

---

---

# Results of the JINR team in ATLAS

---

---



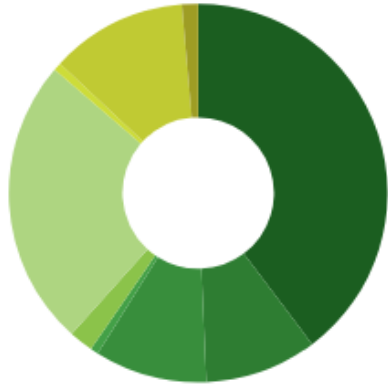
I. Yeletskikh

Dzhelepov Laboratory of Nuclear Problems, JINR

On behalf of the JINR ATLAS team

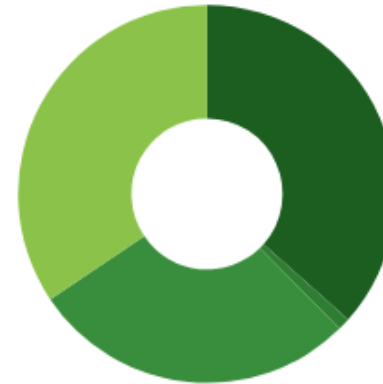
# JINR team in ATLAS Collaboration

## ► Professional Status



- 58 Physicist
- 14 Physics PhD student
- 14 Physics masters/diplom student
- 1 Undergraduate/summer student
- 3 Engineer with PhD
- 36 Engineer without PhD
- 1 Engineering student
- 17 Technician or equivalent
- 2 Administrator/other

## ► Lists



- 34 on Authorlist (A)
- 1 Signing-Only (a)
- 26 counted for M&O (M)
- 0 qualifying members (q)
- 32 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., Gerasimov V., Gladilin L., Glagolev V., Gongadze A., Gongadze L., Gostkin M., Huseinov N., Ivanov Y., Kalinovskaja L., Karpov S., Karpova Z., Kharchenko D., Khramov E., Kostyukhina I., Kruchonak U., Lyabline M., Lyashko I., Lykasov G., Lyubushkin V., Lyubushkina T., Malyukov S., Minashvili I., Minashvili I.(jr.), Nefedov Y., Plontikova E., Potrap I., A. Prokhorov, Romanov V., Rusakovich N., Saprionov A., Serochkin M., Shalyugin A., Shelkov G., Shiyakova M., Souslov I., Tropina A., Usubov Z., Yeletskikh I., Yermolchik V., Zhemchugov A.
- LIT: Alexandrov E., Aleksandrov I., Gromova N., Iakovlev A., Kazymov A., Mineev M., Shigaev V., Zrellov P.
- VBLHEP: Ahmadov F., Cheplakov A., Fillipov Y., Kukhtin V., Ladygin E., Makarov A., Manashova M., Soloshenko A., Shaykhatdenov B., Turtuvshin T., Zimin N.

# ATLAS physics studies at JINR

1. Development of the ReneSANCe MC generator used in precise SM measurements at ATLAS	<b>1 prof., 2 postdoc (1.5 FTE, Kalinovskaya L., Sadykov R., Yermolchuk V.)</b>
2. Modeling of di- $J/\psi$ and $J/\psi+Z(W)$ production	<b>1 PhD student (1FTE, A.Prokhorov)</b>
3. Minbias measurements at 13.6TeV	<b>1 prof., 2 engineers (3 FTE, Koultschitski Y., Plotnikova E., Tsiareshka P.)</b>
4. Gluon TMD studies in pp-collisions	<b>1 prof. (1.0 FTE, Lykasov G.)</b>
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, searches for the HBSM H+ to Wh	<b>4 postdoc, 2 PhD students, 1 m.student (2.6 FTE, I.Boyko, N.Huseynov, I.Yeletsikh, I.Souslov, A.Tropina, A.Didenko)</b>

# ATLAS physics studies at JINR

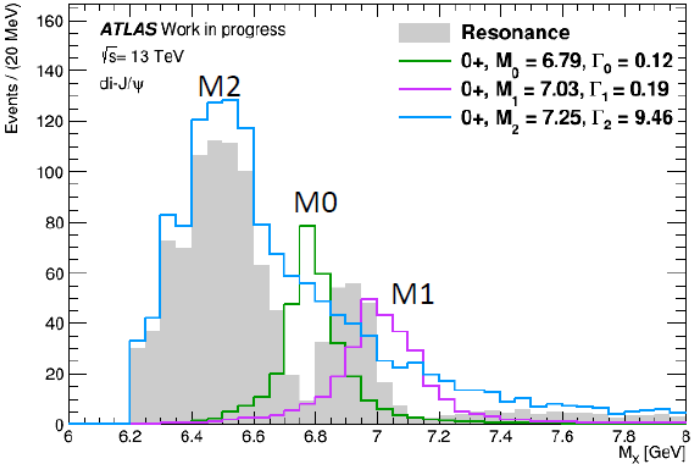
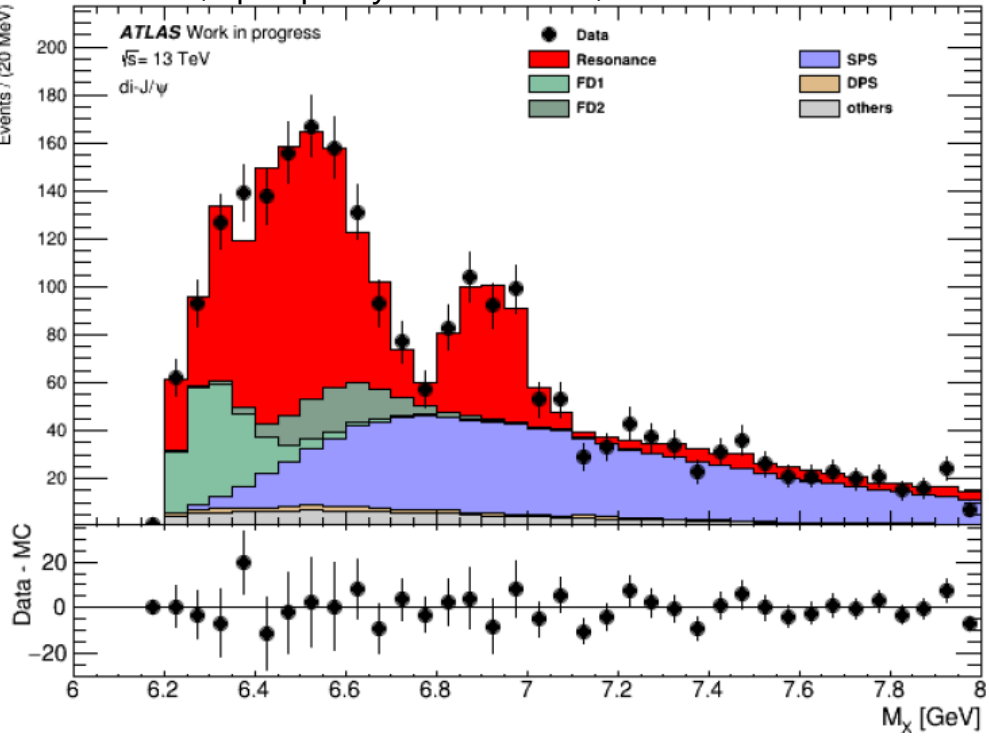
7. Search for (supersymmetric) charged Higgs bosons via their specific decay modes (3 leptons, etc)	<b>1 postdoc, 1 m.student (2 FTE, Soloshenko A., Turtuvshin T.)</b>
8. Searches for Quantum Black Holes in lepton+jet final states	<b>2 postdocs (2 FTE, Karpov S., Karpova Z.)</b>
9. $B_c, B_c^*$ excited states studies	<b>1 prof., 1 postdoc, 1 engineer (1 FTE, Gladilin L., Lyubushkina T., Lyubushkin V.)</b>
10. Studies of exotic states in $B$ -hadron decays and fully charmed tetraquarks	<b>1 prof., 1 postdoc, 2 PhD students (2.4 FTE, Gladilin L., Yeletskikh I., Vasyukov A., Didenko A.)</b>
11. Higgs boson decays to bottom and charm quarks produced in association with a W or Z boson	<b>1 postdoc (0.5FTE, Ahmadov F.)</b>

# ATLAS software/simulation support

1. 'Event index' database development: Event picking service	<b>1 postdoc, 1 PhD (1.0FTE, E.Alexandrov)</b>
2. REST API development for database monitoring	<b>2 PhD students (1.5FTE, A.Gazzaev, D.Kokaev)</b>
3. Calorimeter response studies at the test beam facility	<b>1 postdoc, 2 PhD students (1.0FTE, A.Didenko, A.Tropina, N.Guseynov)</b>

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

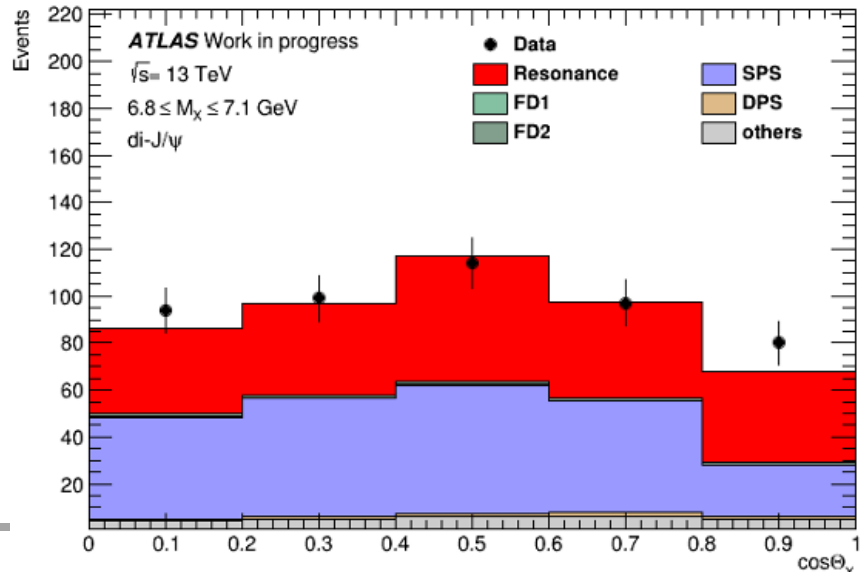
JINR group performs an amplitude analysis of the recently discovered (by ATLAS, CMS and LHCb) di-J/ψ and J/ψ-ψ(2S) resonances. Purpose is to reveal the structure of the new states, their possible fully charmed tetraquark nature, production mechanism, spin-parity measurement, etc.



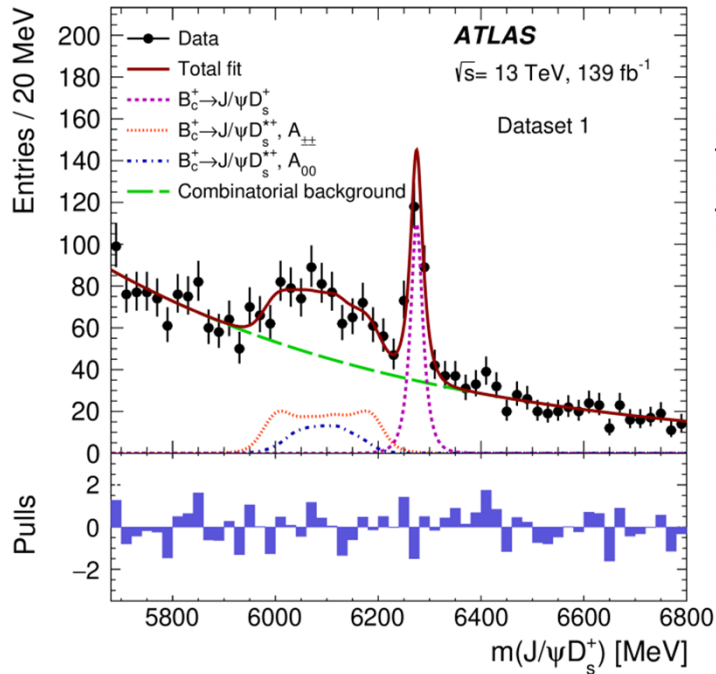
Analysis of the angular distributions of the decay products allows sensitivity to the spin-parities of the new states. Sensitivity to the production mechanisms are possible via pT spectra analysis and polarization of the tetraquark candidates

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 <sub>0</sub>	6786.78	121.93
BW <sub>1</sub>	7027.48	188.99
BW <sub>2</sub>	7248.51	9457.87

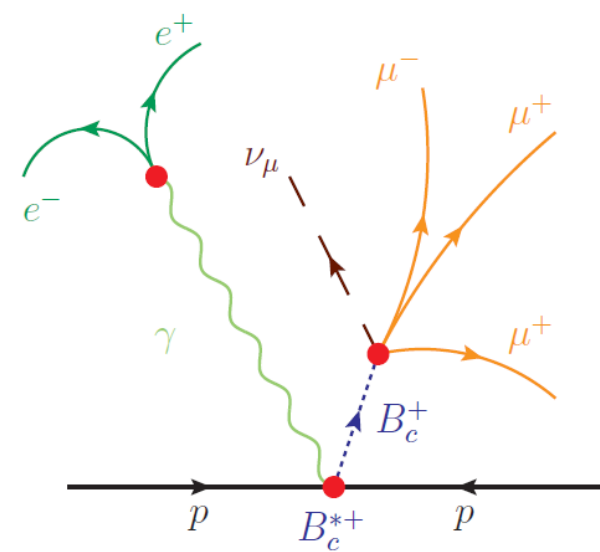


# Studies of $B_c^{*+}$ and $B_c^*$



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

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

# Gluon TMD density in proton from LHC data

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

A.V. Lipatov<sup>1,2</sup>, G.I. Lykasov<sup>2</sup>, M.A. Malyshev<sup>1,3</sup>

April 16, 2024

<sup>1</sup>*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991, Moscow, Russia*

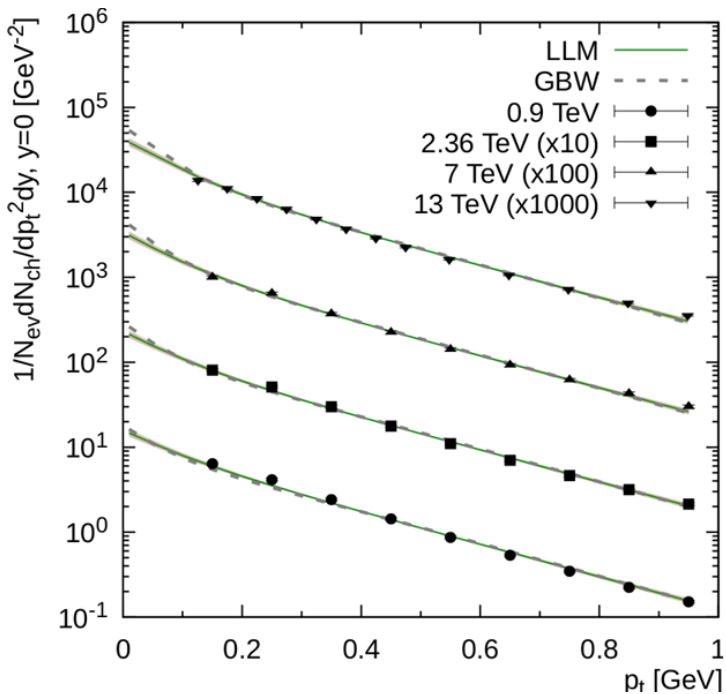
<sup>2</sup>*Joint Institute for Nuclear Research, 141980, Dubna, Moscow region, Russia*

<sup>3</sup>*Moscow Aviation Institute, 125993, Moscow, Russia*

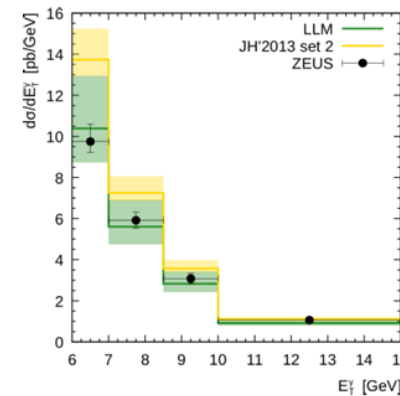
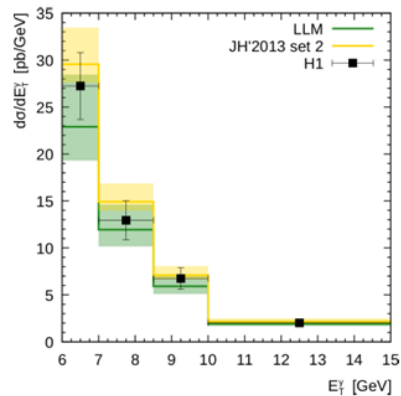
**Abstract**

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. Exploring QCD processes, we performed a convolution comprising a total of 509 points for derived TMD gluon density in a proton from HERA.

Experiment	Collaboration	Year	Reference	Collision	$\sqrt{s}/\text{GeV}$	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
$\sigma_{\text{red}}^c(x, Q^2)$	H1, ZEUS	2018	[50]	$ep$	0.319	51
$\sigma_{\text{red}}^b(x, Q^2)$	H1, ZEUS	2018	[50]	$ep$	0.319	27
incl. $H \rightarrow \gamma\gamma$	CMS	2023	[51]	$pp$	13	37
incl. $H \rightarrow \gamma\gamma$	ATLAS	2018	[51]	$pp$	13	27
incl. $H \rightarrow ZZ^*$	CMS	2023	[52]	$pp$	13	54
incl. $H \rightarrow ZZ^*$	ATLAS	2020	[53]	$pp$	13	54
incl. $\gamma$	H1	2010	[44]	$ep, \text{ low } Q^2$	0.319	25
incl. $\gamma$	ZEUS	2014	[45]	$ep, \text{ low } Q^2$	0.319	8

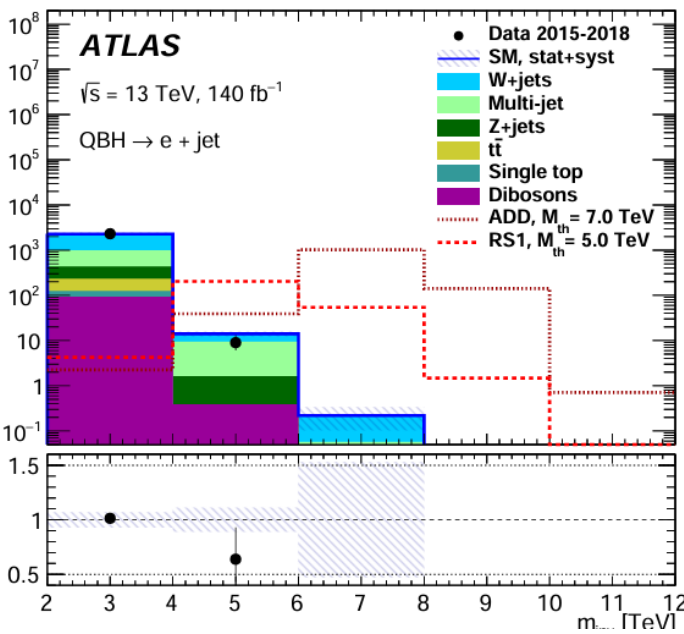


e-print:2404.09550  
[Phys. Lett. B 848 \(2024\) 138390](https://arxiv.org/abs/2404.09550)

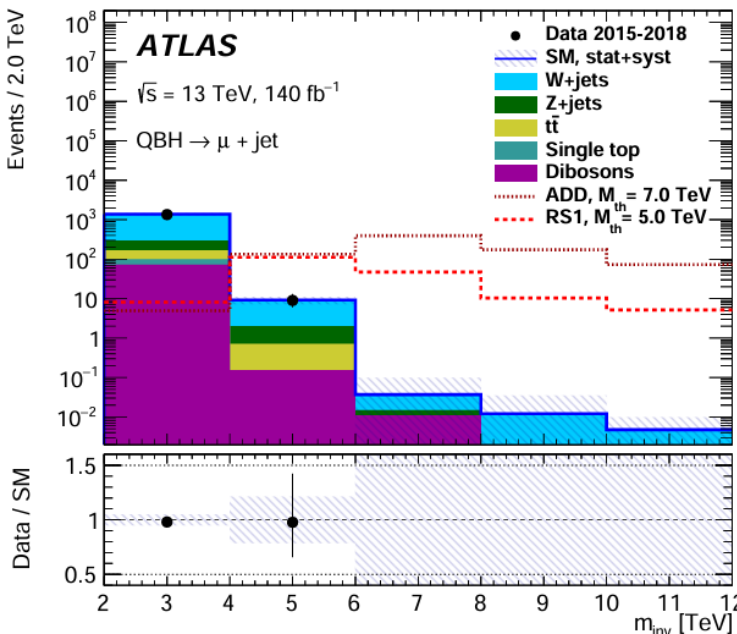




# Search for Quantum Black Holes in lepton+jet final states



Phys. Rev. D. 109 (2024) 032010



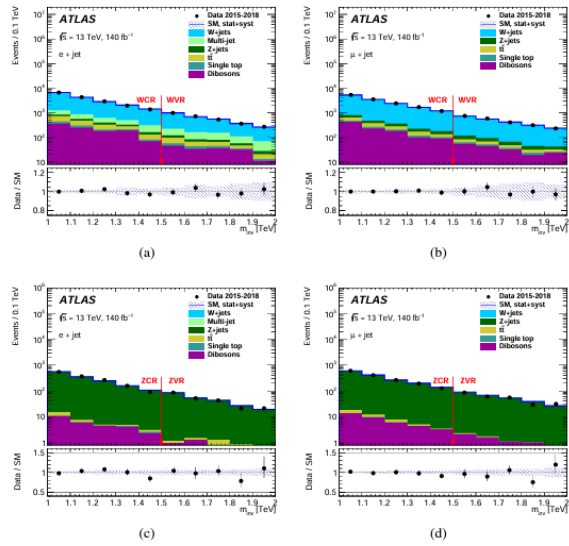
JINR team played a leading role in the search for QBH in lepton+jet final states at ATLAS.

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

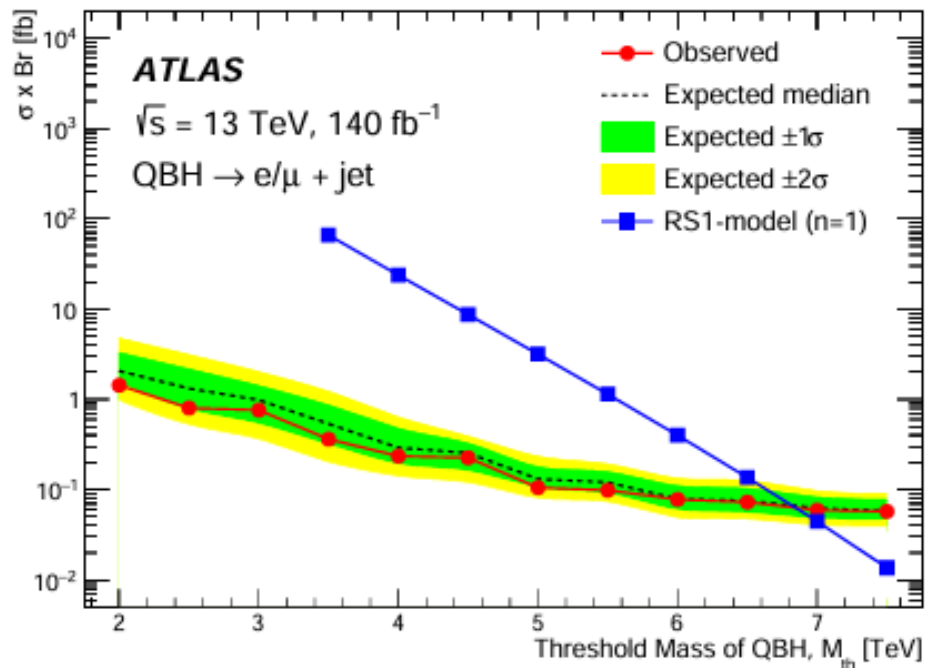
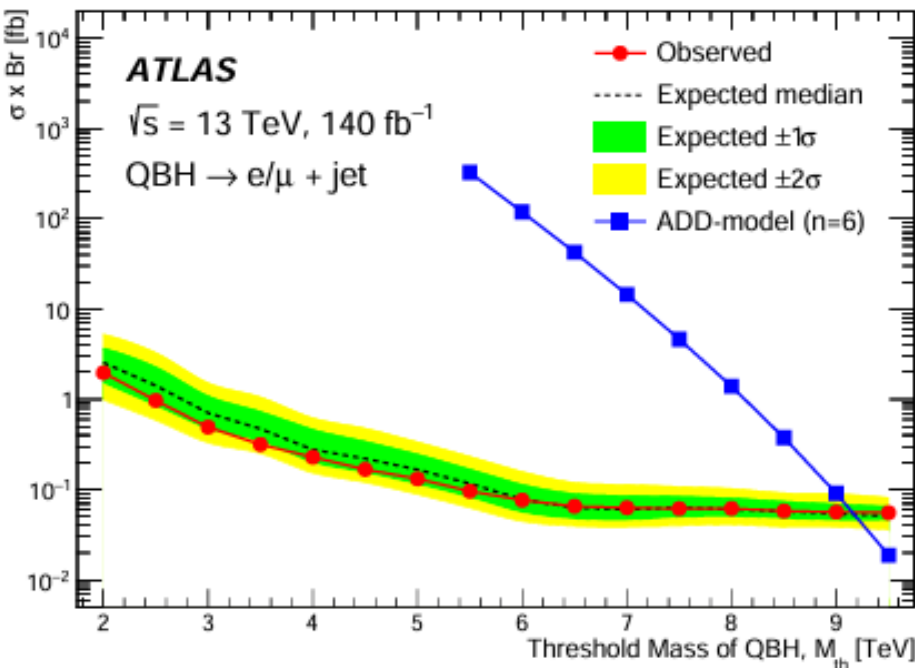
Predicted QBH signals in the Arkani-Hamed-Dimopoulos-Dvali model (ADD) and Randall-Sundrum (RS1) models are shown.

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

	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



# Search for Quantum Black Holes in lepton+jet final states

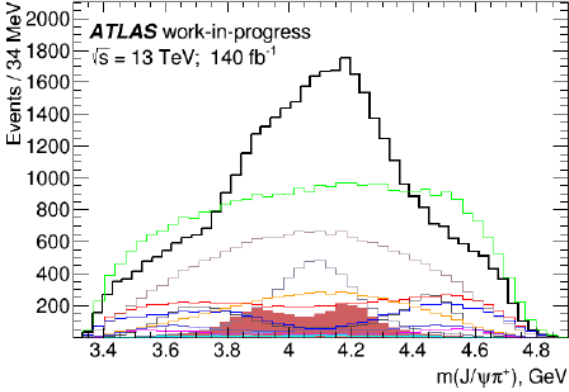
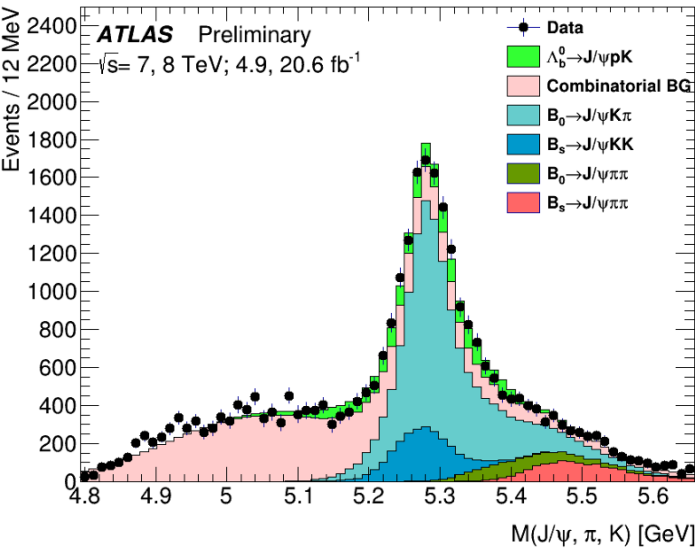


Phys. Rev. D. 109 (2024) 032010

Channel	ADD	ADD	RS1	RS1	Model-independent
	$\sigma \times Br$ [fb]	$M_{th}$ [TeV]	$\sigma \times Br$ [fb]	$M_{th}$ [TeV]	$\sigma(m_{inv} > 5 \text{ TeV}) \times Br$ [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.

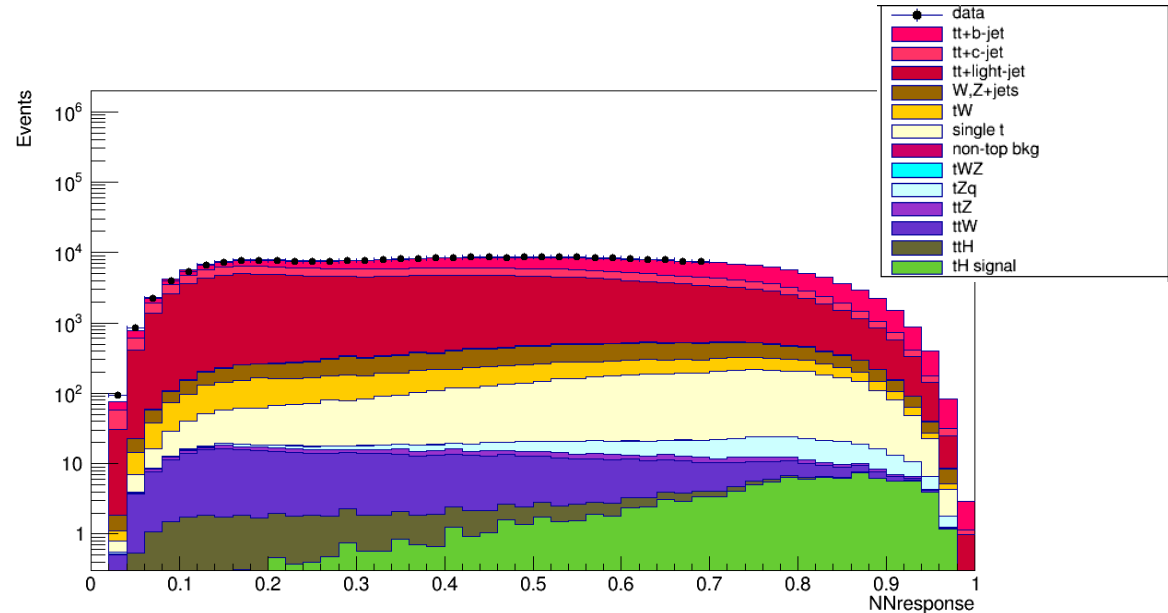
# Other physics analyses in advanced state...



$Z_c(4200)$ 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.

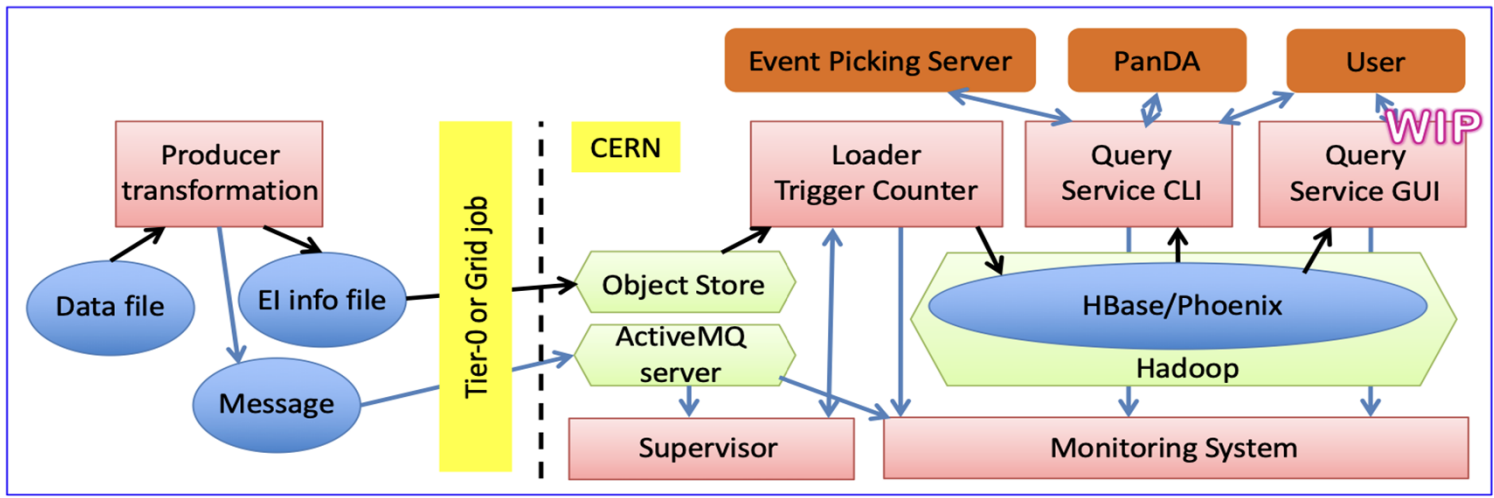
$Z_c^\pm(4200)$  state is observed in the  $J/\psi\pi$  invariant mass spectrum with significance  $>3.7\sigma$ . Mass, width and spin-parity characteristics are measured from ATLAS Run2 data. Significant role is played by the interference effects between signals and background.  $Z_{cs}$  states contributions 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 potential signal significance by  $\sim 1.7$  compared to standard cut and count approaches.

# 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
$\gamma\gamma \rightarrow WW$	50k	1.0.0	2 weeks
		manual	3 months
$\gamma\gamma \rightarrow WW$	136k	Beta version	3 months
$B_c^* \rightarrow B_c$	16K	1.2.37	84h
$Z \rightarrow \text{TauTau}$	11K	1.2.37	40h
$B_c^* \rightarrow B_c$	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  $B_c^* \rightarrow B_c \gamma$  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.

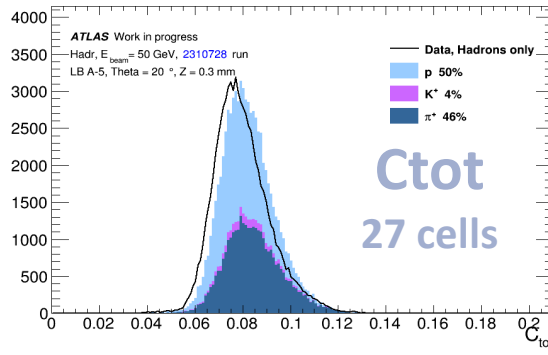
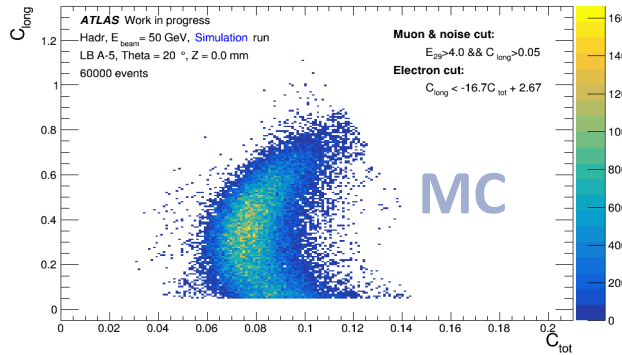
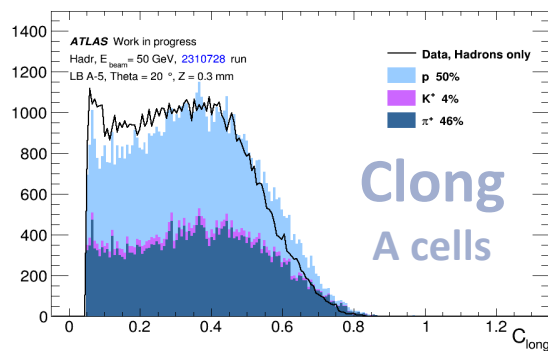
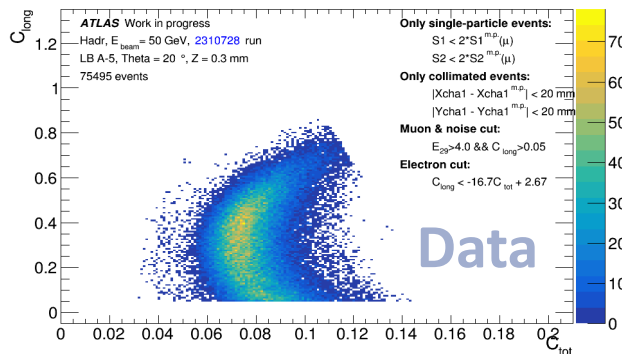
- **P-BEAST Dashboard support**

- 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 dashboard is shown in Figure.



# Measurement of the hadronic shower shapes in ATLAS TileCal

- TestBeam data 2023 have been analyzed.
- 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

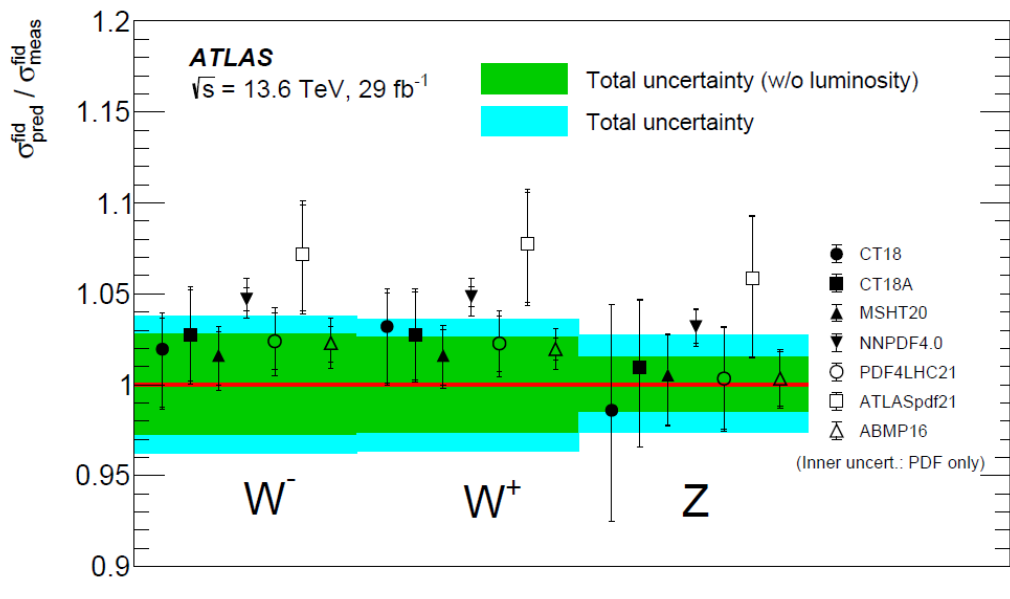


## Plans

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

# Development of ReneSANCe MC generator

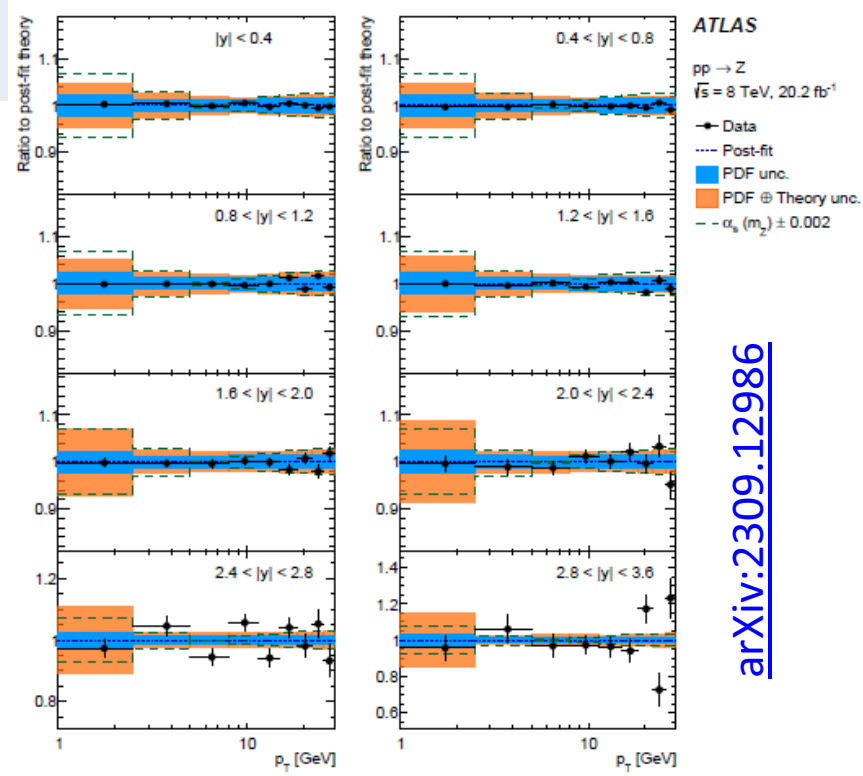
- JINR team develops MC generators and radiation correction libraries: **DIZET, MCSANC, ReneSANCe**
- They are used in several SM studies at ATLAS and other experiments



Physics Letters B 854:138725

## Measurement of vector boson production cross sections and their ratios using pp collisions at $\sqrt{s} = 13.6 \text{ TeV}$ 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 $\sqrt{s} = 8 \text{ TeV}$

Higher order effects on the cross-section normalization from QED initial-state radiation and from electroweak virtual corrections are considered at next-to-leading order are calculated using ReneSANCe

# JINR group participation in the upgrade program

**JINR team fulfilled all obligations** on participation in the **Phase-1** Upgrade program of the ATLAS detector.



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

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

## - LAr Calorimeters:

- optical link components

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

## - High Granularity Timing Detector

- half-disk instrumentation stand
- transportation tools and cavern installation

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







# LHC / HL-LHC Plan



ATLAS Phase 0

ATLAS Phase I

ATLAS Phase II

LHC

TODAY

HL-LHC

Run 1

Run 2

Run 3

Run 4 - 5...

LS1

13 TeV

EYETS

LS2

13.6 TeV

EYETS

LS3

13.6 - 14 TeV

energy

HL-LHC machine checkout  
end of June 2029

7 TeV

8 TeV

splice consolidation  
button collimators  
R2E project

cryolimit  
interaction  
regions

Diodes Consolidation  
LIU Installation  
Civil Eng. P1-P5

pilot beam

inner triplet  
radiation limit

HL-LHC  
installation

2011

2012

2013

2014

2015

2016

2017

2018

2019

2020

2021

2022

2023

2024

2025

2026

2027

2028

2029

2040

experiment  
beam pipes

nominal Lumi

2 x nominal Lumi

ATLAS - CMS  
upgrade phase 1  
ALICE - LHCb  
upgrade

2 x nominal Lumi

ATLAS - CMS  
HL upgrade

5 to 7.5 x nominal Lumi

75% nominal Lumi

30 fb<sup>-1</sup>

190 fb<sup>-1</sup>

450 fb<sup>-1</sup>

integrated  
luminosity  
3000 fb<sup>-1</sup>  
4000 fb<sup>-1</sup>

HL-LHC TECHNICAL EQUIPMENT:

DESIGN STUDY



PROTOTYPES

CONSTRUCTION

INSTALLATION & COMM.

PHYSICS

## Conclusions and plans

---

- During 2024 we were continuing our successful participation in the ATLAS Physics program and realization of attractive ideas in the ATLAS research program proposed by ATLAS at JINR
- ATLAS-JINR team participates in many ATLAS Physics Working Groups
- During LS2 and Run3 significant attention were paid to the software projects
- Few physics analyses started with Run3 data.
- We kept contribution to detector maintenance.
  
- 4 papers released, few physics analysis are expected to be released in 2024, two students completed QT
  
- JINR commitments w.r.t. Phase-II upgrade are being accomplished
  
- Currently it's difficult to plan long-term activities: software support, PhD terms for students, etc.

BACKUP

# JINR group participation in the ATLAS **Phase-I** upgrade program (2013-2022)

## **Muon Spectrometer – NSW project:**

- Infrastructure development
- Production of large Micromegas quadruplets
- NSW assembly and commissioning

**Factor 4 reduction in the rate of fake  $\mu$ -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 $\mu$ triggers

