JOINT INSTITUTE FOR NUCLEAR RESEARCH
JINR ASSOCIATION OF YOUNG SCIENTISTS AND SPECIALISTS
JINR MLIT
28th International Scientific Conference of Young Scientists and Specialists
AYSS
28.10-01.11
2024

Digital twins for solving management and development tasks of distributed computer systems for megascience projects

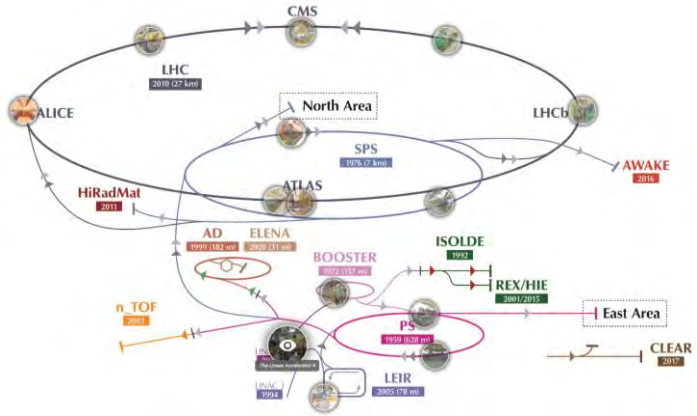
DARIA PRIAKHINA

Meshcheryakov Laboratory of Information Technologies

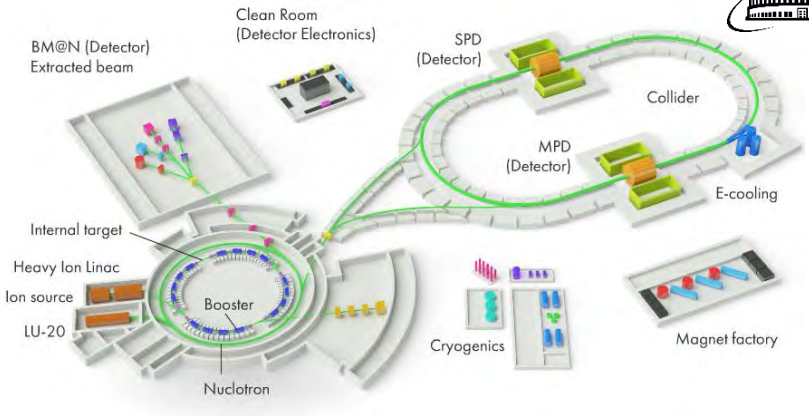
Joint Institute for Nuclear Research

Modern scientific research and megascience experiments

The CERN accelerator complex (Switzerland)



Nuclotron-based Ion Collider fAcility (NICA, JINR, Dubna, Russia)



Beijing Electron Positron Collider (BEPC, China)

These and many others…

High Energy Photon Source project (HEPS, China)

Modern scientific research and megascience experiments

The CERN accelerator complex (Switzerland)

Nuclotron-based Ion Collider fAcility (NICA, JINR, Dubna, Russia)

Beijing Positron Collider (BEPC, China)

These and many others…

High Photon Source project (HEPS, China)

… need large-scale computing systems to store large amounts of data and process them in a relatively short time!

Distributed data acquisition, storage and processing centers (DDC)

WLCG Worldwide LHC Computing Grid

MICC JINR MULTIFUNCTIONAL INFORMATION AND COMPUTING COMPLEX

Data Center Institute of High Energy Physics Chinese Academy of Sciences

- Geographically distributed infrastructure.
- Large-scale systems.
- Designed to work with extremely large amounts of data.
- Consists of various types of resources.
- Collective shared access to data storage and processing resources.

Distributed data acquisition, storage and processing centers (DDC)

WLCG Worldwide LHC Computing Grid

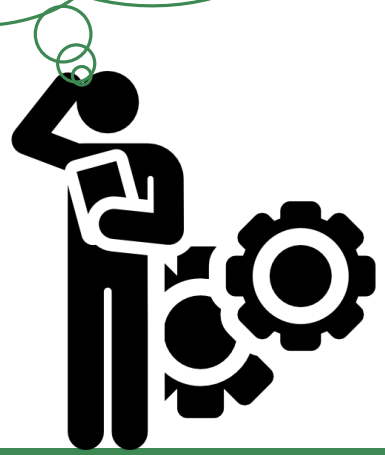
MICC JINR MULTIFUNCTIONAL INFORMATION AND COMPUTING COMPLEX

Data Center Institute of High Energy Physics Chinese Academy of Sciences

Important!

The systems must guarantee high-quality and efficient operation.

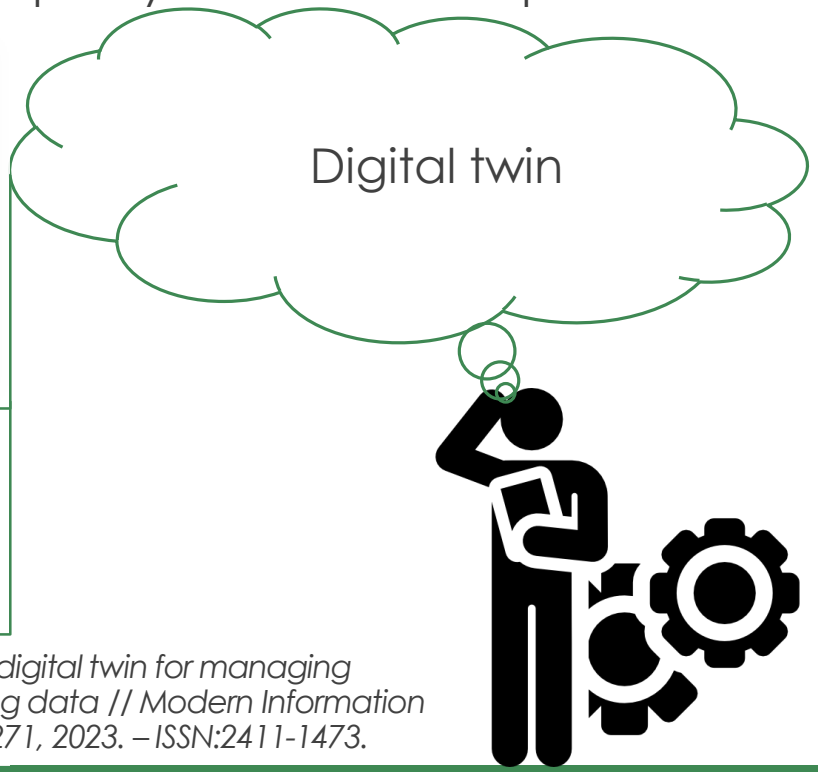
How to ensure design, continuous improvement and scaling of DDC?



Distributed data acquisition, storage and processing centers (DDC)

Important!

The systems must guarantee high-quality and efficient operation.



Problem-oriented management and decision-making systems.

Solving management and development tasks.

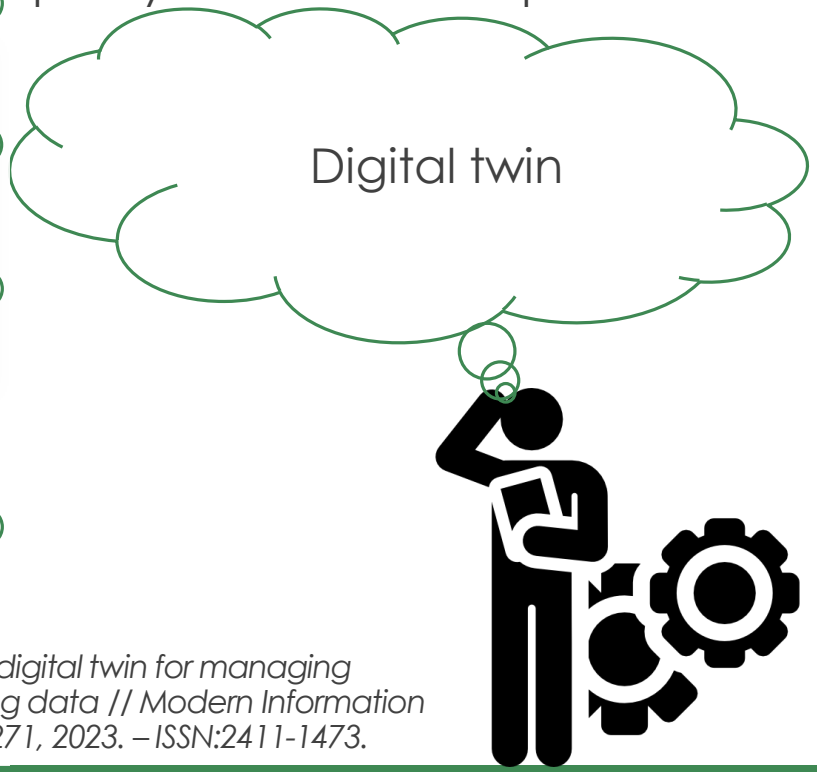
Priakhina D., Korenkov V. The relevance of creating a digital twin for managing distributed centers for collecting, storing and processing data // Modern Information Technologies and IT-Education, Vol. 19, No 2, pp. 262-271, 2023. – ISSN:2411-1473.

Distributed data acquisition, storage and processing centers (DDC)

- Modeling of complex computing systems.
- Describes the system.
- Reflects the processes taking place in the system.
- Testing of the system with different variants of equipment parameters, data flows and jobs.

Important!

The systems must guarantee high-quality and efficient operation.



Priakhina D., Korenkov V. The relevance of creating a digital twin for managing distributed centers for collecting, storing and processing data // Modern Information Technologies and IT-Education, Vol. 19, No 2, pp. 262-271, 2023. – ISSN:2411-1473.

Digital twin (DT)

Real-time operation throughout the entire DDC life cycle.

COMPUTER MODEL

INPUT DATA

- Architecture and hardware parameters of DDC.
- Characteristics of data flows and job flows.

FUNCTIONAL PURPOSE

- Designing of DDC.
- Analysis of the efficiency and reliability of DDC.
- Testing scaling scenarios based on data flows and job flows requirements.
- Assessment of the required amount of resources for specific tasks.
- Checking job flows management strategies.

Priakhina D., Korenkov V., Trofimov V. Method for constructing digital twins to solve problems of effective management and development of distributed centers for collecting, storing and processing data // Modern Information Technologies and IT-Education, Vol. 19, No 2, pp. 272-281, 2023. – ISSN:2411-1473.

Digital twin (DT)

The modeling core provides the functioning of a DT.

- Probabilistic distributions are taken into account when forming data flows, job flows, and criteria for the functioning of equipment.

Generating parameters for data & jobs flows:

$$pr(x) = \frac{1}{b-a}$$

- the probability density function of a uniform distribution, where [a, b) — the interval for changing the parameter value

$$pn(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

- the probability density function of the normal distribution, where μ — the average value of a random variable, σ — standard deviation

Event flow generation (exponential distribution):

$$\tau = -\frac{1}{\lambda} * \ln(r)$$

- the interval between random events

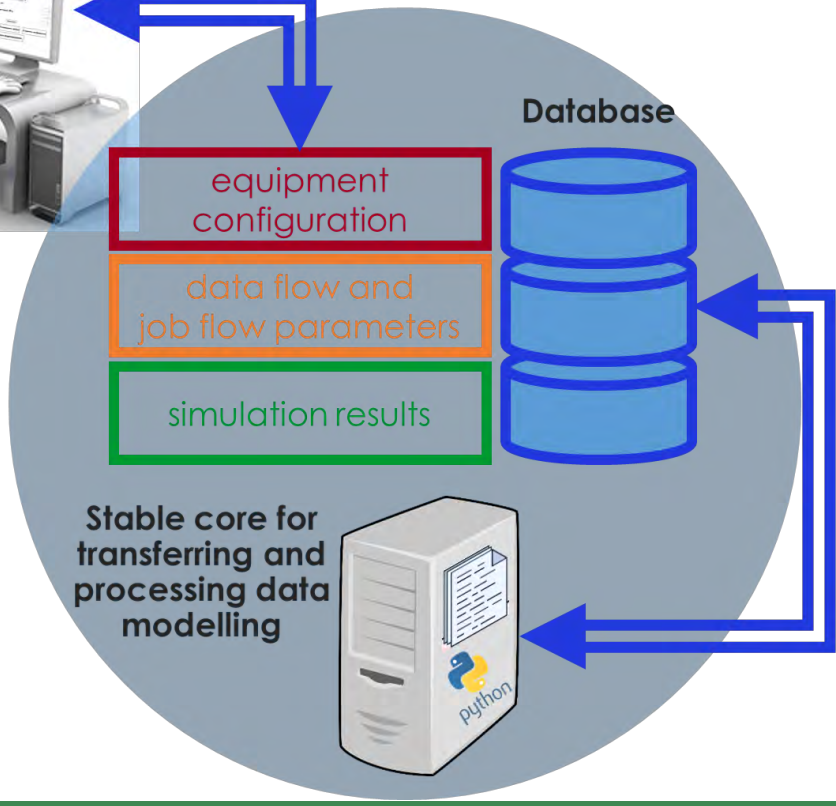
- a uniformly distributed random number [0;1]

- the average number of events per unit of time

Software complex for creating digital twins of DDC

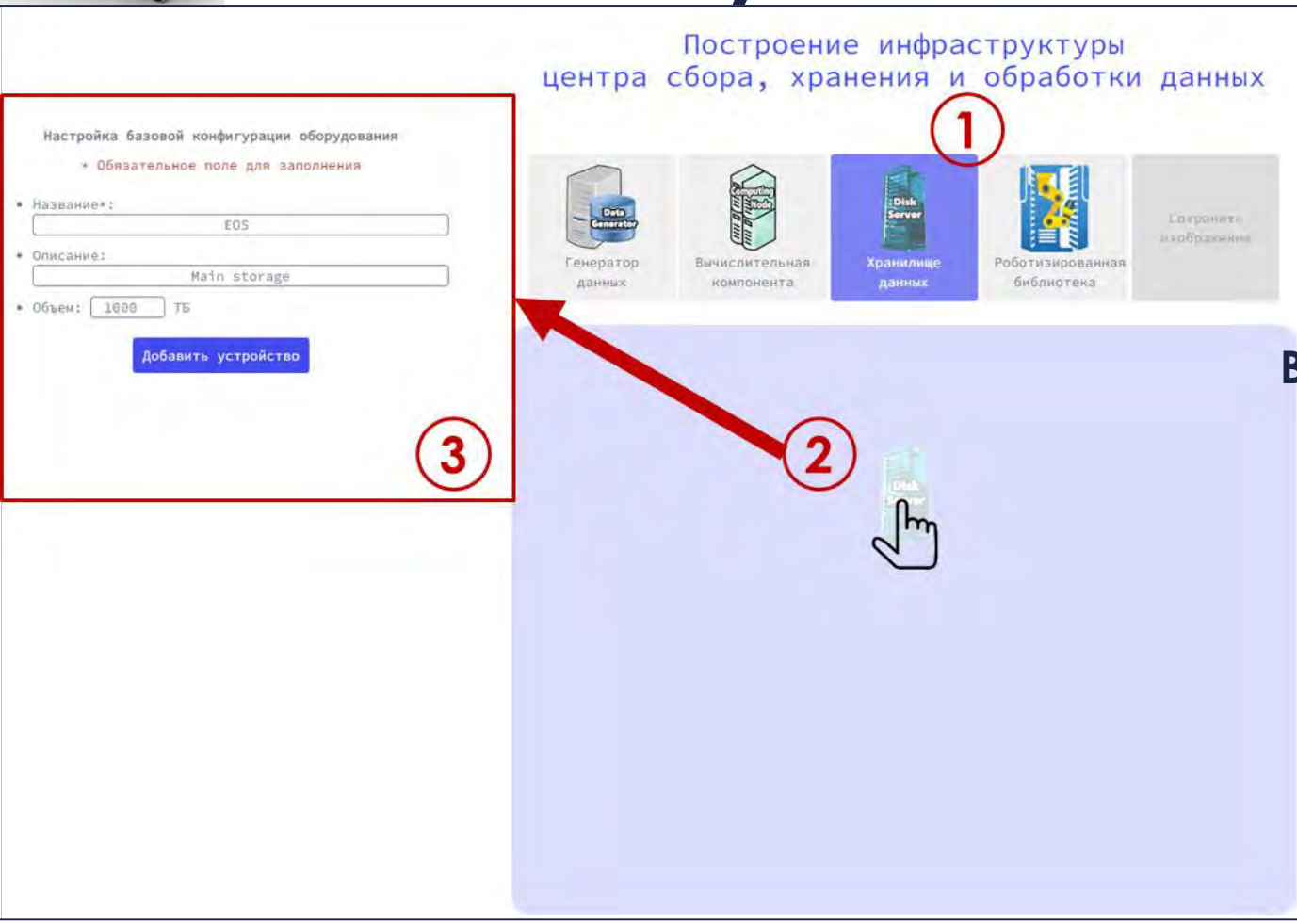
Functionality of the web service

- Setting the parameters of the DDC equipment & characteristics of data flows and jobs flows.
- Configuration of DDC scaling scenarios.
- Building the DDC structure.
- Starting the DT.
- Viewing the results of the DT.

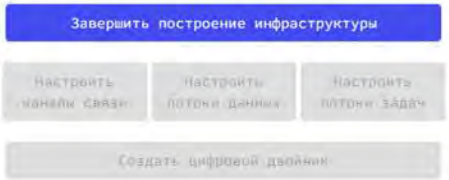


Technology stack

Functionality of the web service



Create a digital twin



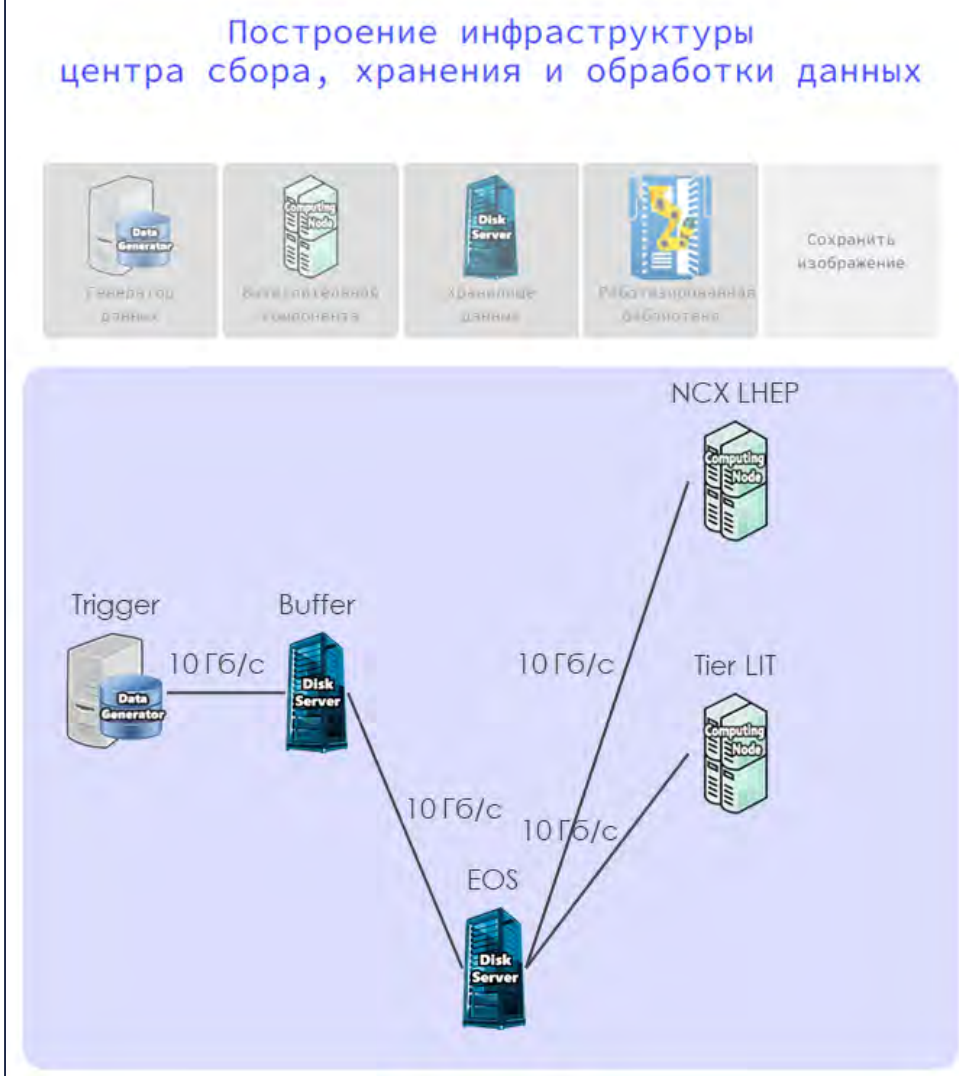
Building the computing infrastructure

1. Selecting some object
2. Putting it in the drawing area
3. Setting the equipment parameters

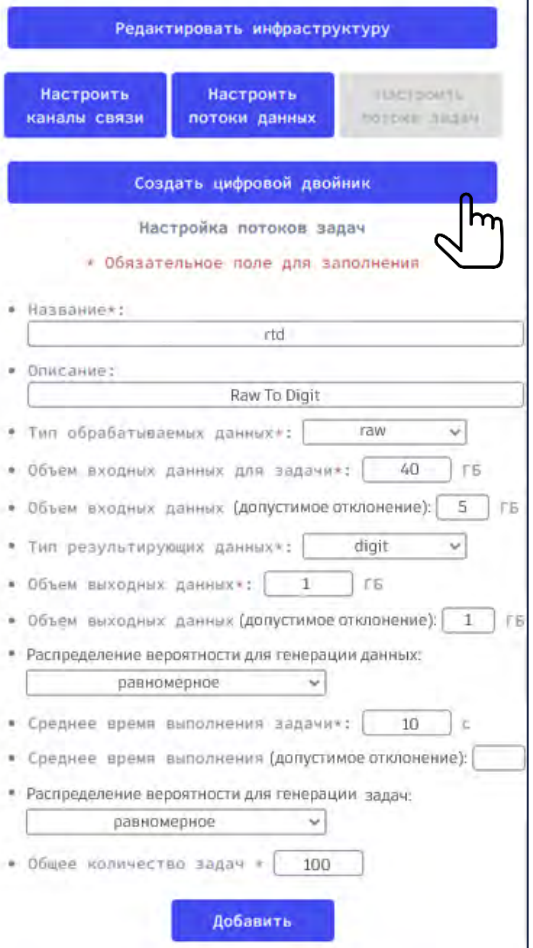
The prototype of the web service has not yet been localized.

Functionality of the web service

Functionality of the web service

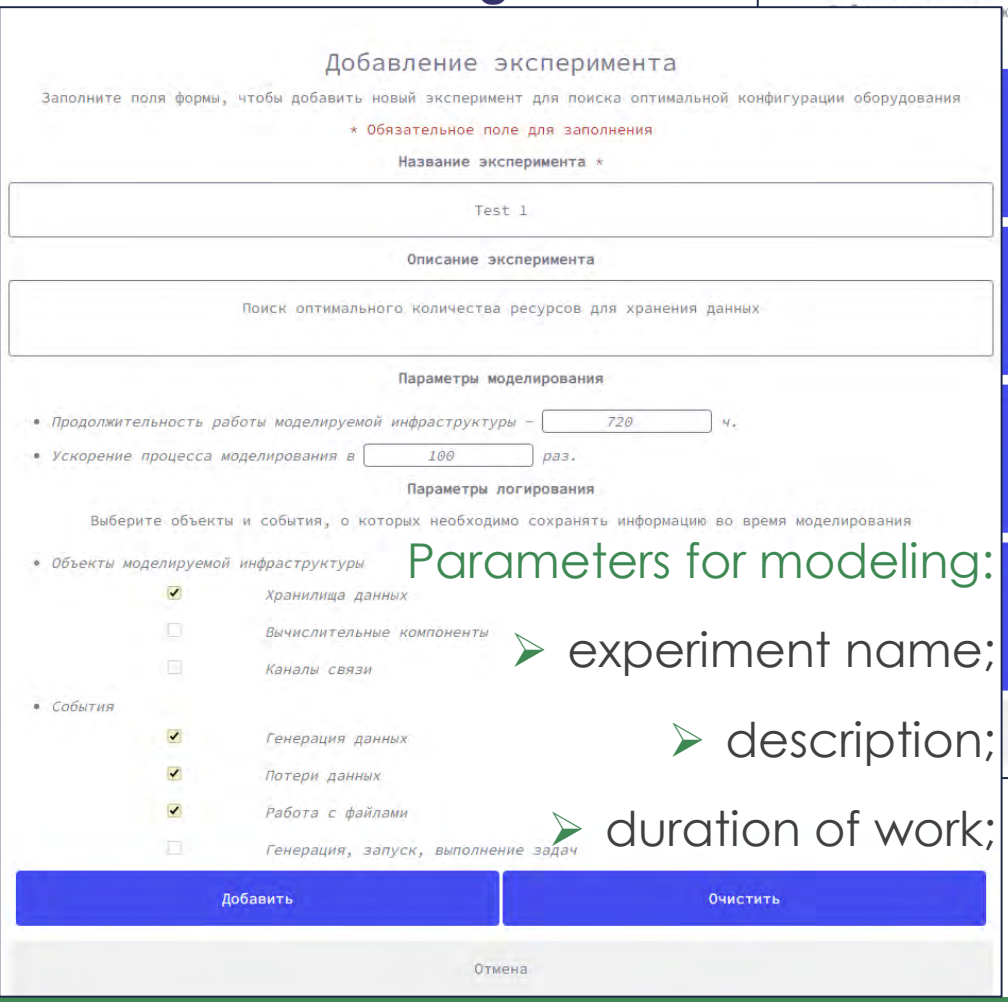


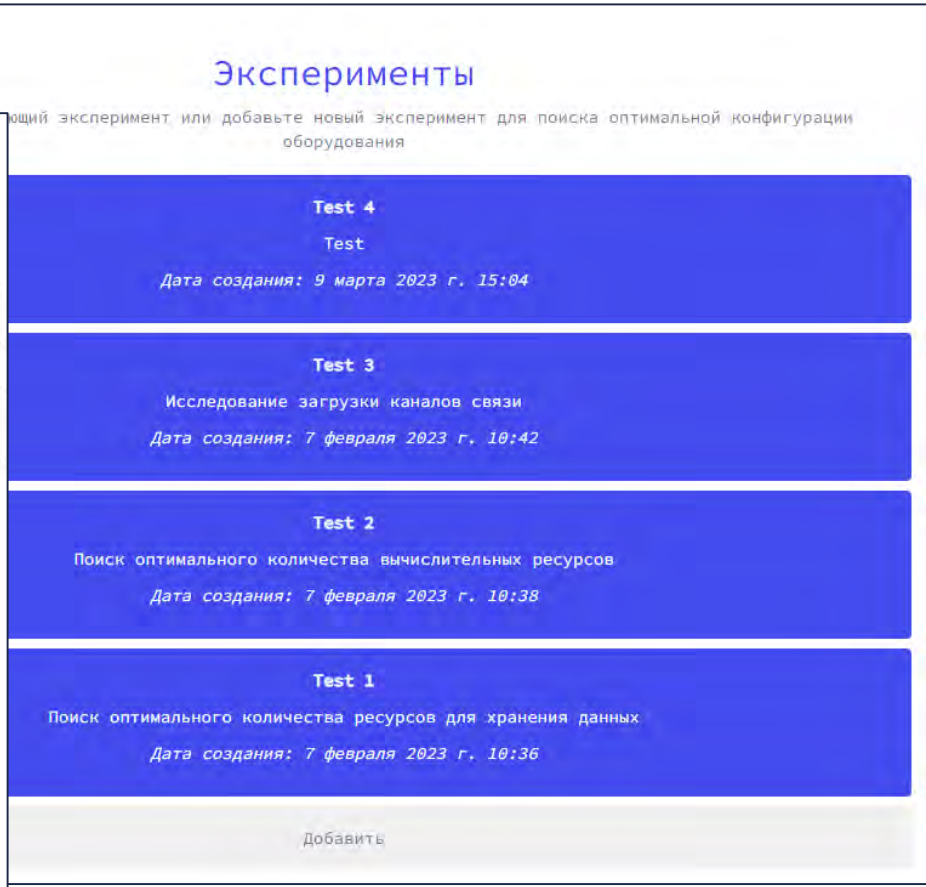
Setting parameters for data flows and job flows



Functionality of the web service

Configuration of computing infrastructure scaling scenarios





Parameters for modeling:

- experiment name;
- description;
- duration of work;
- speed up of modelling;
- objects and events for logging.

Functionality of the web service

Информация об эксперименте

Дата создания: 7 февраля 2023 г. 10:36

Название эксперимента

Test 1

Описание эксперимента

Поиск оптимального количества ресурсов для хранения данных

Параметры моделирования

- *Продолжительность работы моделируемой инфраструктуры – 800 ч.*
- *Ускорение процесса моделирования в 1000 раз.*

Параметры логирования

- *Объекты моделируемой инфраструктуры*
  - ✓ *Хранилища данных*
  - *Вычислительные компоненты*
  - *Каналы связи*
- *События*
  - ✓ *Генерация данных*
  - ✓ *Потери данных*
  - ✓ *Работа с файлами*
  - *Генерация, запуск, выполнение задач*

Посмотреть результаты

Выбрать другой эксперимент

Базовая конфигурация

Хранилища данных

Название	Описание	Объем (ТБ)
trigger	Trigger BM@N	10000,0
buffer	Data receptipon buffer	5400,0
eoslhep	Main storage LHEP	1000,0
eoslit	Main storage LIT	1000,0
dcach	pp	1000,0

Вычислительные компоненты

Название	Описание	Количество ядер
t2lit	LIT T2 farm	500
ncxlhep	LHEP main farm	1200
super	Govorun	190

Каналы связи

Название	Описание	Пропускная способность (Гб/с)
raw0	trigger – buffer	100,0
raw1	buffer – lhep	10,0
raw2	buffer – lit	10,0
compute0	lhep – farm lhep	10,0
compute1	lit – Govorun	10,0
compute2	lit – farm lit	10,0
dataeosLhepLit	eoslhep – eoslit	10,0
dataeosLitLhep	eoslit – eoslhep	10,0

Добавить модификацию

Список модификаций

№	Статус	Дата обновления			
16	NEW	9 марта 2023 г. 14:52	Просмотр	Запуск	Результаты
15	DONE	10 марта 2023 г. 10:18	Просмотр	Запуск	Результаты

Simultaneous run of all modifications is possible

Список событий

Название	Описание	
decrease	уменьшение количества ядер	Подробнее

Добавить событие

Adding and configuring events in the system

Functionality of the web service

The digital twin results

Available for viewing:

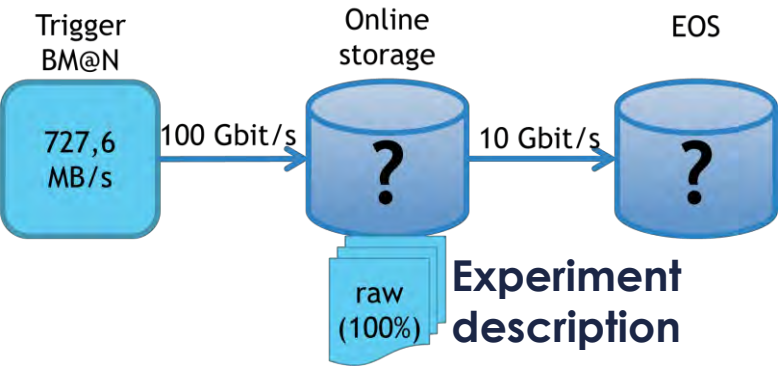
- data storage load volume;
- using cores on computing components;
- load on communication links;
- job queues, the number of completed jobs;
- distribution of files in storages.

DT of distributed systems for megascience experiments

Russia, Moscow region, Dubna, Joint Institute for Nuclear Research

Verified by the example of the BM@N experiment computing infrastructure

Experimental data acquisition and storage



Experiment description

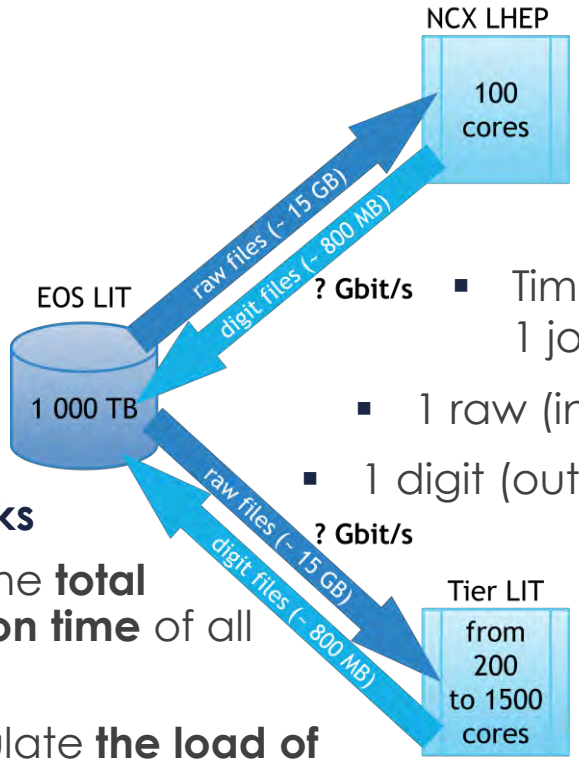
- Duration ≈ 750 hours
- 1 raw file ≈ 15 GB

Tasks

1. Find the **amount of resources** that are needed **to store all raw-data** on the Online storage.

2. Find the **number of raw files** in the EOS storage.

Running experimental data processing jobs



Experiment description

- Number of jobs – 25 800
- Time to complete a 1 job ≈ 2 500 сек
- 1 raw (input) file ≈ 15 GB;
- 1 digit (output) file ≈ 800 MB

Tasks

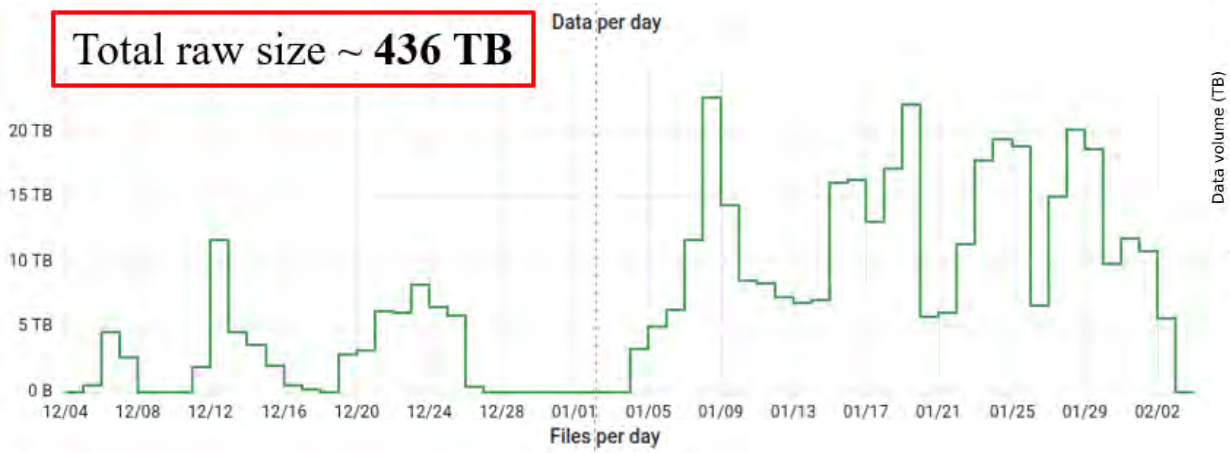
1. Find the **total execution time** of all jobs.

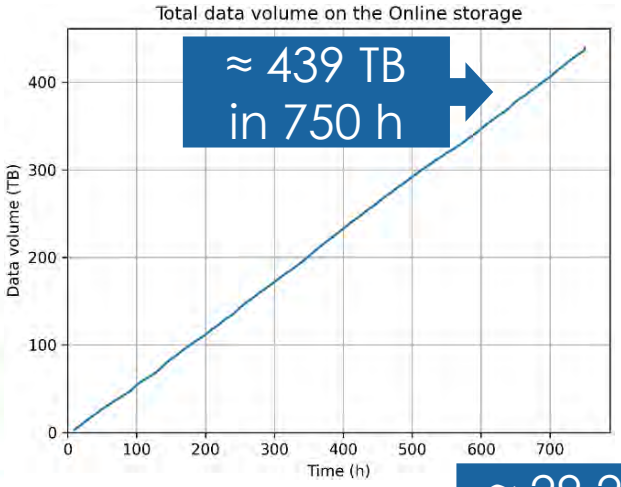
2. Calculate **the load of computing resources** during the execution of jobs.

3. Calculate **the load of communication links**.

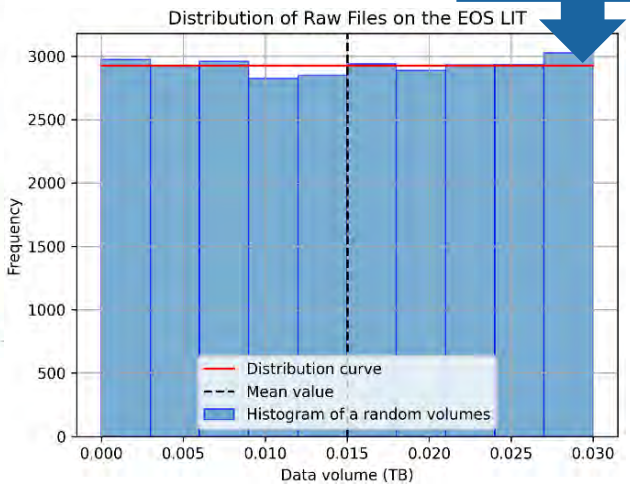
Monitoring VS Digital Twin

The probability of stopping (failure) of the data generator – 80%





≈ 29 241 raw files



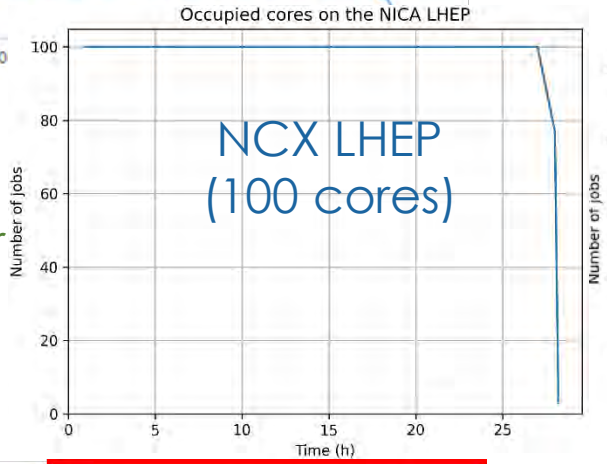
- Non uniform distribution.
- No data is received at all by some periods.

Priakhina D., Korenkov V., Trofimov V., Gertsenberger K. Verification of the simulation program for creating digital twins of distributed data acquisition, storage and processing centers // International Journal of Open Information Technologies, Vol. 12, No 1, pp. 118-128, 2024. – ISSN:2307-8162.

Monitoring VS Digital Twin

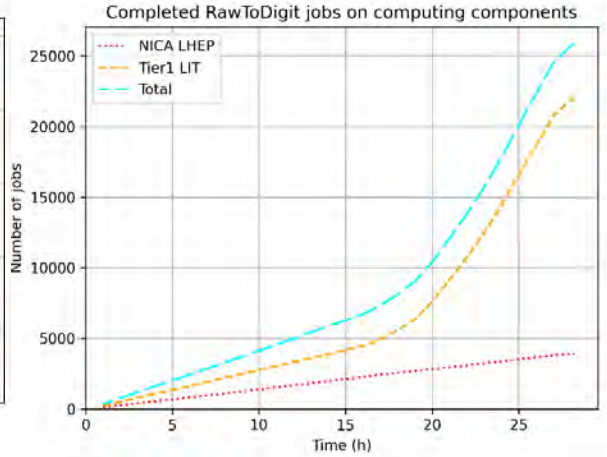
NCX LHEP (100 cores) Processing time of all jobs ≈ 30 h

Total number of jobs **4844**



- Uniform using of resources
- ≈ 100 jobs / h
- 19% jobs of the total number

NCX LHEP ≈ 3 875 jobs (15%)

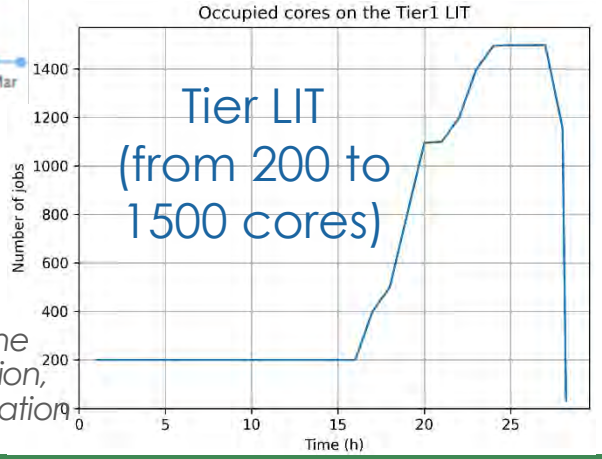


Tier LIT (from 200 to 1500 cores)

Total number of jobs **20956**

- Non uniform using of resources
- 200 – 1 500 jobs / h
- 81% jobs of the total number

Tier LIT ≈ 21 925 jobs (85%)



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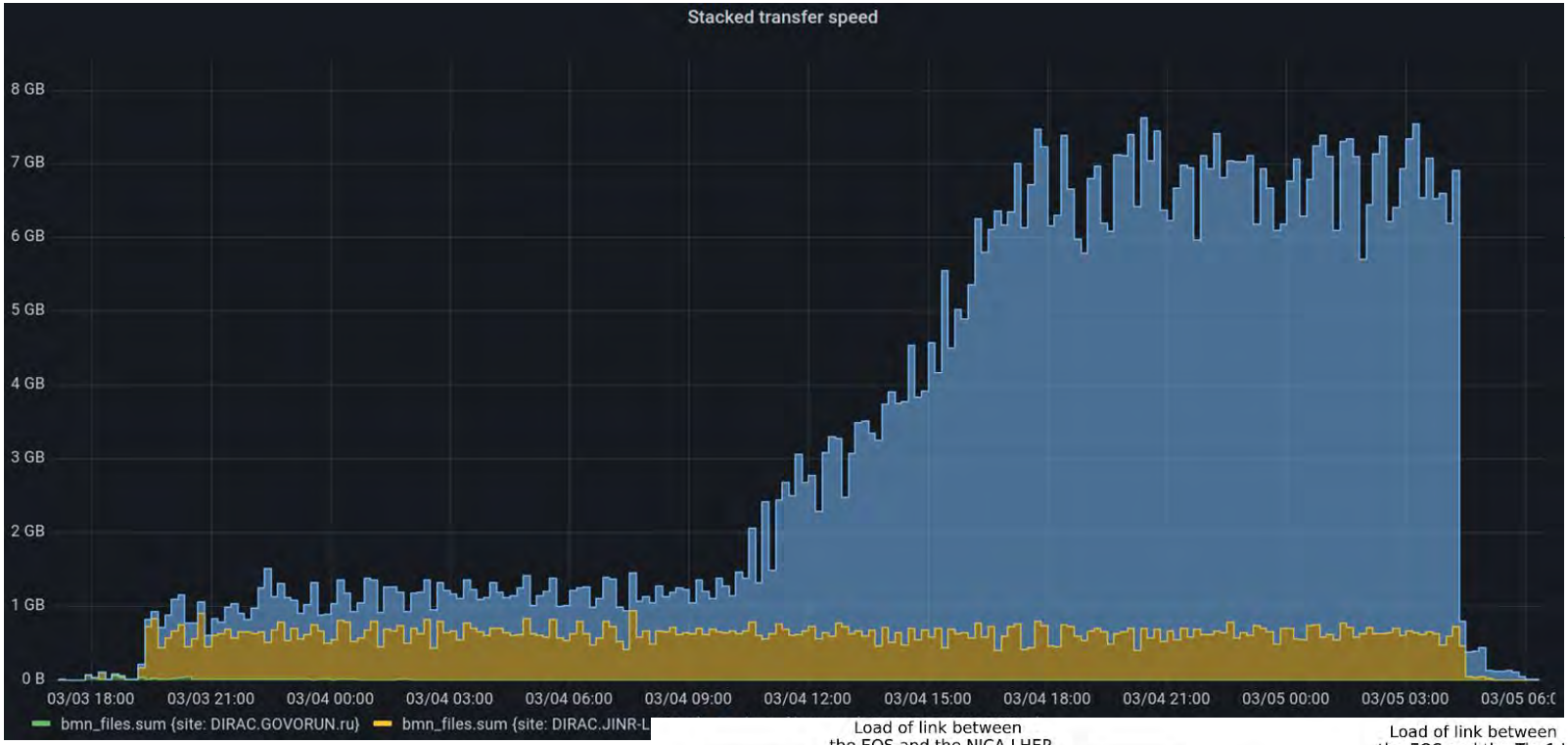
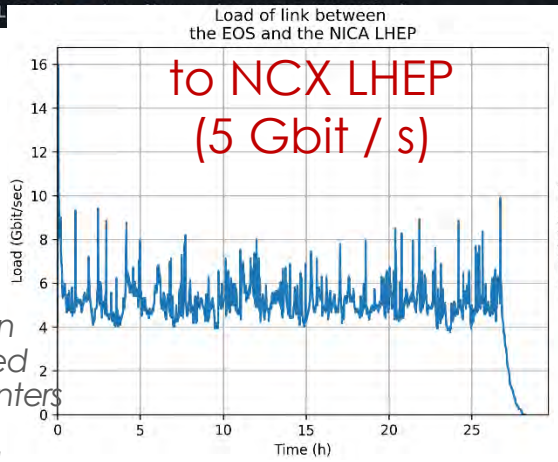
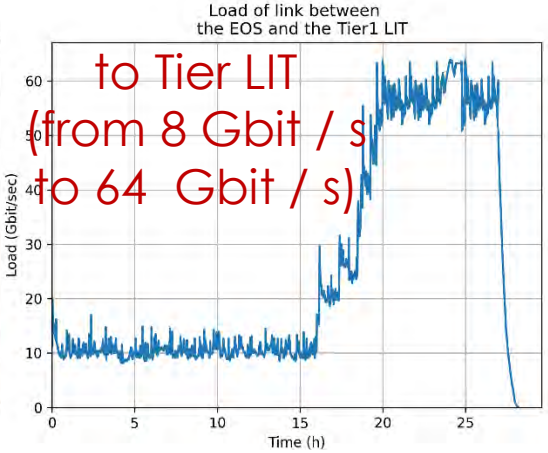


- Avg. data transfer rate to NCX LHEP ≈ 4 Gbit / s
- Avg. data transfer rate to Tier LIT from 8 Gbit / s to 64 Gbit / s





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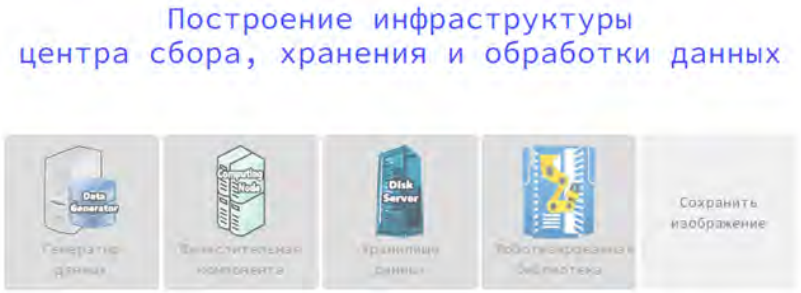
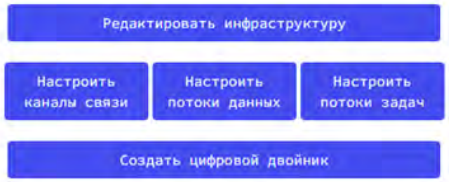
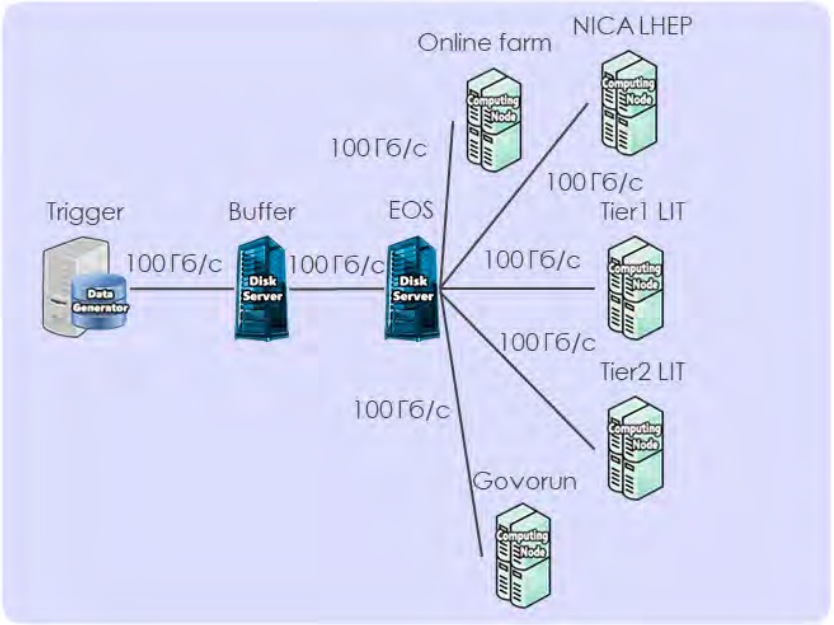
Digital Twin of the BM@N experiment computing infrastructure





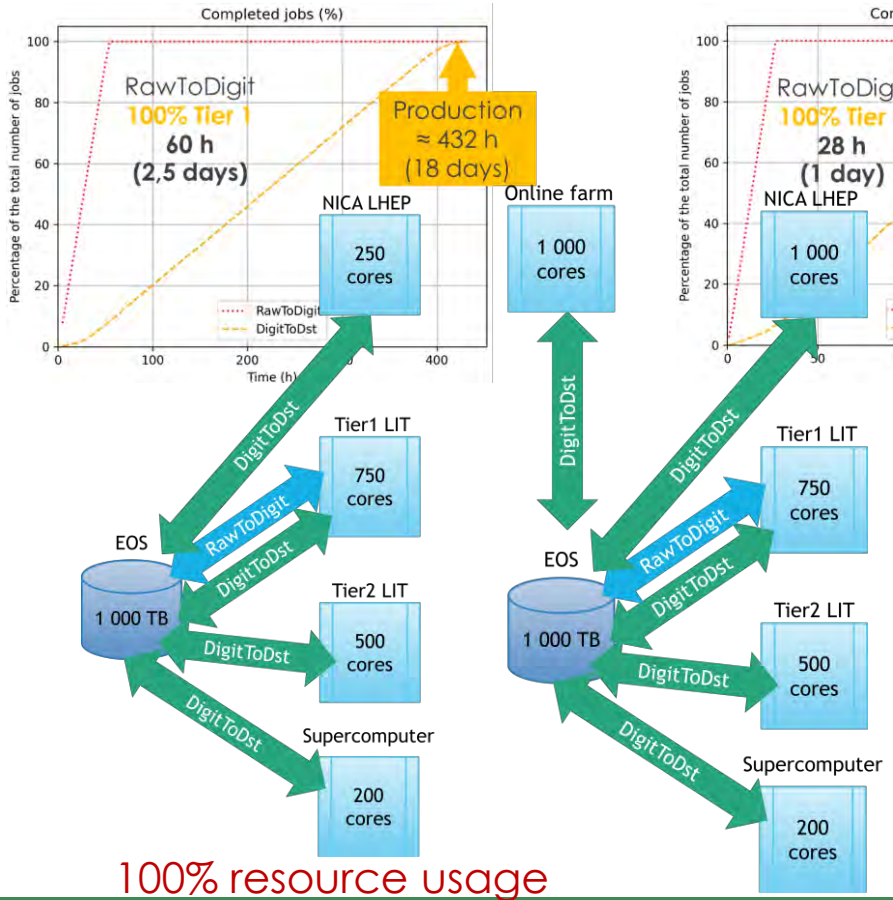


Goals:

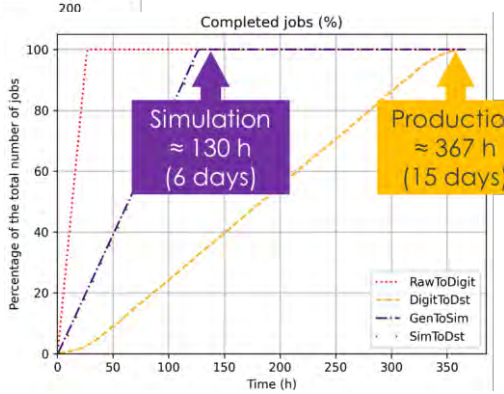
- assessing the resource requirements for data storage and processing, taking into account the planned parameters of the data flows of future experimental Runs;
- obtaining an approximate time that will be required to process the data at the end of the experiment Run.

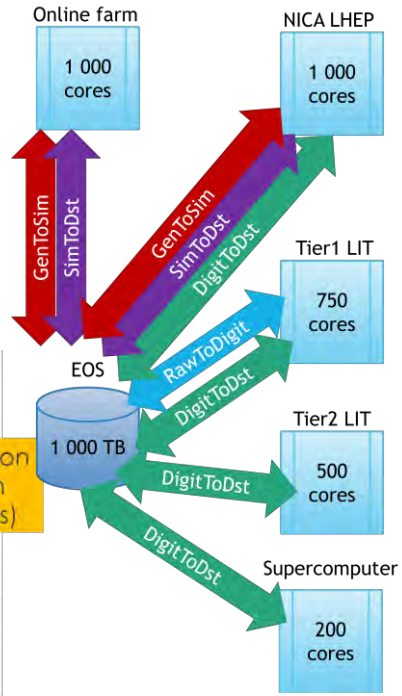
Digital Twin of the BM@N experiment computing infrastructure

Comparison of different data processing infrastructure configurations



100% resource usage





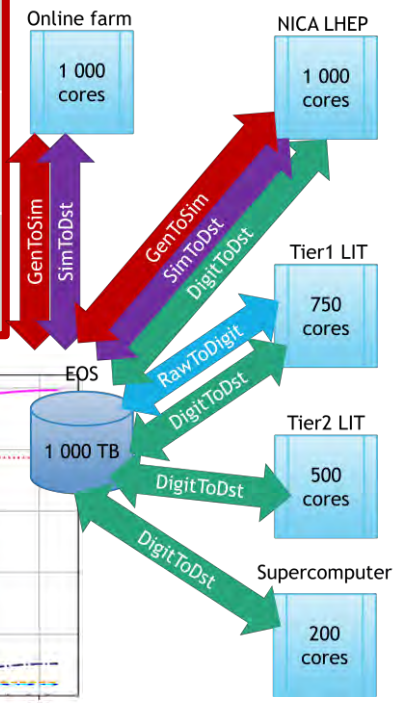
The number of NICA LHEP resources has been increased to 1 000 cores.
Added Online farm resources (1 000 cores).

Digital Twin of the BM@N experiment computing infrastructure

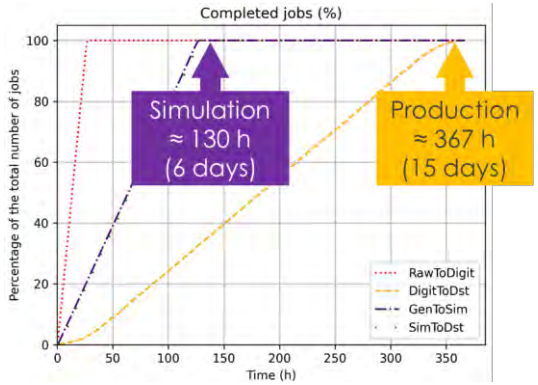
Results

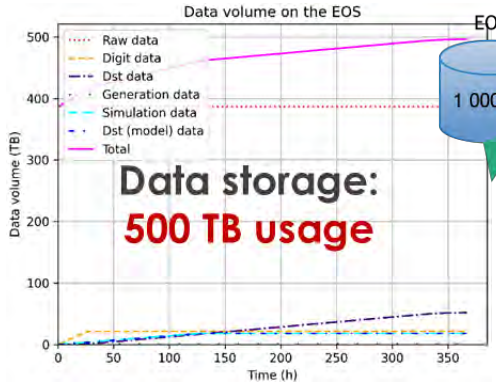
	1	2	3
During of conversion of raw experimental data to digit data (RawToDigit jobs)	60 hours (2,5 days)	**28 hours** (1 day)	**28 hours** (1 day)
During of processing experimental data to reconstruction data	432 hours (18 days)	**240 hours** (10 days)	**367 hours** (15 days)
During of processing simulation data to reconstruction data	---	---	**130 hours** (6 days)

The process of converting raw data is **speed up in 2 times**



A configuration has been found for processing experimental and simulated data in the shortest amount of time using all available resources.

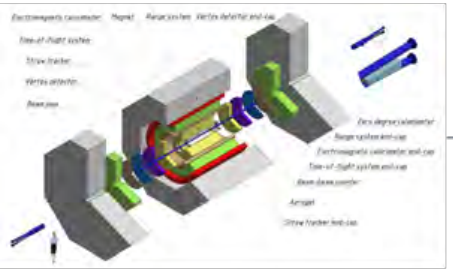




Digital Twin of SPD Online filter

First experience

Raw data rate
20 GB/s



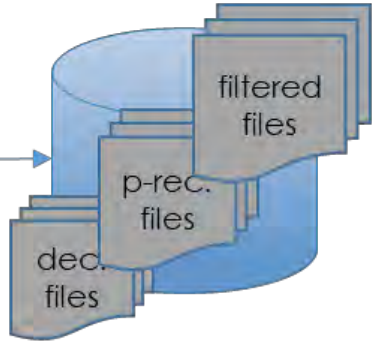
1 raw event = 7 KB

Buffer for
data received
from the detector

1 raw file = 4 GB

Computing
resources

Storage for
intermediate
data



Processing raw file
to filt. file: **10 min**

1) Decryption:
raw file → dec. file — 1 dec. file = 4 GB

2) Partial reconstruction:
dec. file → p-rec. file — 1 p-rec. file = 8 GB

3) Filtering:
p-rec → filt. file — 1 filtered file = 450 MB

Experiment duration: 24 hours

To calculate:

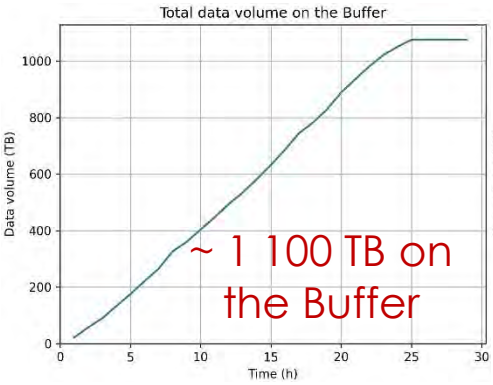
- ? data storage volumes;
- ? network load;
- ? load of computing resources etc.

Digital Twin of SPD Online filter

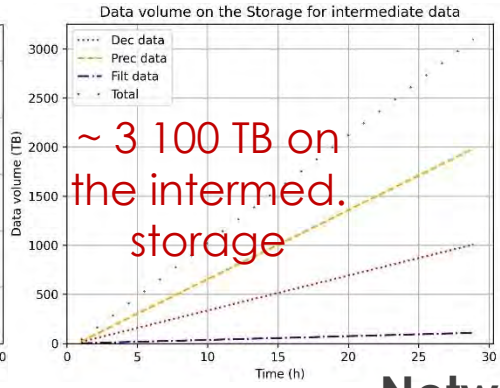
First experience

Data generation efficiency – 60%

Data storages

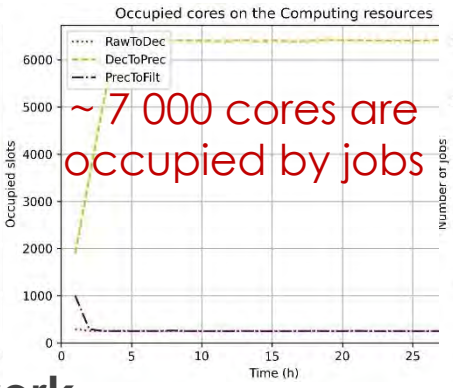


~ 1 100 TB on the Buffer

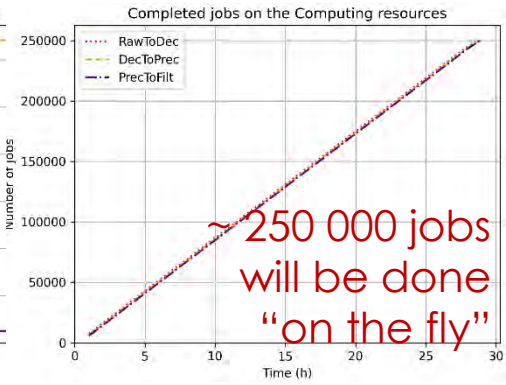


~ 3 100 TB on the intermed. storage

Computing resources

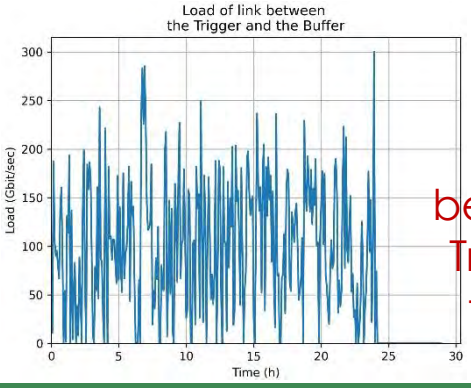


~ 7 000 cores are occupied by jobs

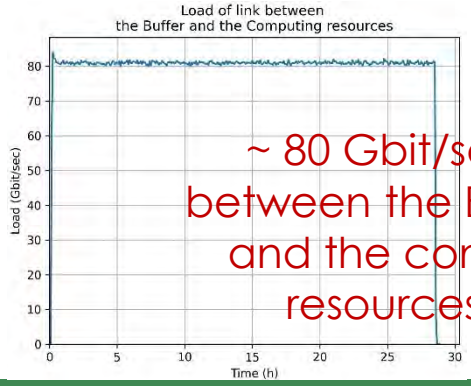


~ 250 000 jobs will be done "on the fly"

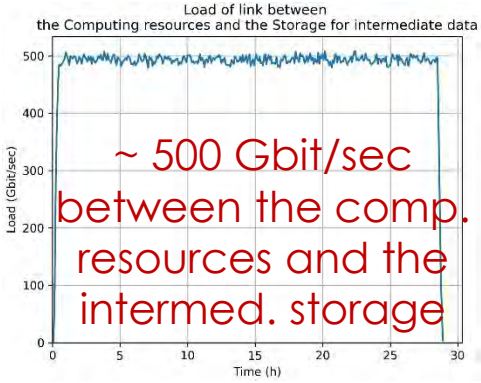
Network



~ 150 Gbit/sec between the Trigger and the Buffer



~ 80 Gbit/sec between the Buffer and the comp. resources



~ 500 Gbit/sec between the comp. resources and the intermed. storage

Conclusions

- Software complex has been developed to create digital twins of distributed data acquisition, storage and processing centers:
  - database;
  - modelling program (**successful approbation**);
  - web-service (prototype: building DT, setting configurations, starting DT, viewing results).
- The modeling program takes into account:
  - the probability of failures and changes in equipment parameters;
  - requirements for stored data flows;
  - requirements for data processing job flows.


РОССИЙСКАЯ ФЕДЕРАЦИЯ

СВИДЕТЕЛЬСТВО

о государственной регистрации программы для ЭВМ

№ 2023667305

Программный комплекс для создания цифровых двойников распределенных центров сбора, хранения и обработки данных

Правообладатель: Объединенный Институт Ядерных Исследований (RU)

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Заявка № 2023665363

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Дата государственной регистрации в Реестре программ для ЭВМ 14 августа 2023 г.

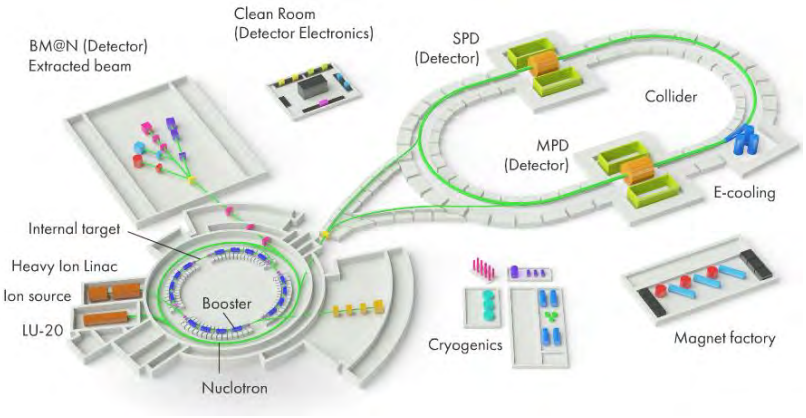
Руководитель Федеральной службы по интеллектуальной собственности Ю.С. Зубов

The certificate of state registration №2023667305 (14.08.2023, Russia)

Conclusions

- Software complex is used for the design of NICA project computing infrastructures.

Nuclotron-based Ion Collider fAcility
(NICA, JINR, Dubna, Russia)



- The examples confirm the possibility of further use of the software complex and digital twins **for solving management and development tasks of distributed computer systems for megascience projects**.

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2. Thanks to **Konstantin Gertsenberger (LHEP)** for providing the source data and the opportunity to use the software complex for modeling of the BM@N experiment computing infrastructure.
3. Thanks to **Igor Pelevanyuk (MLIT)** for providing data monitoring the use of the BM@N experiment computing infrastructure for verification of the modeling program.
4. Thanks **Danila Oleynik (MLIT)** and SPD collaboration for providing the source data and the opportunity to use the software complex to create digital a twin of SPD Online filter.

Thank you for the attention!

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