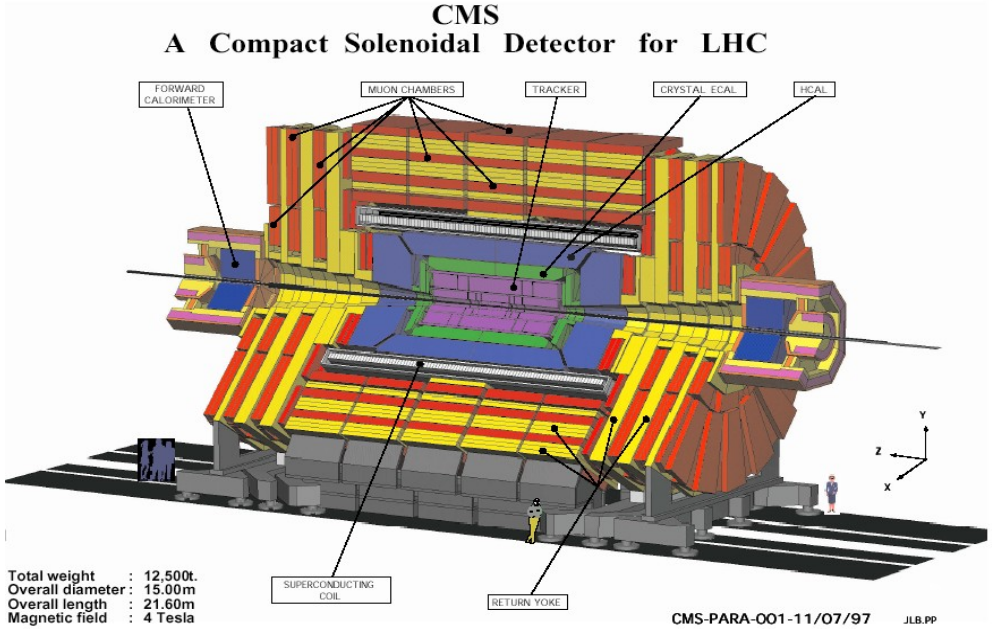
Report on the Scientific Results
JINR Participation in Compact Muon Solenoid at the LHC
Topic 02-0-1083-2009/2022



Igor Golutvin - *scientific leader*

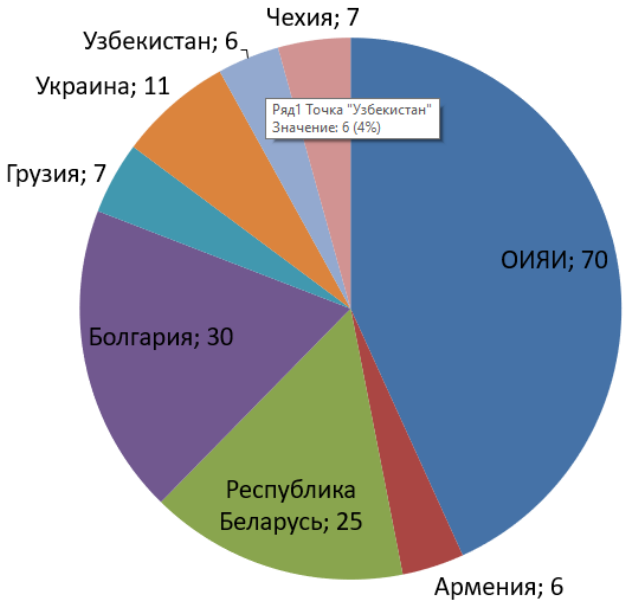
Anatoly Zarubin - *leader*

Ilya Gorbunov

on behalf of the JINR CMS Group

54th Meeting of the Program Advisory Committee for Particle Physics,
January 18, 2021, JINR, Dubna

JINR in the CMS Collaboration



70 participants from JINR
92 participants from JINR member states
16 paid authors and 4 unpaid authors (Ph.D.) from JINR
8 paid authors from JINR member states

33 FTE provided by JINR

In accordance with the M&O category B the JINR ream is responsible for maintenance and operation of detector systems, computing, software development

Also in accordance with Experimental Physics Responsibilities (EPR) each author (paid and free) is required to work on operational, maintenance, upgrade duties, including participation in shifts, at least 4 months (in the calculation of full time equivalent ~90 FTE in 2020).

JINR physicists bears responsibility as conveners for the HCAL Technical Coordination and Muon DQM Coordination

Participation in Analysis Review Committee (ARC) and Institutional Review Procedure

JINR Activity in the CMS Physics Analysis and SW

The fields of research are:

- searches for signals of extended gauge sector, signals of low-energy gravity at TeV scale (extra dimension models), and dark matter particles in the dimuon final states
- searches for signals of dark matter and new scalar bosons beyond SM (extra Higgs bosons) produced leptons/b-quarks and missing ET; studies of Higgs boson properties.
- studies of lepton-flavour violation processes to search for microscopic black holes, extended gauge sector, RPV SUSY, etc
- studies of muon pair production in Drell–Yan process (cross section, asymmetry, angular coefficients) to test SM at new energy scale, measurement of weak mixing angle and tests of PDFs
- measurements of multiplicity in jets for studies of hadronization process, improvement of PDF and

JINR physicists contribute to the seven CMS physics analyses; three of them are subject of full JINR responsibility

Activity in CMS Physics Working Group

- Exotica, Higgs, and Standard Model Analysis
- Muon and Jet/MET Physics Object Groups
- Muon and HCAL Detector Performance Group

Human resources

- 16 scientists from JINR (12 from LHEP, 2 from LIT, 2 from BLTP) and 6 from Dubna Member States (Minsk and Erevan)
- 13.5 FTE from JINR and 5.5 from DMS
- 11 young researchers: 1 PhD from JINR, 5 PhD Students from JINR, 5 PhD Students from DMS

Publications and talks in 2020

- 1 CMS Analysis in refereed journal
- 1 CMS Analysis was approved for submission
- 2 CMS Analysis in the CMS Analysis Notes
- 3 papers in conference proceedings, 5 papers in refereed journals, 4 review papers
- 16 talks were given by JINR physicists at the international conferences (13 of them by young scientists)

The list of JINR Physics and SW Tasks

- Search for physics beyond the standard model in dilepton mass spectra in proton-proton collision
  - ✓ search for new gauge bosons, extra dimensions, new higgs states, dark matter candidates

  2 PhD (0.9 FTE), 1 PhD Student (1 FTE), 1 CMS Analysis in journal papers, 2 journal papers, 1 review
- Search for physics beyond the standard model in processes with fermion flavor violation
  - ✓ search microscopic black holes, dark matter candidates, new higgs states

  5 PhD (3.5 FTE), 4 PhD Student (3 FTE), 1 journal paper and 1 conference paper in 2020, 2 review
- Search for Higgs to bbbar decay in Vector-Boson-Fusion Higgs production process

  1 PhD (0.5 FTE), 1 PhD Student (1 FTE), analysis is ongoing
- Measurement of the differential Drell-Yan cross section in proton-proton collisions

  2 PhD (0.3 FTE), 1 journal paper, 2 conference proceedings
- Forward-backward asymmetry of Drell-Yan lepton pairs in pp collisions

  1 PhD (0.4 FTE), 1 MS Student (1 FTE), 1 CMS Analysis Note in 2020, 1 review
- Angular coefficients of Z bosons produced in pp collisions as a function of transverse momentum and rapidity

  1 PhD (0.4 FTE), 1 PhD Student (1 FTE), 1 conference papers, 1 review
- Measurements of the multiplicity in quark and gluon jets and fractions of gluon jets

  1 PhD (1 FTE), 1 PhD Student (1 FTE), 1 CMS Analysis Note in 2020, 1 arXiv:2008.02054
- Drell-Yan Radiative Corrections

  1 PhD (1 FTE), 1 MS Student (0.5 FTE), 1 monograph
- Development of algorithms for high-momentum muons reconstruction; the muon hit reconstruction and segment builder

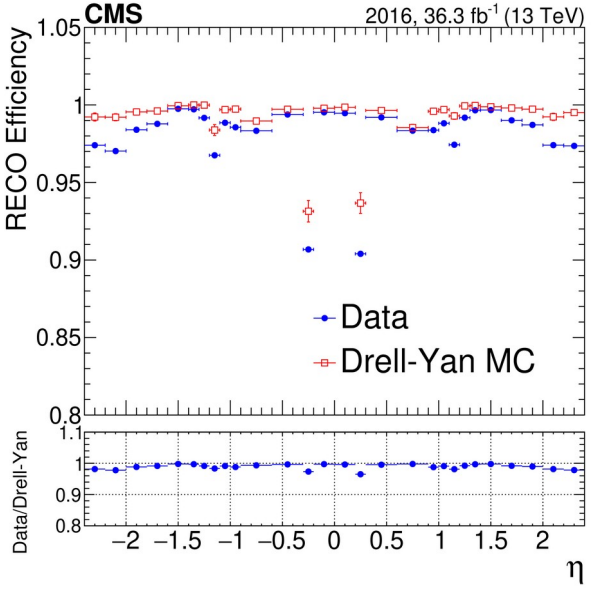
  3 PhD (0.8 FTE), 1 PhD Student (0.5 FTE), 1 CMS Analysis in journal papers

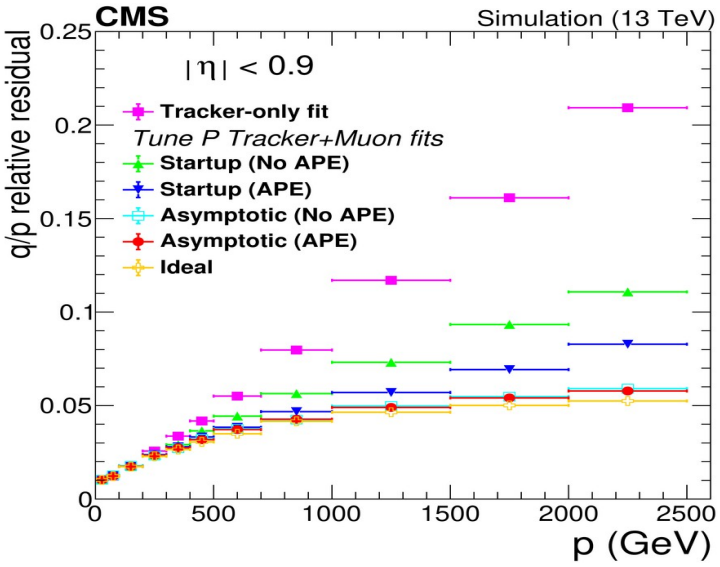
High-p_T Muons Reconstruction SW Development

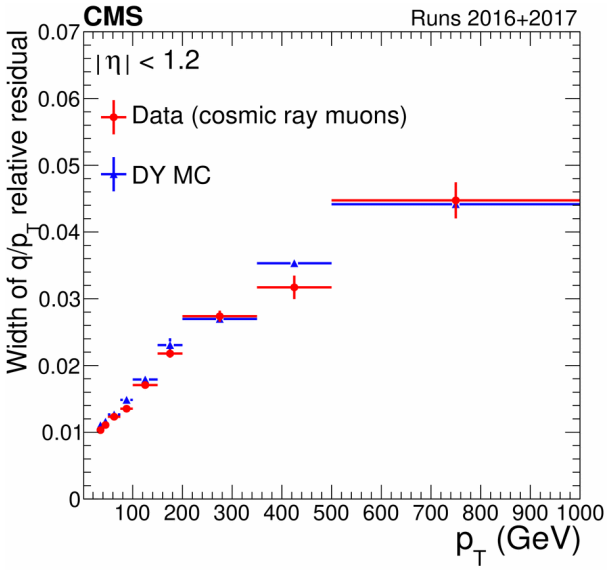
JINST 15 (2020) P02027

The CMS detector at the LHC has recorded events from proton-proton collisions, with muon momenta reaching up to 1.8 TeV in the collected dimuon samples.

These high-momentum muons allow direct access to new regimes in physics beyond the standard model. The dedicated studies are performed using the 2016 and 2017 data at 13 TeV with integrated luminosities of 36.3 and 42.1 fb^{-1}, respectively.



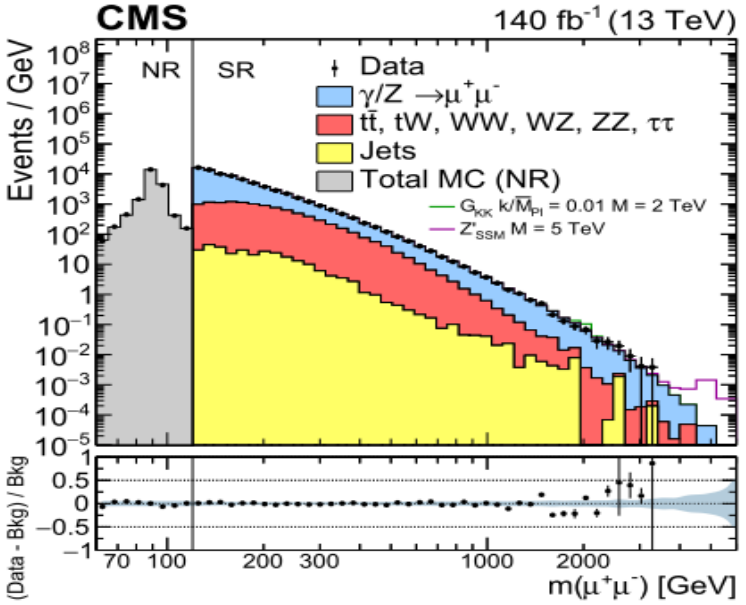




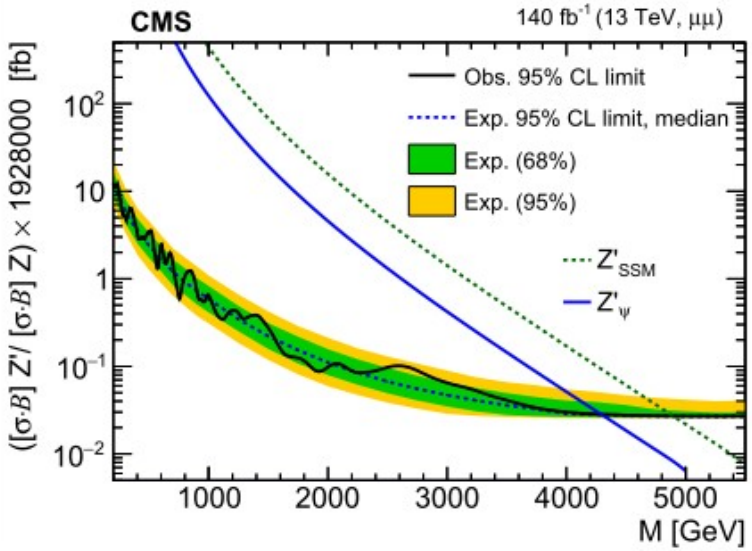
- ✓ The identification efficiency measured in data is >98% over the p_T spectrum, up to 1 TeV for $|\eta| < 2.4$
- ✓ The standalone reconstruction efficiency measured in data is > 98% over the full p_T spectrum and up to 1500 GeV for $|\eta| < 1.6$
- ✓ The Z boson mass resolution is <3 GeV for events with the leading muon p_T up to 450 GeV over the full η range.

New Physics with Dimuons

- A search is performed for a narrow resonance decaying to a pair of muons. No significant deviation from the Standard Model (SM) predictions is observed with respect to the expectation from the standard model backgrounds.
- A data set of proton-proton collisions collected by the CMS experiment at the LHC at 13 TeV recorded in years 2016 to 2018 and corresponding to a total integrated luminosity of up to 140 fb^{-1} is analyzed.
- Upper limits (95% CL) are set on the ratio of the product of production cross section and branching ratio of a new narrow dilepton resonance to that of the Z boson and converted into lower limits on the masses of various hypothetical particles.
- A Z'_{SSM} (Z'_{ψ}) particle, arising in the sequential standard model (superstring-inspired model) is excluded below a mass of 5.15 (4.56) TeV at 95% confidence level.
- Lower limits on the mass of spin-2 gravitons in models with large extra dimensions of 2.16-4.42 TeV are set for values of the coupling parameter k/MPl between 0.01 and 0.1.
- In case of a four-fermion contact interaction, lower limits on the UV cutoff parameter Λ range from 23.6 to 36.6 TeV depending on the helicity structure of the interaction and the sign of its interference with the SM DY background.

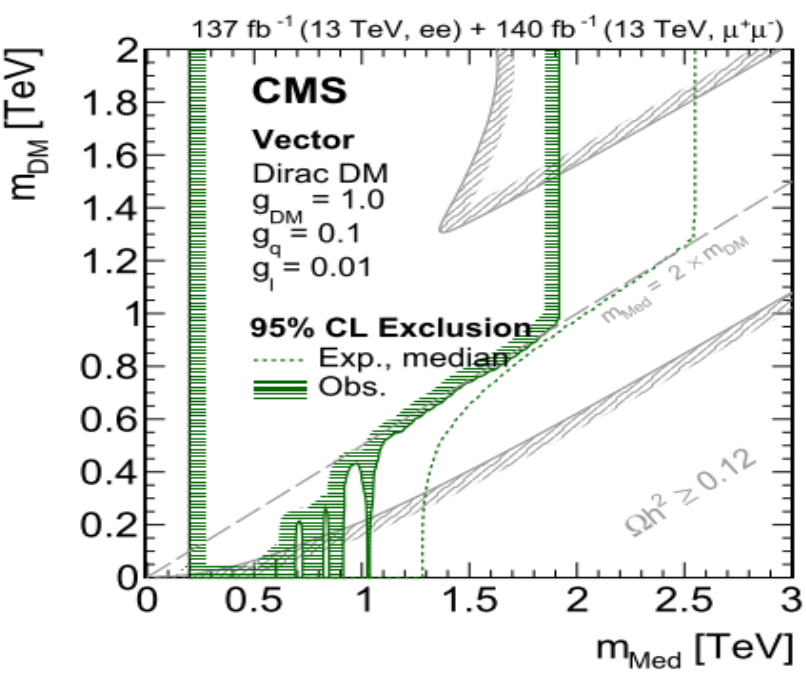


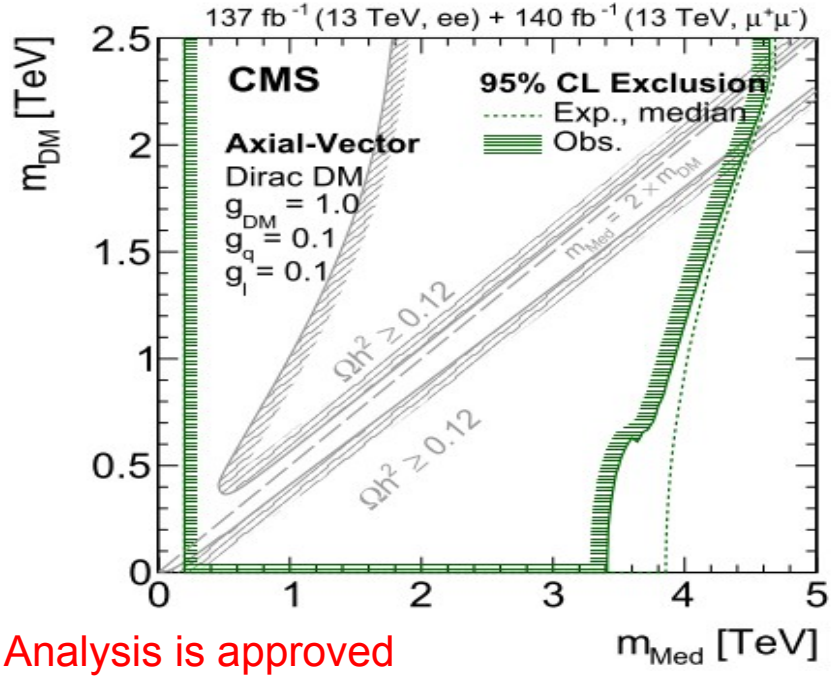
CMS Analysis is approved



Dark Matter with Dimuons

- The dimuon results are also interpreted in the context of the simplified DM models.
- In case of the axial-vector scenario with coupling $g_{DM} = 1.0$ and $g_q = g_l = 0.1$, and assuming $m_{DM} > m_{Med}/2$, the production cross section for electron or muon pairs within detector acceptance ranges from approximately 100 pb for m_{Med} around 200 GeV to 0.1 fb for m_{Med} around 4 TeV.
- For small m_{DM}, the mediator will dominantly decay to DM particles. This decay becomes suppressed for $m_{DM} > m_{Med}/2$, enhancing the decays into leptons and increasing the sensitivity of the dilepton channel.
- Expected and observed limits are therefore calculated for widths between 0.5% and 3.5% in steps of 0.25%



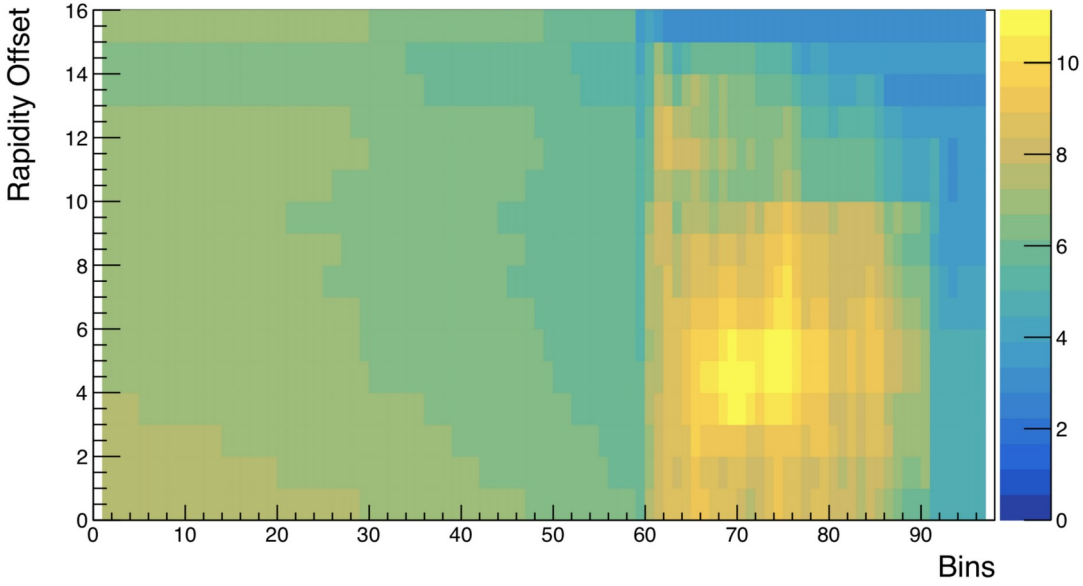


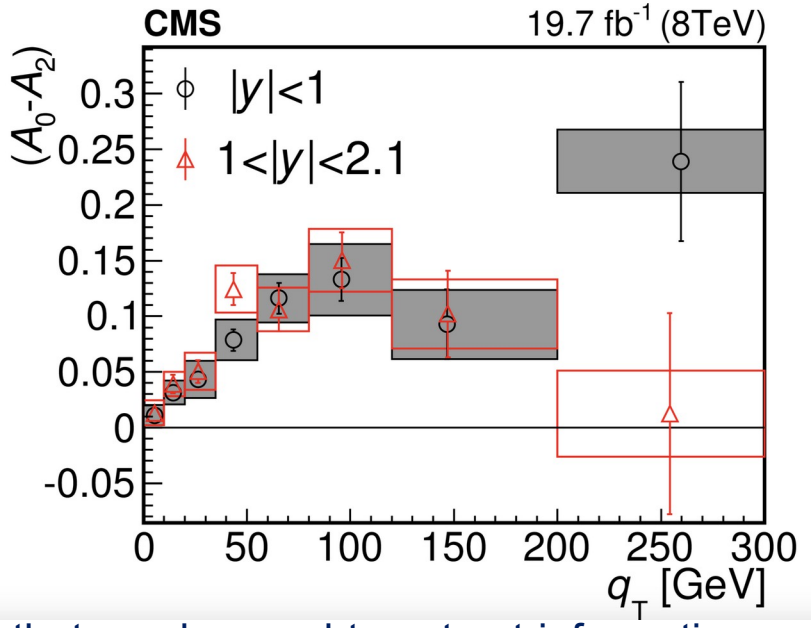
CMS Analysis is approved

- Mediators with masses below 1.92 TeV (4.64 TeV) are excluded in the vector (axial-vector) model.

Test of the Standard Model with Dimuons

- Measurements of the differential cross section, AFB and Angular Coefficients for the Drell-Yan process, based on proton-proton collision data at a centre-of-mass energy of 13 TeV, with full Run-2 dataset started.
- For the first time the measurement will be done in a wide invariant mass range (few GeV to several TeV)
- AFB can be used to improve invariant mass search sensitivity, especially in case of wide resonances. Studies of the ways to improve invariant mass bump search sensitivity to BSM physics by studying AFB are ongoing (rapidity offsets, binning, etc). AFB will be used for the first time to constrain BSM Phvsics.

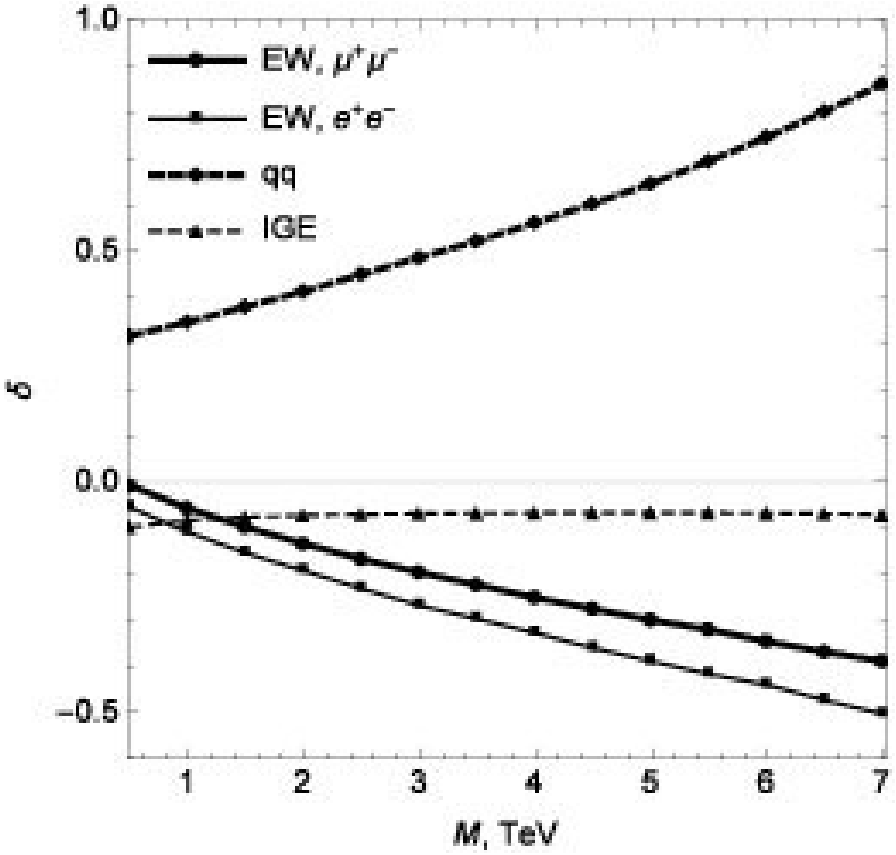




- Angular distributions are an additional set of observables that can be used to extract information on DM. Usage of the angular coefficients to search for DM in models with dark sector are ongoing (studying influence of the DM on polarization).

Theoretical activity: Drell-Yan Radiative Corrections

- One-loop electroweak and QCD radiative corrections in the Drell-Yan process at ultra high energies and invariant mass of lepton pair are calculated.



- The refactoring of code READY is implemented. CMS fiducial volume have been taken into account
- We used READY to estimate radiative corrections effects to observable cross sections and forward-backward asymmetry at the CMS experiment at Run3/HL regime of Large Hadron Collider.

To be published in Phys. Atom. Nucl.

The relative electroweak and QCD (quark-quark and Inverse Gluon Emission) corrections to differential cross section on M for muon and electron cases.

Physics with Jets: Standard Model and Beyond

Processes with jets in the final states are used for tests of SM and looking for new physics

- A method for measuring the fraction of gluon jets in a jet sample based on the quark-gluon likelihood discriminator is developed.
- The fractions of gluon jets were measured in jet samples collected in Run-I and Run-II in the “dijets" channel. The results of the measurement of the gluon fraction confirmed the conclusion made in 2018 about the suppression of gluon jets relative to theoretical and model predictions. Using the measured fraction of gluon jets, the likelihood discriminator distributions of quark and gluon jets were measured.

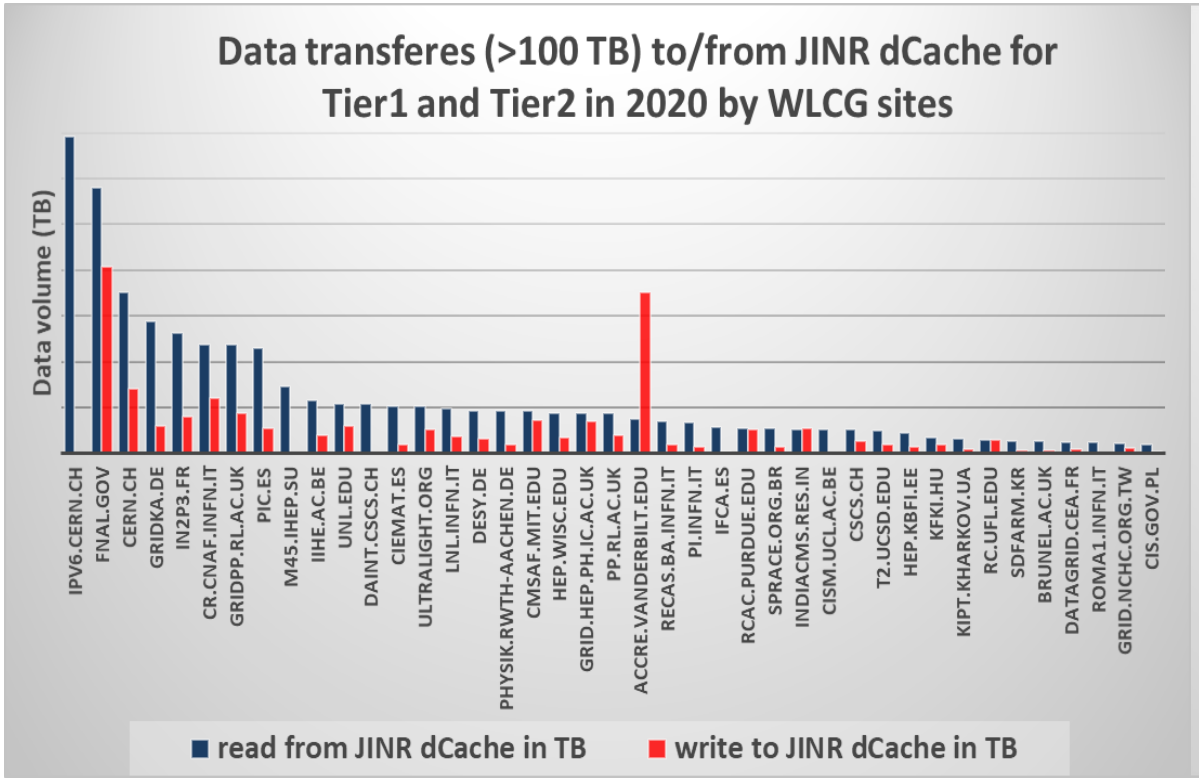
CMS AN-2020/143 is submitted
arXiv:2008.02054, accepted to PEPAN

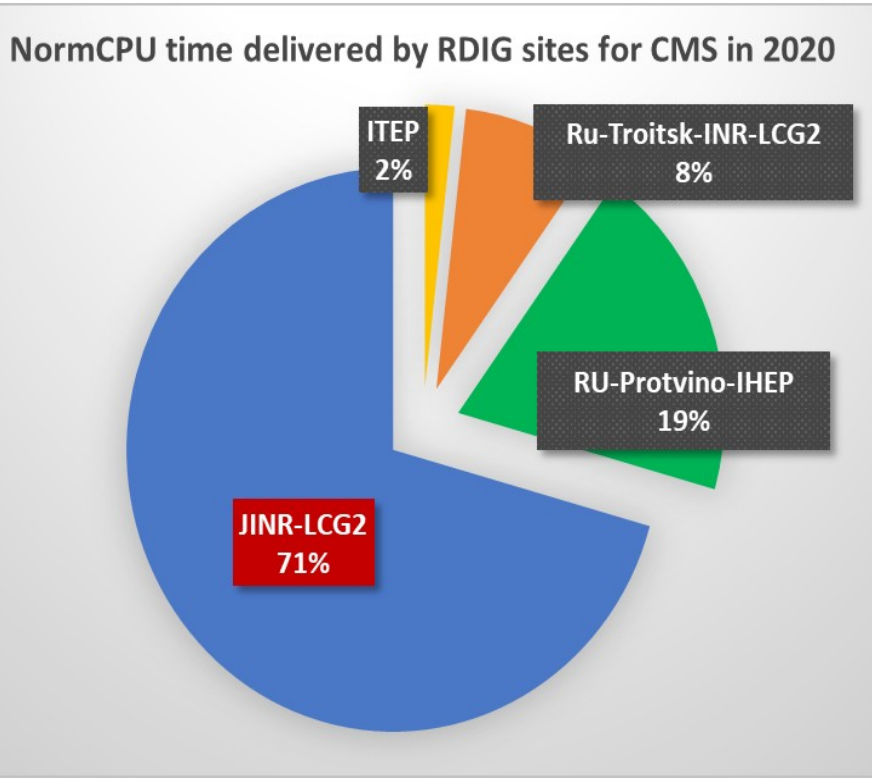
- The analyses was continued to search for H→bb decay in VBF process with CMS data of 2017-2018
  - ✓ dedicated triggers looking for VBF topology and b jets
  - ✓ recorded integral luminosity: 7.7 fb^{-1} (2017) + 59.7 fb^{-1} (2018)
  - ✓ major background is QCD inclusive process, signal background discrimination with multivariate analyses. Signal and background models development/validation
  - ✓ preliminary results indicate that the Monte Carlo are in a good agreement with the measured data

JINR Tier1 and Tier2 for CMS computing

One of the main functions of Tier1 level centers is to provide data exchange with all global sites running the CMS jobs. Since the beginning of the year, ~18 PB of data from more than 180 grid sites have been transferred to Tier1, and more than 30 PB of data have been downloaded.

JINR's Tier2 site is the most productive in the Russian RDIG Consortium (Russian Data Intensive Grid) for CMS data processing. More than 71% of the total CPU time in the RDIG is used for calculations on our Tier1 and Tier2.

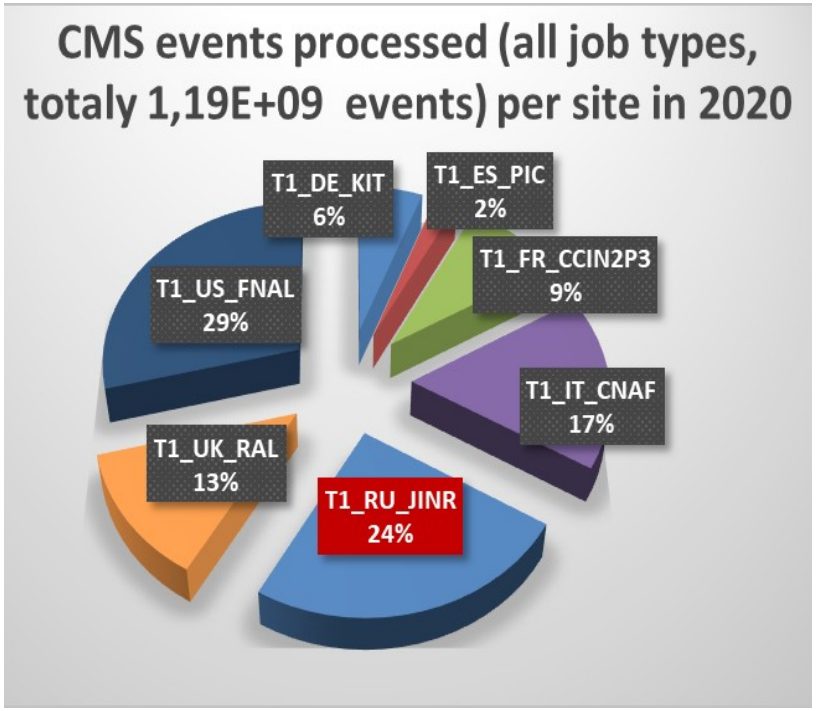


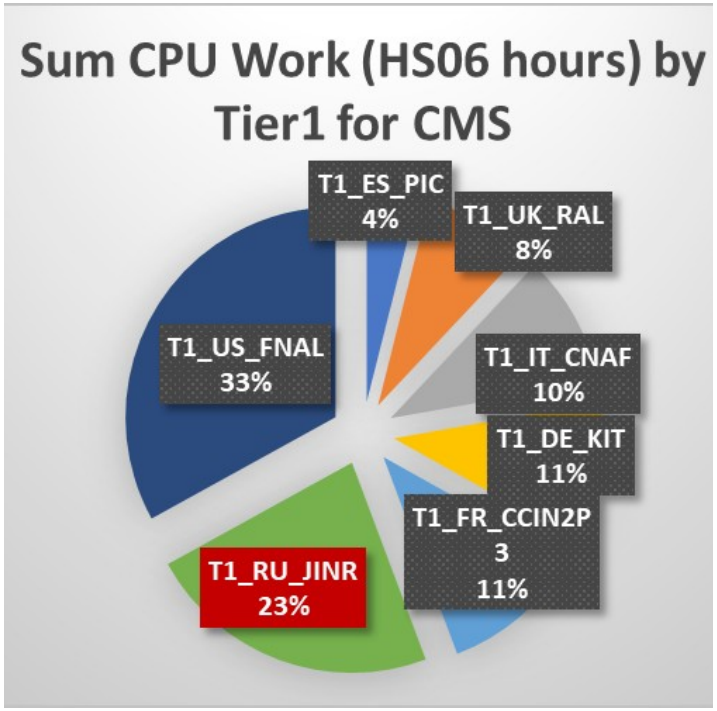


JINR Grid-Infrastructure for CMS computing

JINR grid infrastructure for CMS computing is represented by the Tier1 level center for the CMS experiment and the Tier2 level center, which are components of the LIT MICC and provides data processing for the CMS collaboration.

In terms of performance (number of events processed, jobs per site, etc.) JINR Tier1 ranks second among other world Tier1 centers (FNAL, JINR, CCIN2P, KIT, CNAF, RAL, PIC) for the CMS experiment





The JINR Tier1 site is equipped with novel high-performance computing elements, which gives us the possibility to process massive production jobs with a high speed and throughput.

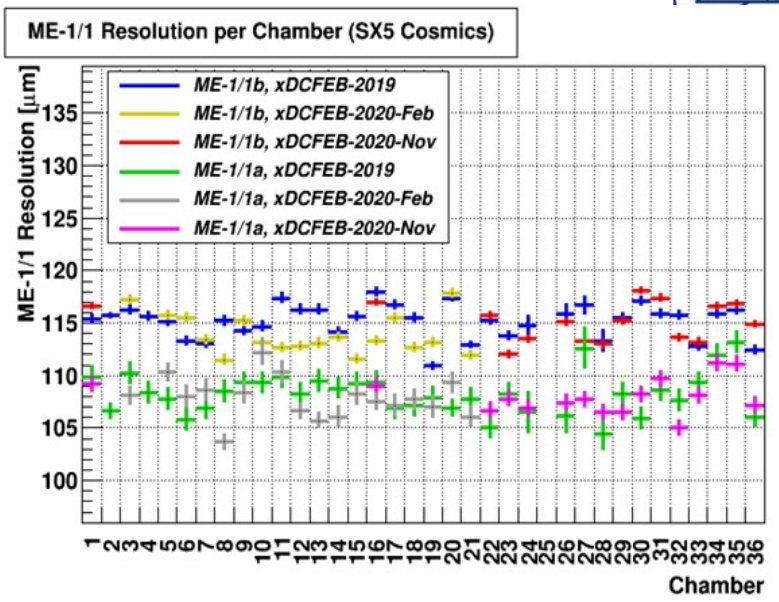
JINR Tier1 is a key site for WLCG infrastructure.

Tier2 play a leading role within RDIG community.

Run3 preparation require JINR sites further improvement with JINR directorate support.

Upgrades, Operation and Service Works

In 2020, during the long-term technical shutdown of the LHC (Long Stop, LS2), the JINR group physicists participated in the upgrade of the electronics and cooling system of ME1/1 station of the Cathode Strip Chambers (CSC)



❑ Total 72 new cooling circuits were installed, chambers were tested and finally reinstalled in the experimental cavern.

❑ Tests of the assembled chambers were done with cosmic rays. Spatial resolution of the chambers obtained in 2020 are in good agreement with the results of 2019

During LS2 in 2020, Phase-1 Hadron Barrel Calorimeter (HB) on silicon photomultipliers (SiPM) has been commissioned.

- ✓The JINR group continues to install new electronics and modified low voltage power supplies for CMS Hadron Calorimeters.
- ✓Installation of lover voltage protection circuits produced by Dubna and Minsk for low voltage power supply of HB was carried out.
- ✓ HB readout boxes temperature measurement studies were started for future cooling modification

The JINR group participated in the research and development (R&D) works for the Phase-2 Upgrade of the CMS Endcap Calorimeter (HGCAL) to operate at a high-luminosity LHC (HL−LHC).

- ✓ A new procedure was developed for assembly of active elements for prototype of the HGCAL scintillator module.
- ✓ Technology for production of cassettes cooling plates for HGCAL is developing and prototypes were successfully built and tested.

The Report on Completion of the Project “Upgrade of CMS Detector through 2020” is attached to the PAC indico page.

Plans for 2021

- In 2021, it is planned to continue searching for new physics with dimuons and measuring the characteristics of the Drell-Yan process. All LHC Run 2 statistics will be used. The Drell-Yan angular coefficients will be measured in triple differential mode for the first time. Drell-Yan cross section measurement extended to lower invariant masses. AFB will be measured on full available statistics and used to constrain BSM Physics.
- Also studies will be focused on verification of some dark matter models, extended gauge models with and without Lepton Flavour Violation (LFV), scenario of extra spatial dimensions and extended higgs sector.
- It is expected to measure the charged particle multiplicities in quark and gluon jets based on the measured fraction of gluon jets in the jet samples selected in the “dijets” channel for Run-I and Run-II (2016).
- Studying the aging effects of the ME1/1 CSC will be continued at GIF ++ setup. With the SPS muon beams, it is planned to study the characteristics of the CSC with background conditions corresponding to the HL LHC operating mode. The new segment builder algorithm to be studied with GIF++ muon beam data. A study of new CSC gas mixtures will be carried out taking into account the requirement to limit the use of greenhouse gases at CERN.
- In 2021, the JINR group plans to continue research on the temperature measurements for the HB readout box, as well as test and install modified clock&control modules and commissioning of Hadron Endcap Calorimeters, completion of work on the installation of modernized low voltage power supplies.
- The Project on JINR participation in CMS Phase 2 Upgrade will be submitted.

Summary

During the LS2 the JINR team successfully participated in

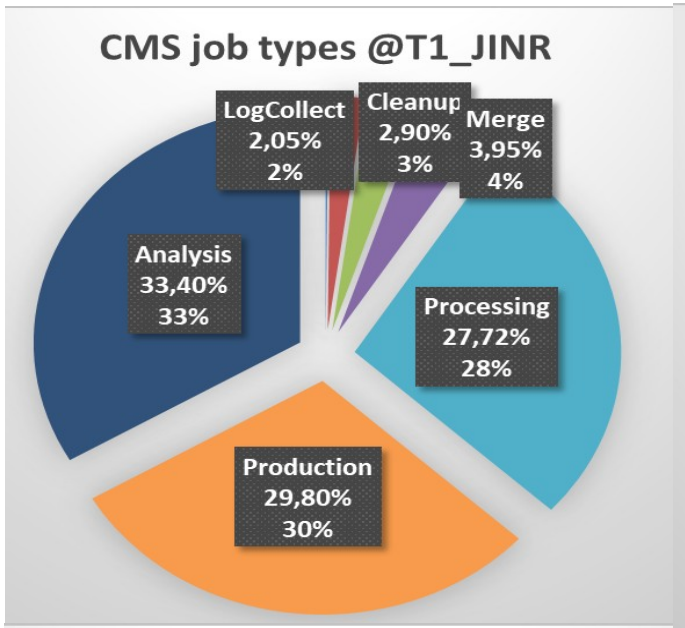
- Physics Program
  - ✓ JINR physicists are involved in the seven CMS Physics Analysis (three of them are subject of the full responsibility) within the Exotica/Higgs/SM Working Groups
  - ✓ 2 CMS papers, 5 papers in referred journal, 2 CMS AN Notes, 3 CMS CR Notes, 3 proceedings in 2020
  - ✓ young physicists are involved actively (11 young researcher < 35), 13 of the 16 talks in 2020 were presented by them)
  - ✓ the results are recognized and included in PDG reviews
- Upgrade, Operation and Service Works
  - ✓ JINR obligations within the JINR Project “CMS Upgrade up to 2020” (phase I) are successfully fulfilled (see the attached project report)
  - ✓ M&O_B (maintenance and operation of detector systems, computing, software development) and EPR (Experimental Physics Responsibilities) obligations for 2020 have been fulfilled
- Preparation of Phase 2 Upgrade
  - ✓ R&D works have been carried out
  - ✓ the project on participation of the JINR team in the Phase 2 CMS Upgrade in preparation
- Clear plans of participation in physics analysis during the LHC Run 3 (up to 2023)

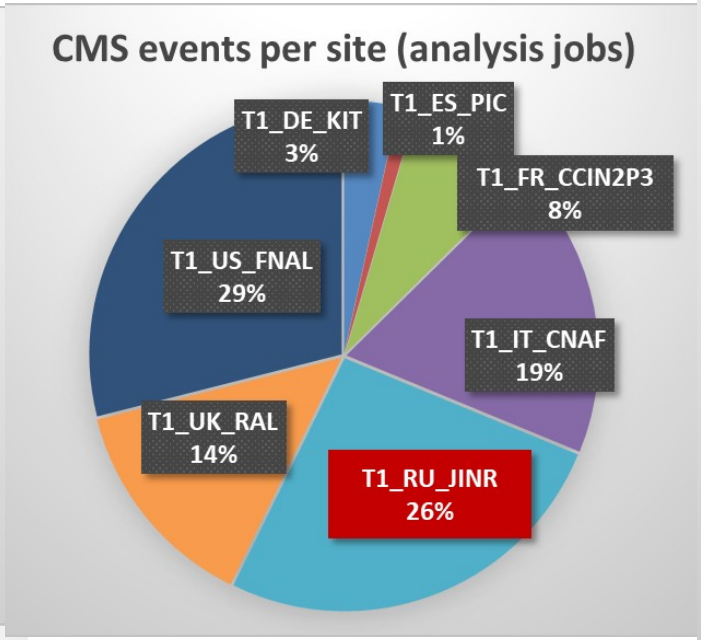
Thank you for your attention!

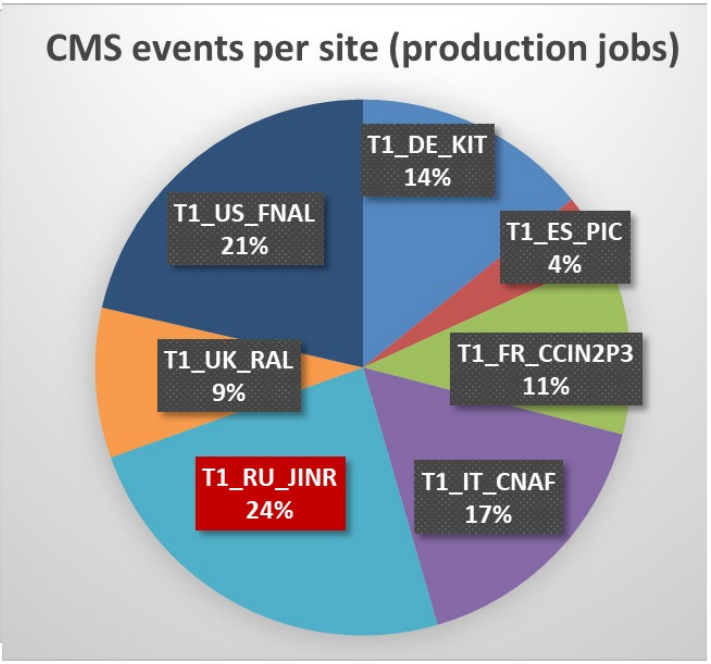
The project-plan (2020-2023) of JINR Participation in CMS research physics program

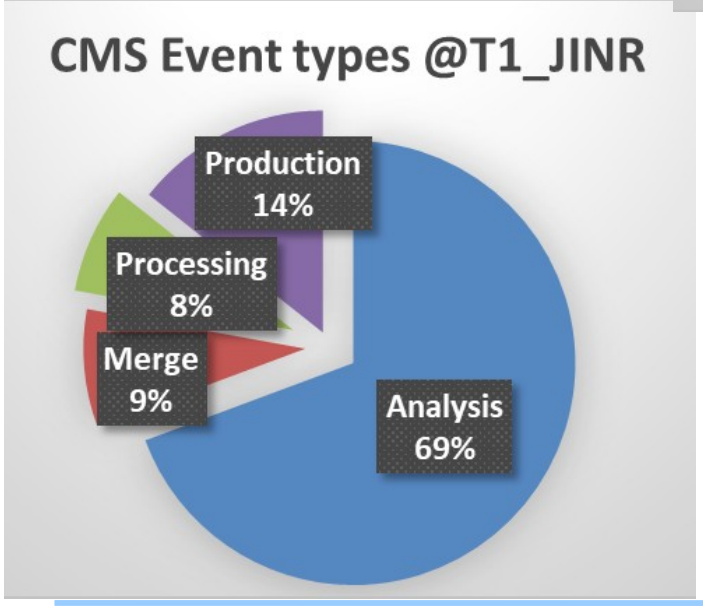
	Task	Participants	FTE	2020	2021	2022	2023/2024
1	Search for physics beyond the standard model in dilepton mass spectra in proton-proton collisions (gauge bosons, extra dimensions, new higgs states, dark matter candidates)	PhD A. Lanev (JINR), PhD S. Shmatov (JINR) PhD St. I. Zhizhin (JINR)	0,7 0,2 1,0	CMS Paper with full Run 2 Data (~150 fb^{-1})		CMS Note with a half of Run 3 Data	CMS Note with full Run 3 Data (~300 fb^{-1})
2	Measurement of the differential Drell-Yan cross section in proton-proton collisions	PhD A. Lanev (JINR), PhD S. Shmatov (JINR)	0,3 0,2		CMS Paper with full Run 2 Data (~150 fb^{-1})		CMS Note with Run 3 Data
3	Forward-backward asymmetry of Drell-Yan lepton pairs in pp collisions	PhD I. Gorbunov (JINR) M.Sc. T. Nechaeva (Minsk)	0,4 1,0	CMS PAS/Paper with full Run 2 Data (~150 fb^{-1})	CMS Note for low and high-mass region with Run 2 Data	CMS Paper for low and high-mass region with Run 2 Data	to be defined
4	Angular coefficients of Z bosons produced in pp collisions as a function of transverse momentum and rapidity	Prof. O. Teryev (JINR) PhD I. Gorbunov (JINR) PhD S. Shmatov (JINR) PhD St. V. Shalaev (JINR)	0,1 0,4 0,2 1,0	CMS Note with Run 2 Data	CMS PAS/Paper with full Run 2 Data (~150 fb^{-1})	CMS PAS/Paper with Run 2 Data for Z+jet	Summary CMS Paper
5	Search for physics beyond the standard model in processes with fermion flavor violation	PhD M. Savina (JINR) PhD S. Shmatov (JINR) PhD St. D. Seitova (JINR)	1,0 0,2 1,0	Estimations of the CMS performance	Paper with MC data	to be defined	
6	Search for Higgs to bbbar decay in Vector-Boson-Fusion Higgs production process	PhD A. Tumasyan (ANSL, Erevan) PhD St. V. Aloyan (ANSL, Erevan)	1,0 1,0	Trigger development for LHC Run 3	CMS Note with Run 2 Data	Analysis strategy development for Run 3	CMS Note with Run 3 Data
7	Measurements of the multiplicity in quark and gluon jets and fractions of gluon jets	PhD S. Shulga (JINR) PhD St. D. Budkovsky (JINR) M.Sc. M. Gavrilenko (JINR)	1,0 1,0 0,8	CMS Note with Run 1 Data for dijet	CMS Note with Run 2 Data for dijet	CMS Note with Run 2 Data for gamma+jet	CMS PAS/Paper
8	Radiative corrections to the Drell-Yan processes	Prof. V. Zykunov (JINR), M.Sc. M. Bugaevskaya (Minsk)	1,0 0,5	AFB estimations for Run 2	Angular coefficients estimations for Run 2	Estimations for Run 3	to be defined
9	Development of algorithms for the muon hit reconstruction and segment builder	PhD V. Palchik (JINR) M.Sc. N. Voytishin (JINR)	0,5 0,5				
10	Study of Higgs to tau leptons decay in Vector-Boson-Fusion Higgs production process to optimize transverse segmentation of endcap hadron calorimeter	PhD V. Alexakhin (JINR)	1,0		to be defined		
	Total	2 Prof, 6 PhD, 5 PhD St., 4 M.Sc.	16				

JINR Tier-1 for CMS computing









The JINR Tier1 site is equipped with novel high-performances computing elements, which gives us the possibility to process massive production jobs with a high speed and throughput. As a result JINR Tier1 holds the first place by the number of processed production jobs and events among all the Tier1 sites.