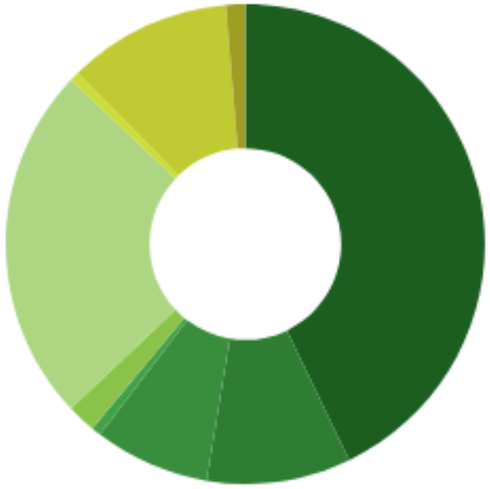
Results of the JINR team in ATLAS

I. Yeletskikh
Dzhelepov Laboratory of Nuclear Problems, JINR

On behalf of the JINR ATLAS team

JINR team in ATLAS Collaboration



- **66** Physicist
- **15** Physics PhD student
- **12** Physics masters/diploma student
- **1** Undergraduate/summer student
- **3** Engineer with PhD
- **37** Engineer without PhD
- **1** Engineering student
- **17** Technician or equivalent
- **2** Administrator/other

- **48** on Authorlist (A)
- **1** Signing-Only (a)
- **37** counted for M&O (M)
- **0** qualifying members (q)
- **45.25** for Operation Tasks (O, o)

DLNP: Atanov N., Batusov V., Bednyakov V., Boyko I., Chizhov M., Dedovich D., Demichev M., Didenko A., Dolovova O., Elkin V., Ershova A., *Filimonov S.*, Gerasimov V., Gladilin L., Glagolev V., Gongadze A., Gongadze L., Gostkin M., Ivanov Y., Kalinovskaja L., Karpov S., Karpova Z., Kharchenko D., Kostyukhina I., Kruchonak U., *Kuchinskaya O.*, Lyabline M., Lyashko I., Lykasov G., Lyubushkin V., Lyubushkina T., Malyukov S., Minashvili I., Minashvili I.(jr.), Nefedov Y., Plontikova E., Potrap I., Prokhorov A., *Ramakoti E.*, Romanov V., Rusakovich N., Sapronov A., Serochkin M., Shalyugin A., Shelkov G., Shiyakova M., *Shreyber I.*, *Soldatov E.*, Souslov I., Tropina A., Usubov Z., Yeletskikh I., Yermolchyk V., Zhemchugov A.
LIT: Alexandrov E., Aleksandrov I., Gromova N., Iakovlev A., Kazymov A., Mineev M., Shigaev V., Zrelov P.
VBLHEP: Ahmadov F., *Amirkhanov A.*, *Anisenkov A.*, *Bobrovnikov V.*, *Buzykaev A.*, Cheplakov A., Fillipov Y., Kukhtin V., Ladygin E., Makarov A., Manashova M., *Maslennikov A.*, *Rezanova O.*, Soloshenko A., Shaykhatdenov B., *Snesarev A.*, *Tikhonov Yu.*, Turtuvshin T., Zimin N.

ATLAS physics studies

1. Development of the ReneSANCe MC generator used in precise SM measurements at ATLAS	**1 prof., 3 postdoc (2.0 FTE, Kalinovskaya L., Sadykov R., Yermolchuk V., Prokhorov A.)**
2. Modeling of di-J/ψ and $J/\psi+Z(W)$ production	**1 PhD student (1FTE, A.Prokhorov)**
3. Minbias measurements at 13.6TeV	**1 prof., 2 engineers (1.5 FTE, Koultchitski Y., Plotnikova E., Tsiareshka P.)**
4. Intrinsic charm and D+D- asymmetry produced in proton-proton collisions	**1 prof. (1.0 FTE, Lykasov G.)**
5. Hbb VH to bb+cc resolved+boosted	**1 postdoc, 1 PhD student (1.0 FTE, Ahmadov F., Manashova M.)**
6. Studies of tH(bb), application of neural networks to the data analysis	**4 postdoc, 2 PhD students, 1 m.student (2.6 FTE, I.Boyko, N.Huseynov, I.Yeletskikh, I.Souslov, A.Tropina, A.Didenko)**

ATLAS physics studies

7. Searches for Quantum Black Holes in lepton+jet final states	**2 postdocs (2 FTE, Karpov S., Karpova Z.)**
8. B_c, B^*_c excited states studies	**1 prof., 1 postdoc, 1 engineer (1 FTE, Gladilin L., Lyubushkina T., Lyubushkin V.)**
9. Studies of exotic states in *B*-hadron decays and fully charmed tetraquarks	**1 prof., 1 postdoc, 2 PhD students (2.4 FTE, Gladilin L., Yeletskikh I., Vasyukov A., Didenko A.)**
10. Higgs boson decays to bottom and charm quarks produced in associated with a W or Z boson	**1 postdoc (0.7FTE, Ahmadov F.)**

ATLAS physics studies

11. Measurement of $Z(\rightarrow\nu\nu)\gamma$+jets differential cross section, cross section measurements on production of $ZZ \rightarrow llvv$ and $ZZjj \rightarrow llvv\ jj$	**1 postdoc, (0.5 FTE, Soldatov E.)**
12. Measurement of the Higgs boson production cross section via ggF and VBF in $H\rightarrow WW^{*}\rightarrow lvlv$	**1 postdoc (0.3 FTE, Ramakoti E.)**
13. Measurement of the CP-violating phase in the B-meson decays	**1 postdoc (0.6 FTE, Lyubushkin V.)**

ATLAS software/simulation support

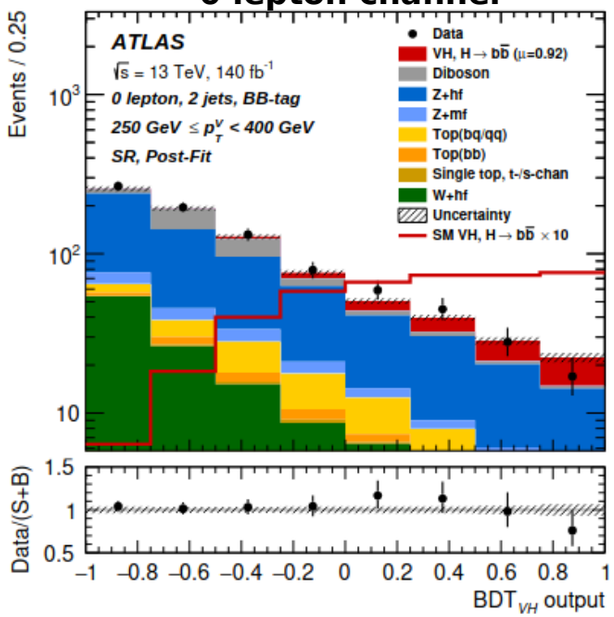
1. ‘Event index’ database development: Event picking service	**1 postdoc, 1 PhD (1.0FTE, E.Alexandrov)**
2. REST API development for database monitoring	**2 PhD students (1.5FTE, A.Gazzaev, D.Kokaev)**
3. Calorimeter simulation and software development, E/gamma reconstruction and performance	**3 postdoc, 2 PhD students (1.5FTE, A.Didenko, A.Tropina, N.Guseynov, E.Ramakoti, O.Rezanova, E.Soldatov)**
4. Software & Computing Infrastructure activities	**1 physicist, 0.3FTE A. Buzykaev**
5. Muon system software (trigger, new small wheel operation, other)	**4 Postdoc, 1 physicist (1.7FTE, V.Lyubushkin, I.Minashvili, S.Filimonov, I.Shreyber, O.Kuchinskaya)**

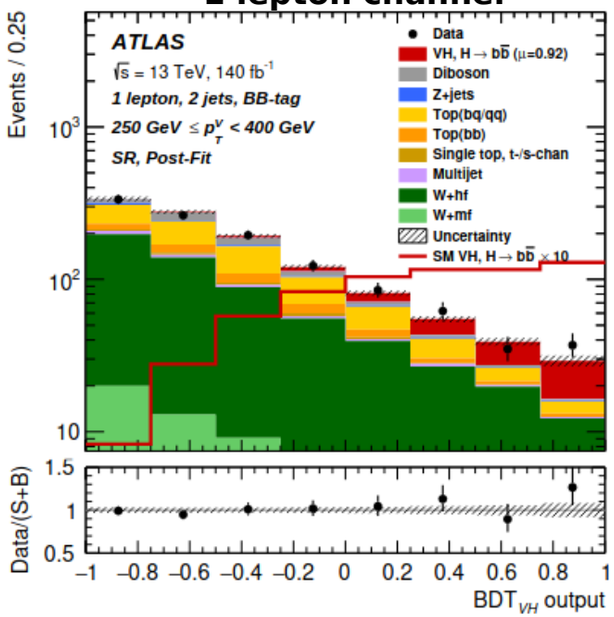
Measurements of WH and ZH production with Higgs boson decays into bottom quarks and direct constraints on the charm Yukawa coupling

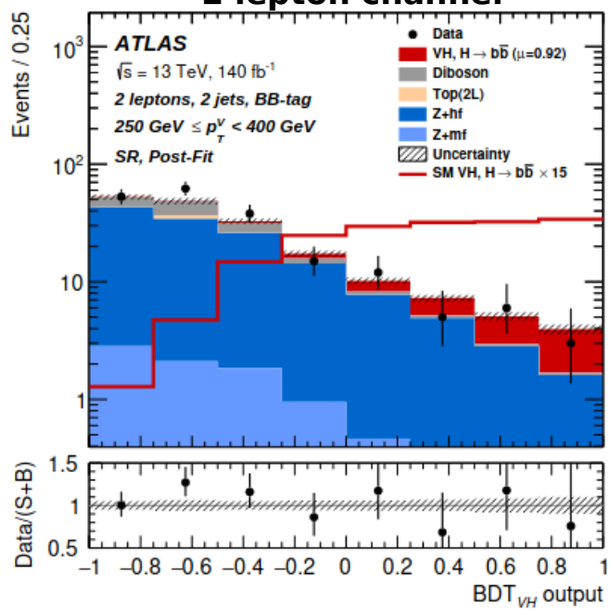
Differential cross-sections of the Higgs boson produced in association with W or Z bosons have been measured in H→bb channel. Vector boson pT specrum is split into ranges 75-150-250-400-600-inf GeV.

0 lepton channel | **1 lepton channel** | **2 lepton channel**

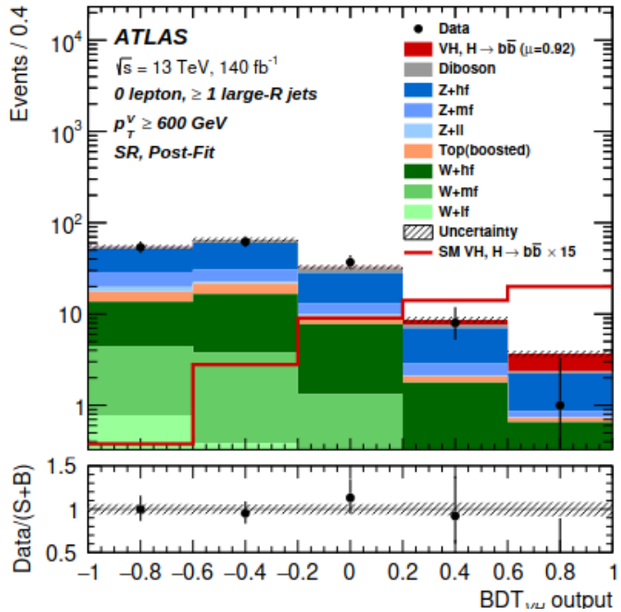
250 GeV < pT < 400 GeV

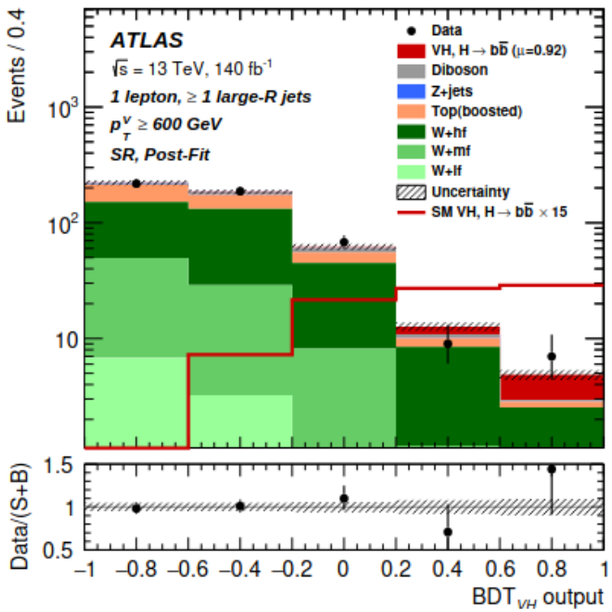


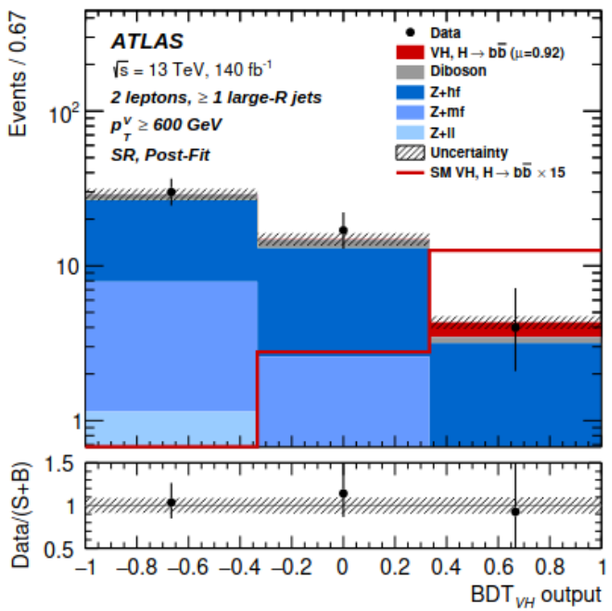




pT > 600 GeV



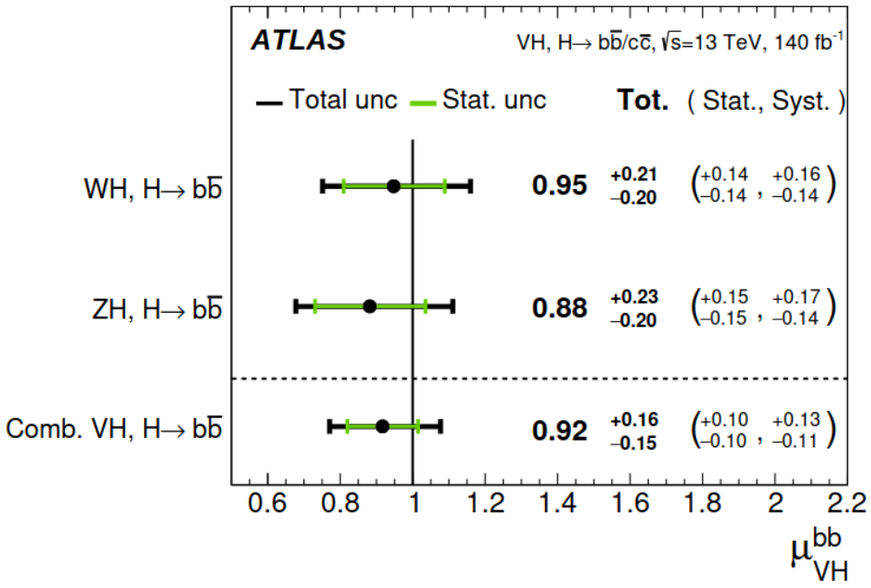




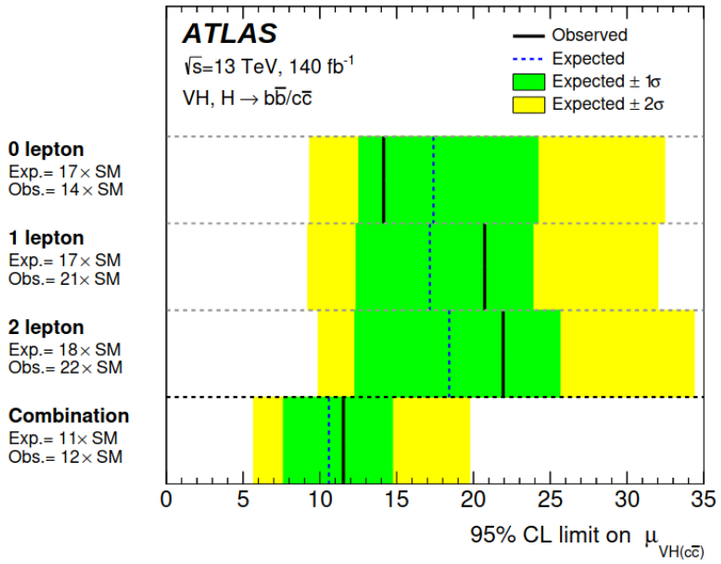
ArXiv:2410.19611, submitted to JHEP

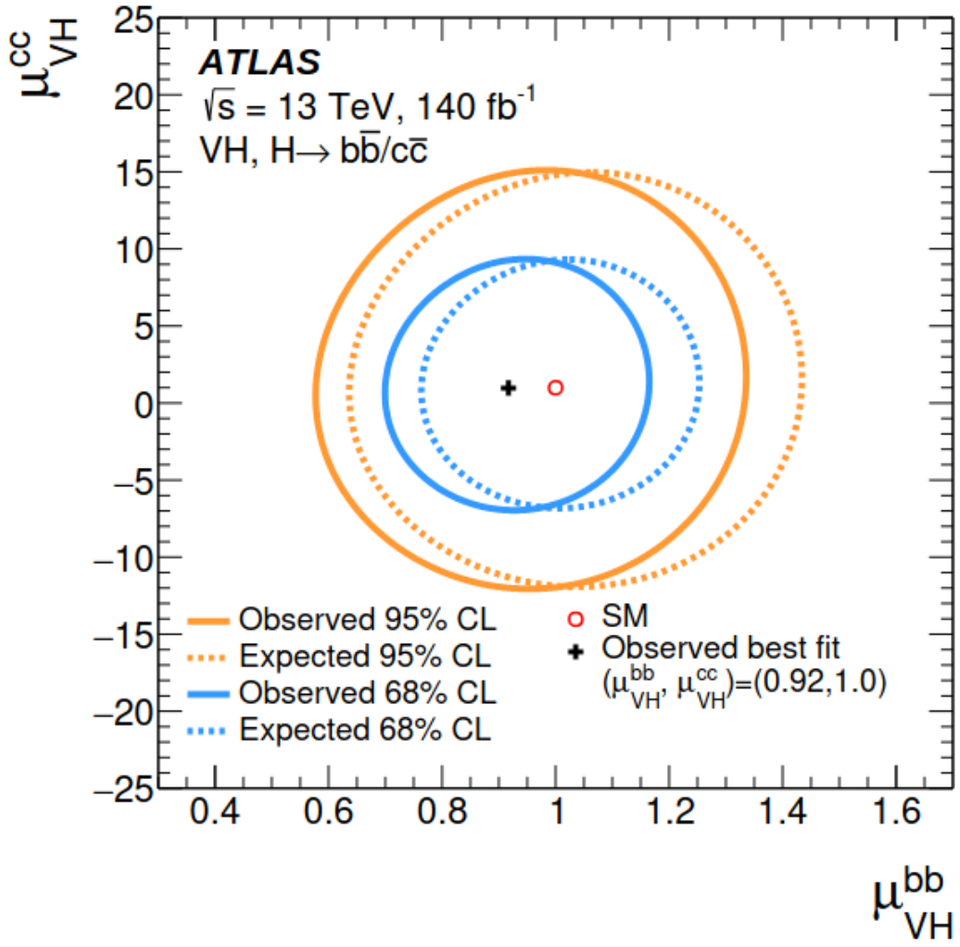
Measurements of WH and ZH production with Higgs boson decays into bottom quarks and direct constraints on the charm Yukawa coupling

Signal strength of $H\to bb$ in the VH production channels has been measured relative to that predicted by Standard Model.



Limit is set on $H\to cc$ signal strength relative to SM.



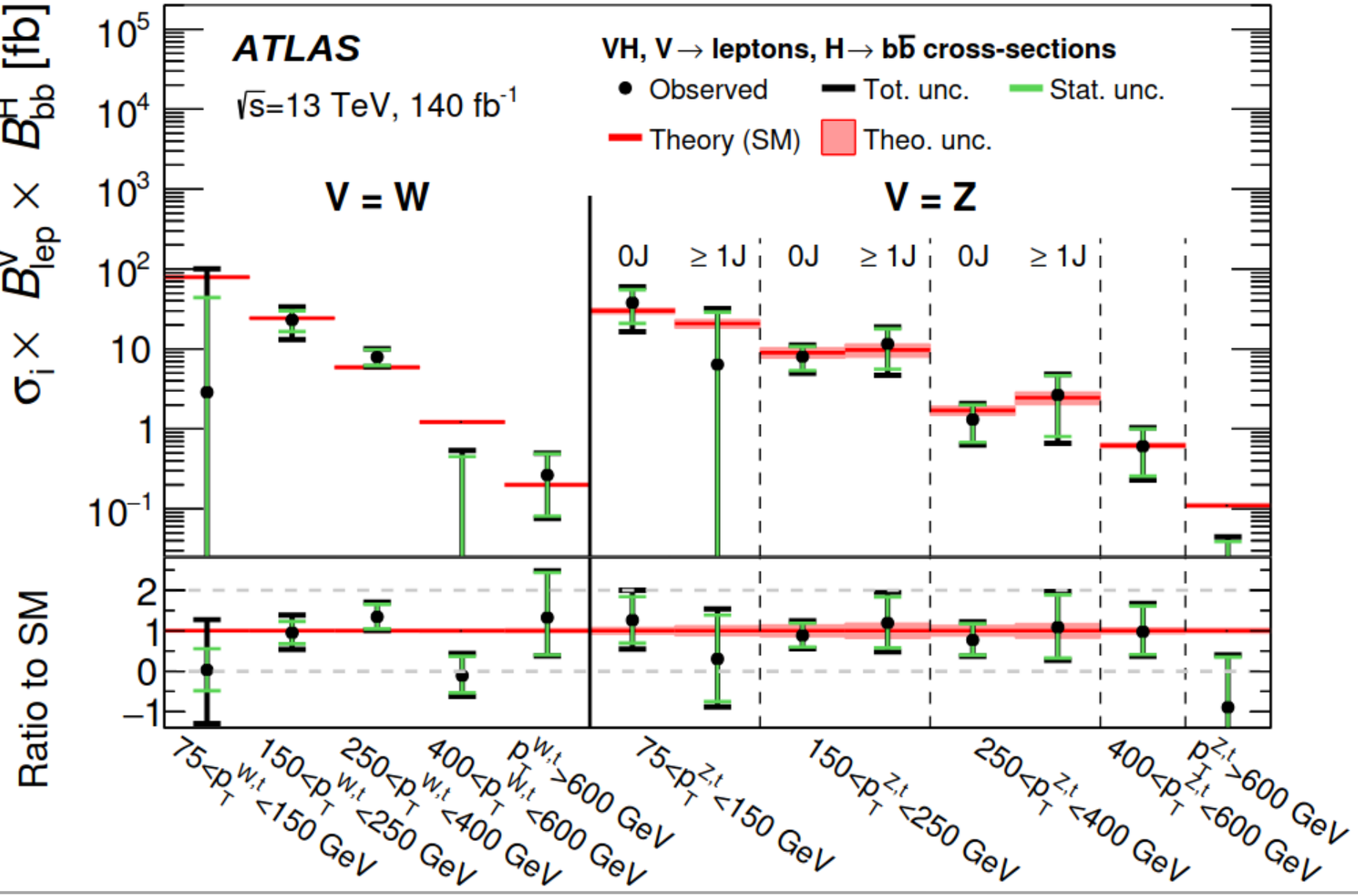


$$\mu_{VH}^{bb} = 0.92^{+0.16}_{-0.15} = 0.92 \pm 0.10\ (\text{stat.})^{+0.13}_{-0.11}\ (\text{syst.}),$$

$$\mu_{VH}^{cc} = 1.0^{+5.4}_{-5.2} = 1.0^{+4.0}_{-3.9}\ (\text{stat.})^{+3.7}_{-3.5}\ (\text{syst.}).$$

ArXiv:2410.19611, submitted to JHEP

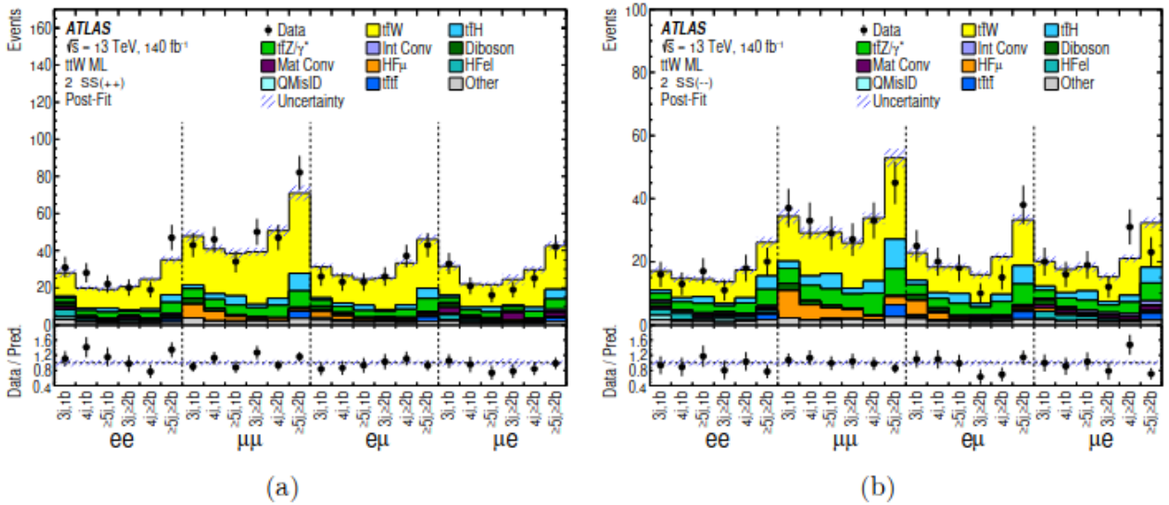
Summary of the differential cross section measurements in different channels

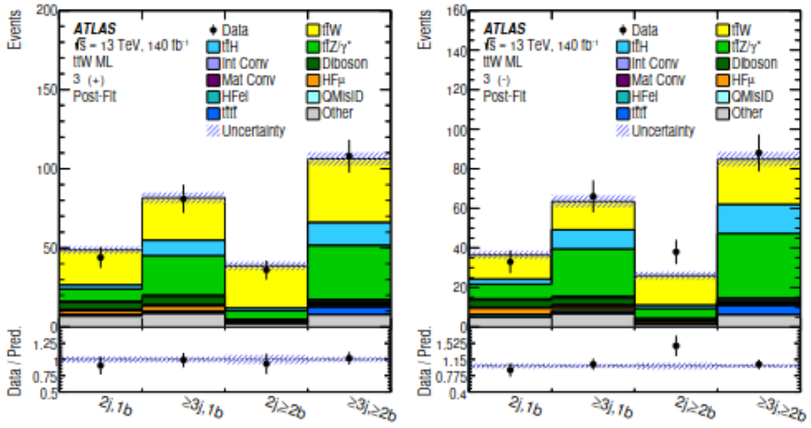


ArXiv:2410.19611, submitted to JHEP

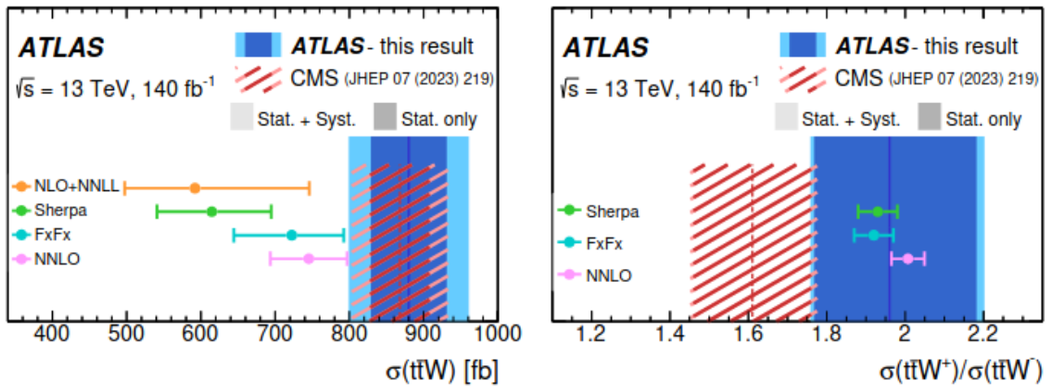
Measurement of the total and differential cross-sections of ttW production

Cross-section of the top-antitop pairs produced in association with W-bosons has been measured with ATLAS Run2 13TeV data

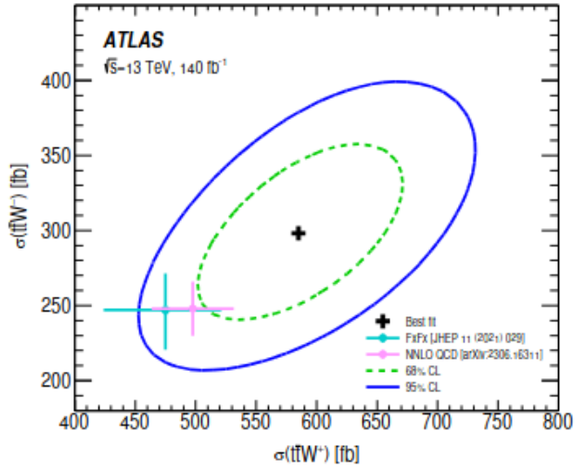




Comparison of data to MC prediction in 2-lepton (top) and 3-lepton (bottom) channels



Inclusive cross section and ratio between W+ and W- production cross sections.



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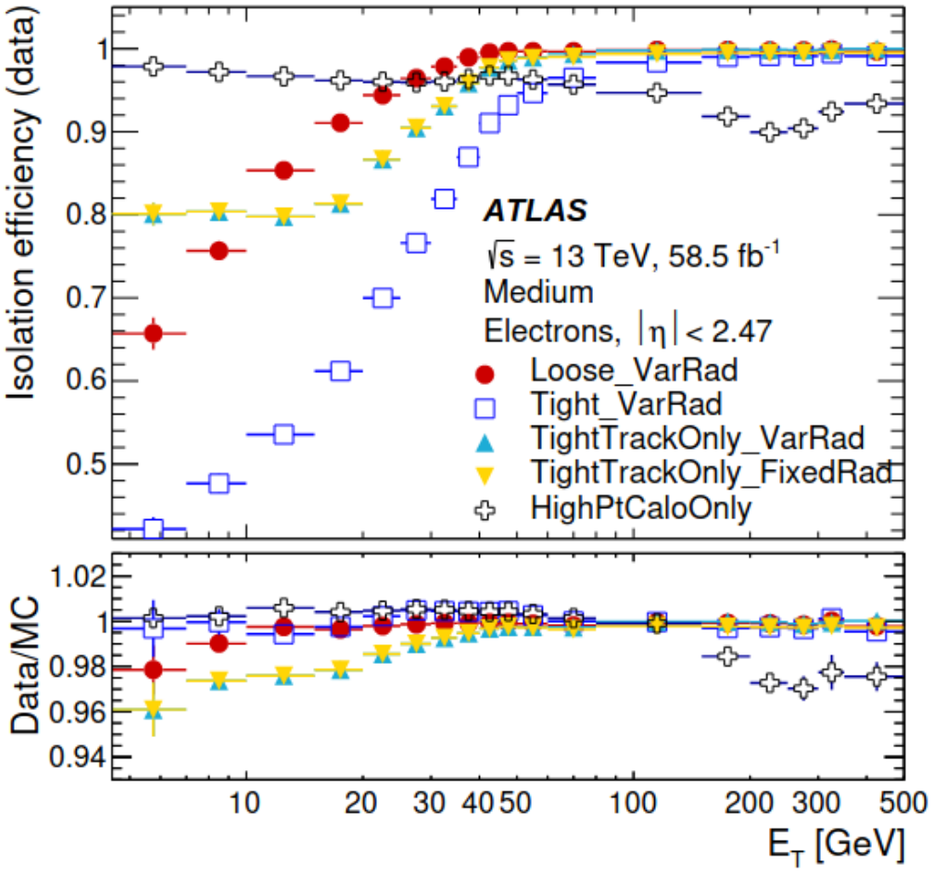
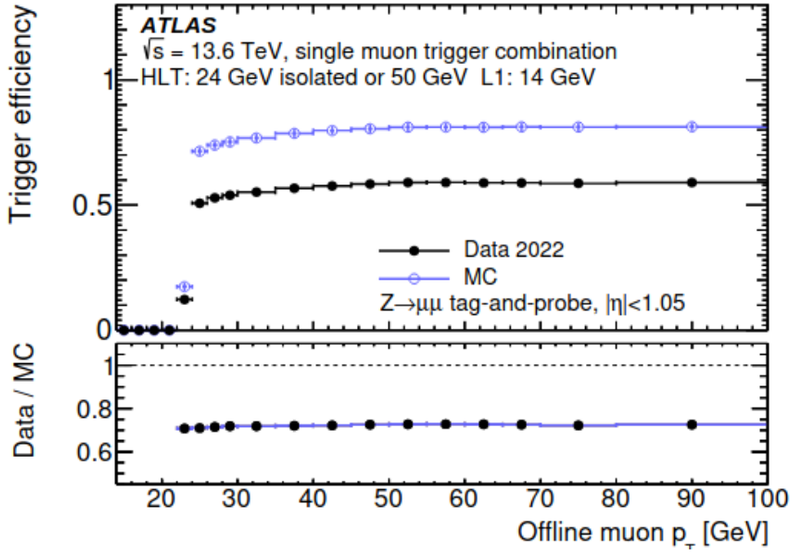
$$\sigma(t\bar{t}W^+) = 583 \pm 34\,(\text{stat.}) \pm 47\,(\text{syst.}) = 583 \pm 58\ \text{fb},$$

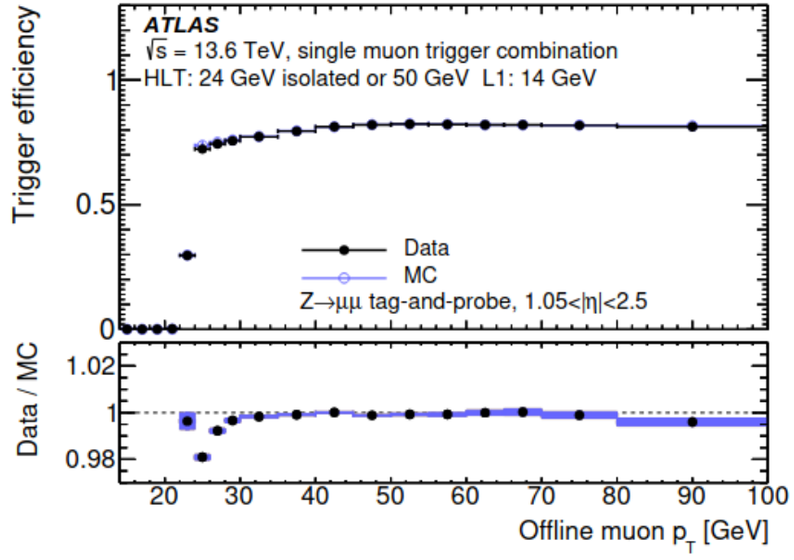
$$\sigma(t\bar{t}W^-) = 296 \pm 28\,(\text{stat.}) \pm 29\,(\text{syst.}) = 296 \pm 40\ \text{fb}.$$

Reconstruction performance studies

JINR group took active part in performance studies, in particular, in measurements of E/gamma reconstruction efficiencies, muon trigger efficiencies in Run 2 data.



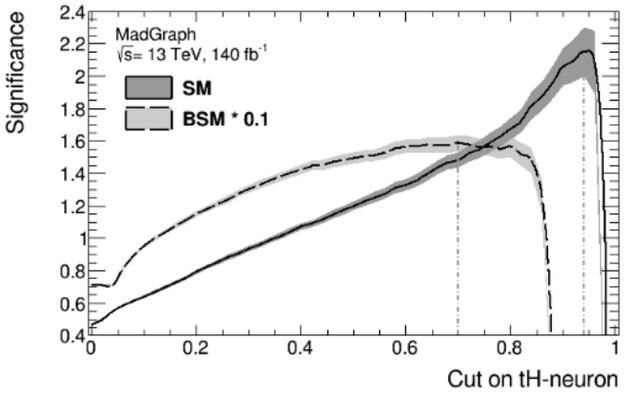




JINST 19 (2024) P06029
JHEP 05 (2024) 162

Other physics and software activities

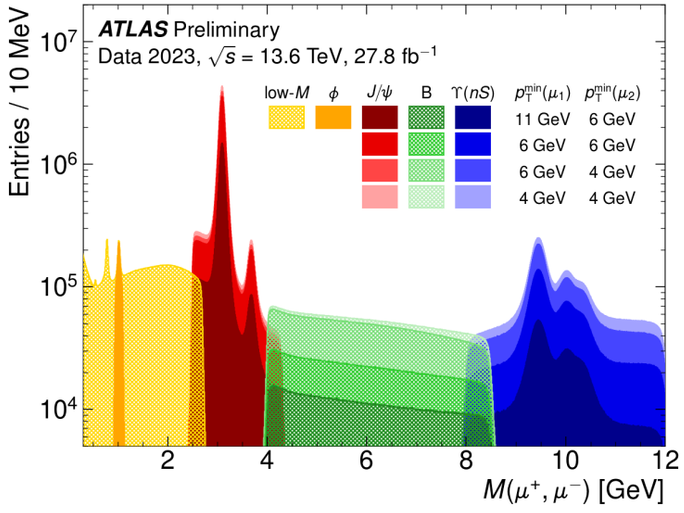
Search for the Higgs boson production in association with a single top quark



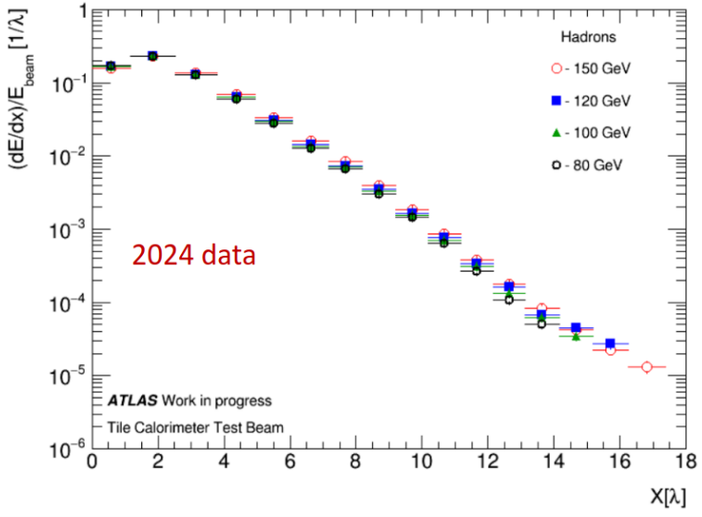
New machine learning techniques allow better signal/bg classification and higher expected signal significance

PEPAN, 21, pages 615–618, (2024)

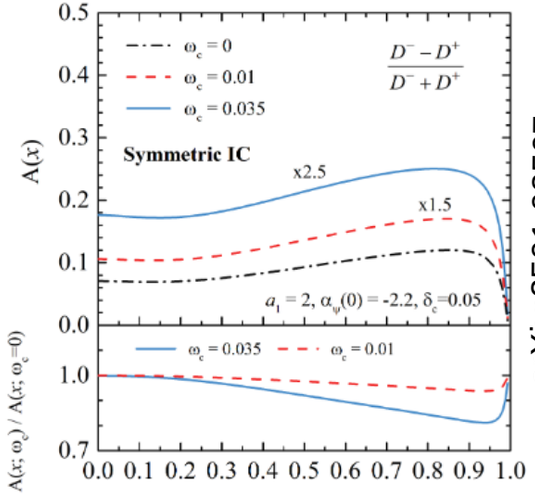
Development of the B-physics triggers software for Run3 has been accomplished during last years



Studies are ongoing on the calorimeter simulation using test beam data

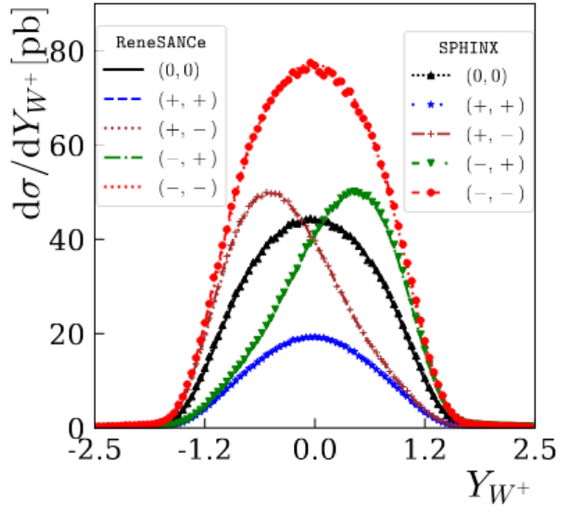


Intrinsic charm and D+D- asymmetry produced in proton-proton collisions



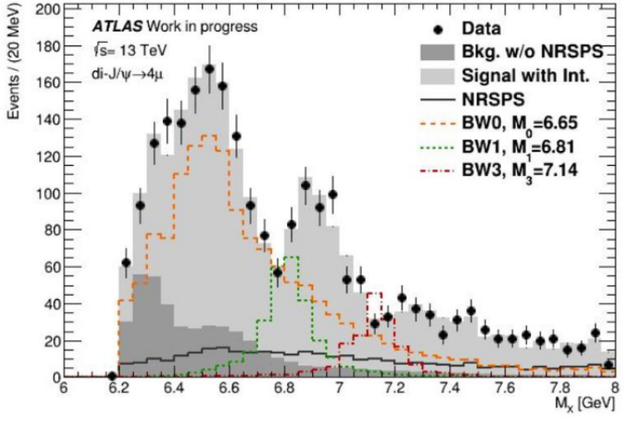
arXiv:2501.02507

Development of the ReneSANCe generator for pp-collisions simulation



arXiv:2411.11120

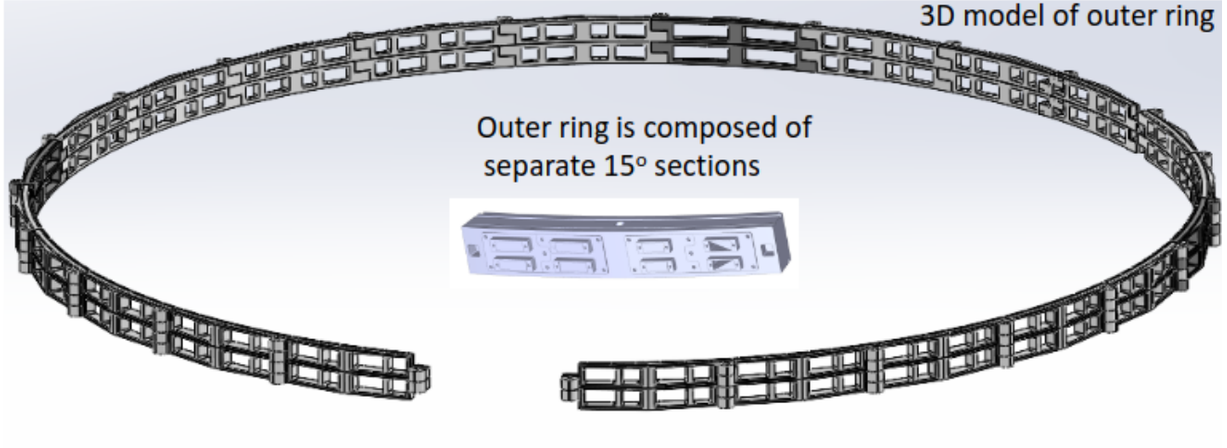
Exotic hadrons studies are ongoing

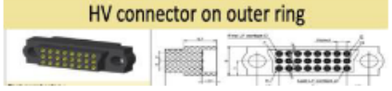


Fully charmed tetraquarks decaying to charmonia pairs. Zc, Zcs states in B-meson decays.

JINR in ATLAS upgrade

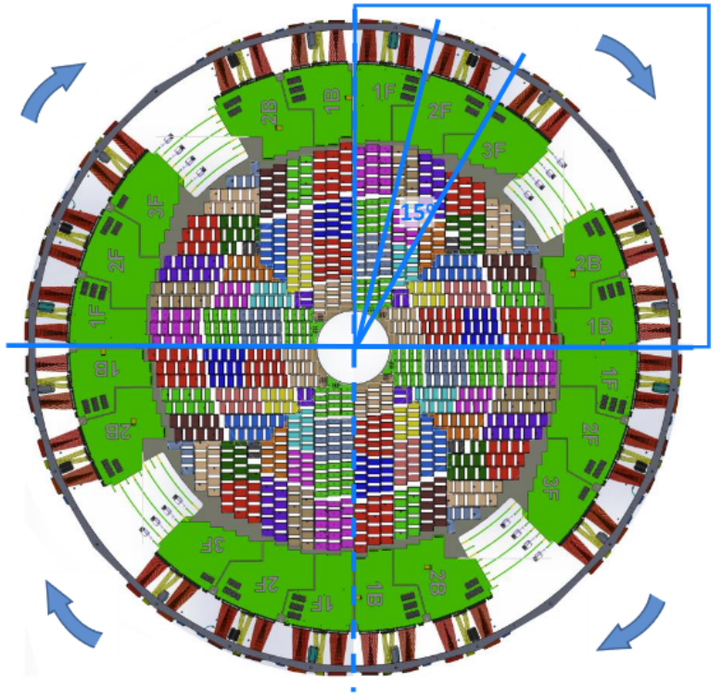
- Commitments to ATLAS w.r.t. RPC panels production and delivery are completely fulfilled.
- JINR takes active part in the new HGTD (High Granularity Timing Detector) development and production:
  - The scheme of modules layout and peripheral electronics was suggested, number of identical components maximized
  - The outer ring is designed and modelled





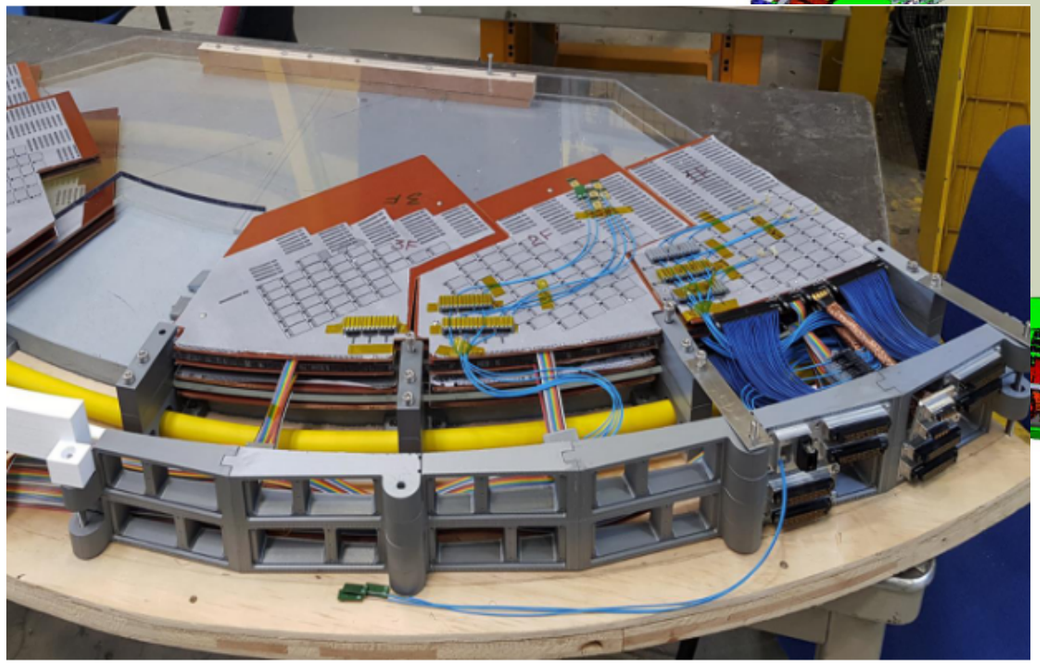

15° section of outer ring, 3D printed from PEEK

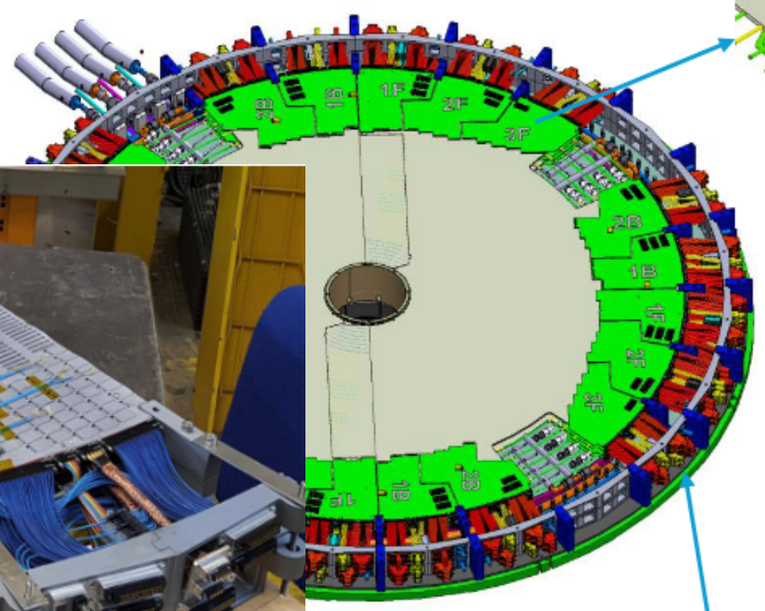

AL plates with flanges

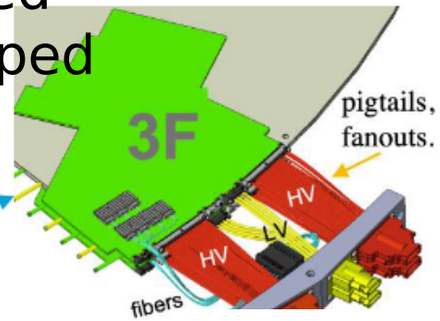


JINR in ATLAS upgrade

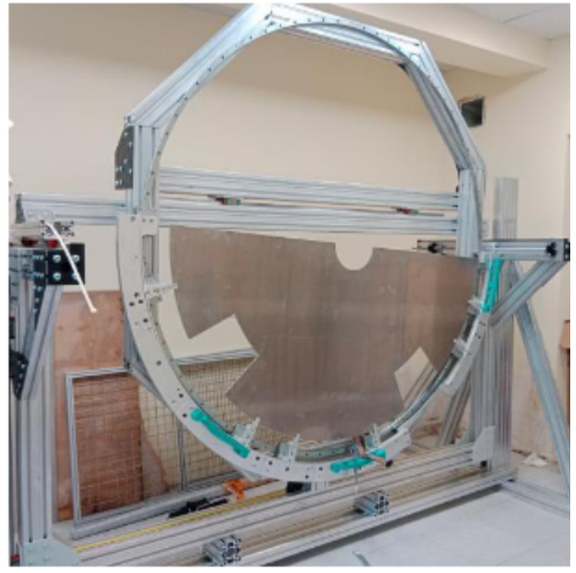
- JINR takes active part in the new HGTD (High Granularity Timing Detector) development and production:
  - Layout of the electrical and optical services inside the HGTD designed
  - Systems for temp., humidity and pressure monitoring designed
  - 3D model of services is developed and prototyped
  - Dedicated tool for half-disks assembly is prototyped
  - Cable routing is developed and prototyped







All cables and fibers
connected to outer ring.



Conclusions and plans

- During 2024 we were continuing our participation in the ATLAS Physics program – Higgs physics, SM physics, B-physics, Exotics, etc.
- 4 papers released since previous report to PAC
- Several physics analyses are expected to be released in 2025

- Participation in software development and support is being increased
- We take part in calorimeter software and simulation activities, e/gamma reconstruction software, muon reconstruction software and trigger software, etc. We plan to take part in 2025 software development grants.

- JINR takes active part in HGTD design and production
- Our other commitments to Phase-II upgrade (in Muon and LAr systems) are currently being actively discussed with colleagues in the ATLAS experiment. Detailed report to be presented at the next PAC session

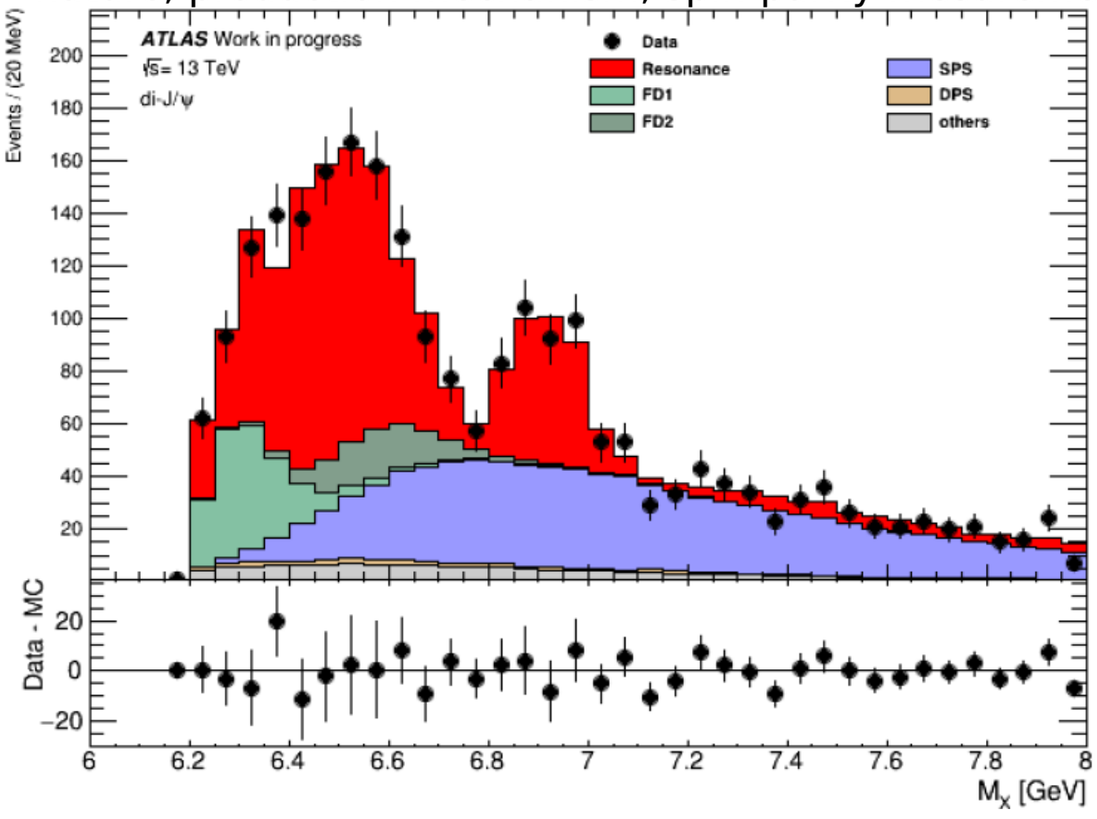
- Data analysis, software and hardware development expertise gained at ATLAS is used in other JINR projects (Baikal-GVD, MPD, SPD, etc.)

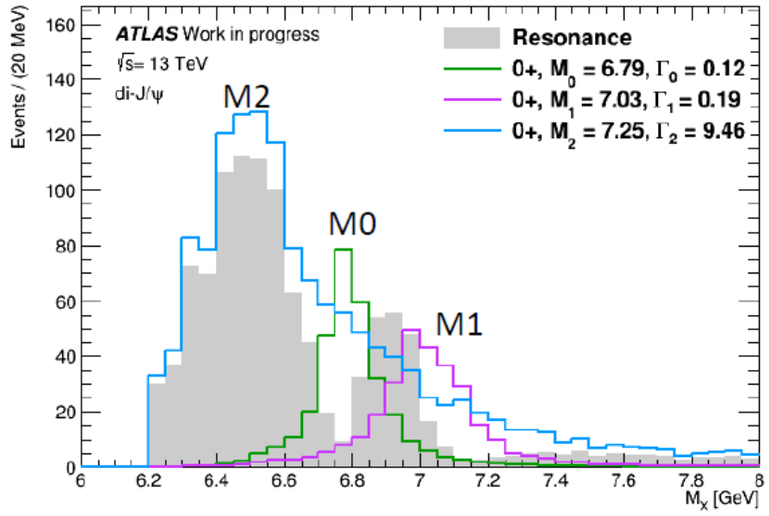
THANK YOU FOR ATTENTION!

BACKUP

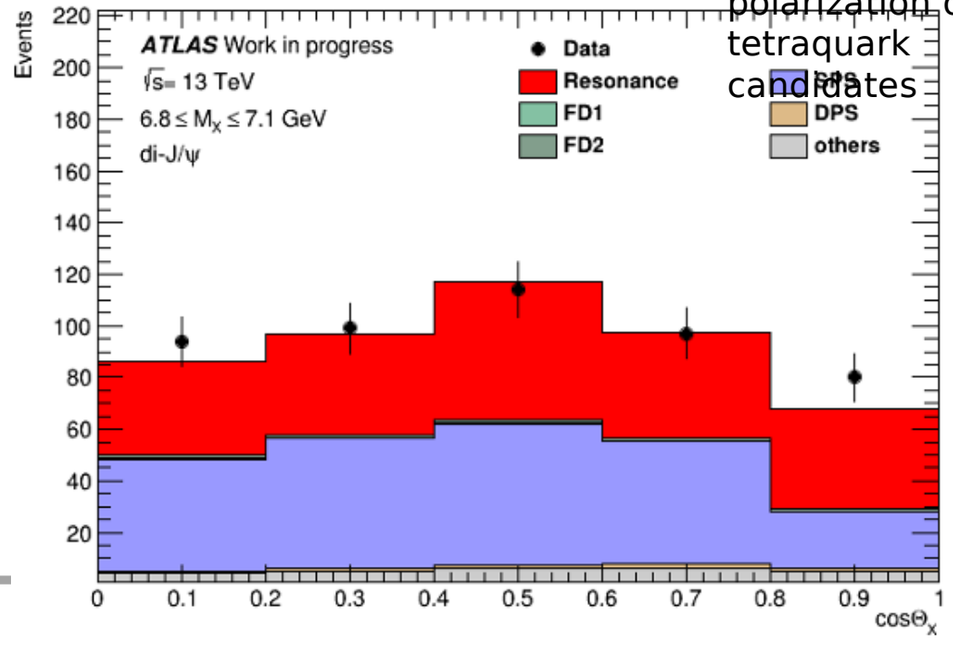
J/ψ-pair resonant production at ATLAS: fully charmed tetraquarks

JINR group performs an amplitude analysis of the recently discovered (by ATLAS, CMS and LHCb) di-J/ψ and J/ψ-ψ(2S) resonances. Purpose is to reveal the structure of the new states, their possible fully charmed tetraquark nature, production mechanism, spin-parity mesurement, etc.





Analysis of the angular distributions of the decay products allows sensitivity to the spin-parities of the new states. Sensitivity to the production mechanisms are possible via pT spectra analysis and polarization of the tetraquark candidates

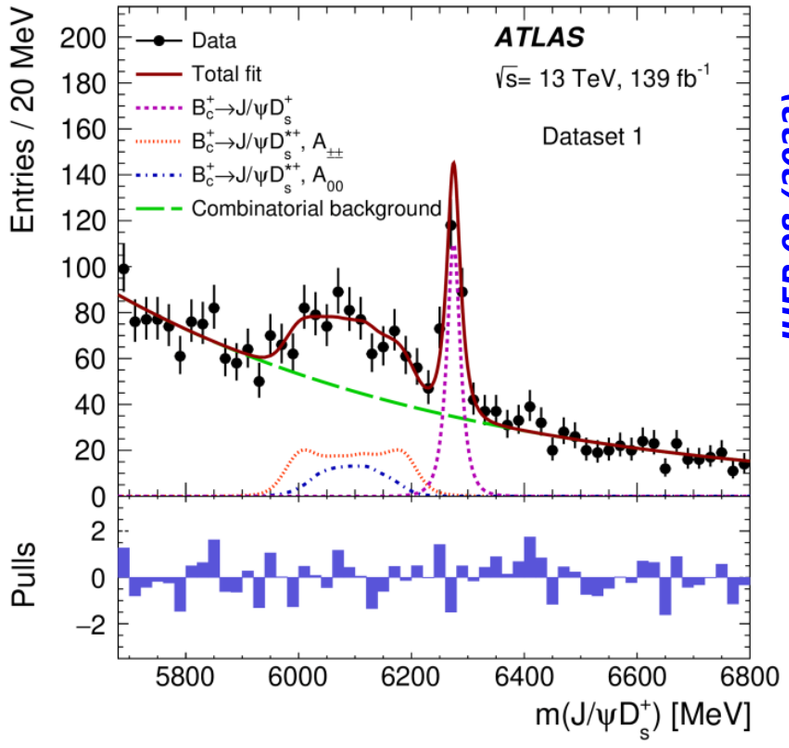


Signal interference effects play significant role in spectrum description. Best model corresponds to 0+ spin-parity of the X-6900 resonance

di-J/ψ	M, MeV	Γ, MeV
BW_0	6786.78	121.93
BW_1	7027.48	188.99
BW_2	7248.51	9457.87

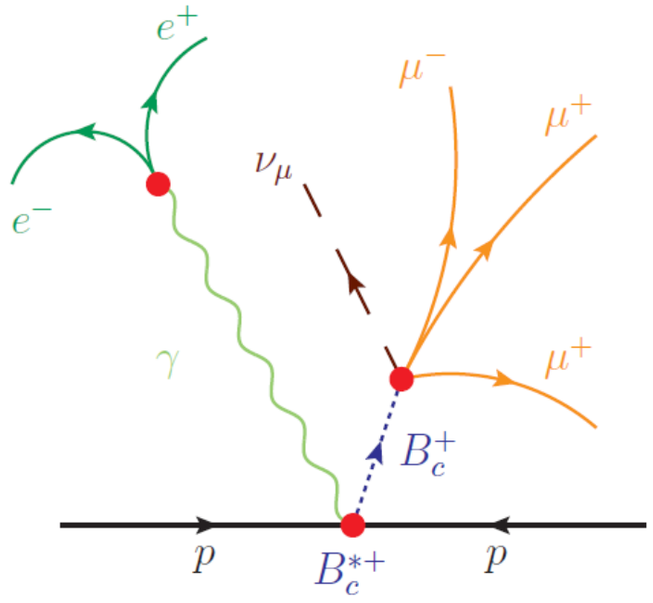
Phys. Rev. Lett. **131**, 151902

Studies of B_c^{+*} and B_c^*



JHEP 08 (2022) 087

Study of B_c mesons spectra is an interesting ground for the physics of systems of different heavy quarks.
Besides B_c ground state, only $B_c(2S)$ states were observed experimentally.
B_c^* decays involve a very soft photon which is challenging w.r.t. reconstruction.

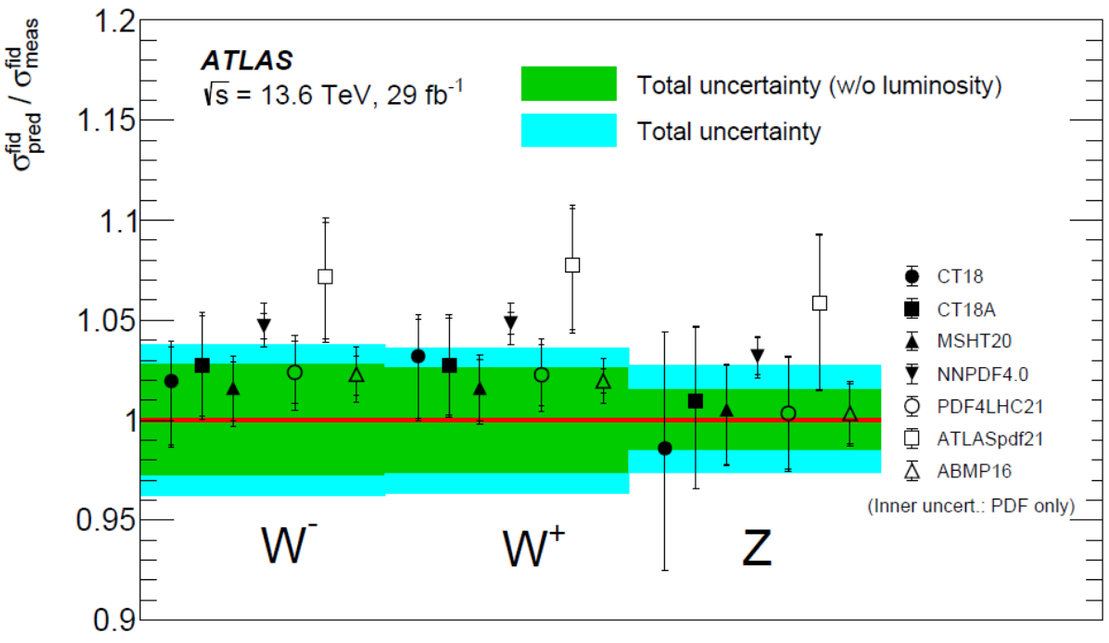


Parameter	low p_T tracking	all tracks
$Q_{B_c^{*+}}$ [MeV]	55.8 ± 1.4	55.3 ± 1.5
$\sigma_{B_c^{*+}}$ [MeV]	5.2 ± 1.6	4.5 ± 1.5
$N_{B_c^{*+}}$	162 ± 44	143 ± 45
Q_{B^+} [MeV]	42.4 ± 0.6	42.6 ± 0.8
σ_{B^+} [MeV]	2.3 ± 0.8	2.8 ± 0.3
N_{B^+}	93 ± 27	102 ± 36

Alternative decay channels of B_c^* are being studied by JINR team at ATLAS:
$B_c^* \to B_c \gamma$ with subsequent leptonic decay of B_c

Development of ReneSANCe MC generator

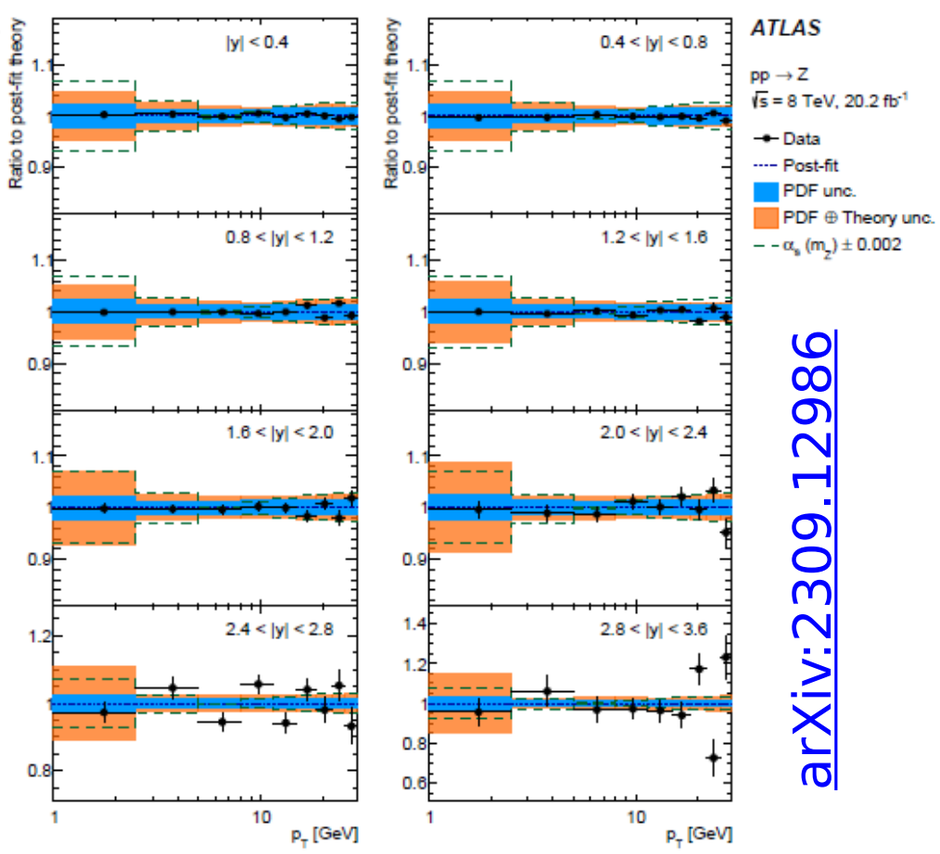
- JINR team develops MC generators and radiation correction libraries: **DIZET, MCSANC, ReneSANCe**
- They are used in several SM studies at ATLAS and other exper



Physics Letters B 854:138725

Measurement of vector boson production cross sections and their ratios using pp collisions at √s = 13.6 TeV with the ATLAS detector

Theoretical predictions are calculated using ReneSANCe generator



arXiv:2309.12986

A precise determination of the strong-coupling
constant from the recoil of Z bosons with the ATLAS
experiment at $\sqrt{s}$ = 8 TeV
Higher order effects on the cross-section normalization from QED initial-state radiation and from electroweak

Gluon TMD density in proton from LHC data

Refined TMD gluon density in a proton from the HERA and LHC data

A.V. Lipatov[1,2], G.I. Lykasov[2], M.A. Malyshev[1,3]

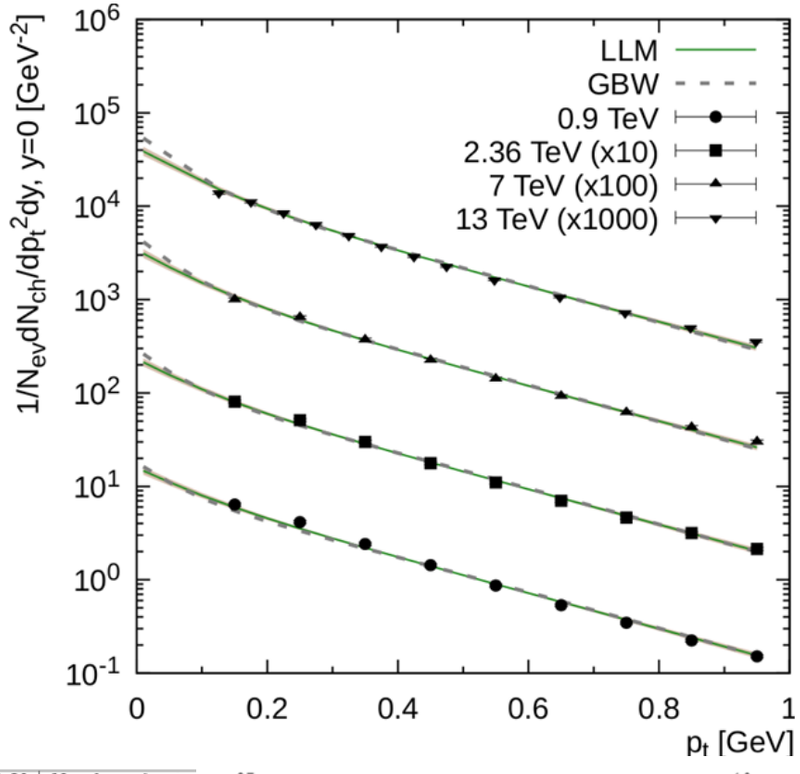
April 16, 2024

[1] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991, Moscow, Russia*
[2] *Joint Institute for Nuclear Research, 141980, Dubna, Moscow region, Russia*
[3] *Moscow Aviation Institute, 125993, Moscow, Russia*

Abstract

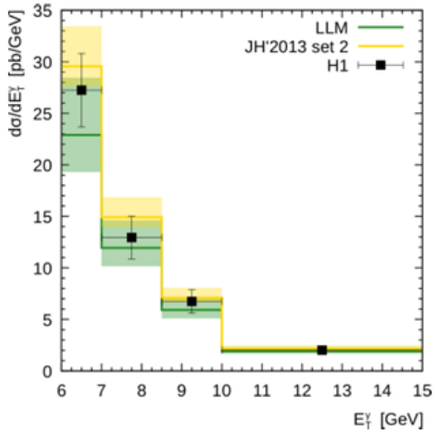
We update the phenomenological parameters of the Transverse Momentum Dependent (TMD, or unintegrated) gluon density in a proton proposed in our previous studies. This analysis is based on the analytical expression for starting gluon distribution which provides a self-consistent simultaneous description of HERA data on proton structure function $F_2(x, Q^2)$, reduced cross section for the electron-proton deep inelastic scattering at low Q^2 and soft hadron production in pp collisions at the LHC conditions. We extend it to the whole kinematical region using the Catani-Ciafaloni-Fiorani-Marchesini (CCFM) evolution equation. Expl… QCD processes, we performed a con… comprising a total of 509 points fro… derived TMD gluon density in a pr… HERA.

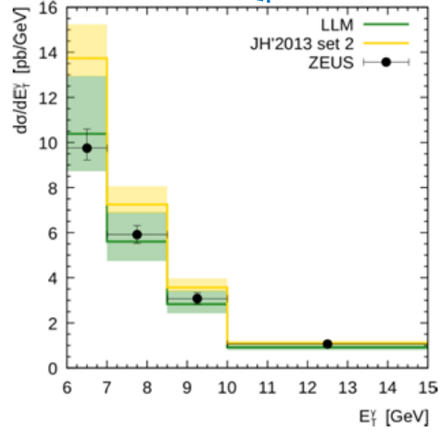
Experiment	Collaboration	Year	Reference	Collision	$\sqrt{s}$/GeV	Number of point
incl. c-jet	CMS	2017	[43]	pp	2.76	5
incl. c-jet	CMS	2017	[43]	pp	5.02	5
incl. b-jet	ATLAS	2011	[42]	pp	7	46
incl. b-jet	CMS	2012	[46]	pp	7	98
$F_2^c(x, Q^2)$	H1	2010, 2011	[47,48]	ep	0.319	25
$F_2^c(x, Q^2)$	ZEUS	2014	[49]	ep	0.319	18
$F_2^b(x, Q^2)$	H1	2014	[47]	ep	0.319	12
$F_2^b(x, Q^2)$	ZEUS	2014	[49]	ep	0.319	17
$\sigma_{\rm red}^c(x, Q^2)$	H1, ZEUS	2018	[50]	ep	0.319	51
$\sigma_{\rm red}^b(x, Q^2)$	H1, ZEUS	2018	[50]	ep	0.319	27
incl. $H \to \gamma\gamma$	CMS	2023	[51]	pp	13	37
incl. $H \to \gamma\gamma$	ATLAS	2018	[51]	pp	13	27
incl. $H \to ZZ^*$	CMS	2023	[52]	pp	13	54
incl. $H \to ZZ^*$	ATLAS	2020	[53]	pp	13	54
incl. γ	H1	2010	[44]	ep, low Q^2	0.319	25
incl. γ	ZEUS	2014	[45]	ep, low Q^2	0.319	8



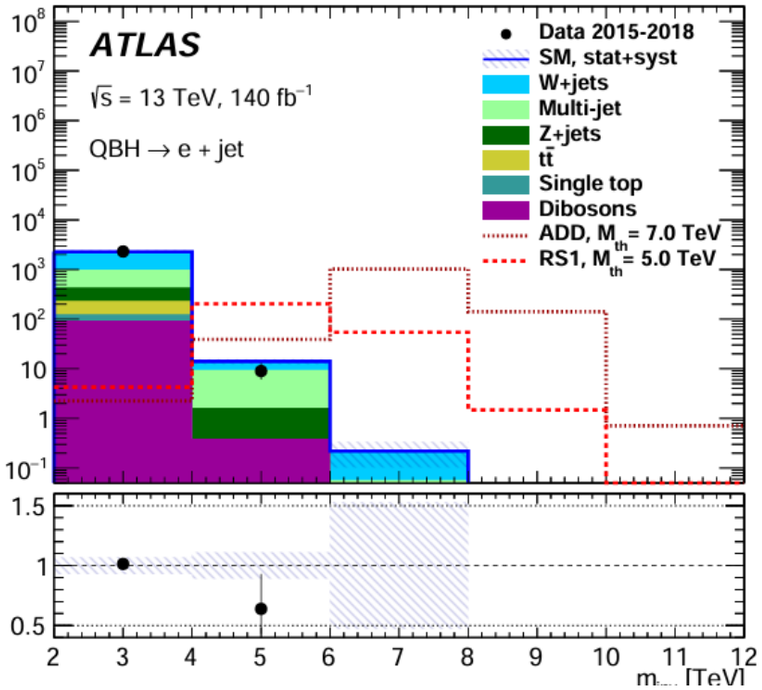
e-print:2404.09550

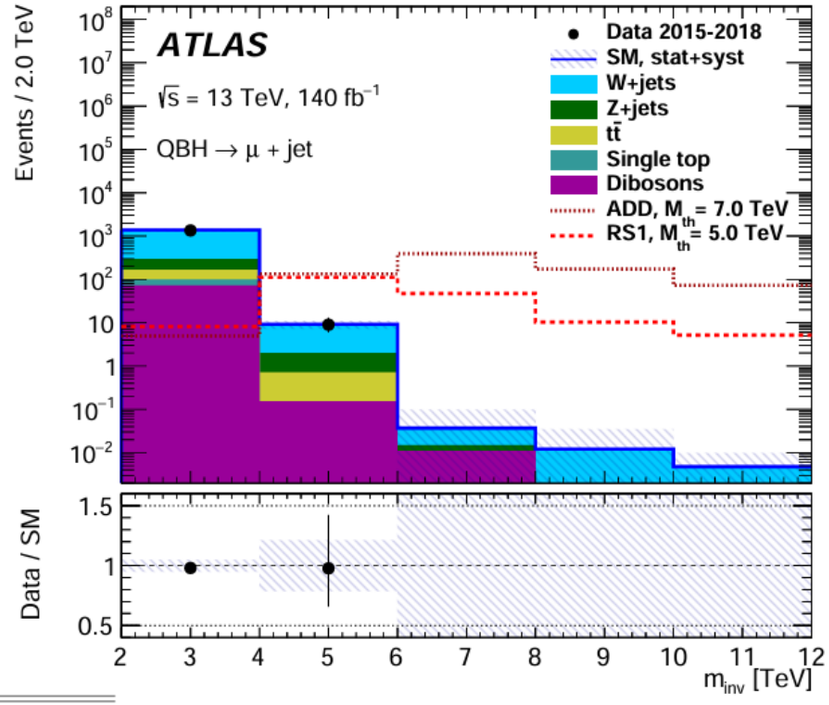
Phys.Lett.B 848 (2024) 138390





Search for Quantum Black Holes in lepton+jet final states





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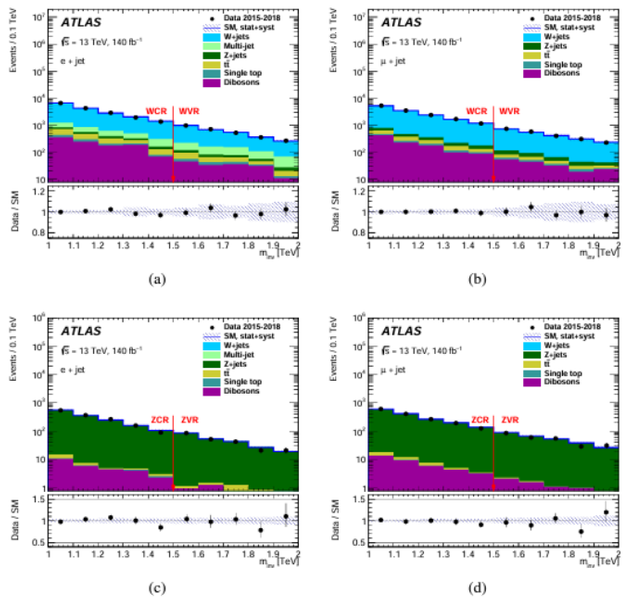
	SVR electron+jet	SVR muon+jet	SR electron+jet	SR muon+jet
Observed data	9053	5504	2319	1359
Fitted events	8900 ± 320	5380 ± 200	2290 ± 110	1386 ± 70
W+jets	5590 ± 270	4190 ± 200	1290 ± 70	1087 ± 54
Multijet	1670 ± 200		570 ± 47	
Z+jets	646 ± 73	439 ± 27	199 ± 17	131 ± 13
$t\bar{t}$	527 ± 10	351 ± 7	109 ± 5	69 ± 5
Single top	143 ± 7	112 ± 5	31 ± 2	28 ± 2
Dibosons	335 ± 22	289 ± 14	94 ± 9	72 ± 8
Expected events	9390 ± 340	5260 ± 220	2647 ± 94	1303 ± 55
W+jets	6090 ± 270	4080 ± 210	1654 ± 65	1016 ± 48
Multijet	1690 ± 210		577 ± 38	
Z+jets	598 ± 85	408 ± 23	186 ± 18	122 ± 12
$t\bar{t}$	546 ± 14	366 ± 7	109 ± 6	71 ± 5
Single top	141 ± 7	104 ± 4	29 ± 2	28 ± 2
Dibosons	327 ± 23	298 ± 12	92 ± 10	66 ± 8



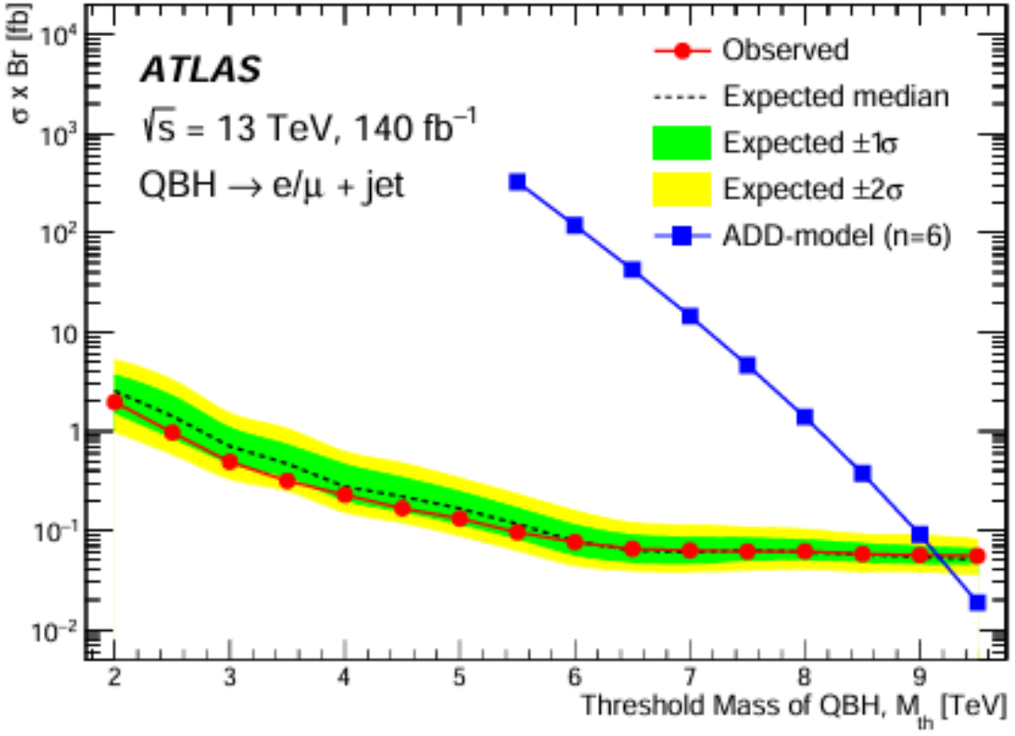
JINR team played a leading role in the search for QBH in lepton+jet final states at ATLAS.

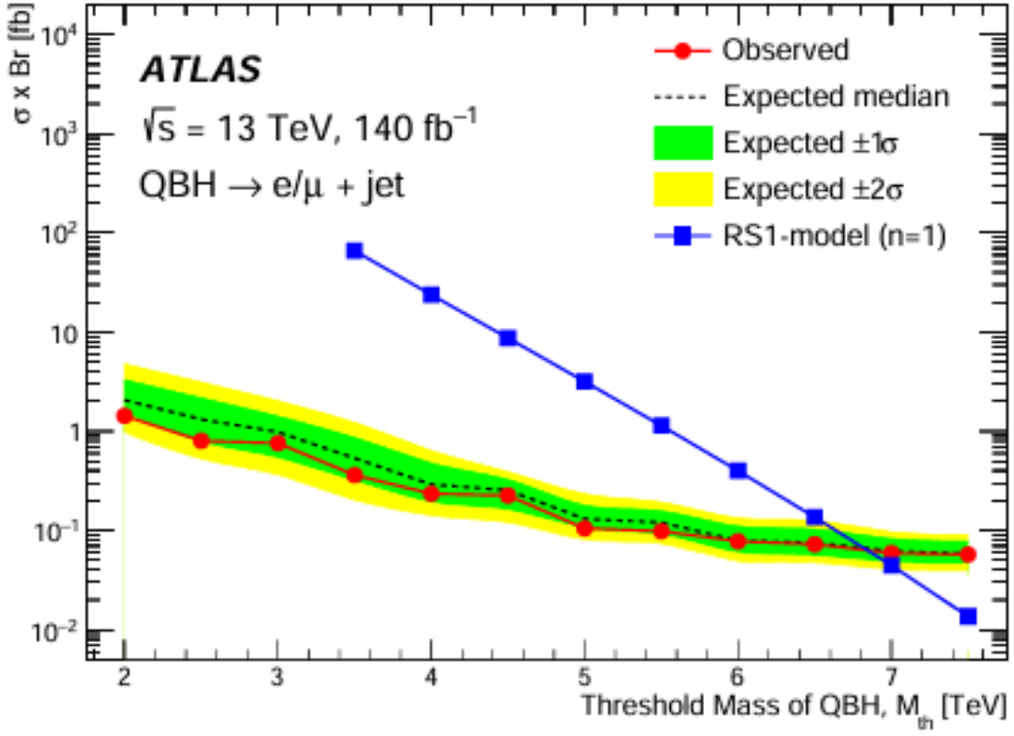
Full Run2 data are analyzed. Plots show invariant mass distributions of the electron+jet (left) and muon+jet (right).

Predicted QBH signals in the Arkani-Hamed-Dimopoulos-Dvali model (ADD) and Randall-Sundrum (RS1) models are shown.

Few CR and VR are analysed to ensure accurate description for all background processes.

Search for Quantum Black Holes in lepton+jet final states





Channel	ADD $\sigma \times Br$ [fb]	ADD M_{th} [TeV]	RS1 $\sigma \times Br$ [fb]	RS1 M_{th} [TeV]	Model-independent $\sigma(m_{\text{inv}} > 5\ \text{TeV}) \times Br$ [fb]
Electron+jet	0.091	9.0	0.099	6.6	0.095
Muon+jet	0.083	9.0	0.087	6.7	0.084
Combined	0.056	9.2	0.061	6.8	0.052

New mass/cross-section limits are set for the ADD and RS1 models as well as for model-independent approach.

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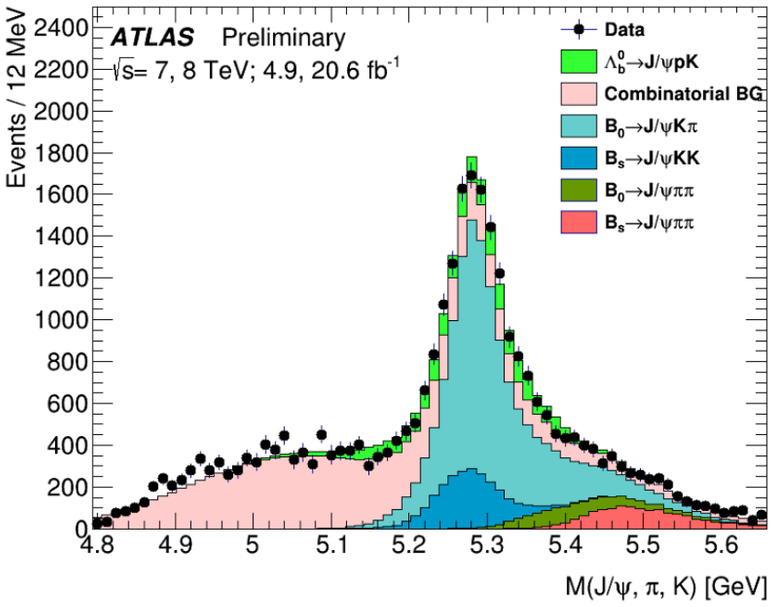
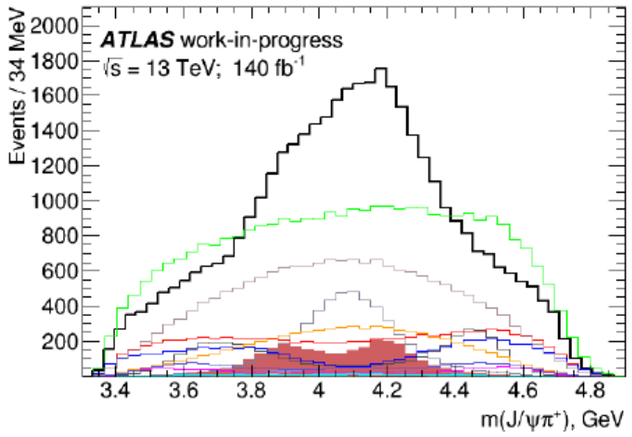
Other physics analyses in advanced state…

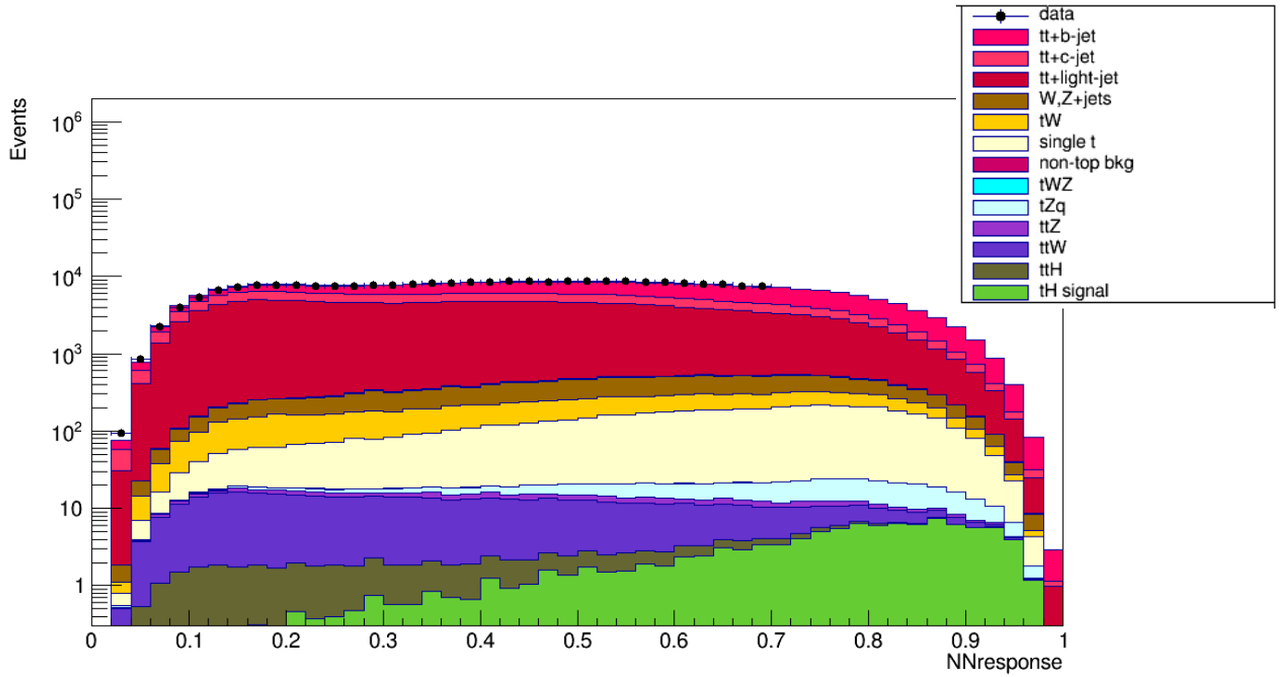




$Z_c(4200)$ mass	$4207^{+13}_{-22}(\text{stat.})^{+8}_{-19}(\text{syst.})$
$Z_c(4200)$ width	$185^{+38}_{-23}(\text{stat.})^{+48}_{-11}(\text{syst.})$

Amplitude analysis of the exotic contributions to B^0, B_s-meson decays.

$Z_c^{\pm}(4200)$ state is observed in the $J/\psi\pi$ invariant mass spectrum with significance >3.7σ. Mass, width and spin-parity characteristics are measured from ATLAS Run2 data.
Significant role is played by the interference effects between signals and background. Z_{cs} states contributions are discussed. To be released in 2024.



Search for the Higgs production in association with single top quark.

Aim of the analysis is observation of the SM signal and/or setting limit on the ITC models predicting higher production cross sections.
One of the JINR contributions is MVA analysis of the signal (*tH*) and background (*tt* mainly) processes. Few novel ML approaches have been developed to increase potantial signal significance by ~1.7 compared to standard cut and count approaches

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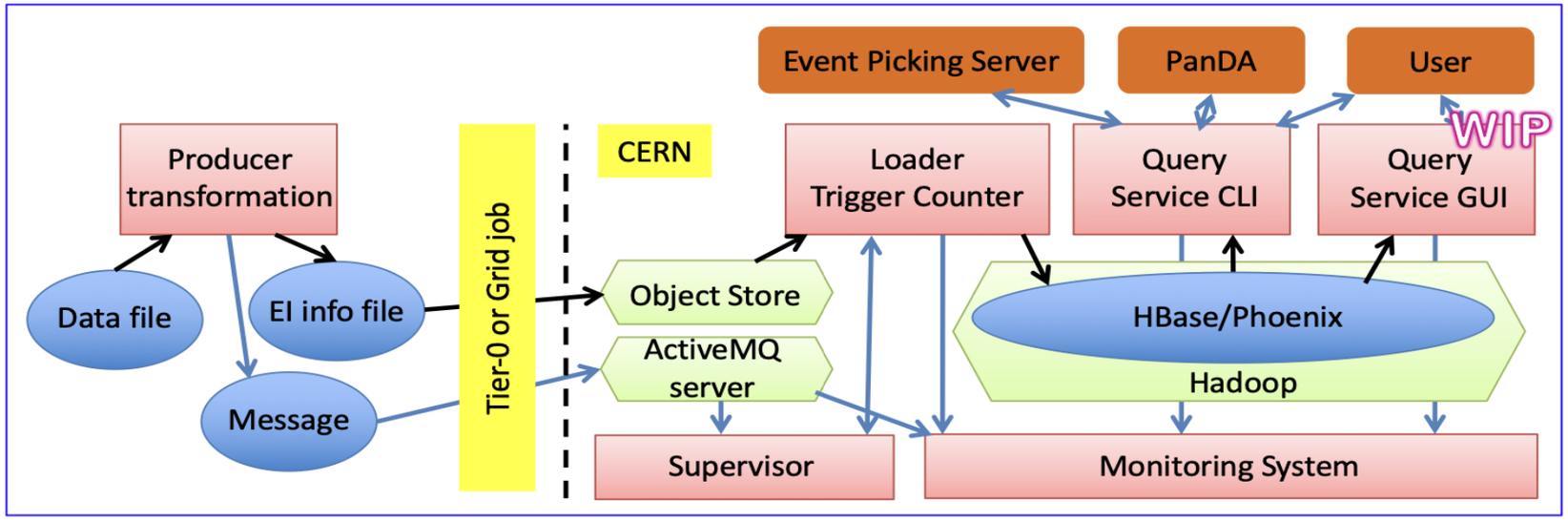
Event index: Event picking service



JINR team developed and tested the 'Event Picking service' that allow selection of the sets of 'interesting' events for physics analyses from the Event Index database.

2024 Operations:

Request	Number of events	Version	Time
γγ -> WW	50k	1.0.0	2 weeks
		manual	3 months
γγ -> WW	136k	Beta version	3 months
B_c^* -> B_c	16K	1.2.37	84h
Z -> TauTau	11K	1.2.37	40h
B_c^* -> B_c	240K	1.3.25	17 days

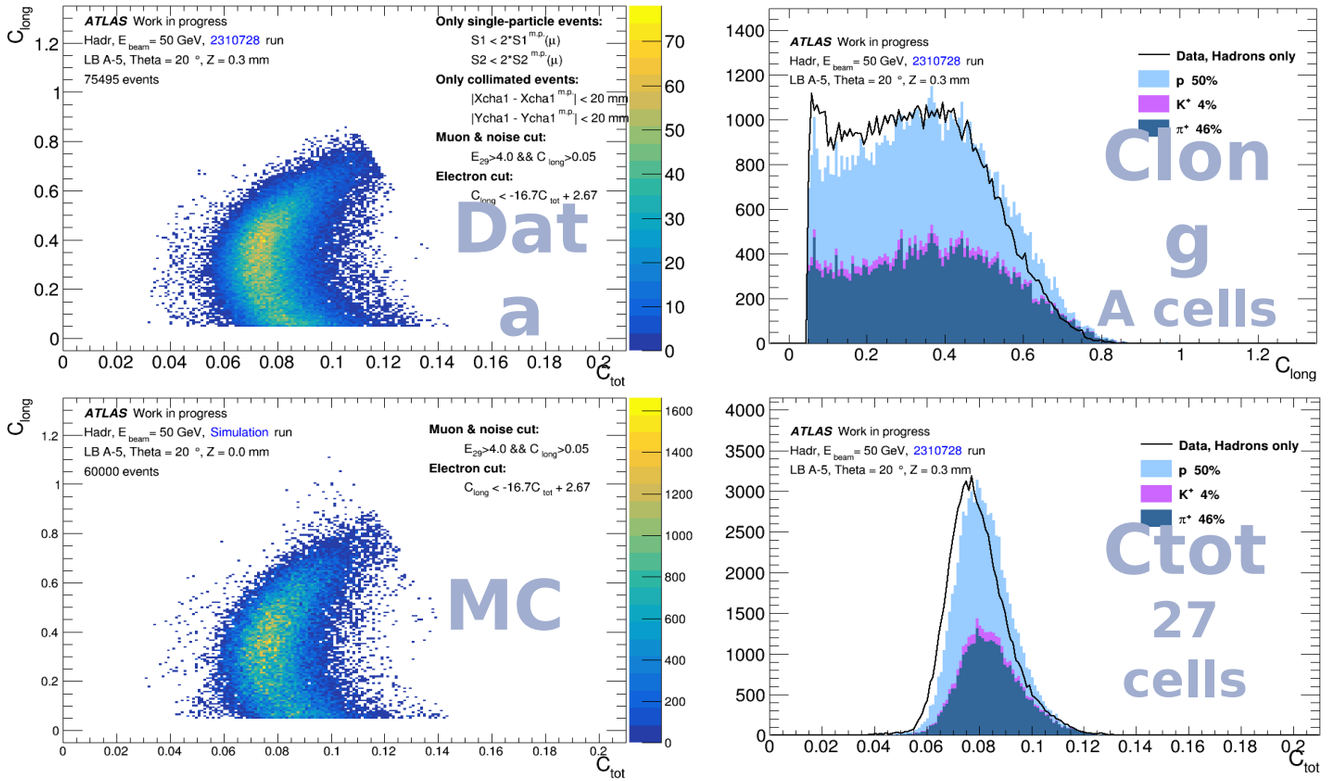
- The Event Picking Server is now fully functional and can be used for large scale operations
- Used so far by only a small number of analyses
- Largest number of events ~600k for the B_c^*->$B_c\gamma$ analysis (see above)

Participation in TDAQ online project

- **Resource Manager development and support**
  - The Resource Manager is one of the core components of the **Data Acquisition system** of the ATLAS experiment at the LHC.
  - The Resource Manager **marshals the right for applications** to access resources which may exist in multiple but limited copies, in order to avoid conflicts due to program faults or operator errors.
- **P-BEAST Dashboard support**
  - This web application offers an interface to visualize any operational monitoring data published by the TDAQ system through configurable and customizable dashboards.
  - An example of an operational

Measurement of the hadronic shower shapes in ATLAS TileCal

- TestBeam data 2023 have been analized.
- Cuts for selection of beam hadrons/muons/electrons are developed
- Noise level in data is estimated and subtracted
- Transverse and longitudinal shower profiles are measured. Some discrepancies with Geant4 are observed
- Two JINR students completed ATLAS QT



Plans

- Finalize energies above 50 GeV (need to produce MC)
- Understand remaining puzzles:
  - ☐ Total energy deposition dependence on ΔZ
  - ☐ Feature in MC: 10 GeV in a single PMT
- Prepare article
- Tune Geant4 interaction model for better description of transverse profile

IR group participation in the upgrade program

<u>n fulfilled all obligations</u> on participation in the **Phase-1** Upgrade program of the ATLA

The most significant contribution was made in the upgrade of the Muon Spectrometer: 32 large-scale Micromegas quadruplets for New Small Wheel were manufactured in the JINR DLNP workshop, delivered to CERN and installed in the ATLAS detector. They show good efficiency during Run3 of the data taking.

Our plans for the **Phase-2** of the ATLAS upgrade aimed at HL-LHC operation include:

- Muon Spectrometer:
  - BI readout panels
  - power distribution system
  - RPC gas system
- LAr Calorimeters:
  - optical link components
- High Granularity Timing Detector
  - half-disk instrumentation stand
  - transportation tools and cavern installation

Production site for RPC panels is ready, 3 BI panels were manufactured and test

Prototype cables were produced and used at CERN in half-crate test

The tools were designed at DLNP and assembled, delivery to CERN is planned in about two months

group participation in the ATLAS Phase-I upgrade program (2013-2

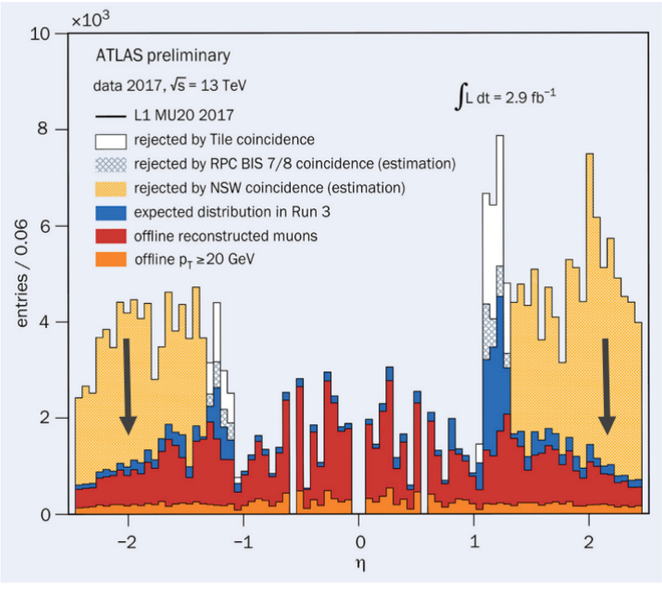
Muon Spectrometer – NSW project:
- Infrastructure development
- Production of large Micromegas quadruplets
- NSW assembly and commissioning

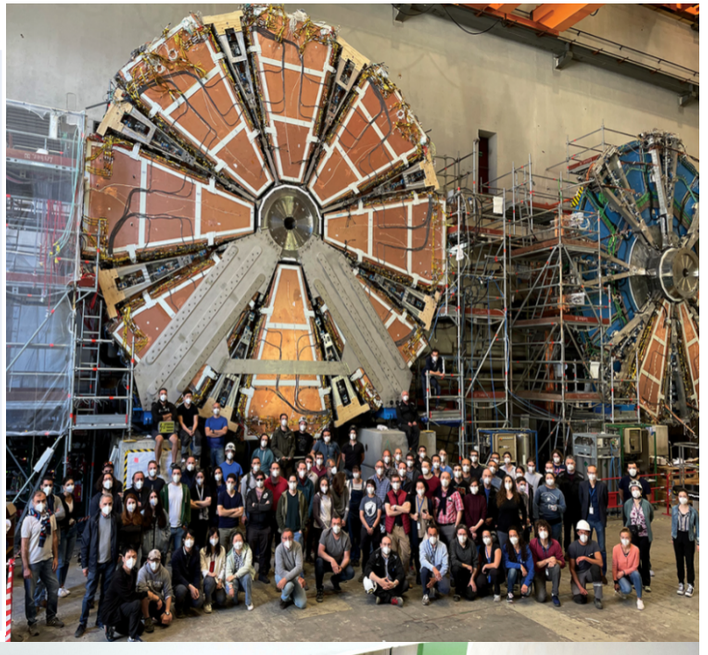
Factor 4 reduction in the rate of fake μ-triggers

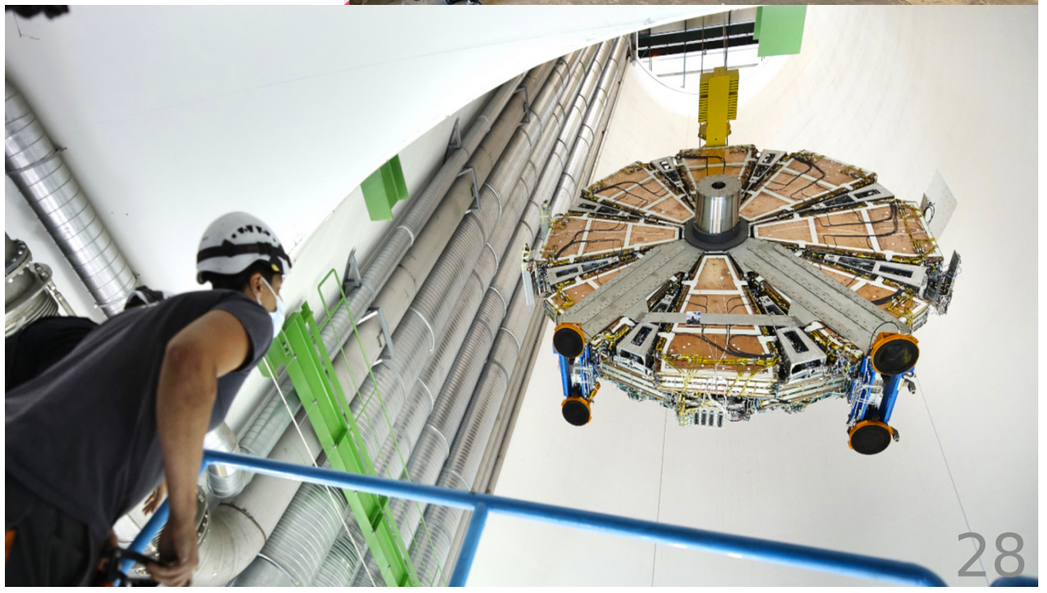
Liquid Argon Calorimetry:
- Design of baseplane and preshaper
- Radiation tests and
- Simulation of signal degradation

TILE scintillator calorimeter:
- Min.bias trigger modules
- Development of new electronics for the readout Demonstrator

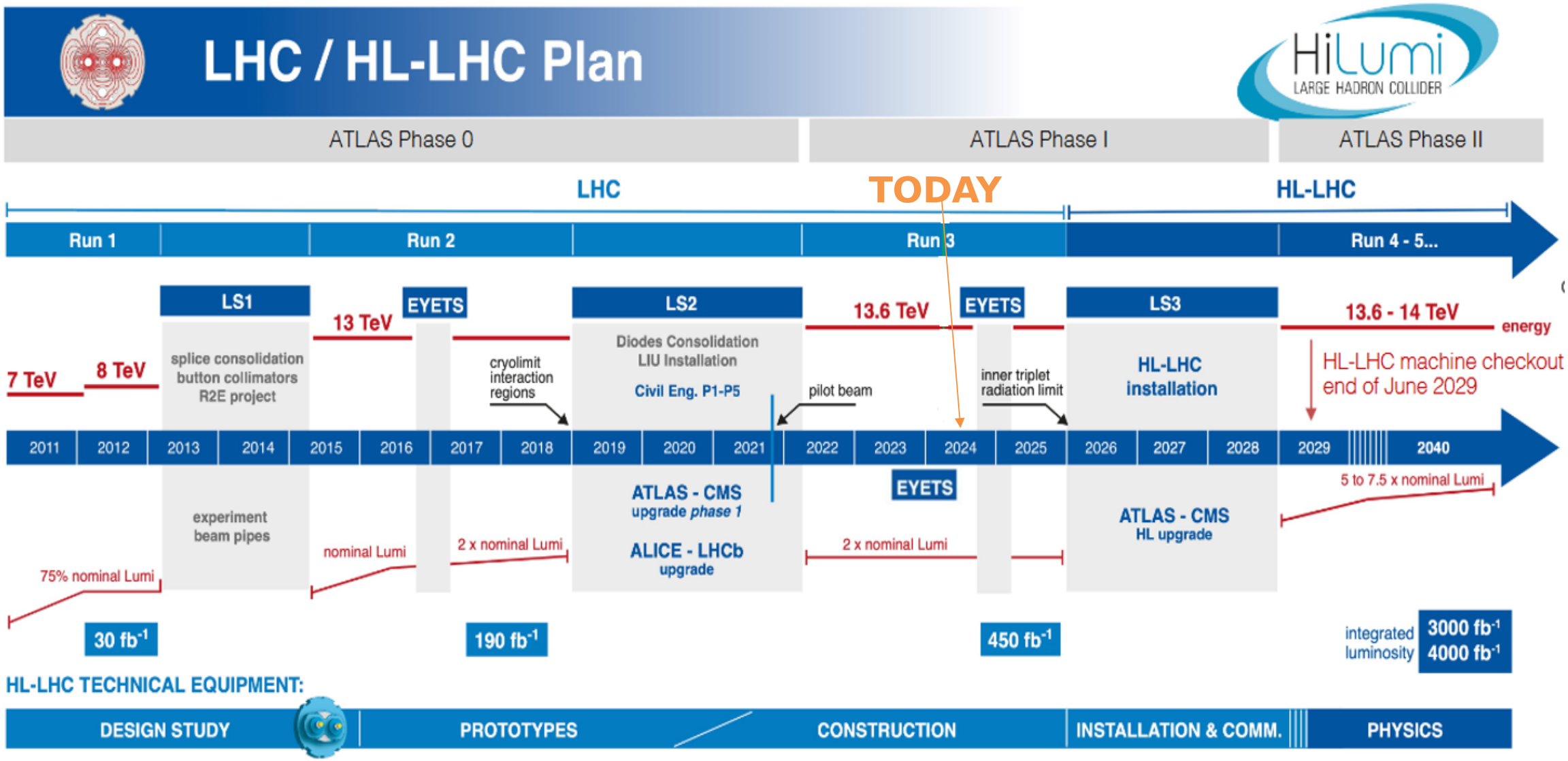
NSW: Reduction of fake μ triggers







LHC / HL-LHC Plan

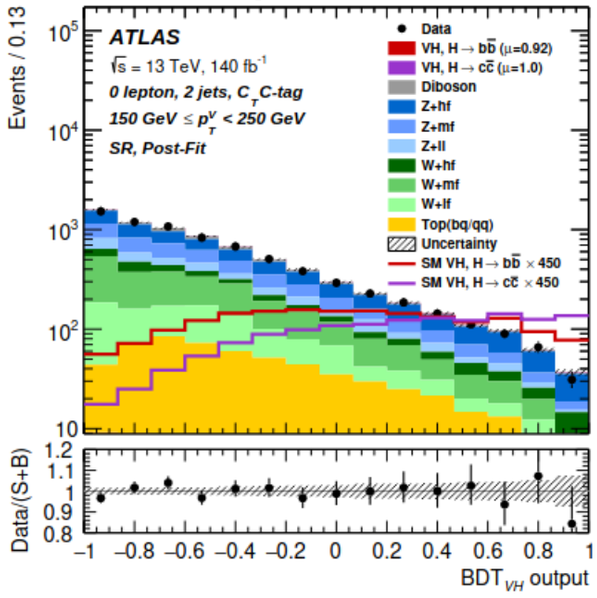


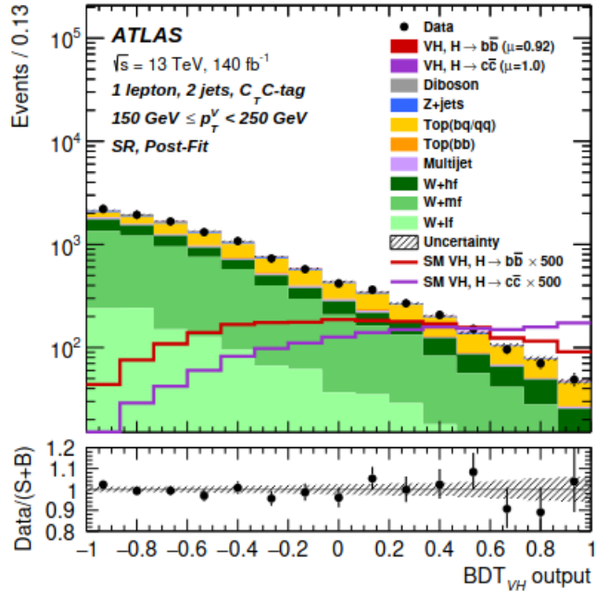
Measurements of WH and ZH production with Higgs boson decays into bottom quarks and direct constraints on the charm Yukawa coupling

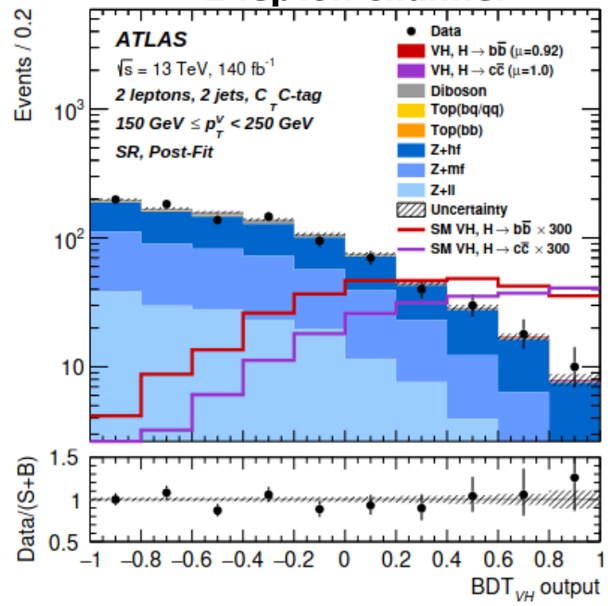
In addition to *H→bb* channel, the *H→cc* channel has been analysed to set limit on cH coupling.
Vector boson pT specrum is split into ranges 75-150-250-inf GeV

0 lepton channel | **1 lepton channel** | **2 lepton channel**

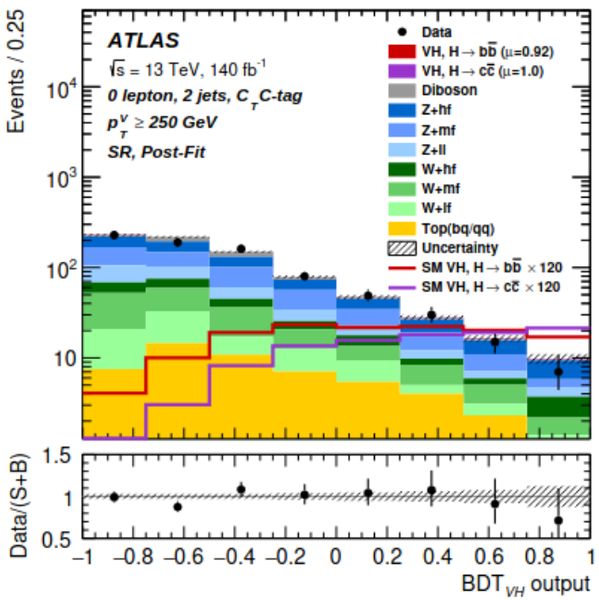
150 GeV < pT < 250 GeV

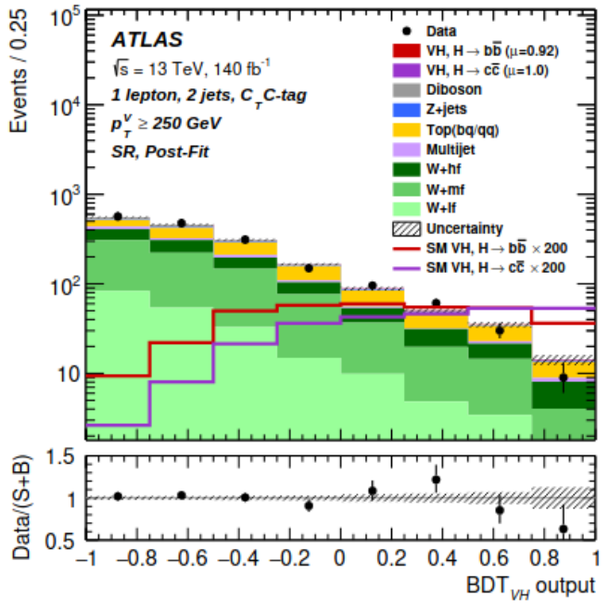


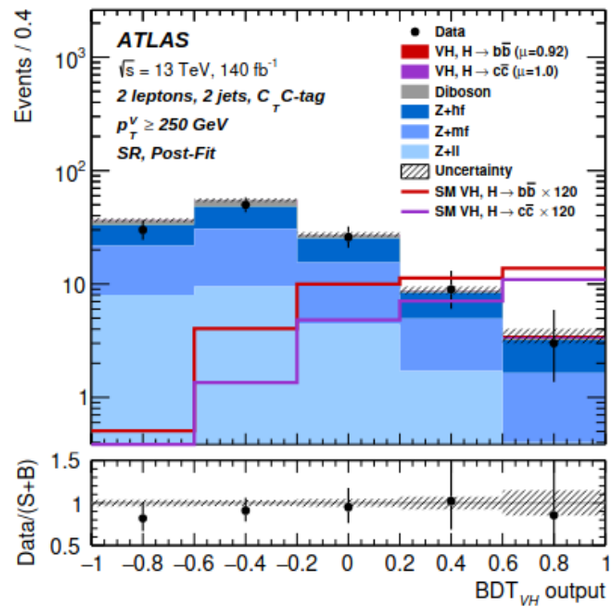




pT > 250 GeV







ArXiv:2410.19611, submitted to JHEP