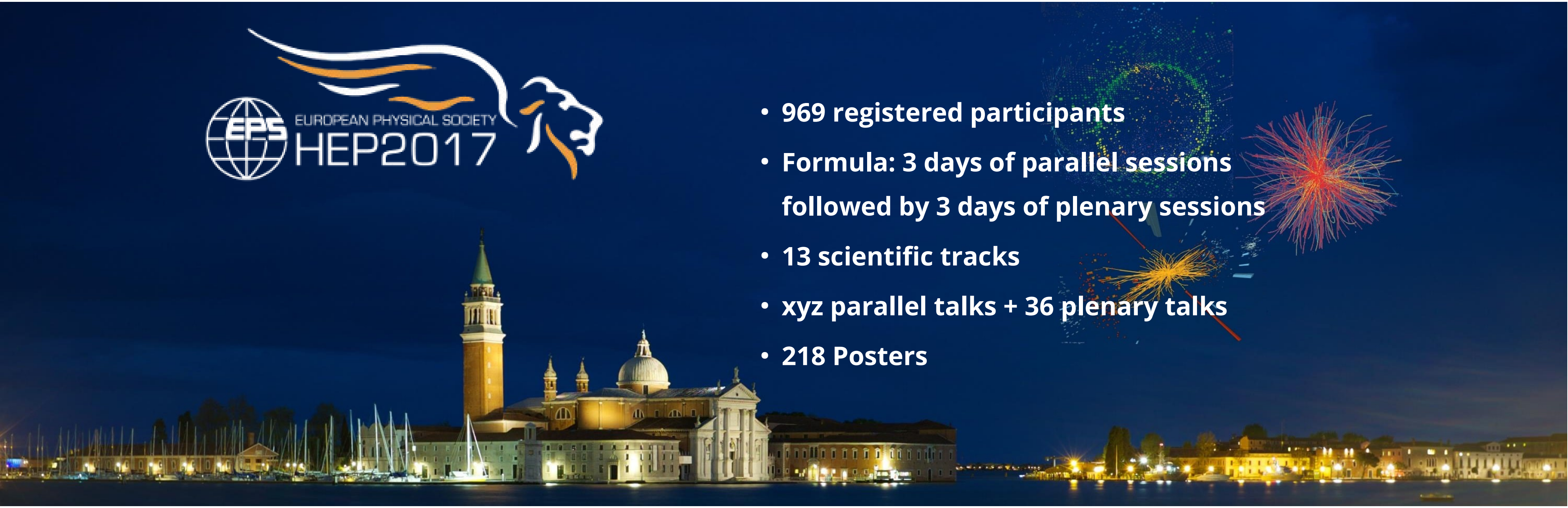
EPS 2017
Highlights on collider physics

Paolo Mastrandrea

6/10/2017 – LAPP



- **969 registered participants**
- **Formula: 3 days of parallel sessions followed by 3 days of plenary sessions**
- **13 scientific tracks**
- **xyz parallel talks + 36 plenary talks**
- **218 Posters**

HEP Panorama

- **The Highest Energies**
  - Our pride, source of great hope(s); SM, Higgs, BSM, Flavor, matter at its extremes
- **The neutrino sector**
  - Cause ν's are so very different; PMNS, fermion nature, BSM, sterility
- **The dark sector**
  - The experimental evidence for physics outside the SM
- **The cosmos**
  - Not strictly always "particle" physics; equally fundamental
- **Dedicated-measurement experiments**
  - Complementary to high E; fundamental symmetries
- **Theory: because we need to understand what we're doing**

P. Sphicas
Highlights from EPS 2017

EPS HEP 2017, Venice
July 12, 2017

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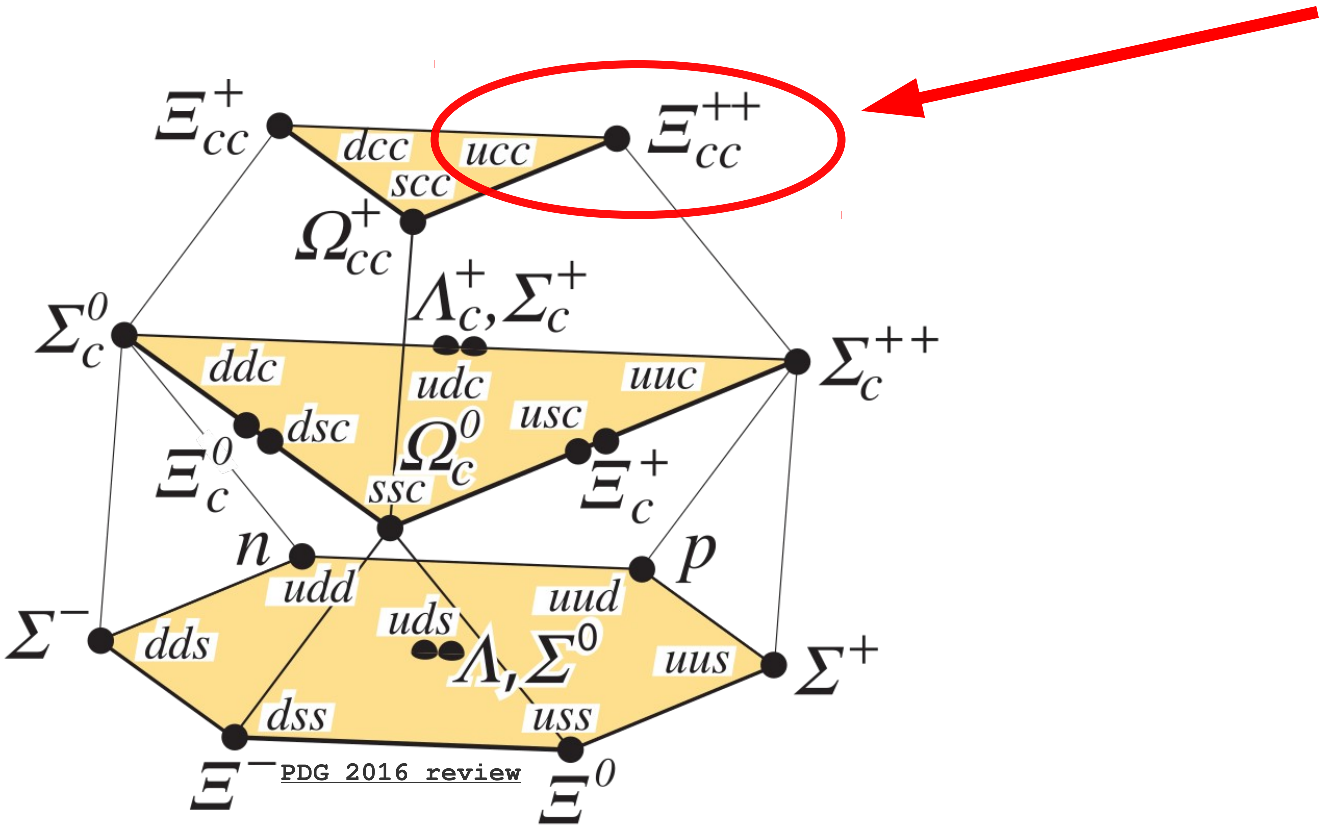
From: **Highlights from this EPS-HEP 2017 Conference** by Paris Sphicas

- arXiv:1707.01621
- LHCb public page
- Phys. Rev. Lett. 119, 112001

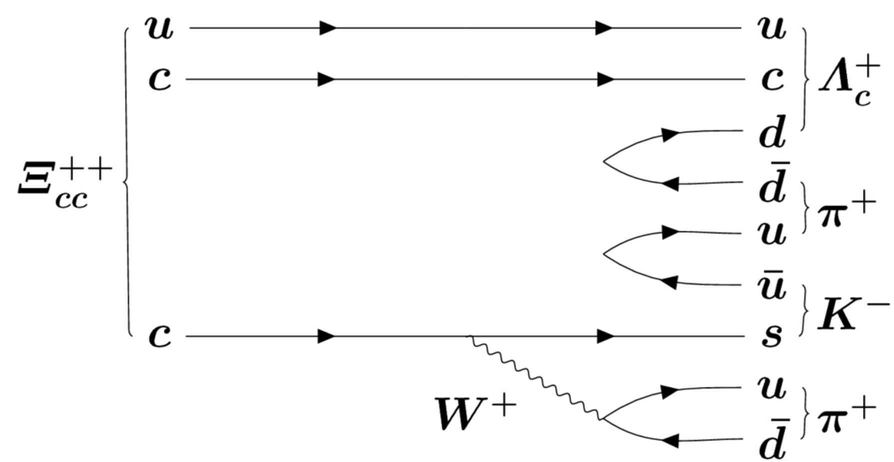


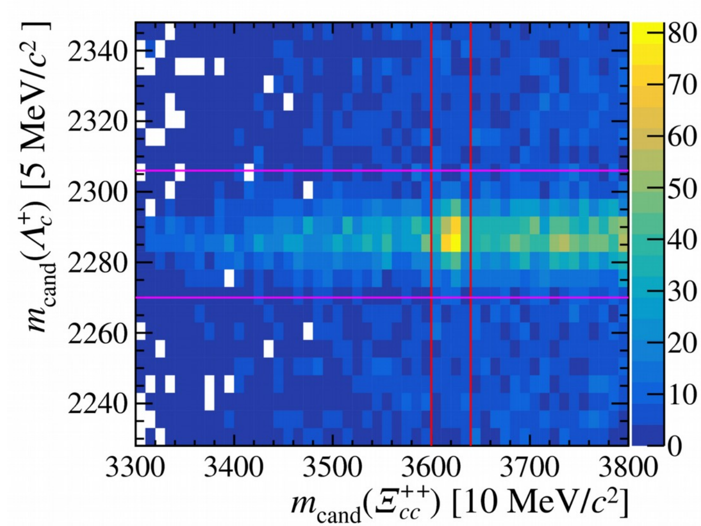
PDG 2016 review

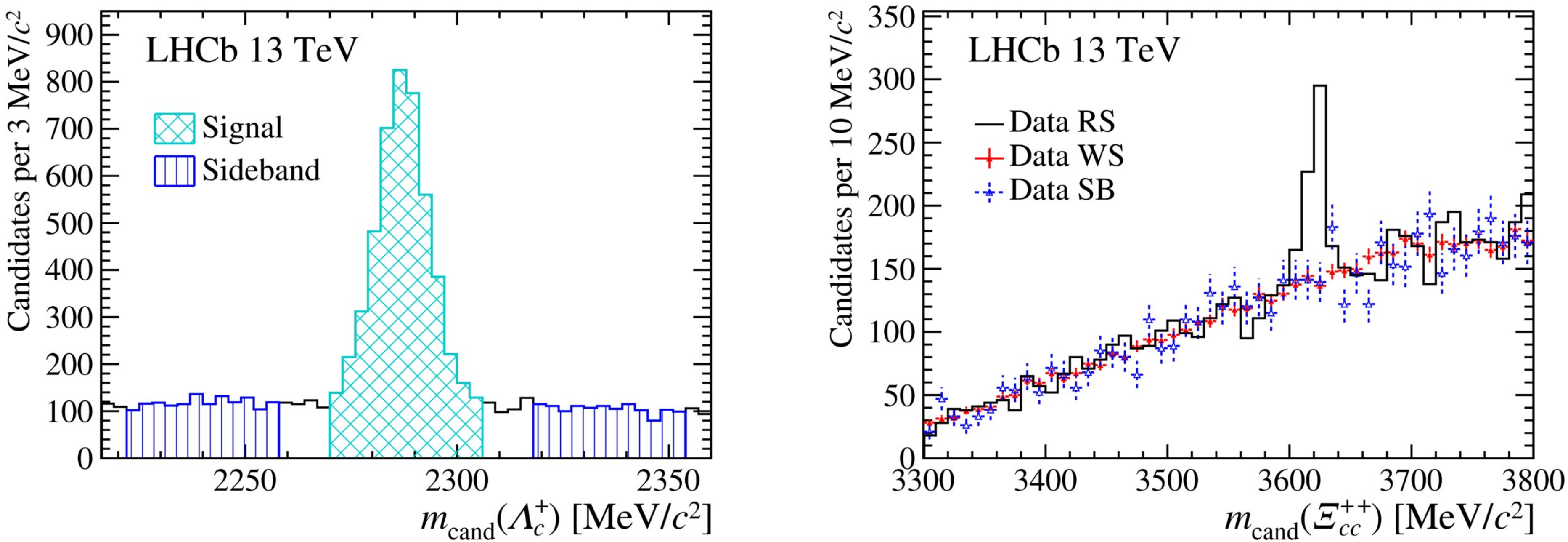
Observation of Ξ_{cc}^{++}

- Λ_c^+ reconstructed in the final state $p K^- \pi^+$
- This decay channel is expected to have a branching fraction up to 10%
- Trigger and high-stat. charm datasets.
- **1.7 fb^{-1}** of *pp* 13 TeV collisions with collected in 2016
  - ~ **60M** $\Lambda_c^+ \to p K^- \pi^+$
- Standard selection + multivariate selector to further reduce the background level
- Ξ_{cc}^{++} mass resolution improved by 40% using:

$$m_{\rm cand}(\Xi_{cc}^{++}) \equiv m(\Lambda_c^+ K^- \pi^+ \pi^\pm) - m_{\rm cand}(\Lambda_c^+) + m_{\rm PDG}(\Lambda_c^+)$$

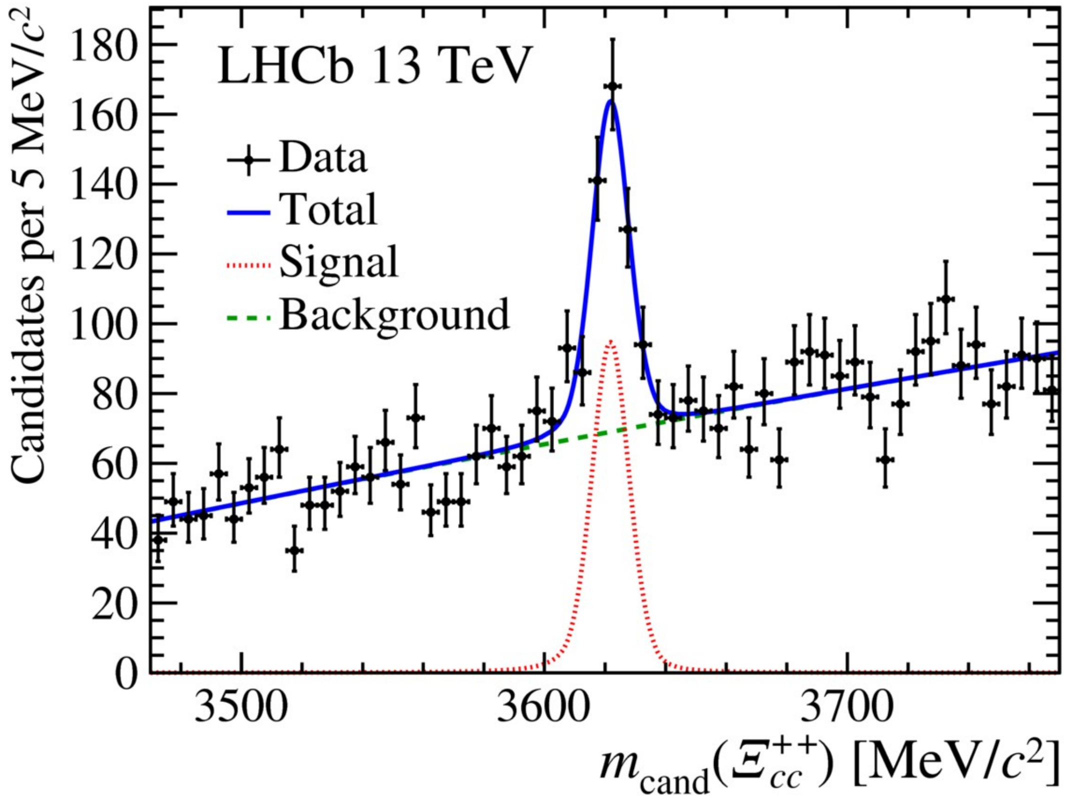






- A structure is visible in the signal mode at a mass of approximately 3620 MeV/c^2
- The background control sample consists of wrong-sign (WS) $\Lambda_c^+ K^- \pi^+ \pi^-$ combinations
- No significant structure is visible in the WS control sample, or for events in the Λ_c^+ mass sidebands

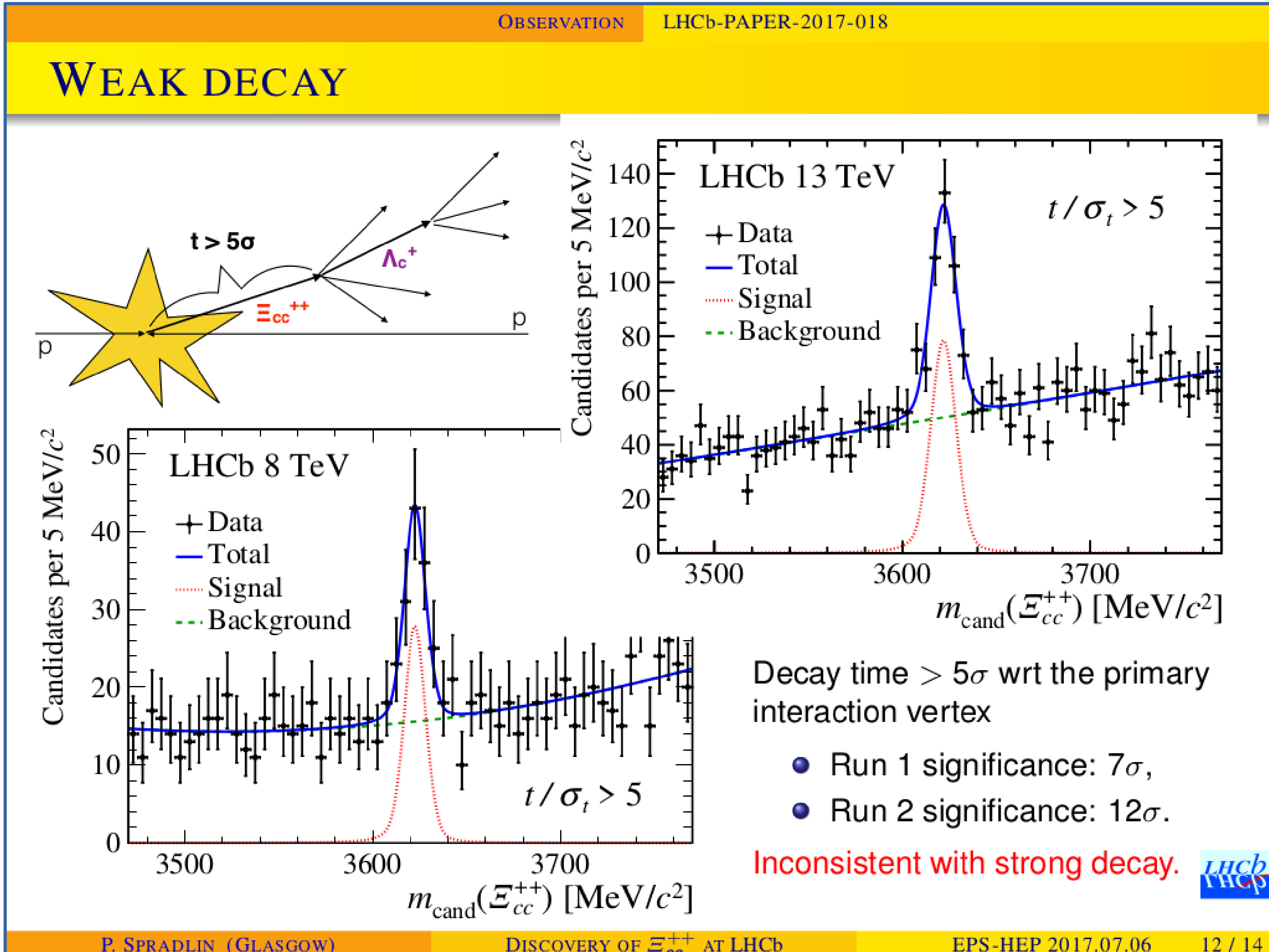
Observation of Ξ_{cc}^{++} *(or Xi)*



$m(\Xi_{cc}^{++})$ = 3621.40 ± 0.72 (stat.) ± 0.27 (syst.) ± 0.14 (Λ_c^+) MeV/c^2

Signal yield = 313 ± 33 → Local statistical significance = 12 σ

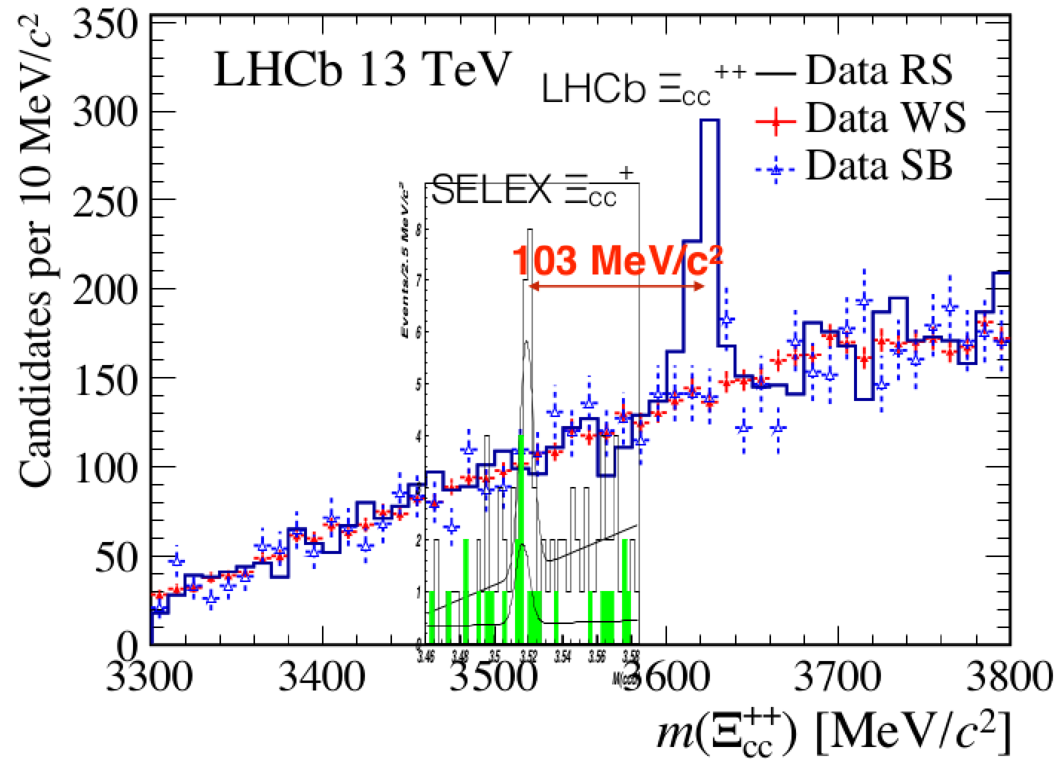
Observation of Ξ_{cc}^{++}



Talk by **Patrik Spradlin**

COMPARISON WITH SELEX

$$m(\Xi_{cc}^{++})_{\mathrm{LHCb}} - m(\Xi_{cc}^{+})_{\mathrm{SELEX}} = 103 \pm 2\,\mathrm{MeV}$$



Inconsistent with being isospin partners.

[E.g., Hwang and Chung, PRD 78 073013; Brodsky, Guo, Hanhart, and Meissner, PLB 698 251-255; Karliner and Rosner, arXiv:1706.06961]

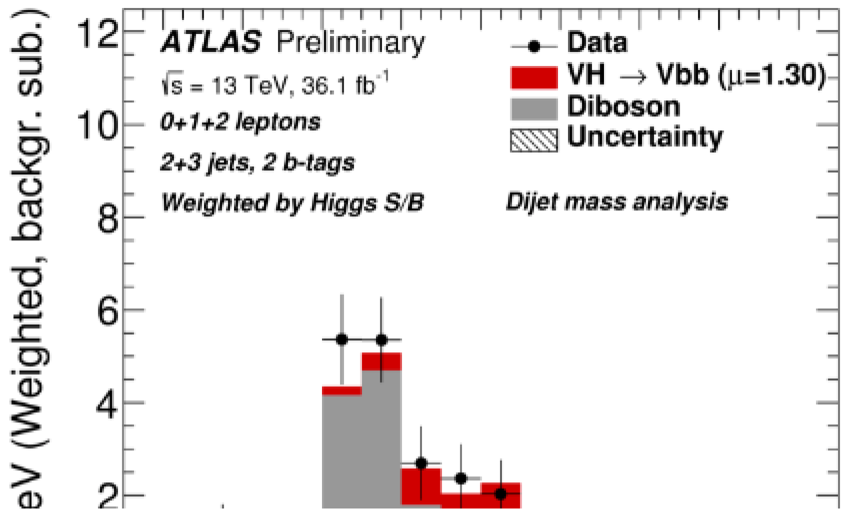
Talk by **Patrik Spradlin**

- **arXiv:1708.03299**
- **ATLAS press release**

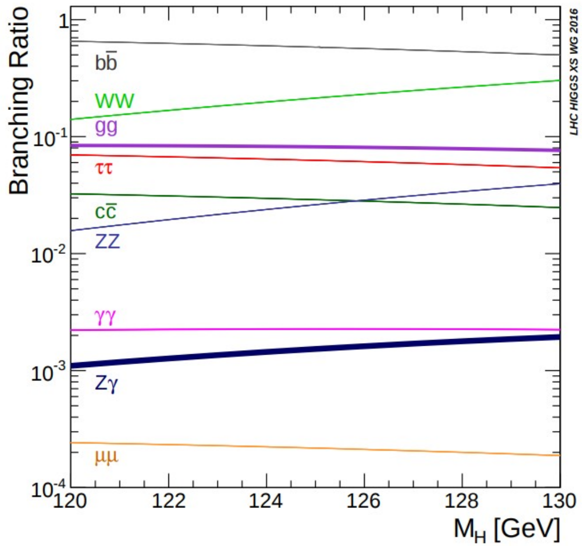
A first LHC sighting of the Higgs boson in its favourite decay

By ATLAS Collaboration, 6th July 2017

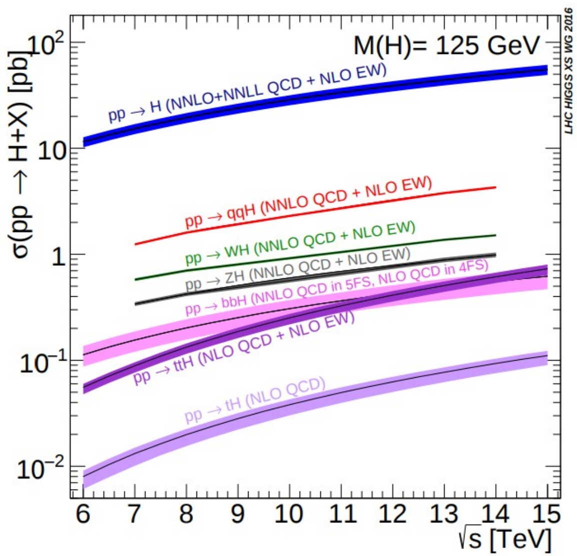
Until now, the Higgs boson had been observed decaying to photons, tau-leptons, and W and Z bosons. However, these impressive achievements represent only 30% of the Higgs boson decays! The Higgs boson's favoured decay to a pair of b-quarks (H→bb), which was predicted to happen around 58% of the time and thus drives the short lifetime of the Higgs boson, had so far remained elusive. Observing this decay would fill in one of the big missing pieces of our knowledge of the Higgs sector. It would confirm that the Higgs mechanism is responsible for the masses of quarks and might also provide hints of new physics beyond our current theories. All in all, it is a vital missing piece of the Higgs boson puzzle!



Standard Model Higgs boson



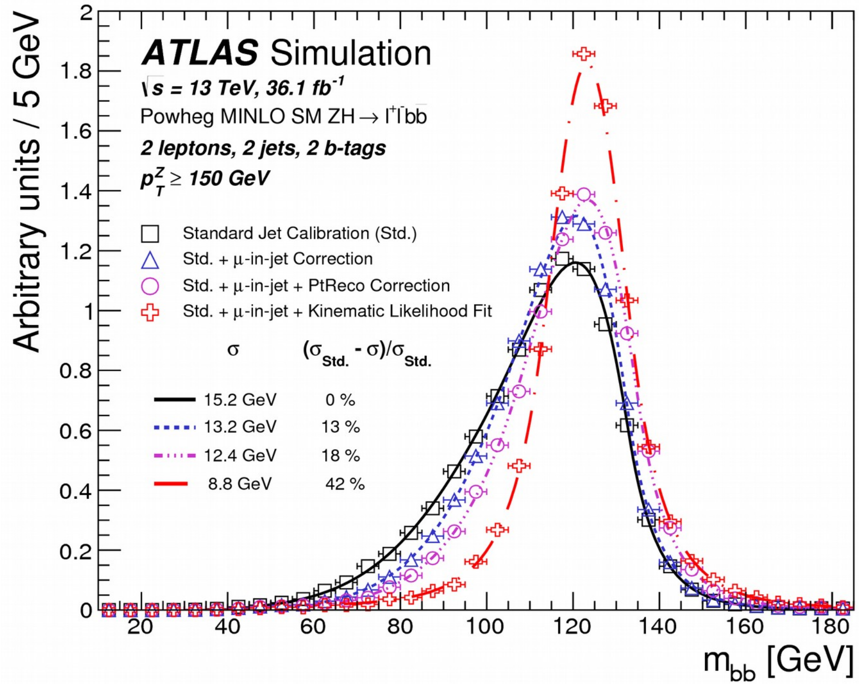
Decay channel	Branching ratio	Rel. uncertainty
$H \to \gamma\gamma$	2.27×10^{-3}	$^{+5.0\%}_{-4.9\%}$
$H \to ZZ$	2.62×10^{-2}	$^{+4.3\%}_{-4.1\%}$
$H \to W^+W^-$	2.14×10^{-1}	$^{+4.3\%}_{-4.2\%}$
$H \to \tau^+\tau^-$	6.27×10^{-2}	$^{+5.7\%}_{-5.7\%}$
$H \to b\bar{b}$	5.84×10^{-1}	$^{+3.2\%}_{-3.3\%}$
$H \to Z\gamma$	1.53×10^{-3}	$^{+9.0\%}_{-8.9\%}$
$H \to \mu^+\mu^-$	2.18×10^{-4}	$^{+6.0\%}_{-5.9\%}$



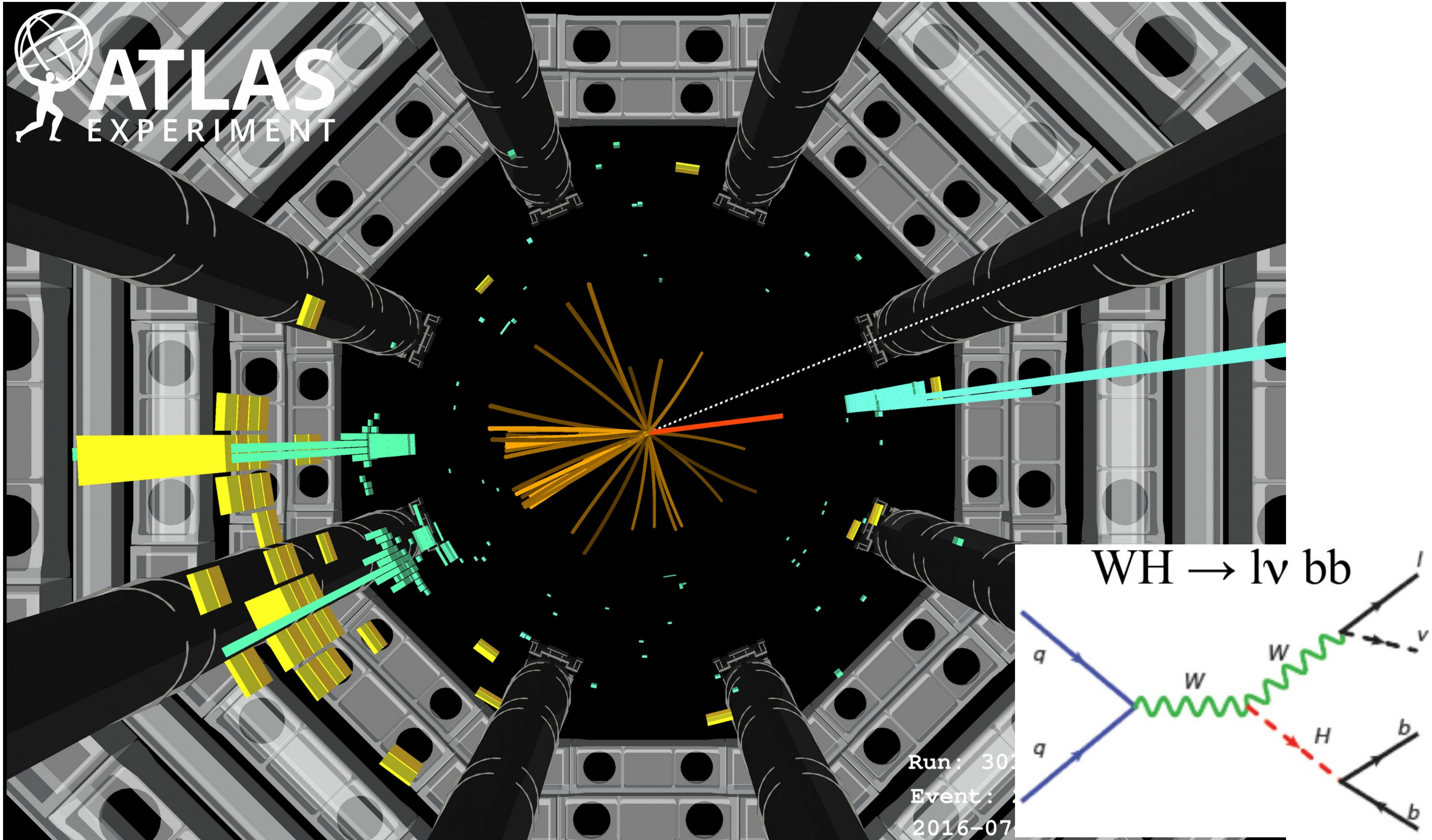
$\sqrt{s}$ (TeV)	Production cross section (in pb) for $m_H = 125\,\mathrm{GeV}$					
	ggF	VBF	WH	ZH	$t\bar{t}H$	total
1.96	$0.95^{+17\%}_{-17\%}$	$0.065^{+8\%}_{-7\%}$	$0.13^{+8\%}_{-8\%}$	$0.079^{+8\%}_{-8\%}$	$0.004^{+10\%}_{-10\%}$	1.23
7	$15.3^{+10\%}_{-10\%}$	$1.24^{+2\%}_{-2\%}$	$0.58^{+3\%}_{-3\%}$	$0.34^{+4\%}_{-4\%}$	$0.09^{+8\%}_{-14\%}$	17.5
8	$19.5^{+10\%}_{-11\%}$	$1.60^{+2\%}_{-2\%}$	$0.70^{+3\%}_{-3\%}$	$0.42^{+5\%}_{-5\%}$	$0.13^{+8\%}_{-13\%}$	22.3
13	$44.1^{+11\%}_{-11\%}$	$3.78^{+2\%}_{-2\%}$	$1.37^{+2\%}_{-2\%}$	$0.88^{+5\%}_{-5\%}$	$0.51^{+9\%}_{-13\%}$	50.6
14	$49.7^{+11\%}_{-11\%}$	$4.28^{+2\%}_{-2\%}$	$1.51^{+2\%}_{-2\%}$	$0.99^{+5\%}_{-5\%}$	$0.61^{+9\%}_{-13\%}$	57.1

PDG 2016 review – for ggF N3LO corrections are not included

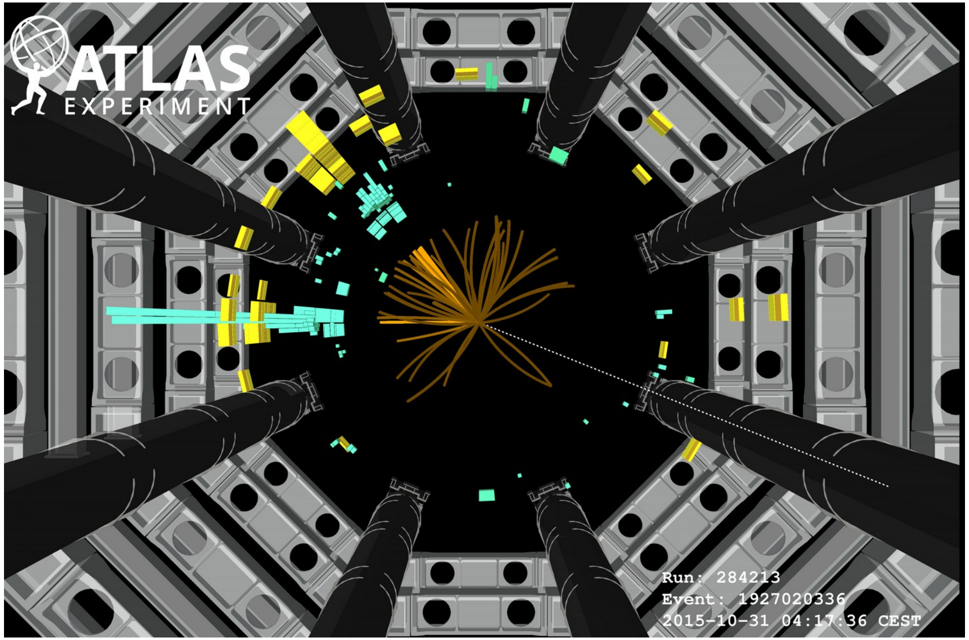
- Search for ***associated production*** VH (V = Z, W):
  - Clean signatures from V leptonic decays
  - High trigger efficiency
  - Reduced multi-jet background
- Improve H ***mass resolution***
  - *Muon-in-jet* correction
  - *b-jet* p_T correction
  - *Kinematic Likelihood fit* for 2-lepton channel
- Maximize sensitivity by event ***categorization***
  - **8** signal regions
  - **6** control regions

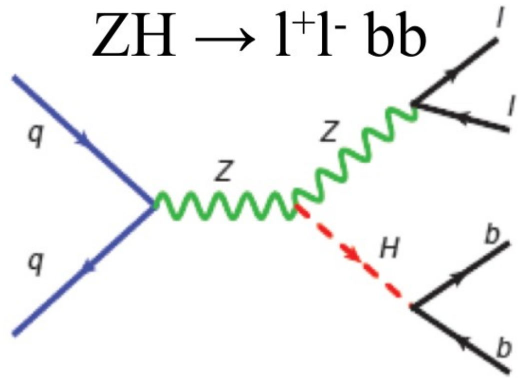


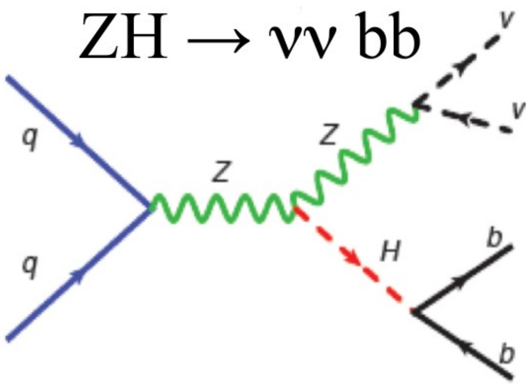
Leptons	$75 < P^V_T < 150$		$P^V_T > 150$	
0	-		2J	3J
1	-		2J	3J
2	2J	3+J	2J	3+J

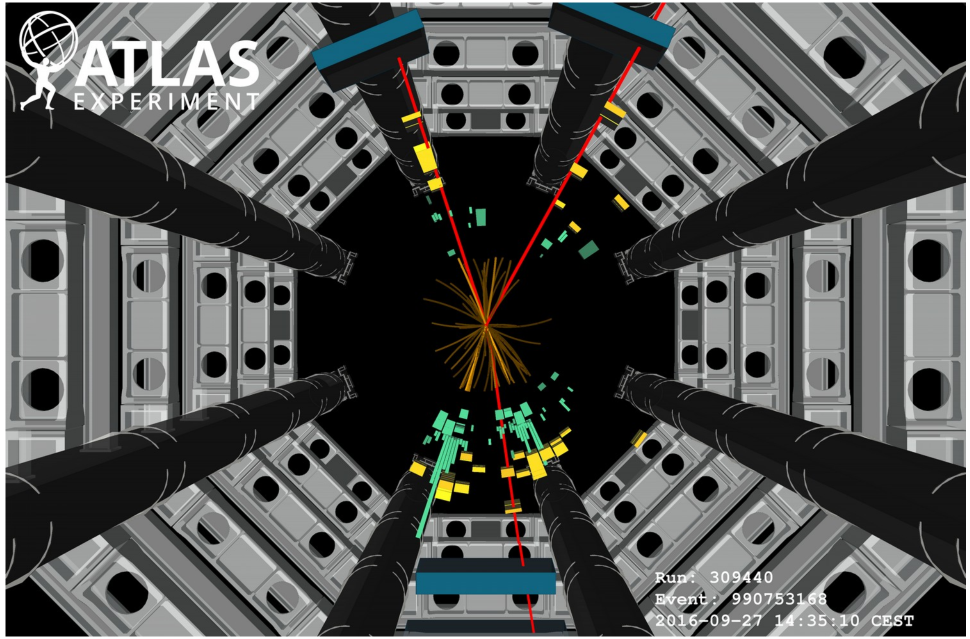

ATLAS
EXPERIMENT
WH → lν bb
q
q
W
W
H
l
ν
b
b

H→bb – 0-lepton and 2-lepton





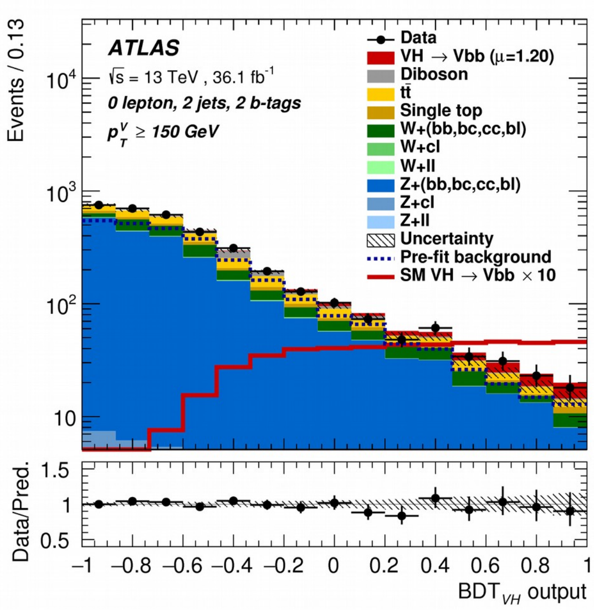


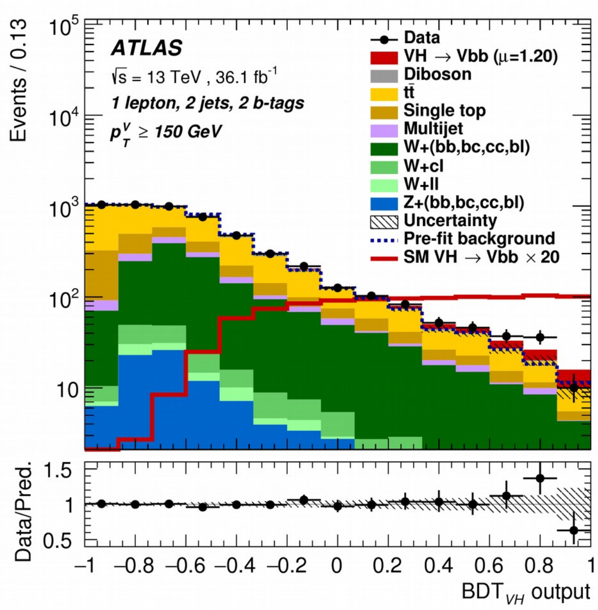


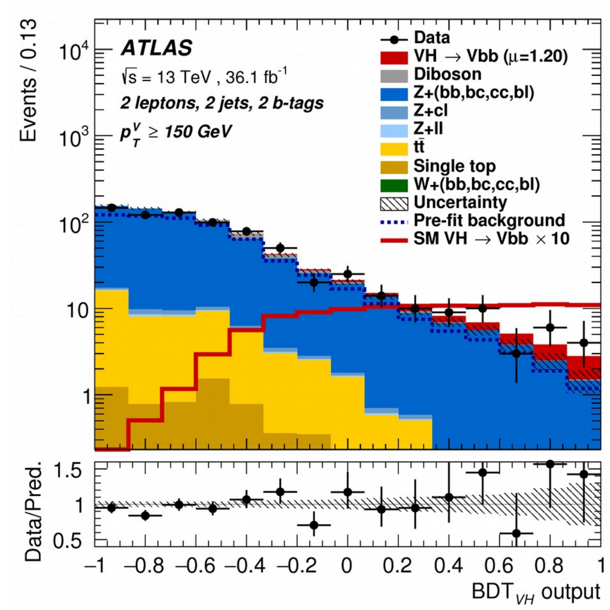
H→bb - Analysis strategy

- ***MVA discriminant*** (BDT) trained for each signal region
- ***Signal strength*** is evaluated using a ***global fit*** to 8 SR + 6 CR

Channel	SR/CR	Categories			
		$75\ \text{GeV} < p_T^V < 150\ \text{GeV}$		$p_T^V > 150\ \text{GeV}$	
		2 jets	3 jets	2 jets	3 jets
0-lepton	SR	-	-	BDT	BDT
1-lepton	SR	-	-	BDT	BDT
2-lepton	SR	BDT	BDT	BDT	BDT
1-lepton	W + HF CR	-	-	Yield	Yield
2-lepton	$e\mu$ CR	m_{bb}	m_{bb}	Yield	m_{bb}





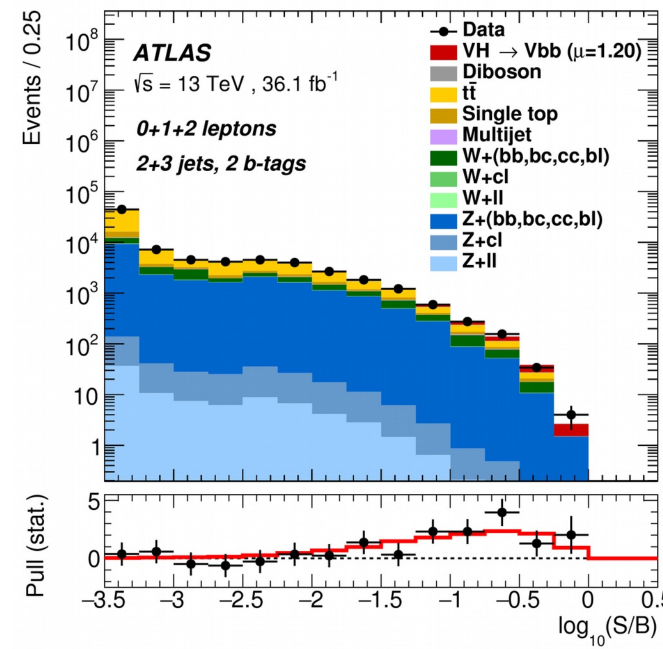


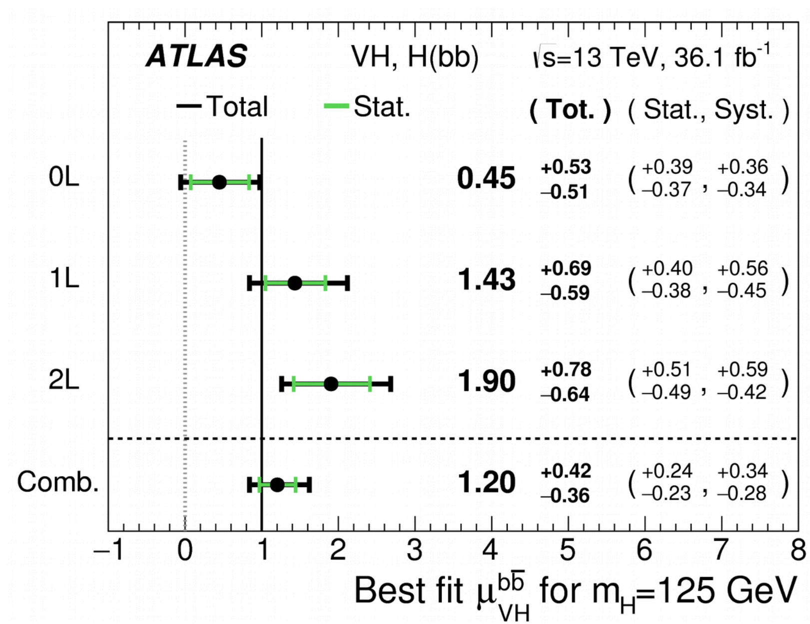
H→bb - Results

$$\mu = 1.20\ ^{+0.24}_{-0.23}\ \text{(stat.)}\ ^{+0.34}_{-0.28}\ \text{(syst.)}$$

$$\sigma(VH) \times B(H\rightarrow bb) = 1.58\ ^{+0.55}_{-0.47}\ \text{pb}\quad \text{(expectation 1.31 pb)}$$

- 3 lepton channels compatibility = 10%
- Dominant uncertainties: signal modeling, MC statistics, b-tagging





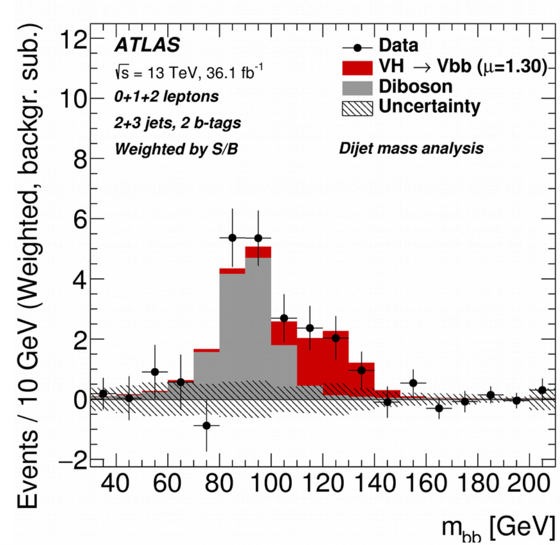
Dataset	p_0 Exp.	p_0 Obs.	Significance Exp.	Significance Obs.
0-lepton	4.2%	30%	1.7	0.5
1-lepton	3.5%	1.1%	1.8	2.3
2-lepton	3.1%	0.019%	1.9	3.6
Combined	0.12%	0.019%	3.0	3.5

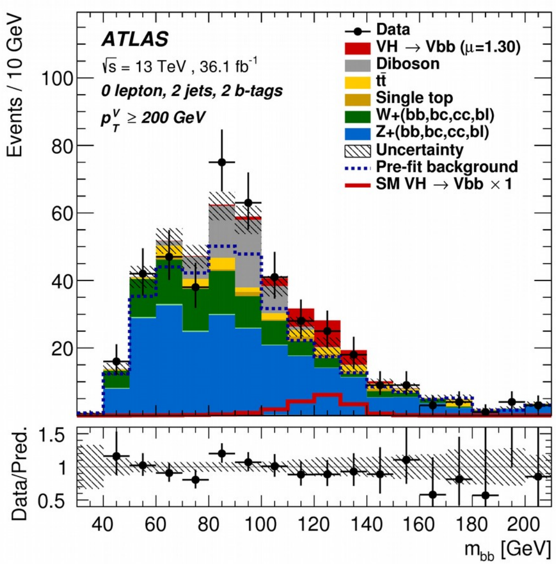
H→bb – Cross check

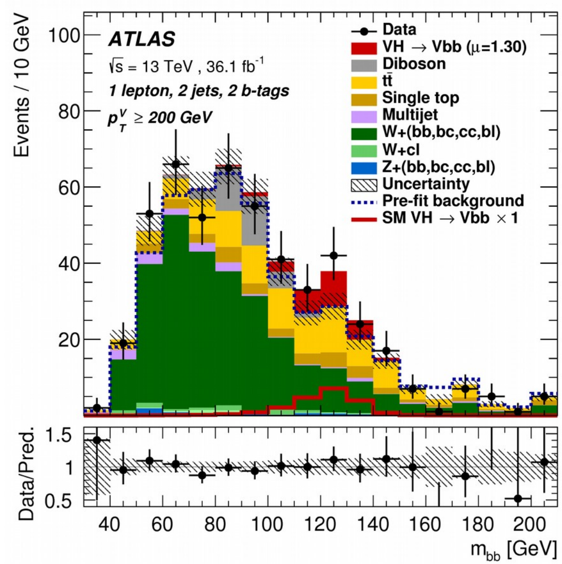
- VH(bb) search using $\boldsymbol{m_{bb}}$ as discriminant

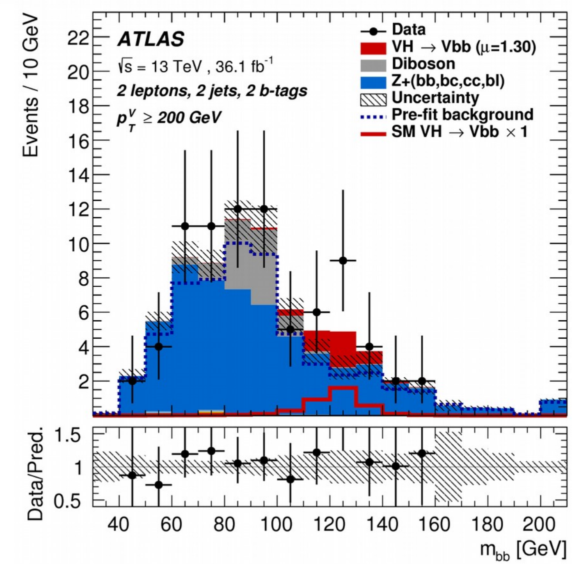
$$\mu = 1.30\ ^{+0.28}_{-0.27}\ \text{(stat.)}\ ^{+0.37}_{-0.29}\ \text{(syst.)}$$

Observed excess: 3.5 σ (2.8 expected)







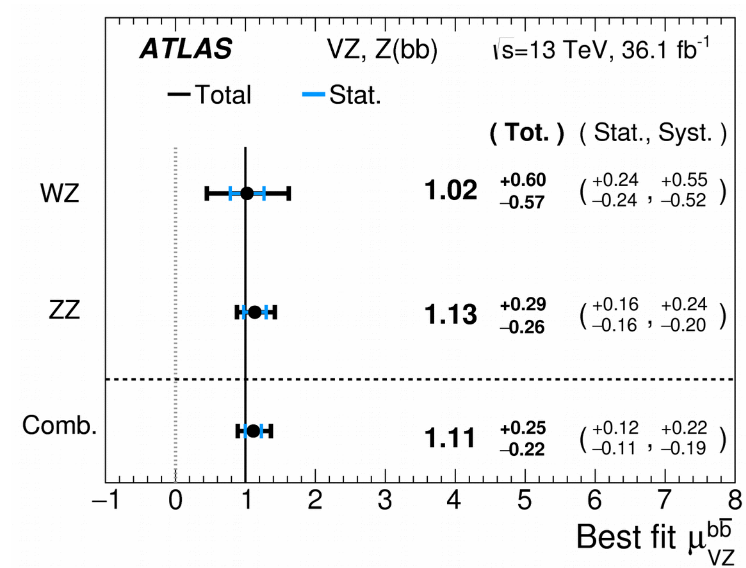


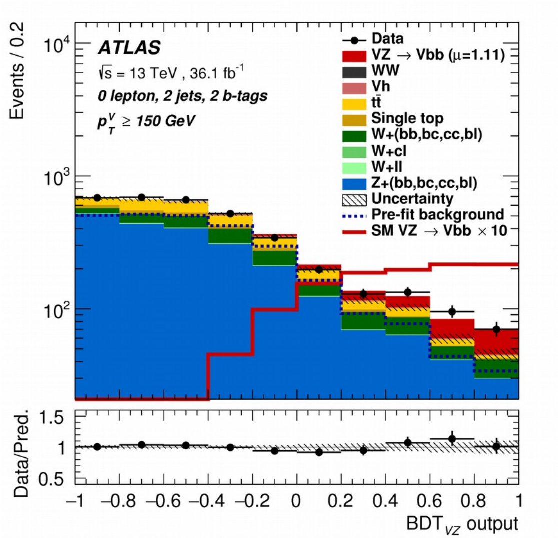
H→bb – Validation VZ(bb)

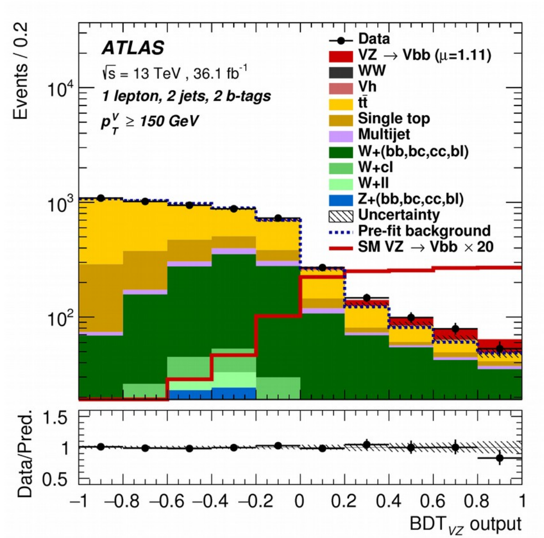
- Full search with MVA for ***diboson search*** (***VZ***)

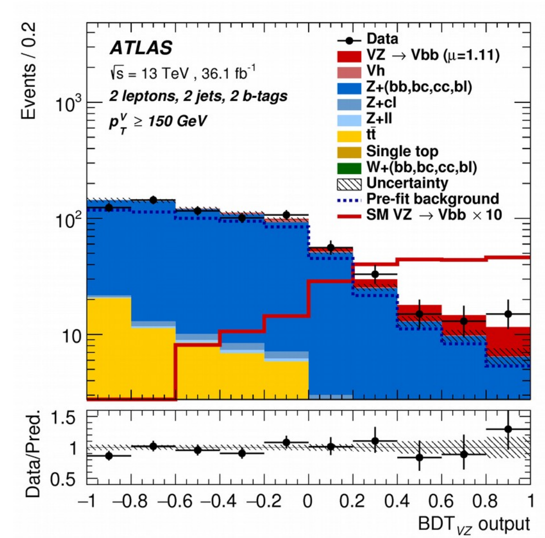
$\mu_{VZ} = 1.11\ ^{+0.12}_{-0.11}\ \text{(stat.)}\ ^{+0.22}_{-0.19}\ \text{(syst.)}$

Observed excess: 5.8 σ (5.3 expected)





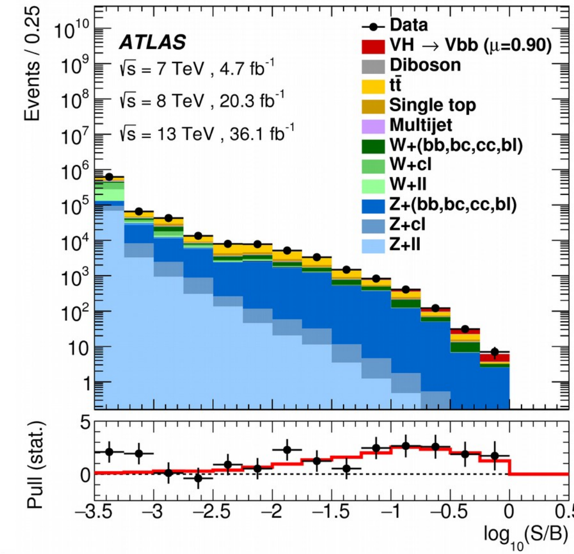


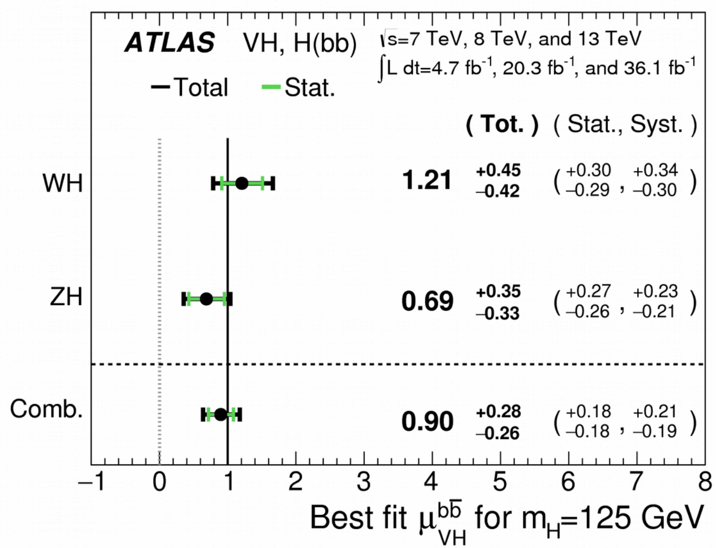


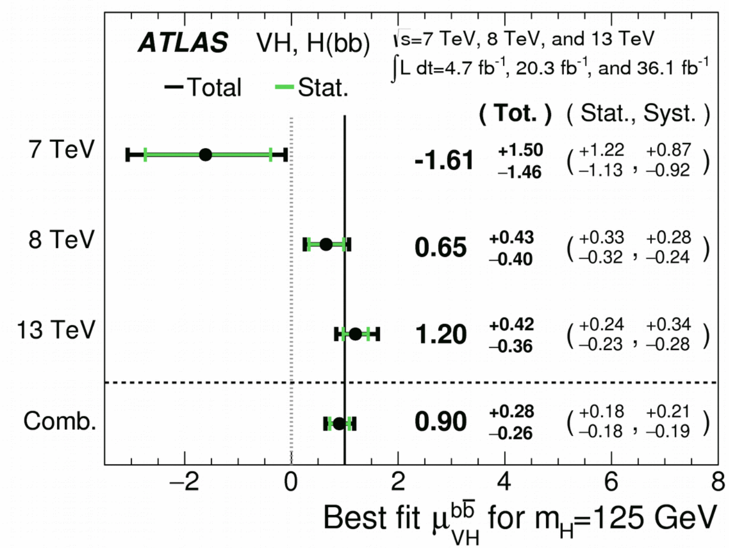
μ = 0.90 ± 018 (stat.) $^{+0.21}_{-0.19}$ (syst.)

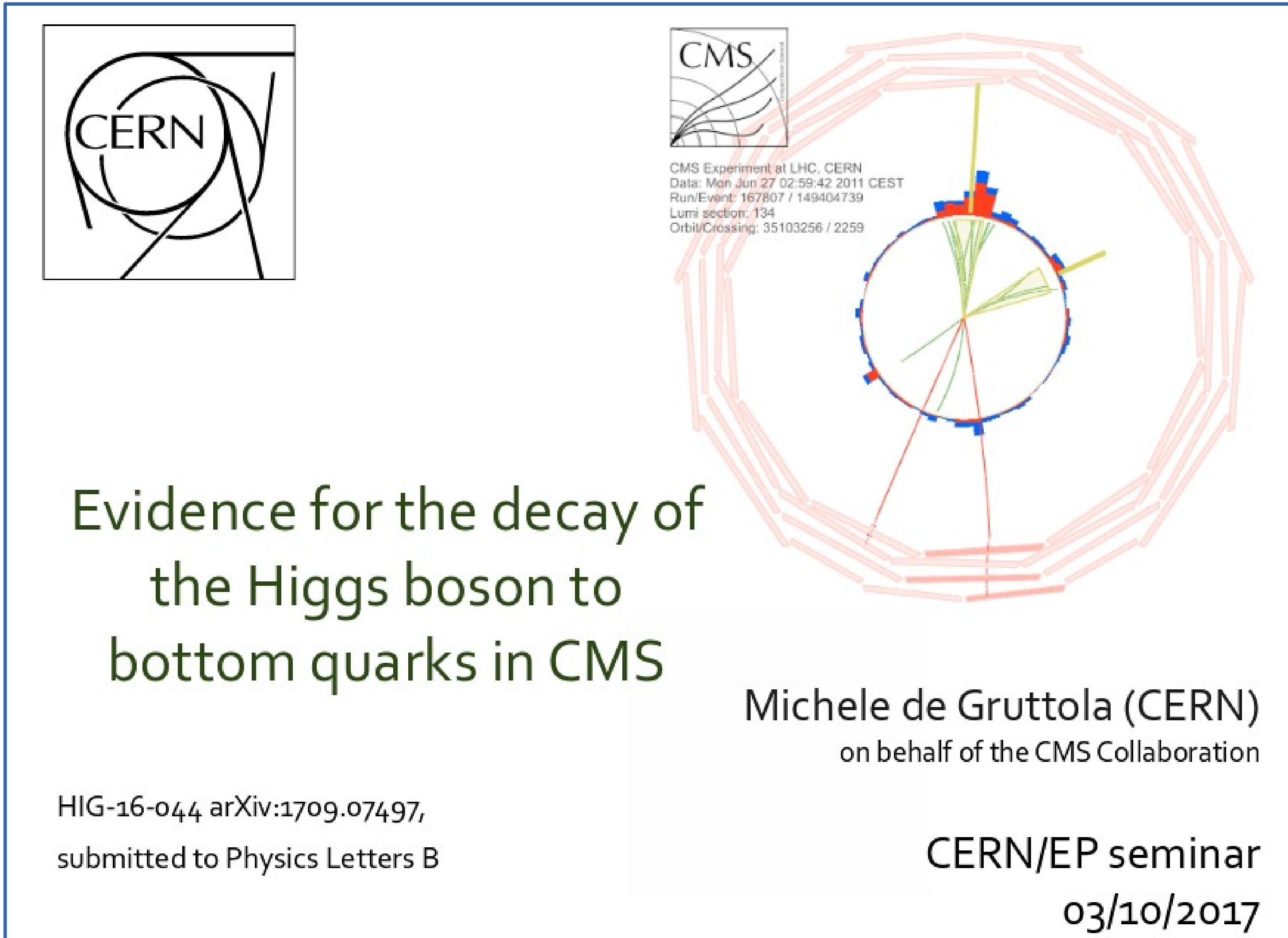
Observed significance 3.6 σ (4 expected)

- Compatibility : **Run1 vs Run2: 21%** ; **WH vs ZH: 34%**
- Signal theoretical uncertainties correlated
- Observed minimum impact of (de-)correlation of the other uncertainties



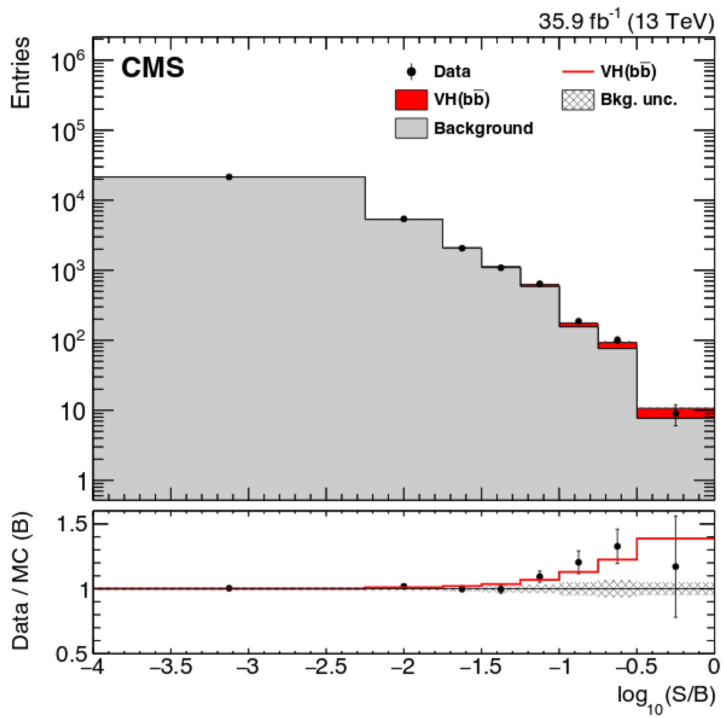


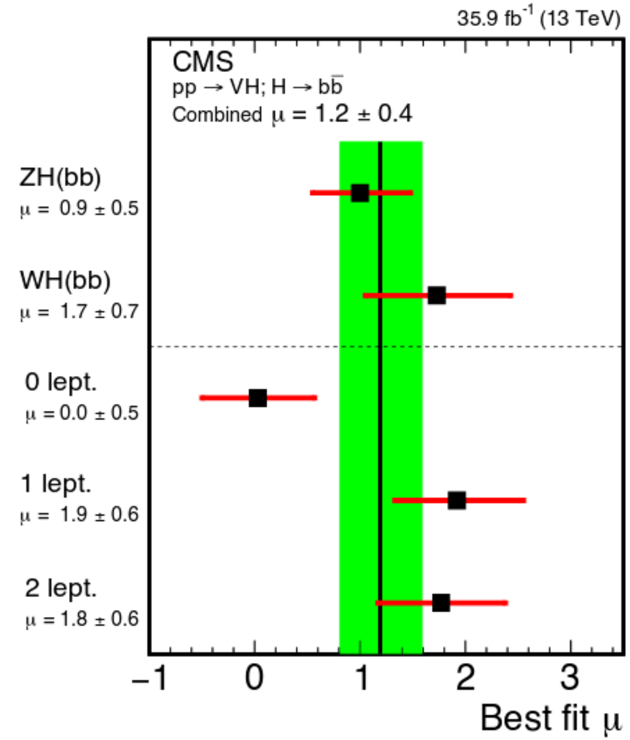



CERN
CMS
CMS Experiment at LHC, CERN
Data: Mon Jun 27 02:59:42 2011 CEST
Run/Event: 167807 / 149404739
Lumi section: 134
Orbit/Crossing: 35103256 / 2259
Evidence for the decay of the Higgs boson to bottom quarks in CMS
Michele de Gruttola (CERN)
on behalf of the CMS Collaboration
HIG-16-044 arXiv:1709.07497,
submitted to Physics Letters B
CERN/EP seminar
03/10/2017

LHC seminar

H→bb – CMS result





Data used	Significance expected	Significance observed	Signal strength observed
Run 1	2.5	2.1	$0.89^{+0.44}_{-0.42}$
Run 2	2.8	3.3	$1.19^{+0.40}_{-0.38}$
Combined	3.8	3.8	$1.06^{+0.31}_{-0.29}$

<u>significance</u>

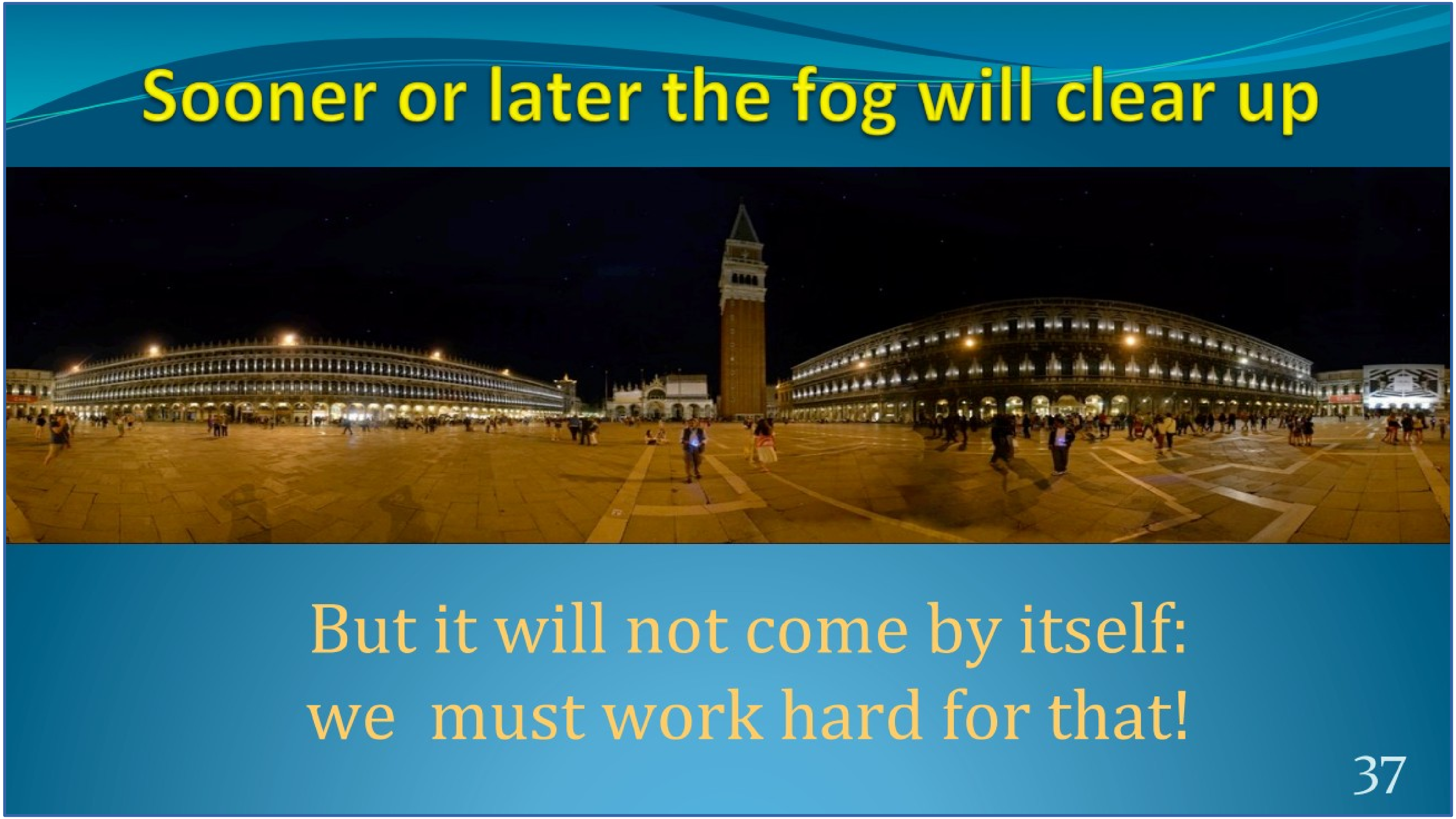
3.8σ expected

3.8σ observed !

LHC seminar

From: **Outlook** by Fabio Zwirner

… full of hope! … and hard work …

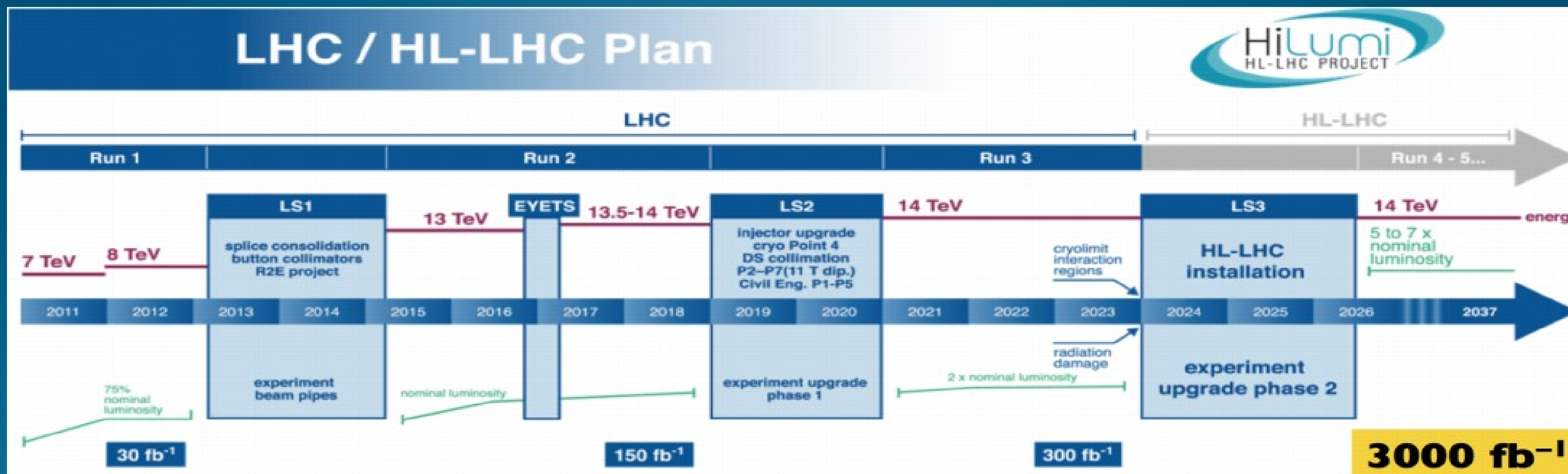


From: **Outlook** by Fabio Zwirner

Beyond the SM with energy

Energy frontier: direct searches for new particles

$\sqrt{S_{LHC}}/\sqrt{S_{Tev}} \sim 6.5$ (~7 Run≥3) but $s=x_1 x_2 S$ & PDFs count



Data collected so far < 2% of the final statistics:
still (moderate) room for new particles at the LHC
Another factor of 2 with 16T magnets at HE-LHC?

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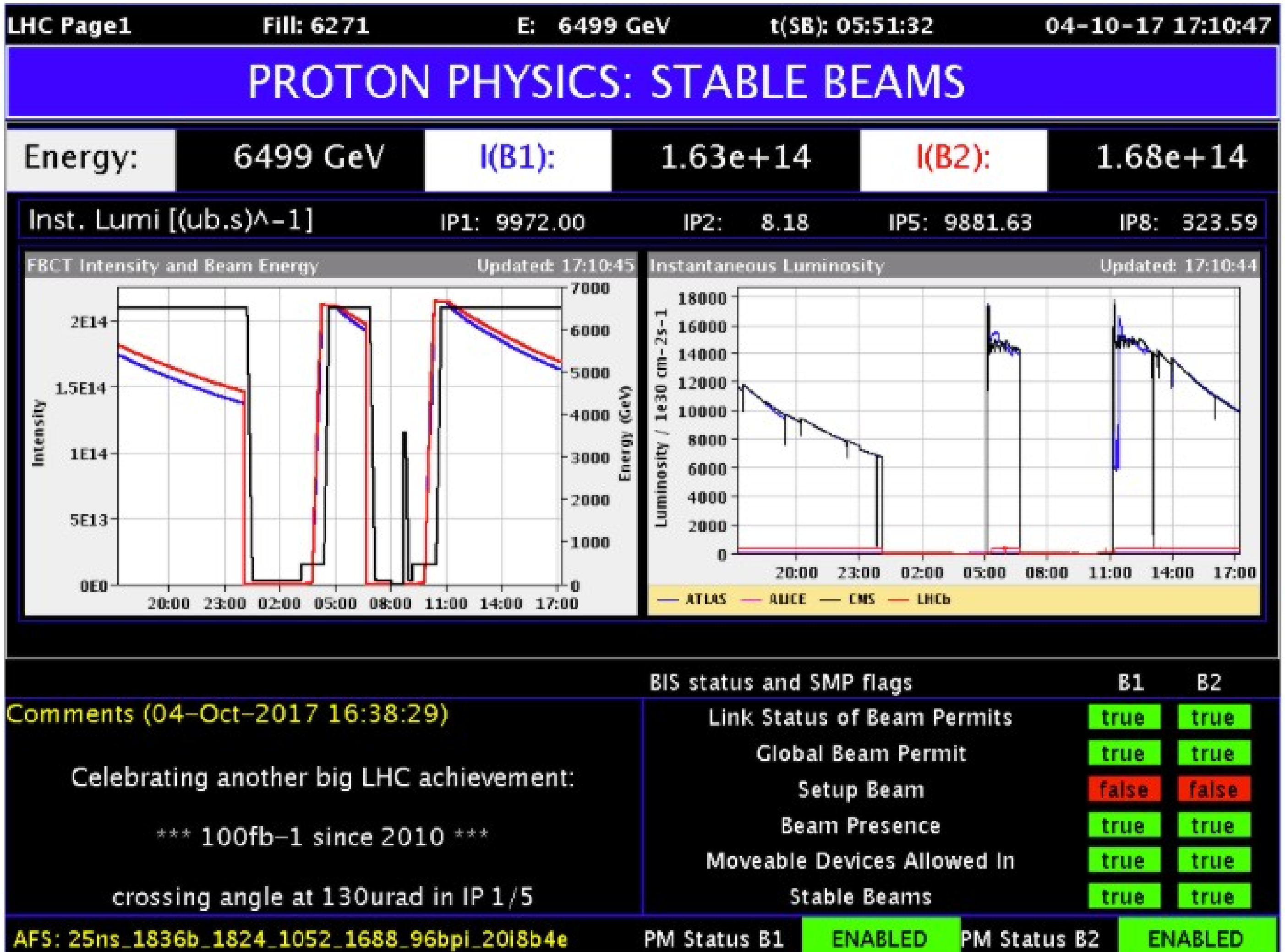
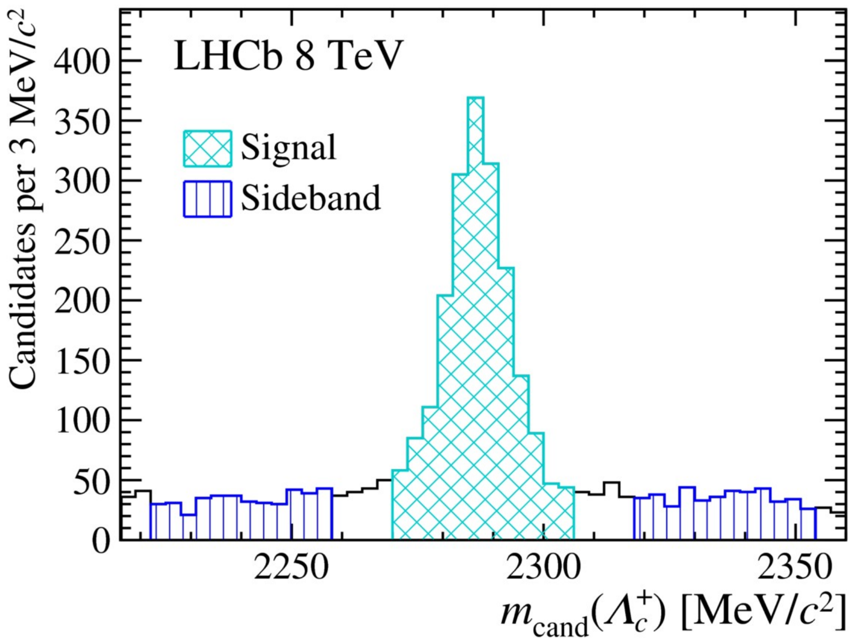
From: **Outlook** by Fabio Zwirner

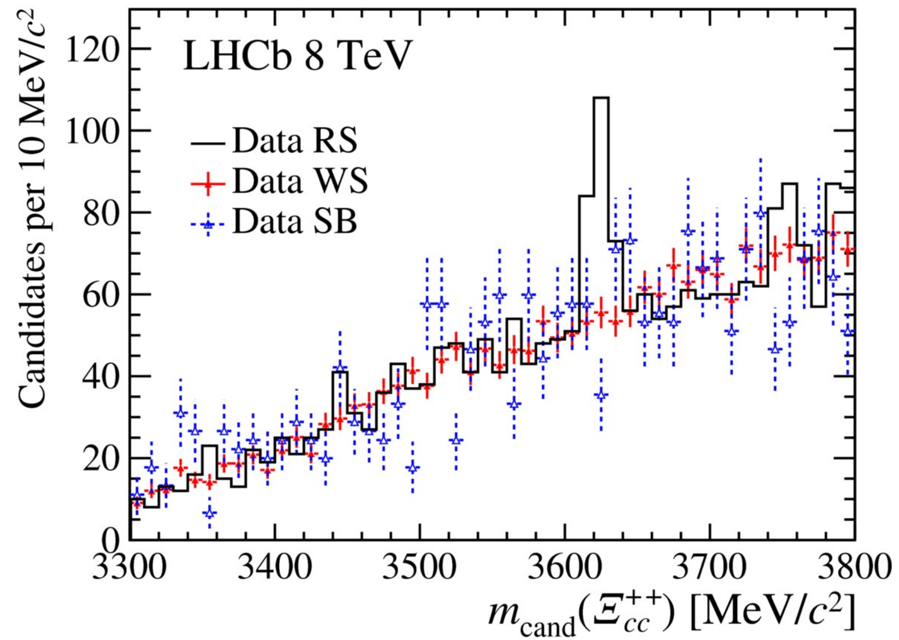
so far so good



Backup

Observation of Ξ_{cc}^{++} - 8 TeV sample





H→bb – Event selection

Selection	0-lepton	1-lepton		2-lepton
		e sub-channel	μ sub-channel	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton
Leptons	0 loose leptons with $p_{\mathrm{T}} > 7$ GeV	1 tight electron $p_{\mathrm{T}} > 27$ GeV	1 medium muon $p_{\mathrm{T}} > 25$ GeV	2 loose leptons with $p_{\mathrm{T}} > 7$ GeV ≥ 1 lepton with $p_{\mathrm{T}} > 27$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 30 GeV	–	–
$m_{\ell\ell}$	–	–		81 GeV $< m_{\ell\ell} <$ 101 GeV
Jets	Exactly 2 or 3 jets			Exactly 2 or ≥ 3 jets
Jet p_{T}	> 20 GeV			
b-jets	Exactly 2 b-tagged jets			
Leading b-tagged jet p_{T}	> 45 GeV			
H_{T}	> 120 (2 jets), >150 GeV (3 jets)	–		–
$\min[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{\mathrm{jets}})]$	$> 20°$ (2 jets), $> 30°$ (3 jets)	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{bb})$	$> 120°$	–		–
$\Delta\phi(\vec{b}_1, \vec{b}_2)$	$< 140°$	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{E}_{\mathrm{T,trk}}^{\mathrm{miss}})$	$< 90°$	–		–
p_{T}^{V} regions	> 150 GeV			(75, 150] GeV, > 150 GeV
Signal regions	✓	$m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV		Same-flavour leptons Opposite-sign charge ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV		Different-flavour leptons

H→bb – signal Acceptance

$m_H = 125$ GeV at $\sqrt{s} = 13$ TeV				
Process	Cross-section × B [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$qq \to ZH \to \ell\ell bb$	29.9	< 0.1	< 0.1	7.0
$gg \to ZH \to \ell\ell b\bar{b}$	4.8	< 0.1	< 0.1	15.7
$qq \to WH \to \ell\nu b\bar{b}$	269.0	0.2	1.0	–
$qq \to ZH \to \nu\nu b\bar{b}$	89.1	1.9	–	–
$gg \to ZH \to \nu\nu b\bar{b}$	14.3	3.5	–	–