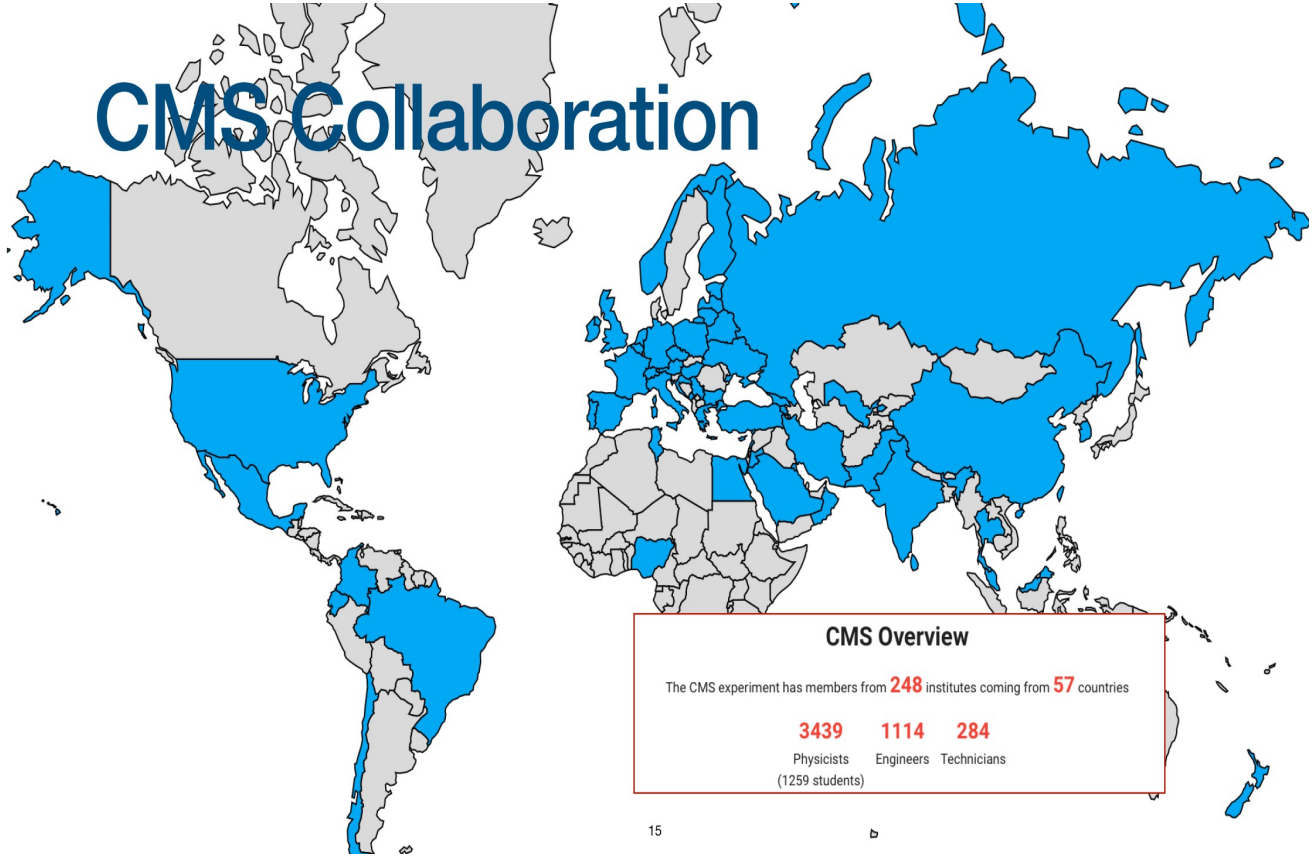
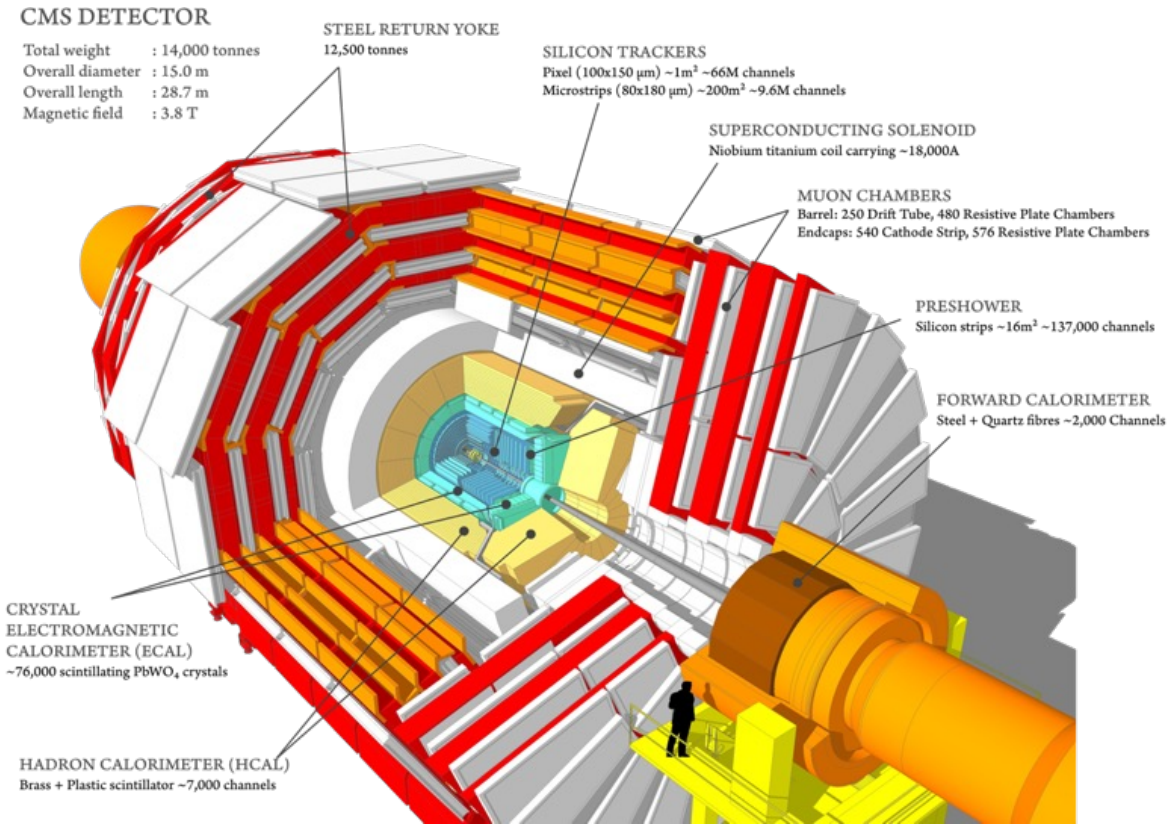
JINR Participation in CMS Experiment
Report on the Research Results

JINR Topic 02-0-1083-2009/2023



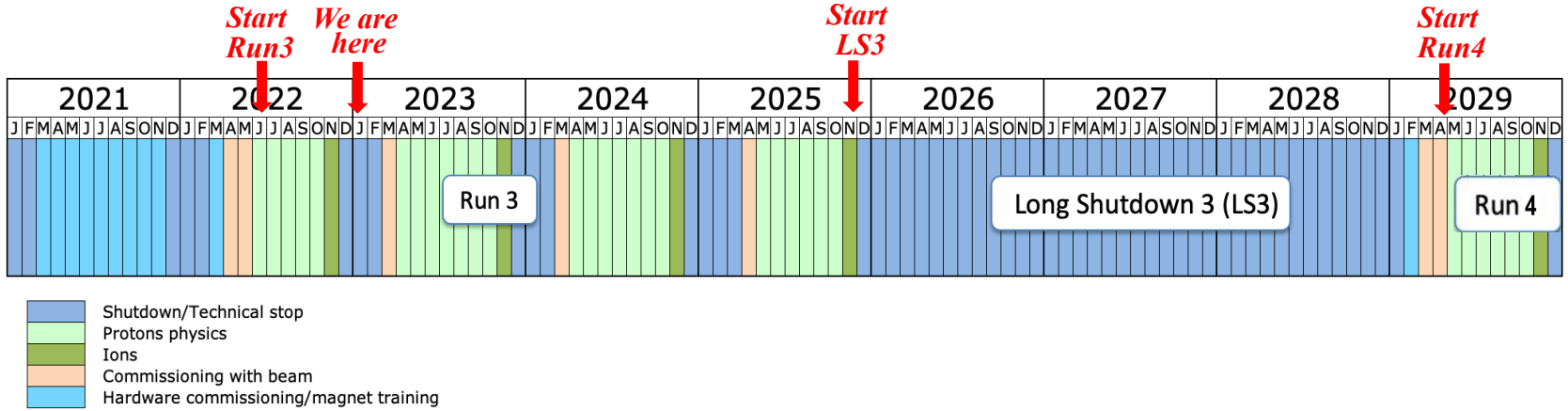
https://cms.cern/



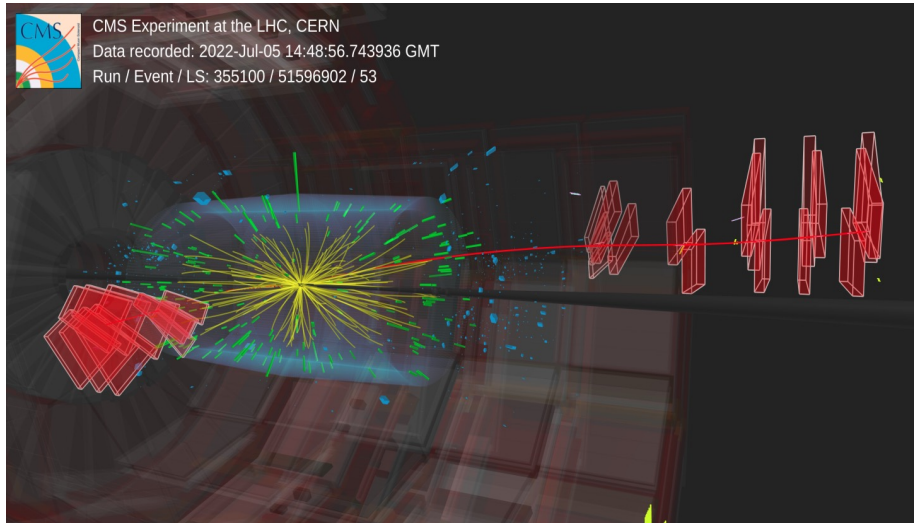
Vladimir Karjavine

57th Meeting of the Programme Advisory Committee. 23.01.2023.

LHC Schedule and CMS 2022 Operation

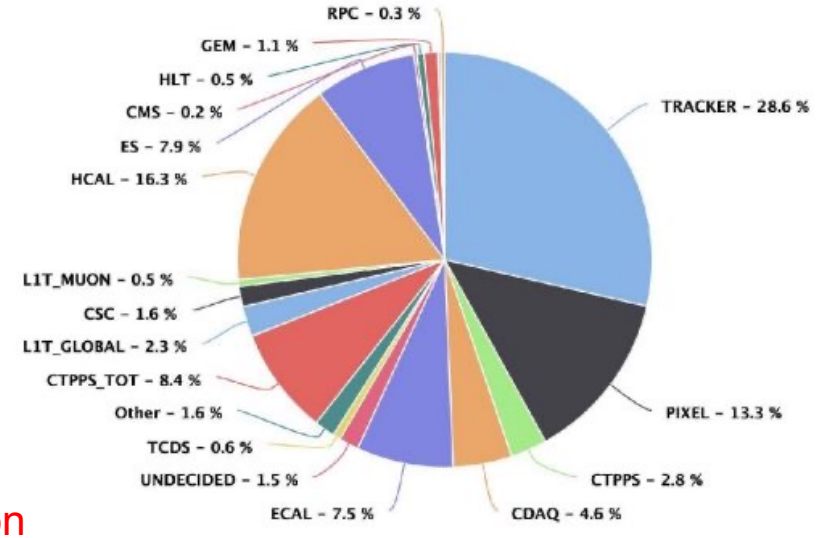


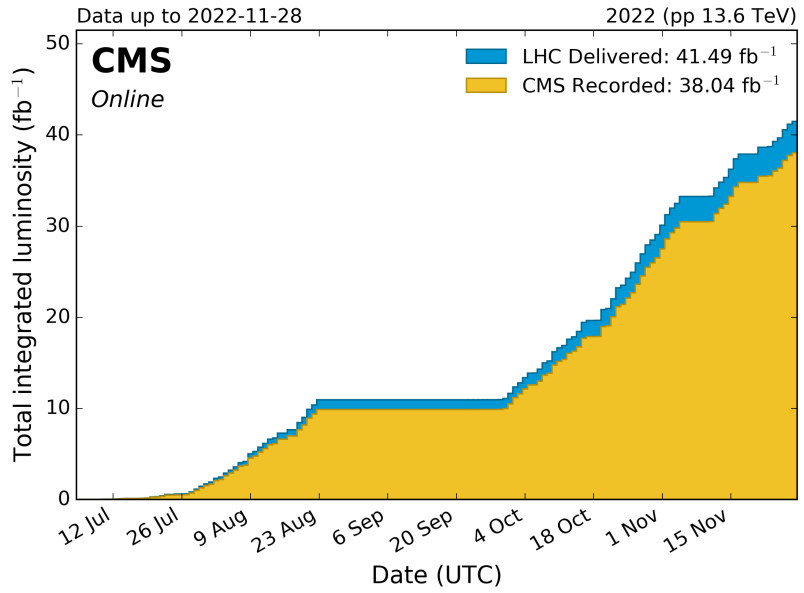
The long-awaited LHC Run 3 has started on 5th of July 2022!



CMS recorded first collision events at 13.6 trillion electron volts (TeV). LHC set a new world record!

Reliability of the CMS subdetectors





2022 Run 3 summary

- ~41 fb^{-1} delivered
  ~38 fb^{-1} recorded by CMS
- 91.7% data-taking efficiency overall

2022 Run ended, November 28

JINR Activities in CMS Collaboration in 2022

JINR responsibilities:

- JINR physicists are responsible for 9 physics analysis based on RUN2 data and RUN3 data
- in accordance with the M&O category B the JINR team is responsible for commissioning after Phase-I Upgrade, maintenance and operation of detector systems in RUN3, computing, software development
- under the MoUs concerning JINR participation Phase-II Upgrades JINR contributes in HGCAL and Muon systems

- Total number of participants from JINR: 70
- Authors from JINR: 21
- 11 young researchers: 1 PhD from JINR, 5 PhD Students from JINR, 5 PhD Students from DMS
- JINR team full time equivalent (FTE): 105.32 FTE-months*
- 62 central shifts - served by JINR physicists in 2022

**) According to Experimental Physics Responsibilities (EPR) each author (paid and unpaid) is required to work on operational, maintenance, upgrade duties, including participation in shifts, at least 4 months*

*From the talk of CMS Spokesperson **Patricia McBride***
CMS Week, December 5, 2022

- **Run 3 Operations:** CMS relies on Russia and JINR personnel for essential expertise in operations. Largest potential impact would be in HCAL, BRIL and MUON.
- There were also plans for Russian personnel to help with **installation and commissioning of HGCAL**.
- The potential impact of sanctions on **Computing Tier 1 resources** are significant for CMS. For the moment, these resources are available.

CMS duties executed by JINR physicists:

- work as conveners in HCAL Technical Coordination, Muon DQM Coordination and CMS data managers of Tier-2 and Tier-1 sites
- Participation in Analysis Review Committee (ARC) and Institutional Review (IR) procedure

JINR Activity in the CMS Physics Analysis and SW

The list of JINR Physics and SW Tasks (1)

Physics beyond the Standard Model and Higgs Physics

We focus on analysis that can be completed before the end of 2024

1. 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). The analyses of RUN2 data is completed. Analysis of RUN3 data is started.

2. Searches for signals of dark matter and new scalar bosons beyond SM (extra Higgs bosons) produced pairs of leptons/b-quarks and missing ET.

   5 PhD (3.5 FTE), 4 PhD Student (3 FTE). Analysis of RUN3 data is started.

3. Search for a mu+mu-+b-jet event excess at the dimuon mass of 28 GeV in pp collisions at 13 TeV.

   2 PhD (0.5 FTE), 1 PhD Student (0.2 FTE). Analysis of RUN2 data is ongoing.

4. Search for physics beyond the standard model in processes with fermion flavor violation (microscopic black holes, dark matter candidates, new higgs states).

   1 PhD (0.5 FTE), 1 PhD Student (1 FTE). Simulation for RUN3 data analysis is started.

5. Studies of Higgs bosons with bbar-decays in Vector-Boson-Fusion Higgs production process.

   1 PhD (0.5 FTE), 1 PhD Student (1 FTE). Analysis of RUN2 data is pre-approved.

The list of JINR Physics and SW Tasks (2)

Standard Model

6. Measurement of the differential Drell-Yan cross section in proton-proton collisions. Drell-Yan Radiative Corrections.
   2 PhD (1.3 FTE), 1 MS Student (0.5 FTE). Analysis of RUN2 data is finished.
7. Forward-backward asymmetry of Drell-Yan lepton pairs in pp collisions.
   1 PhD (0.4 FTE), 1 MS Student (1 FTE). Analysis of RUN2 data is finished.
8. 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). Analysis of RUN2 data continues.
9. Measurements of the multiplicity in quark and gluon jets and fractions of gluon jets.
   1 PhD (1 FTE), 1 PhD Student (1 FTE). Analysis of RUN2 data continues.

Algorithms and Software

10. 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).
11. Data Certification (DC) software development with machine learning (ML) algorithms.
    1 PhD (0.5 FTE), 1 MS Student (0.5 FTE).

The selected physics results are given below

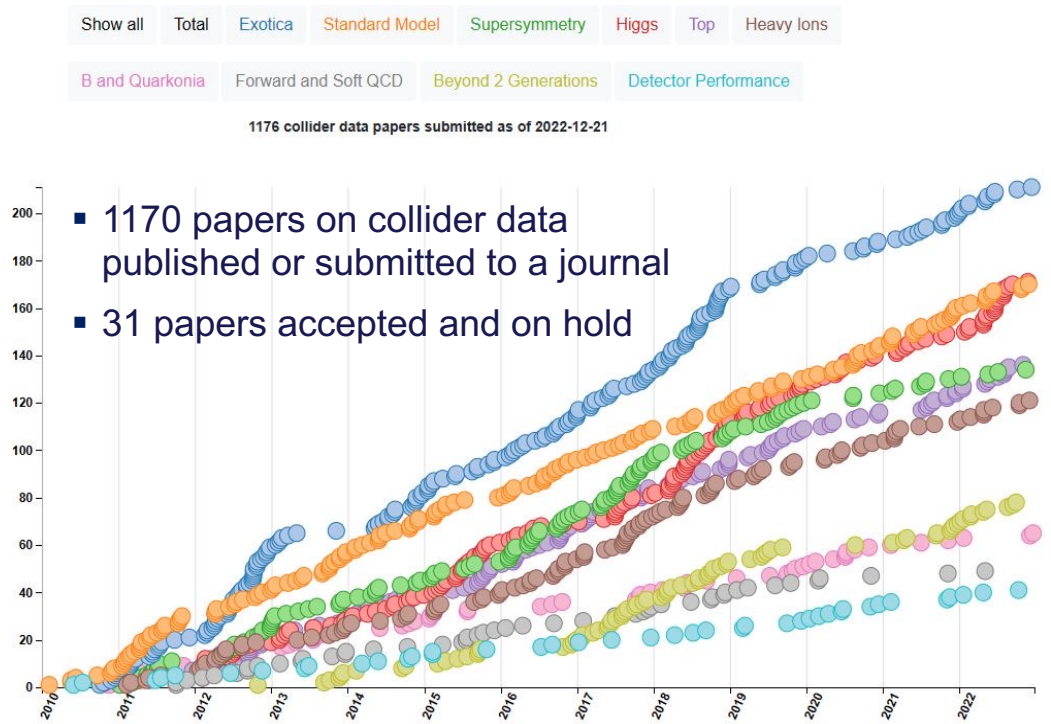
Publications and Talks

In 2022 the CMS Collaboration with the key role of physicists from JINR obtained new unique results:

- Searches for new physics (dark matter, extra Higgs bosons beyond SM, new gauge bosons, extra dimensions, etc) with dileptons/bbar + missing transverse energy.
- Studies of Higgs boson with bbar-decays.
- Testing the Standard Model with dileptons and jets.

JINR Group Contribution in publications

- In 2022, JINR physicists made a significant contribution to the preparation of 22 scientific papers and one patent.
- The results of the scientific research were presented in 38 reports at various conferences (at least half of them is given by the young scientists).
- Successful international scientific meeting at Dubna “The Physics of the Dimuons at the LHC” 23-24 Jun 2022.



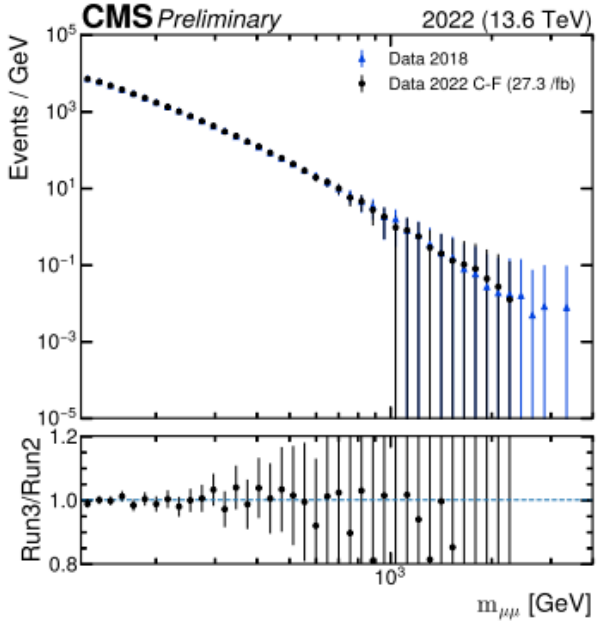
Activity in CMS Physics working groups

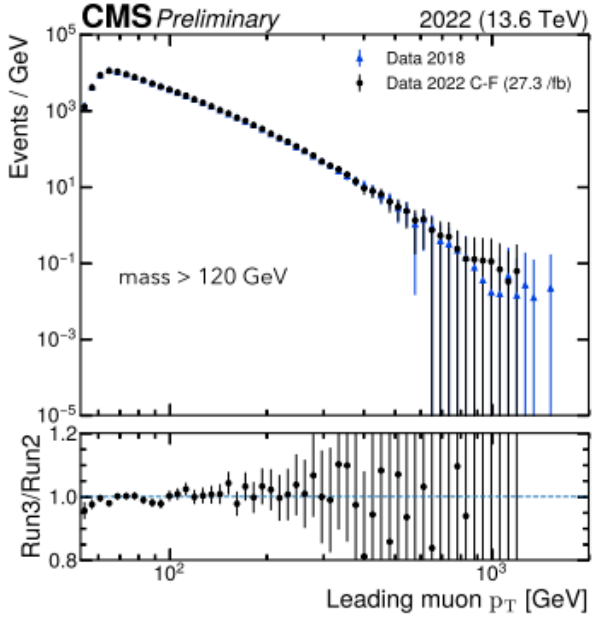
- Exotica, Higgs, and Standard Model Analysis.
- Muon and Jet/MET Physics Object Groups.
- Muon and HCAL Detector Performance Group.

The First Look on RUN3 Data (Dimuons)

Data-to-data comparison of dimuon events between 2018 and RUN3.

- ✓ RUN3 data: 27.3 fb^{-1} (normalized to 2018 integrated luminosity for the comparison).
- ✓ Two muons passing high-p_T ID and loose tracker isolation with opposite charge (same as Run 2 analysis).

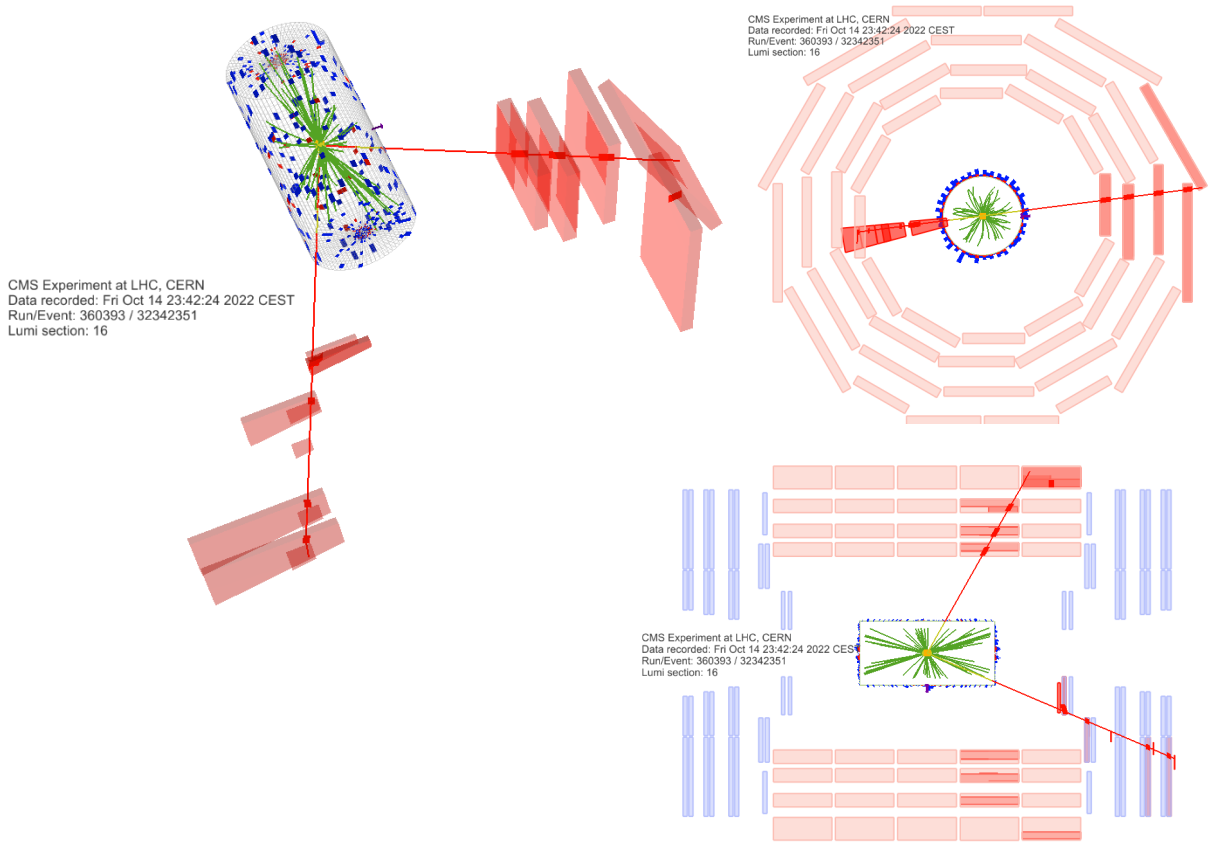




To search for:

- New resonances (dark matter, extra gauge bosons, graviton states, etc).
- Non-resonant signals (extra dimensions, compositeness, etc.).
- Lepton-flavor violated processes.

Event 360393:16:32342351 taken on 14-Oct-2022.



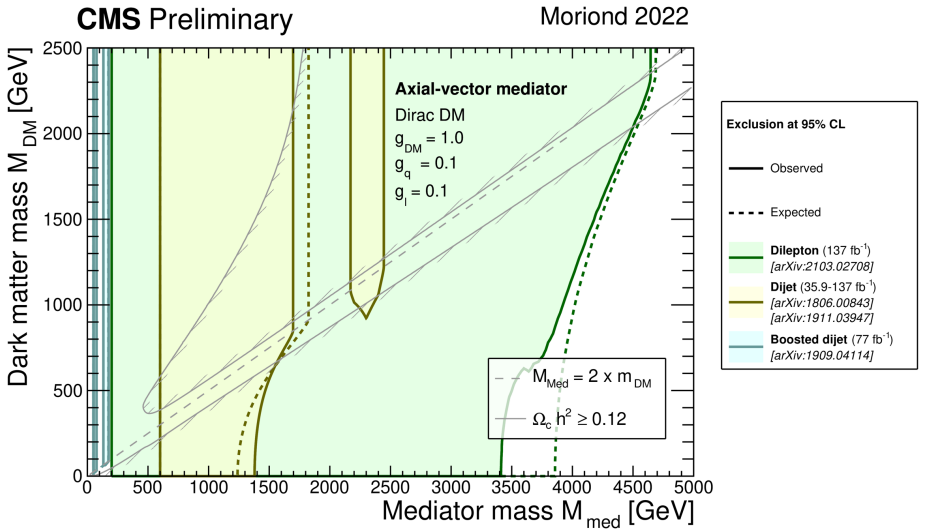
Good event, passes all the cuts, the run was certified by the data quality as good. M = 2407 GeV.

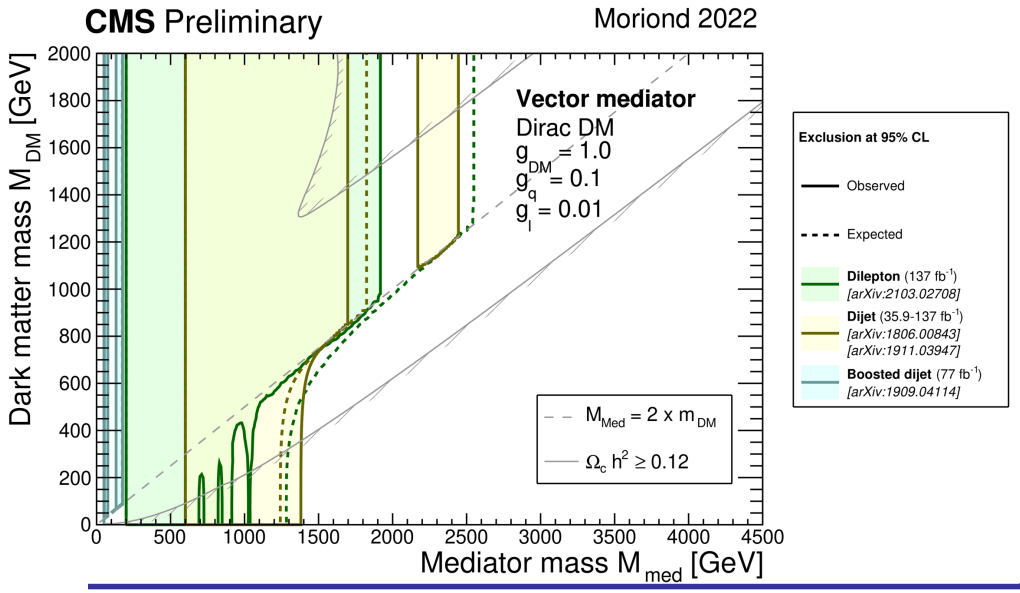
Muon1: p_T = 1161 GeV eta = 1.589 phi = -3.014 (hits CSC including ME1/1).

Muon2: p_T = 935 GeV eta = 0.538 phi = 0.131 (hits DT chambers).

Search for New Physics: Dark Matter Candidates with RUN2/3 Data

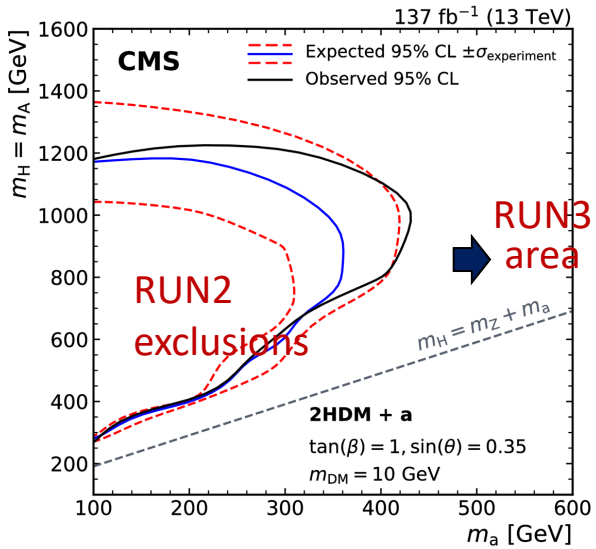
95% confidence level (CL) observed and expected exclusions have been set for combined di-jet and di-lepton searches in the simplified dark matter (DM) scenario. The mass limits are presented in the plane of the Dirac DM particle m_{DM} and mediator m_{med}.





- **The exclusions are computed for:**
  - Leptophilic scenarios with he axial-vector mediator (a universal quark coupling of $g_q = 0.1$, lepton coupling $g_l = 0.1$, and for a DM coupling of $g_{DM} = 1.0$).
  - And for leptophobic scenarios with the vector mediator (a universal quark coupling of $g_q = 0.1$, lepton coupling $g_l = 0.01$, and for a DM coupling of $g_{DM} = 1.0$).

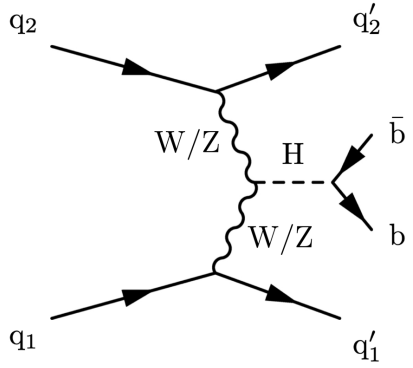
- **The analysis of the RUN3 data within the framework of the extended two-Higgs-doublet models (2HDM+a/2HDM+S).**
  - The cross sections are calculated for the processes of production of dark matter particles associated with Higgs or Z boson at an energy of 13.8 TeV.
  - The analysis parameters were tuned, and the simulation of the CMS setup response was started.

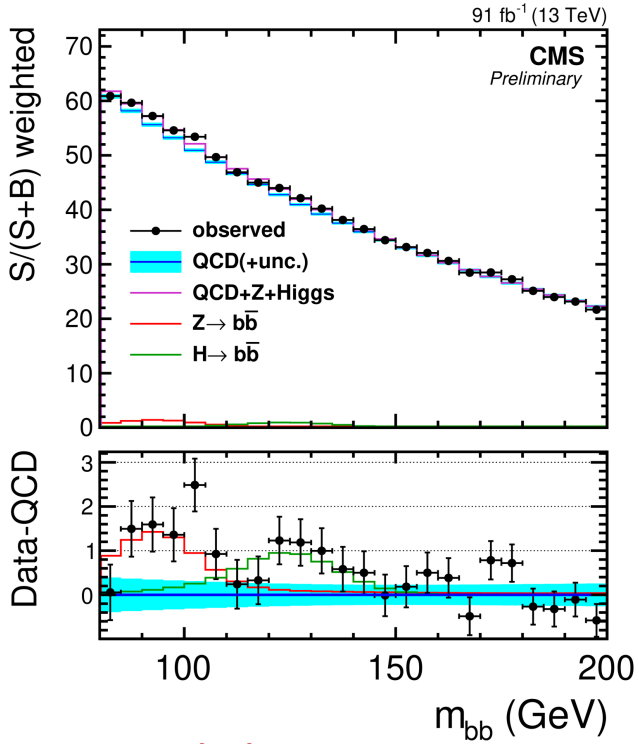


Higgs Physics and Standard Model

Analysis of VBF Higgs boson in bb decay is pre-approved

- The vector boson fusion (VBF) signal is measured with a significance of 2.5 (2.9 expected).
- Deep neutral network (DNN) is used for VBF selection.





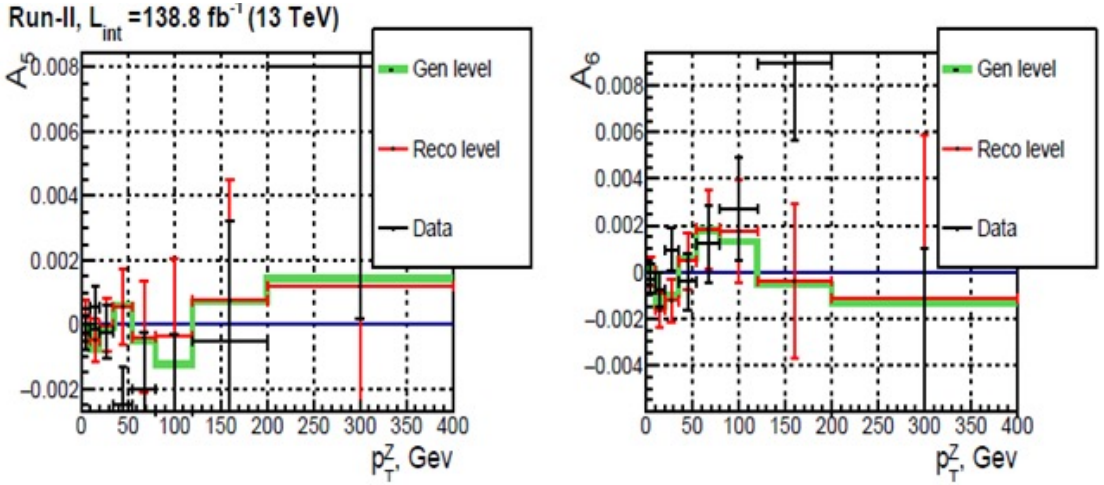
The measured inclusive signal strength $\mu_{Hb\bar{b}} = 0.92^{+0.45}_{-0.39}$

Search for additional Higgs bosons μ+μ− + b–jet events

- The blind analysis @ 13 TeV is continued with the full Run2 dataset. CMS AN-21-089, the last release 2023/01/07.
- The SINP MSU, Moscow and JINR, Dubna groups have performed the synchronization running independent codes and using AOD.

Drell-Yan angular polarization coefficients

- Coefficients A_5, A_6, A_7 were measured for the first time at the CMS experiment. Full Run 2 statistic at $\sqrt{s} = 13$ TeV was used. A_5, A_6, A_7 are small as expected in the standard model.

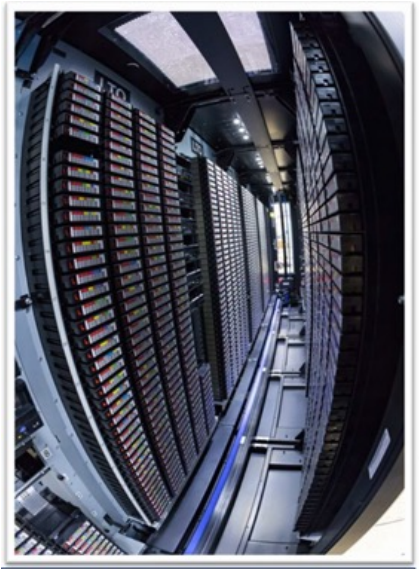


Drell-Yan Radiative Corrections

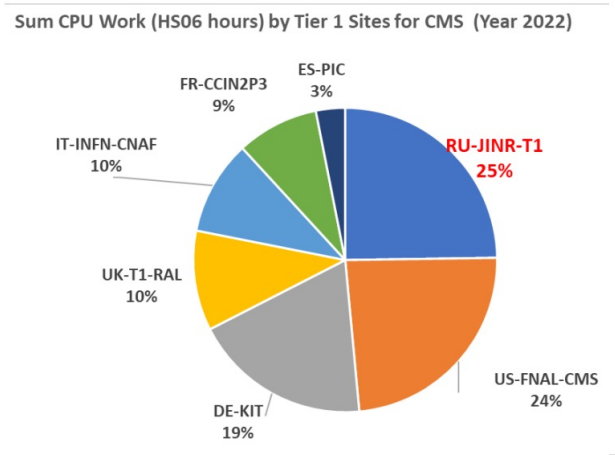
- Detailed numerical analysis of electromagnetic radiative effects is performed for differential cross sections in wide kinematical region including the CMS experiment in Run3 HL-LHC operation mode corresponding ultra-high energies and dilepton invariant masses.

JINR for CMS Computing

The JINR Tier-1 site holds the first place in the list of the all CMS Tier-1 sites



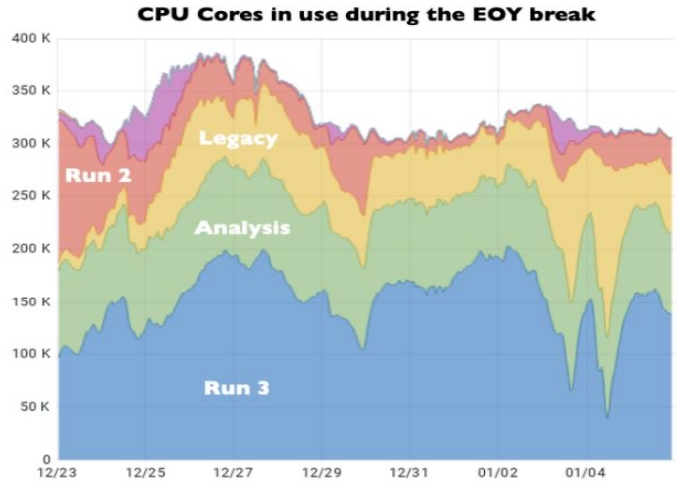
- 18656 cores
- 260 kHS06
- 14 PB disks
- 50.6 PB tapes
- 100% reliability and availability



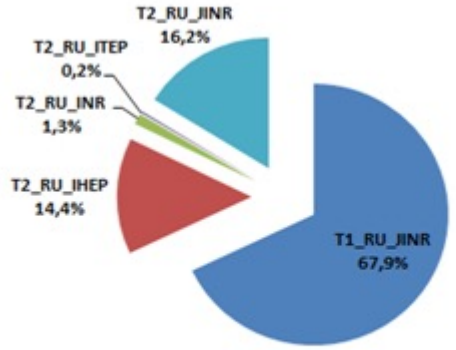
Status of JINR Computing reported by O. Derenovskaya and V. Korenkov @ Meetings of the PAC for Condensed Matter Physics and Nuclear Physics.

From CMS SP Team Report January 12, 2023

The computing infrastructure delivered very well during the break - Several sites, e. g. Tier-1's, generously provided beyond pledge CPU capacity that helped compensate the reduction of batch capacity at CERN.



JINR Contribution in RDMS Computing is crucial



User jobs ratio completed by Russian sites

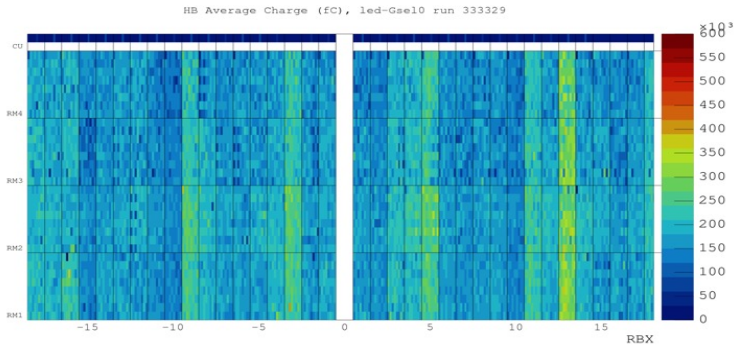
JINR Tier2 is the most productive in the Russian Data Intensive Grid (RDIG) Federation.

CMS Detector Commissioning and Operation

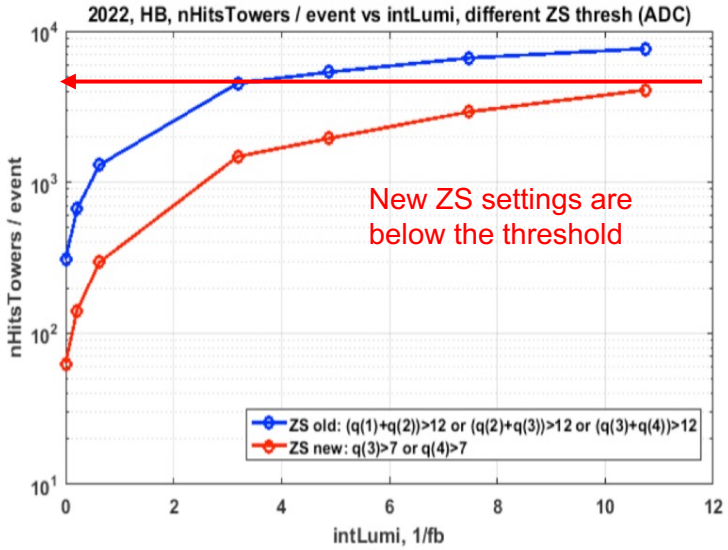
JINR Contribution to HE and ME detector systems in 2022

Completion of Phase1 upgrade, commissioning and launch experimental data taking Run3

- **HCAL** readout system upgraded (HB HPD -> HB SiPMs)
  - new segmentation and radiation hardness.
- HF LV power supplies moved from high radiation area.
- High deadtime at the beginning of Run3 (overflow in L1 trigger) has been fixed by monitoring of pedestal evolution and updates of the zero-suppression (ZS) thresholds.
  - Irradiation dose in HB ~10 times larger than in HE.
  - SiPM radiation damage cause higher dark current and wider pedestal distribution.

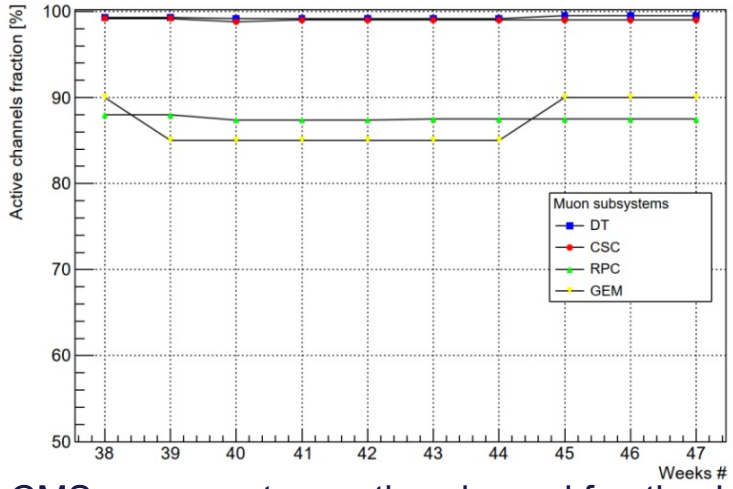


Distribution of average signal amplitudes from HB SiPMs (from LED).

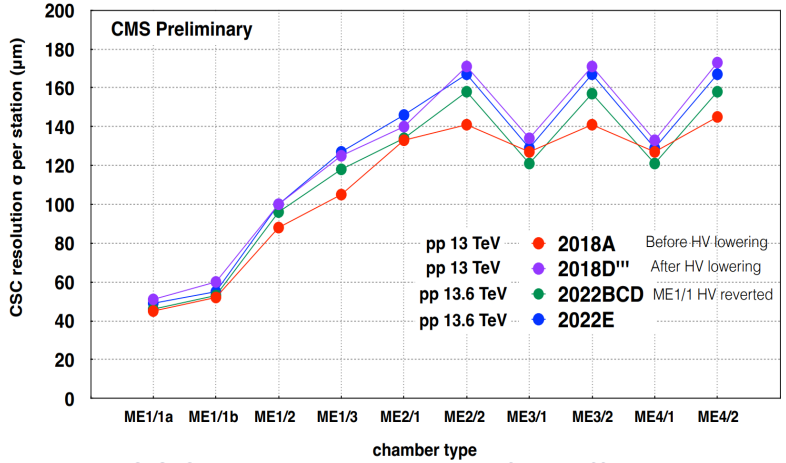


Events occupancy in HB vs integrated luminosity. Limit is ~4k events per TS (25ns).

CSC parameters study base on Run3 experimental data.

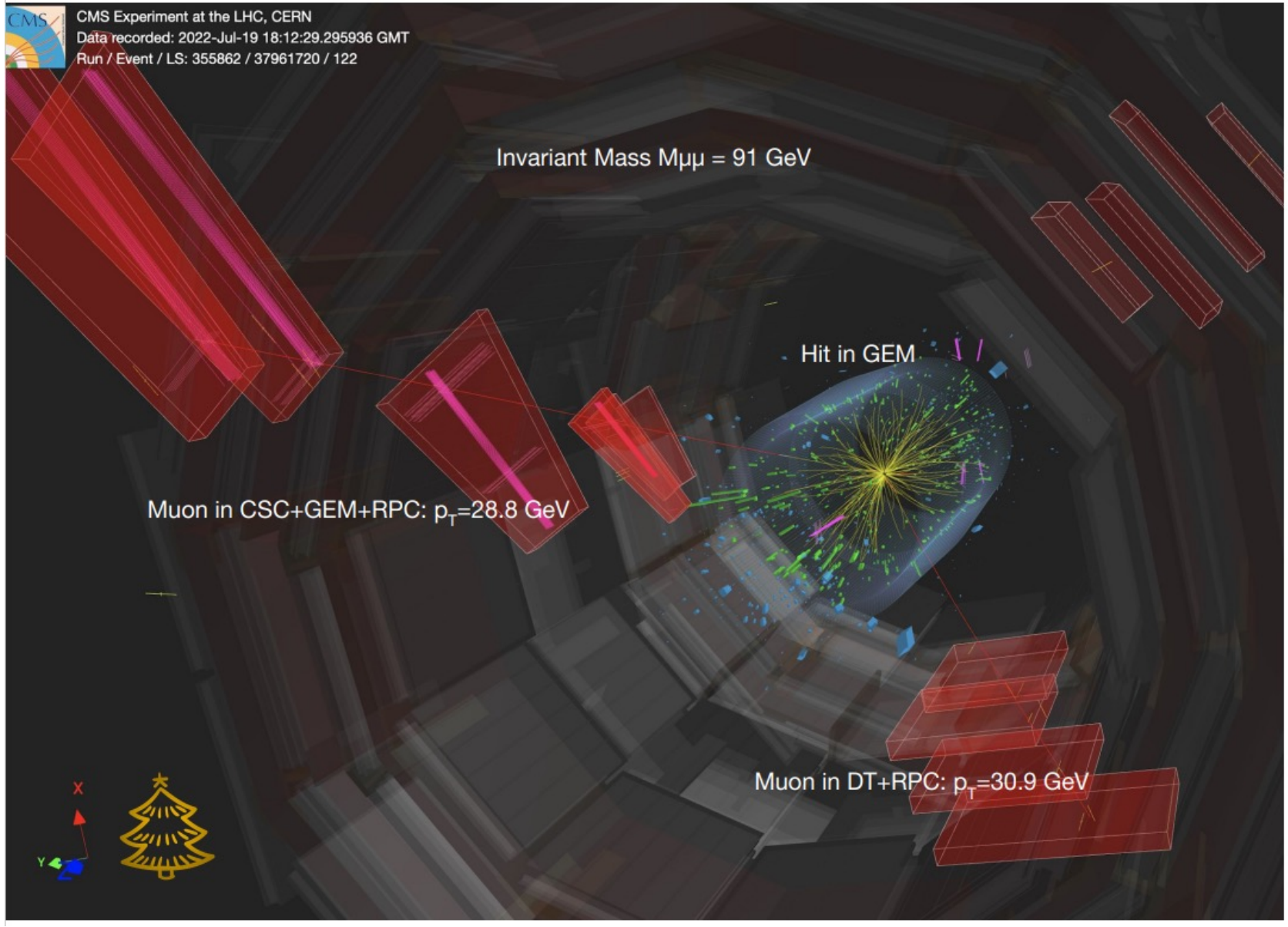


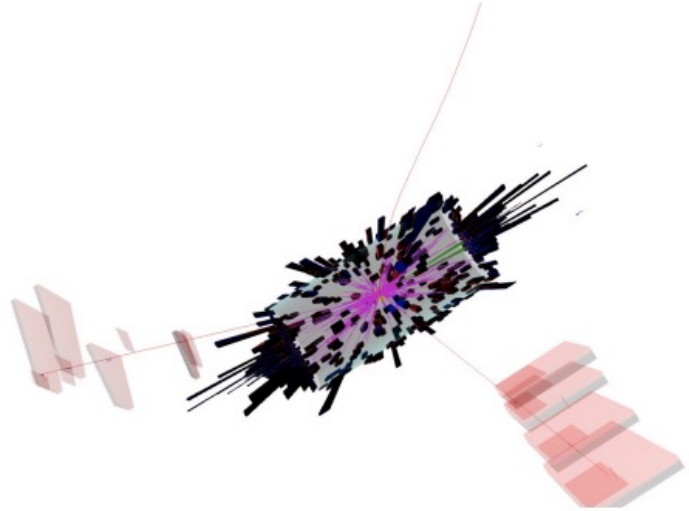
CMS muon system active channel fraction in 2022 p-p collisions data taking (99% for CSC)

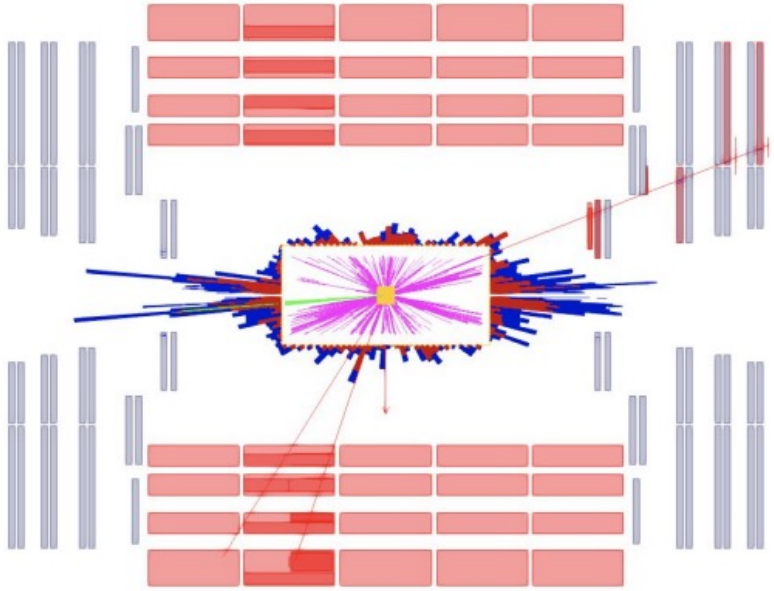


CSC spatial resolution for different muon Station/Rings is consistent with 2018 data.

Run3 Event with Muons in all Detectors of Muon System







JINR group contribution to CMS Phase 2 Upgrade

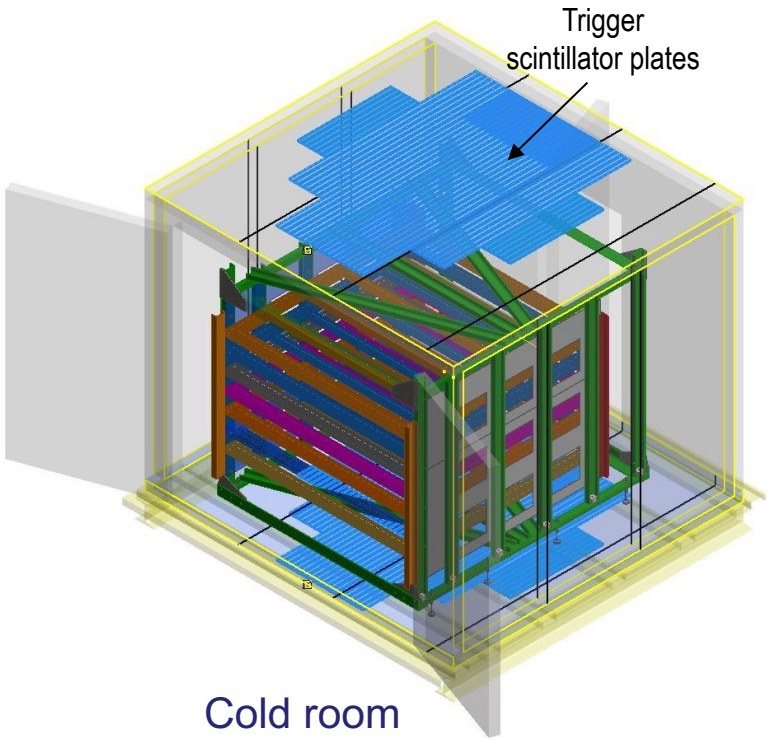
- **Participation in HGCal Project.**
  - Cooling plate of HGCal cassettes design and construction.
  - Design and construction of the HGCAL silicon and scintillator cassettes test facility.
- **Participation in the endcap Muon system upgrade.**
  - Cathode Strip Chambers maintenance during LS3 long shutdown period.
  - Cathode Strip Chamber Longevity Study R&D.
  - Upgrade of the ME1/1 CSCs cables and services layout for the new CMS Endcap detectors configuration.
  - Design and construction of the new ME1/1 Patch Panel.
  - Design and construction of new tooling for ME1/1 CSC assembly and installation.

Phase 2 Upgrade. JINR Contribution to HGCal Project.

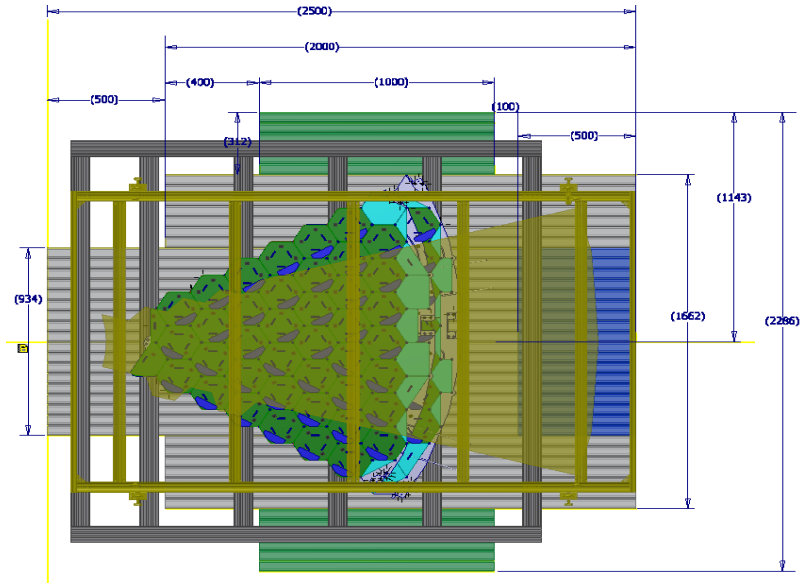
Cold room for HGCAL silicon and scintillator cassettes test setup

Main results in 2022

Cold room construction.



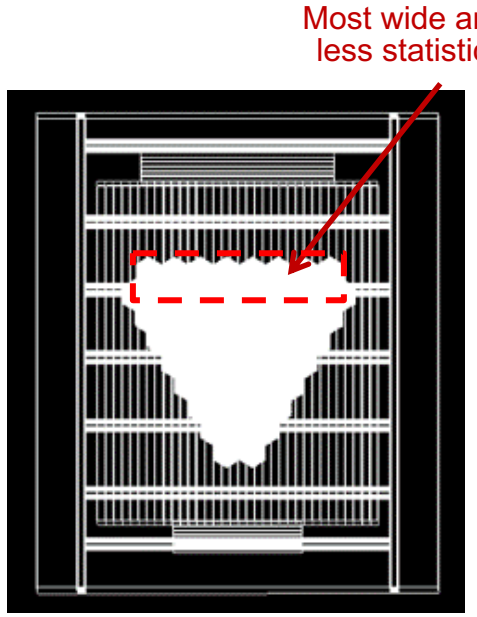
Cold room



Supporting frame for cassettes

- Cold room delivery to CERN ~Feb 2023.
- Rack for cassettes testing deigned - construction this year.

Simulation of trigger for test setup.



Cassette in MC model

- Performance estimations, detector evaluation algorithms tests.
  - Scintillator trigger planes of cosmic test setup optimization.
  - 2 Cold room trigger planes position options: inside and outside cold room.

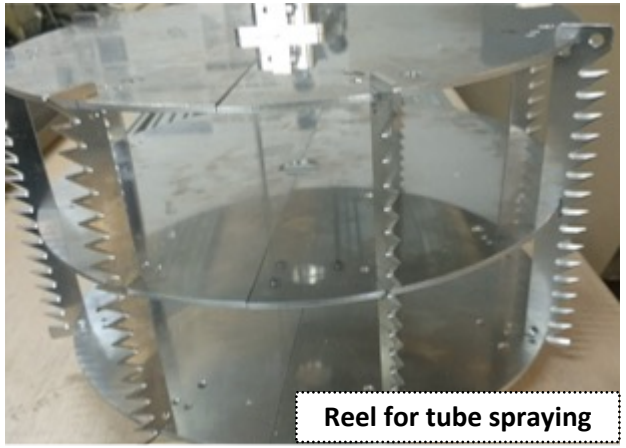
Cooling Plate of HGCal Cassettes

Main results in 2022

For development of the production technology 4 prototypes of cooling plates of different sizes were produced by potential production plants in Minsk (Artmash and StroyTechProgress).

- **Production technologies were tested during prototypes construction:**
  - Automatic soldering using a heating table.
  - Copper sheet straightening before and after machining.
  - Raw vs. annealed steel tube bending.
  - Heat dissipation with press-fitted tube.
  - Copper spray coating technique.
- **Special tooling for plates production was produced:**
  - Press fit + glue tube binding technique.
  - Soldering the spray-coated tube.

Press-fit + glue



Reel for tube spraying

Comprehensive test of these prototypes planned at CERN early 2023.
Based on tests results the mass-production technology will be fixed.

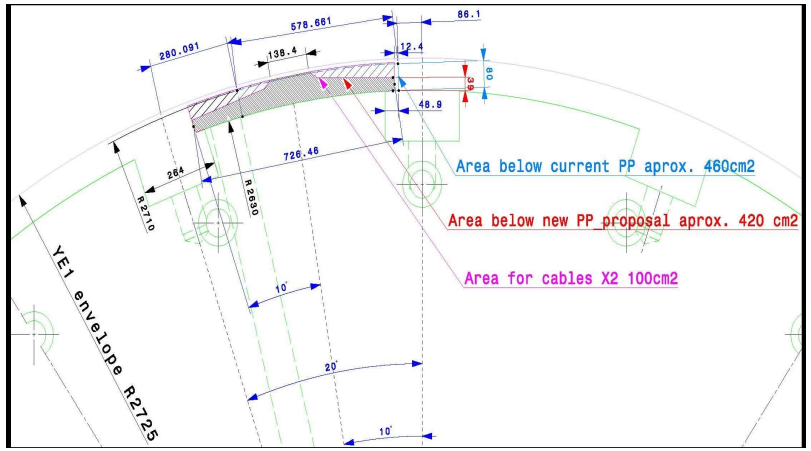
ME1/1 CSC Integration and Tooling

Main results in 2022

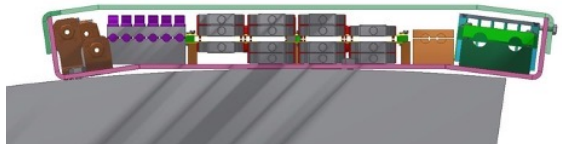
Design and prototyping of the new ME1/1 Patch Panel.

Integration issues:

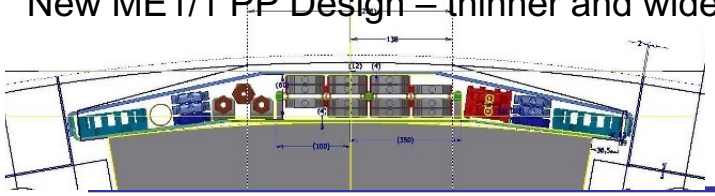
- HGCal cables to be routed above ME1/1 in R = 2725 mm envelope.
- ME1/1 PP should be modified to release more space for HGCal services and cables.



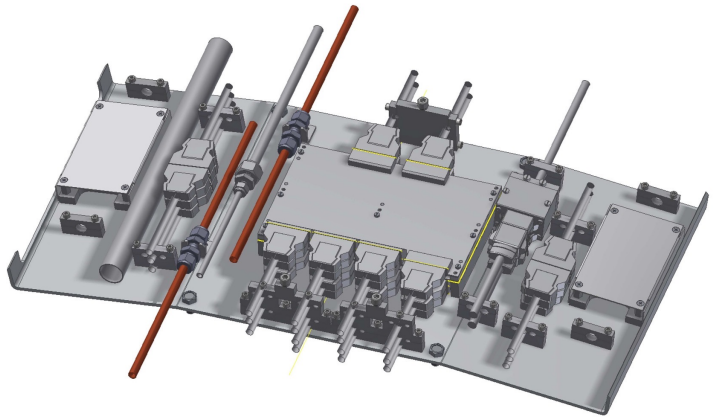
Current ME1/1 PP Design.

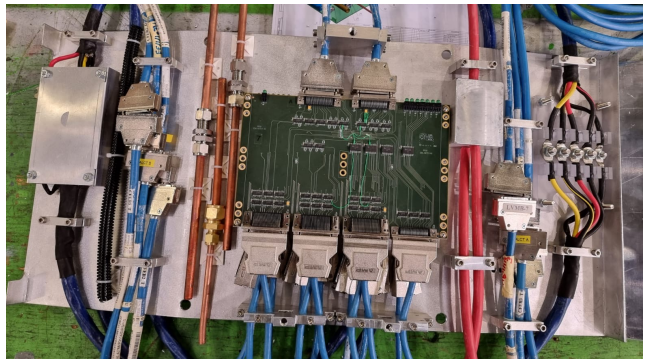


New ME1/1 PP Design – thinner and wider.



ME1/1 Patch Panel mockup.

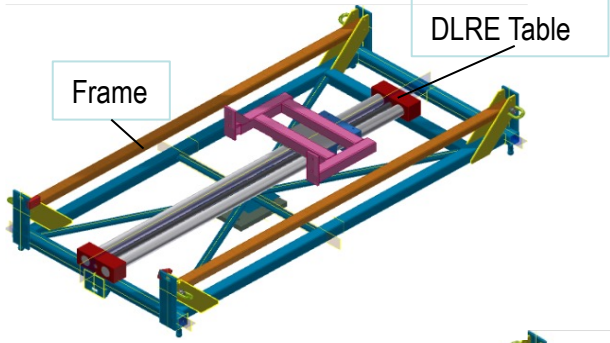


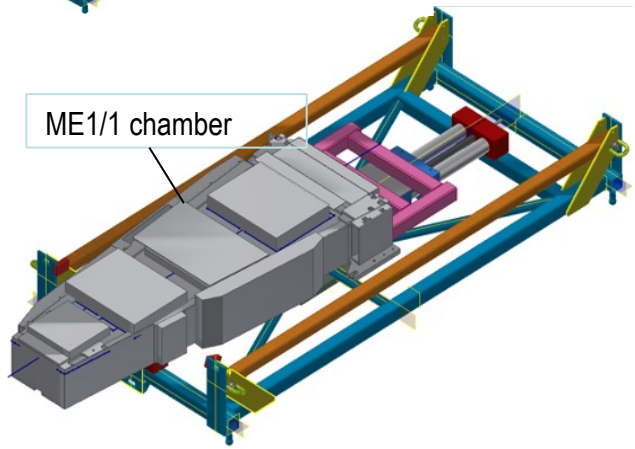


36 new ME1/1 PP should be constructed before LS3.

Design of the new ME1/1 Loading Machine.

New ME1/1 loading machine design is based on ROLLON DRLE table.



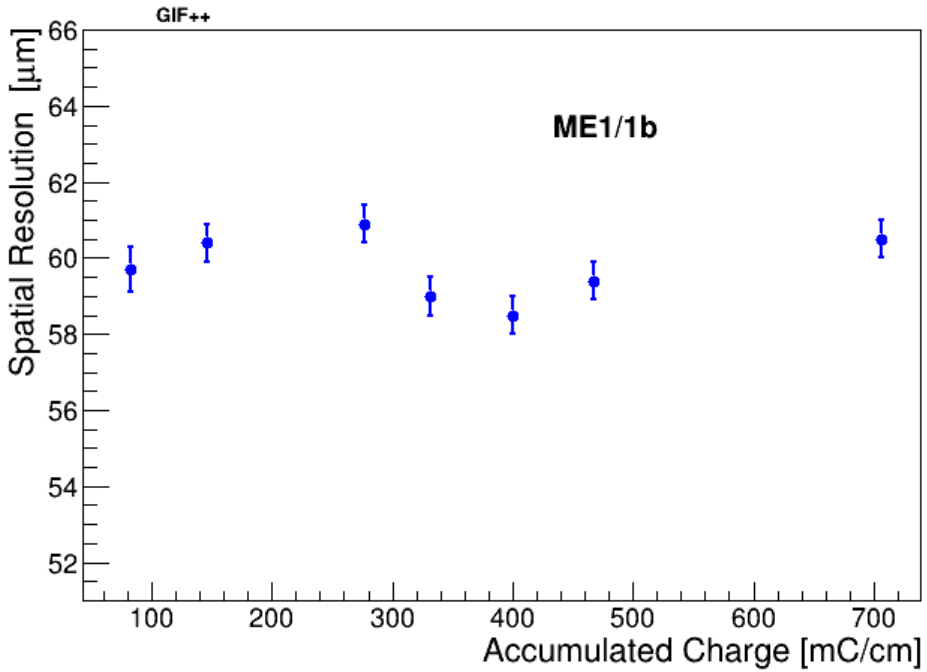


- Overall dimensions and connections remain the same.
- Possibility to use an electric or manual drive.
- The weight of the machine will be lower.

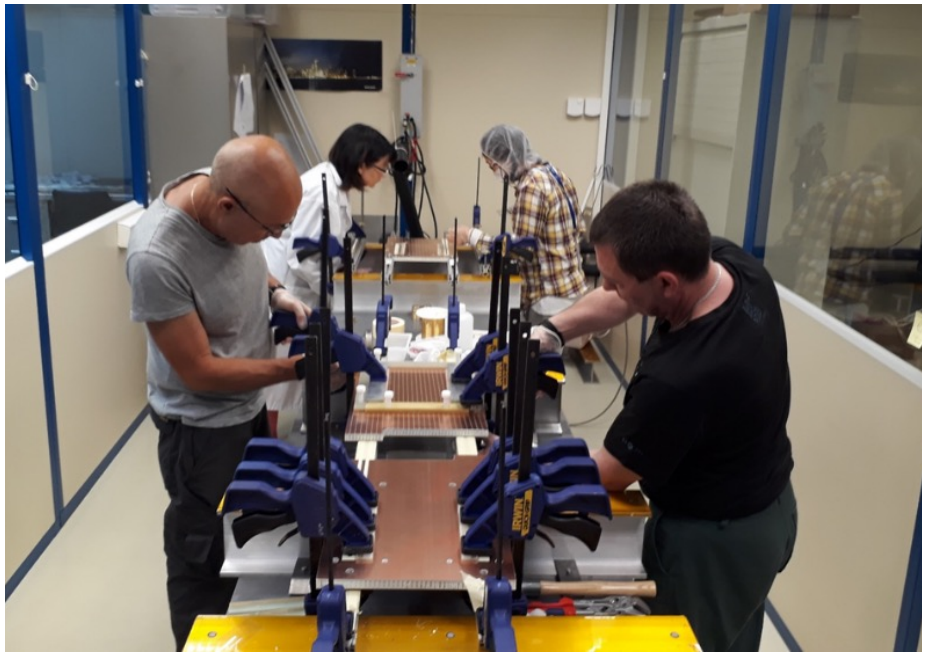
Cathode Strip Chamber Longevity Study at the GIF++ setup (CERN)

Main results in 2022

Beam test (on SPS, H4) of the ME1/1 CSC exposed with the with GIF++ 12TBq Cs-137 gamma source.



Six 2-layer mini-CSCs with sensitive area (30x30 cm^2) were designed and produced at CERN by JINR group.



Spatial resolution is stable up to accumulated charge of 706 mC per the centimeter of anode wire length - 3 times higher than expected in the HL-LHC operation period.

Chambers will be used for ageing effects study and tests of the CSC operation with the new gas mixtures.

Plans for 2023

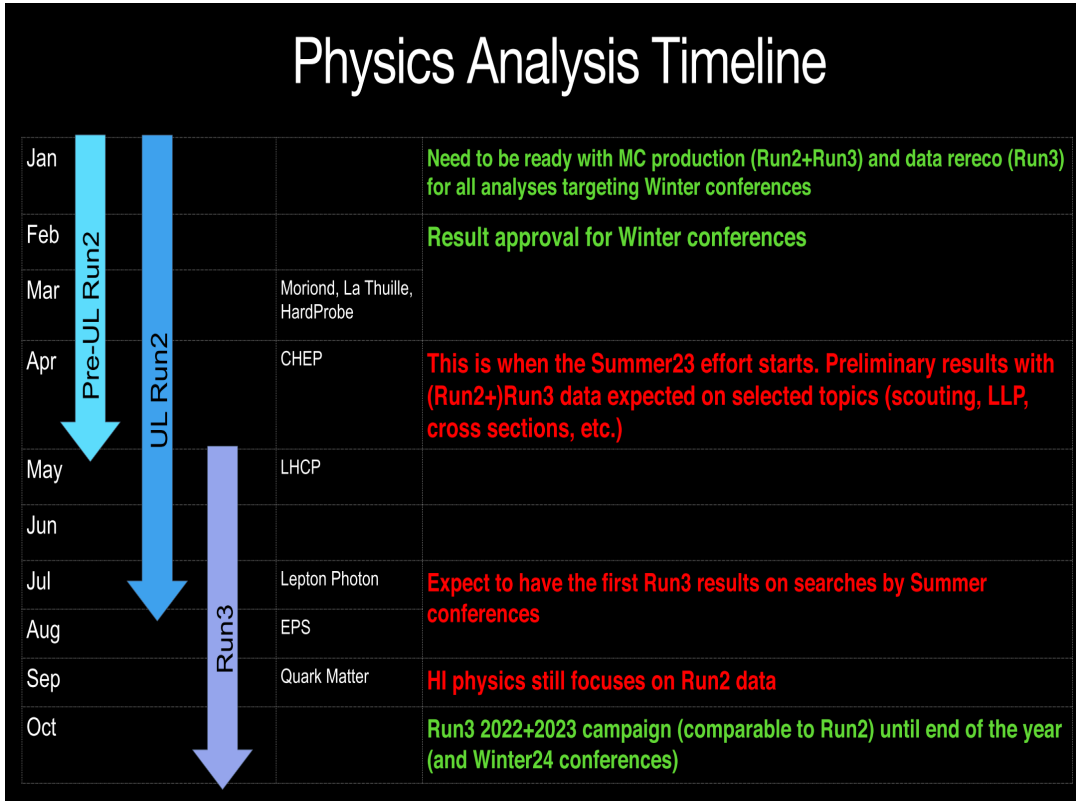
- **Continue RUN2 and RUN3 data analysis**

- Dimuons, dimuons + MET, Z + MET, bbar + MET to search for new physics and to test the SM.
- We focus on analysis that can be completed before the end of 2024.

- **Participation in RUN3 data taking within JINR responsibilities (CMS operation, maintenance of detector systems, shifts).**

- **Continue Phase-2 upgrade of Muon system and construction of HGCAL in accordance with corresponding MoUs.**

- Cold room delivery to CERN before March 15.
- Design of the rack for HGCaL cassettes test setup.
- Simulation of trigger system of the HGCal cassettes test setup, algorithms for detector evaluation tests.
- Design and tests of cooling HGCal plate prototypes. Elaboration of the mass production technology.
- Studying the ageing effects of the CMS muon endcap detectors (CSC) at GIF ++ setup.
- Participation in the new gas mixture studies (different CF4 contamination).
- Development and test of algorithms for reconstruction of muon track segments.



Summary

JINR group plans for 2022 have been successfully fulfilled

- JINR group actively participate in the development of physics research, based on the analysis of the RUN2 data as well as RUN3.
  - The first RUN3 data on dimuon production @ 13.6 TeV are processed and analyzed.
  - The significant contribution of JINR physicists done with RUN2 data in setting of the most stringent lower limits to date on the masses for dark matter particles and spin-1 mediators with dark sector for combined di-jet and di-lepton searches.
  - One physics analysis is pre-approved, five other analyses are continued.
- The considerable contribution was done by JINR group to the upgrade, commissioning and launching of CMS detectors for the RUN3 data taking period.
  - CMS endcap muon system (ME) and hadron calorimeter (HCAL) shows a good performance with RUN3 data..
- JINR group is actively involved in the Phase 2 CMS upgrade to HL-LHC operation mode.
  - Participation in high-granularity calorimeter (HGCal) project.
  - Modernization of the forward muon station (ME1/1).
- JINR group, including young researchers made a significant contribution to CMS publications.
  - 22 papers and one patent.
  - 38 conference reports at various conferences (at least half of them is given by the young scientists).....

Happy Birthday CMS!

Celebrated on Dec 6th in the Main Auditorium with the CMS 30-year Birthday Symposium.

Thank you for your attention!!!