Computing @ LHC and NICA

Korenkov Vladimir
Director MLIT

The Physics of the Dimuons at the LHC
24 June 2022

Грид технологии – путь к успеху

На торжестве по поводу получения Нобелевской премии за открытие бозона Хиггса директор ЦЕРНа Рольф Хойер прямо назвал **грид-технологии одним из трех столпов успеха** (наряду с ускорителем LHC и физическими установками).

Без организации грид-инфраструктуры на LHC было бы невозможно обрабатывать и хранить колоссальный объем данных, поступающих с коллайдера, а значит, совершать научные открытия.

Сегодня уже ни один крупный проект не осуществим без использования распределенной инфраструктуры для обработки данных.

Концепция Грид

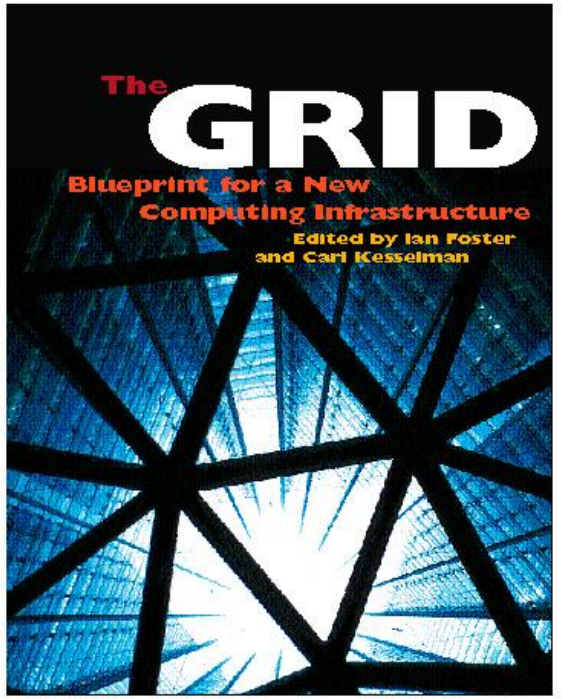
«**Грид** - это система, которая:

· координирует использование ресурсов при отсутствии централизованного управления этими ресурсами

· использует стандартные, открытые, универсальные протоколы и интерфейсы.

· обеспечивает высококачественное обслуживание»

(Ian Foster: "What is the grid? ", 2002 г.)



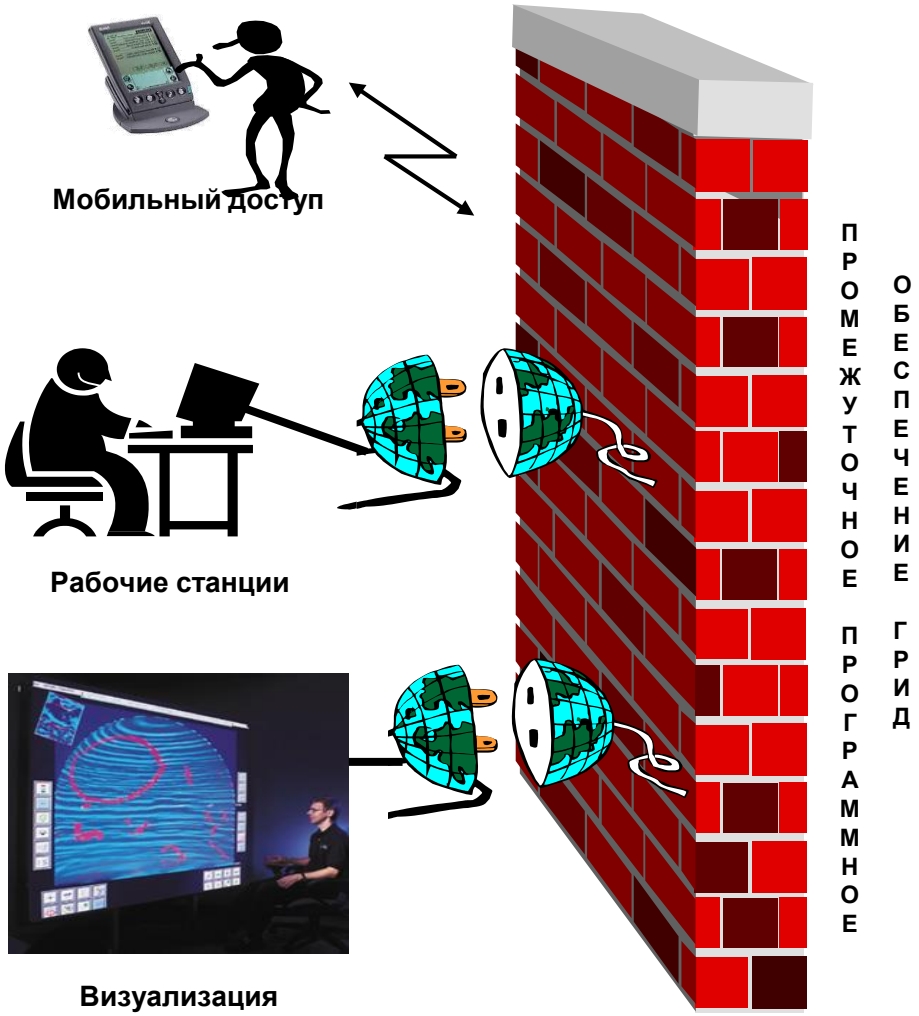
Модели грид:

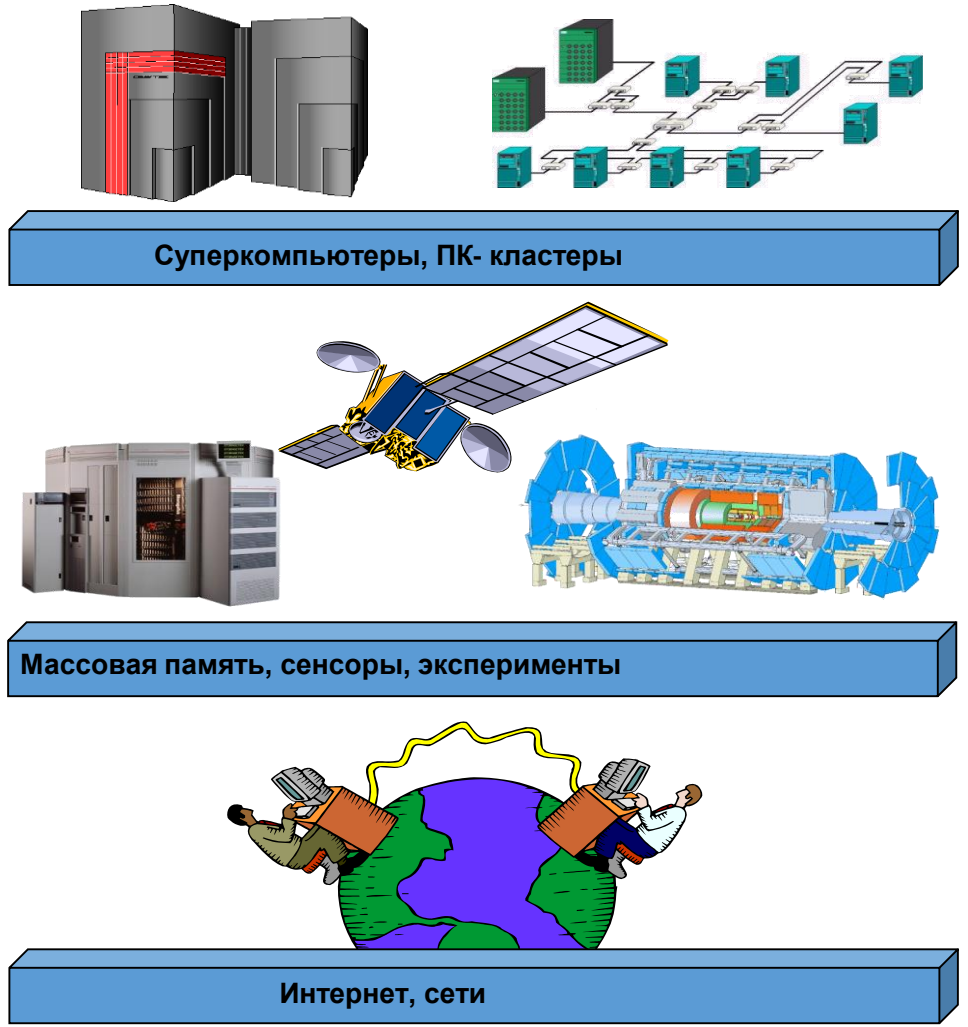
- **Distributed Computing**
- **High-Throughput Computing**
- **On-Demand Computing**
- **Data-Intensive Computing**
- **Collaborative Computing**

Междисциплинарный характер грид: развиваемые технологии применяются в физике высоких энергий, космофизике, микробиологии, экологии, метеорологии, различных инженерных и бизнес приложениях.

Виртуальные организации (VO)

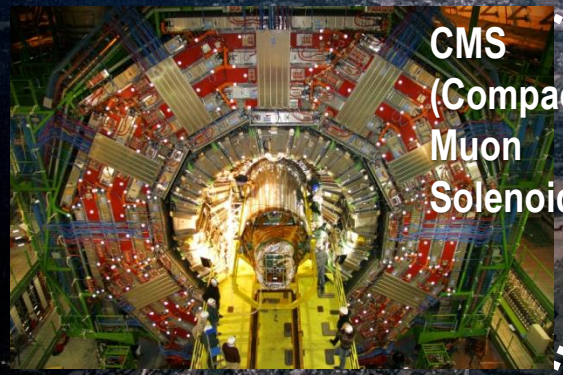
Грид - это средство для совместного использования вычислительных мощностей и хранилищ данных посредством интернета





Large Hadron Collider

The Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.

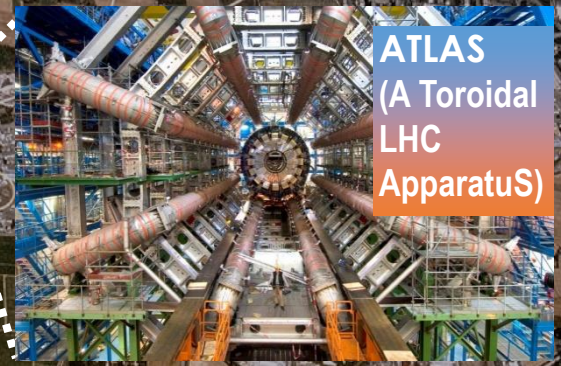


CMS (Compact Muon Solenoid)

LHCb (Large Hadron Collider beauty experiment)

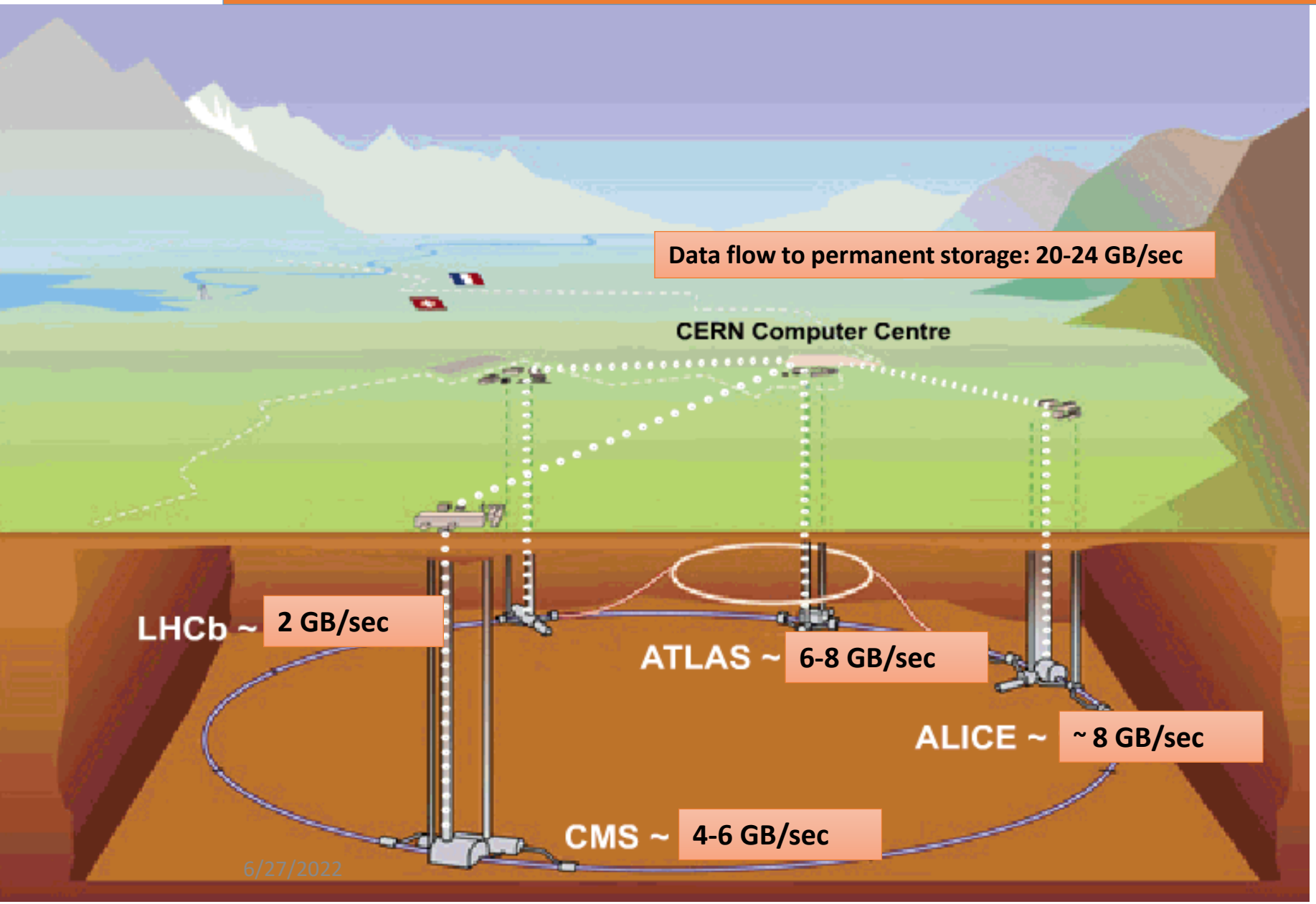
Data flow to permanent storage: 4-6 GB/sec

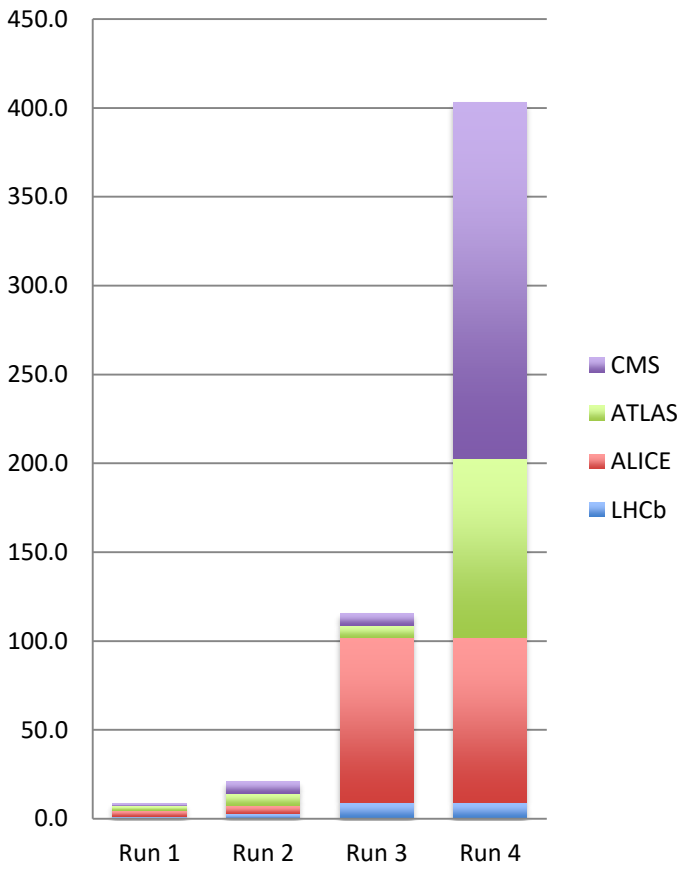
ALICE (A Large Ion Collider Experiment)



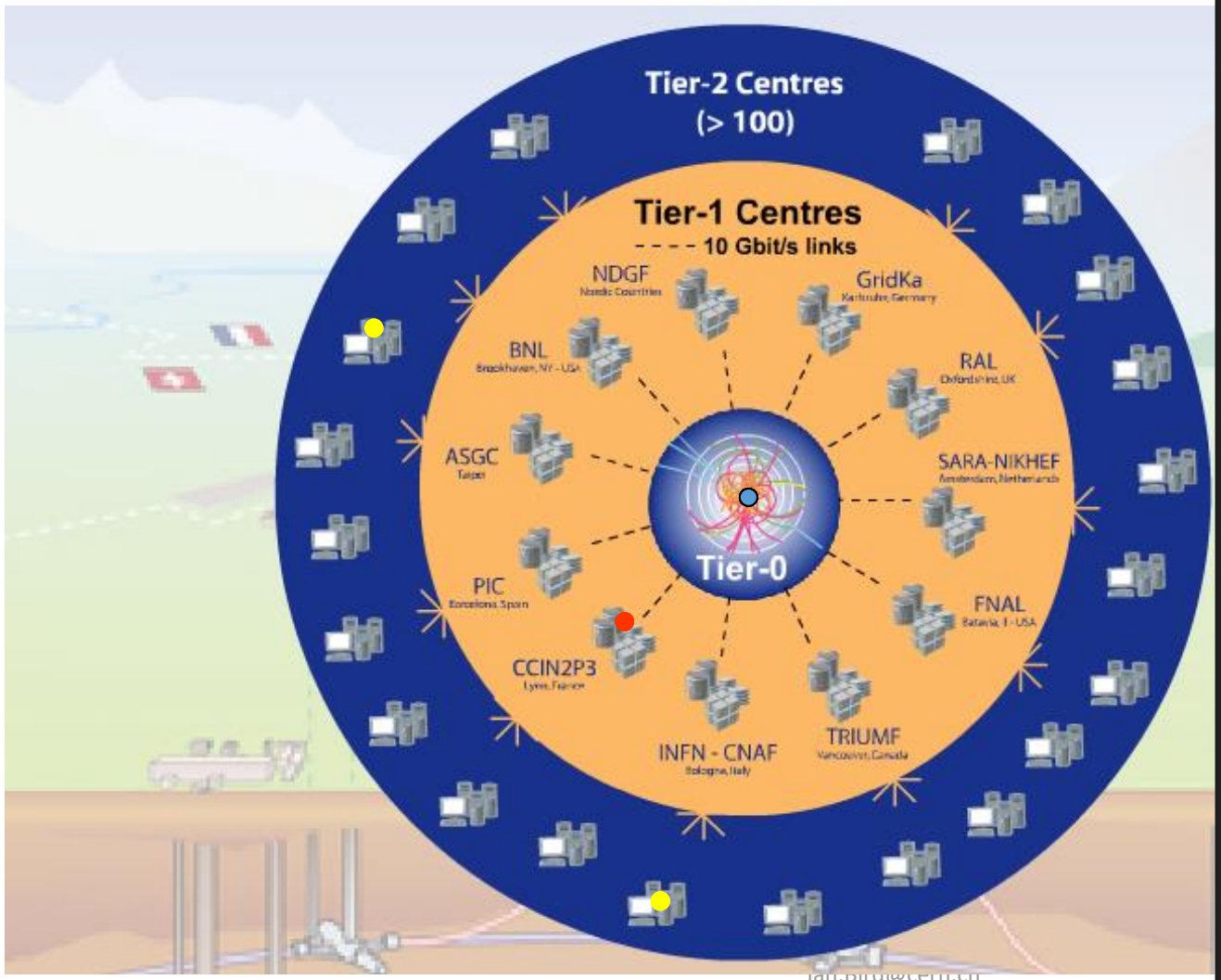
ATLAS (A Toroidal LHC ApparatuS)

Data Collection and Archiving at CERN





Tier Structure of GRID Distributed Computing: Tier-0/Tier-1/Tier-2



Tier-0 (CERN):

- accepts data from the CMS Online Data Acquisition and Trigger System
- archives RAW data
- the first pass of reconstruction and performs Prompt Calibration
- data distribution to Tier-1

Tier-1 (11 centers):

- receives a data from the Tier-0
- data processing (re-reconstruction, skimming , calibration etc)
- distributes data and MC to the other Tier-1 and Tier-2
- secure storage and redistribution for data and MC

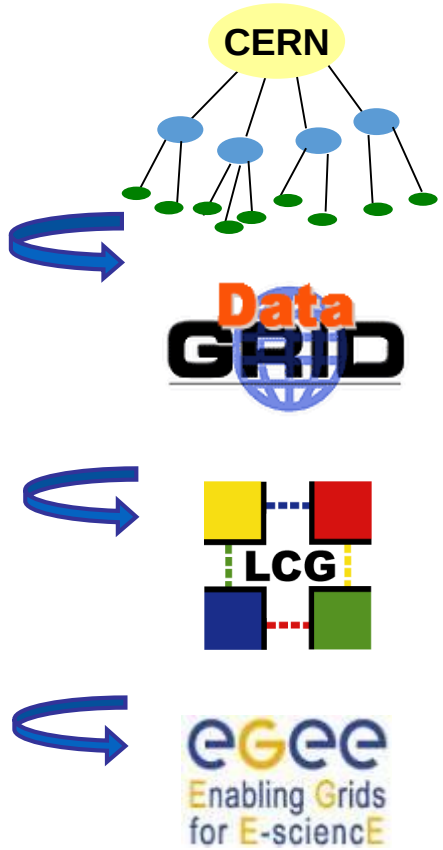
Tier-2 (>200 centers):

- simulation
- user physics analysis

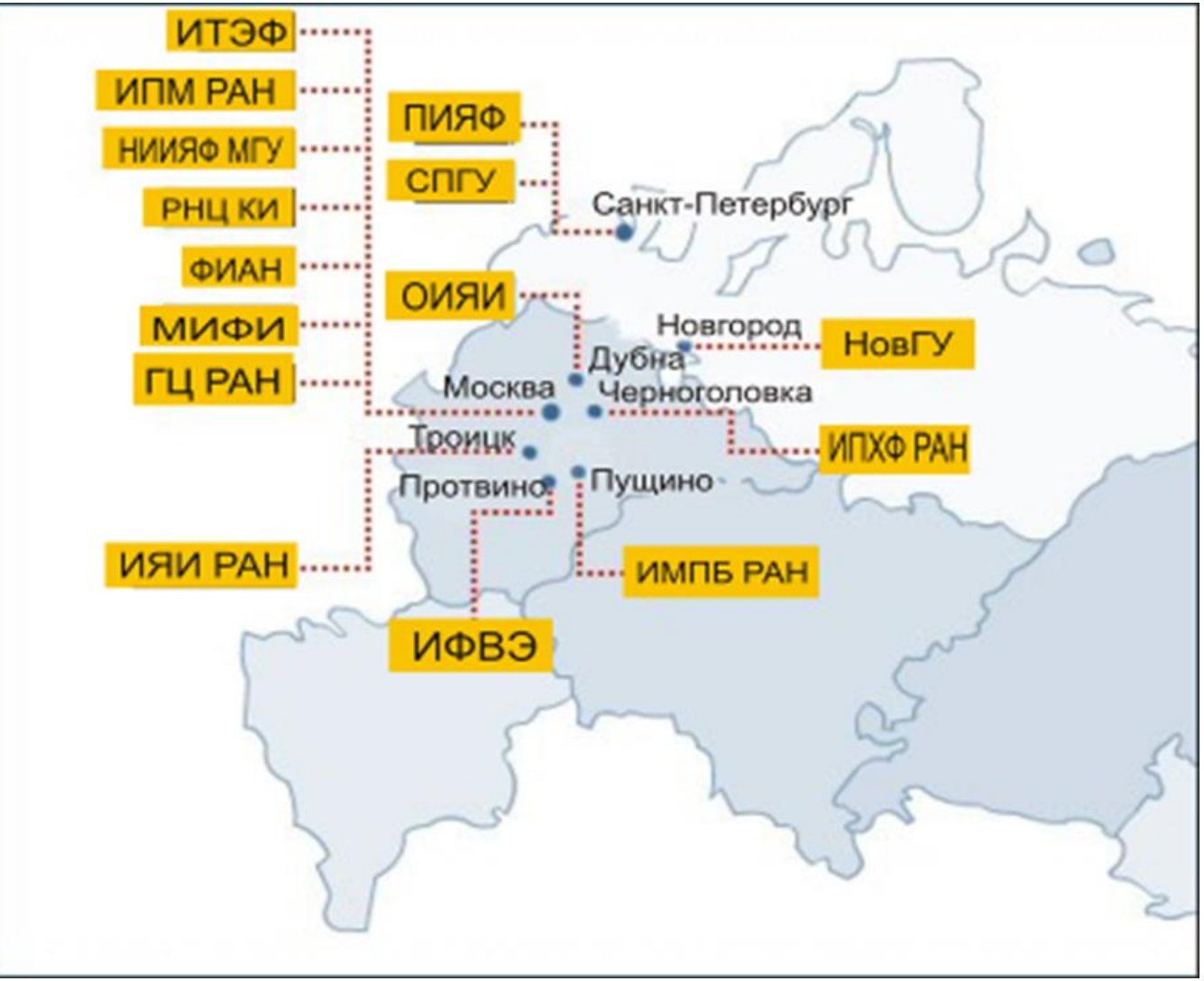
Ian.Bird@cern.ch

Some history

- **1999 – Monarc Project**
  - **Early discussions on how to organise distributed computing for LHC**
- **2001-2003 - EU DataGrid project**
  - **middleware & testbed for an operational grid**
- **2002-2005 – LHC Computing Grid – LCG**
  - **deploying the results of DataGrid to provide a production facility for LHC experiments**
- **2004-2006 – EU EGEE project phase 1**
  - **starts from the LCG grid**
  - **shared production infrastructure**
  - **expanding to other communities and sciences**
- **2006-2008 – EU EGEE-II**
  - **Building on phase 1**
  - **Expanding applications and communities …**
- **2008-2010 – EU EGEE-III**
- **2010-2012 - EGI-InSPIRE**



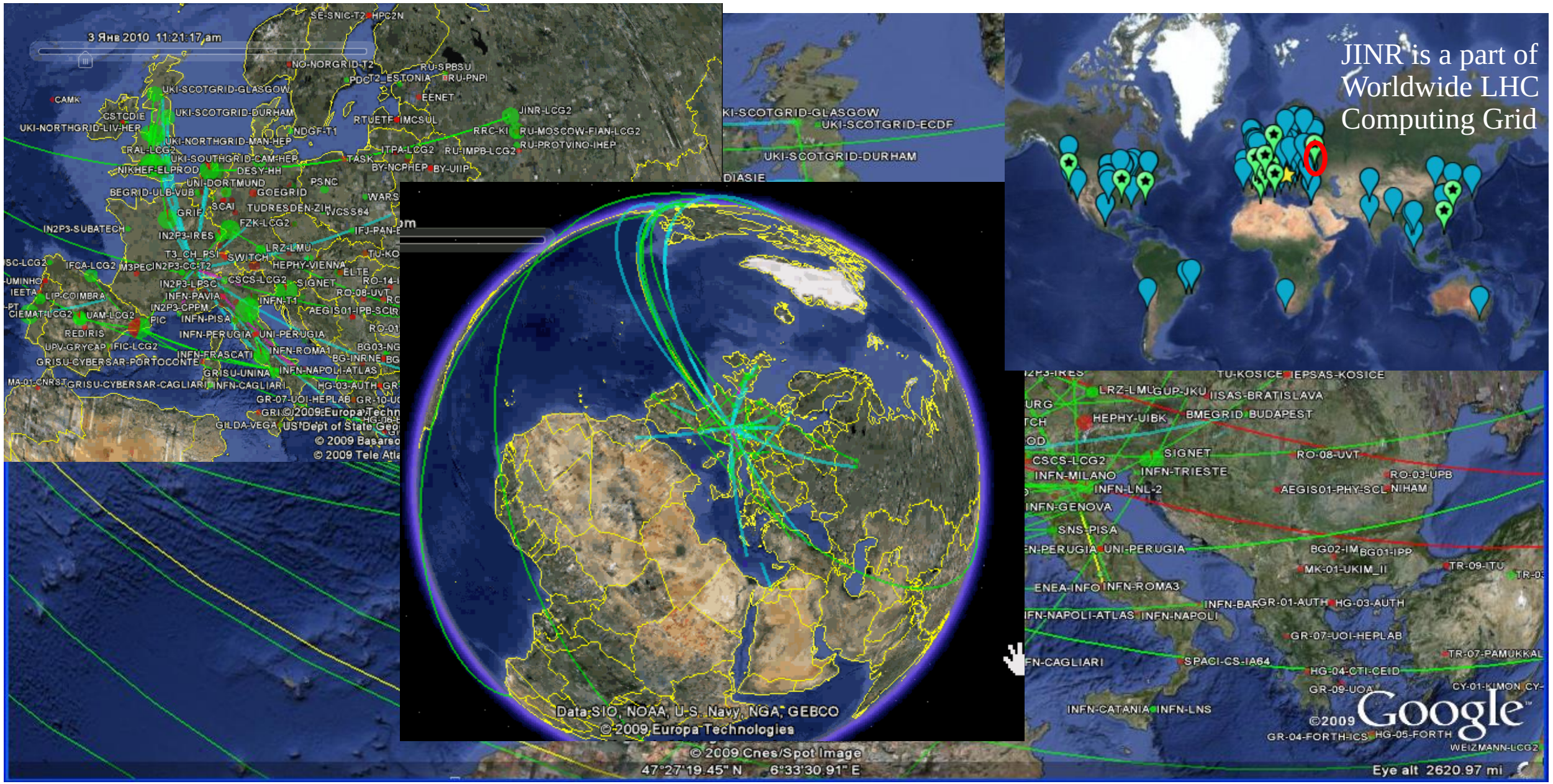
Russian Data Intensive Grid



The primary goal of the WLCG project is to create a global infrastructure of regional centers for processing, storage and analysis of data of the LHC physical experiments. The grid-technologies are a basis for constructing this infrastructure.

The Russian consortium RDIG (Russian Data Intensive GRID) was set up in September 2003 as a national federation in the EGEE project.
A protocol between CERN, Russia and JINR on participation in the LCG project was signed in 2003. MoU about participation in the WLCG project was signed in 2007.

The Worldwide LHC Computing Grid (WLCG)

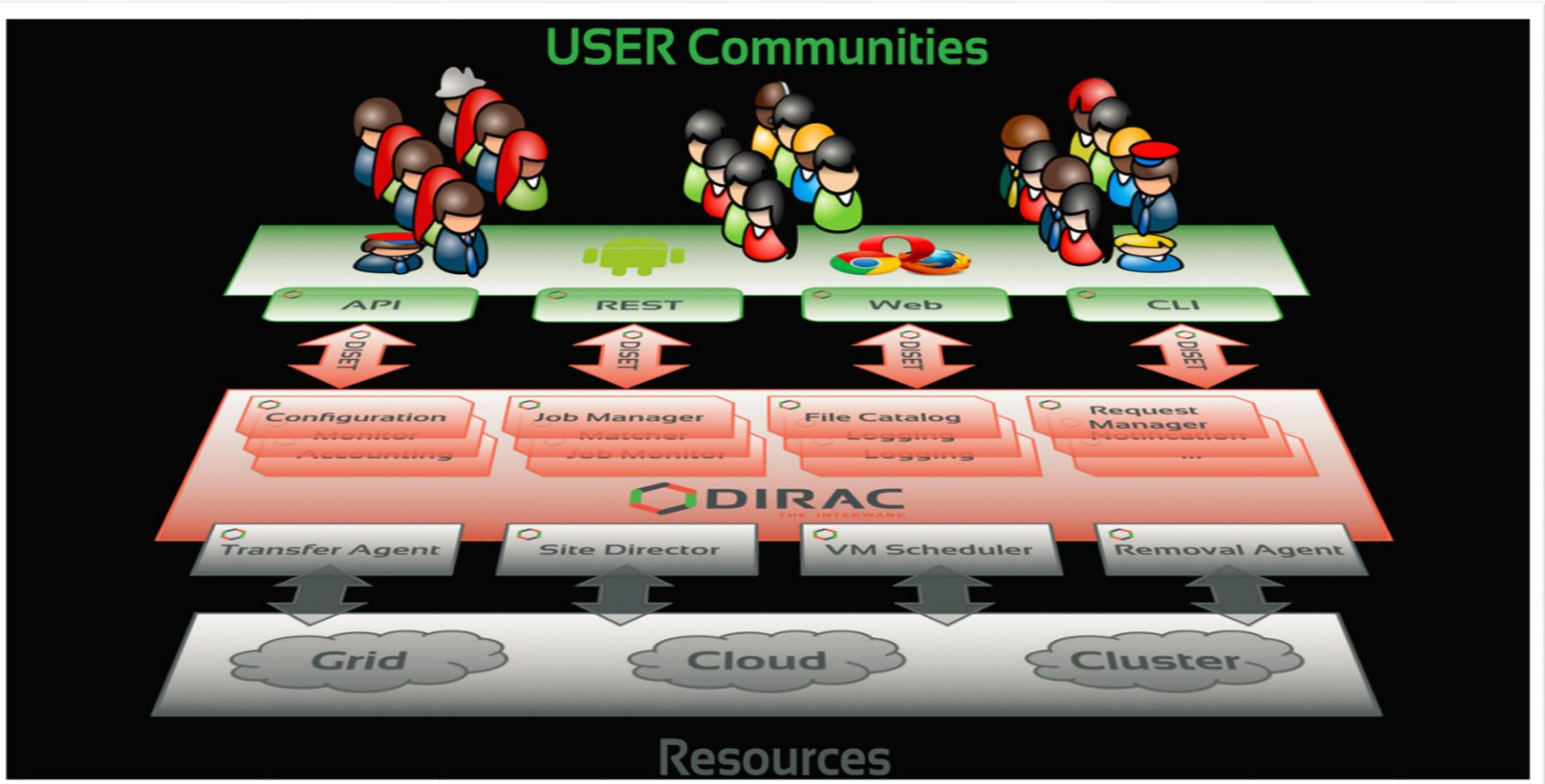


Эволюция модели компьютинга

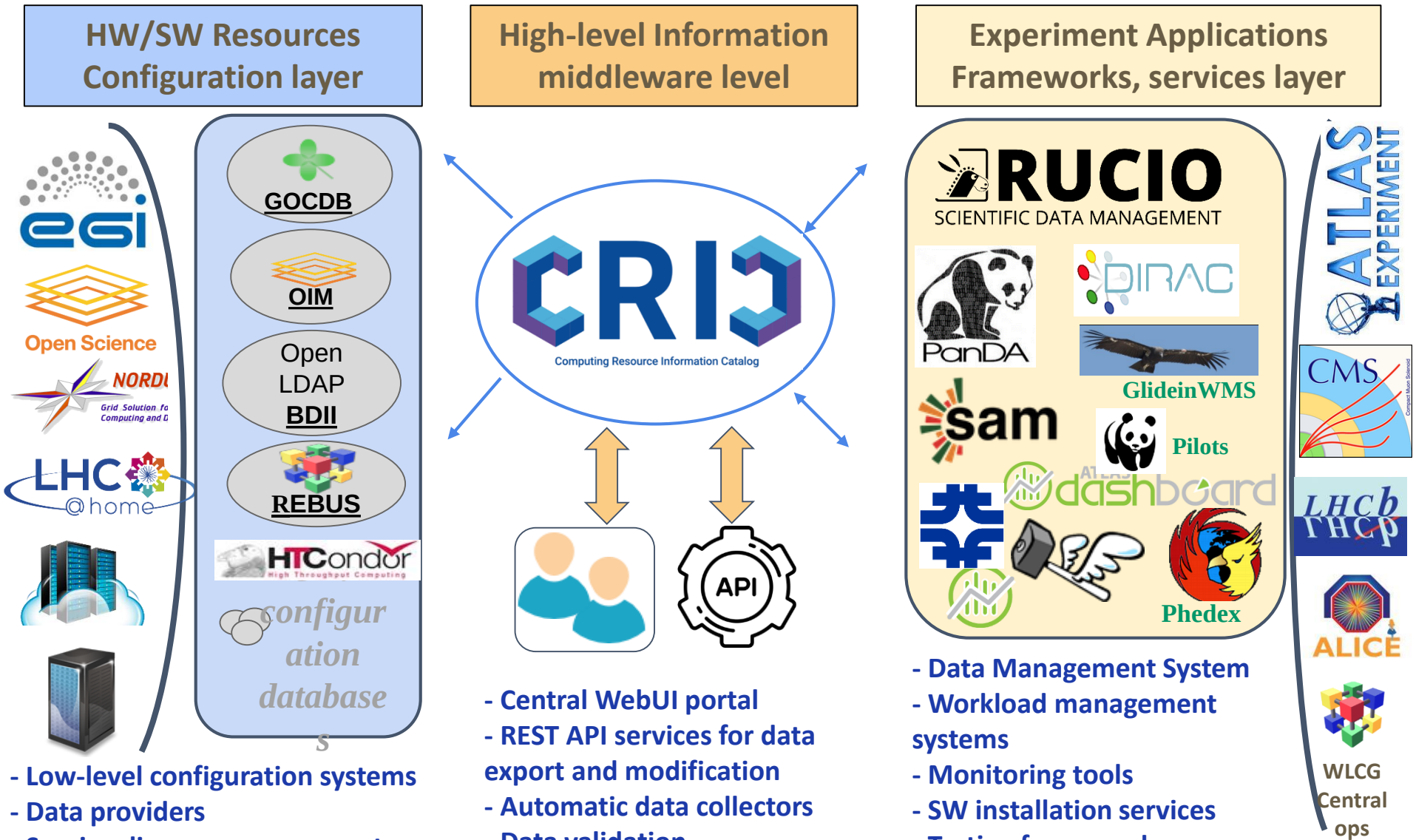
- Расширение компьютерных ресурсов за счет использования внешних невыделенных ресурсов (HLT, Clouds, HPC…)
- Изменения модели компьютинга в каждом эксперименте, с целью оптимизации использования ресурсов
- Значительные усилия вкладываются в развитие программного обеспечения, чтобы улучшить общую производительность при использовании современных архитектур (многоядерность, GPU…)
- Оптимизации процессов обработки, количество хранящихся реплик данных и др.

Платформа DIRAC

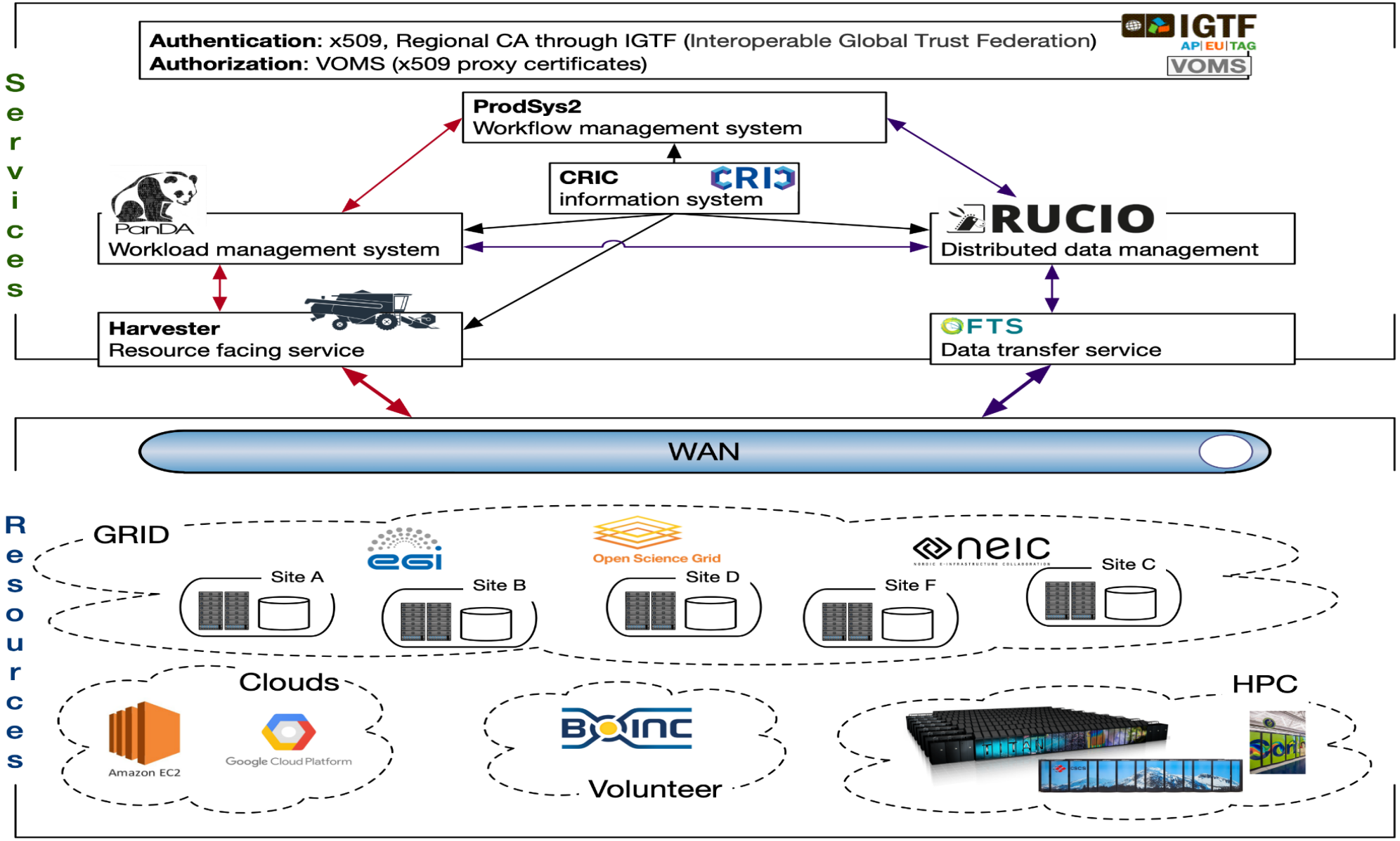
- DIRAC has all the necessary components to build ad-hoc grid infrastructures **interconnecting** computing resources of different types, allowing **interoperability** and simplifying **interfaces**.
- This allows to speak about the DIRAC ***interware***.



CRIC: a unified topology system for a large scale, heterogeneous and dynamic computing infrastructure



ATLAS computing



CHALLENGES: distributed data storage evolution: DATALAKES

GOAL:

•to provide a computing infrastructure to the experiments and the community to store and analyze data,

•to achieve storage consolidation where geographically distributed storage centers (potentially deploying different storage technologies) are operated and accessed as a single entity.

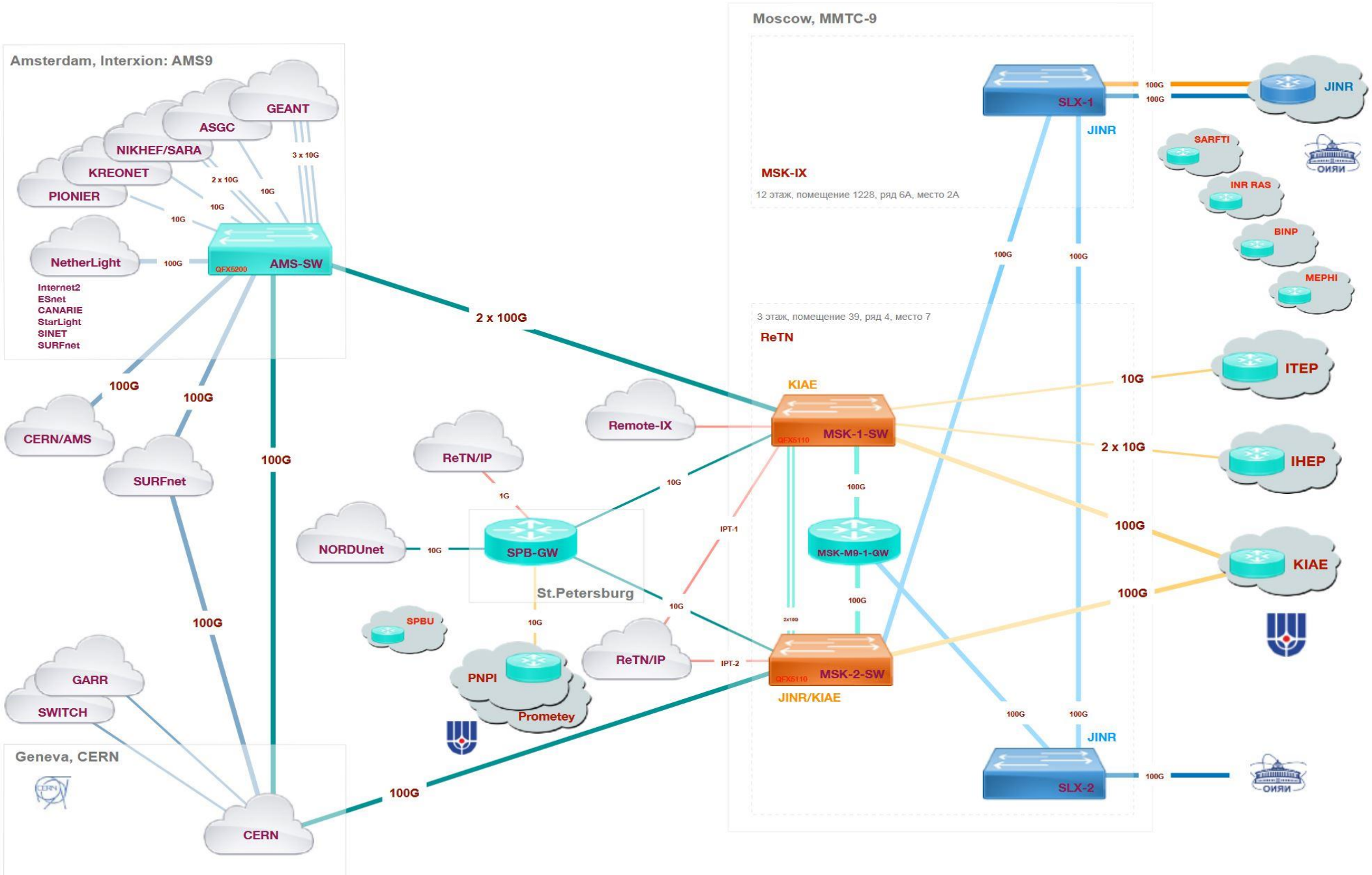
EOS - a CERN open-source storage software solution to manage multi PB storage.

XRootD - core of the implementation framework providing a feature-rich remote access protocol.

Improvement of already existing production quality Data Management services.

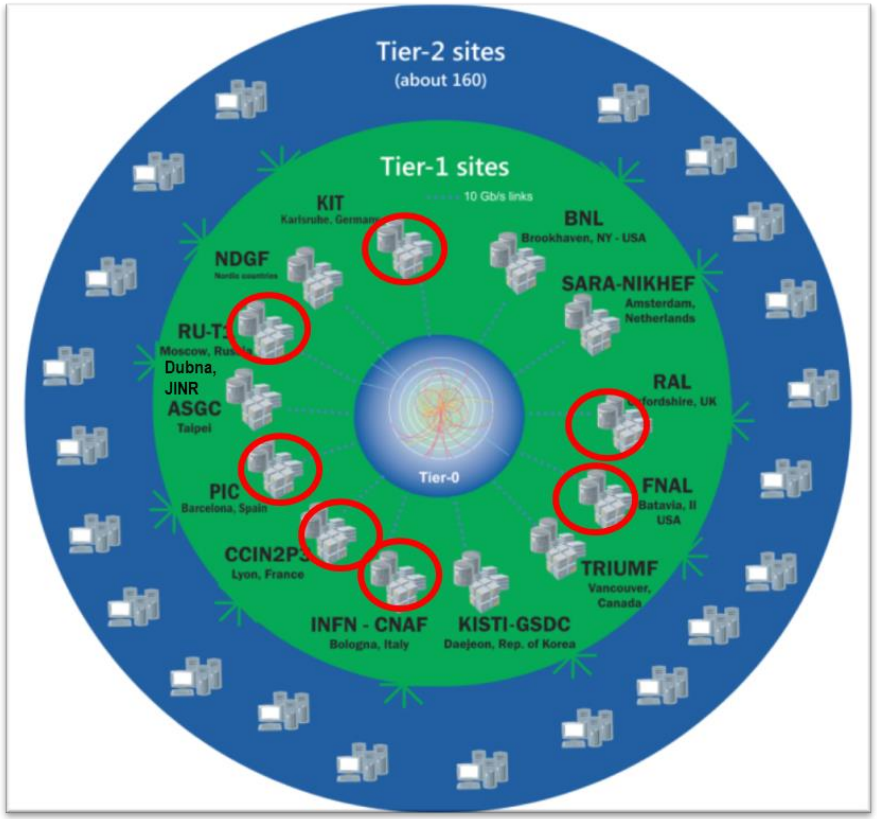
Scalable technologies for federating storage resources and managing data in highly distributed computing environments.

RDIG Network Infrastructure 2021



The Worldwide LHC Computing Grid

WLCG: an International collaboration to distribute and analyse LHC data. Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists



The mission of the WLCG project is to provide global computing resources to store, distribute and analyze the ~50-70 Petabytes of data expected every year of operations from the Large Hadron Collider.

WLCG computing enabled physicists to announce the discovery of the Higgs Boson.

161 sites

42 countries

~1M CPU cores

1 EB of storage

> 3 million jobs/day

10-100 Gb links

Worldwide LHC Computing Grid - 2019

Tier0 (CERN): data recording, reconstruction and distribution

Tier1: permanent storage, re-processing, analysis

Tier2: Simulation, end-user analysis

International Large-scale projects

Russian research institutes and universities actively participate in international large-scale projects:

- LHC, CERN (experiments: ATLAS, ALICE, LHCb, CMS)
- XFEL, DESY (European free electron laser)
- ESRF, France (European synchrotron center)
- FAIR, GSI, Germany (CBM, PANDA experiments)
- ITER, France …

International large-scale projects are being prepared in Russia:

- **NICA**, JINR, Dubna (proton and heavy ion collider)
- **PIK**, PNPI, Gatchina (high-flow reactor complex)
- **SKIF**, INP SB RAS Novosibirsk (Siberian ring photon source)
- **Super S-Tau Fabric**, Sarov (electron-positron collider)
- **синхротронно-нейтронная программа исследований**
- **Нейтринная программа**

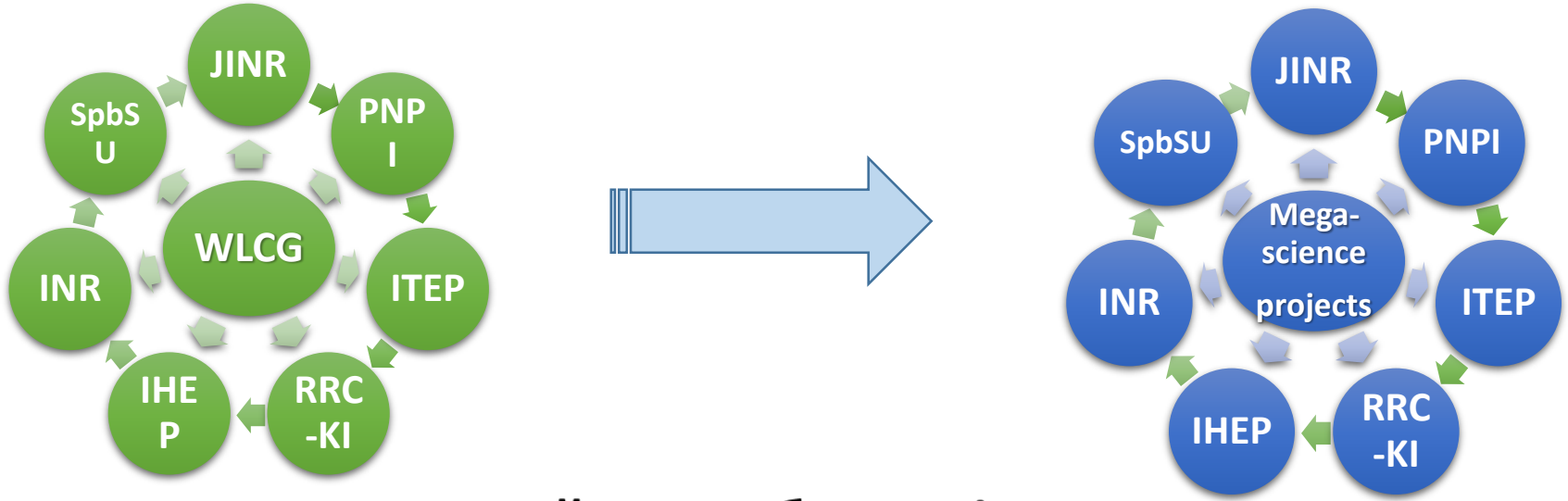
JOINT INSTITUTE FOR NUCLEAR RESEARCH 1956

СКИФ СИБИРСКИЙ КОЛЬЦЕВОЙ ИСТОЧНИК ФОТОНОВ

Институт ядерной физики имени Г. И. Будкера СО РАН

From RDIG to RDIG-M

Consortium RDIG-M – Russian Data Intensive GRID for Megascience projects



Проекты класса мегасайенс в области физики высоких энергий и астрофизики, синхротронно-нейтронных исследований, нейтринной программы.

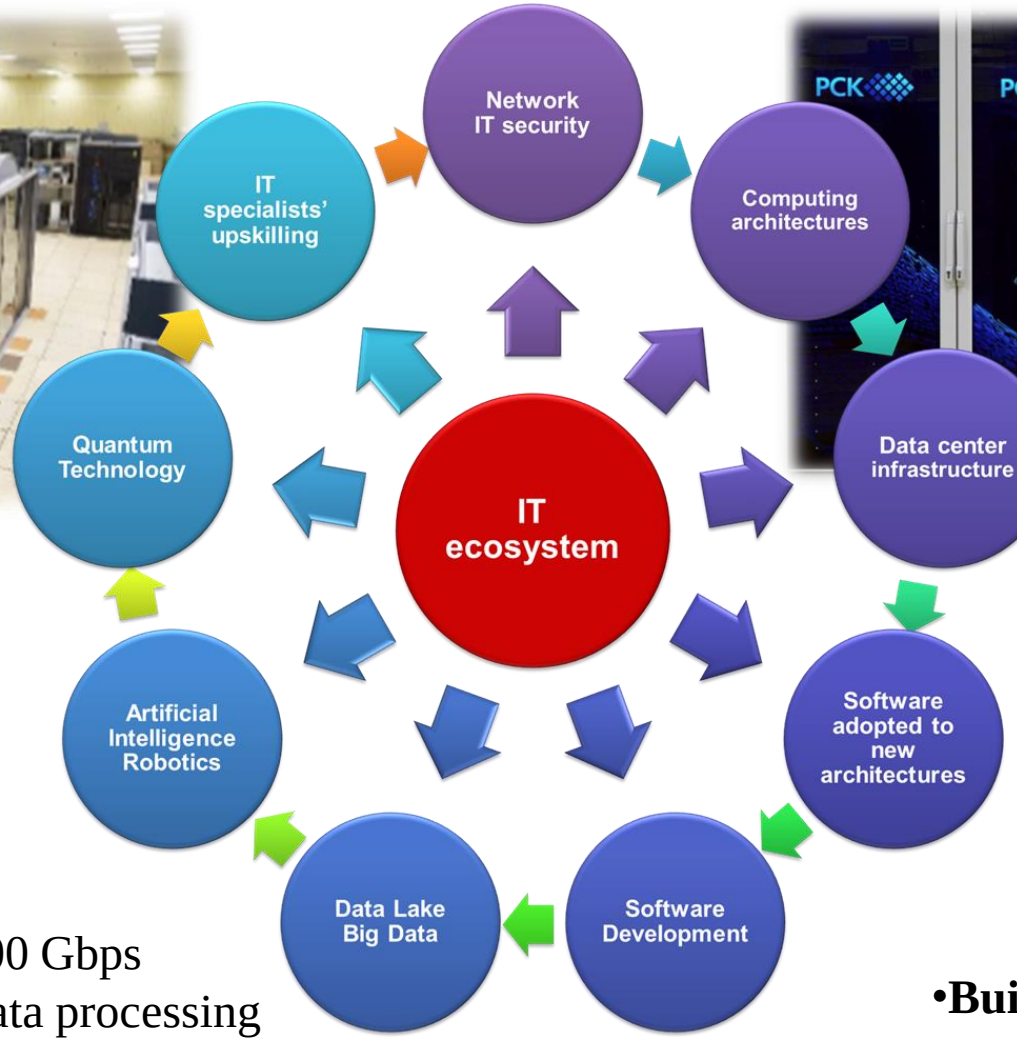
- Развитие методов и алгоритмов искусственного интеллекта для анализа данных экспериментов;
- Развитие суперкомпьютерных, грид, облачных технологий, распределенных хранилищ данных для моделирования, обработки и анализа данных;
- Развитие технологий высокоскоростной передачи научных данных.

Meshcheryakov Laboratory of Information Technologies

M.G. Mesheryakov
(17.09.1910 - 24.05.1994)

N.N. Govorun
(18.03.1930 - 21.07.1989)

MLIT today



Staff: 325
Scientists: 100
Doctors of Science: 24
Candidates of Science: 61
Campus network 2x100 Gbps
Multisite network 4x100 Gbps
Telecommunication channel 3x100 Gbps
Grid Tier1 and Tier2 for global data processing
JINR Cloud computing
JINR Member States' Cloud environment
"Govorun" supercomputer

MLIT Fundamentals:

•**Provide** IT services necessary for the fulfillment of the JINR Topical Plan on Research and International Cooperation in an efficient and effective manner.

•**Building** world-class competence in IT and computational physics.

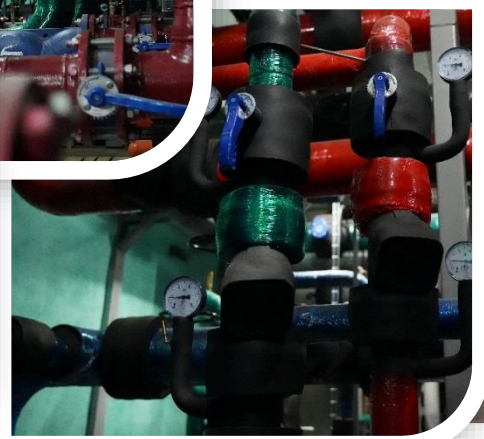
•**24/7** support of computing infrastructure and services such availability is called nonstop service.

Engineering Infrastructure



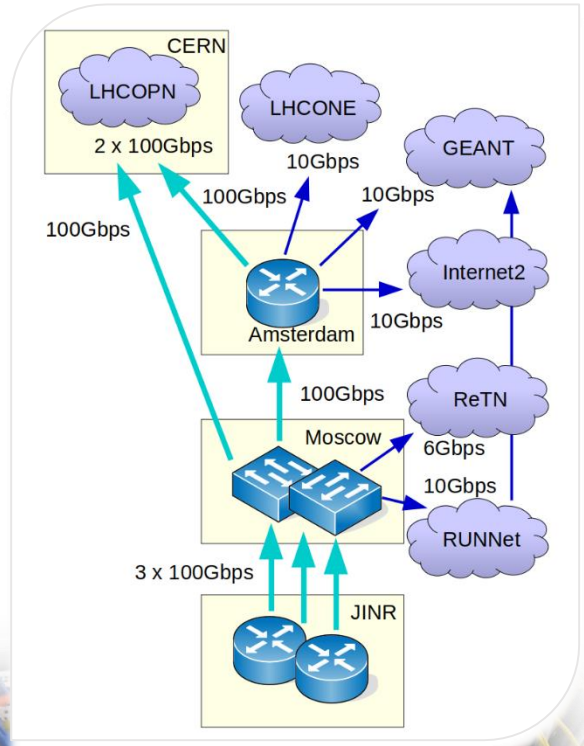






- ✓ Power supply expansion
- ✓ New cooling system for the MICC machine hall
- ✓ 100% “hot water” cooling system of the “Govorun” supercomputer
- ✓ Guaranteed power supply using diesel generators and uninterruptible power supplies

Networking



- JINR-Moscow 3x100 Gbit/s
- JINR-CERN - 100 Gbit/s and JINR-Amsterdam 100 Gbit/s for LHCOPN, LHCONE, GEANT networks
- Direct channels up to 100 Gbit/s for communication using RU-VRF technology with the collaboration of RUHEP research centers and with Runnet, ReTN networks
- The multi-site cluster network with a bandwidth 4x100 Gbit/s between VBLHEP and MLIT

The JINR LAN comprises:

8768 network elements

17602 IP-addresses

6377 users registered within the network

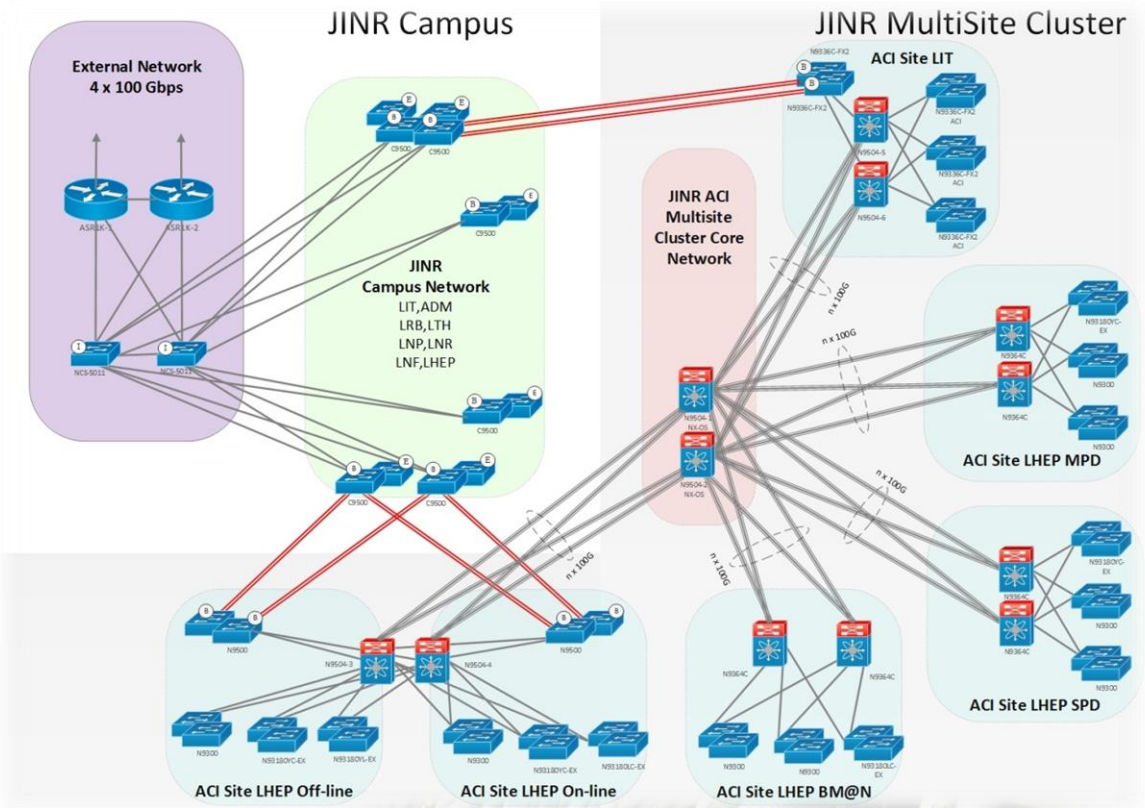
4203 *.jinr.ru service users

1419 digital library users

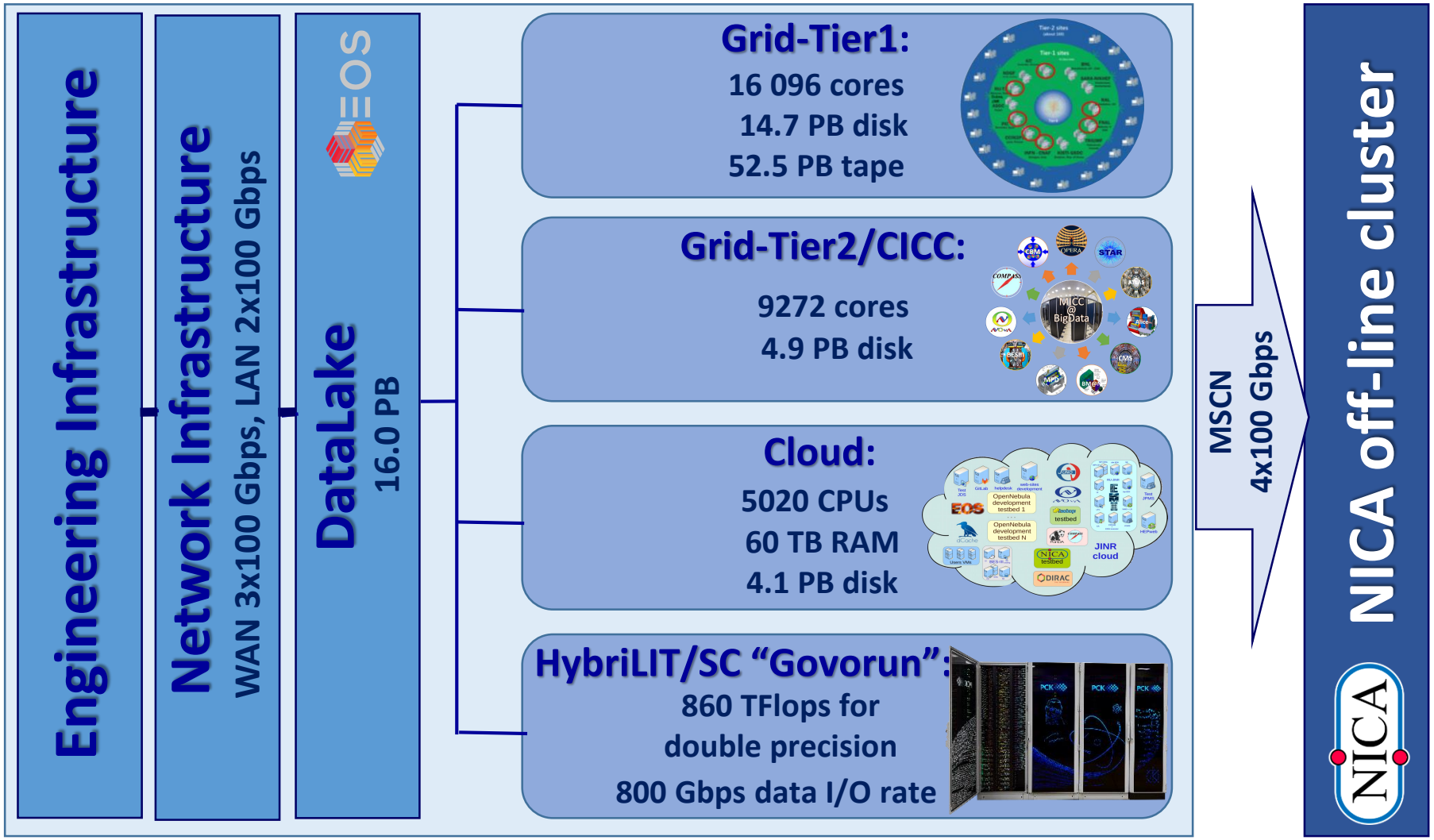
504 remote VPN and EDUROAM users

network traffic in 2021

- **33.23 PB - input**
- **35.86 PB - output**



Multifunctional Information and Computing Complex at JINR

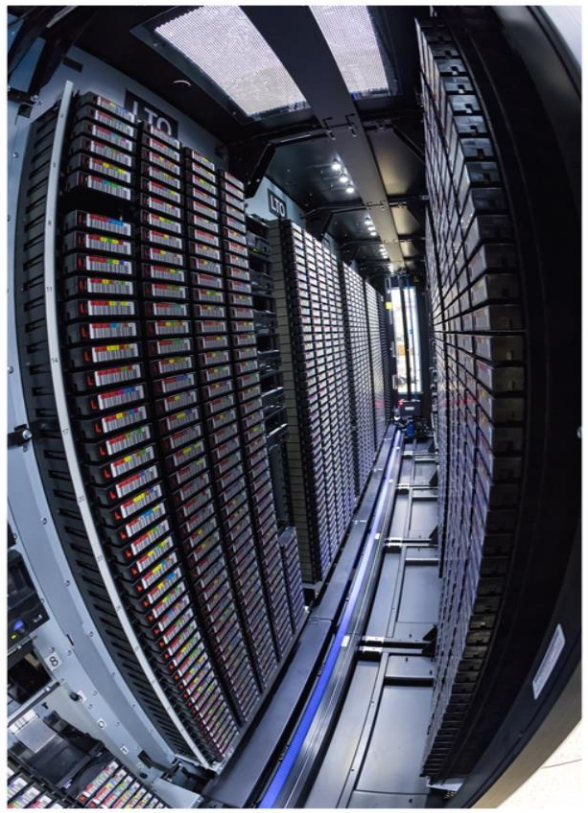


The **MICC** meets the requirements for a modern highly performant scientific computing complex:

- multi-functionality,
- high performance,
- task-adapted data storage system,
- high reliability and availability,
- information security,
- scalability,
- customized software environment for different user groups,
- high-performance telecommunications and modern local network.

The IT infrastructure is one of JINR's basic facilities.

JINR Tier1 for CMS



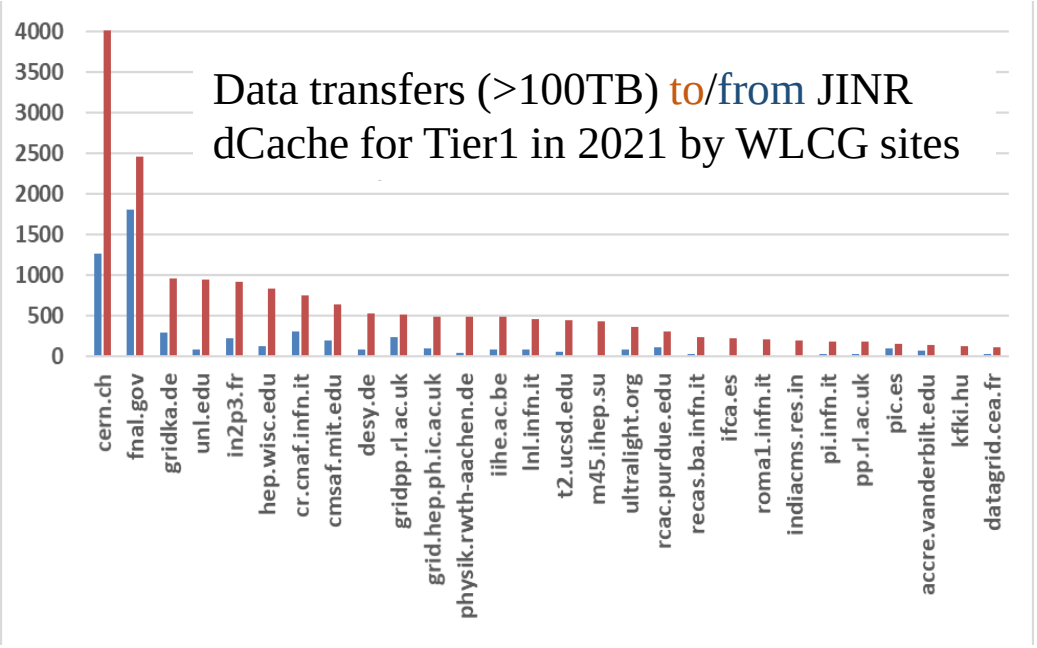
The CMS Tier1 center at JINR has demonstrated stable work through the entire period since its launch into full operation. The Tier1 site for CMS is ranked first among world centers for CMS.

One of the main functions of Tier1 centers is to provide data exchange with all global sites that run CMS jobs. In 2021, more than 30.5 PB of data from more than 210 grid sites were transferred to and from our Tier1.

- 16096 cores
- 260 kHS06
- 14.1 PB disk
- 52.6 PB tapes
- 100% reliability and availability

Tier1 — Sum CPU Work (HS06 hours) 2021-2022

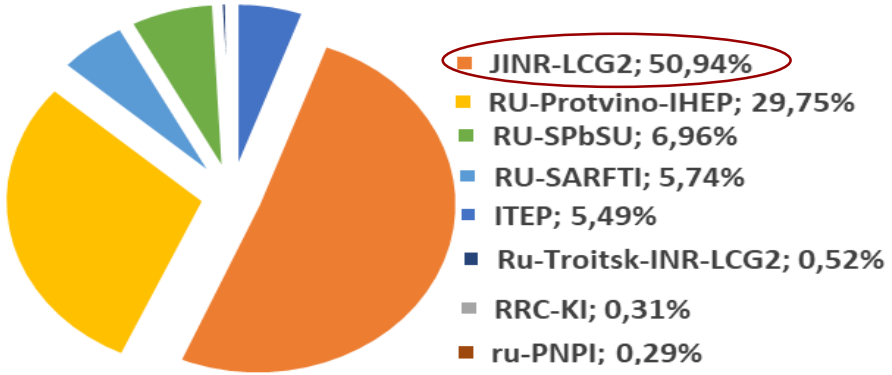
RU-JINR-T1	2,069,498,327	27,88%
US-FNAL-CMS	1,612,815,957	21,72%
DE-KIT	1,460,440,934	19,67%
IT-INFN-CNAF	743,512,935	10,01%
FR-IN2P3	668,957,987	9,00%
UK-T1-RAL	601,454,698	8,09%
ES-PIC	263,218,979	3,54%

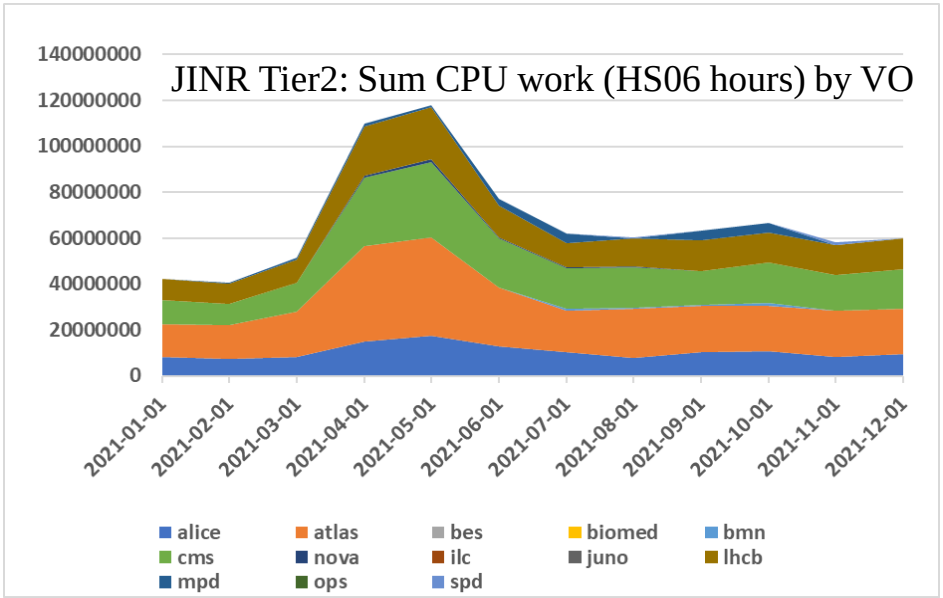


Tier2 for Experiments and JINR Laboratories

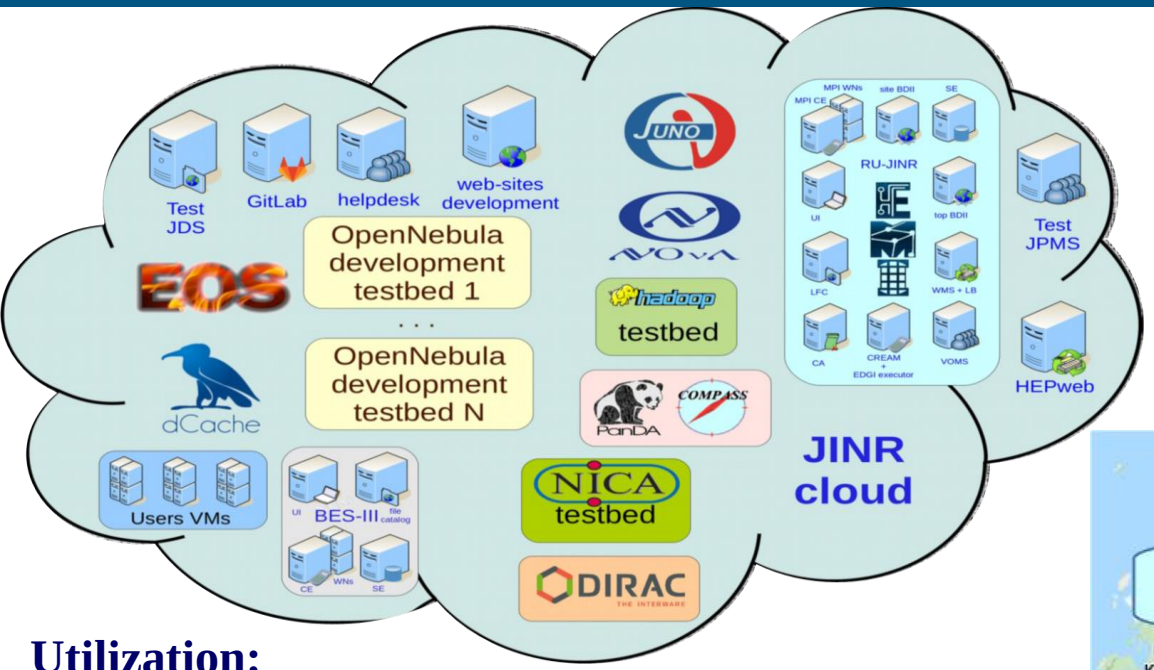
Tier2 for Alice, ATLAS, CMS, LHCb, BES, BIOMED, COMPASS, MPD, NOvA, STAR, ILC, etc. is recognized the best in the Russian Data Intensive Grid (RDIG) Federation.

RDIG: distribution by the number of jobs by the web sites of the organizations





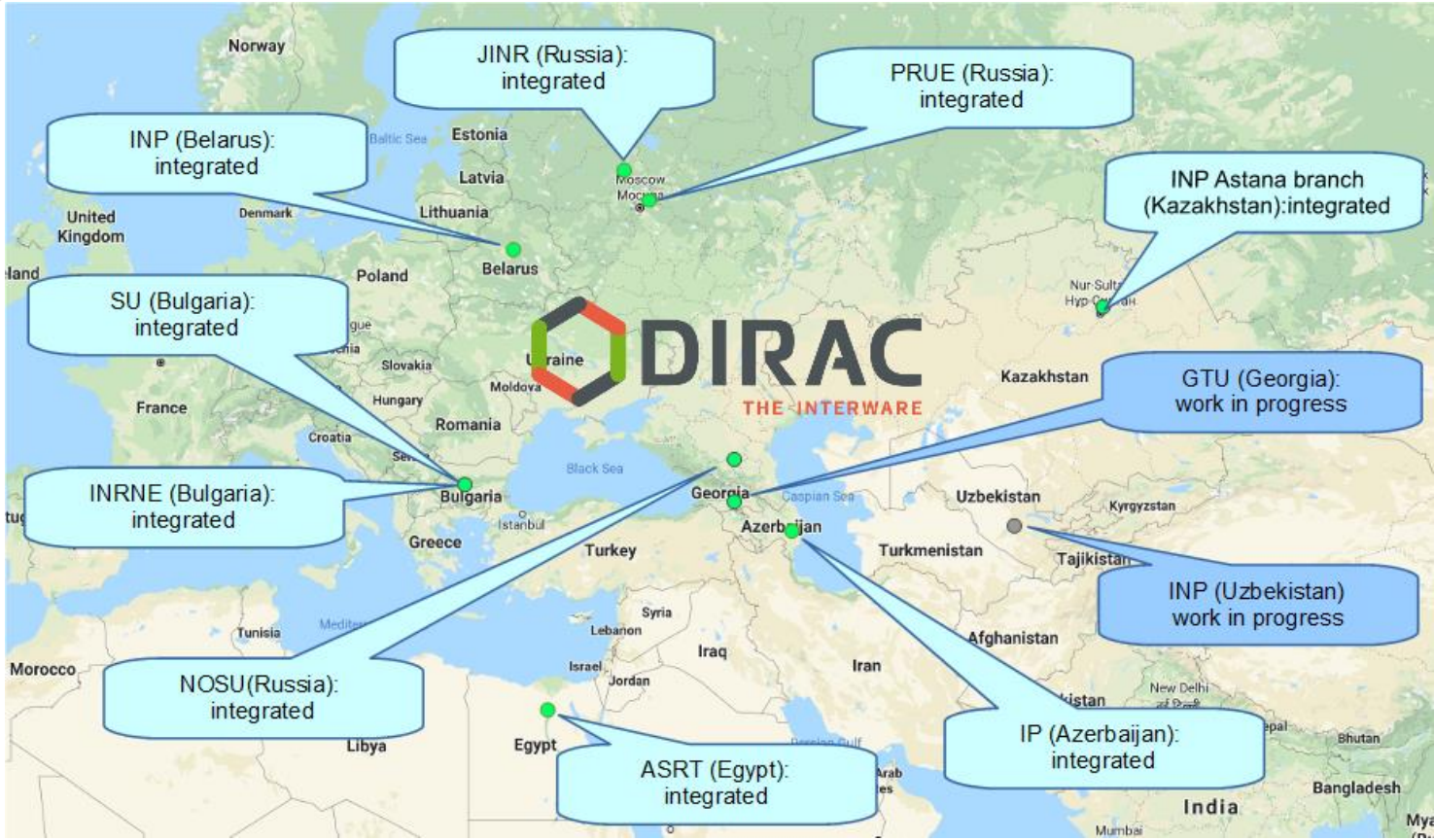
Cloud Infrastructure



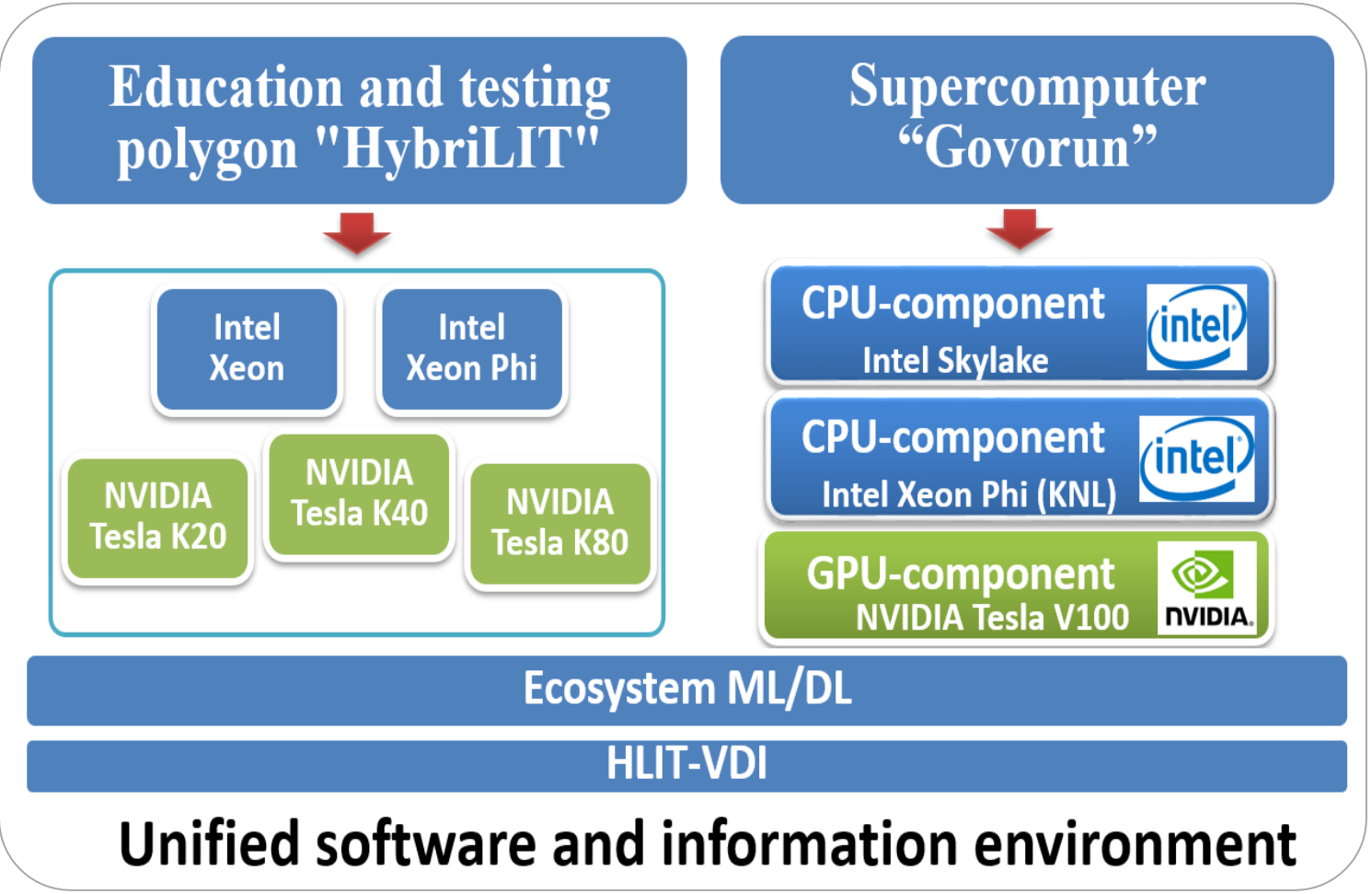
- Cloud Platform - OpenNebula
- Virtualization - KVM and OpenVZ
- Storage (Local disks, Ceph)
- Total Resources
  - 5020 CPU cores
  - 4.1 PB of raw ceph-based storage

Utilization:

– VMs for JINR users,
– Computational resources for neutrino experiments,
– Testbeds for R&D in IT,
– COMPASS production system services,
– Data management system of the UNECE ICP Vegetation,
– Scientific and engineering computations,
– Service for data visualization based on Grafana, jupyterhub head and execute nodes for it,
– Gitlab and its runners, as well as some others.



MICC Component: HybriLIT Platform

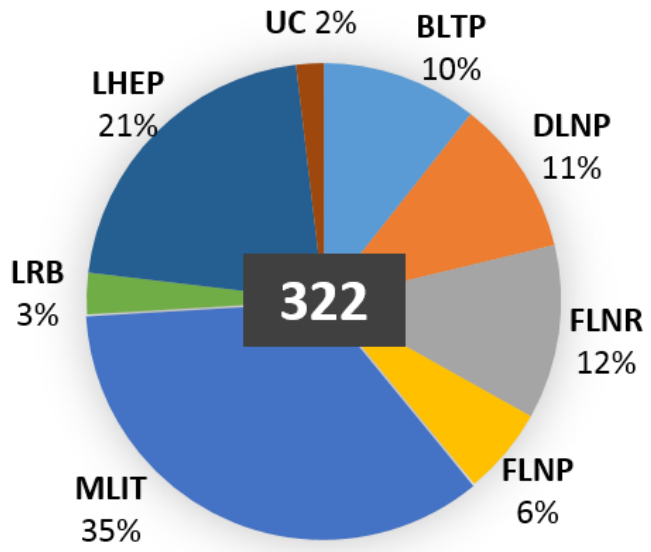


- Hyper-converged software-defined system
- Total peak performance: 860 TFlops DP
- Scalable solution Storage-on-demand
- Multilayered storage system for maximum efficiency
- Hot water cooling (compute, storage, interconnect)
- The most energy-efficient center in Russia (PUE = 1,06)
- Storage performance >300 GB/s
- The DAOS polygon of the "Govorun" supercomputer takes the 1st place among Russian supercomputers in the current IO500 list.

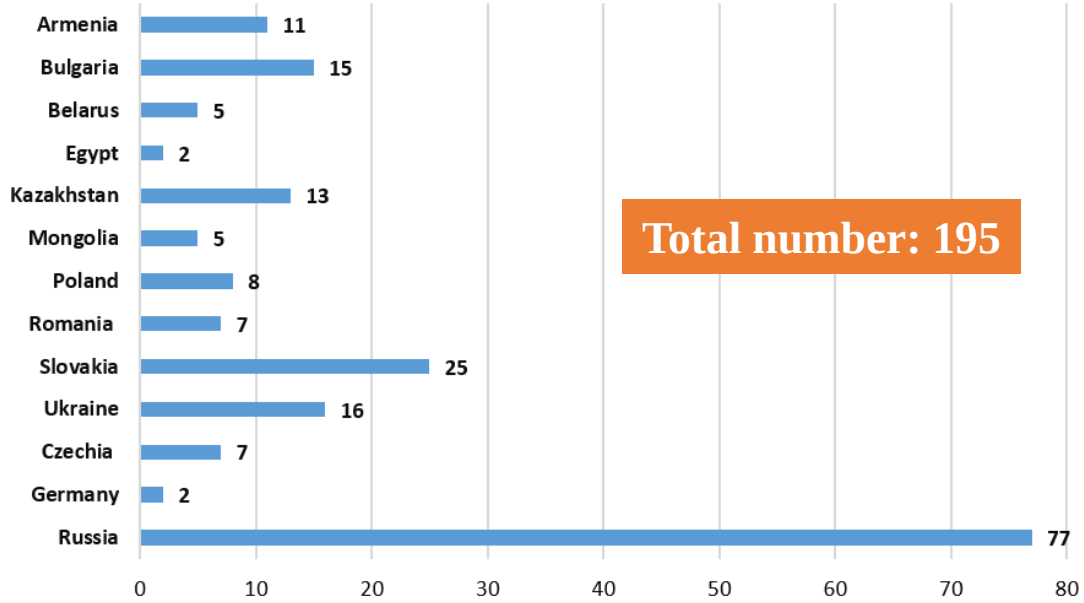
The unified software and information environment of the HybriLIT platform allows users to use the education and testing polygon is aimed at exploring the possibilities of novel computing architectures, IT-solutions, to develop and debug their applications, furthermore, carry out calculations on the supercomputer, which allows them to effectively use the supercomputer resources.

“Govorun” supercomputer

Total number of registered users of the "Govorun" supercomputer: 517



Number of users by Laboratory



Number of users by Member State

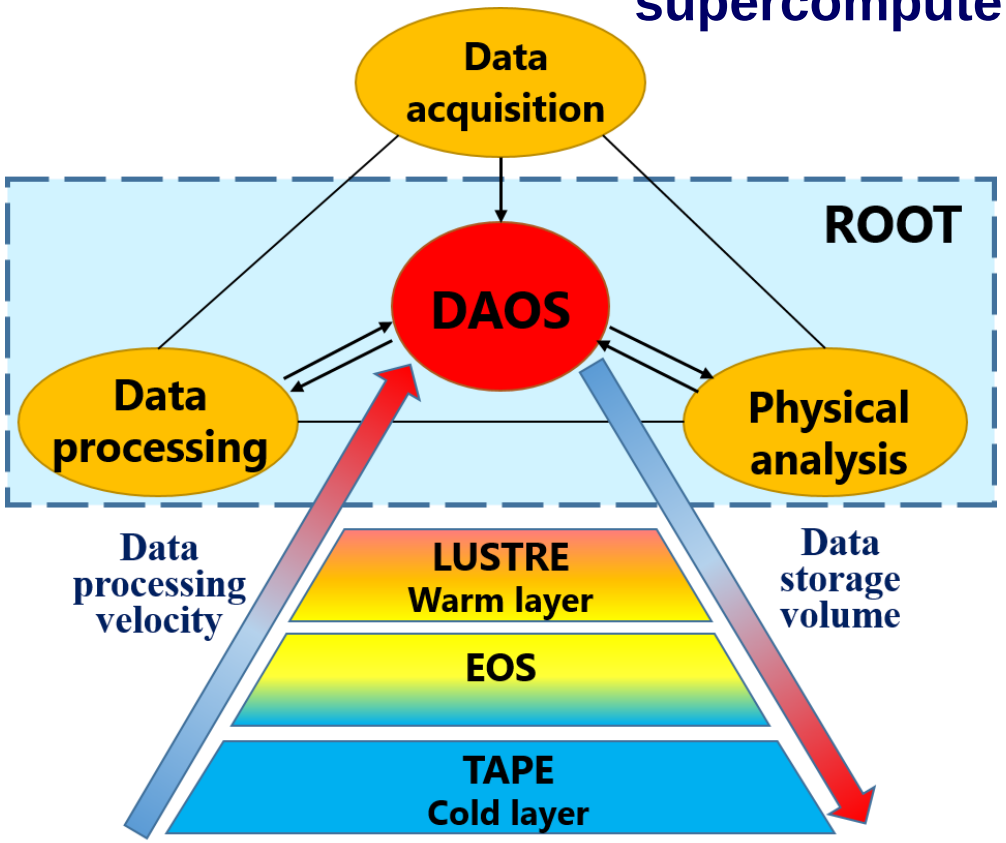
Key projects that use the resources of the “Govorun” supercomputer: NICA megaproject, calculations of lattice quantum chromodynamics, computations of the properties of atoms of superheavy elements, studies in the field of radiation biology, calculations of the radiation safety of JINR’s facilities.

In 2021, HybriLIT platform users published 38 papers, 11 of them in Q1 and 4 in Q2.

DAOS polygon of the “Govorun” supercomputer for data processing and storage in experimental high-energy physics

To work with Big Data, including for the NICA megaproject, a hierarchical data processing and storage system with a software-defined architecture was developed and implemented on the “Govorun” supercomputer. The fastest layer of the hierarchical system is based on the latest DAOS (Distributed Asynchronous Object Storage) technology.

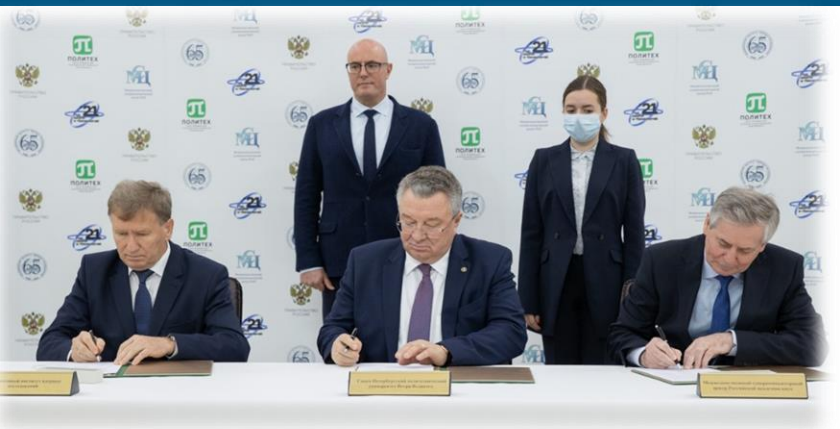
The DAOS polygon of the “Govorun” supercomputer takes the 1st place among Russian supercomputers in the current IO500 list.

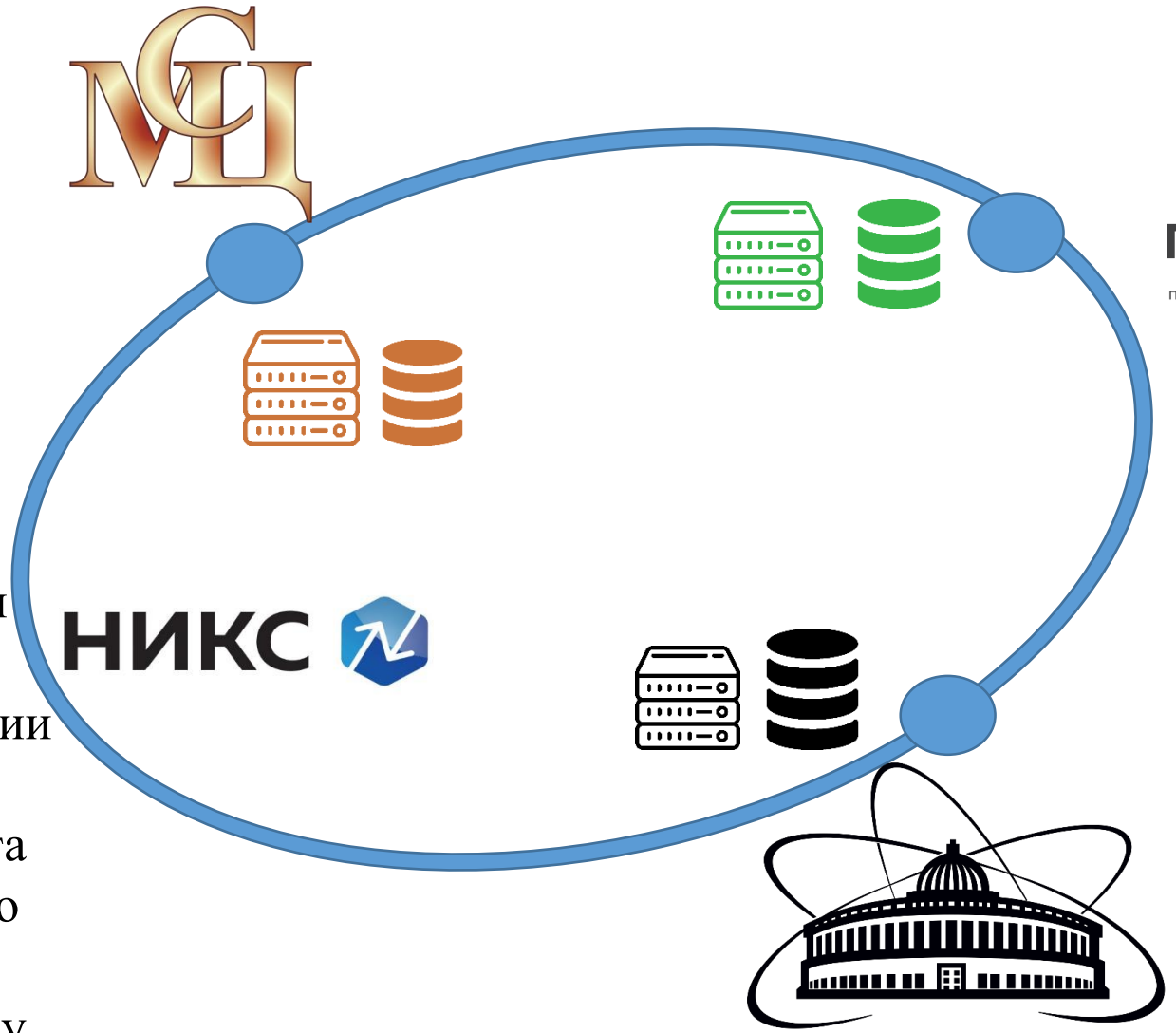


The use of DAOS in high-energy physics enables to:

- Store and read multidimensional data structures of TB scale in a single address space
- Create a multi-user presentation layer for analyzing physics results
- Reduce hot storage costs in hundreds of times compared to using DDR (Double Data Rate) memory
- Significantly reduce the use of the GRID infrastructure (computing/storage/network) at the stage of physics analysis
- Easily integrate with other hot/warm storages

Объединенная географически распределенная суперкомпьютерная инфраструктура



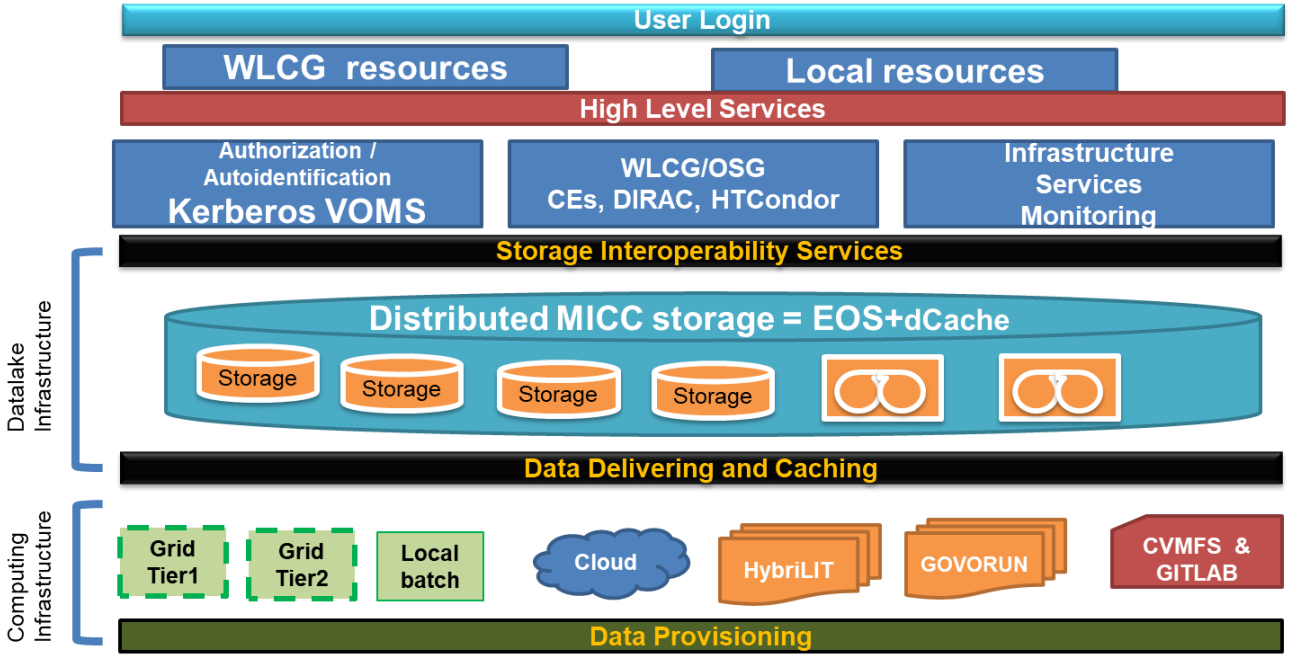


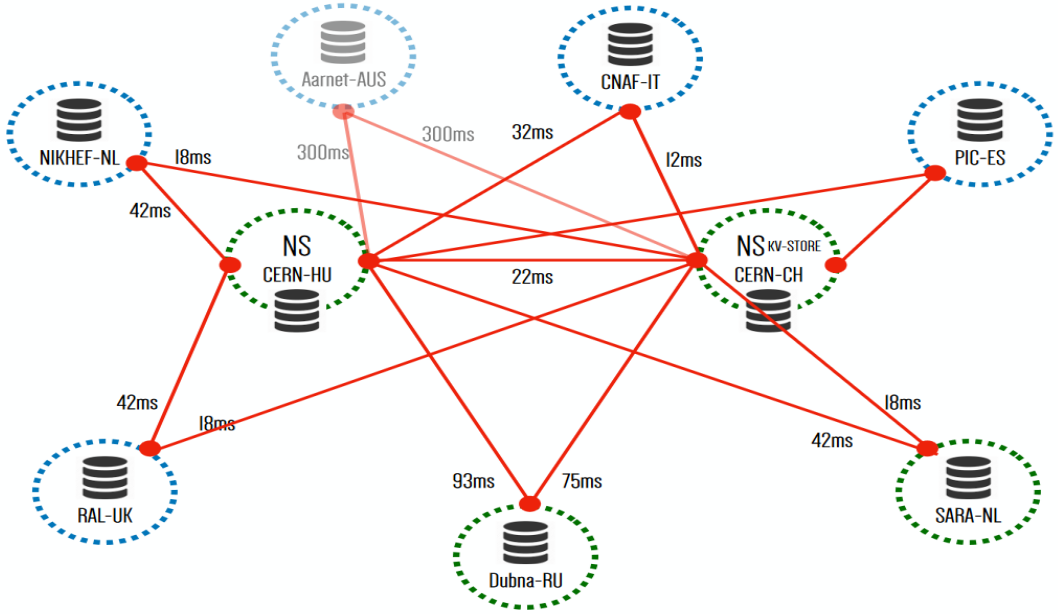
ПОЛИТЕХ
Санкт-Петербургский политехнический университет Петра Великого

В январе 2022 года успешно завершен первый совместный эксперимент по использованию объединенной суперкомпьютерной инфраструктуры для задач проекта NICA.
Всего было запущено 3000 задач генерации данных методом Монте-Карло и реконструкции событий для эксперимента MPD. Сгенерировано и реконструировано порядка 3 миллионов событий.
Полученные данные перемещены в Дубну для дальнейшей обработки и физического анализа

JINR in DataLakes

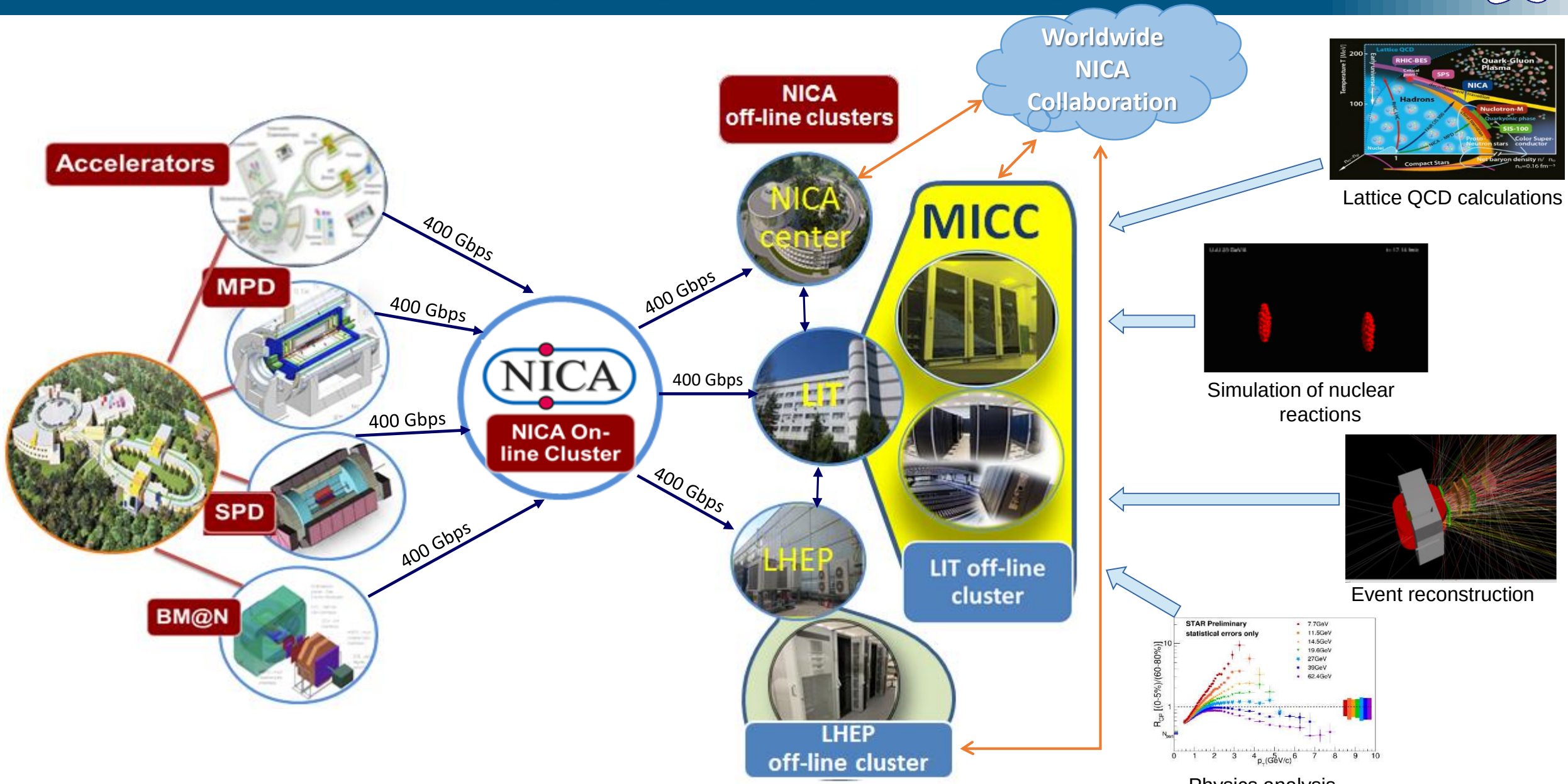
- The JINR data lake prototype was built as a distributed EOS storage system.
- EOS was successfully integrated into the MICC structure.
- EOS is used for storing and accessing big arrays of information.
- It can be applied for collective data simulation, storage of raw data gathered from experimental setups, data processing and analysis.





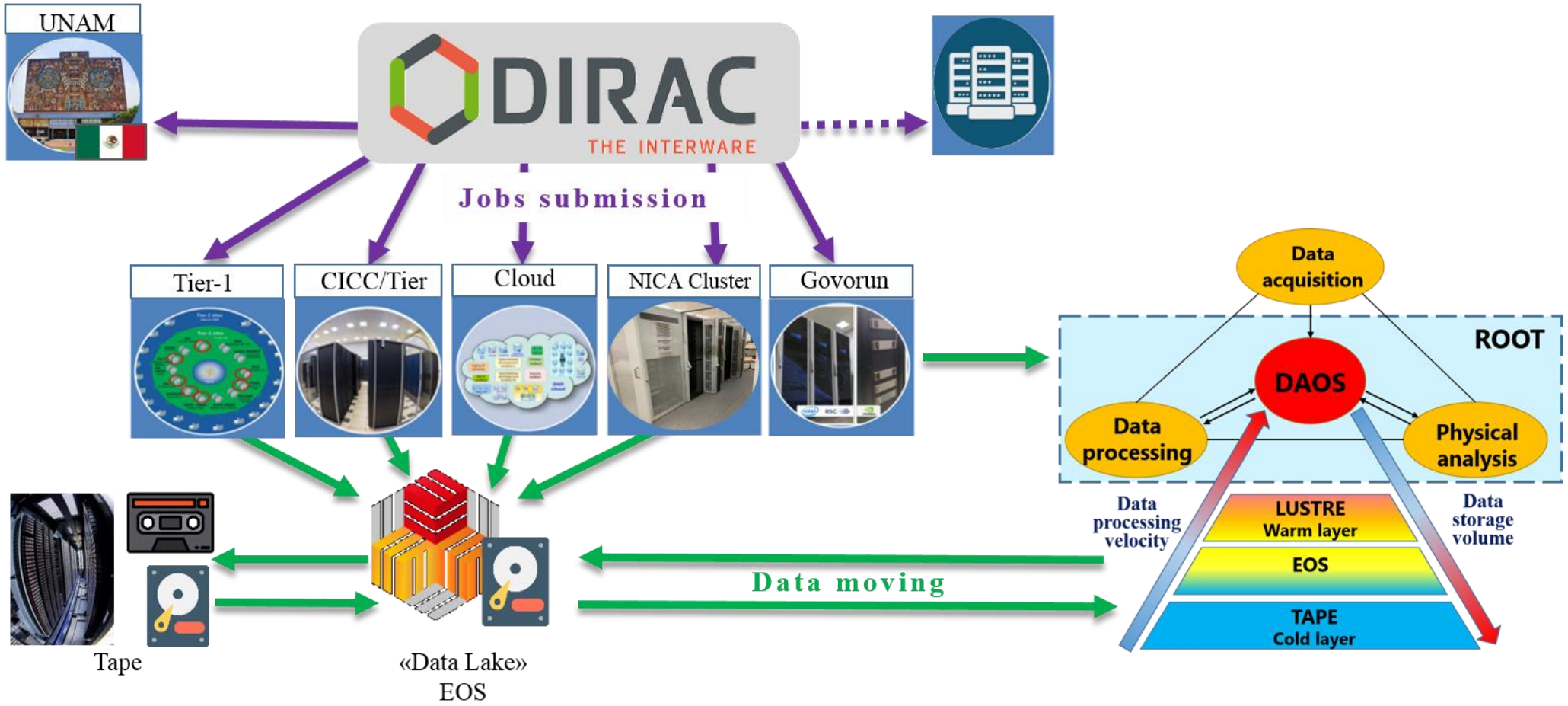
- There is currently 16.7 PB of disk space available for EOS.
- Baikal-GVD, DANSS, FOBOS, JUNO, BM@N, MPD, SPD, PANDA are its major users.
- EOS is visible as a local file system on the MICC working nodes and allows authorized users (by the kerberos5 protocol) to read and write data.

NICA Computing Concept & Challenges



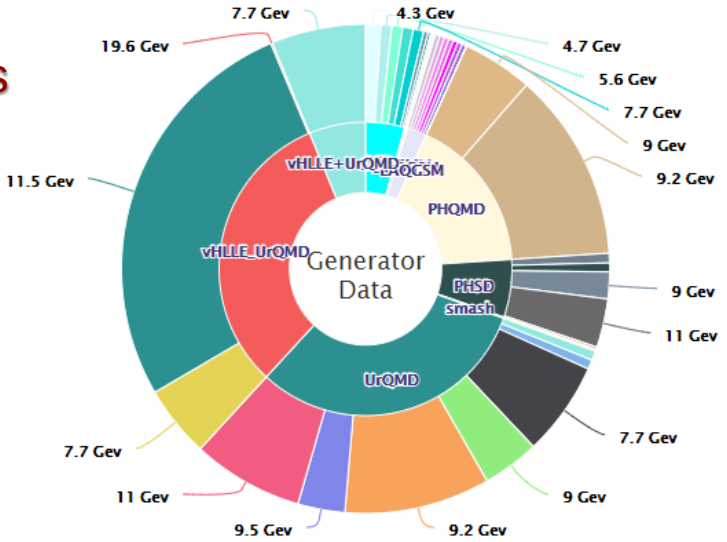
Heterogeneous distributed computing environment

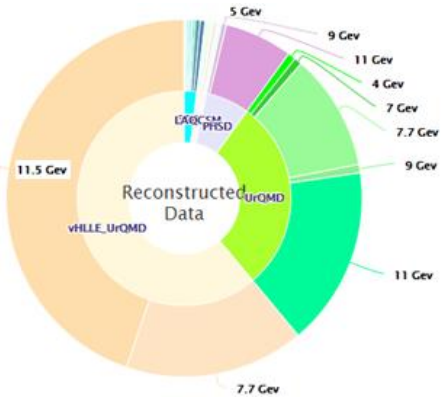
A heterogeneous computing environment, based on the DIRAC platform, was created for processing and storing data of the experiments conducted at JINR. By the end of 2021, Tier1, Tier2, the “Govorun” supercomputer, the clouds of the JINR Member States, the NICA cluster, as well as the cluster of the National Autonomous University of Mexico (NAUM, within the cooperation on the MPD project), were integrated into DIRAC. For the time being, the distributed infrastructure is used by the following experiments: MPD, Baikal-GVD, BM@N, SPD.



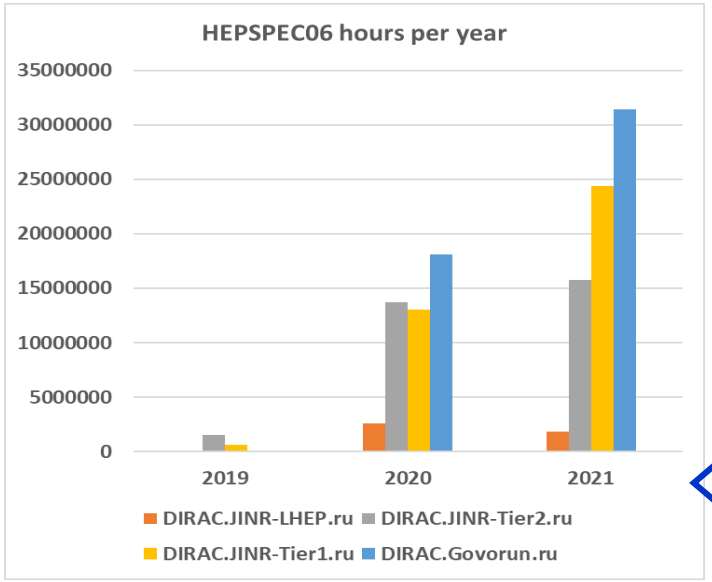
Heterogeneous distributed computing environment for the MPD experiment

✓1076∗ 10^6events were generated using *UrQMD*, *LAQGSM*, *PHSD* and other models





✓242∗10^6events were reconstructed



Available resources of the DIRAC platform for the MPD experiment:

- "Govorun" supercomputer: up to 1,586 cores in the latest production
- Tier1: 920 cores
- Tier2: 1,000 cores
- Clouds (JINR and JINR Member States): 70 cores
- NICA offline cluster: 250 cores (limit for users)
- UNAM (Mexico University): 100 cores
- National Research Computer Network of Russia (NIKS, now resources from SPBTU and JSCC): 672 cores – New resource, added in 12.2021.

The mass production storages integrated into the Dirac File Catalog are 1.5 PB in size.

The histogram illustrates the accounting data from the centers. The metric shown is Sum CPU Work, grouped by center and year.

Methods, Algorithms and Software

Numerical modeling of complex physical systems,

Experimental data processing and analysis,

Big Data,

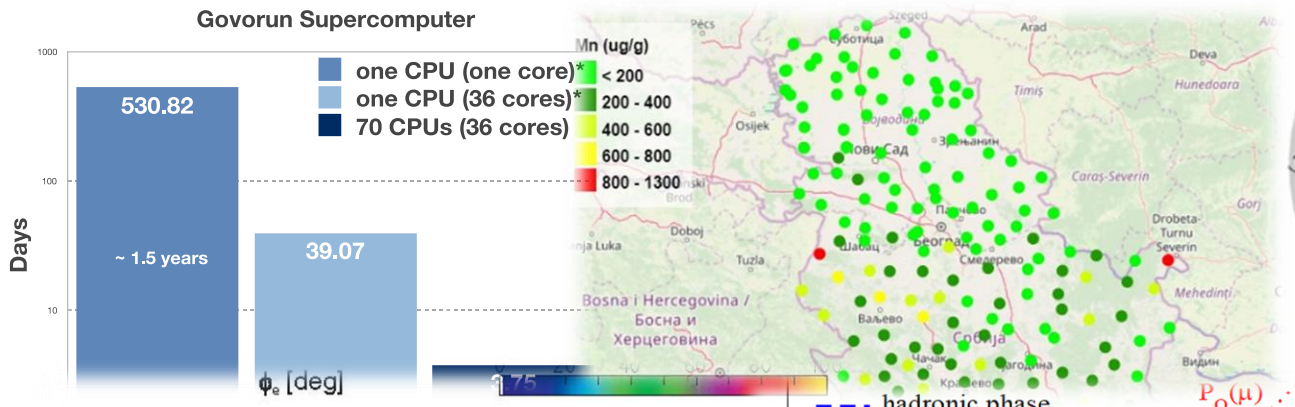
Neural networks,

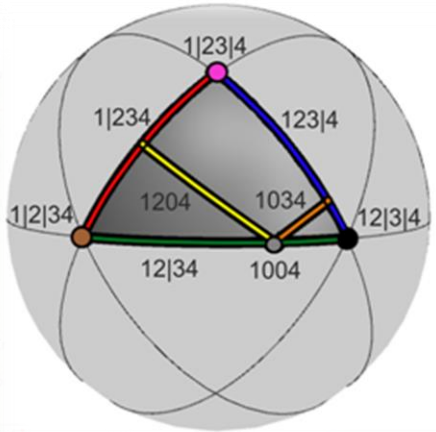
Machine and deep learning,

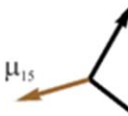
Artificial intelligence and robotics,

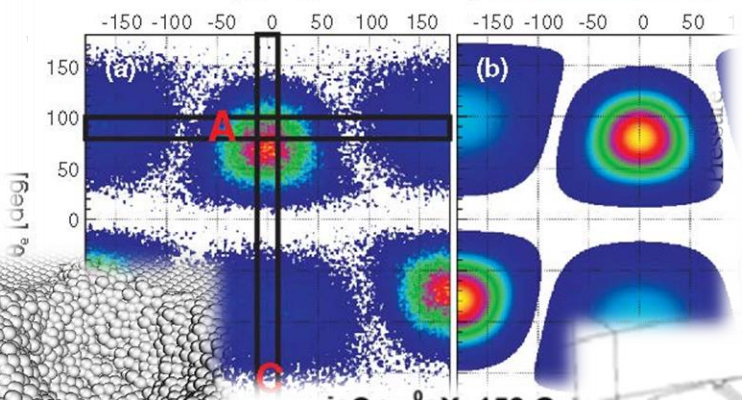
Computer algebra,

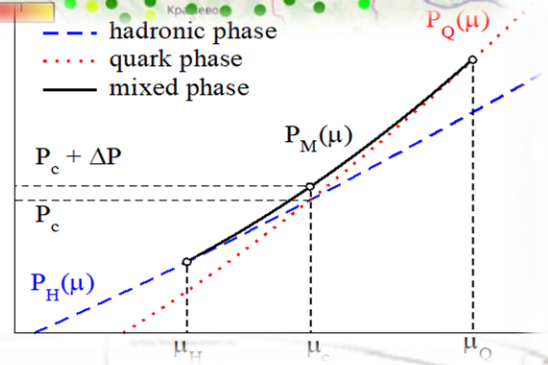
Quantum computing

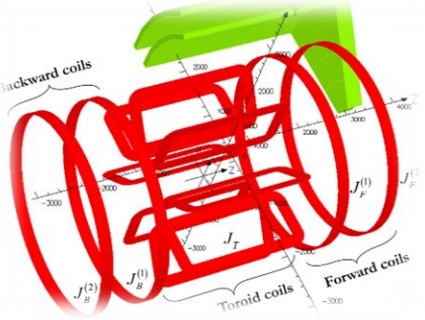


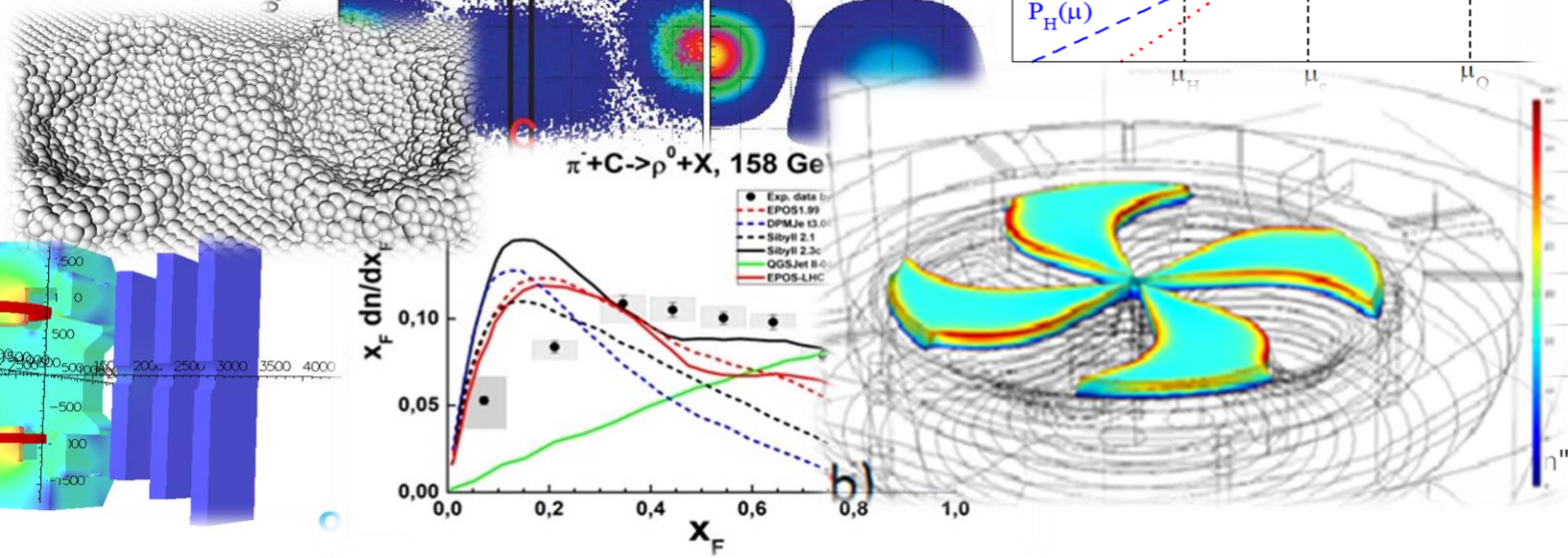




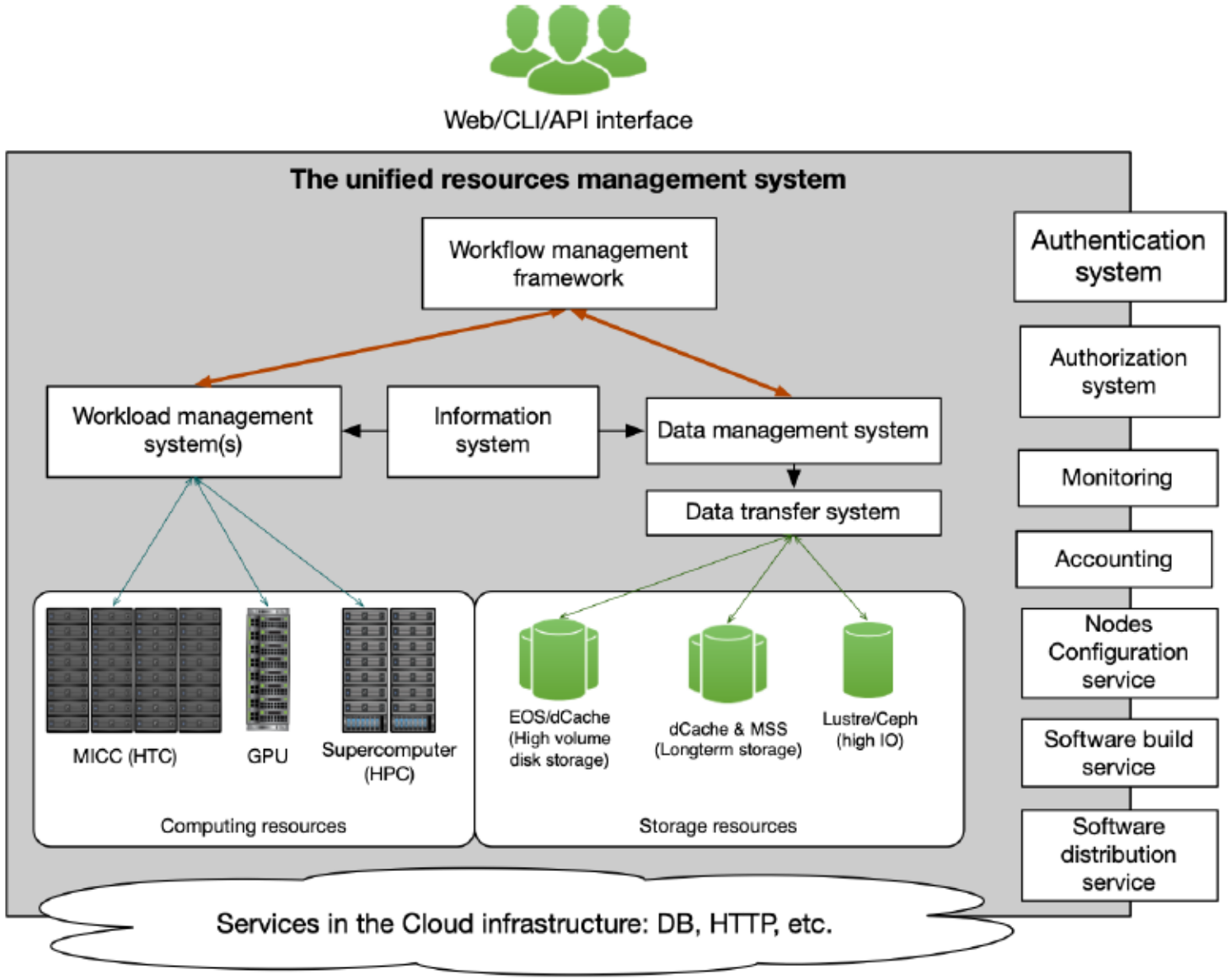








MICC Unified Resource Management System



The main objectives of the unified resource management system are:

- to provide the ability to process large amounts of data
- to enable the organization of massive computing tasks
- to optimize the efficiency of using computing and storage resources
- to effectively monitor resource loading
- to consolidate resource accounting
- to provide a unified interface for accessing resources

Development of the system for training and retraining IT specialists

Training courses, master classes and lectures

MLIT staff and leading scientists from JINR and its Member States

Leading manufacturers of modern computing architectures and software

Parallel programming technologies

OpenMP

MPI

OpenCL

NVIDIA CUDA

Tools for debugging and profiling parallel applications

Intel Cluster Studio

Work with applied software packages

COMSOL MULTIPHYSICS

Wolfram Mathematica

ROOT Data Analysis Framework

MATLAB

GEANT4

Maple

Frameworks and tools for ML/DL tasks

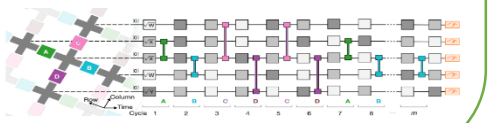
jupyterhub

TensorFlow

NumPy

scikit learn

Quantum algorithms, quantum programming and quantum control



The International Conference "Distributed Computing and Grid Technologies in Science and Education"

- Distributed computing systems
- Computing for MegaScience Projects
- Distributed computing applications
- Data Management, Organisation and Access
- HPC
- Virtualization
- Big data Analytics and Machine learning
- Research infrastructure

The International Symposium Nuclear Electronics and Computing

- Detector & Nuclear Electronics
- Triggering, Data Acquisition, Control Systems
- Distributed Computing, GRID and Cloud Computing
- Machine Learning Algorithms and Big Data Analytics new!
- Research Data Infrastructures
- Computations with Hybrid Systems (CPU, GPU, coprocessors)
- Computing for Large Scale Facilities (LHC, FAIR, NICA, SKA, PIC, XFEL, ELI, etc.)
- Innovative IT Education

MMCP

MATHEMATICAL MODELING AND COMPUTATIONAL PHYSICS

- ❑methods, software and program packages for data processing and analysis;
- ❑mathematical methods and tools for modeling complex physical and technical systems, computational biochemistry and bioinformatics;
- ❑methods of computer algebra, quantum computing and quantum information processing;
- ❑ machine learning and big data analytics;
- ❑ algorithms for parallel and hybrid calculations.

MLIT Schools