Fizikai (fejlesztési) problémák, innovatív megoldások, új foglalkozások

Lévai Péter
HUN-REN WIGNER FK

Csillebérc, November 30. 2024

Előszó:

Az alapkutatás hosszú múltra tekint vissza, számos sikeres pillanattal, amelyek elősegítették az emberiség fejlődését, és minden eddiginél jobbá tették a mindennapi életet. Napjainkban a tudomány minden területén az összegyűjtött tudás gyors növekedését tapasztaljuk, ami új kihívásokat és igényeket támaszt a tudósok következő generációjával szemben.
Az egyik megoldás lehet a mesterséges intelligencia alkalmazása, kapcsolódó módszereivel és kihegyezett, specializált alkalmazásaival.
Azonban ez az új típusú tevékenység új készségeket igényel a tudósoktól.

Előadásomban a legújabb tendenciákról és elvárásokról fogok beszámolni, miként javítsuk képességeinket, növeljük hatékonyságunkat, hogy sikeresen tudjunk szembenézni ezekkel az új kihívásokkal.

Magfizika és nukleáris tudományok: komplex rendszerek → fenomelógia

A Világgazdaság története: komplex rendszer → fenomenológia

Kondratev Waves: „new mechanism” after 50 (40?) years of solid development (jump after linear accumulation)

Waves:	KW-1	KW-2	KW-3	KW-4
Time-period:	1780-1830	1830-1880	1880-1930	1930-1970
Propulsion: („Innovation”)	Steam machine	Railway, steel	Electricity, chemicals	Cars, petrolchemistry
Primary application fields	Textil ind. mining ind. energy prod.	Transport infrastr., cities	Public services, mass prod.	Personal mobility, delivery of goods and anything
Human interest	New tools for a better life	Go further, go higher	Maintenance of buildings	Desire for freedom

History of World Economy: complex systems → phenomenology

Kondratev Waves: „new mechanism" after 40 (30?) years of solid development (jump after linear accumulation)

Waves:	KW-5	KW-6	KW-7	KW-8
Time-period:	1970-2010	2010-2050	2050-2080	2080-2100
Propulsion: („Innovation")	Digital com. technology	Intelligent, efficient technologies	?? ??	??? ???
Primary application fields	Personal comp. mobil phone	Material and energy production, consumption	?? ??	??? ???
Human interest	Creating new space, virtual reality	Coherence between private sphere, Nature and Technology	?? ?? ??	??? ??? ???

Research and Education

at the boundary line

of KW-5 and KW-6

(details/examples with/on our daily experiences)

HUN-REN
Hungarian Research Network

Wigner Research Centre for Physics of the Hungarian Research Network

Institute for Particle and and Nuclear Physics

Particle and nuclear physics
Innovativ materials, AI/NI
Space science, Qcomputing
Information technology

Institute for Solid State Physics and Optics

Solid state physics, crystals
Laserphysics, optics
Quantum tech & communication
Complex system, fluids

HUN-REN Wigner RCP – Resources (in general)

Human resources

- 400 employees
- 34 research groups
- 6 academicians, 41 DsC of HAS
- 220 researchers (125 PhD)
- 45 PhD students

Projects and collaborations

- 8 national consortia (cons. leader)
- 62 NRDIO projects (national)
- 13 EU consortial projects (HE)
- 40 industrial partners
- 90 international academic partners, with joint publications in 2024

Budget in 2024: 18 M€

Mechanical and electronic workshops

Wigner Data Centre

Library

Flagship projects on Large Scale Research Infrastructures:

1. High Energy Paritcle and Nuclear Physics

CERN

ALICE

CMS Compact Muon Solenoid

TOTEM

SHINE NA61

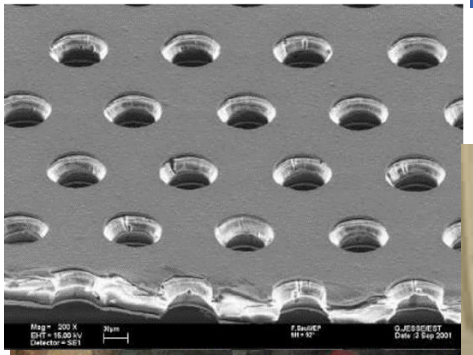
Collaboration spotting

WLCG

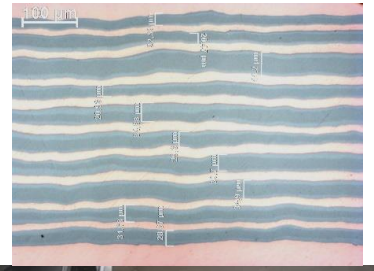
RD51

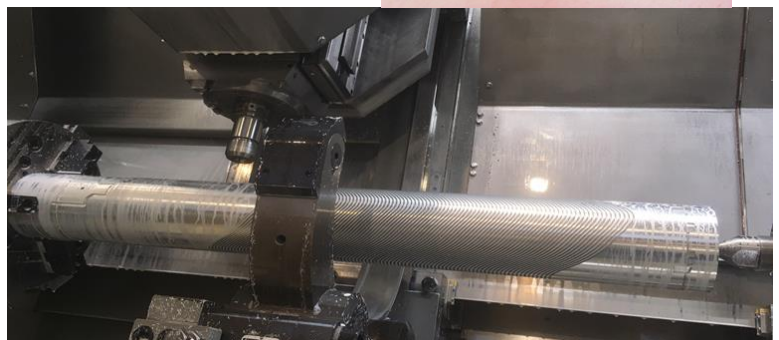
FCC hh ee he

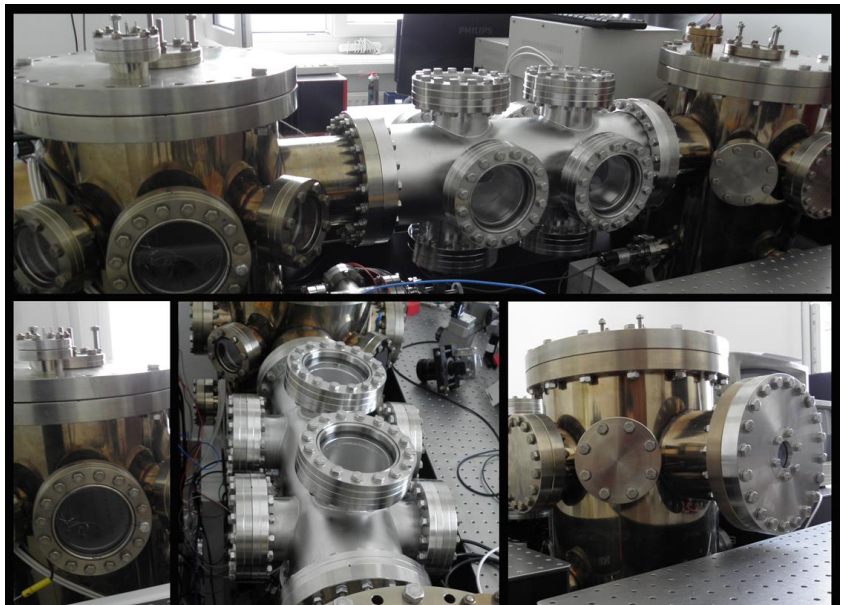
2. New-Tech Detectors and Accelerators – Superconducting magnets, Laserplasma Accel.

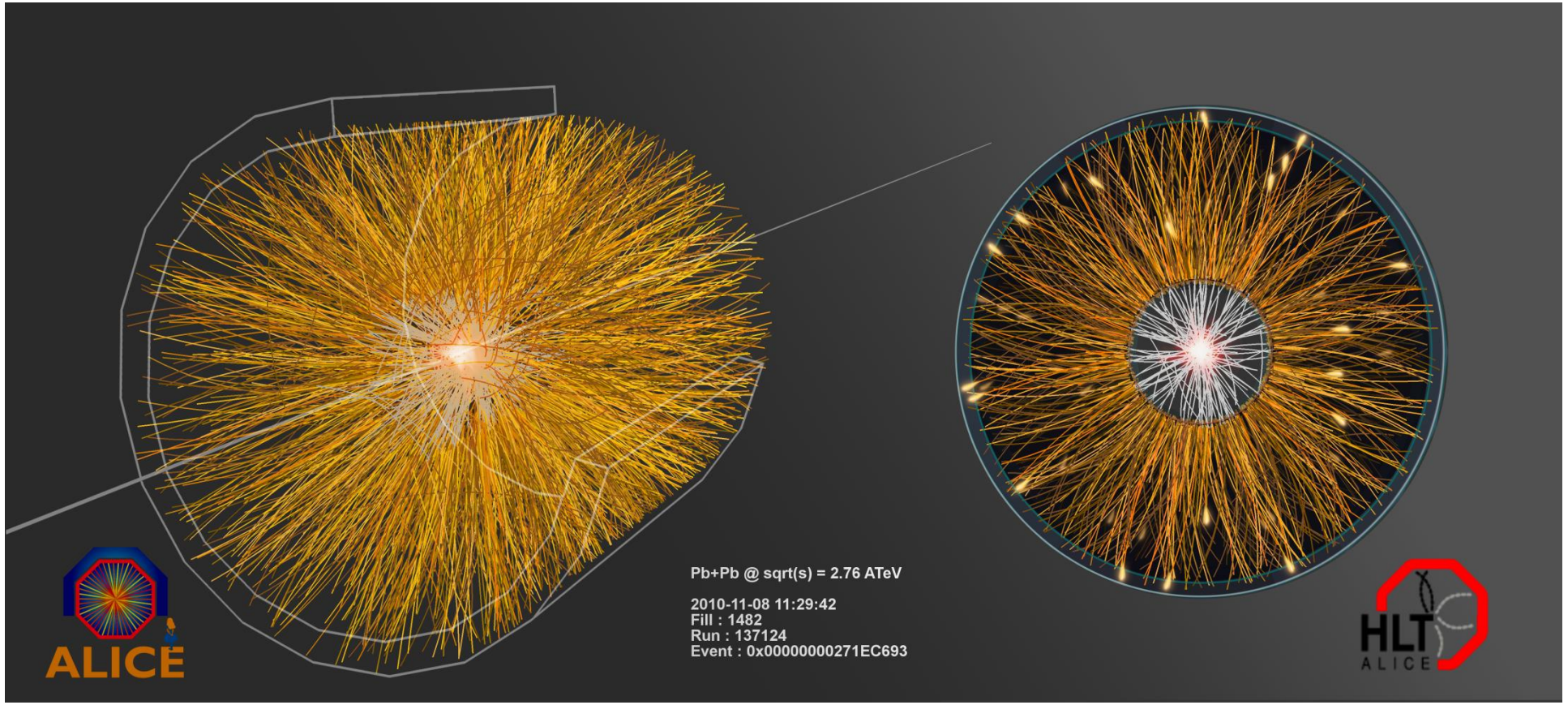


NbTi/Nb/Cu
multilayer
for SUSHI@FCC









Visualization of Pb+Pb collisions (ALICE TPC and ITS).

100 MB digital camera → fast data collection and transfer (DAQ)

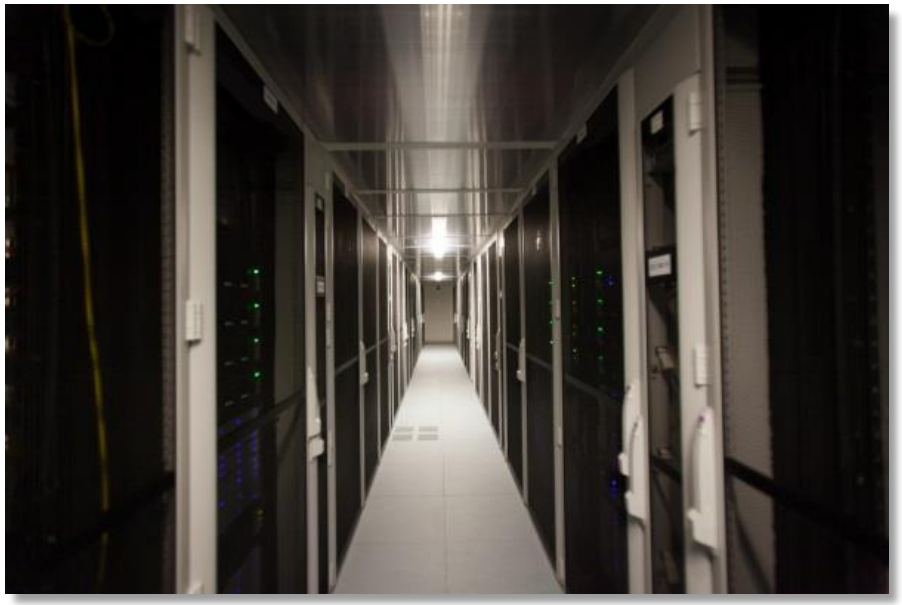
ALICE: Hungarian contribution (2006/2015/2025)

ALICE AF : Analysing Facility → modern version of TIER-X stations (2021-2026)

WIGNER Datacenter --- WIGNER RCP

2013-2019: hosting CERN TIER-0 [1300 km 2 x 100 Gbit/s]

2020- : National Center of IT-related Knowledge Transfer



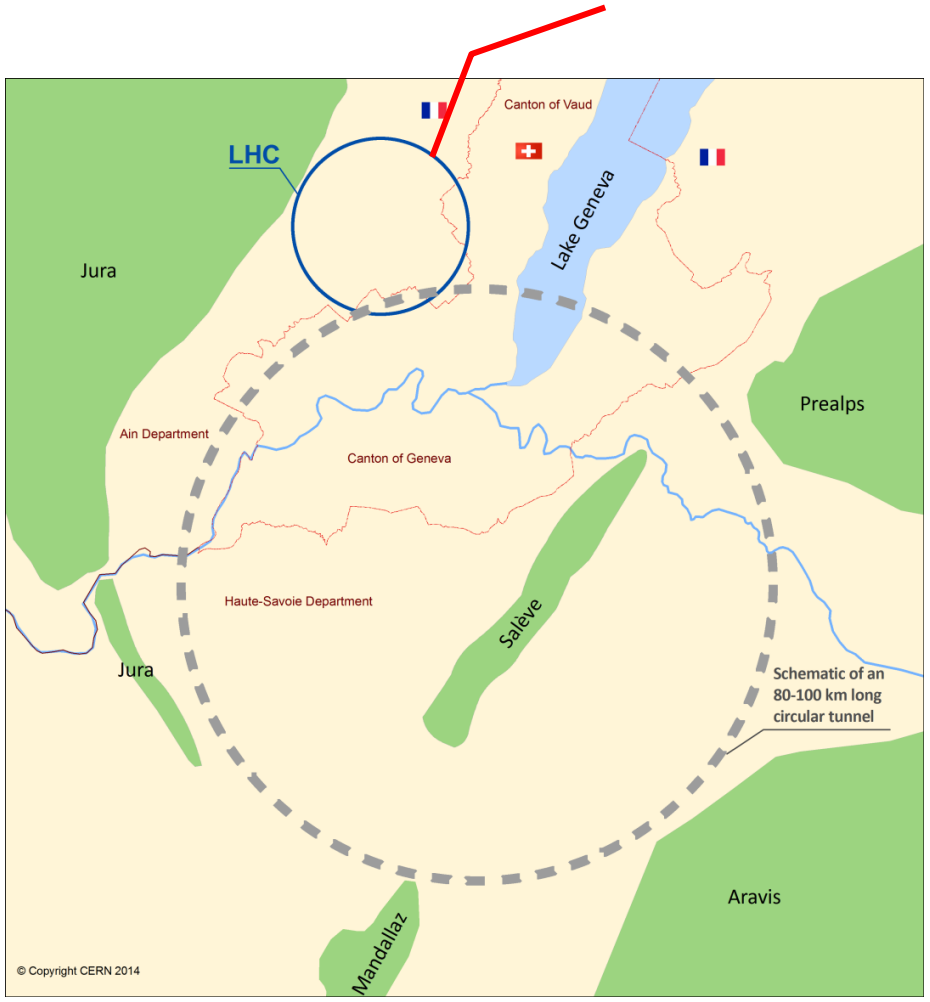
High reliability data transfer, data handling, data mining
Big Data Day, GPU - Multicore Workshop, (2012 –)
HEPTECH AIME ICT (2015 –); TIER-2 & ALICE AF
Wigner Cloud (1000+ core), ELKH National Cloud (1500+ core), 2 PB HD
+ GPU minisuper comp. + FPGA → Quantum Computer Emulators
+ EuroHPC; + Euro QCI (Quantum Communication Initiative); + …

Next Step: "High Energy LHC„ → FCC

HE-LHC :33 TeV with 20T magnets

First studies on a new 80 km tunnel in the Geneva area

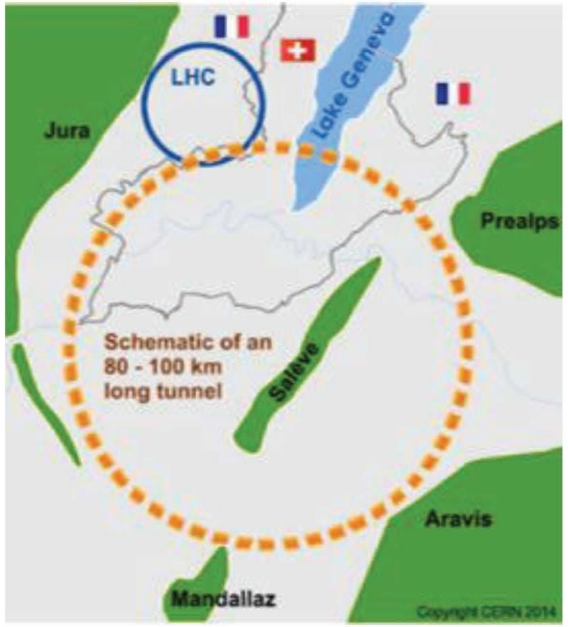
- **42 TeV with 8.3 T using present LHC dipoles**
- **80 TeV with 16 T based on Nb_3Sn dipoles**
- **100 TeV with 20 T based on HTS dipoles → FCC_max**

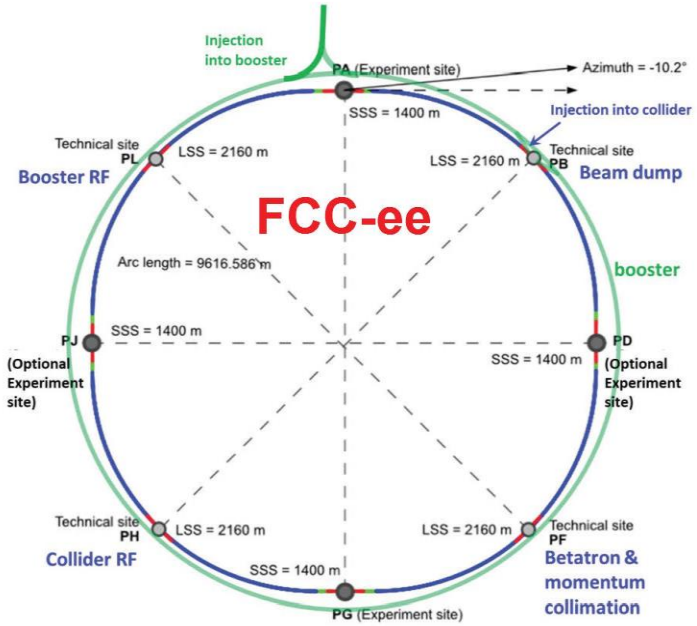


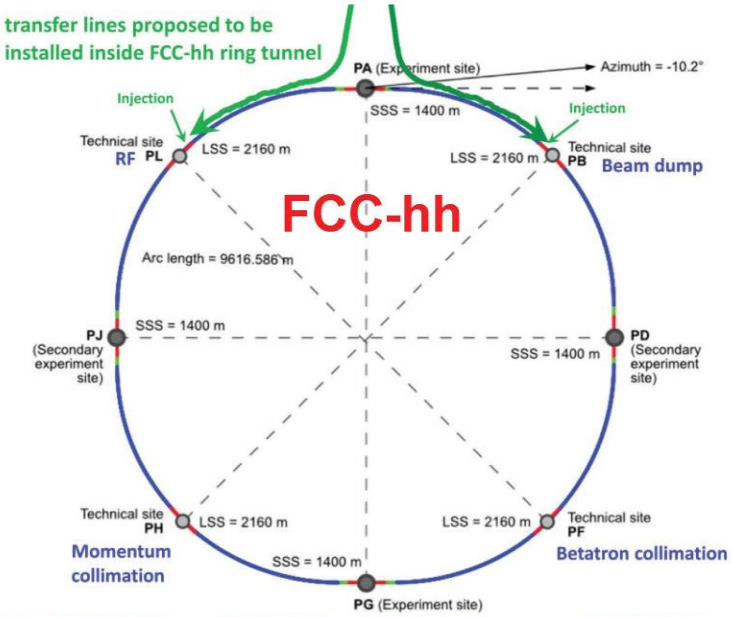
FCC integrated program

comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, tt̄) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders (e.g. model-independent measurements of the Higgs couplings at FCC-hh thanks to input from FCC-ee; and FCC-hh as "energy upgrade" of FCC-ee)
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC

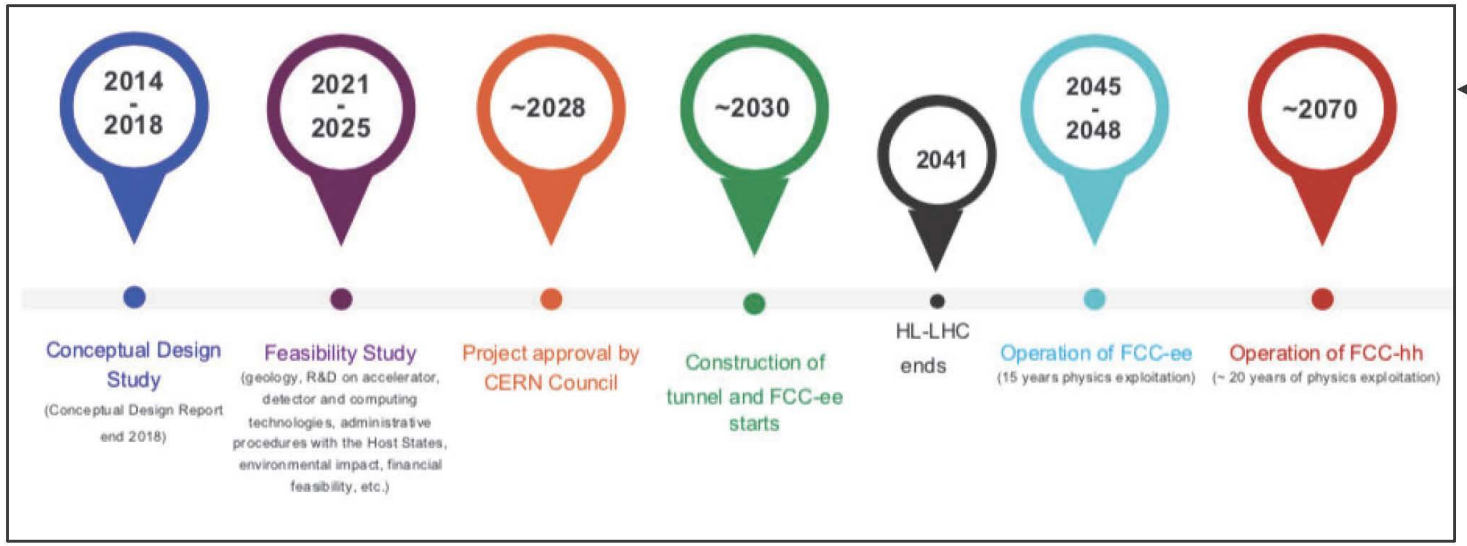






2020 - 2040 | 2045 - 2063 | 2070 - 2095

FCC estimated timeline



"Realistic" schedule taking into account:

- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until 2041

→ **ANY future collider at CERN cannot start physics operation before ~ 2045**

1st stage collider, FCC-ee: electron-positron collisions 90-360 GeV
Construction: 2033-2045 → Physics operation: 2048-2063

2nd stage collider, FCC-hh: proton-proton collisions at ≥ 100 TeV
Construction: 2058-2070 → Physics operation: ~ 2070-2095

Note:
Care should be taken when comparing to other proposed facilities, for which in some cases only the (optimistic) technical schedule is shown

History of World Economy: complex systems → phenomenology

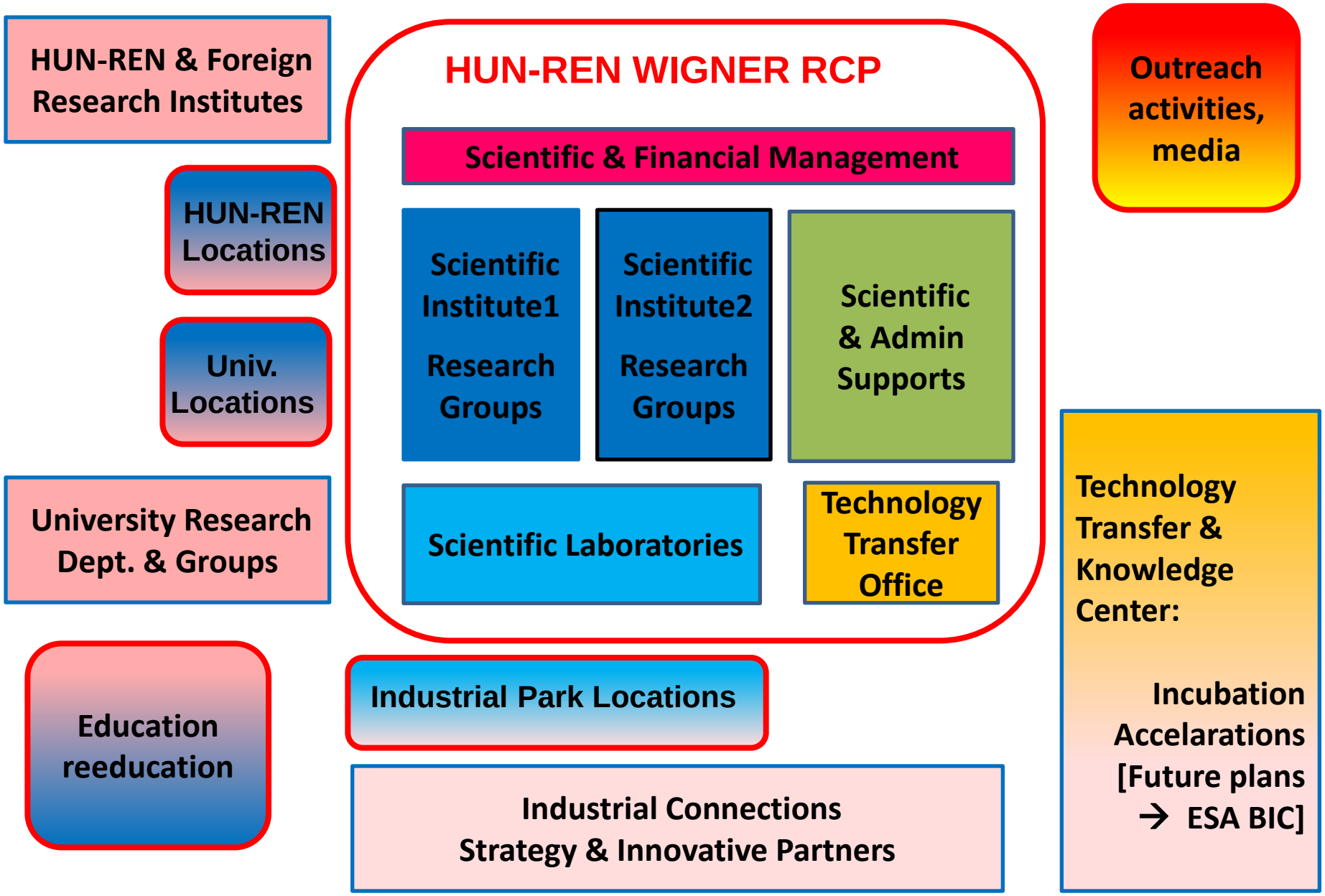
Kondratev Waves: „new mechanism" after 40 (30?) years of solid development (jump after linear accumulation)

Waves:	KW-5	KW-6	KW-7	KW-8
Time-period:	1970-2010	2010-2050	2050-2080	2080-2100
Propulsion: („Innovation")	Digital com. technology	Intelligent, efficient technologies	?? ??	??? ???
Primary application fields	Personal comp. mobil phone	Material and energy production, consumption	?? ??	??? ???
Human interest	Creating new space, virtual reality	Coherence between private sphere, Nature and Technology	?? ?? ??	??? ??? ???

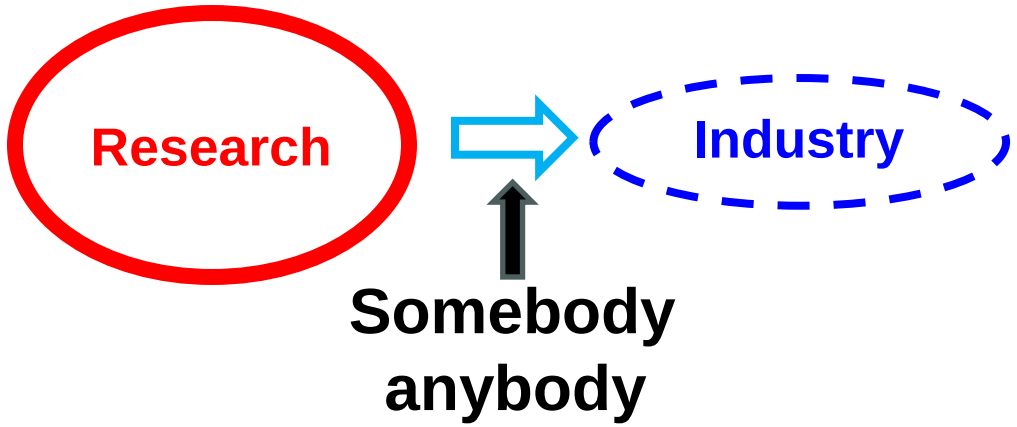
The key-missions of the HUN-REN Wigner RCP

Annual reports: the summary of our yearly activities

https://wigner.hu/en/yearbook


HUN-REN & Foreign Research Institutes
HUN-REN Locations
Univ. Locations
University Research Dept. & Groups
Education reeducation
HUN-REN WIGNER RCP
Scientific & Financial Management
Scientific Institute1 Research Groups
Scientific Institute2 Research Groups
Scientific & Admin Supports
Scientific Laboratories
Technology Transfer Office
Industrial Park Locations
Industrial Connections Strategy & Innovative Partners
Outreach activities, media
Technology Transfer & Knowledge Center:
Incubation
Accelarations
[Future plans → ESA BIC]

Traditional Research Institute



„Curiosity driven" research activity

„Transformation" of the scientific and technological achievements

Research is dominant (overwhelming) industrial application is „interesting"

Industrial success is secondary bonus

New Wave Research Institute

Application oriented research [R&D&I] activity

New definitions for the „real value" of scientific research (scientific + socio-economical impact + green + …)

Deep „integration" into industry and university activities (strategic partners and business expectations)

„Demand driven" scientific research plan

Collaborations („Best Practice") yield essential inputs, strengthening competitiveness (flexibility, adaptability)

Human factor:

„New-wave” scientists for KW-6

personal skills + external support

→ AI/ML extensions

(What are these extensions?)

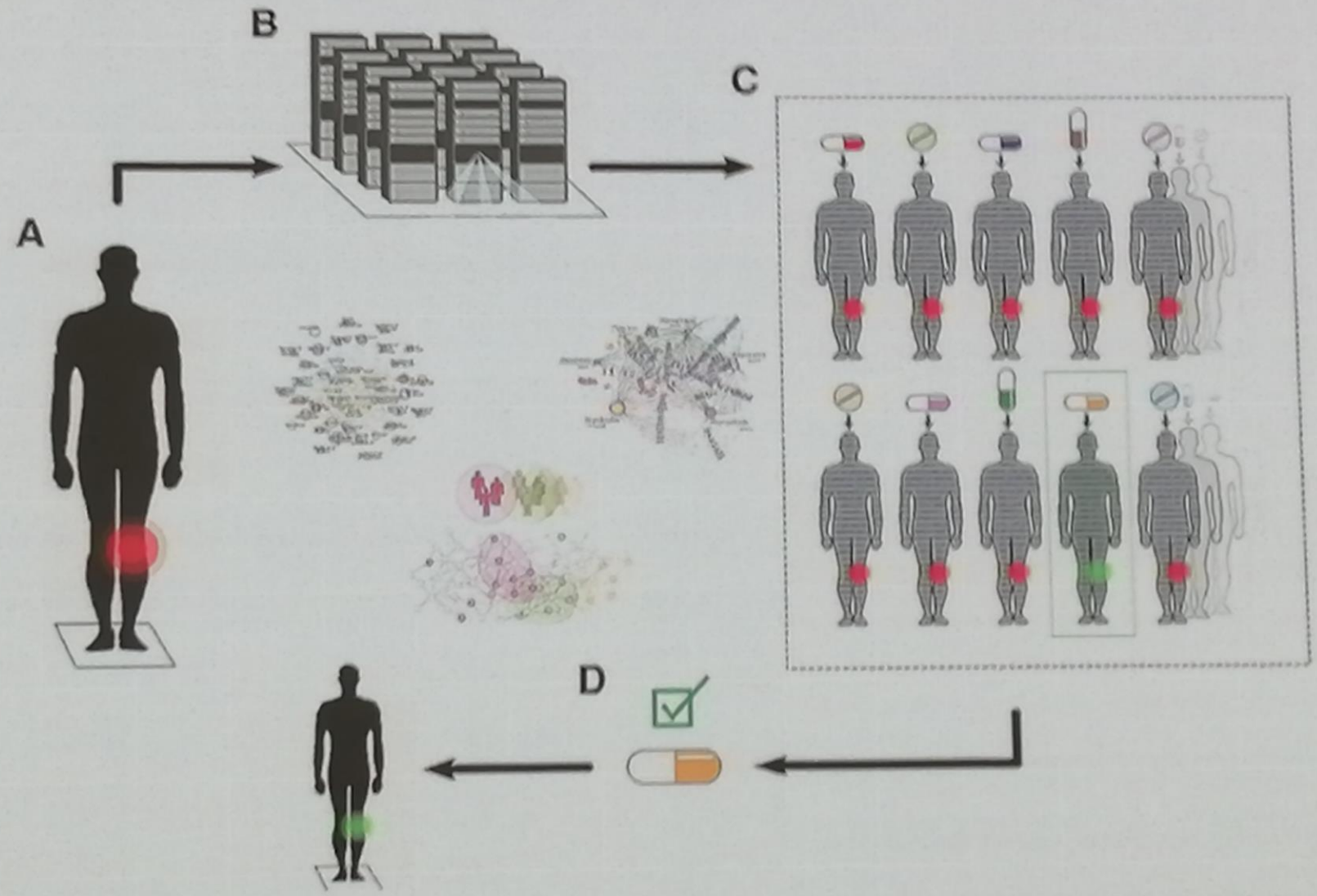
Well-known „AI-assistant”: ChatGPT in daily life and education

AI-support for Science: „Open Science Foundation Models”

[Bommasani et al: arXiv: 2108.07258 (2021); Trillion Parameter Consortium (TPC)]

Scientific and engineering datasets:	Text and code disciplines	Tools for training	Downstream scientific tasks
Mathematics	Scientific journals	HPCs	Scientific discovery
Physics	Digital libraries	+	Accelerated simulations
Chemistry	arXiv	Open Science	Autonomous experiments
Biology	Code repositories	Foundation	Code optimization
Computer science	General texts	Models	Inverse design
Medicine	Media	+	
Climate	News	Tuning and	Digital twins
Cosmology	Humanities	Adopting	(scientific, educational,
Energy systems	History, law	Downstream	medical, personal, …
Manufacturing	Agency archives	Models	→ „AI avatar”)

Digital Twins in Personalised Medicine



What can we do with this movement in Nuclear Science (Physics)?

We have

- **--- scientific datasets (GB/TB/EB of data);**
- **--- refereed scientific articles (thousands of article);**
- **--- conference proceedings, drafts (enormous number/increasing/arXiv);**
- **--- books, textbooks, notes in electronic format;**
- **--- scientists and experts with excellent IT-skills;**
- **--- institutions with solid financial support (universities, research networks);**
- **--- economical interest and industrial connections ;**

YES, this is promising!

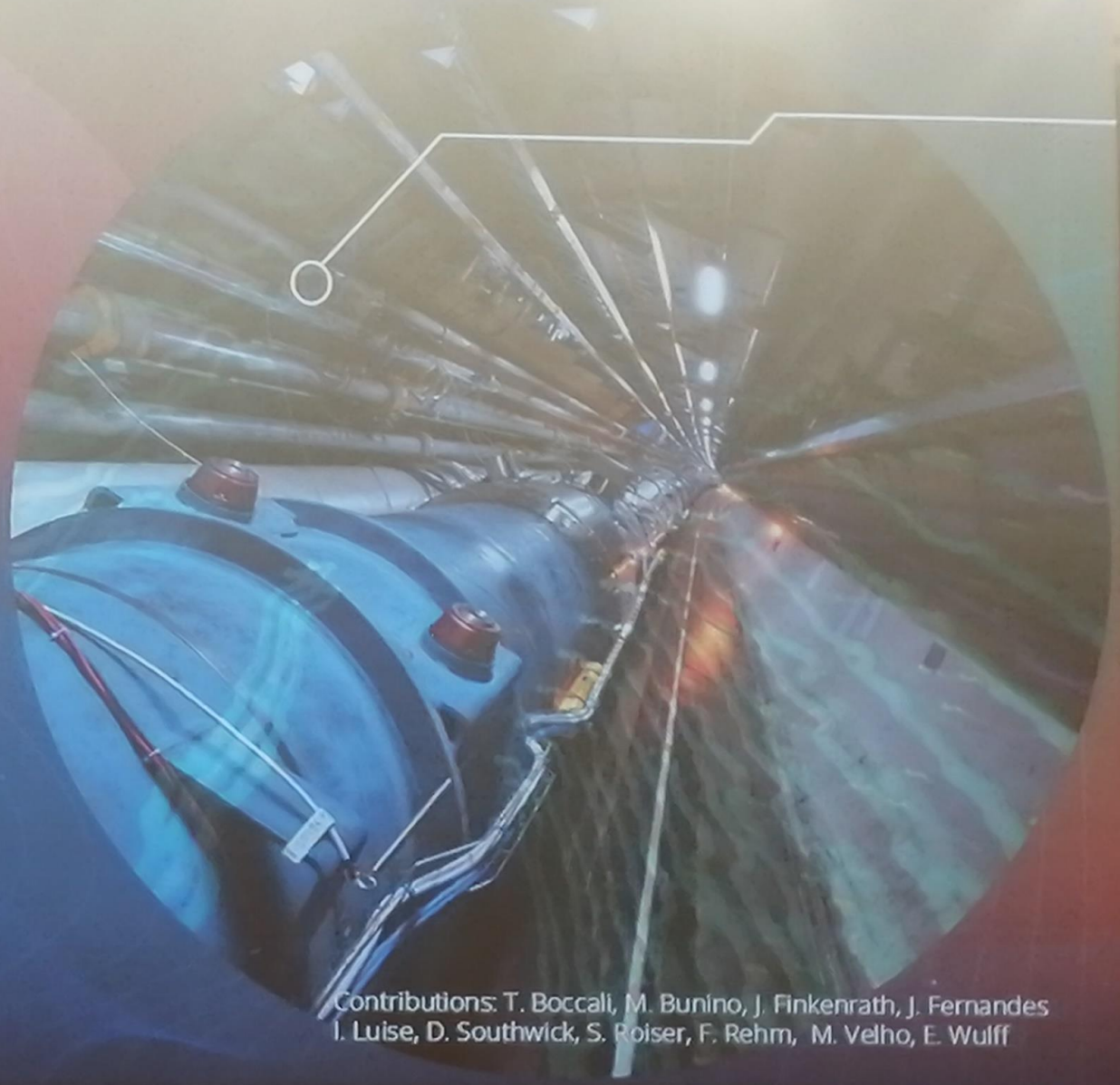
BUT, all of this KW-5 (maybe), even KW-4 (minority, textbooks) !

How could we work in KW-6 style? Who will do this? Who will help in this?

HPC and AI at CERN

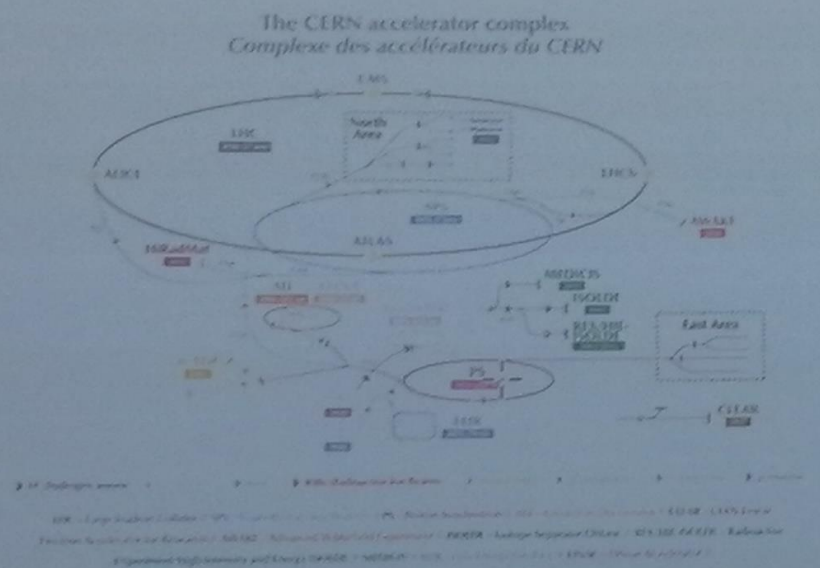
Maria Girone
Head of CERN openlab
CERN IT HPC Strategy Coordinator

CERN openlab



Contributions: T. Boccali, M. Bunino, J. Finkenrath, J. Fernandes
I. Luise, D. Southwick, S. Roiser, F. Rehm, M. Velho, E. Wulff

AI for Particle Accelerators



CERN-ATS (Accelerator Technology Sector) is actively integrating AI and machine learning to enhance accelerator operations, including areas such as optimization, predictive maintenance, fault analysis, and advanced modelling

- **Progress limited by the availability of GPU resources**

CERN-ATS is also developing an LLM called *AccGPT*, a chatbot designed for CERN-specific information.

- *AccGPT* assists users in quickly retrieving documentation, streamlining onboarding processes, and reducing the support burden by providing instant, accurate responses. This project highlights the potential of LLMs in improving efficiency across the organization.

With the Efficient Particle Accelerators (EPA) project, CERN is pushing to improve accelerator efficiency in preparation for the high-luminosity era.

- This involves AI-driven automation to optimize beam scheduling, magnet hysteresis correction, and overall machine operation, targeting energy savings and better physics outcomes.

Distributed Training for AI

HEP community increasingly adopts targeted AI/ML applications

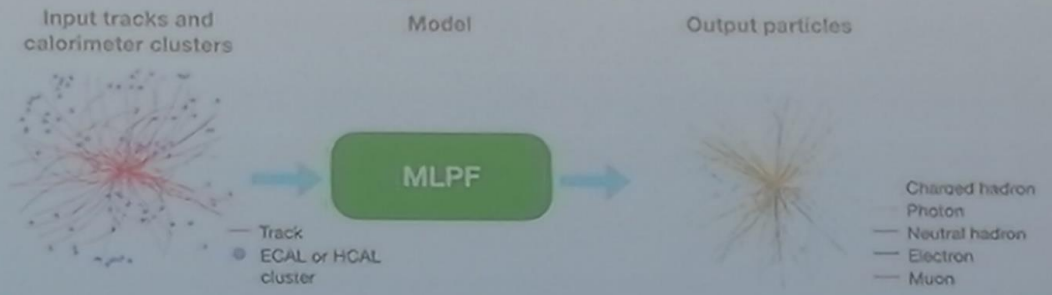
- We do not expect single massive models that try to explain everything any time soon

The scale of HEP AI/ML workflows is driven by exploring and optimizing models and the volume of training data

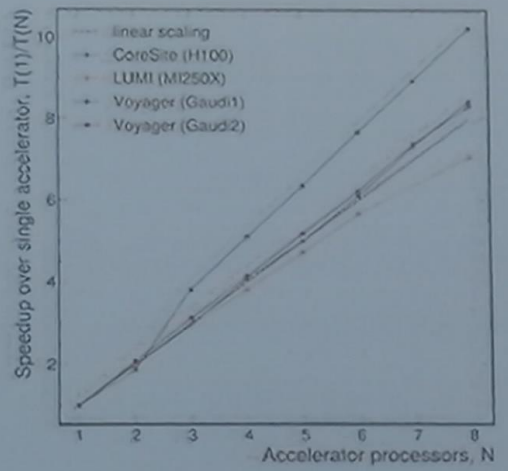
- HPC sites provide resources optimized for AI/ML that can be scaled out

The ability to distribute training allows resources to be dynamically scaled

- Completing the problem faster when resources are available, but also enabling to share resources and work opportunistically



Use case example: Machine Learned Particle-Flow Reconstruction (MLPF)



Scaling of distributed training of MLPF on different hardware accelerators

CoE RAISE

Pata, J., Wulff, E., Mokhtar, F. *et al.* Improved particle-flow event reconstruction with scalable neural networks for current and future particle detectors. *Commun Phys* 7, 124 (2024). https://doi.org/10.1038/s42005-024-01599-5

CERN Quantum Technology Initiative

Discussions about a Quantum Technology Initiative took place in 2020 with representatives of quantum initiatives in the CERN Member States, the CERN community, the Worldwide LHC Computing Grid, the CERN Scientific Computing Forum, with LHC experiments and the HEP Software Foundation

T1 - Scientific and Technical Development and Capacity Building

T3 - Community Building

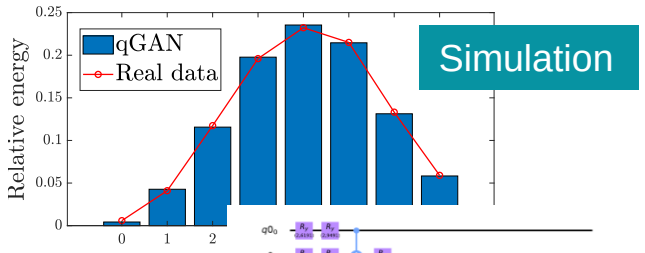
T2 - Co-development

T4 - Integration with national and international initiatives and programmes

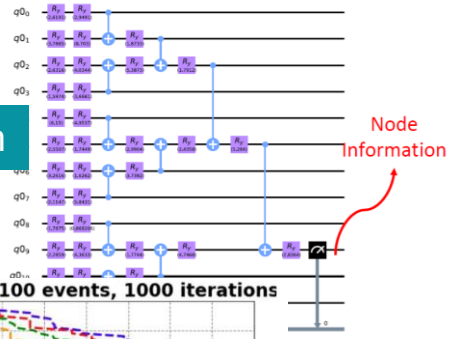
https://doi.org/10.5281/zenodo.5553774

Quantum Technology: R&D Activities

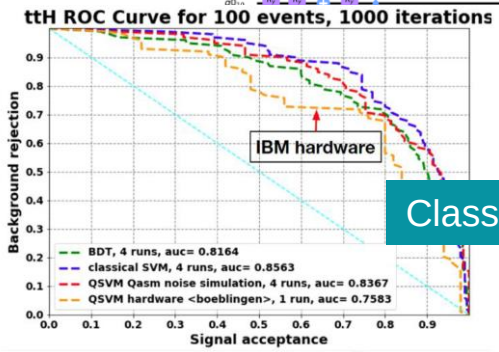
Computing



Simulation

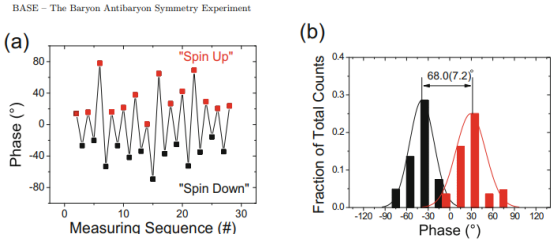


Reconstruction



Classification

Sensing

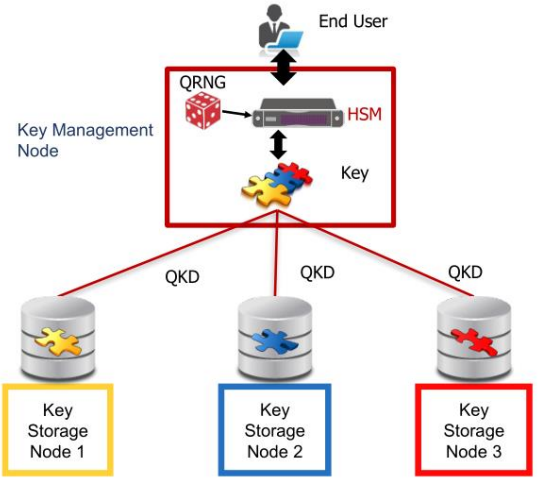


https://doi.org/10.1140/epjst/e2015-02607-4

Low-energy experiments, quantum states measurements, nano-technologies

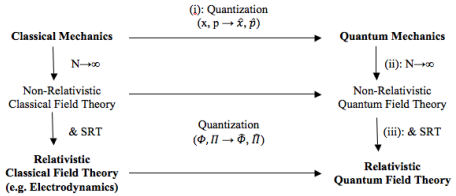
Future HEP Detectors

Communications

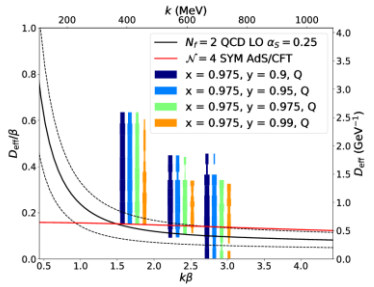


QKD infrastructures Quantum Internet

Theory



Quantum Field Theory



https://cds.cern.ch/record/2703396

Lattice QCD

Mit csinálunk mi itt Wigner FK-ban/Magyarországon?

A Wigner FK munkatársainak tevékenysége:

- --- actív együttműködés a CERN projektekkel (QTI-tag, FCC-tagság);
- --- HE-EU projektek, pl. EuroHPC, EuroQCI, …;
- --- Kvantum Informatikai Nemzeti Lab (QNL) + AINL;
- --- 2020: Komputációs Tudományok Osztálya a Wigner RMI-ben;
- --- HUN-REN Felhő Szolgáltatás – alap és GPU-kiterjesztett (+ QComp)
- --- Adat Repozitórium Program - alapszint (ARP) [2024/11/25];
- --- Adat Repozitórium Program - AI kiterjesztéssel (ARP+);
- --- WIGNER DC számolási és adattárolási kapacitás [4 MW, 400 rack];
- --- WSCLAB, benne legmodernebb GPU, FPGA, QC-emulator + támogatás.

IGEN, ezek ígéretes események, folyamatok a KW-6-hoz! **DE, elég lesz?**

Ki fogja mindezt folytatni, továbbfejleszteni? → Ma még diákok!

A kutatók és fejlesztők nevében
kérem a középiskolás tanárok
és az egyetemi kollégák
figyelmét/munkáját/lelkesedését ahhoz,
hogy megszülessen és felnőjön
a „fáklyavivők” következő generációja