"Report of Azerbaijan team in JINR" Meeting

Subject:

Measurements of *WH* and *ZH* production in the $H \to b\bar{b}$ decay channel using the ATLAS detector

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15.04.2021

Scientific Activities

- Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a bb pair in pp collisions using the ATLAS detector
- After the discovery, the study of the properties of the Higgs boson and the use of this channel to go beyond the standard model and search for new particles.
- Determination of radiation resistance of the liquid-argon calorimeter of the ATLAS detector and its electronics at the high-luminosity LHC and the study of new, more resistant materials.
- Control of experimental data collection in ATLAS detector. Checking of systems operation during data taking and periodic calibration.
- NICA mega-project. Search for quark-gluon plasma in the MPD detector of the NICA collider.

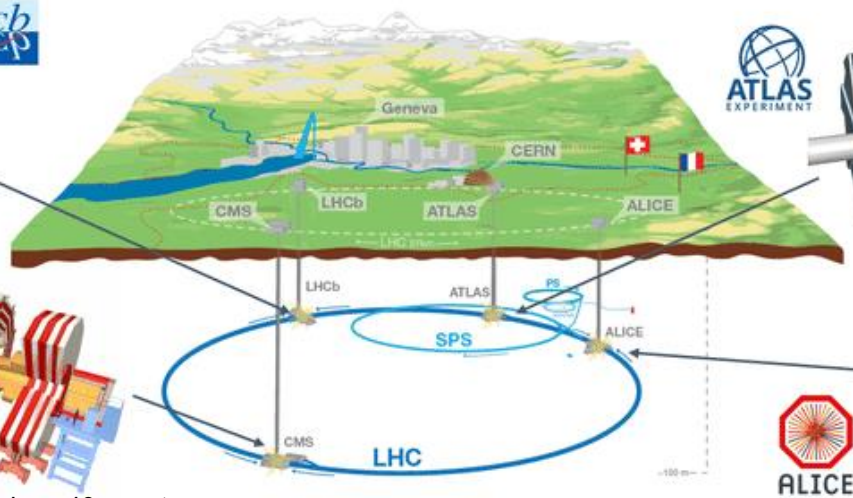
Outline

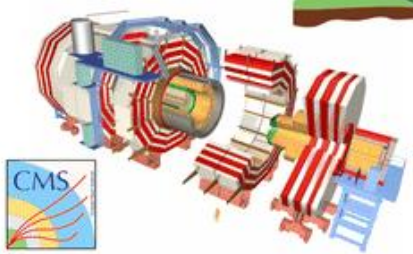
- LHC, ATLAS detector. Degradation of the ATLAS HEC in HL-LHC
- SM Higgs boson production & decay channels, $WH\,(H\rightarrow b\bar{b})$ and $ZH(H\rightarrow b\bar{b})$ process
- Object and event selection
- Analysis methods, MVA & Cut-Flow analysis results
- Cross-section measurement & Effective interactions
- Conclusion & Physics highlights
- Publications, Talks, Awards, Other activities and Plans.

LHC and its experiments

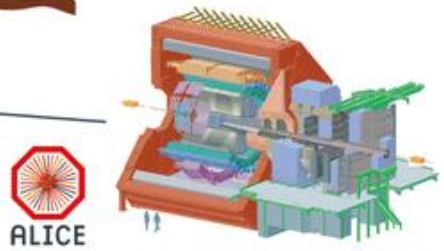
1400 memb, 86 ins., 18 count.

5000 memb, 183 ins., 38 count.





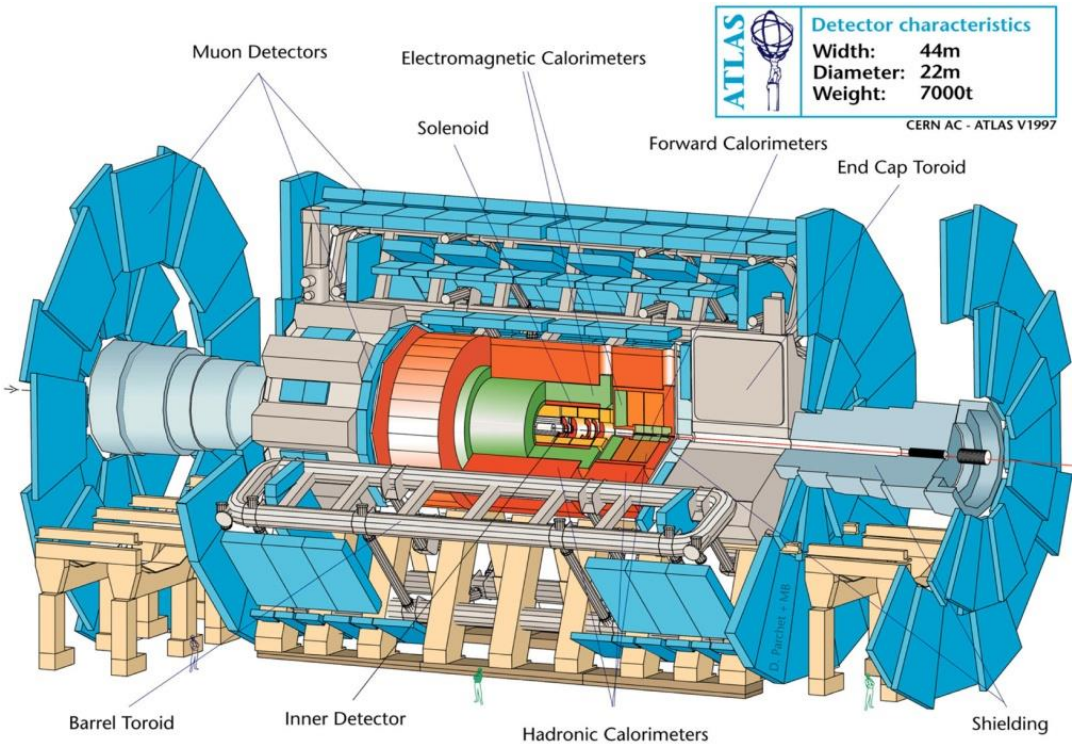
4000 memb, 200 ins., 40 count.

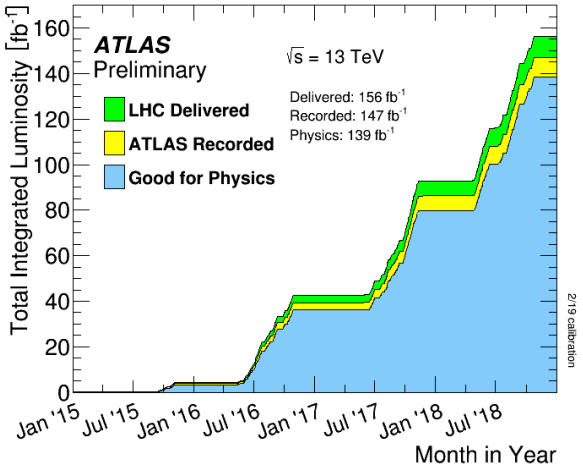


2000 memb, 173 ins., 39 count.

What is the nature of our universe?
What is it made of?
Scientists from around the world come to CERN to find answers to such fundamental questions using particle accelerators and pushing the limits of technology.

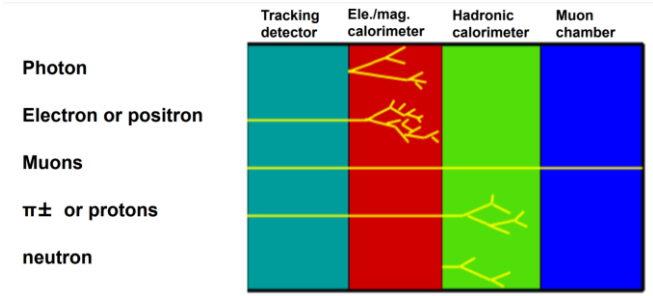
ATLAS detector





Cumulative integrated luminosity versus time during stable beams for pp collisions at √s = 13 TeV between 2015-2018

ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis coinciding with the axis of the beam pipe. The x-axis points from the IP towards the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r,ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. The distance in (η,ϕ) coordinates, $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$, is also used to define cone sizes.



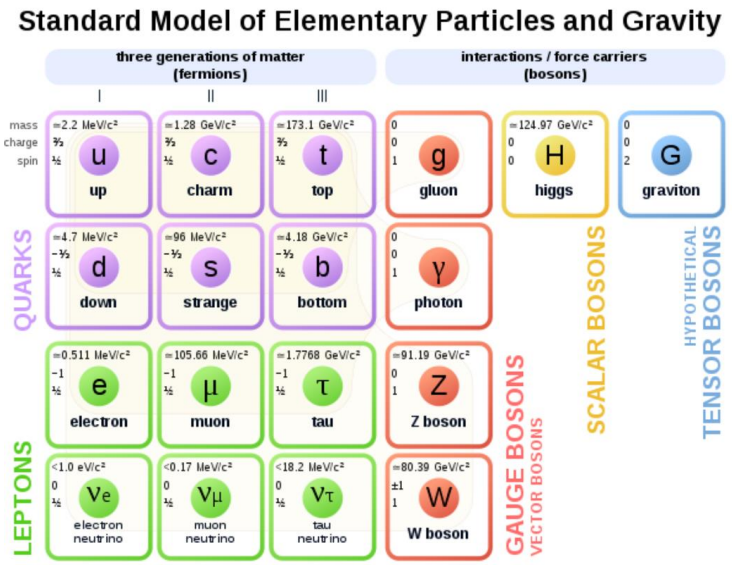
SM Higgs Boson

- Half a century ago, Englert, Brout, Higgs, and Guralnik proposed a mechanism (Higgs mechanism) for spontaneous breaking of gauge symmetries that, explain why bosons carrying the weak force have mass, unlike those carrying electromagnetic and strong forces.

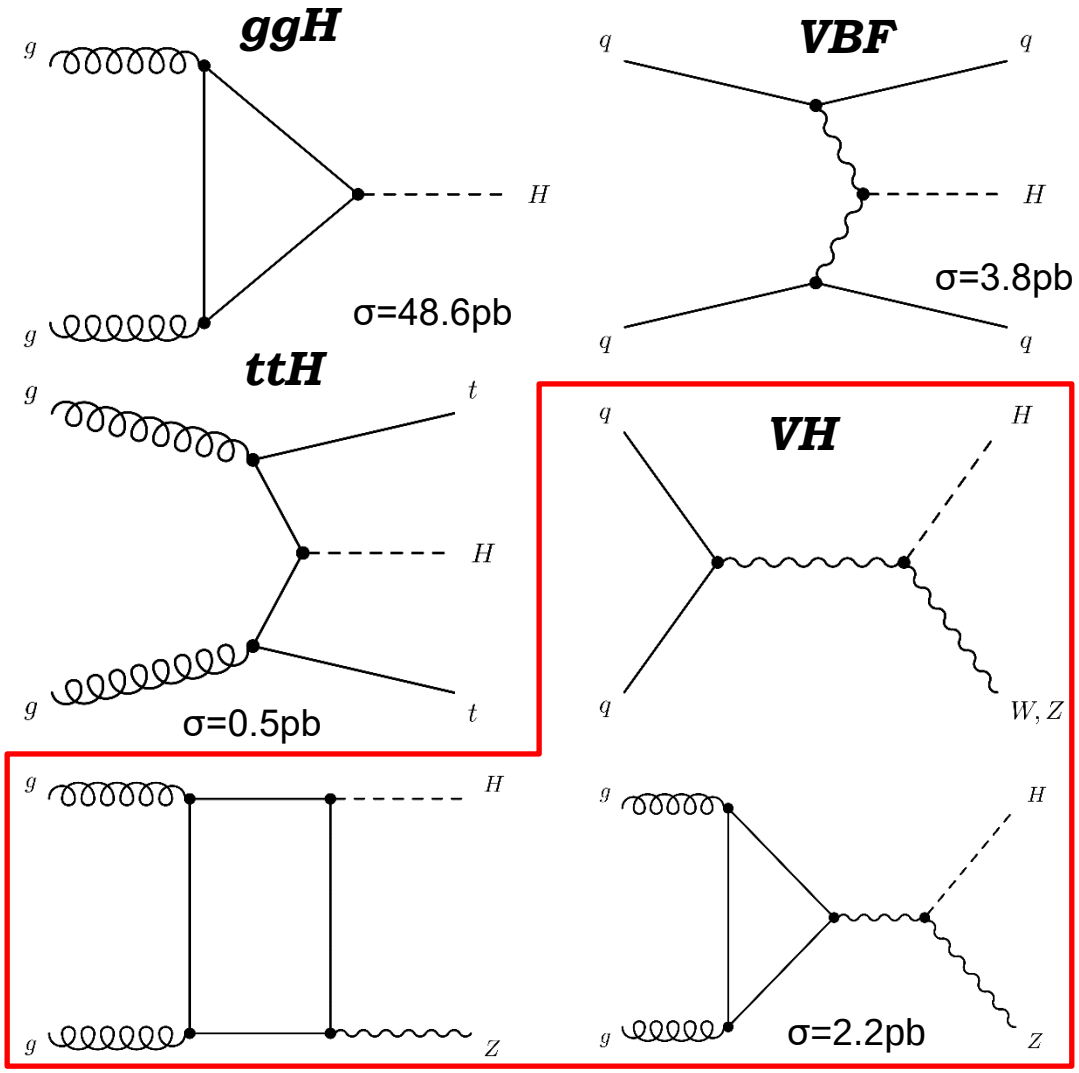
- Higgs mechanism explains electroweak symmetry breaking and the mass origin of all known elementary particles in Standard Model

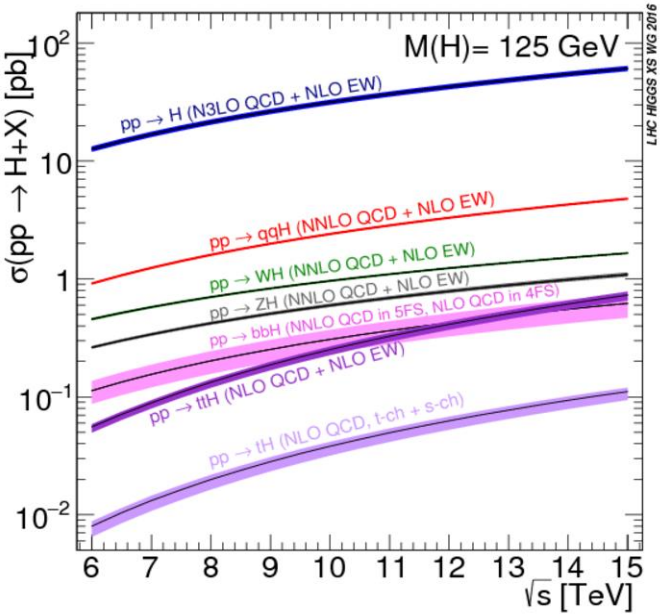
- The Higgs boson is the fundamental particle associated with the Higgs field, a field that gives mass to other fundamental particles such as electrons and quarks.

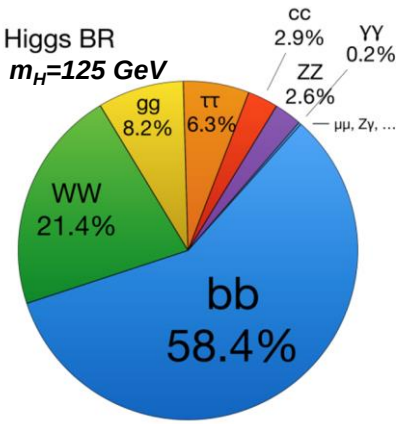
- A particle's mass determines how much it resists changing its speed or position when it encounters a force.



Higgs boson production & decay





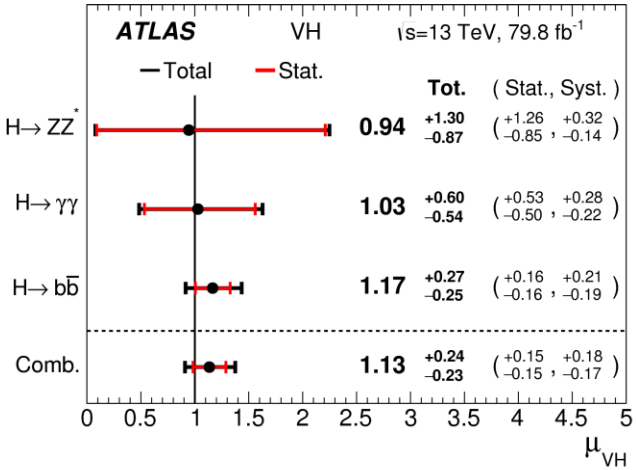


Observation of VH & H→$b\bar{b}$ decays

VH

Channel	Significance	
	Exp.	Obs.
$H \to ZZ^* \to 4\ell$	1.1	1.1
$H \to \gamma\gamma$	1.9	1.9
$H \to b\bar{b}$	4.3	4.9
VH combined	4.8	5.3

Expected and observed significance values (in standard deviations) for the VH production channels from the combined fit, using 13 TeV data.

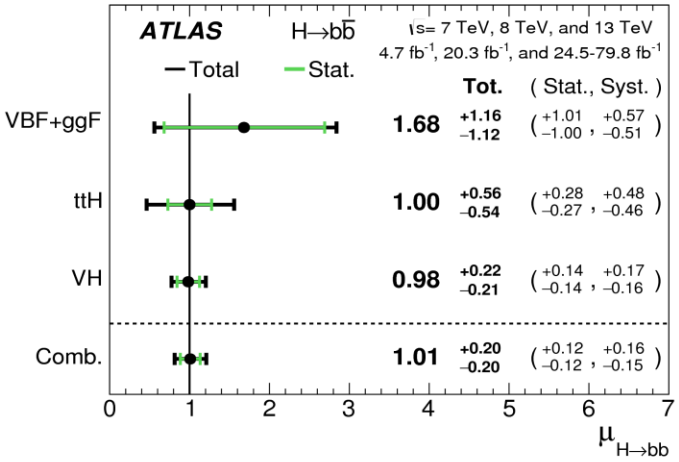


The fitted values of the Higgs boson signal strength μ_{VH} for m_H=125 GeV separately for the H→bb, H→γγ and H→ZZ→4ℓ decay modes, along with their combination.*

H→$b\bar{b}$

Channel	Significance	
	Exp.	Obs.
VBF+ggF	0.9	1.5
$t\bar{t}H$	1.9	1.9
VH	5.1	4.9
$H \to b\bar{b}$ combination	5.5	5.4

Expected and observed significance values (in standard deviations) for the H→bb channels fitted independently and their combination using the 7 TeV, 8 TeV and 13 TeV data.

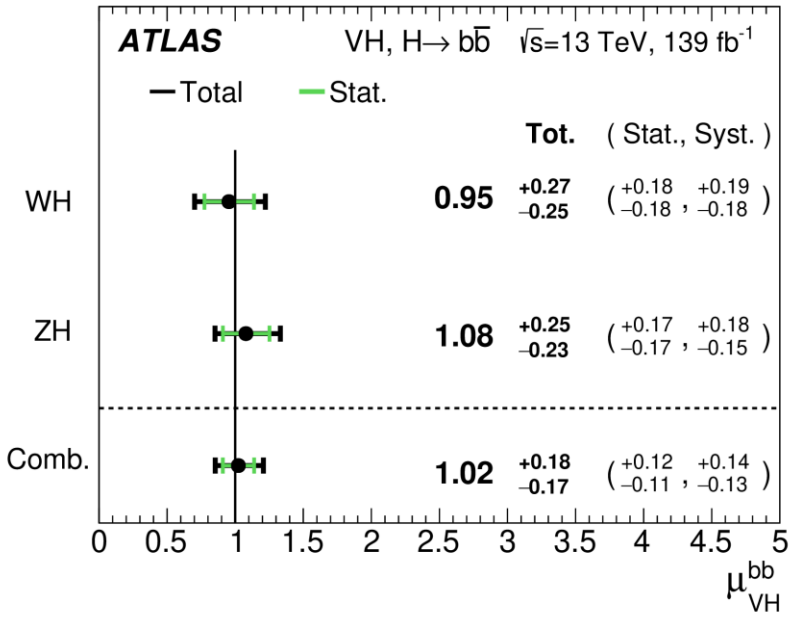


The fitted values of the Higgs boson signal strength $\mu_{H\to bb}$ for m_H=125 GeV separately for the VH, ttH and VBF+ggF analyses along with their combination, using the 7 TeV, 8 TeV and 13 TeV data.

MVA analysis results

Source of uncertainty		σ_μ VH	WH	ZH
Total		0.177	0.260	0.240
Statistical		0.115	0.182	0.171
Systematic		0.134	0.186	0.168
Statistical uncertainties				
Data statistical		0.108	0.171	0.157
$t\bar{t}$ $e\mu$ control region		0.014	0.003	0.026
Floating normalisations		0.034	0.061	0.045
Experimental uncertainties				
Jets		0.043	0.050	0.057
$E_{\mathrm{T}}^{\mathrm{miss}}$		0.015	0.045	0.013
Leptons		0.004	0.015	0.005
b-tagging	b-jets	0.045	0.025	0.064
	c-jets	0.035	0.068	0.010
	light-flavour jets	0.009	0.004	0.014
Pile-up		0.003	0.002	0.007
Luminosity		0.016	0.016	0.016
Theoretical and modelling uncertainties				
Signal		0.072	0.060	0.107
Z + jets		0.032	0.013	0.059
W + jets		0.040	0.079	0.009
$t\bar{t}$		0.021	0.046	0.029
Single top quark		0.019	0.048	0.015
Diboson		0.033	0.033	0.039
Multi-jet		0.005	0.017	0.005
MC statistical		0.031	0.055	0.038

Process and category	Normalisation factor
$t\bar{t}$ 2-jet	0.98 ± 0.09
$t\bar{t}$ 3-jet	0.93 ± 0.06
W + HF 2-jet	1.06 ± 0.11
W + HF 3-jet	1.15 ± 0.09
Z + HF 2-jet, $75 < p_{\mathrm{T}}^{V} < 150$ GeV	1.28 ± 0.08
Z + HF 3-jet, $75 < p_{\mathrm{T}}^{V} < 150$ GeV	1.17 ± 0.05
Z + HF 2-jet, 150 GeV $< p_{\mathrm{T}}^{V}$	1.16 ± 0.07
Z + HF 3-jet, 150 GeV $< p_{\mathrm{T}}^{V}$	1.09 ± 0.04



VH(bb) obs. (exp.) σ=6.7(6.7)

WH(bb) obs. (exp.) σ=4.0(4.1)

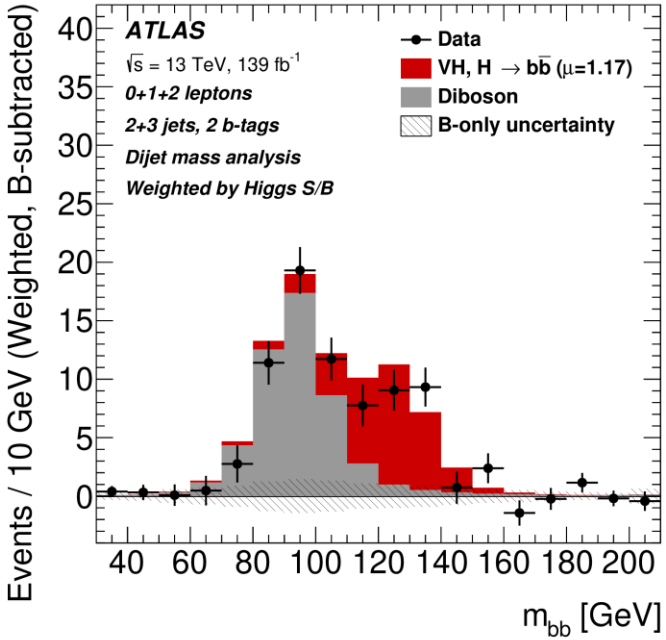
ZH(bb) obs. (exp.) σ=5.3(5.1)

Dijet-mass & Diboson results

VH(bb)

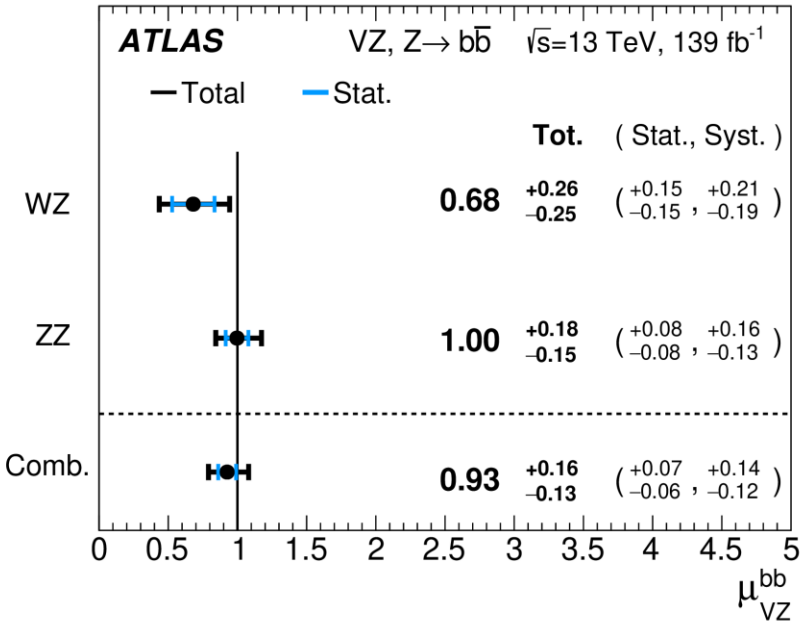
Channel	Expected sig.	Observed sig
m_{bb} VH		
0L	3.3	3.5
1L	2.7	3.4
2L	2.9	3.5
0L+1L+2L	4.9	5.5

$$\mu_{VH}^{bb} = 1.17 \pm 0.16(stat.)^{+0.19}_{-0.16}(syst.)$$



VZ(bb)

Channel	Expected sig.	Observed sig.
MVA VZ		
0L	8.1	7.7
1L	4.0	2.9
2L	7.5	7.8
0L+1L+2L	10.5	10.3

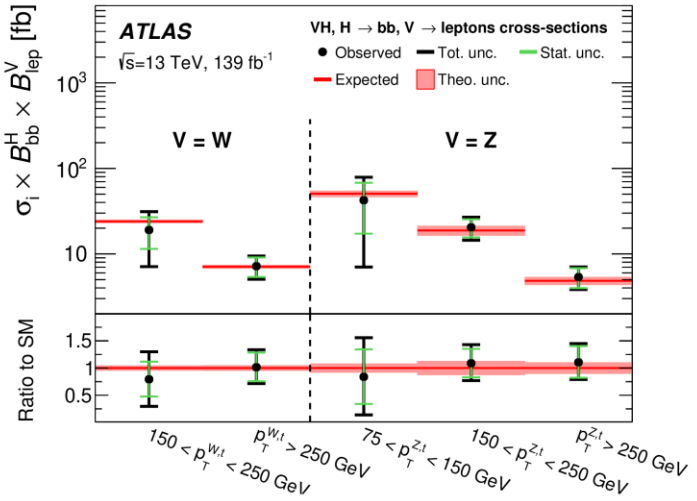


Cross-section measurement

Best-fit values and uncertainties for the *VH, V→ leptons* cross-section times the $H\to b\bar{b}$ branching fraction, in the reduced STXS scheme.

STXS region		SM prediction	Result	Stat. unc.	Syst. unc. [fb]		
Process	$p_{\mathrm{T}}^{V,\,\mathrm{t}}$ interval	[fb]	[fb]	[fb]	Th. sig.	Th. bkg.	Exp.
$W(\ell\nu)H$	150–250 GeV	24.0 ± 1.1	19.0 ± 12.1	± 7.7	± 0.9	± 5.5	± 6.0
$W(\ell\nu)H$	>250 GeV	7.1 ± 0.3	7.2 ± 2.2	± 1.9	± 0.4	± 0.8	± 0.7
$Z(\ell\ell/\nu\nu)H$	75–150 GeV	50.6 ± 4.1	42.5 ± 35.9	± 25.3	± 5.6	± 17.2	± 19.7
$Z(\ell\ell/\nu\nu)H$	150–250 GeV	18.8 ± 2.4	20.5 ± 6.2	± 5.0	± 2.3	± 2.4	± 2.3
$Z(\ell\ell/\nu\nu)H$	>250 GeV	4.9 ± 0.5	5.4 ± 1.7	± 1.5	± 0.5	± 0.5	± 0.3

- The cross-sections are all consistent with the SM expectations and are measured with relative uncertainties varying from 30% in the highest p_T^V region to 85% in the lowest p_T^V region.
- The data statistical uncertainty is the largest single uncertainty in all regions, although in the lower p_T^V regions systematic uncertainties make a sizeable contribution to the total uncertainty.
- For the *ZH* measurements, the signal uncertainties also make a sizeable contribution due to the limited precision of the theoretical calculations of the $gg\to ZH$ process.



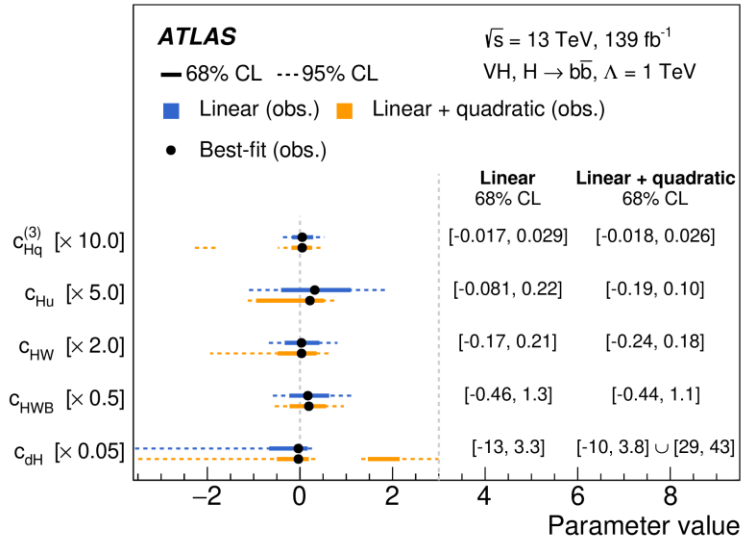
Effective interactions

- The strength and tensor structure of the process VH, $H \to b\bar{b}$ are investigated using an effective Lagrangian approach.
- Extra terms are added to the SM Lagrangian ($\mathcal{L}_{SM}$) to obtain an effective Lagrangian ($\mathcal{L}_{SMEFT}$) following the approach in Ref.[JHEP 12, 070 (2017)]:

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_i \frac{c_i^{(D)}}{\Lambda^{D-4}} \mathcal{Q}_i^{(D)}$$

where Λ is the energy scale of the new interactions, $\mathcal{Q}_i^{(D)}$ are dimension-D operators, and $c_i^{(D)}$ are numerical Wilson coefficients.

- Only D = 6 operators are considered in this study, since D = 5 and D = 7 operators violate lepton or baryon number, D > 7 operators are further suppressed by powers of Λ.
- Thirteen operators directly affect the VH cross section.
- This analysis has significant sensitivity to the six operators, in addition the operator which directly affects the $H \to b\bar{b}$ decay width.
- The allowed range of the individual or linear combinations of the coefficients, to which the analysis has the greatest sensitivity, is limited to a few percent.

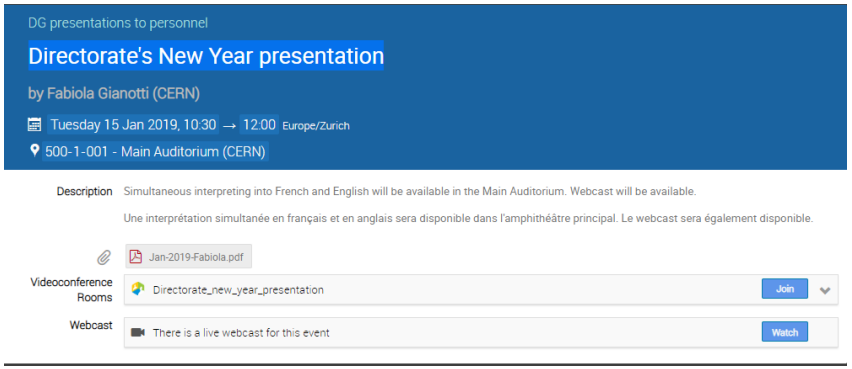


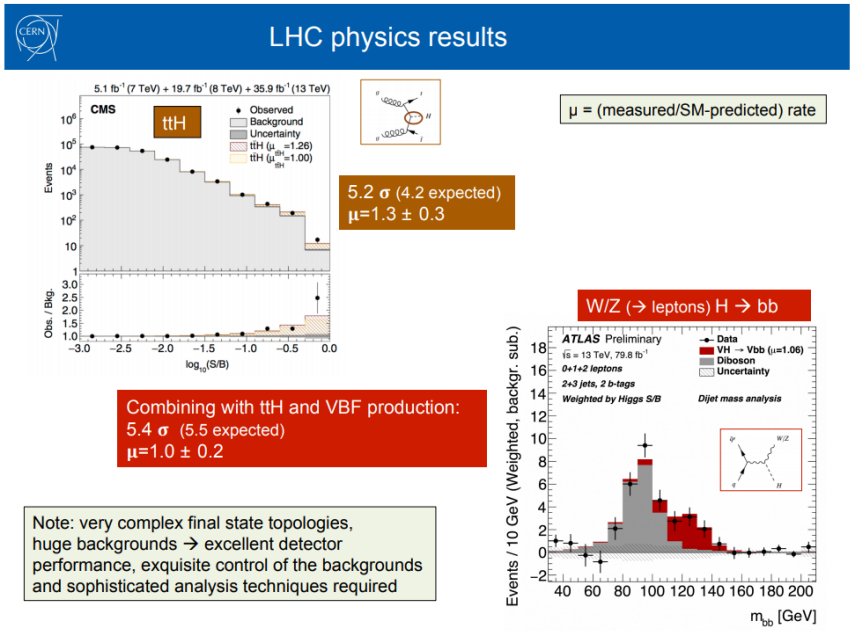
Conclusion

- Measurements are presented of the SM Higgs boson decaying into a $b\bar{b}$ pair and produced in association with a W or Z boson.
- For a Higgs boson with m_H = 125 GeV produced in association with either a Z or W boson, an observed (expected) significance of 6.7σ (6.7σ) is found and a signal strength relative to the SM prediction of
$$\mu_{VH}^{bb} = 1.02^{+0.12}_{-0.11}(stat.)^{+0.14}_{-0.13}(syst.)$$ is measured.
- For a Higgs boson produced in WH, an observed (expected) significance of 4.0σ (4.1σ) is found and a signal strength relative to the SM prediction for m_H=125GeV of $\mu_{WH}^{bb} = 0.95 \pm 0.18(stat.)^{+0.19}_{-0.18}(syst.)$ is measured.
- For a ZH an observed (expected) significance of rejecting the background-only hypothesis of 5.3σ (5.1σ) is found and a signal strength of
$$\mu_{WH}^{bb} = 1.08 \pm 0.17(stat.)^{+0.18*}_{-0.15}(syst.)$$ is measured.
- Cross-sections of $VH \rightarrow llbb$ are measured as a function of the p_T^V in kinematic fiducial volumes in the STXS framework. The uncertainties in the measurements vary from 30% in the highest p_T^V regions to 85% in the lowest, and are in agreement with the SM predictions.
- Limits are also set on the coefficients of effective Lagrangian operators which affect the VH production and $H \rightarrow b\bar{b}$ decay.

Eur. Phys. J. C (2021) 81:178

Physics highlights





Fabiola Gianotti
Directorate's New Year presentation

Karl Jakobs

ATLAS Induction Day + Software Tutorial

Giacinto Piacquadio
ICHEP-2018

CERN Press release:
Long-sought decay of Higgs boson observed

ATLAS press release:
ATLAS observes elusive Higgs boson decay to a pair of bottom quarks

Газета Дубна ЕЖЕНЕДЕЛЬНИК ОИЯИ :
О «неуловимом» распаде бозона Хиггса

ATLAS paper:
Observation of *H→bb* decays and *VH* production with the ATLAS detector
Phys. Lett. B 786 (2018) 59

"Measurement of VH, H->bb ..." is published in JHEP 05 (2019) 141
"Measurements of WH and ZH, H->bb ..." is published in Eur. Phys. J. C (2021) 81:178

Publications I

1. F. Ahmadov et al. (ATLAS Collaboration), Measurements of WH and ZH production in the $H \to b\bar{b}$ decay channel in pp collisions at 13 TeV with the ATLAS detector, Eur. Phys. J. C (2021) 81:178.
2. F.N. Ahmadov, M.A. Manashova, Stady of WH production at LHC using different event generators, AJP FIZIKA 2021, Vol. XXVII №1, pp. 3-7.
3. F. Ahmadov et al. (ATLAS Collaboration), Measurements of *WH* and *ZH* production in the $H \to b\bar{b}$ decay channel in pp collisions at 13TeV with the ATLAS detector, ATLAS-CONF-2020-006.
4. M.A. Manashova, F.N. Ahmadov, Spin effects in the process of associative production of the Higgs boson and $W^{\pm}$ boson, Eurasian Journal of Physics and Functional Materials - EJPFM 2020, 4(2), 132-138.
5. F. Ahmadov et al., ATLAS Collaboration, Measurement of *VH,* $H \to b\bar{b}$ production as a function of the vector-boson transverse momentum in 13TeV pp collisions with the ATLAS detector, JHEP 05 (2019) 141. (İF: ~6)
6. Ф. Ахмадов, Труды VIII Межинститутского молодежной конференции "Физика элементарных частиц и космология 2019", МФТИ (ГУ) Москва, 2019, https://belle.lebedev.ru/conf_mipt_2019/ .
7. F. Ahmadov, A study of the VH associated production process, Proceedings of the XXIII International Scientific Conference of Young Scientists and Specialists, 2019.
8. F.N. Ahmadov, Standart modeldə Hiqqs bozonun vektor bozonla birgə yaranma prosesinin tədqiqi, AJP Fizika 2019, Vol.XXV, №4, 59-63.
9. F. Ahmadov et al., (ATLAS collaboration), Observation of $H \to b\bar{b}$ decays and VH production with the ATLAS detector. Phys. Lett. B 786 (2018) 59.
10. F. Ahmadov et al., (ATLAS collaboration), Observation of $H \to b\bar{b}$ decays and V H production with the ATLAS detector, ATLAS CONF Note: ATLAS-CONF-2018-036.

Publications II

11. F. Ahmadov et al., (ATLAS collaboration), Measurement of VH, Hbb production as a function of the vector boson transverse momentum in 13 TeV *pp* collisions with the ATLAS detector, ATLAS CONF Note ATLAS-CONF-2018-053;
12. F. Ahmadov et al., Simplified Template Cross-Section measurements for the VH(bb) process with the ATLAS detector, ATLAS preprint, ATLAS NOTE ATL-COM-PHYS-2018-1215.
13. Ахмадов Ф., Поиск распада бозона Хиггса на пару b-кварков при ассоциативном его рождении с W-бозоном, Тезисы конференции "Физика фундаментальных частиц и космология 2018", ст.6.
14. F. Ahmadov et al., ATLAS LAr Calorimeter Phase-II Upgrade Technical Design Report, ATLAS collaboration, CERN-LHCC-2017-018 ATLAS-TDR-027.
15. F. Ahmadov et al., (ATLAS collaboration), Evidence for the $H \to b\bar{b}$ decay with the ATLAS detector, ATLAS collaboration, JHEP12(2017)024, (*IF: 6.063*).
16. F. Ahmadov et al., (ATLAS Collaboration), Evidence for the $H \to b\bar{b}$ decay with the ATLAS detector, ATLAS Conf Note, ATLAS-CONF-2017-041.
17. F. Ahmadov, Анализ реакции ассоциативного рождения бозона Хиггса и W-бозона в эксперименте ATLAS, 2290.01 – Физика высоких энергий, ИФ НАНА, Баку, 2016.
18. F. Ahmadov et al., (ATLAS collaboration), Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a bb pair in pp collisions at 13 TeV using the ATLAS detector, ATLAS Conf Note, ATLAS-CONF-2016-091.
19. F. Ahmadov et al., Object selections for SM Higgs boson produced in association with a vector boson in which $H \to b\bar{b}$ and V decays leptonically with Run-2 data, ATLAS preprint. ATLAS NOTE ATL-COM-PHYS-2016-1674.
20. F. Ahmadov et al., (VHbb Group) Modelling Studies for the Standard Model VH, $H \to b\bar{b}$, ATLAS preprint, ATLAS NOTE ATL-COM-PHYS-2016-1747.

And over 200 paper with ATLAS Collaboration.

Talks in Conf. & Sem. I

1) Общеинститутский семинар ОИЯИ, планируется 17 Марта 2021.
2) JINR-ATLAS Physics Weekly Meeting, JINR, Dubna, Russia, 25 Feb. 2021.
3) Physics & Computing Russian Institutes meeting, INP MSU, Moscow, Russia, 21 Jan. 2020.
4) JINR-ATLAS Physics Weekly Meeting, JINR, Dubna, Russia, 21 May 2020.
5) Kick-off meeting for the VH legacy analysis, CERN, Geneva, Switzerland, 20 May 2020.
6) The XXIII International Scientific Conference of Young Scientists and Specialists (AYSS-2019), JINR, Dubna, Russia, 15-19 April 2019;
7) VIII Межинститутская молодежная конференция, Физика элементарных частиц и космология 2019; МФТИ (ГУ), Москва, Россия, 11-12 апреля 2019;
8) Physics and Computing Russian Institutes meeting, MEPhI, Moscow, Russia, 21 Jan. 2019;
9) 50th meeting of the PAC for Particle Physics, JINR, Dubna, Russia, 21-22 Jan. 2019;
10) ATLAS: H(bb) Meeting, CERN, Geneva, Switzerland, 9 Jan. 2019;
11) ATLAS: VH(bb) resolved analysis meeting, CERN, Geneva, Switzerland, 17 Jan. 2019;
12) Seminar, VBLHEP, JINR, Dubna, Russia, 31 May 2019;
13) ATLAS: H(bb) Meeting, CERN, Geneva, Switzerland, 24 April 2019;
14) ATLAS JINR internal meeting, JINR, Dubna, Russia, 13 Jun 2019;
15) Physics and Computing Russian Institutes meeting, JINR, Dubna, Russia, 16-17 Sep. 2019;
16) VII межинститутская молодёжная конференция, Физика элементарных частиц и космология, ФИАН, 9 – 10 апреля 2018;
17) The XXII International Scientific Conference of Young Scientists and Specialists (AYSS-2018), JINR, Dubna, Russia, 23-27 Apr. 2018.

Talks in Conf. & Sem. II

18) VII Annual Scientific Conference of Young Scientists and Specialists of JINR “Alushta-2018”, Alushta, Krim, 11-18 June 2018.

19) 46th meeting of the PAC for Particle Physics, Joint Institute Research, Dubna, Russia, 18-19 June 2018

20) Russian Institutes meeting "Physics and Computing in ATLAS", JINR, Dubna, Russia, 16-17 October 2018.

21) 46th meeting of the PAC for Particle Physics, JINR, Dubna, Russia, 16-17 Jan. 2017 / Search for the SM Higgs boson produced in association with a vector boson and decaying to b-quarks with the ATLAS Detector at LHC.

22) Russian Institutes meeting "Physics and Computing in ATLAS", MEPhI, Moscow, Russia, 24 Jan. 2017 / Status of the Higgs analyses.

23) International Conference “25th anniversary of JINR in ATLAS”, Budva, Montenegro, 24-29 aprel 2017 / Study of *WH (W→lv, H→* $b\bar{b}$*)* associated production process in ATLAS.

24) Russian Institutes meeting "Physics and Computing in ATLAS", JINR, Dubna, Russia, 19-20 Sep. 2017 / Status of the VH(bb) analysis.

25) ATLAS SM VHbb meeting, CERN, Geneva, Switzerland, 03 Oct. 2016 /New input variables for 1-lepton analysis.

26) JINR-ATLAS Weekly Meeting, Dubna, Russia, 21 Oct. 2016 / New input variables for VHbb MVA.

27) Seminar, High Energy Physics Institute of Tbilisi State University, Tbilisi, Georgia, 13 May. 2016.

28) JINR-ATLAS Weekly Meeting, Dubna, Russia, 01 Dec. 2016 / WH(bb) analyses.

29) Seminar, BSU, Bakı, 2016/ATLAS eksperimentində Hiqqs və W-bozonun assosiativ yaranma reaksiyasının analizi.

30) PhD müdafiə, “2290.01-Yüksək enerjilər fizikası”, AMEA Fİ, Bakı, Azərbaycan, 01 İyun 2016.

31) The XXI International Scientific Conference of Young Scientists and Specialists (AYSS-2017), JINR, Dubna, Russia, 2-6 Oct. 2017 / The study of the associated production of the Higgs boson with the W boson and decay into a pair of b-quarks.

Publication rates & links

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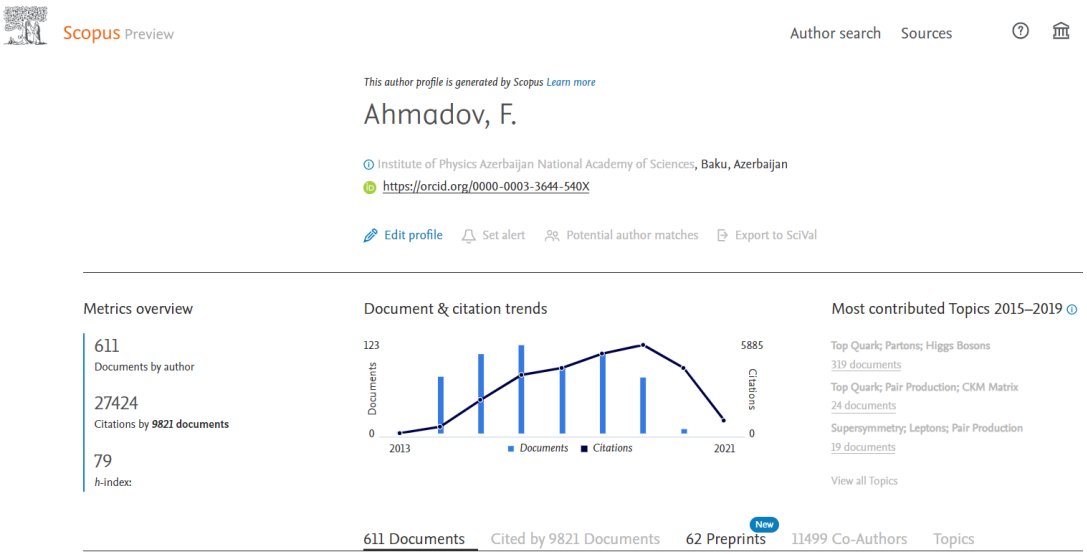
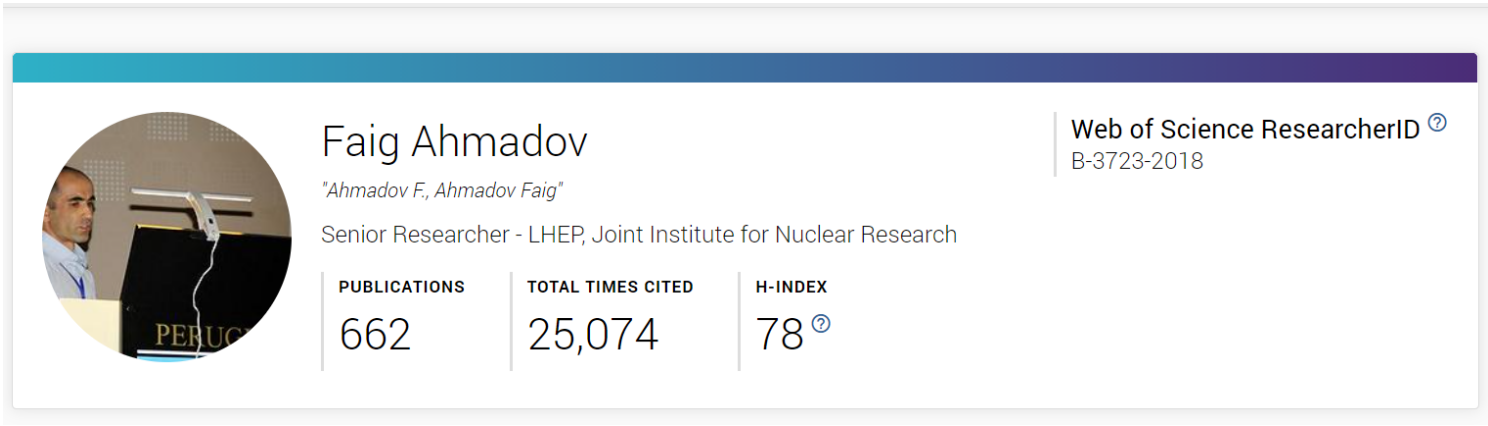
[Research Gate link]





Diplomas & awards

- Winner of the scholarship competition named after academician MA Markov (scholarship and diploma) for young scientists and specialists of LHEP JINR for 2016.
- Winner of the scholarship competition named after academician MA Markov (scholarship and diploma) for young scientists and specialists of LHEP JINR for 2018.
- Winner of the JINR Award Competition for 2018.

Other activities

- Scientific supervision of a student of Dubna University. Successful defense of bachelor's degree in 2019.
- Monitoring the data collection process in the ATLAS detector (in the control room of the ATLAS detector, a trip to CERN for several months).
- Scientific supervision of the master of Dubna University. It is planned to defend the master's thesis in the summer.

Plans

- Continue research to separate observation $WH \rightarrow lvb\bar{b}$ process in the ATLAS experiment. For this purpose, the analysis of experimental data obtained from the detector so far using new programs.
- Selecting a more effective method by exploring various multivariate analysis methods.
- Improvement of the neural network (NN) method and use in future research. At the same time to test the possibility of using this method in other fields of physics.
- Improving results by including new variables into research. Improving the accuracy of cross-section measurements.
- Search for deviations from the Standard model via the WH channel.
- Physical analysis in the NICA megaproject in parallel with my main job when needed.

Thank You!