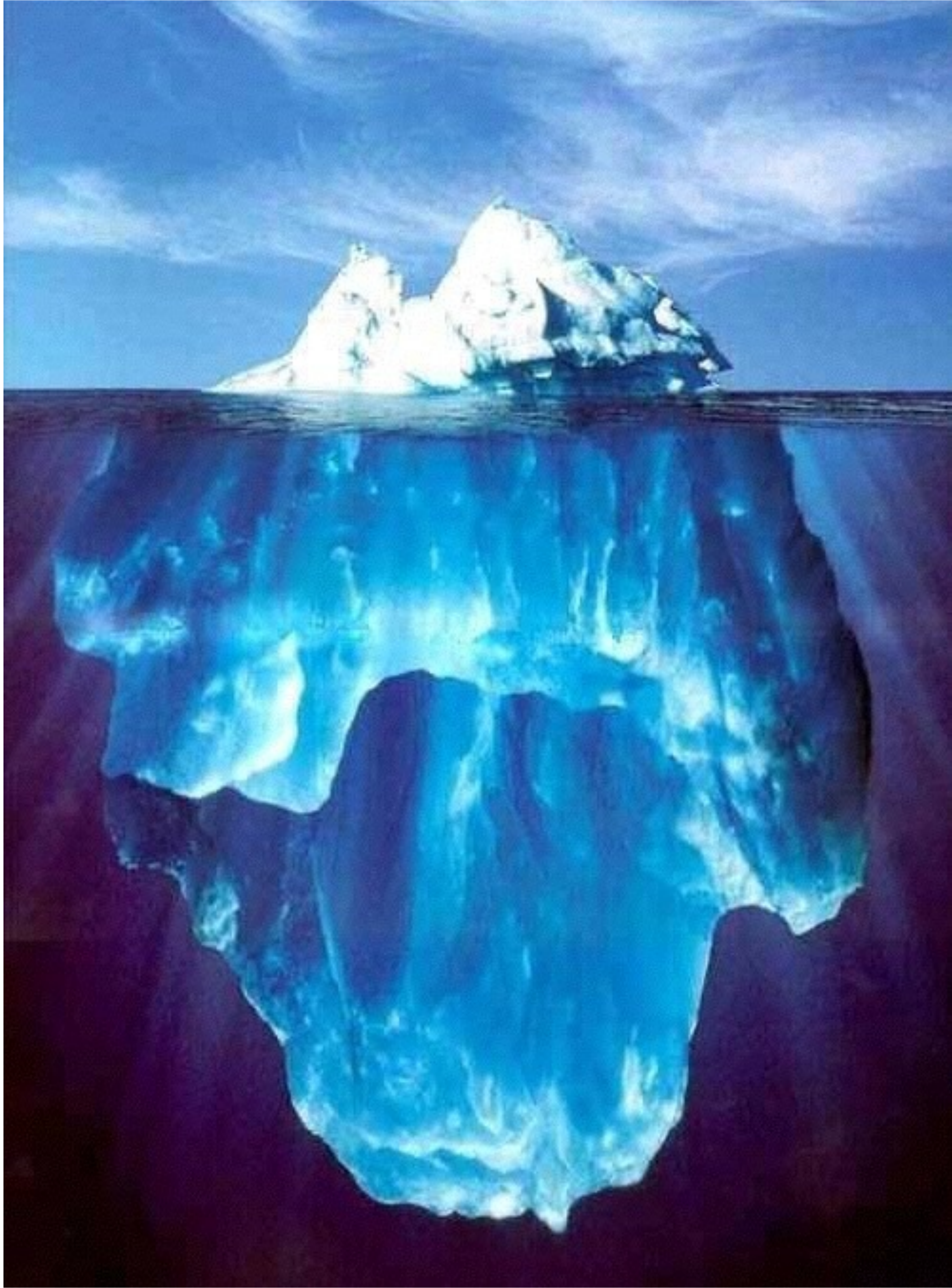
bbWW	bbττ	WWW	γγbb	γγγγ	bbνννν
30000	9000	6000	320	1	150

probably, among the others, bbττ could be the most promising

Given the BR=0.57, signatures with H→bb will play a relevant role

Conclusions

- We have just seen the peak of the iceberg.



Conclusions

- We have just seen the peak of the iceberg.

- Surprises will come!