Pushing Boundaries:

Femtoscale **Research** with Large-Scale **Tech**

(in accelerator-driven "nuclear" physics)

FAIR The Universe in the Laboratory

GNURadio 4.0 Days
27th - 30th August 2024

Johan Messchendorp (GSI/FAIR),
GNU Radio Days, August 27-30, 2024, GSI, Darmstadt

FAIR GSI


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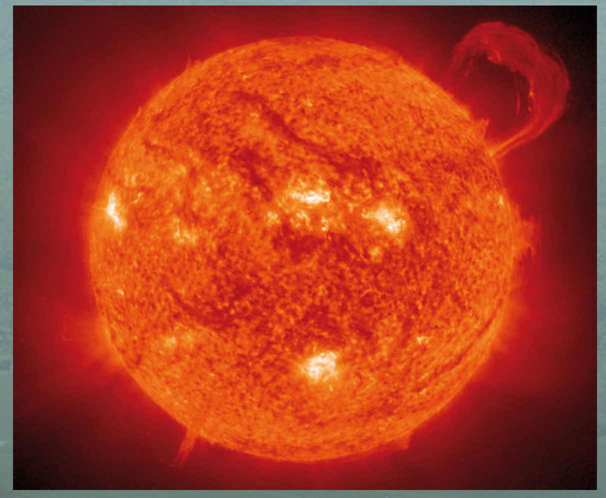
APPA



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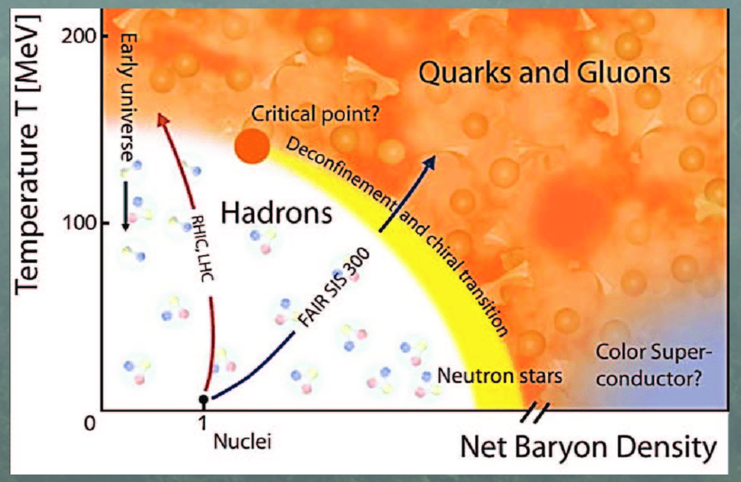

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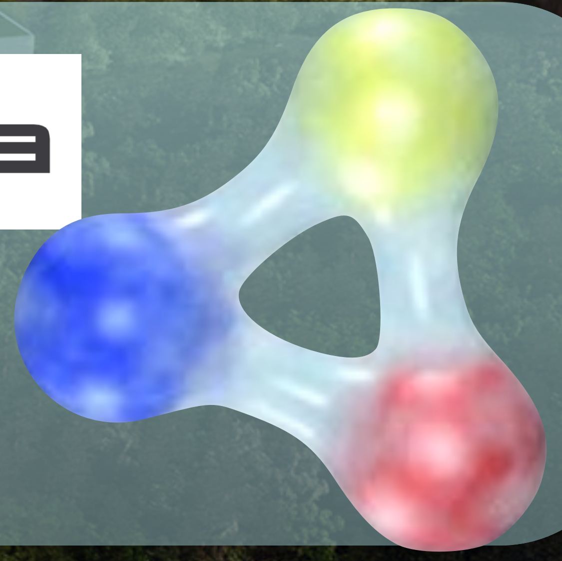
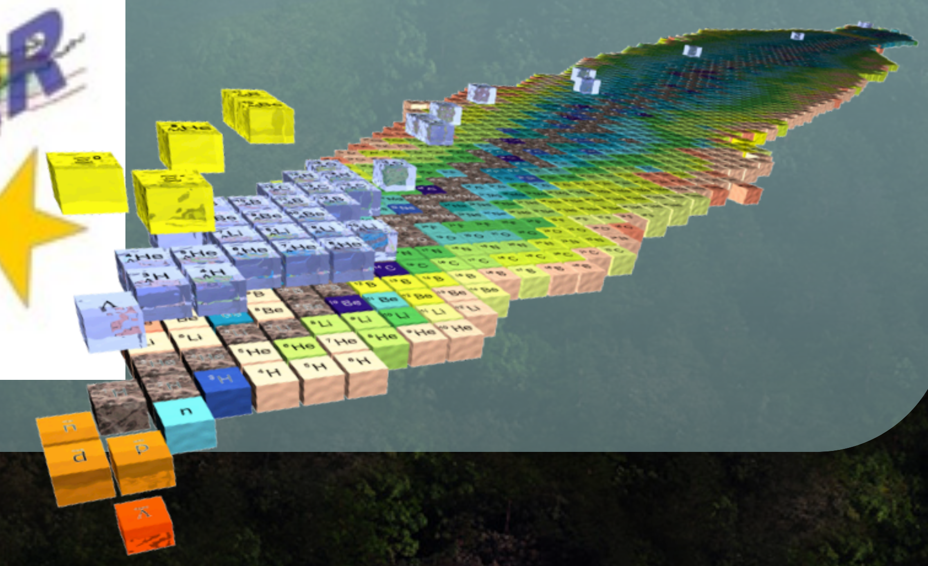


NUSTAR



Facility for Antiproton and Ion Research -
"The Universe in the Laboratory"

+THEORY and BEAM physics

Cutting-edge science and technology

- ESFRI Landmark near Frankfurt, Germany
- Top priority for European Nuclear Physics Community
- International: 50 countries, 3000 researchers
- Diverse community from atomic to particle physics
- High intensity+precision+diversity+parallel operation
- Monolitic and modular experimental setups

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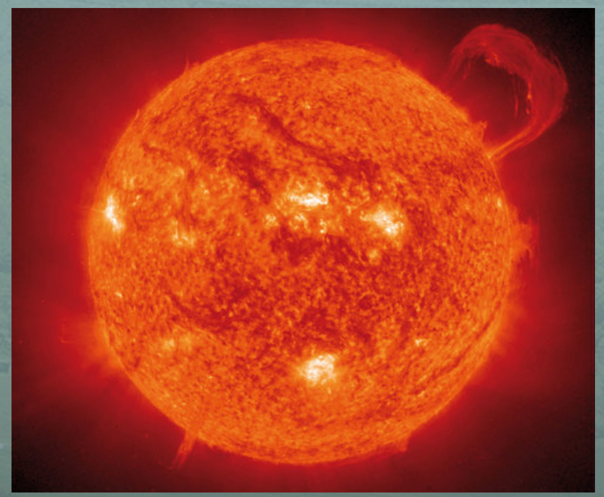

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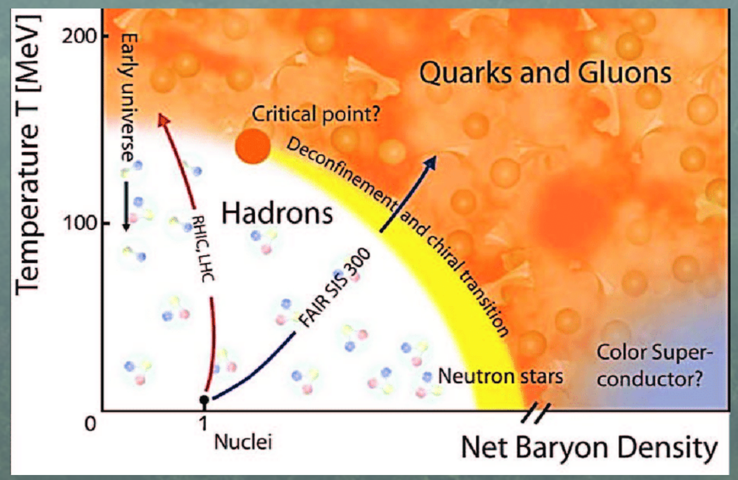

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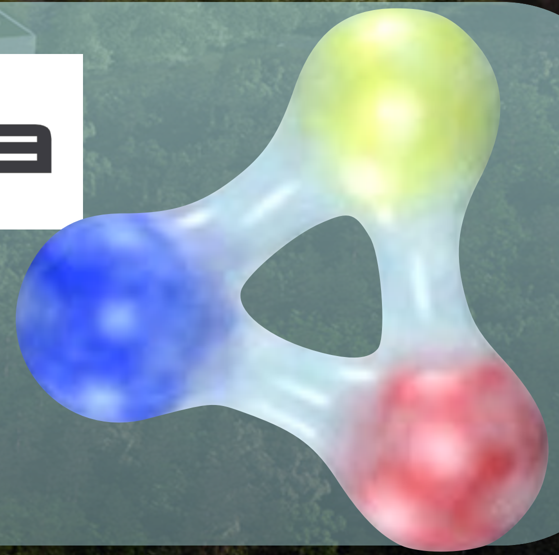

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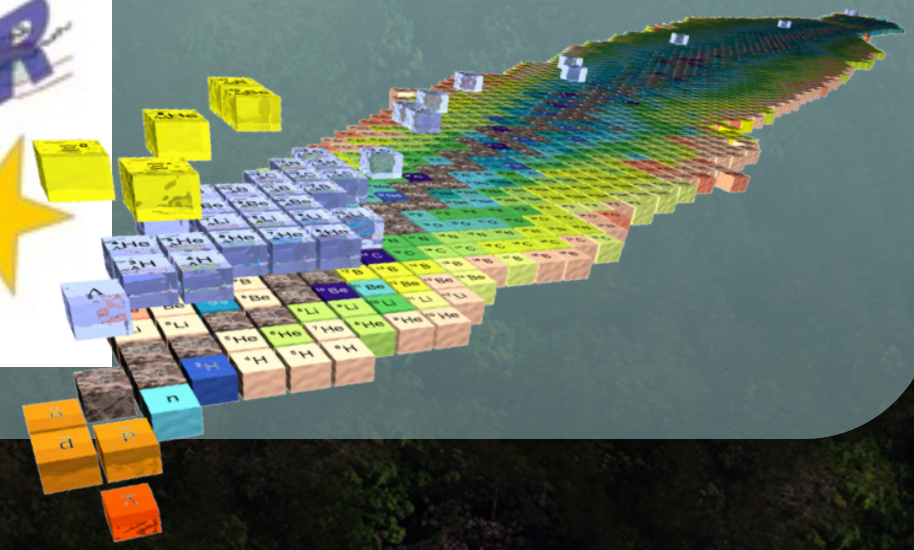

+THEORY and BEAM physics

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A confession…

- My background: physicist with "self-educated" (software) engineering skills (if any)
- GNURadio$^{4.0}$ only learned about it recently (via this event)

Even more embarrassing…

How can I use GNUradio$^{4.0}$ for doing hadron physics experiments?

Even more embarrassing…

How can I use GNUradio$^{4.0}$ for doing hadron physics experiments?

GNU Radio 4.0, like its predecessors, is a flexible and powerful tool that can be applied to various aspects of hadron physics experiments, especially in signal processing, data acquisition, and analysis. While GNU Radio is primarily designed for software-defined radio (SDR), its modular and customizable architecture makes it adaptable for tasks in hadron physics, particularly in areas where signal processing and data acquisition are critical.

1. **Signal Processing from Detectors**

- **Pulse Processing and Shaping:**
    - **Detectors in Hadron Physics:** In hadron physics, detectors like calorimeters, Cherenkov detectors, scintillators, and wire chambers are commonly used. These detectors generate pulses in response to interactions with hadrons.
    - **Using GNU Radio:** GNU Radio 4.0 can be used to process these pulses by applying filtering, amplification, and shaping techniques. You can implement algorithms to smooth out the signal, remove noise, and extract useful features such as pulse height (which correlates with energy) or timing information.
- **Fourier Transform and Frequency Analysis:**
    - **Use Case:** In some hadron physics experiments, especially those involving particle identification, analyzing the frequency components of signals can be crucial.
    - **Using GNU Radio:** The FFT (Fast Fourier Transform) block in GNU Radio 4.0 can be employed to perform frequency domain analysis on signals, helping to distinguish between different types of particles or interactions based on their frequency signatures.

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2. **Real-Time Data Acquisition and Monitoring**
   - **Integration with DAQ Systems:**
     - **DAQ in Hadron Experiments:** Data Acquisition (DAQ) systems are critical in hadron physics experiments for collecting data from detectors.
     - **Using GNU Radio:** GNU Radio 4.0 can interface with DAQ hardware to acquire data in real-time. You can set up a flowgraph to capture, process, and monitor the data as it is collected, enabling real-time analysis and decision-making.
   - **Triggering Systems:**
     - **Importance of Triggers:** Triggers are used in hadron physics experiments to capture events of interest, such as specific particle interactions.
     - **Using GNU Radio:** Implement custom trigger logic within GNU Radio to capture only the relevant events. For example, you could set a threshold condition on signal amplitude or pulse width to trigger data recording.

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3. Timing and Synchronization

- **Time-of-Flight (ToF) Measurements:**
  - **ToF in Hadron Physics:** ToF measurements are critical in experiments where you need to determine the speed or type of a hadron by measuring the time it takes to travel between two detectors.
  - **Using GNU Radio:** Use GNU Radio 4.0 to process timing signals and calculate the ToF. This can involve precise time-stamping of signals and correlating them between detectors.
- **Clock Synchronization Across Detectors:**
  - **Synchronization Needs:** Accurate timing is essential for correlating events between different detectors in a hadron experiment.
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4. Data Analysis and Event Reconstruction

- Signal Reconstruction:
  - **Reconstruction in Hadron Physics:** In many experiments, raw detector signals need to be reconstructed into meaningful data, such as particle trajectories or interaction points.
  - **Using GNU Radio:** Implement algorithms in GNU Radio for reconstructing events from raw signal data. This could involve combining signals from multiple detectors to reconstruct a hadron's path or interaction vertex.
- Noise Filtering and Data Cleaning:
  - **Noise in Detectors:** Noise is a common issue in detector data, potentially obscuring important signals.
  - **Using GNU Radio:** Apply filters in GNU Radio to clean up the data, removing noise while preserving the signal of interest. You can use adaptive filters, matched filters, or custom-designed filters specific to the characteristics of your detector and experiment.

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5. **Simulation and Prototyping**

- **Signal and Noise Simulation:**
  - **Simulation in Hadron Physics:** Before running actual experiments, it's often useful to simulate the expected signals and noise.
  - **Using GNU Radio:** Use GNU Radio 4.0 to simulate the signals you expect from your detectors, including realistic noise models. This can help in testing and refining your data processing algorithms before applying them to real data.
- **Prototype Development:**
  - **Detector Prototyping:** Developing and testing new detector systems often requires rapid prototyping of signal processing algorithms.
  - **Using GNU Radio:** Quickly prototype and test signal processing algorithms using GNU Radio's graphical interface and modular block system. This allows for rapid iteration and testing of ideas.

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6. **Networked Data Collection and Distributed Experiments**

- **Distributed Data Acquisition:**
  - **Networked Experiments:** Large-scale hadron physics experiments often involve distributed data acquisition systems spread across different locations.
  - **Using GNU Radio:** Set up GNU Radio 4.0 to collect and process data from multiple distributed sensors or detectors. You can use network blocks in GNU Radio to handle data transmission and synchronization across these systems.
- **Remote Experiment Monitoring:**
  - **Remote Monitoring Needs:** Monitoring experiments remotely is important in large collaborations or when physical presence at the experimental site is not feasible.
  - **Using GNU Radio:** Stream data over the internet using GNU Radio's networking capabilities, allowing researchers to monitor and analyze experiments in real-time from remote locations.

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7. **Educational and Training Applications**

- **Training in Signal Processing:**
  - **Educational Value:** GNU Radio is a powerful tool for teaching the principles of signal processing as applied to hadron physics.
  - **Using GNU Radio:** Set up educational modules using GNU Radio 4.0 to teach students about signal processing techniques, detector physics, and data analysis in the context of hadron physics.
- **Demonstrations of Particle Physics Concepts:**
  - **Public Outreach:** Demonstrations can help explain complex hadron physics concepts to the public or students.
  - **Using GNU Radio:** Create interactive demonstrations using GNU Radio that visualize particle interactions, signal processing, and data analysis, making these concepts more accessible to a wider audience.

1. Signal Processing from Detectors

- Pulse Processing and Shaping:
  - **Detectors in Hadron Physics:** In hadron physics, detectors like calorimeters, Cherenkov detectors, scintillators

4. Data Analysis and Event Reconstruction

- Signal Reconstruction:
  - **Reconstruction in Hadron Physics:** In many experiments, raw detector signals need to

Conclusion

GNU Radio 4.0 offers a versatile platform for a wide range of applications in hadron physics experiments. Whether you are processing signals from detectors, performing real-time data acquisition, implementing timing and synchronization, or prototyping new systems, GNU Radio provides the tools necessary to handle these tasks effectively. Its flexibility, combined with the ability to interface with other hardware and software, makes it a valuable resource in both research and educational contexts within hadron physics.

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1. Wow, somebody wake me up!

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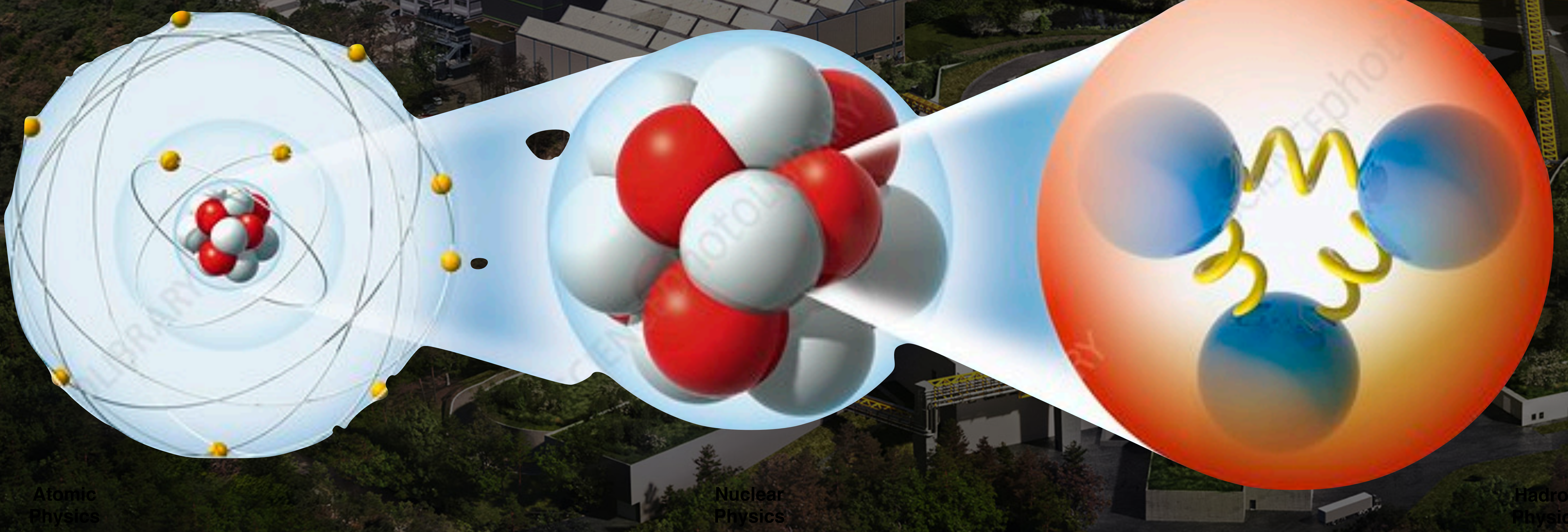
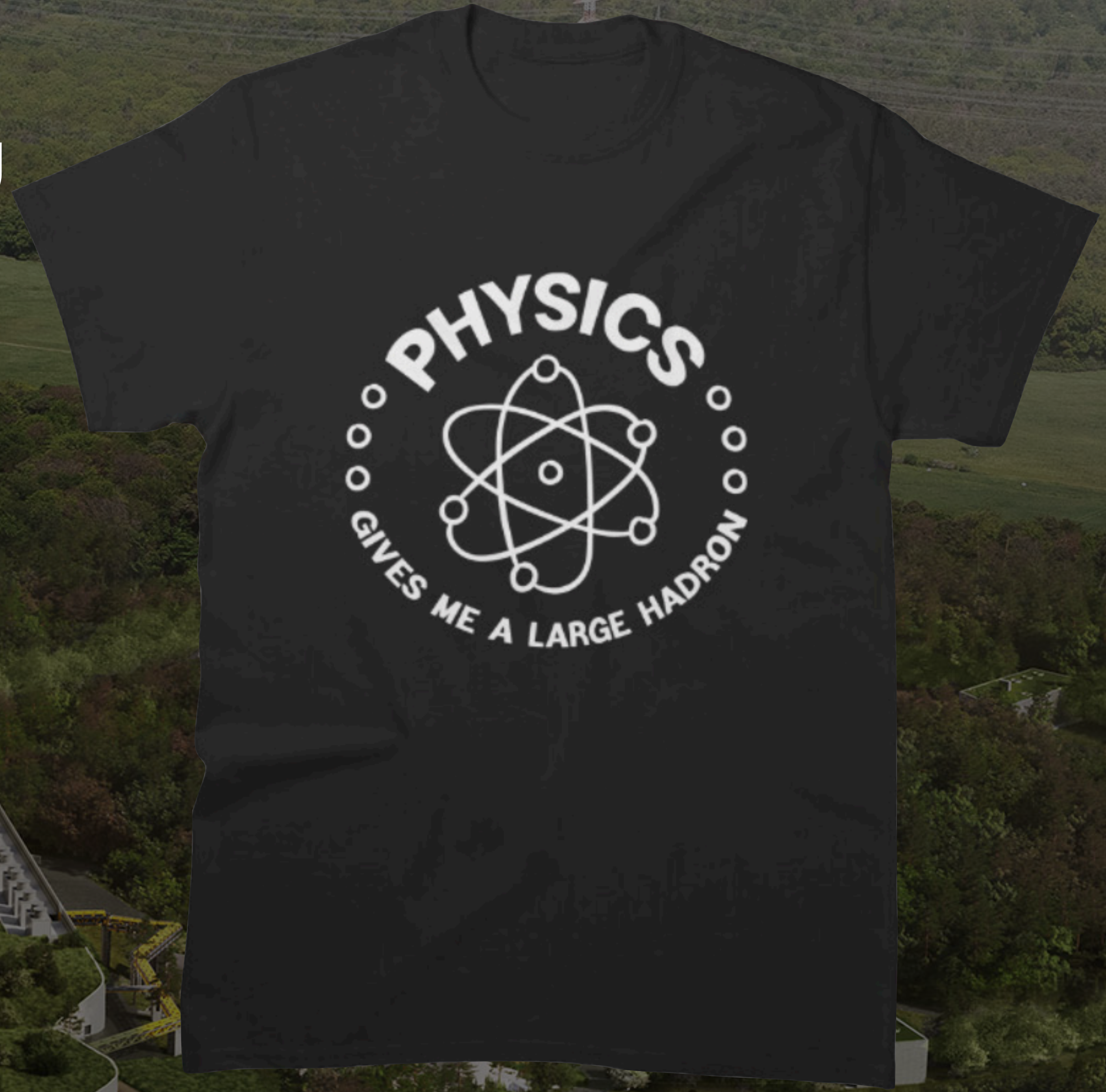
1. Wow, somebody wake me up!
2. Who says that AI cannot be *creative*?

This talk, the objectives…

- Science & Tech at GSI/FAIR: *the* why, *the* how, *the* what?
- (Typical) example case based on personal experiences
- Lessons from the past, developments in the present, towards the needs and challenges for the future

A few words on “the why”





“Hadron physics”

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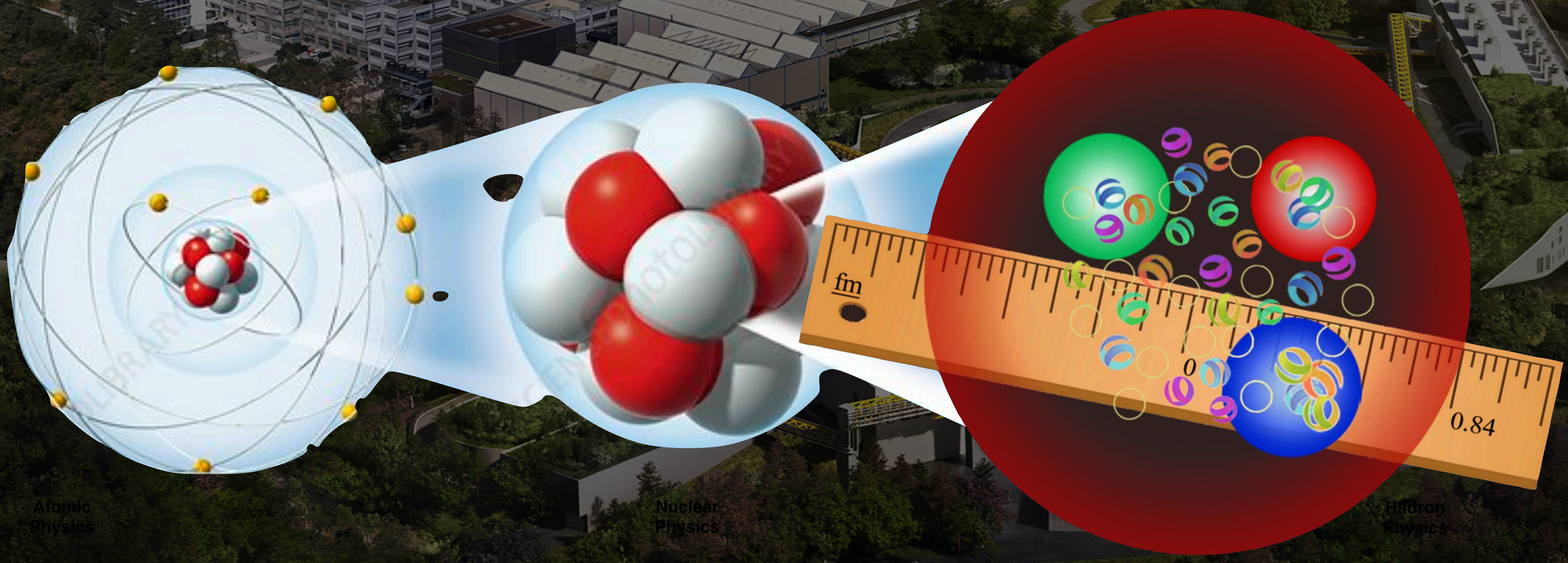


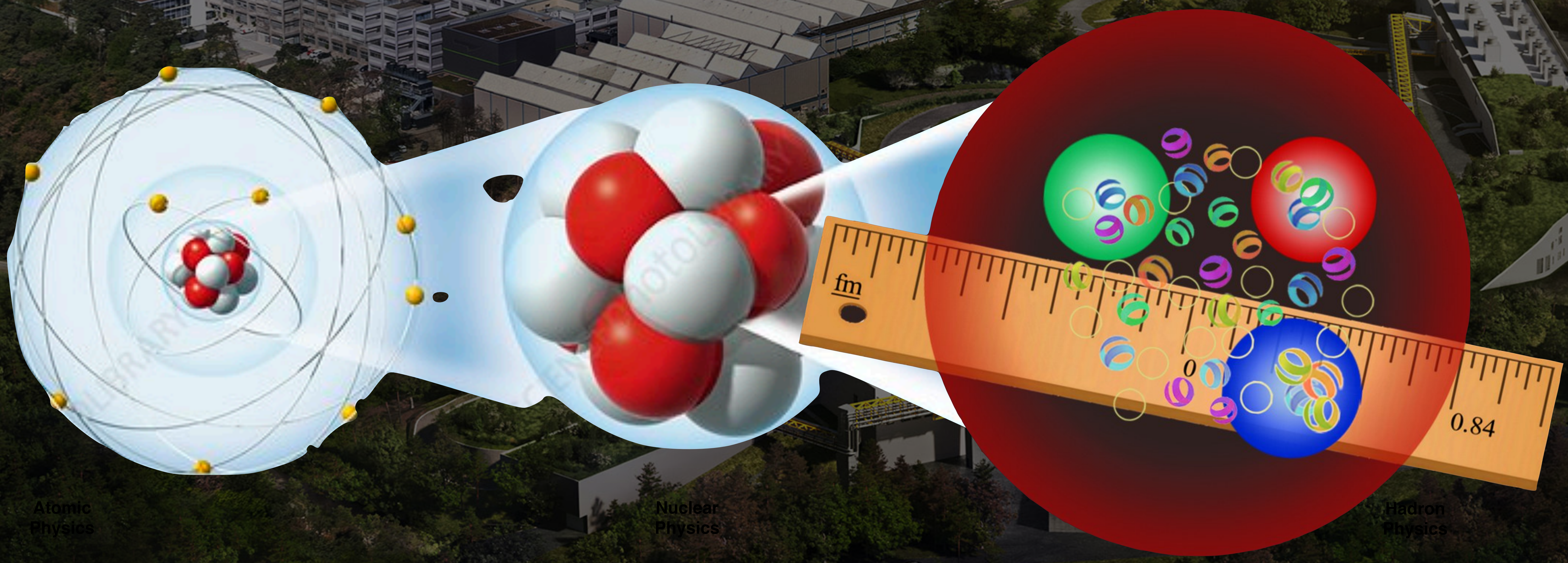
Proton

Mass 940 MeV/c^2 = 1.7×10^{-27} kg

Radius ~0.83 fm = 0.83×10^{-15} m

Mass density (mass/volume):

A few words on “the why”



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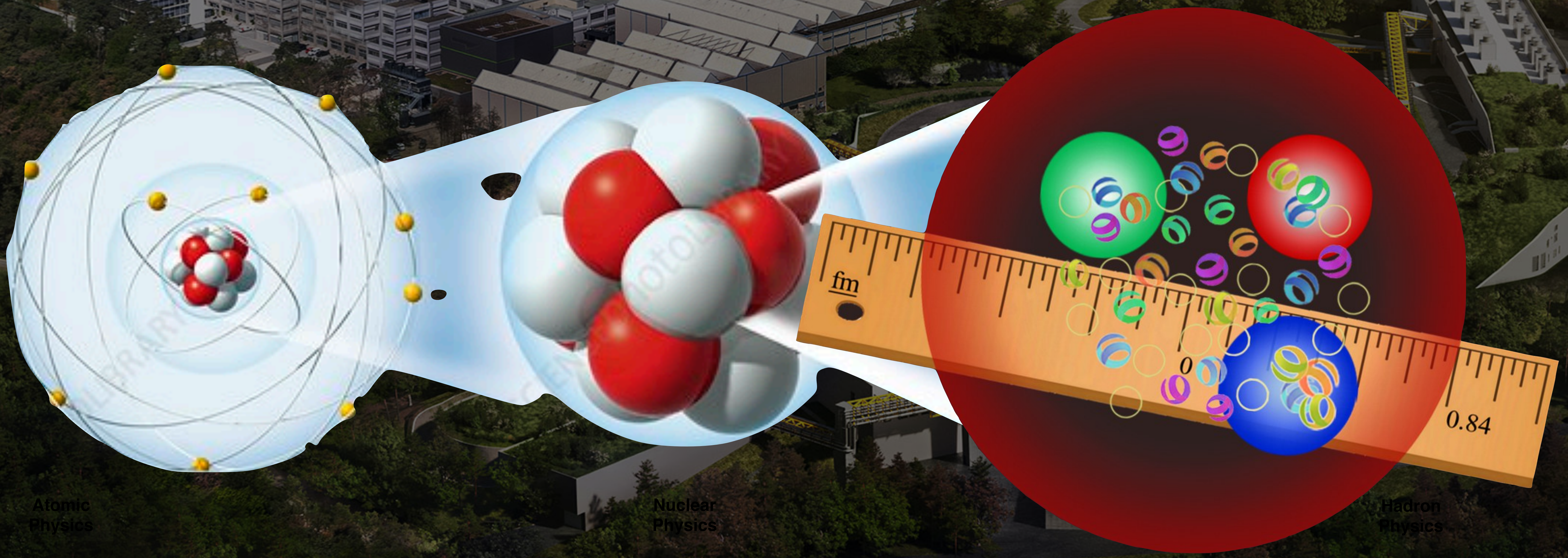

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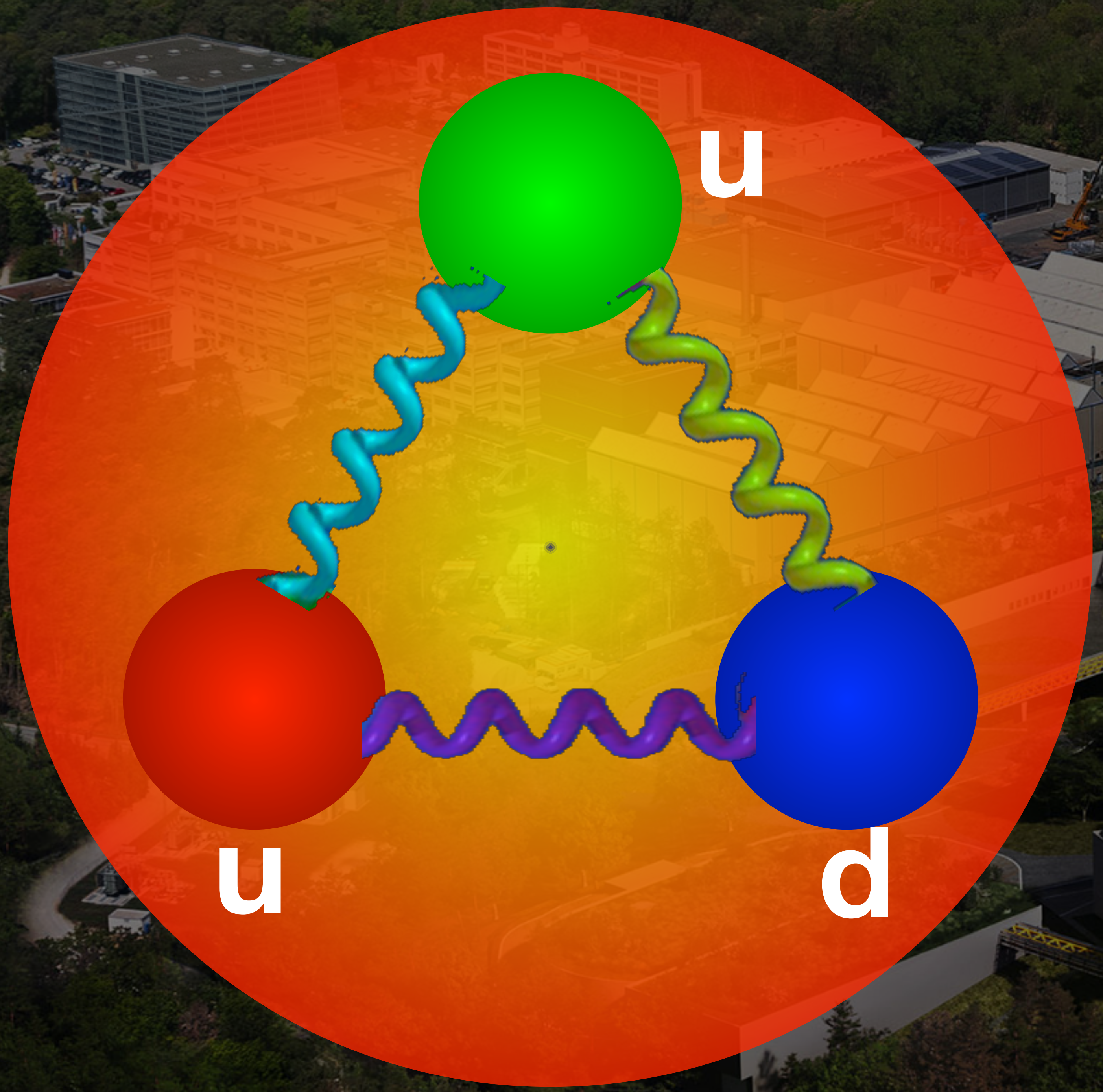
~10^{18} kg/m^3

density of Earth ~5×10^3 kg/m^3
density of a neutron star is ~10^{17} kg/m^3

Proton = three light quarks?



Higgs: 3 x quark-mass ≈ 10 MeV/c²

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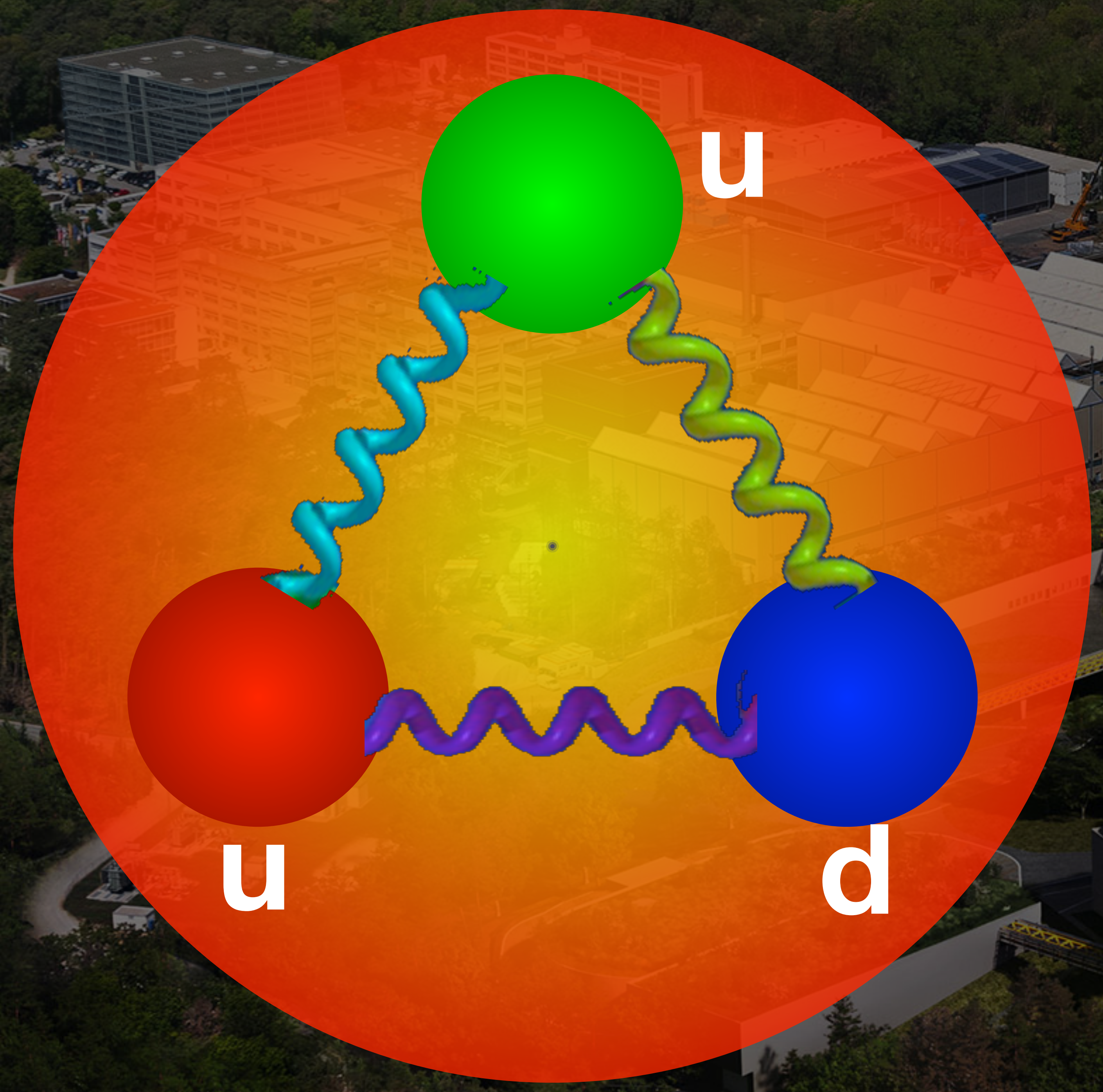

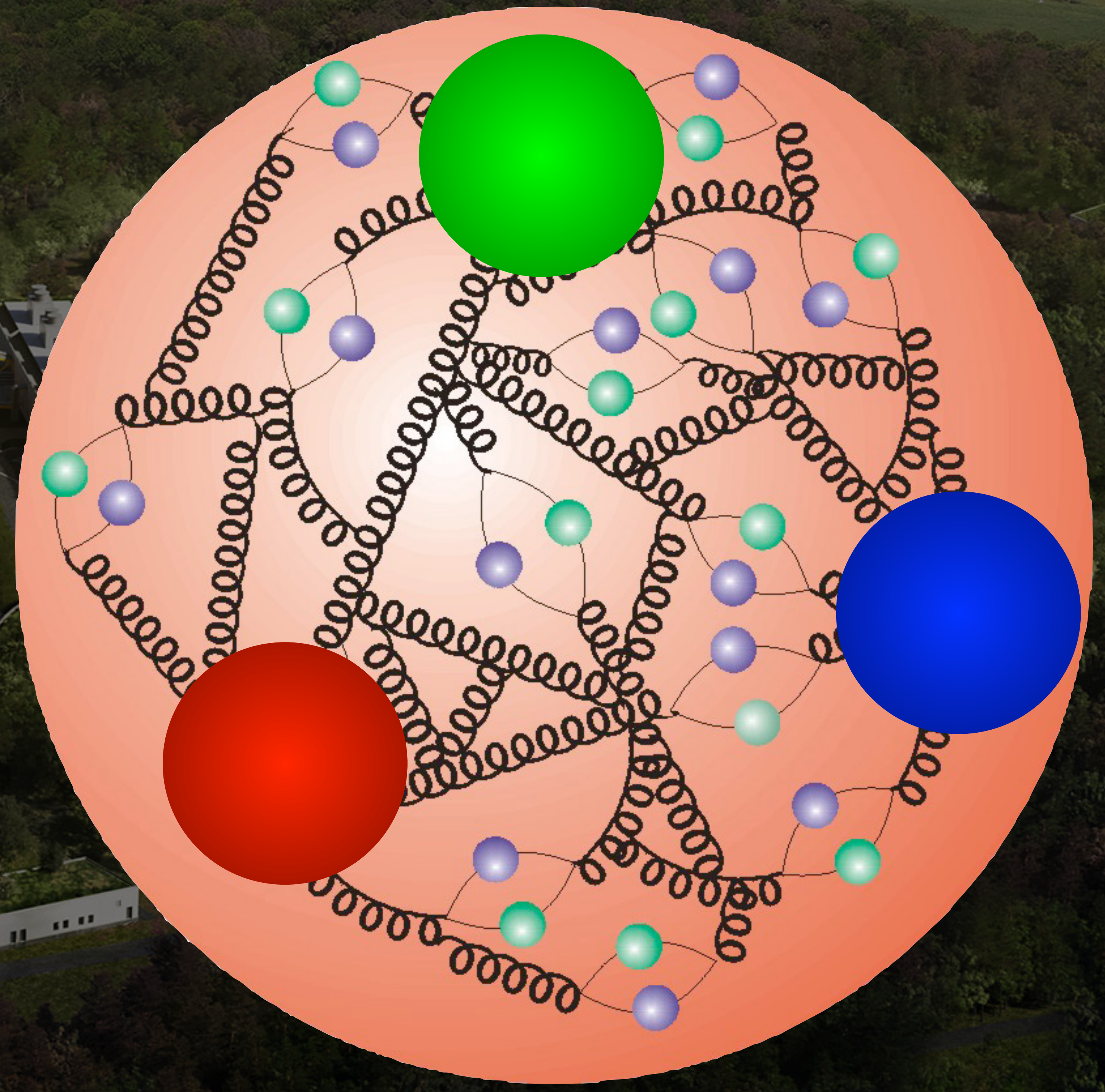

Higgs: 3 x quark-mass ≈ 10 MeV/c²

Reality: proton mass ≈ 940 MeV/c²

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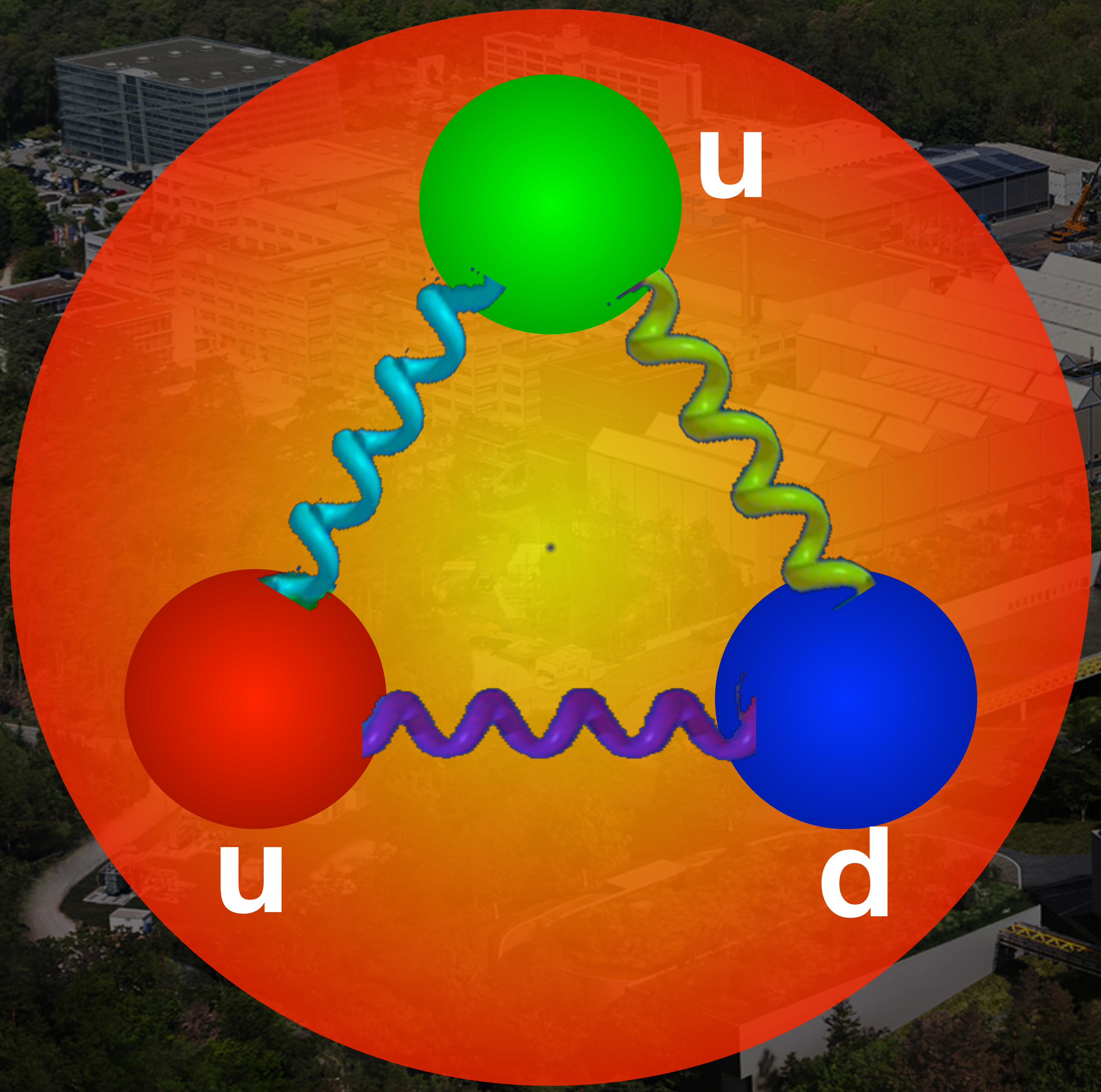
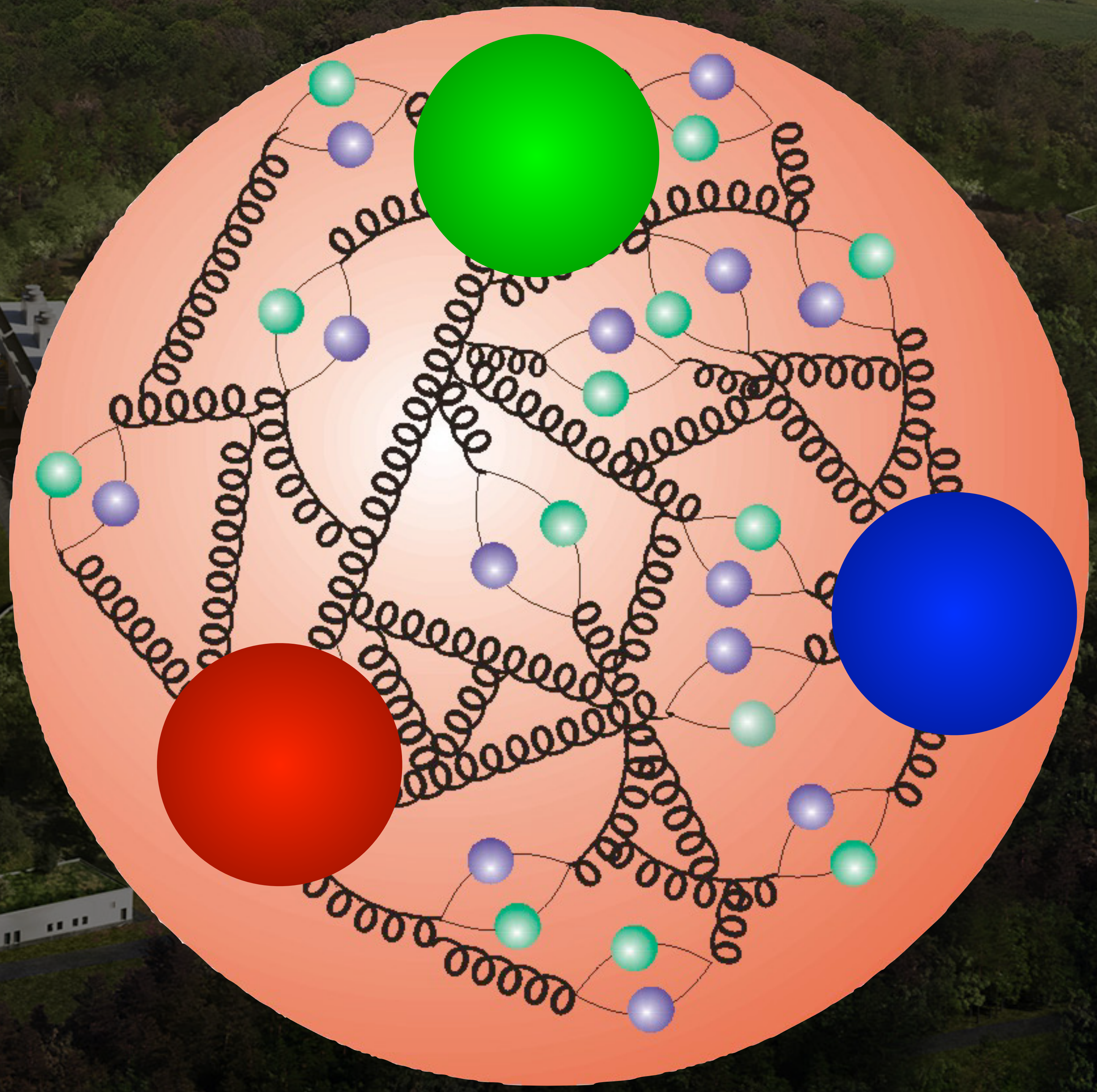




Higgs: 3 x quark-mass ≈ 10 MeV/c²

Reality: proton mass ≈ 940 MeV/c²

Strong interaction = mass !

$$\mathcal{L}_{QCD} = \sum_{q=u,d,s,c,b} \bar{q}\,(\,i\gamma_\mu D^\mu - m_q\,)\,q - \frac{1}{4} G^{\mu\nu} G_{\mu\nu}$$

Quantum **C**hromo **D**ynamics

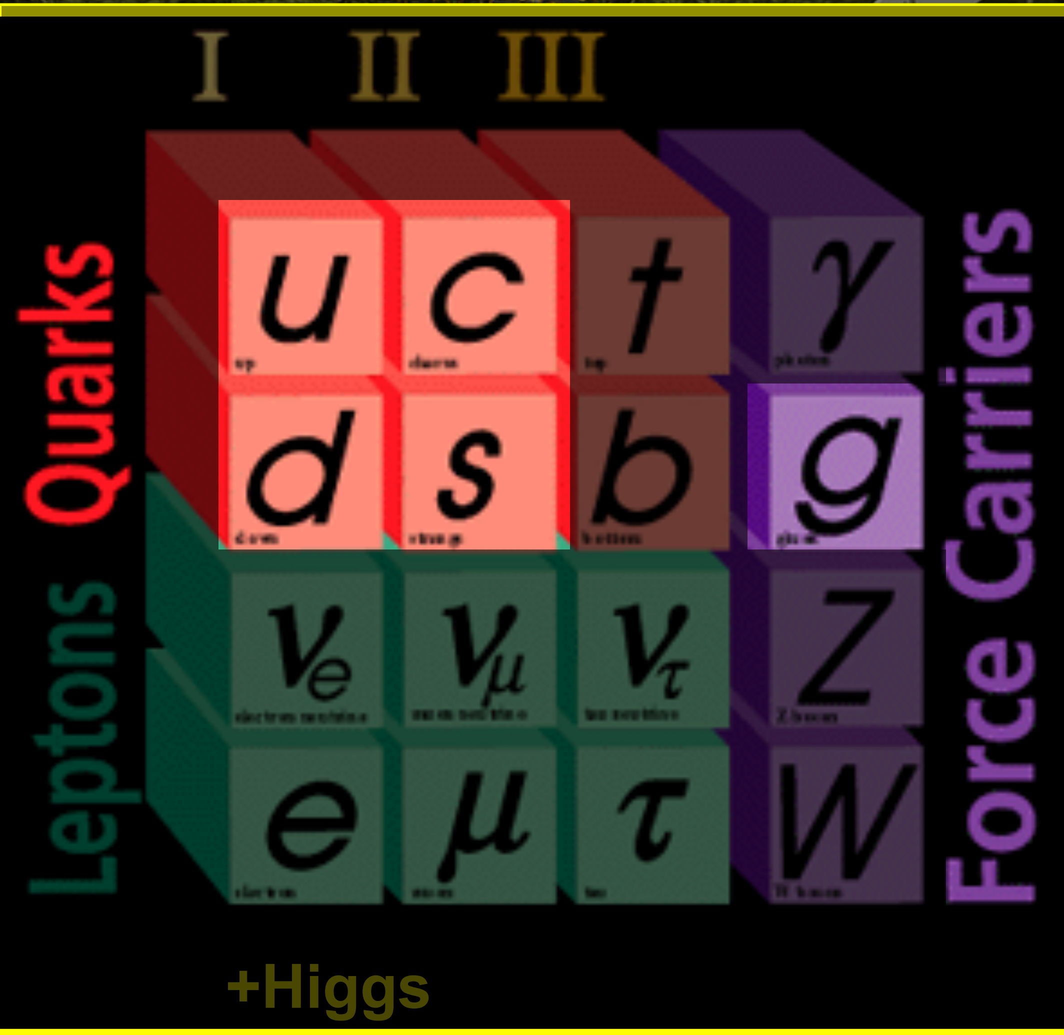
50 years of QCD!

Origin of mass?

Properties of hadrons?

Formation of hadrons?

Underlying symmetries



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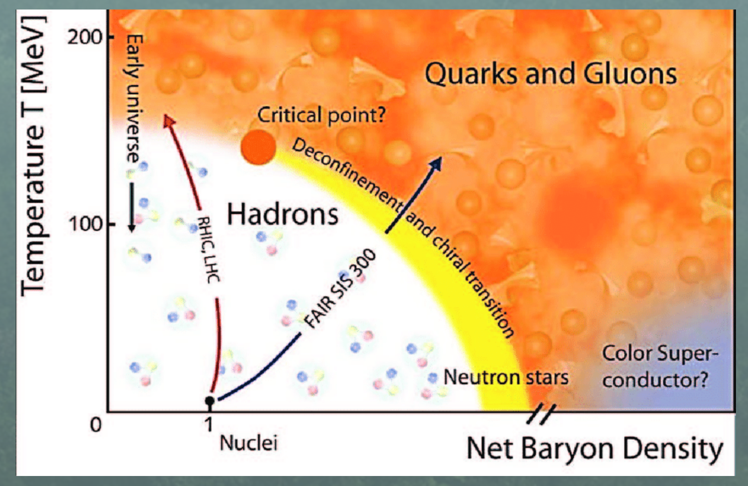

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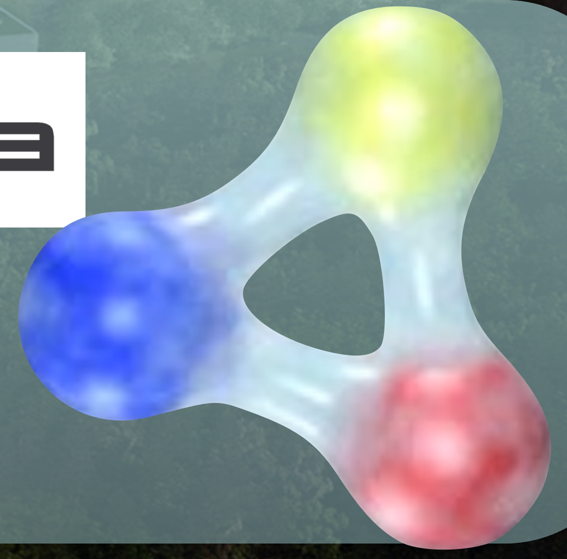
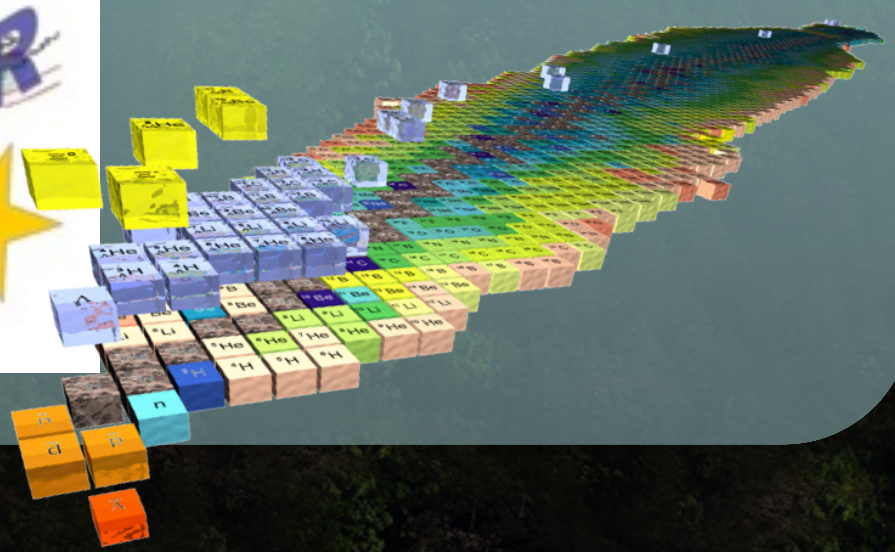


NUSTAR



The methodology

An international scientific collaboration

The methodology

An international scientific collaboration

"ordinary matter"

The methodology

An international scientific collaboration

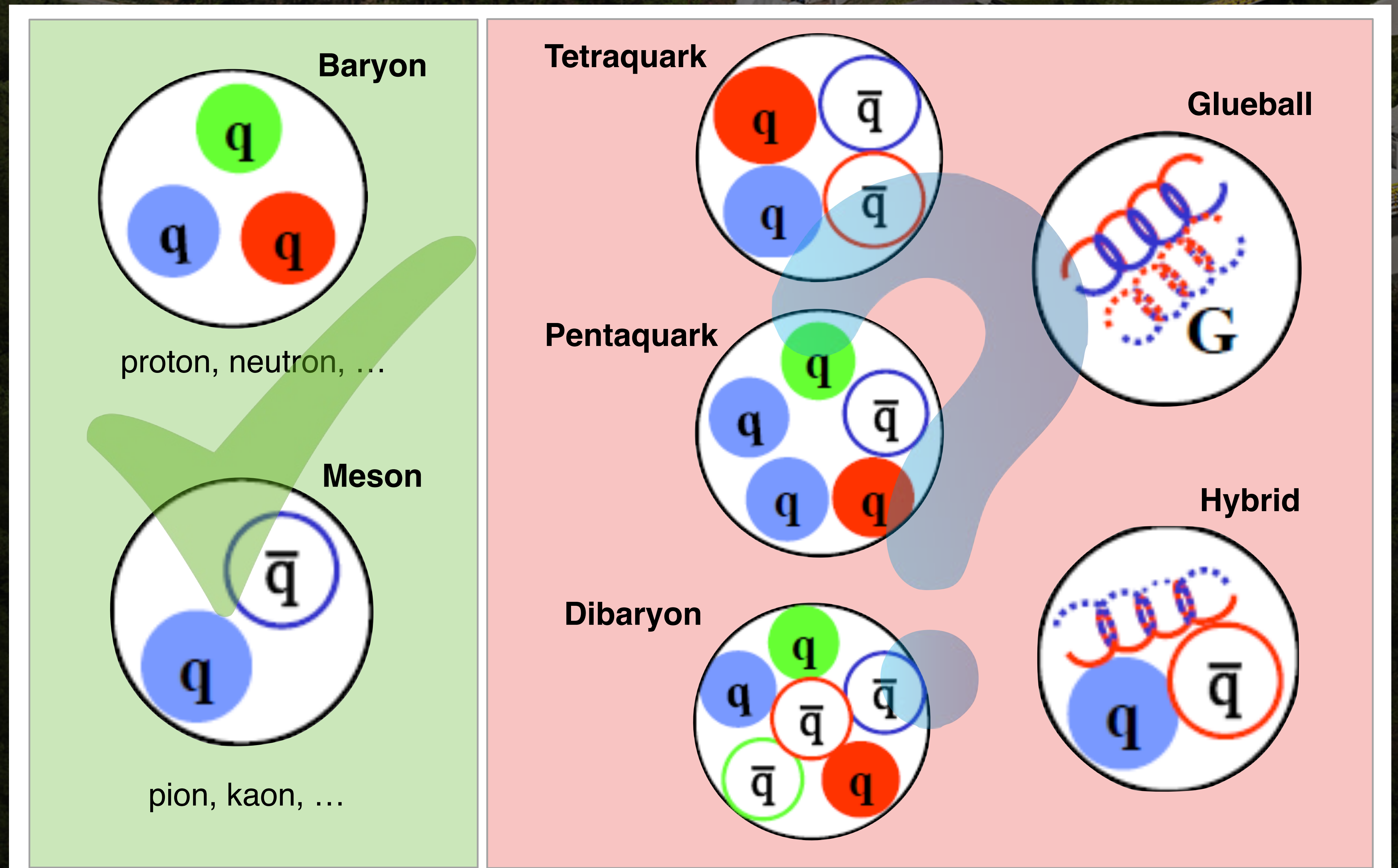
“ordinary matter”

“matter at extremes”

The methodology

...QCD matter at *extremes*

Exotic form of hadrons
(PANDA)



The methodology

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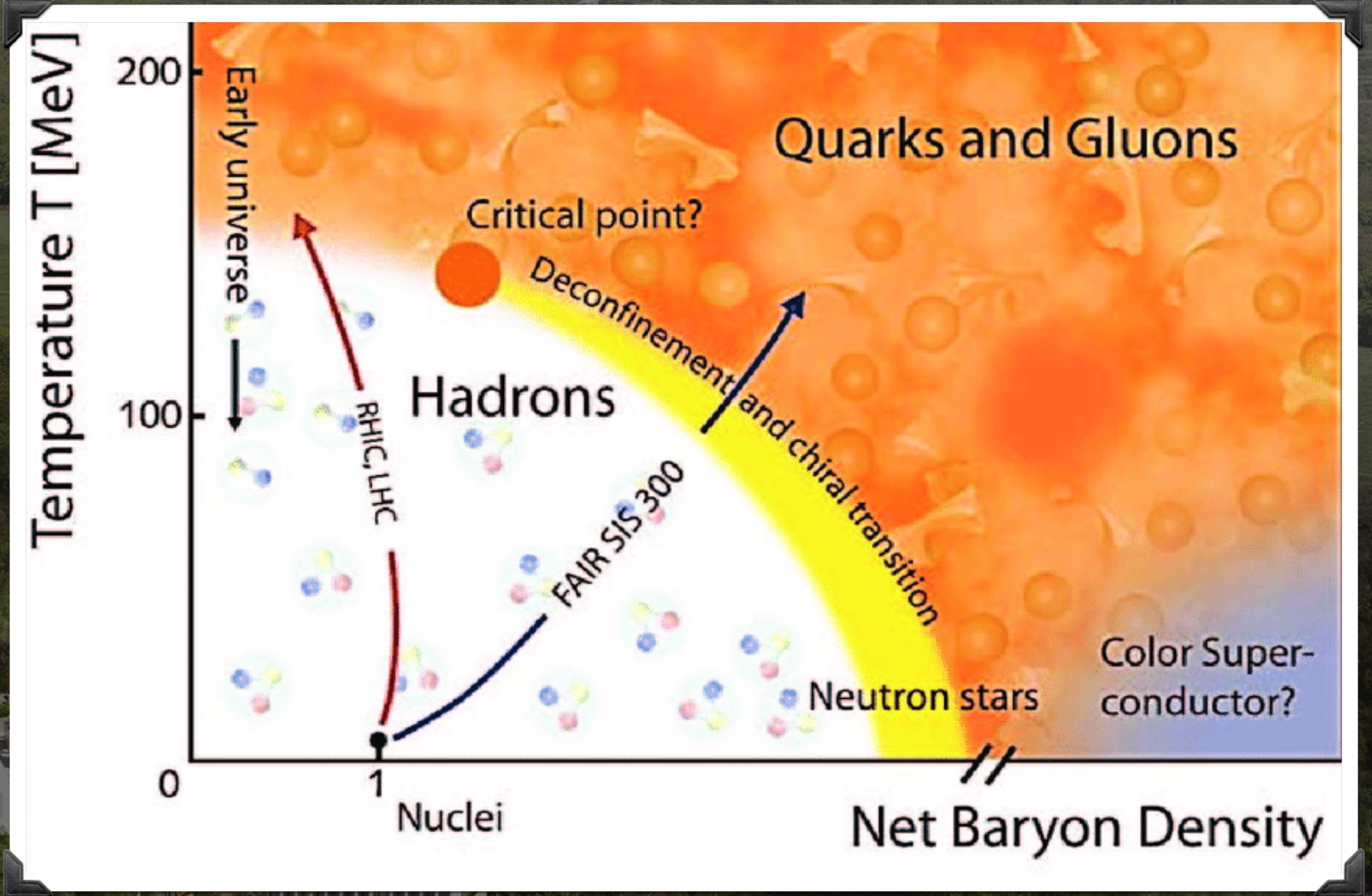
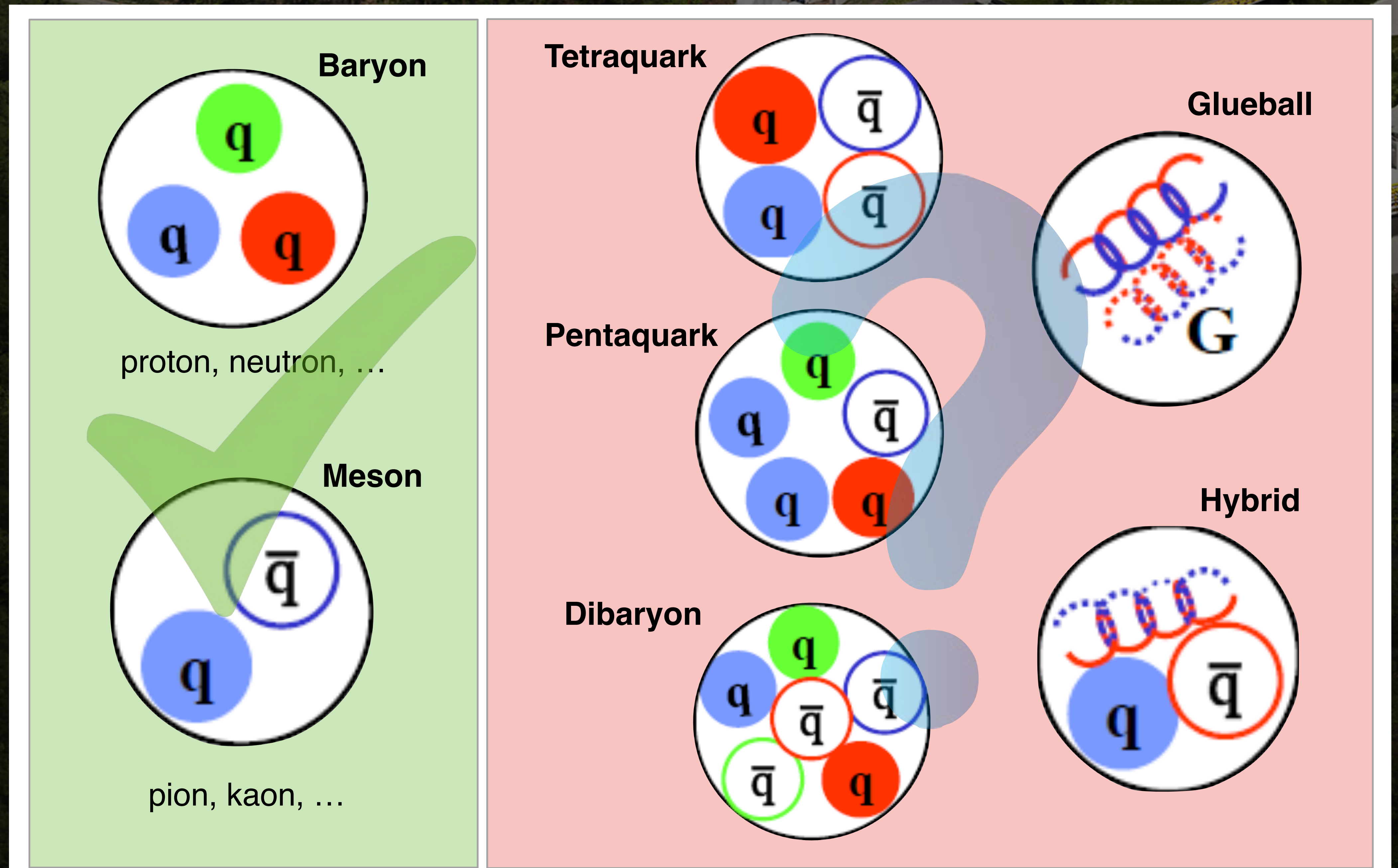


Baryonic matter at high densities (CBM)

Exotic form of hadrons (PANDA)



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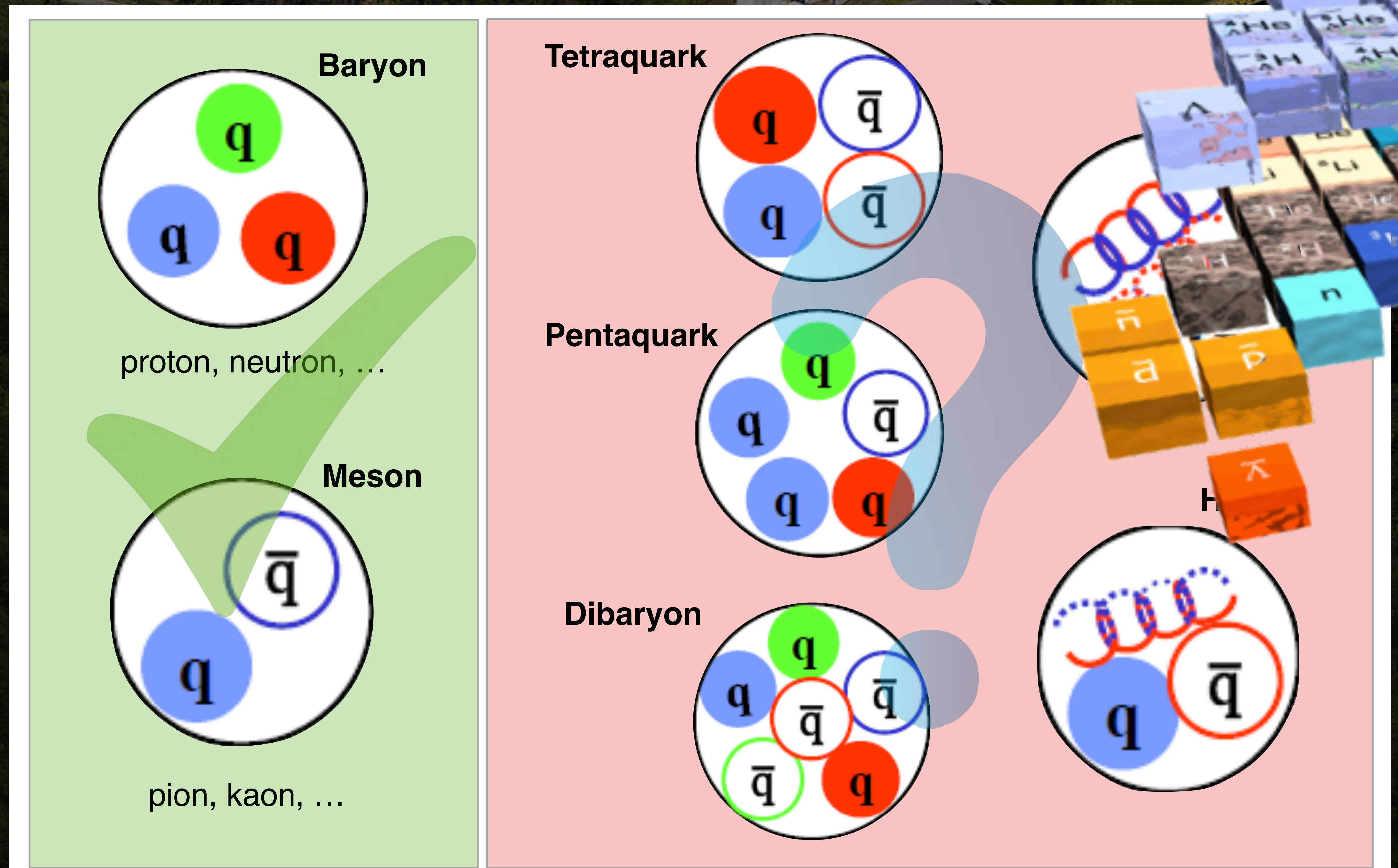
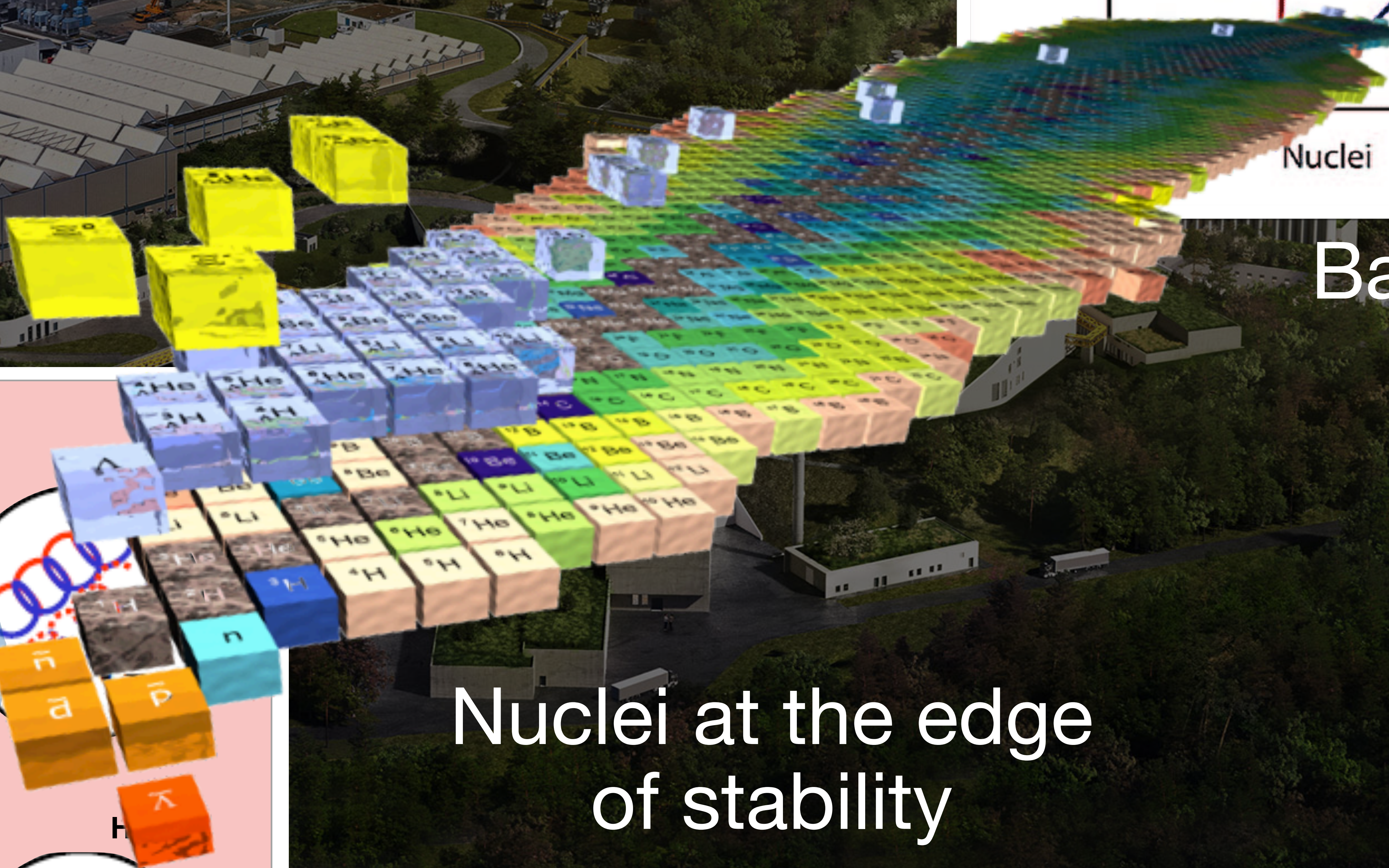
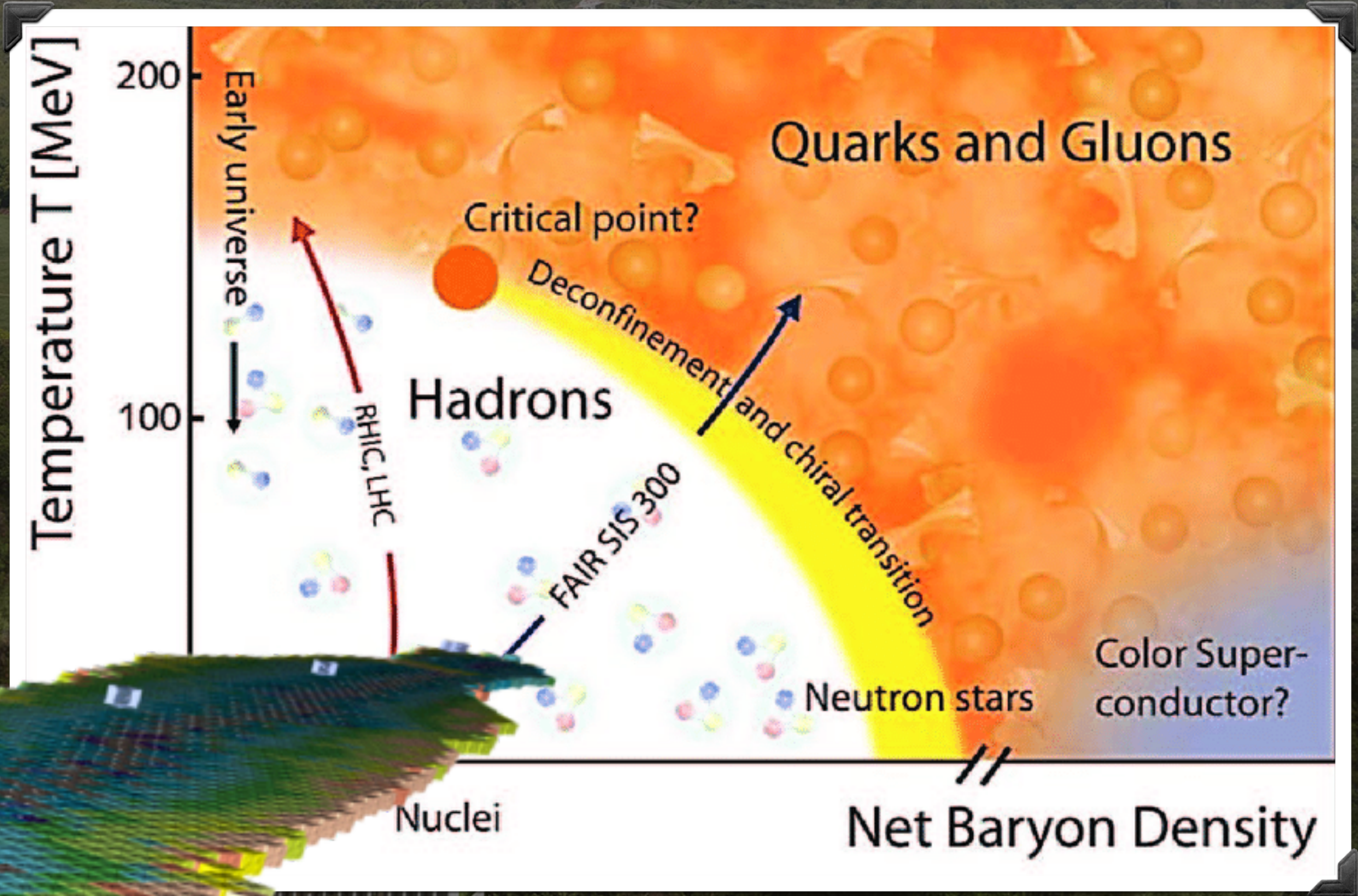




Nuclei at the edge of stability (NUSTAR)



Baryonic matter at high densities (CBM)

Hadron Physics Facilities at FAIR

Hadron Physics Facilities at FAIR

~2032

antiProtons ANnihilations at DArmstadt (PANDA)

$p, d \ldots$(SIS100)
Compressed Baryonic Matter (CBM)
~2028
$\bar{p}, p \ldots$(HESR)
~2032
Hadron Physics
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High Acceptance Di-Electron Spectrometer (HADES)
(FAIR Phase Zero)
$\pi, p, d \ldots$(SIS18)
Today!
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Green IT Cube (HPC)
35 PB/year (60 PB)
300.000 (54.000) cores
500 GPUs

Illustrative flagship case

Mysterious “XYZ” hadrons

Illustrative flagship case

Mysterious “XYZ” hadrons

Scientists Detect A Particle That Could Be A New Form Of Matter

Brian Koberlein — Universe Today
4/11/14 9:00pm · Filed to: PHYSICS

Science / Science Now

Meet the pentaquark, just spotted at CERN's Large Hadron Collider

Fysici ontdekken nieuw, exotisch deeltje met vier 'smaken' quarks

Vijf jaar nadat de grote Tevatron-versneller van Fermilab in Batavia, Illinois, werd stopgezet heeft een van de deeltjesexperimenten daar toch nog een opmerkelijk

PHYSICS

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NATURE | NEWS

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14 July 2015 | Updated: 14 July 2015

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November 14, 2003
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NATALIE WOLCHOVER, QUANTA MAGAZINE SCIENCE 09.09.14 6:30 AM

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Science & Environment

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By Paul Rincon
Science editor, BBC News website

14 July 2015 Science & Environment Share

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15 januari 2017 15:14 DE EN FR

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BINNENLAND BUITENLAND ECONOMIE WETENSCHAP CULTUUR & MEDIA

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WETENSCHAP

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Door Wendy Docters

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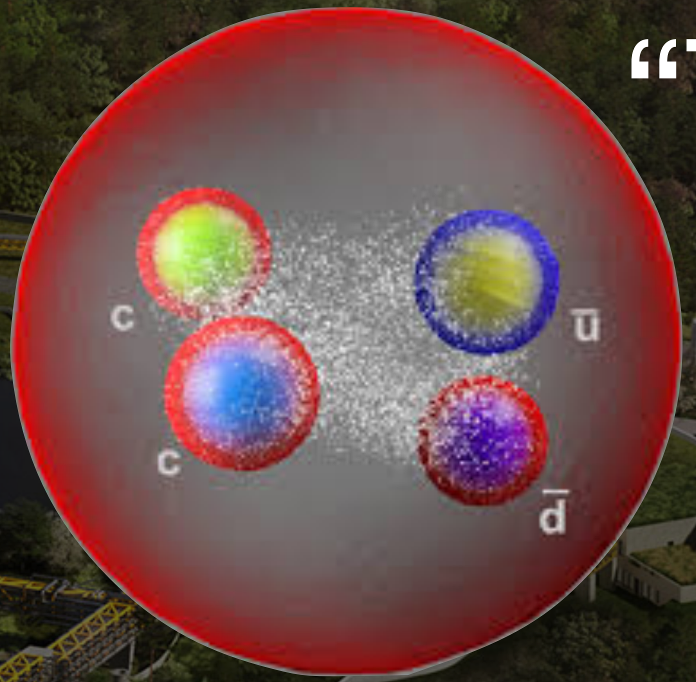
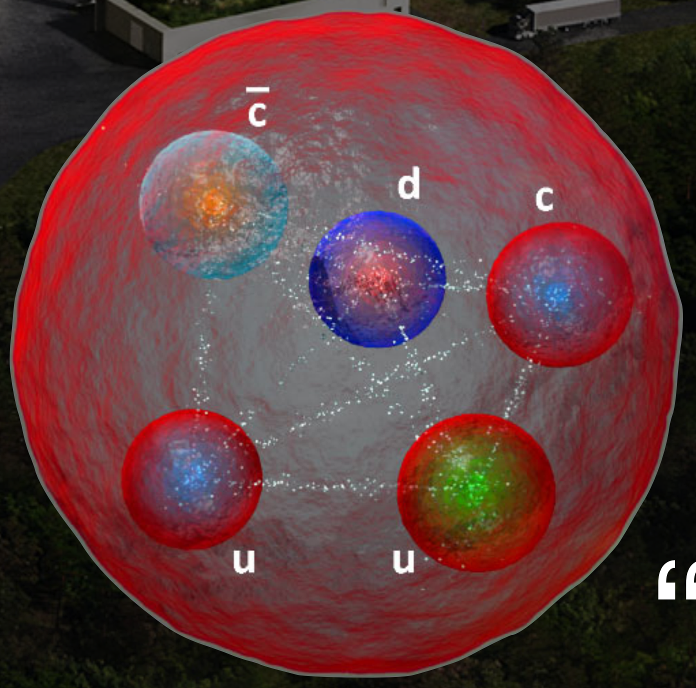


"Tetraquarks"



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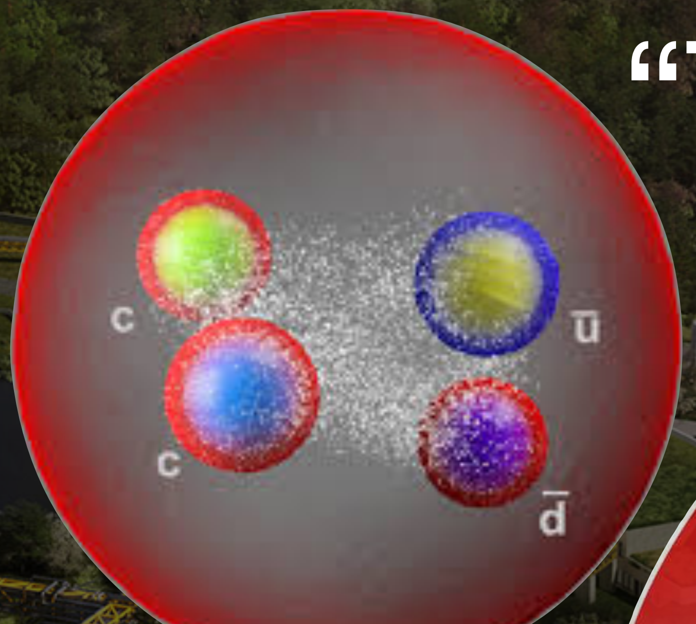
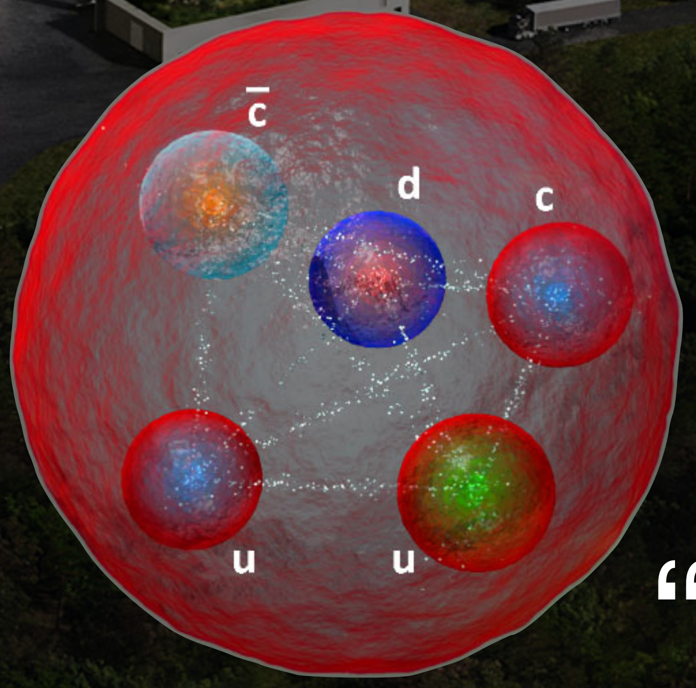


“Tetraquarks”

Composition remains puzzling!



“Pentaquarks”

The “how” and why “FAIR”?

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Key to discovery: ***precision***

Resolution **Statistics**

Accurate mass measurements

$\Delta M/M \approx 10^{-5}$ → Storage rings

The "how" and why "FAIR"?

Key to discovery: ***precision***

Resolution → Accurate mass measurements

$\Delta M/M \approx 10^{-5}$ → Storage rings

Statistics → High sensitivity to rare production processes

$\sigma_{\text{sens}} < \text{nb}$ → High beam intensities & detection capabilities

High Energy Storage Ring at FAIR

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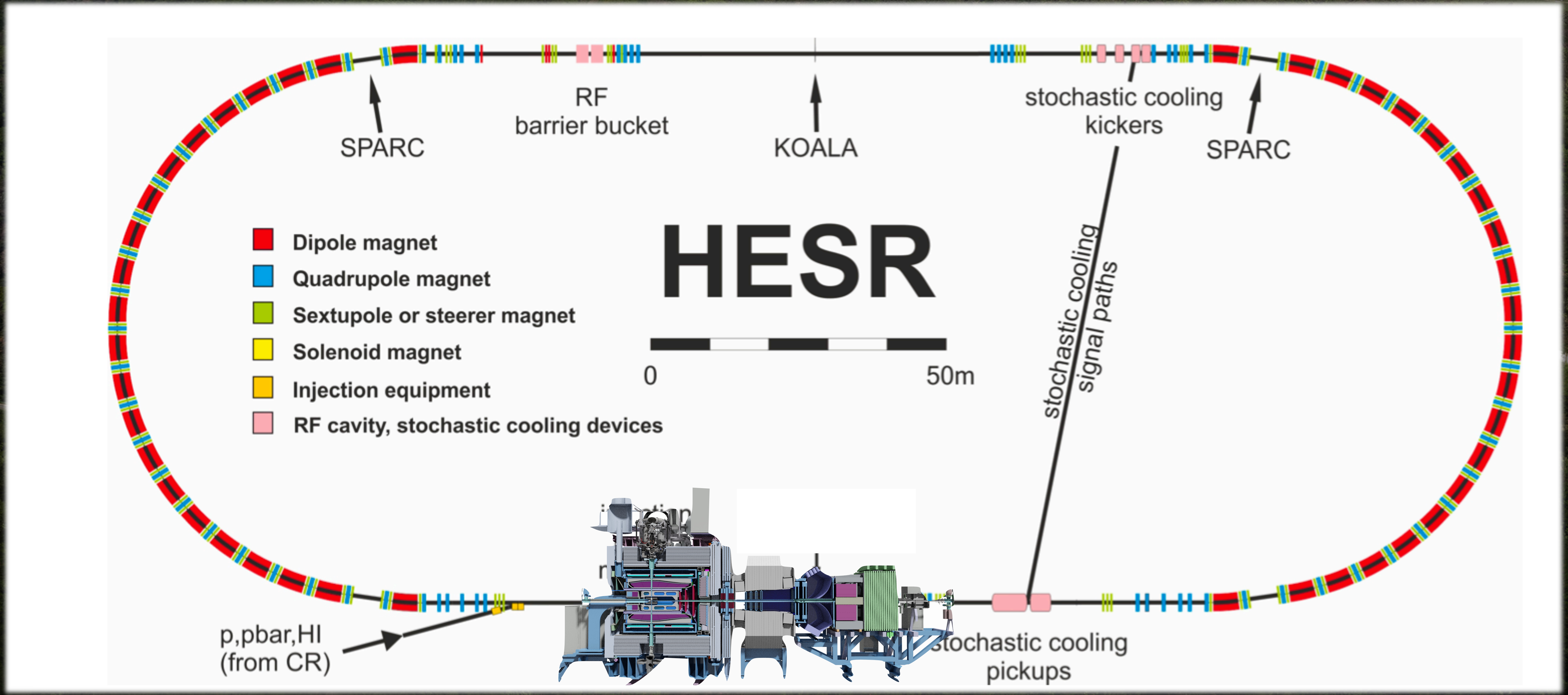
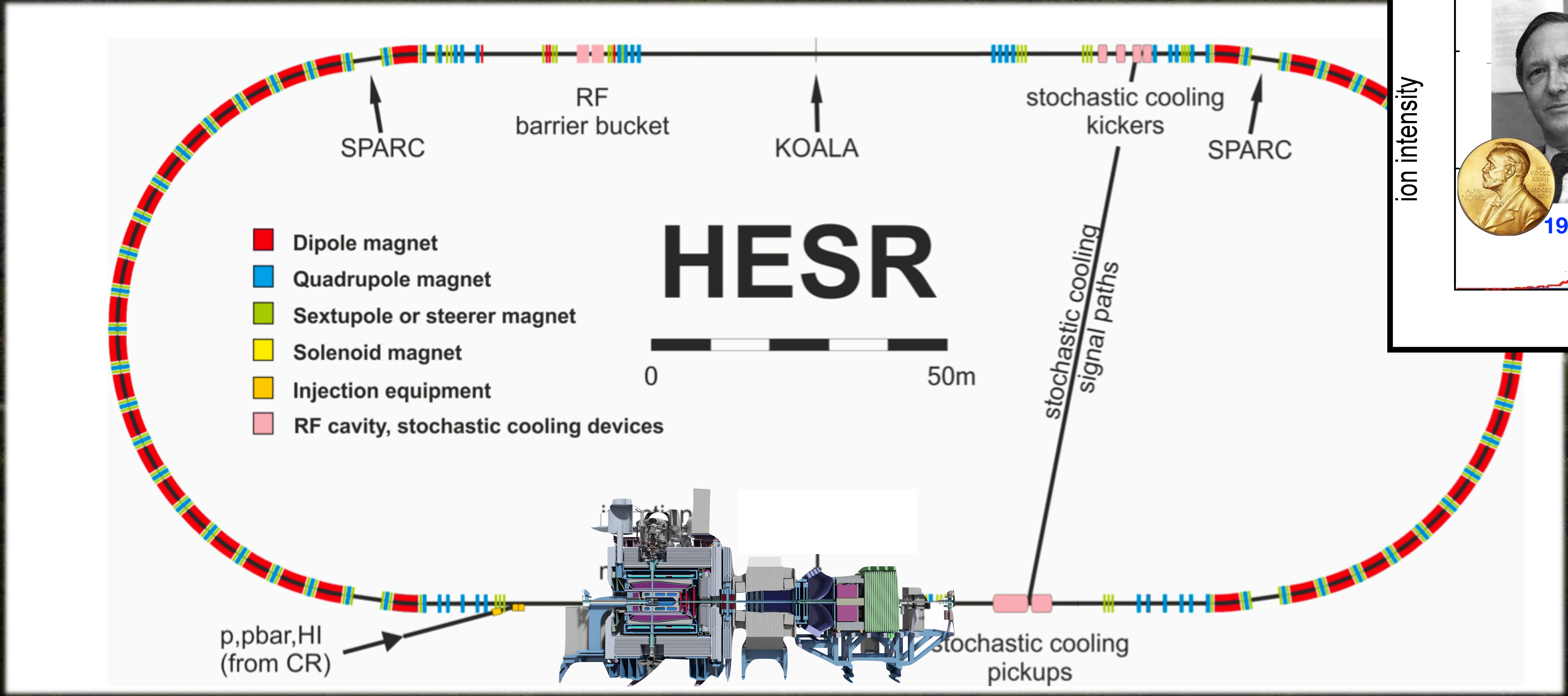
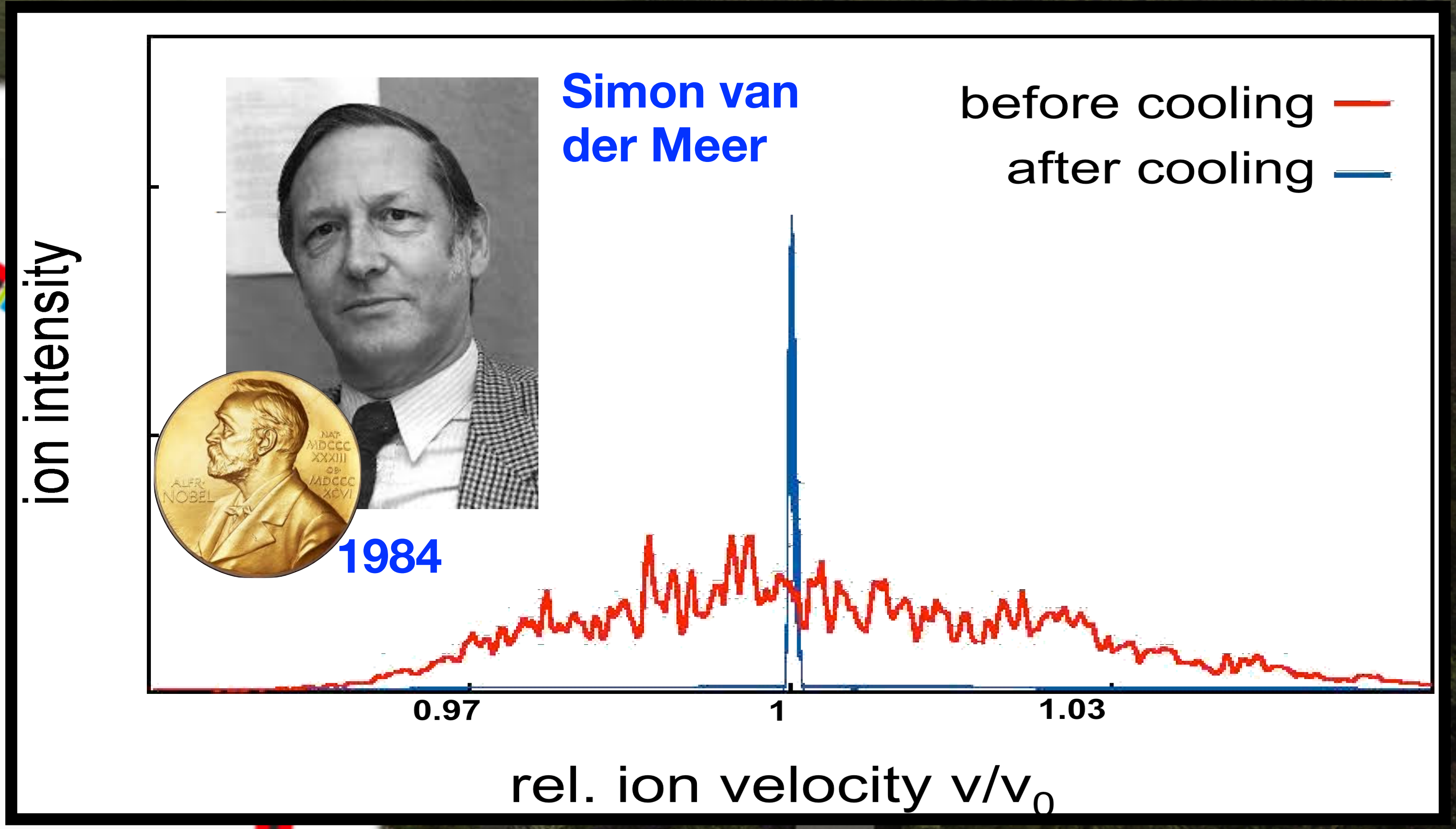


Stochastic **cooling**: $\Delta p/p \approx 3 \times 10^{-5}$

Accumulation: 10^{11} antiprotons$\rightarrow L \approx 2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

High Energy Storage Ring at FAIR





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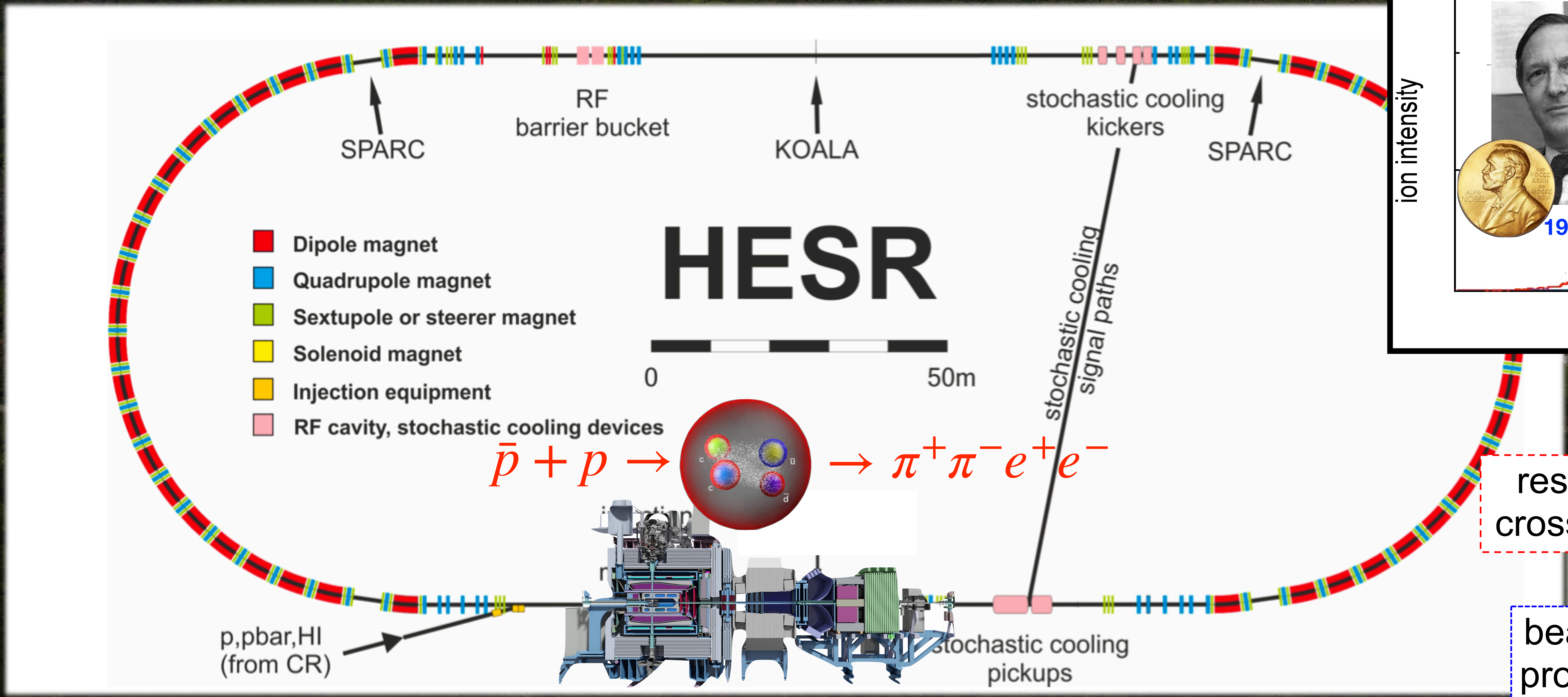

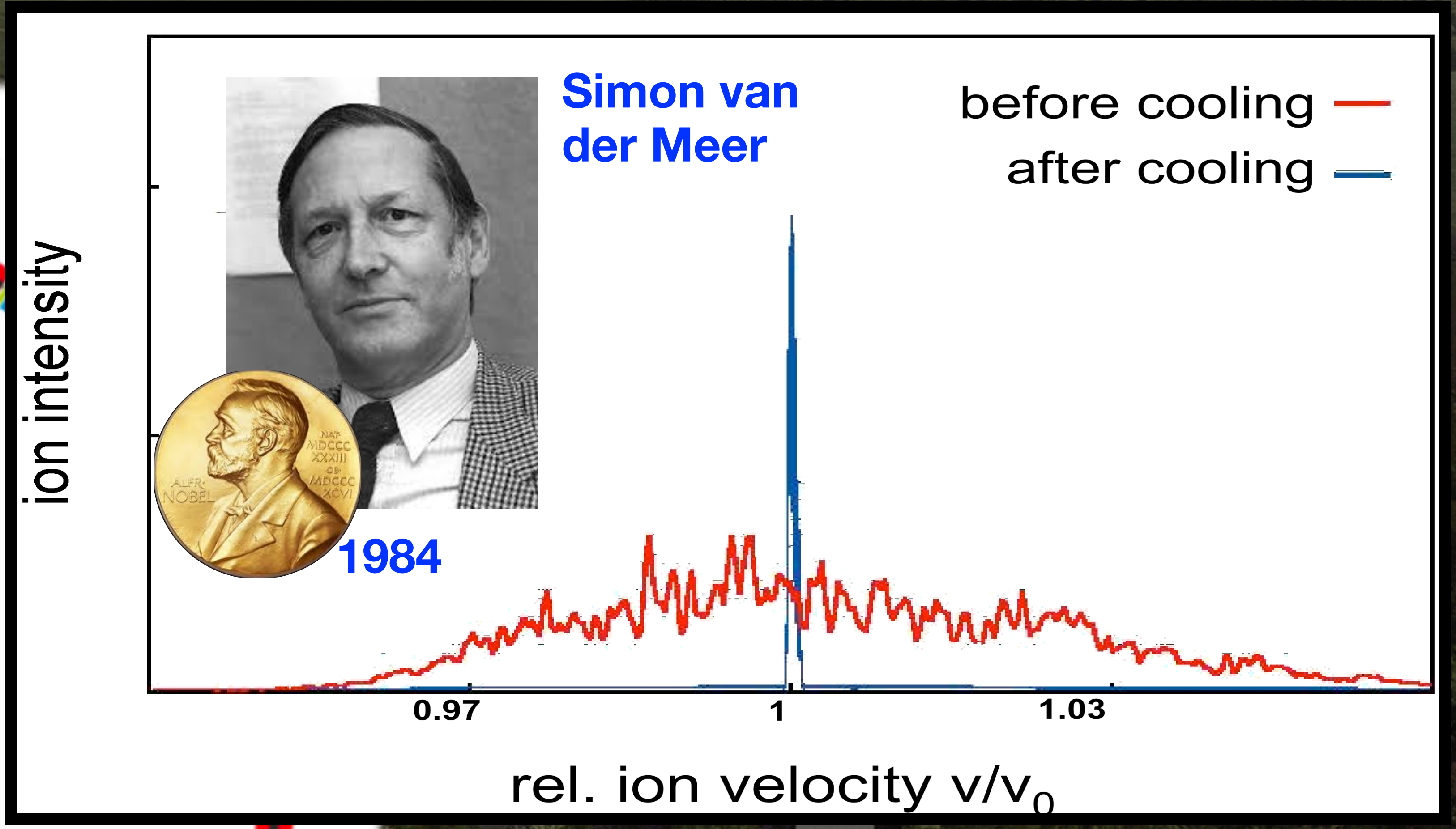

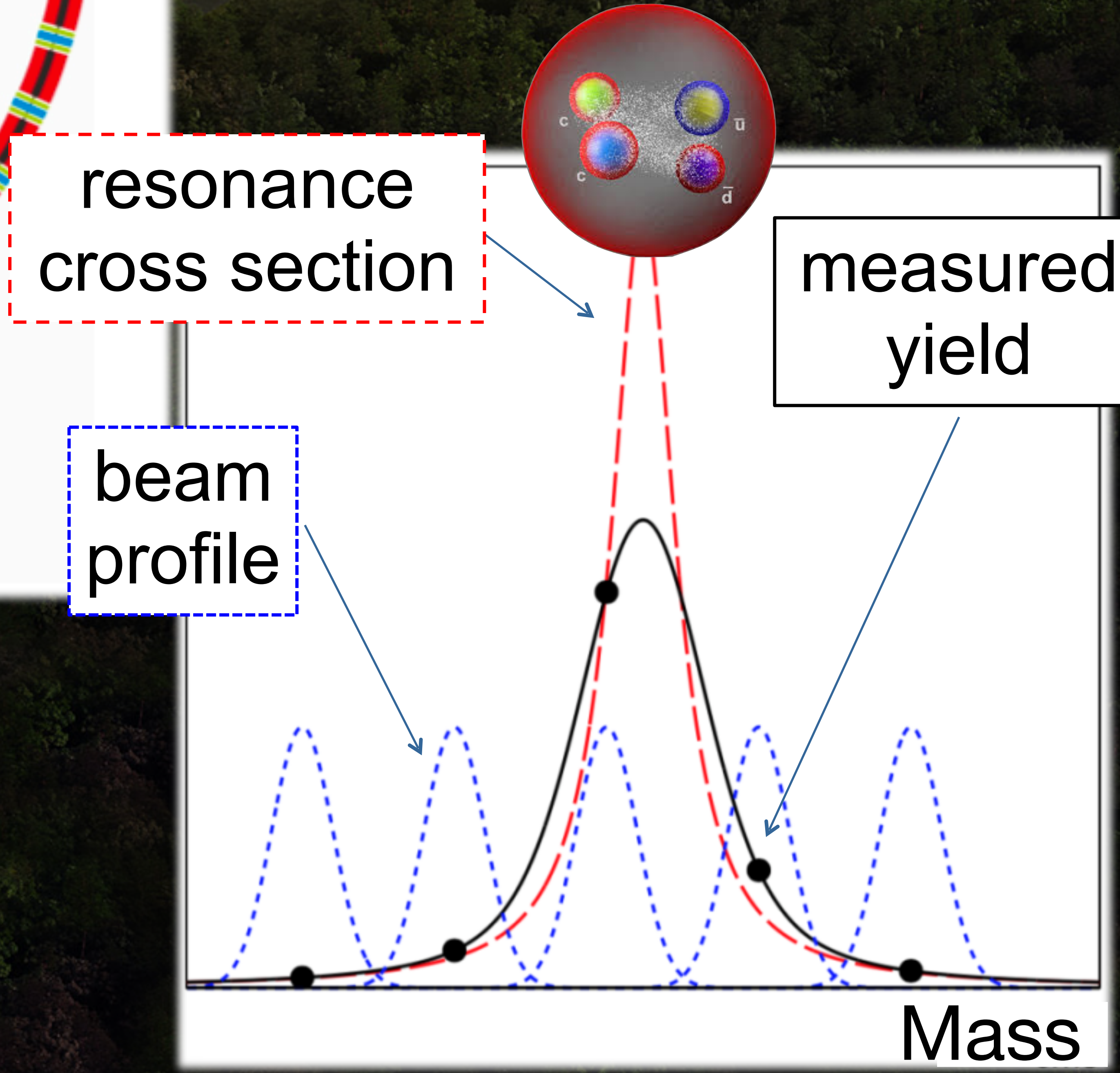

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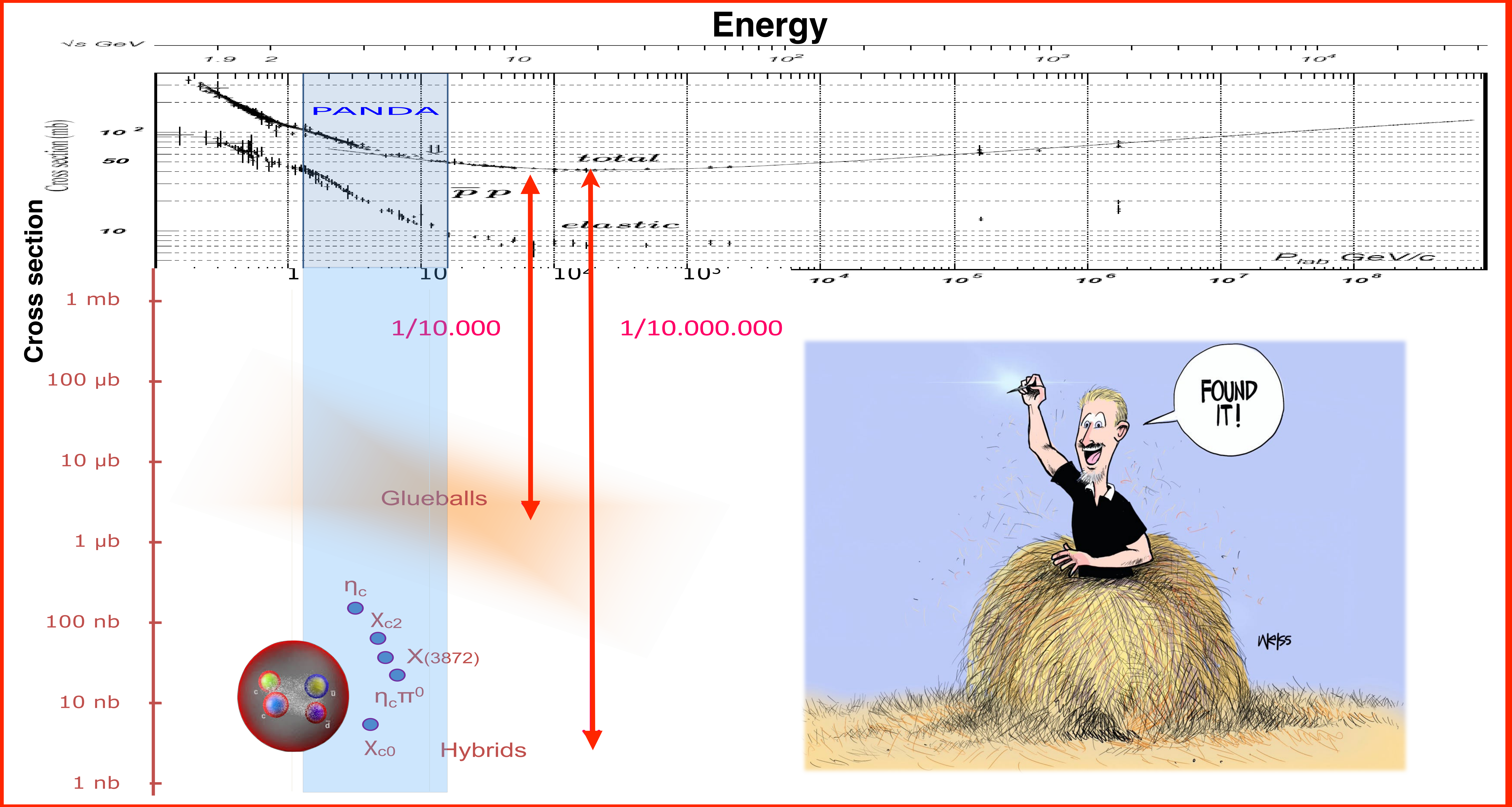
Needles-in-a-haystack



Data processing scheme

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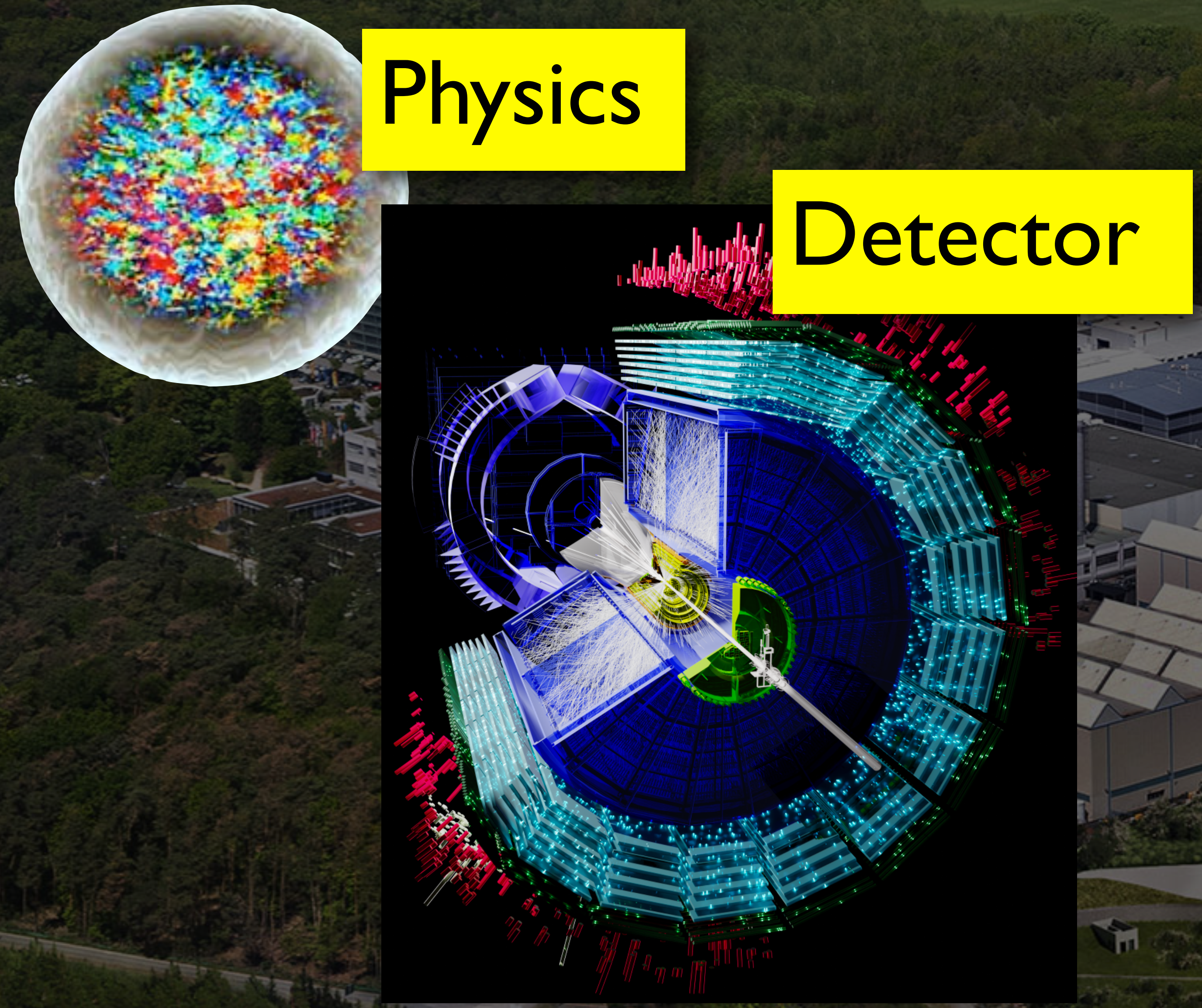

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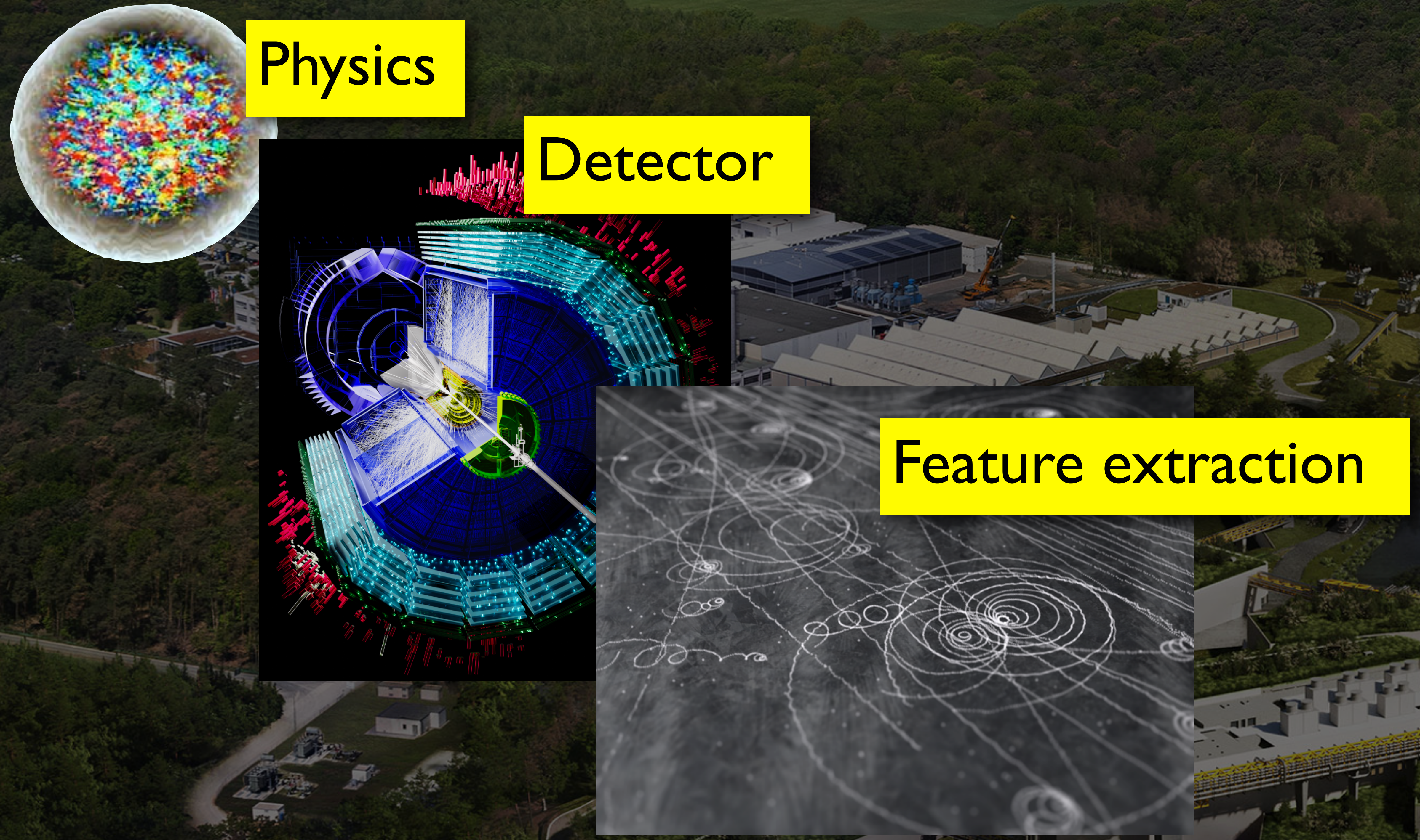

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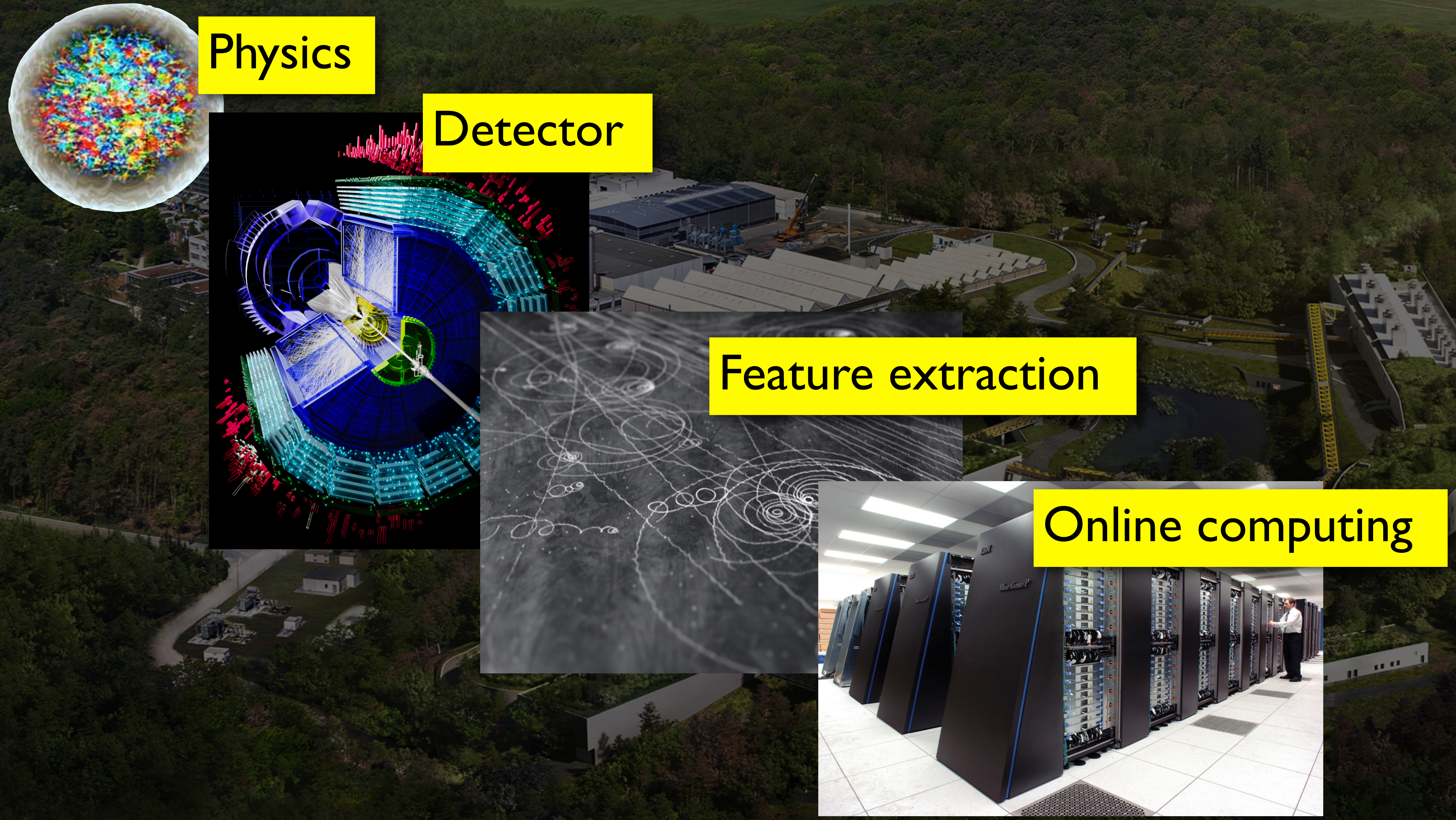

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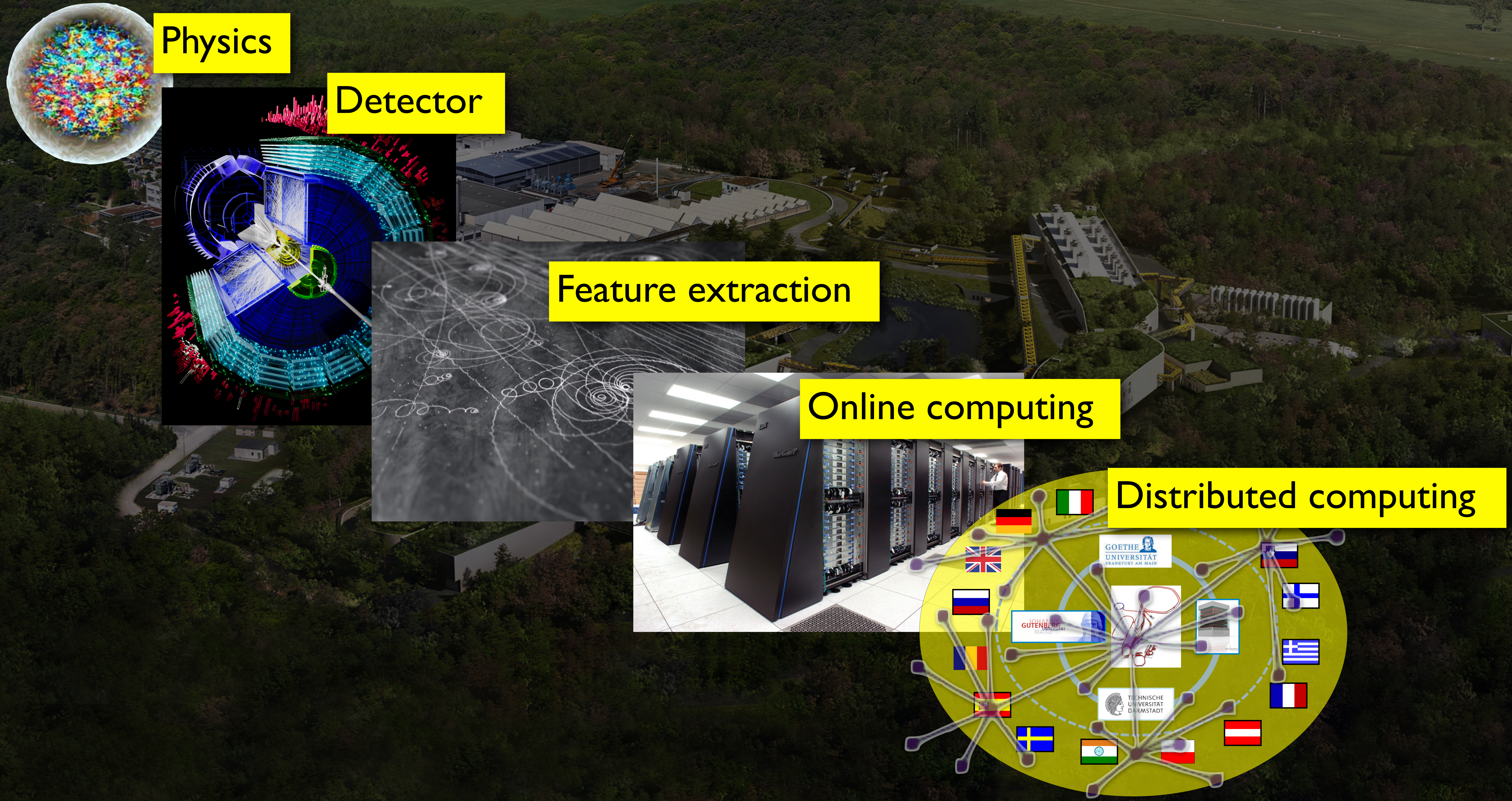

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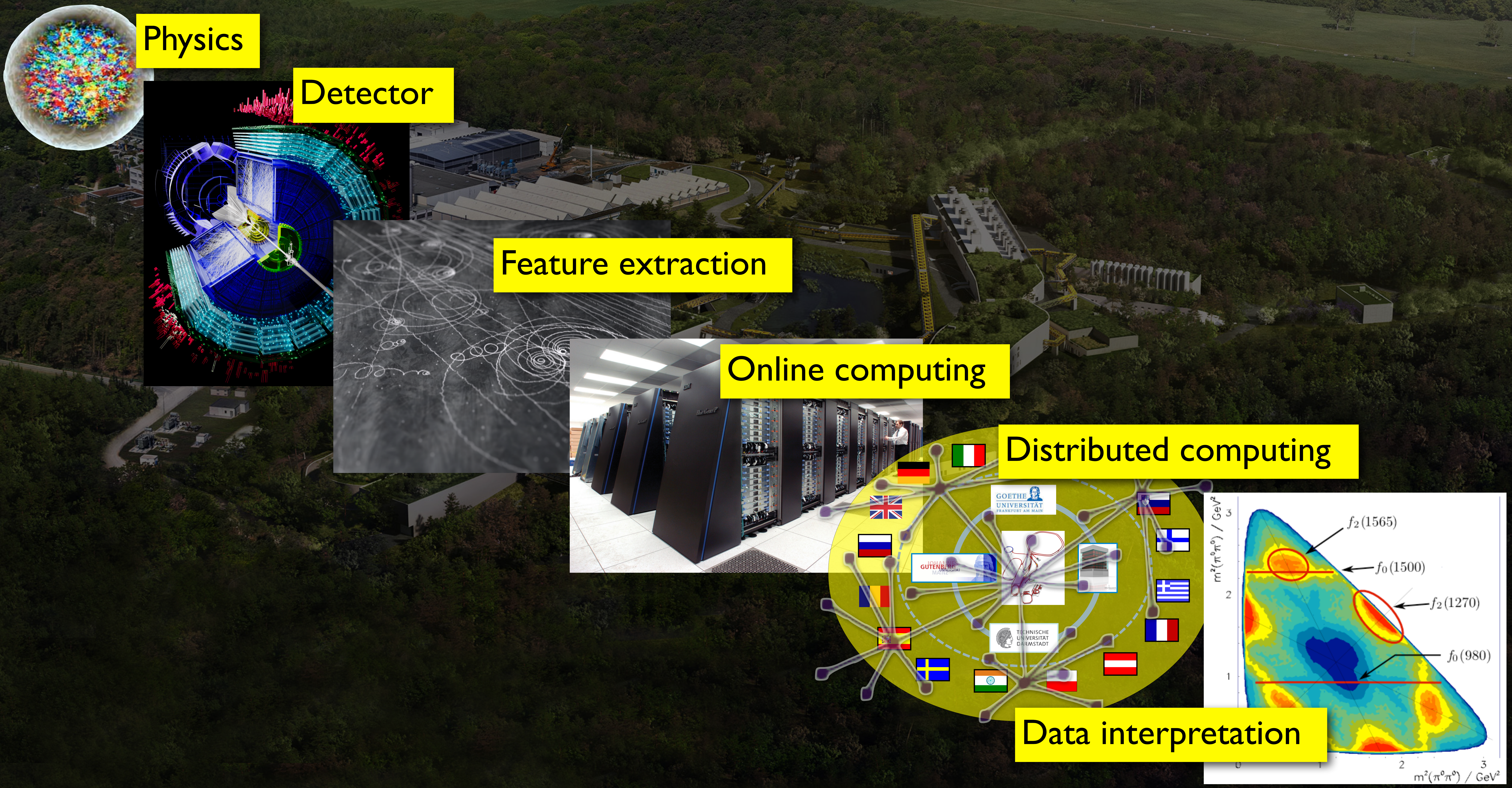

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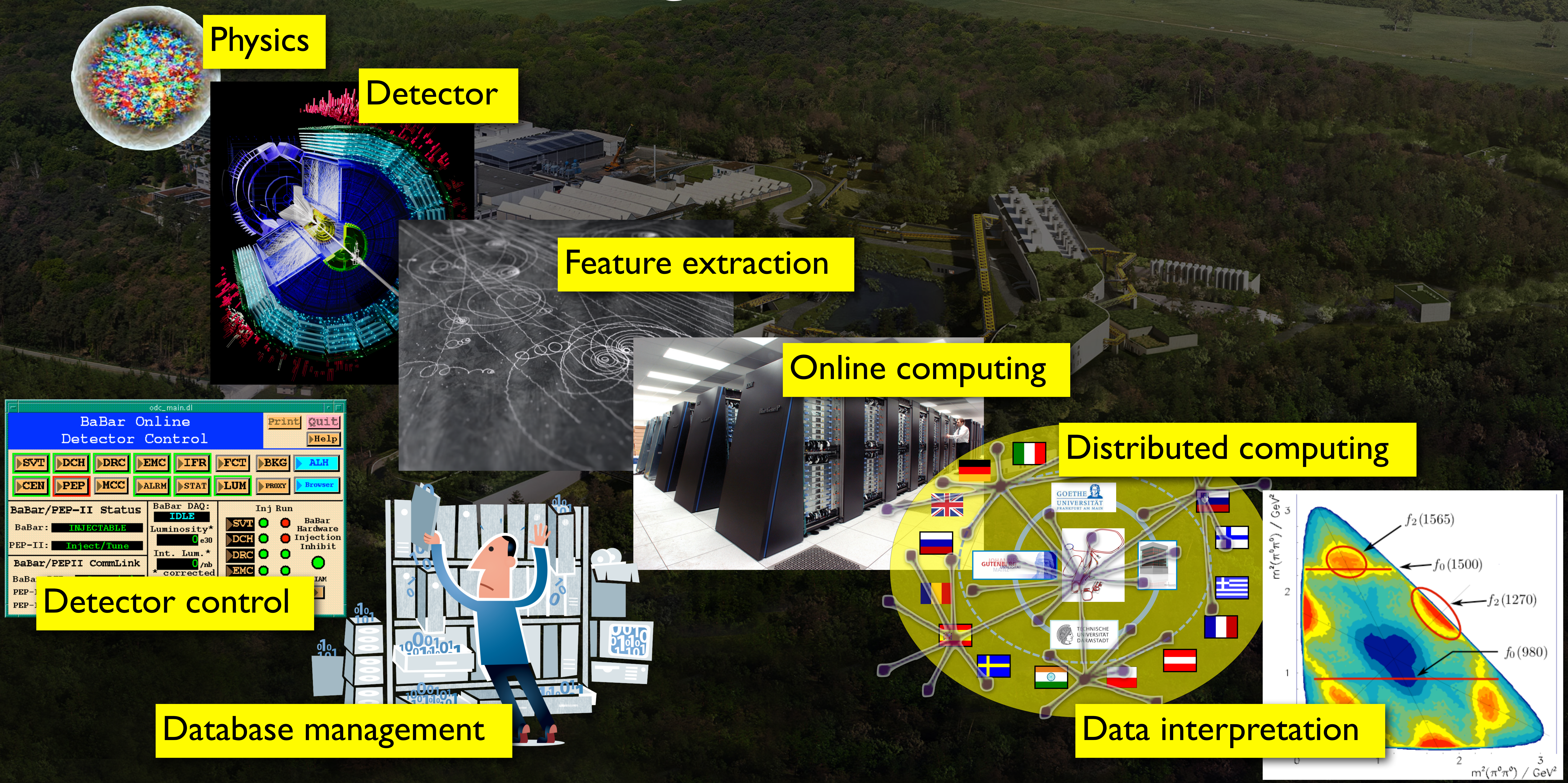

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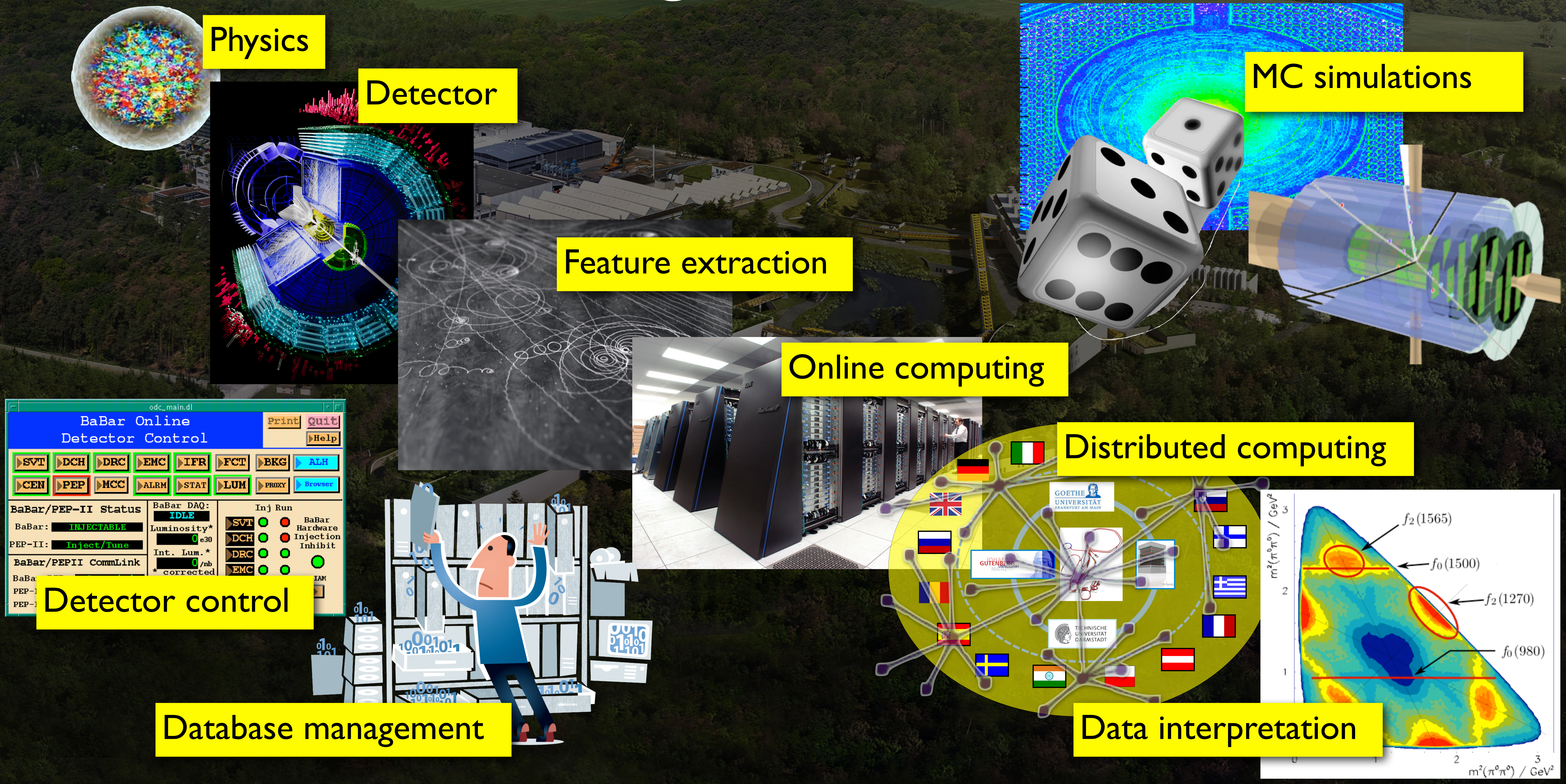

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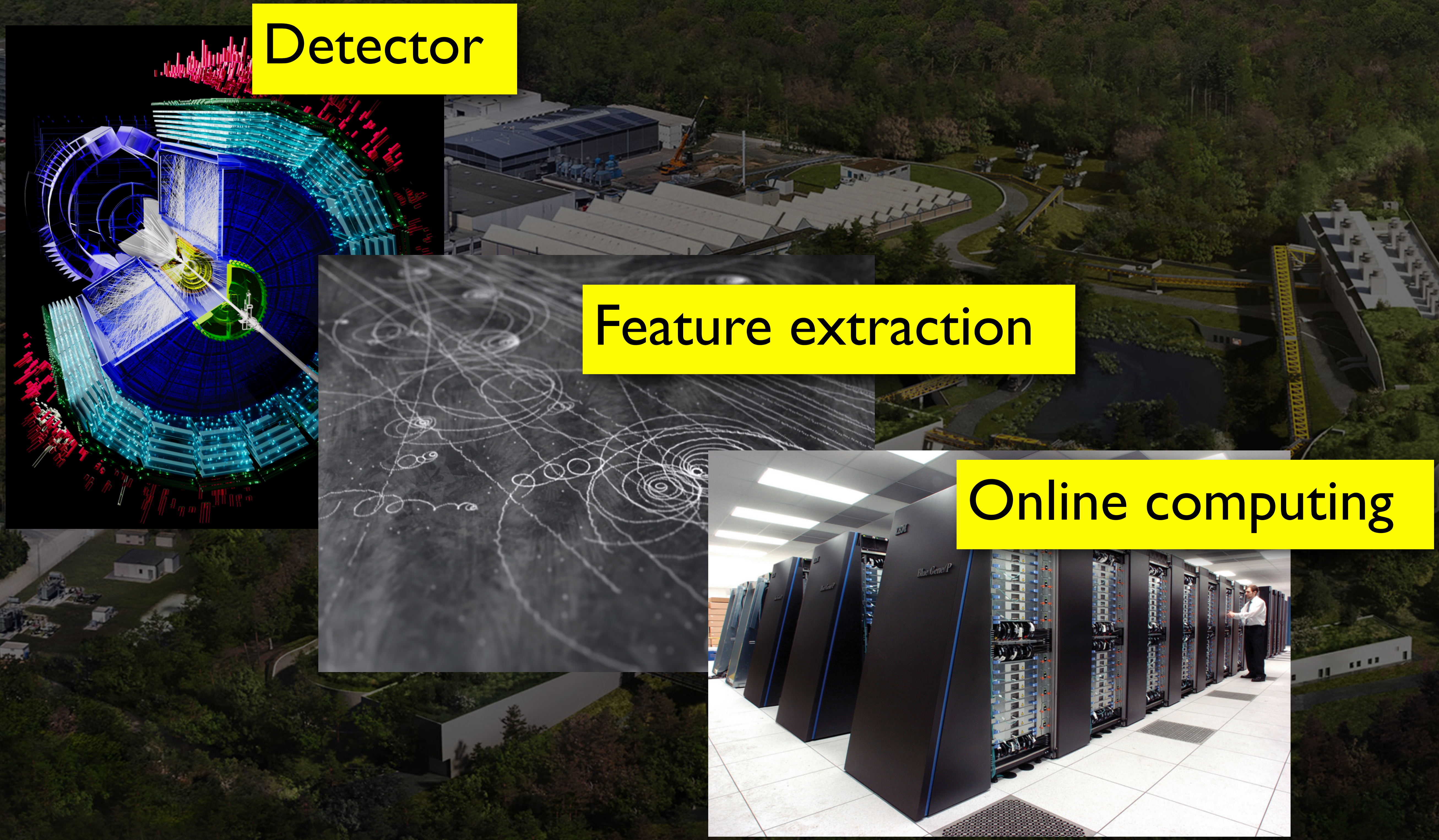

Back to the (late) 90-ties

Groningen,
Netherlands
~1998

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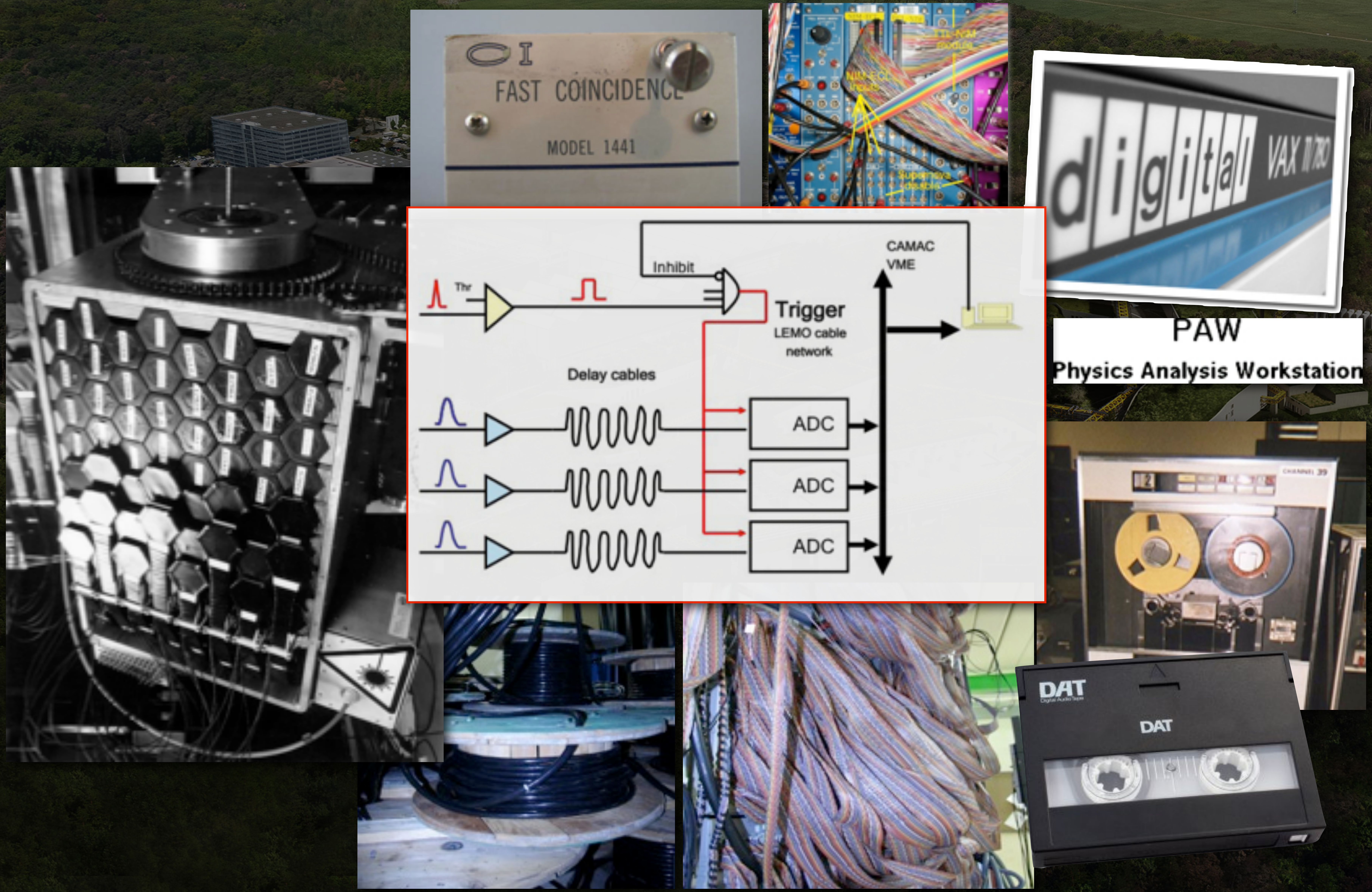

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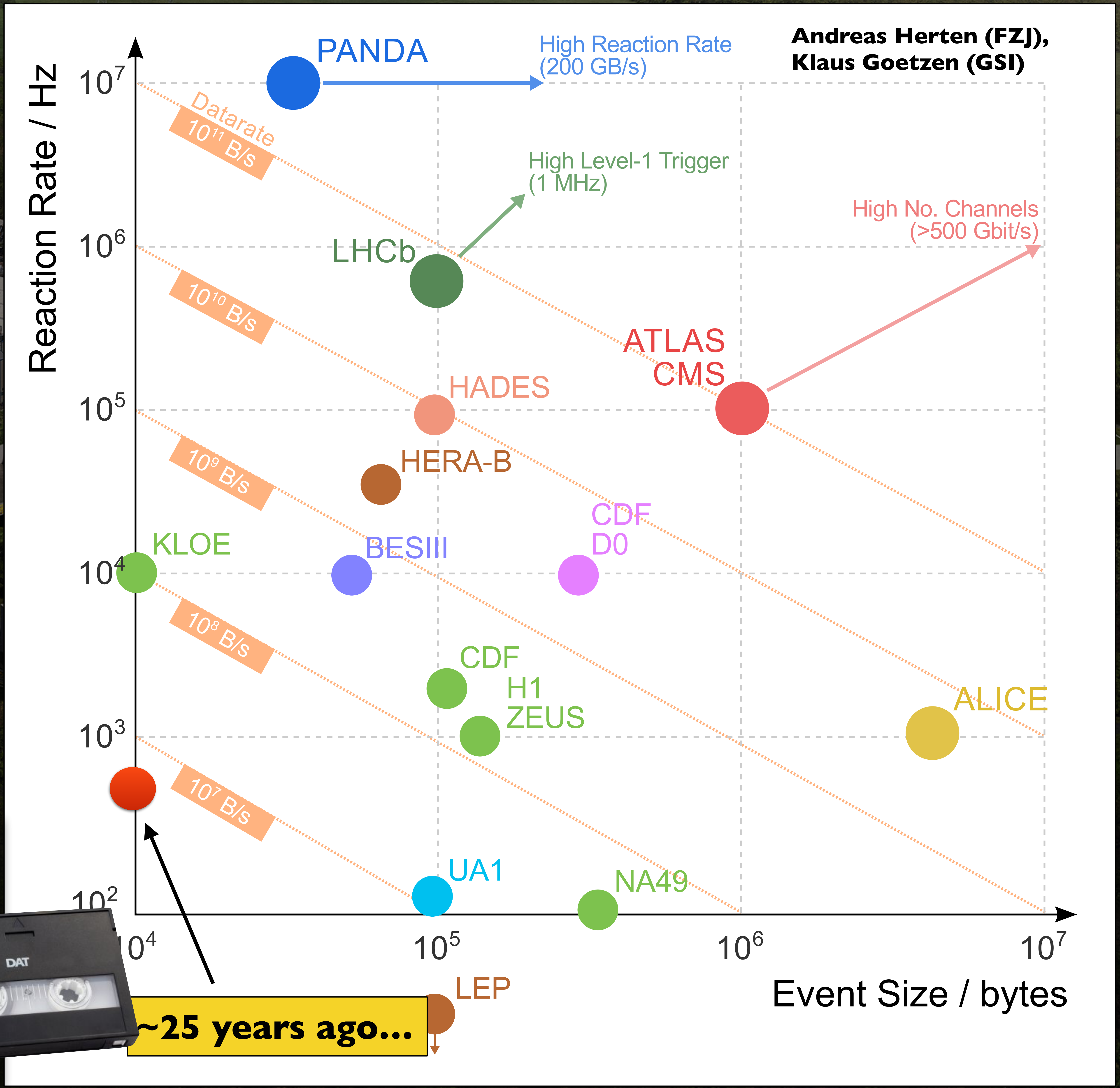
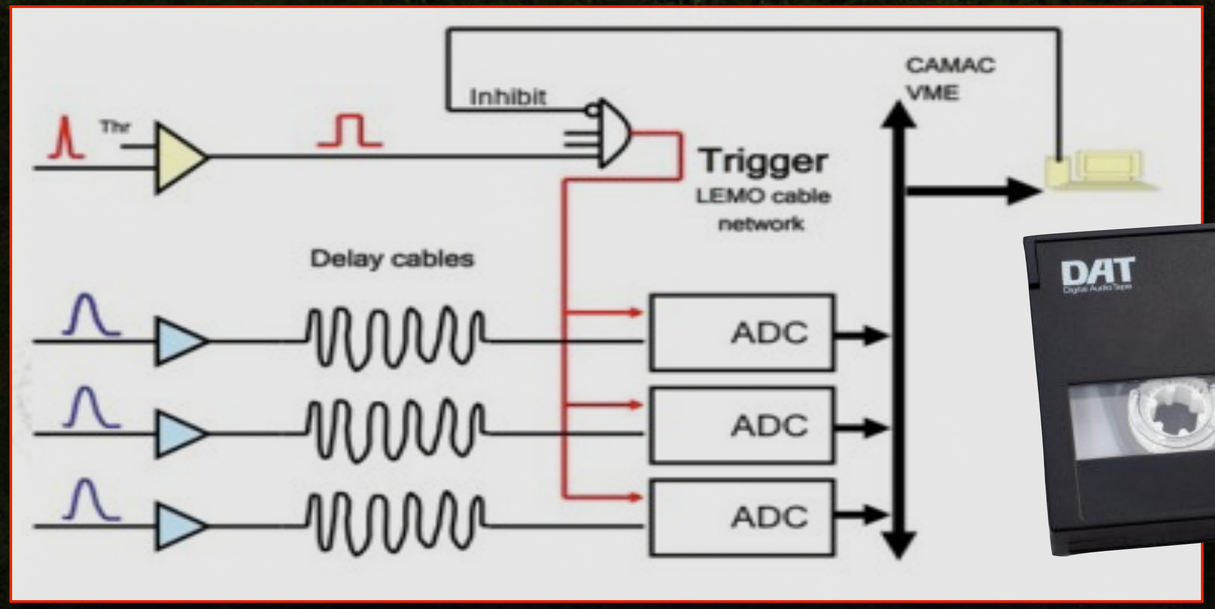
Evolution in hadron physics experiments





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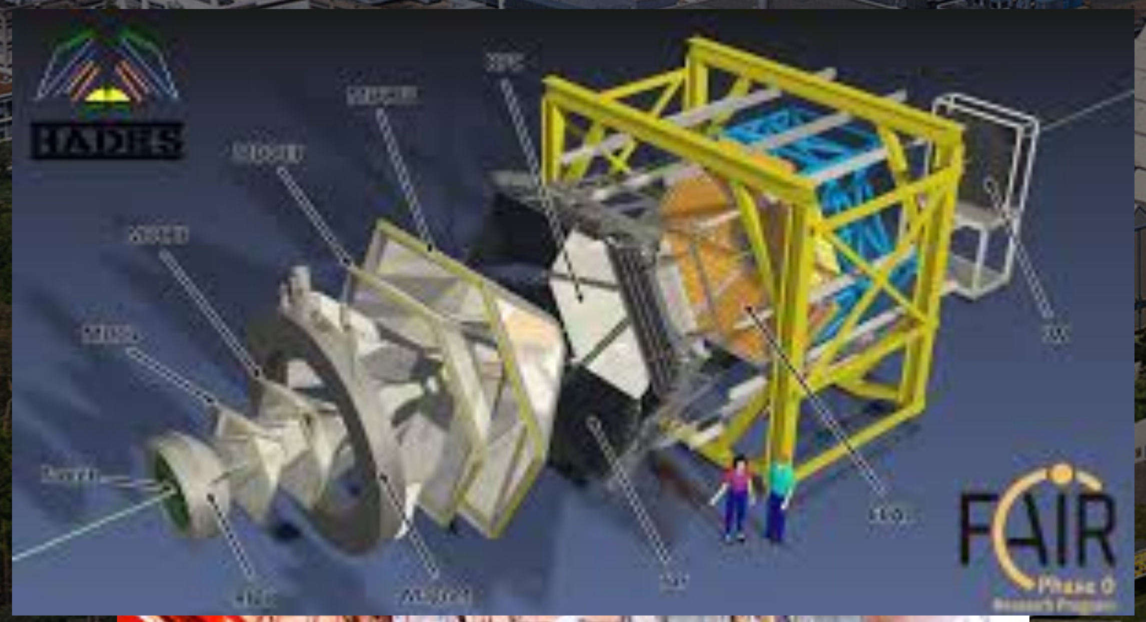

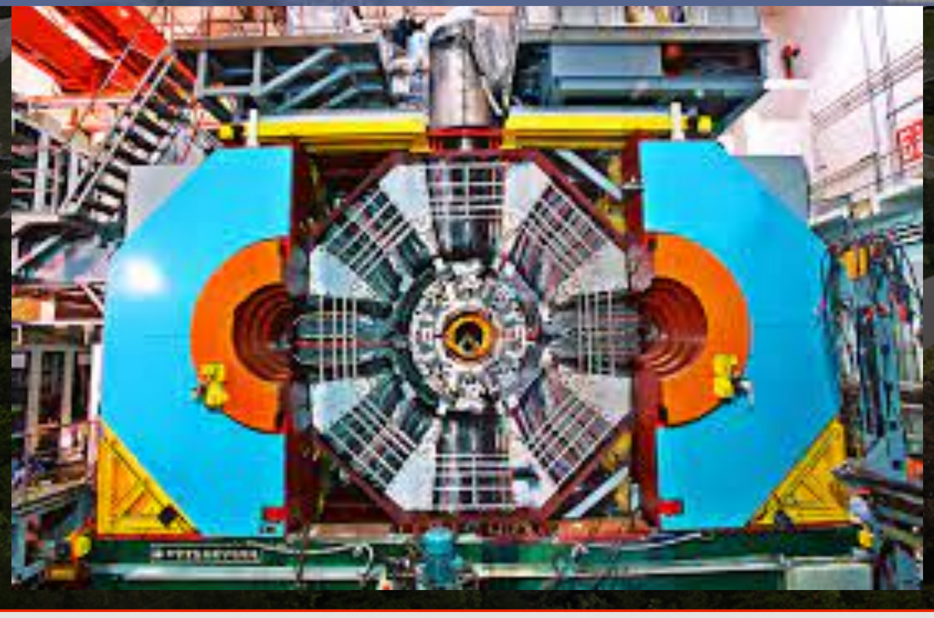

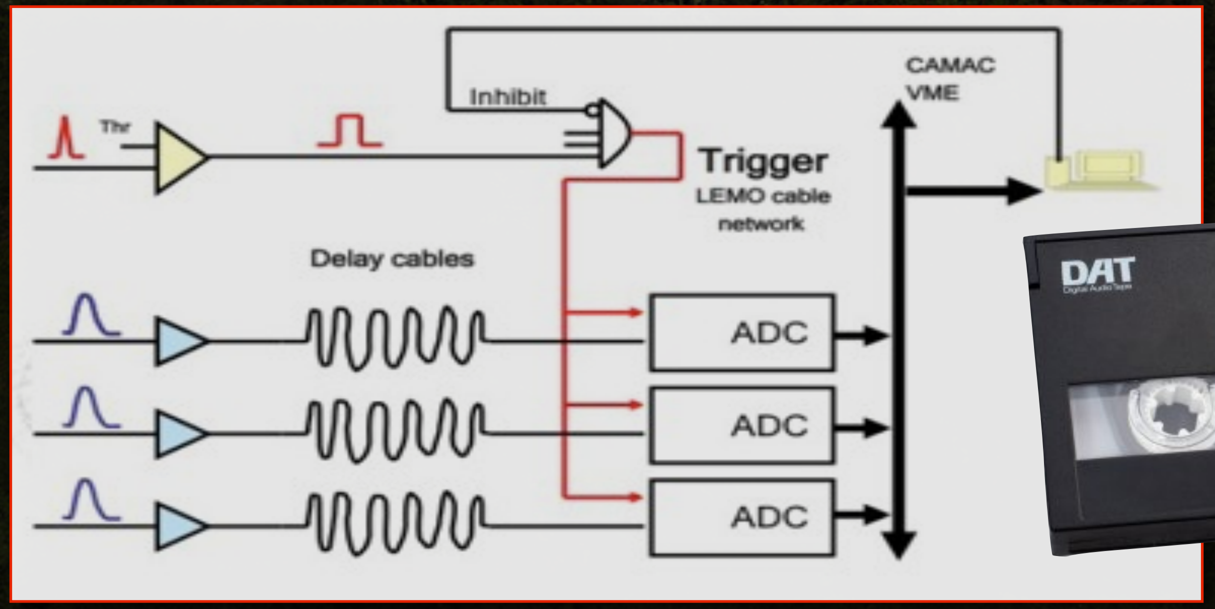

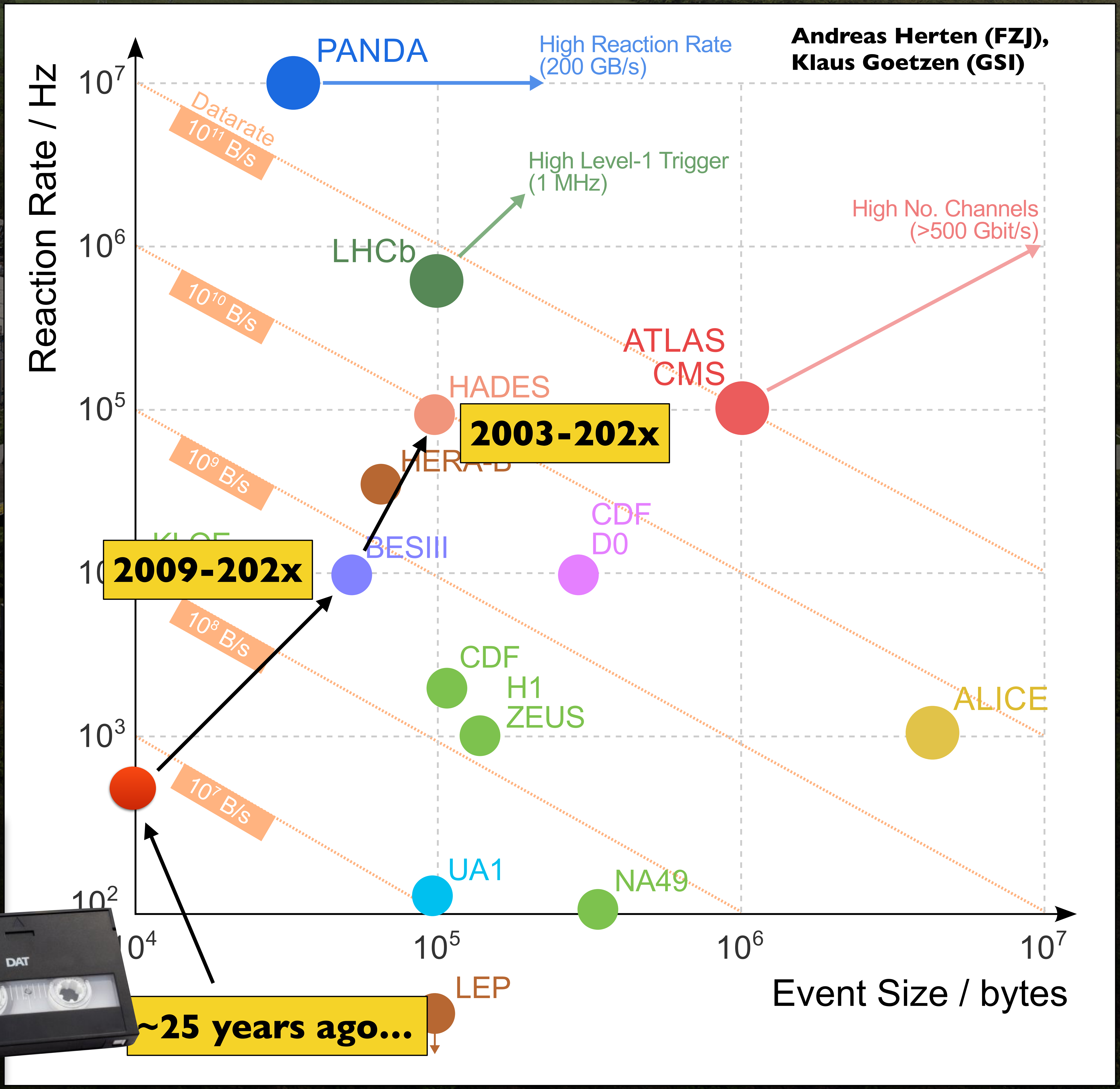

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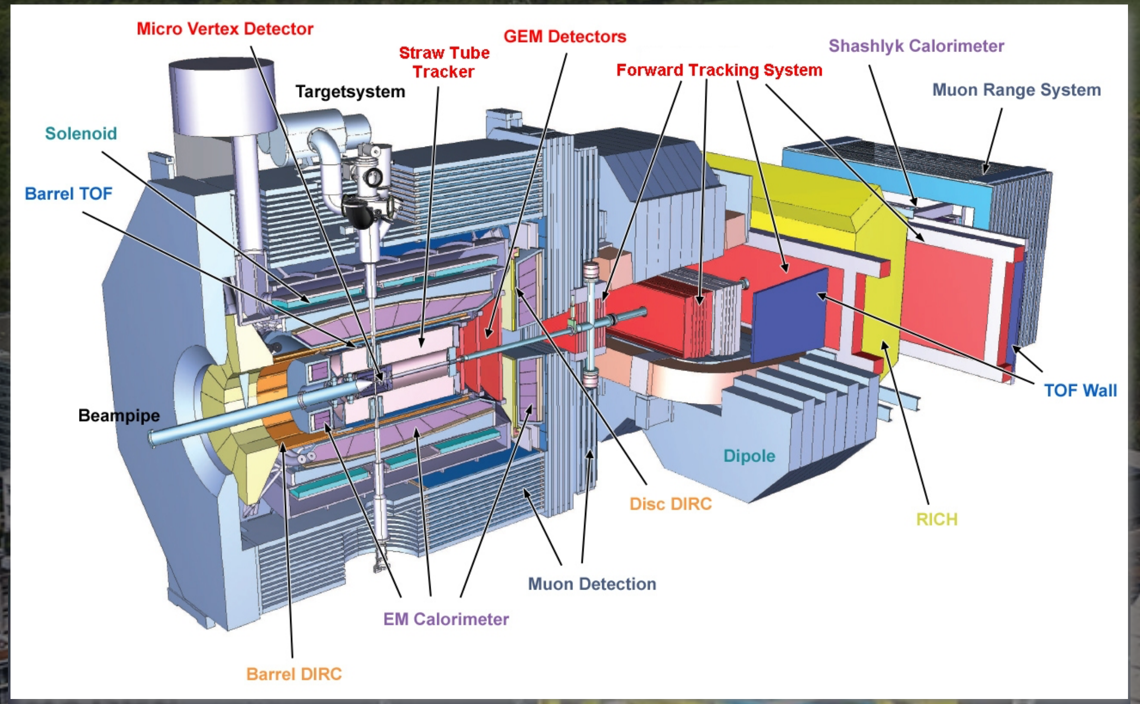
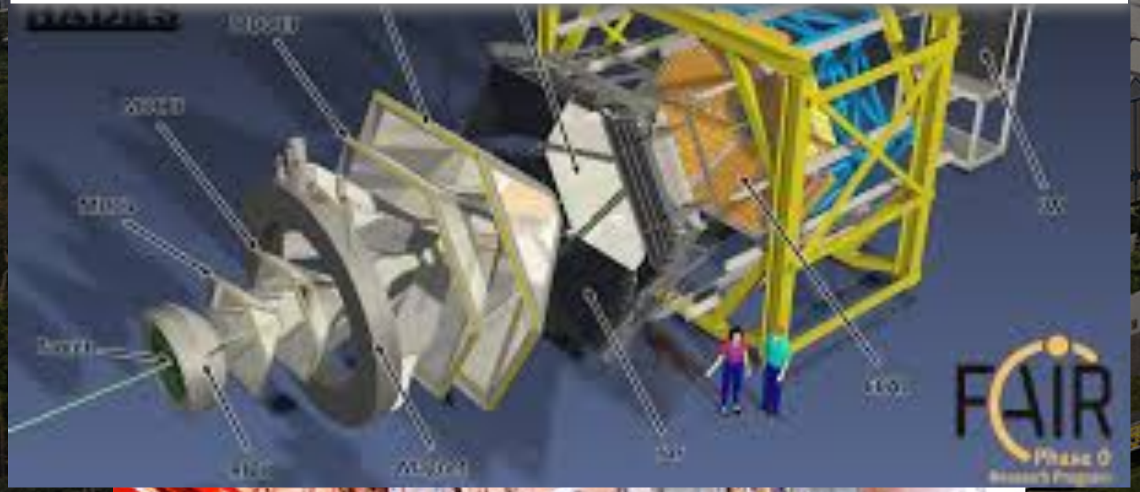
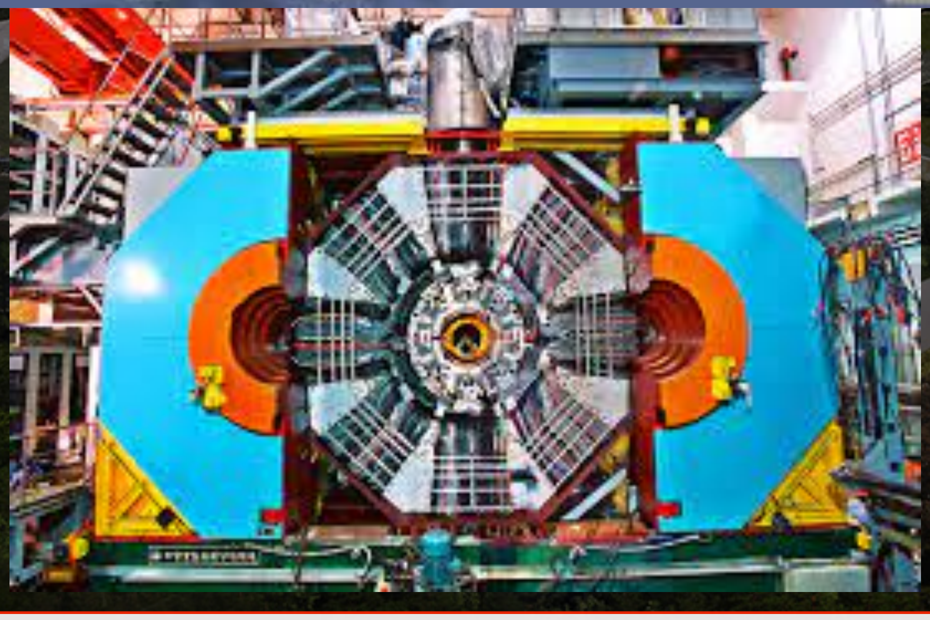
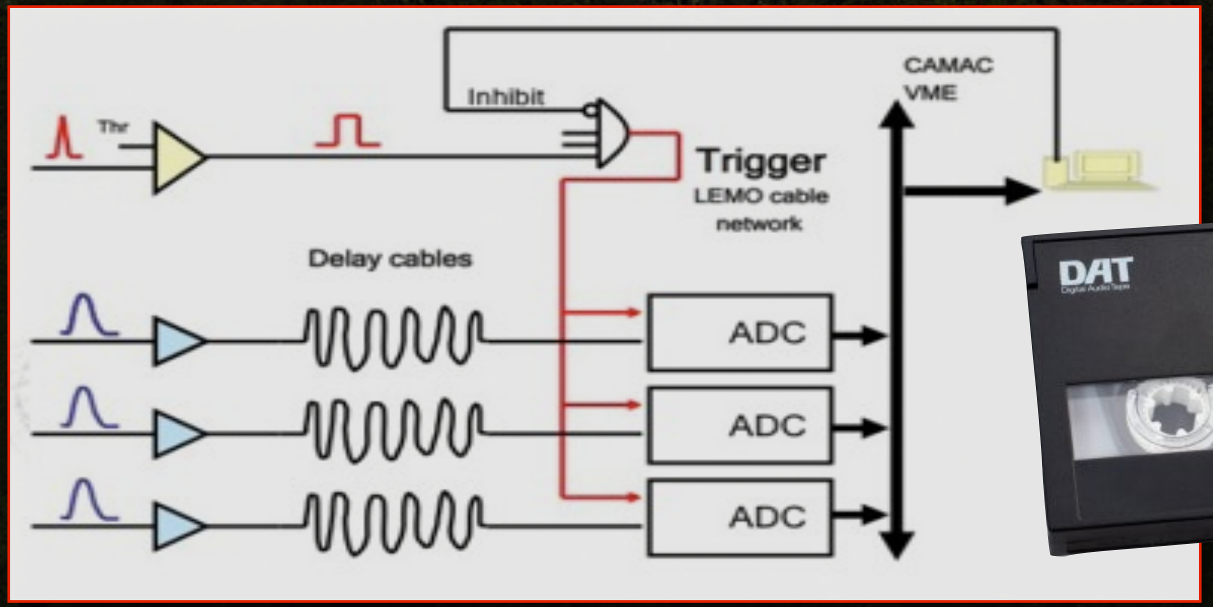
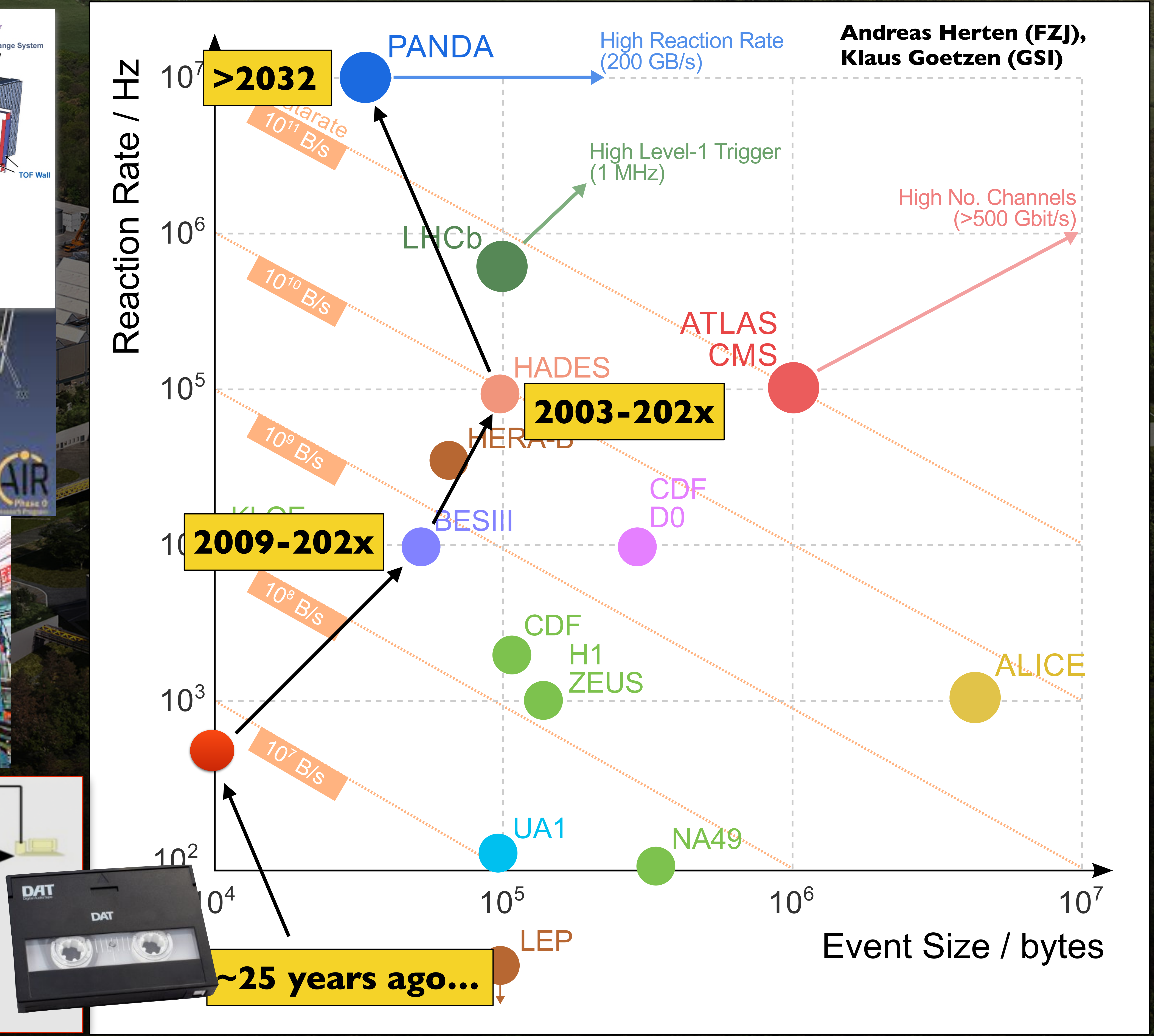




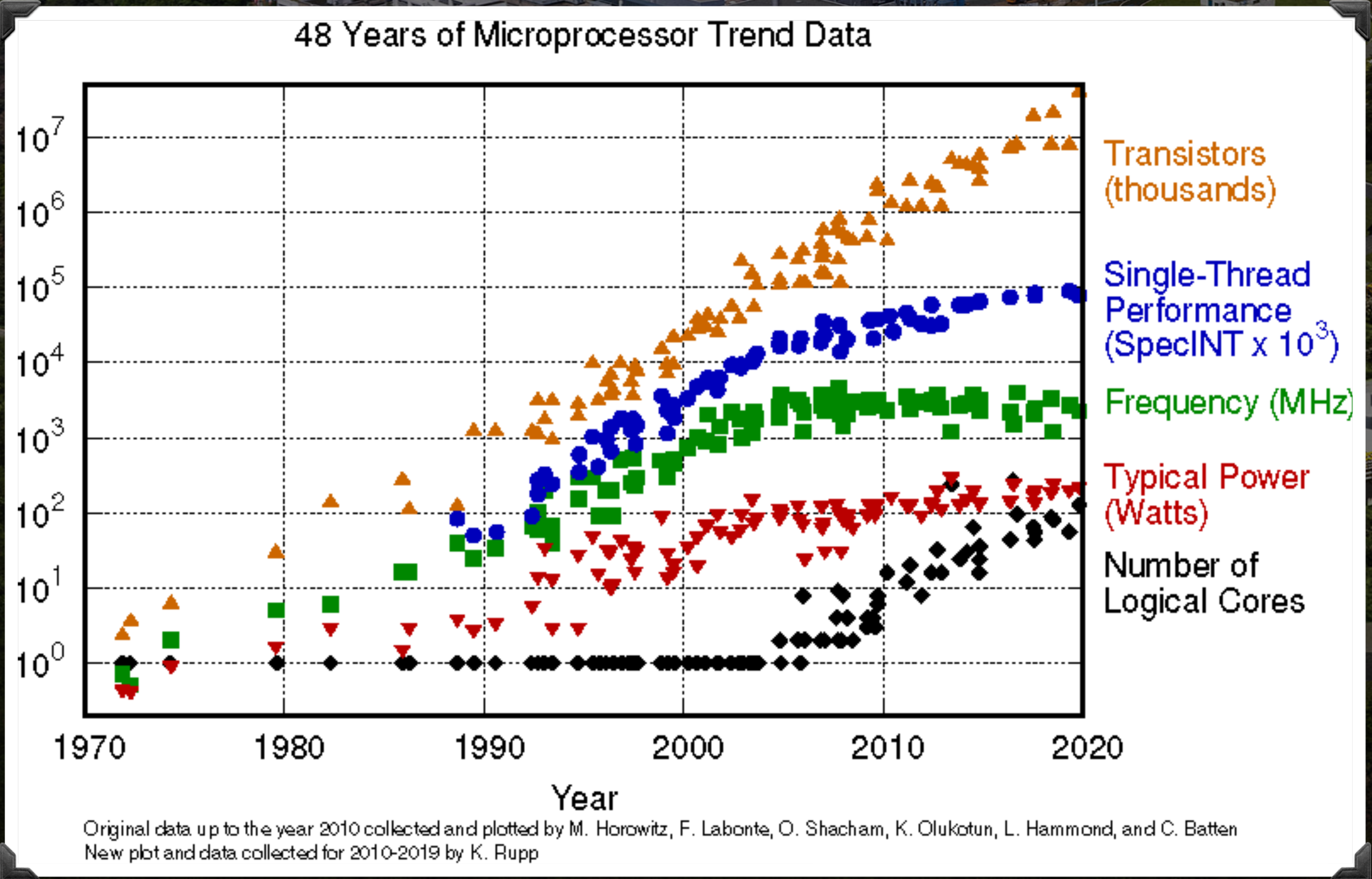






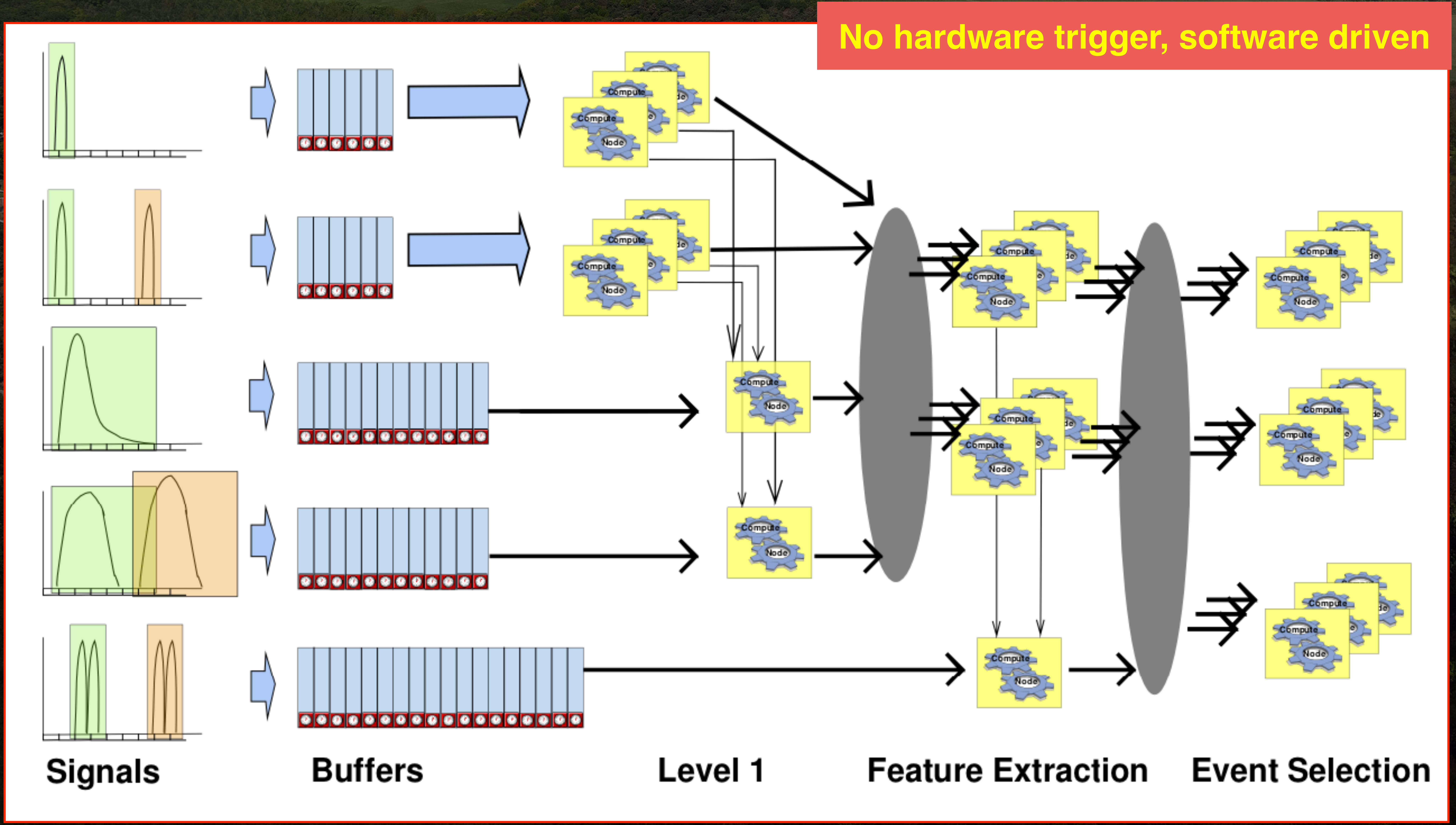
Bigger shovel?

Moore's law

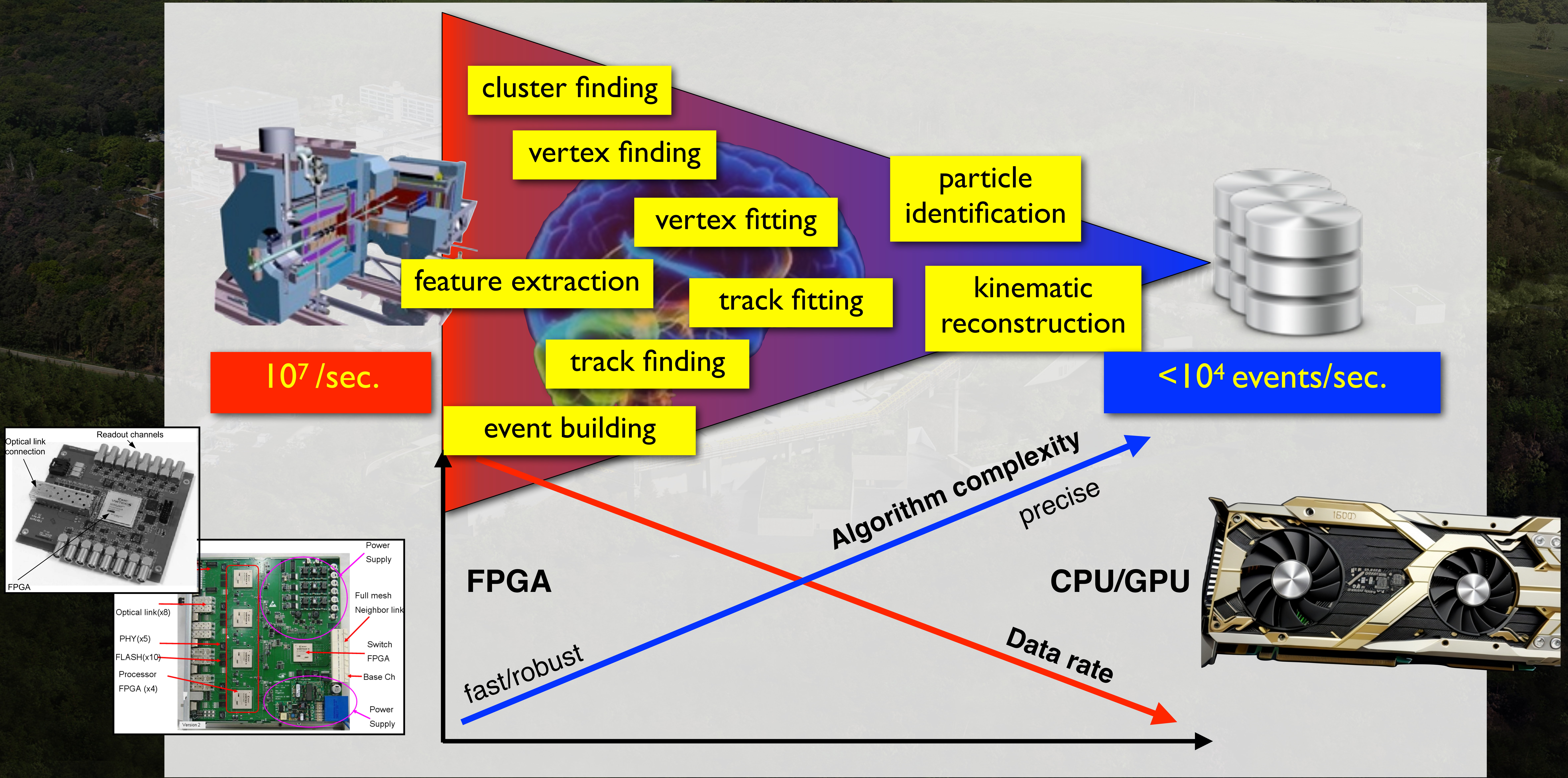


Paradigm shift in data processing!

Free-streaming online data-processing



Intelligent in-situ data processing



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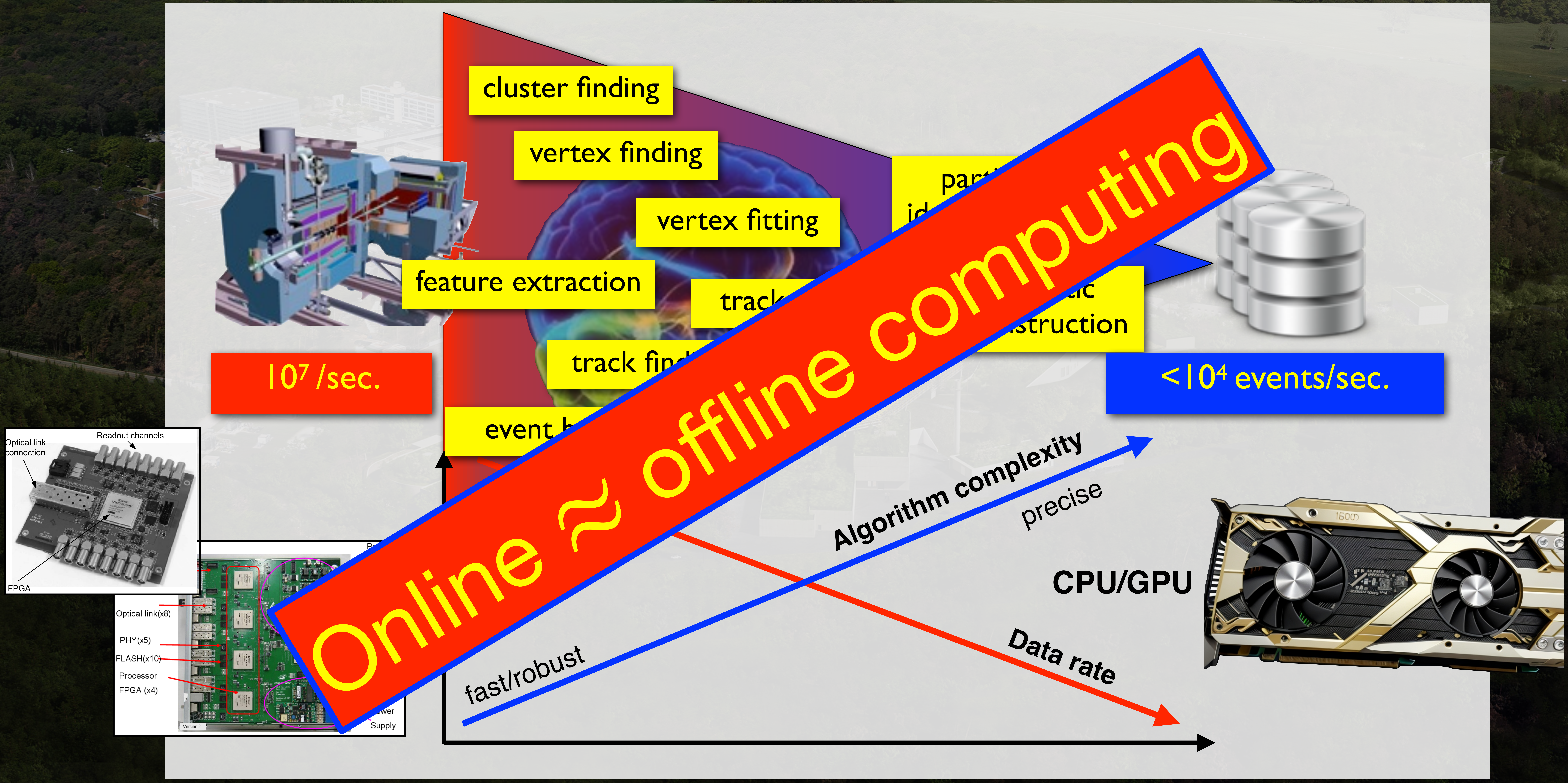

Computing developments

...how to tackle the data challenges in the field

Computing developments

…how to tackle the data challenges in the field

- *Federation* in hardware & software
- *Federation* in on- and offline computing
- *Federation* in distributed computing
- *Federation* between IT and research
- *Federation* in data management
- *Federation* in computing R&D
- …

Federation

...in software design

A couple of (cultural) facts to realise:

Federation

...in software design

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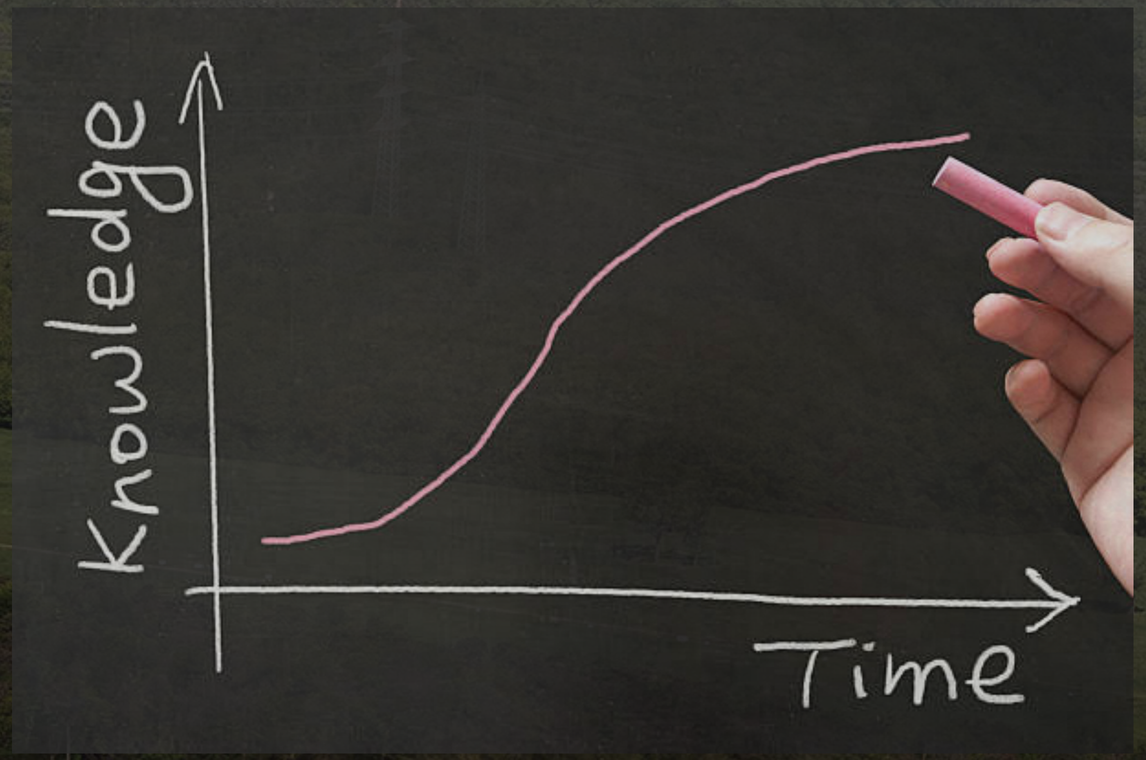
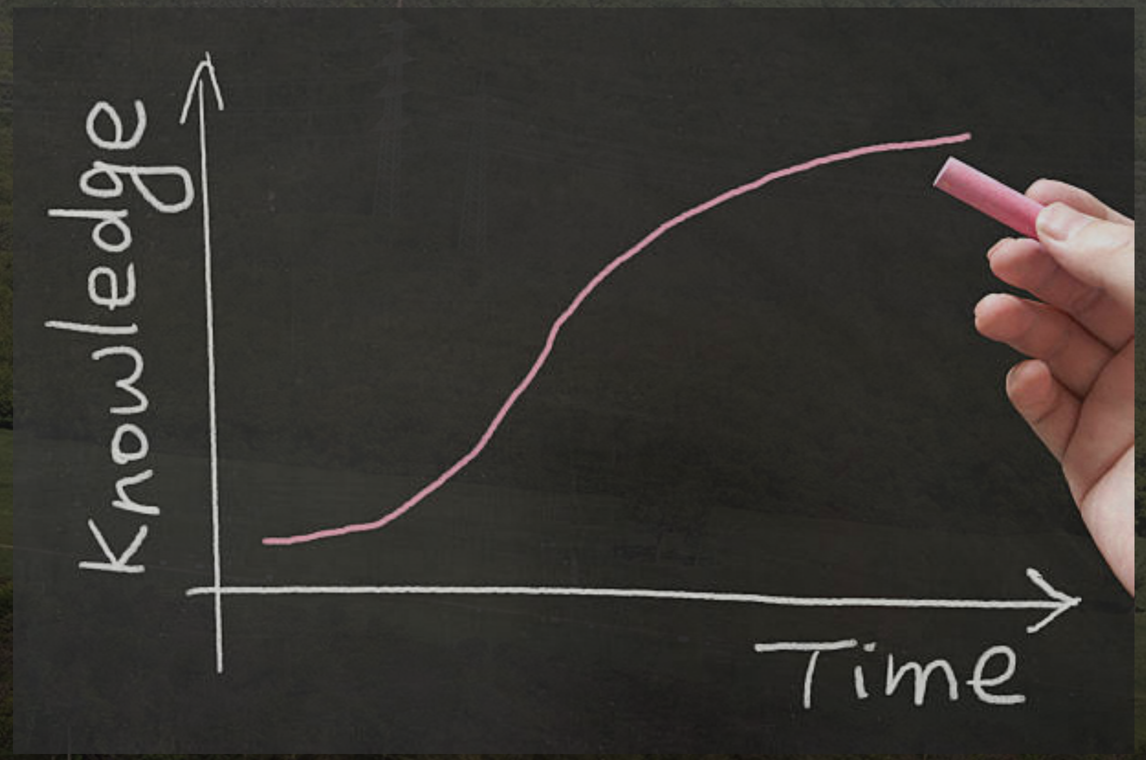


1. Progress using the software needs to be fast (low threshold)

Federation
...in software design



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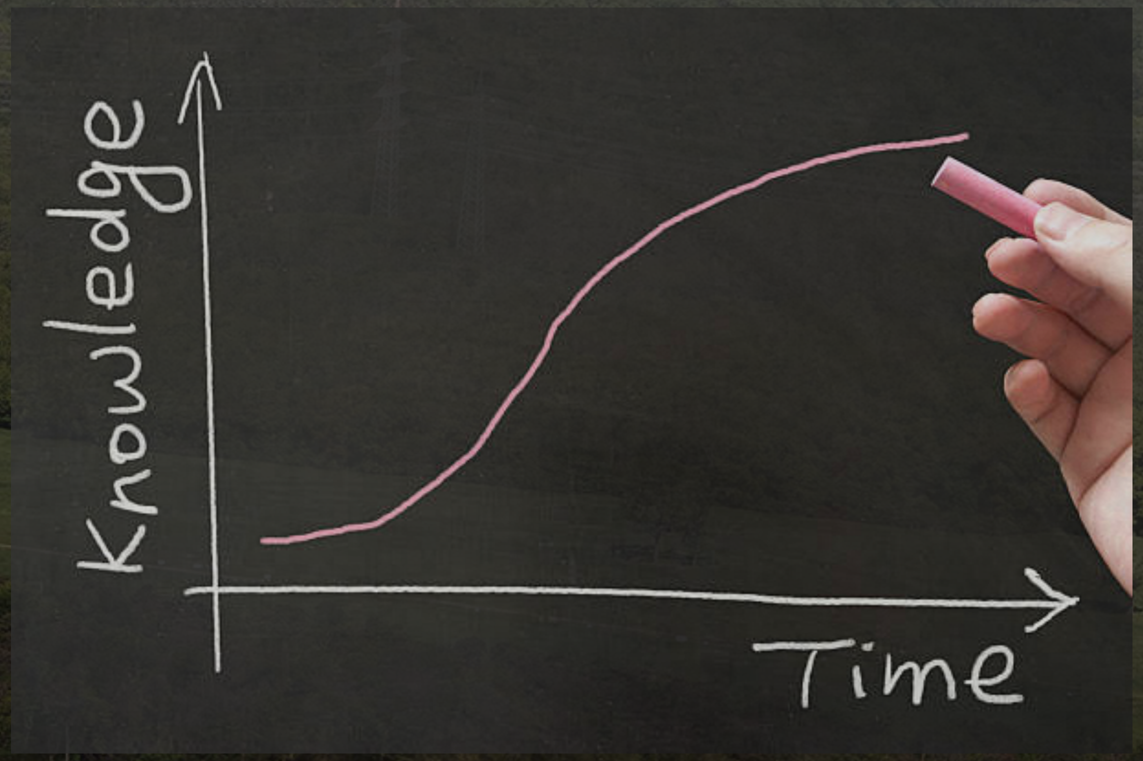

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3. Code often developed by temporary physicists (PhD, PD)

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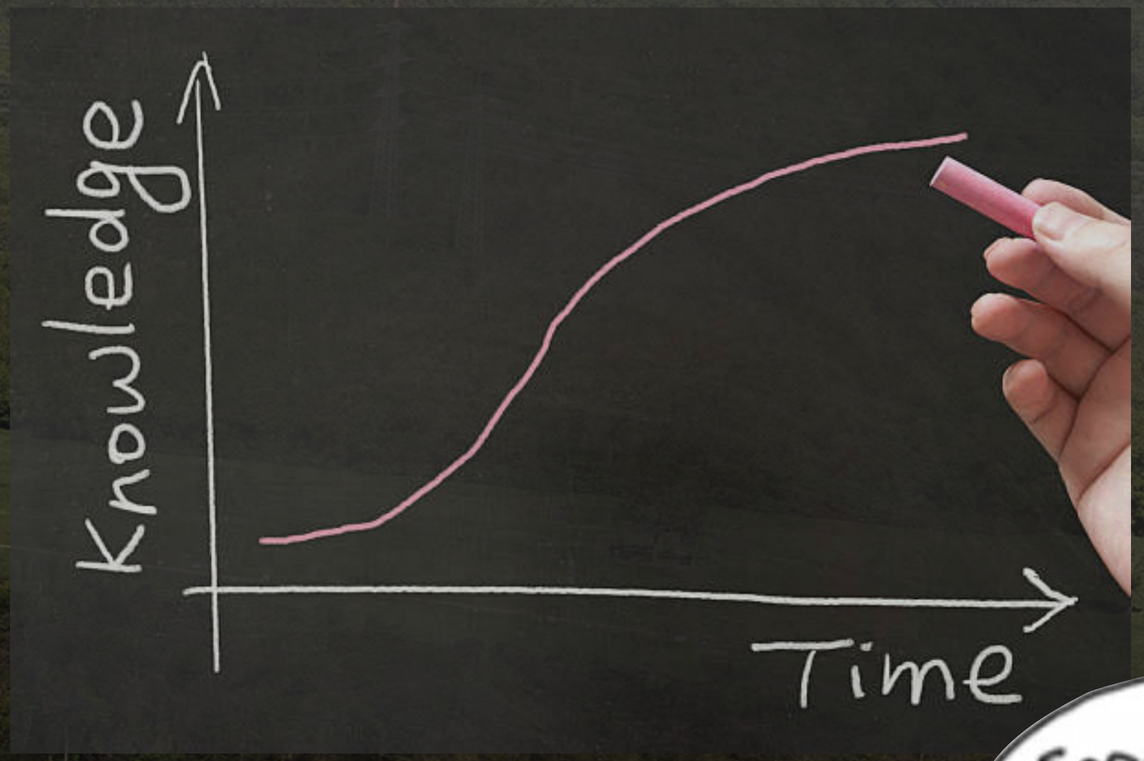
1. Progress using the software needs to be fast (low threshold)
2. There is no clear distinction between users and developers
3. Code often developed by temporary physicists (PhD, PD)
4. Reinventing the wheel is *unfortunately* a common practise

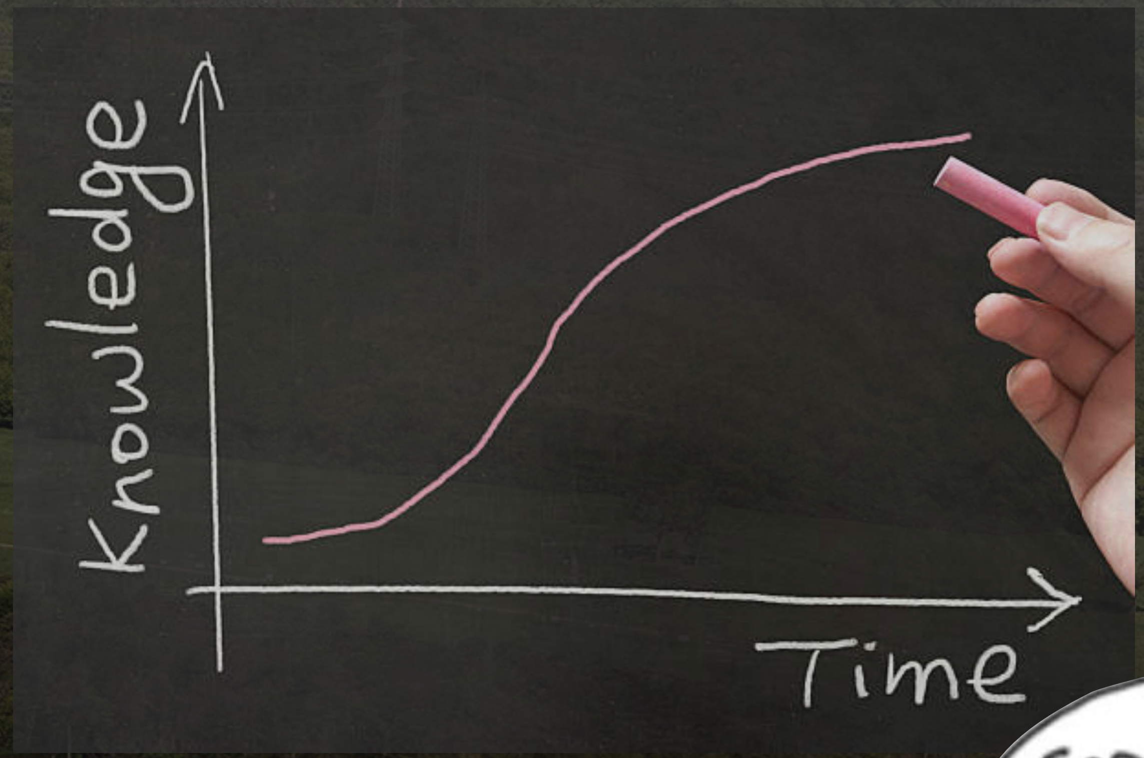


Federation

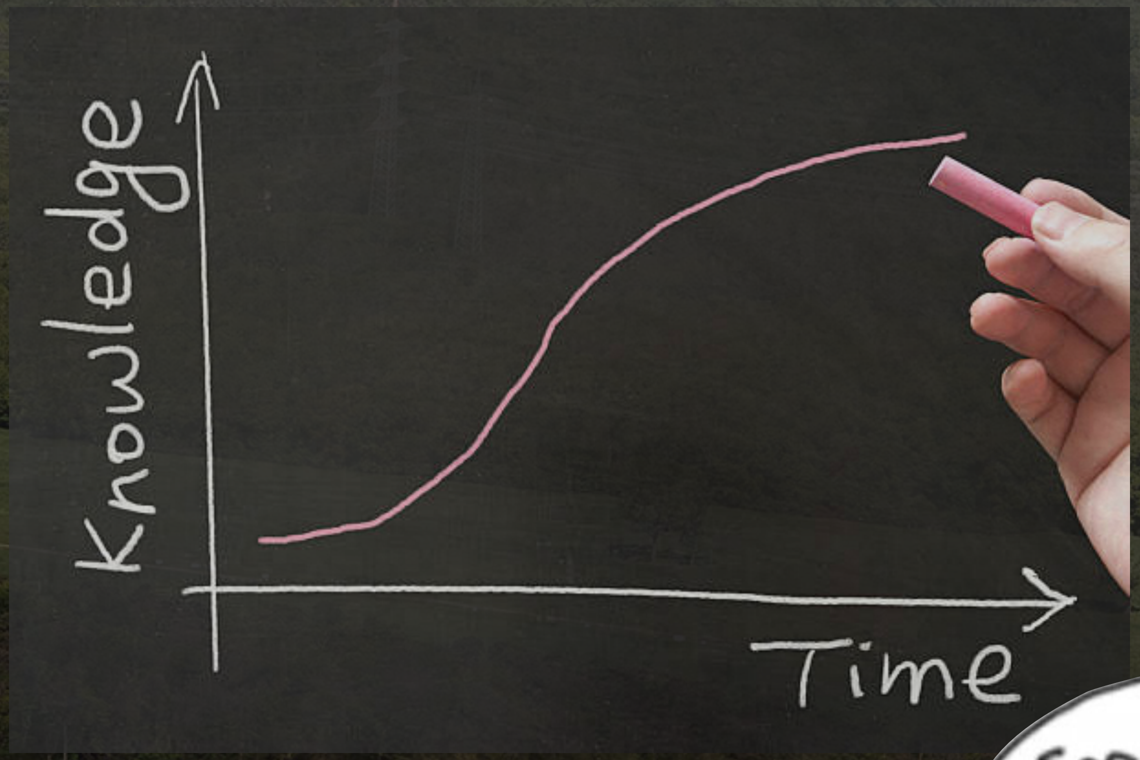
...in software design

A couple of (cultural) facts to realise:

1. Progress using the software needs to be fast (low threshold)
2. There is no clear distinction between users and developers
3. Code often developed by temporary physicists (PhD, PD)
4. Reinventing the wheel is *unfortunately* a common practise
5. Software developments are evolutionary driven



Federation
...in software design



A couple of (cultural) facts to realise:

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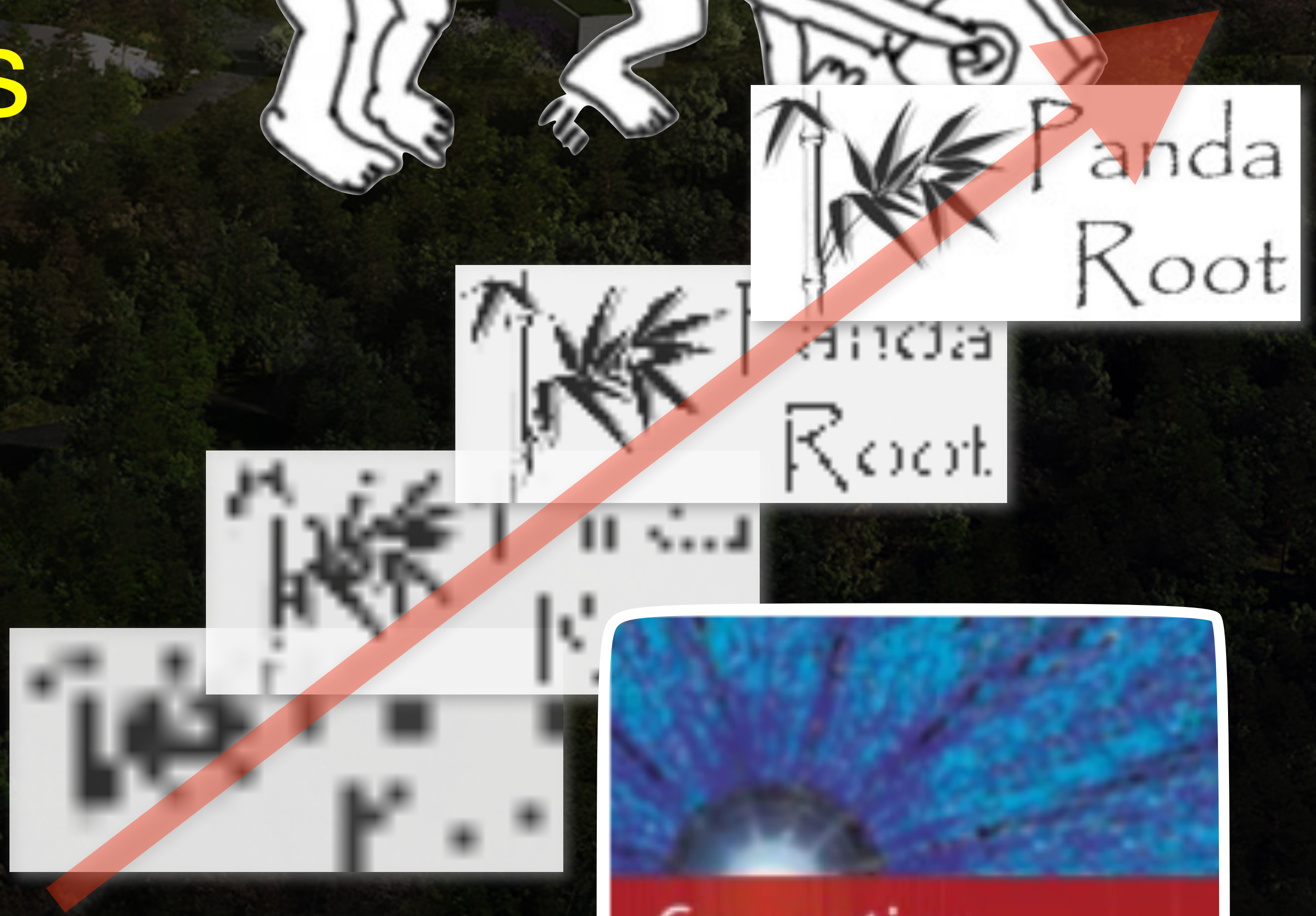
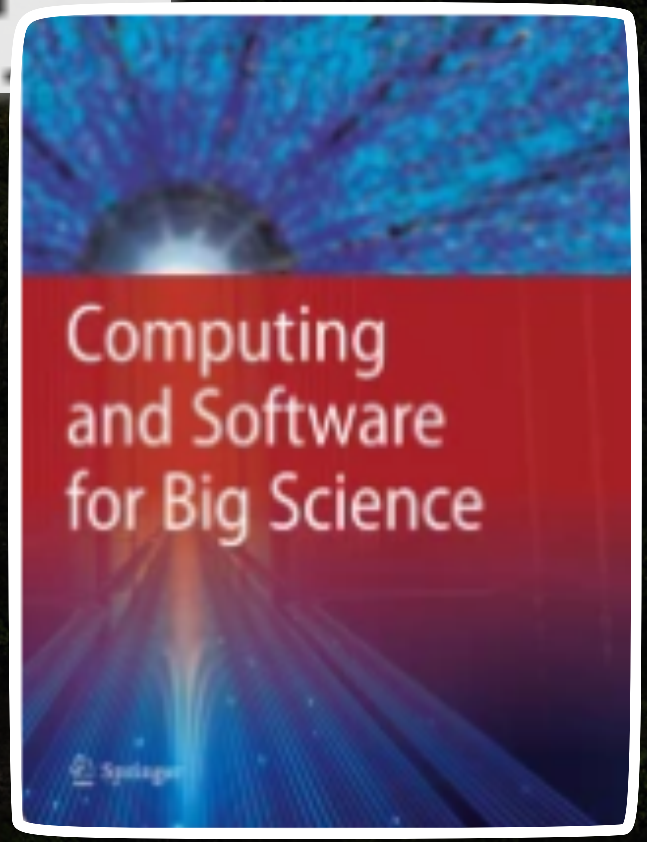
4. Reinventing the wheel is *unfortunately* a common practise
5. Software developments are evolutionary driven
6. Recognition of software R&D (still) lacks behind other R&D





Software frameworks

...an absolute key element

- Code Reusability
- Productivity Boost & Accessibility
- Scalability and Flexibility
- Security & Consistency
- Community Support & Documentation
- Maintenance and Debugging
- Quality and Performance

Software frameworks

…an absolute key element

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- Productivity Boost & Accessibility
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- Community Support & Documentation
- Maintenance and Debugging
- Quality and Performance

Well, guess I don't have to explain this to the GNUradio community ;-)
The real question is how to make a framework successful (lifetime, usage, …)!

ROOT

…since 1996

*“**R**apid **O**bject-**O**riented **T**echnology”*

Rene Brun

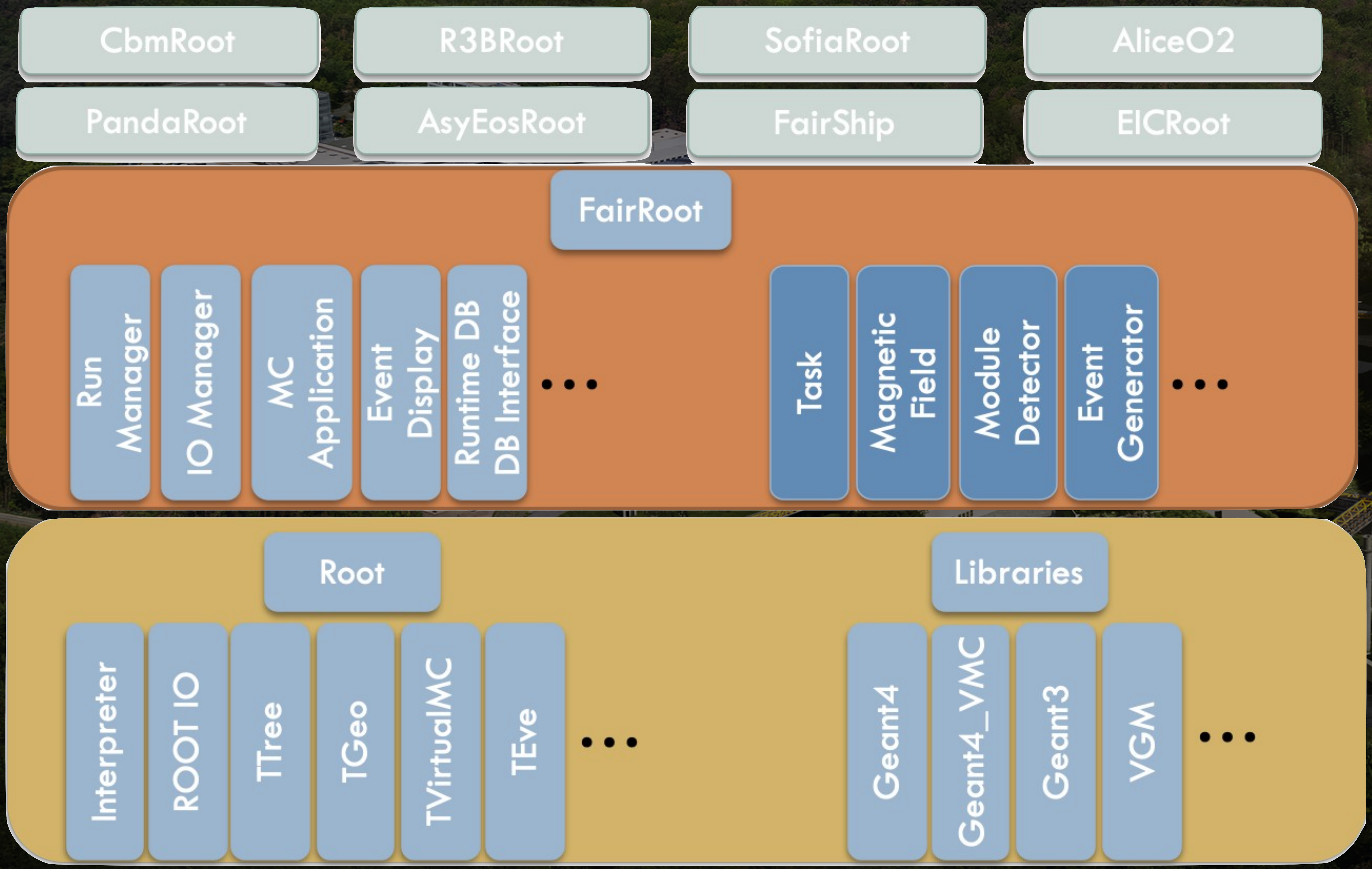
Fons Rademakers

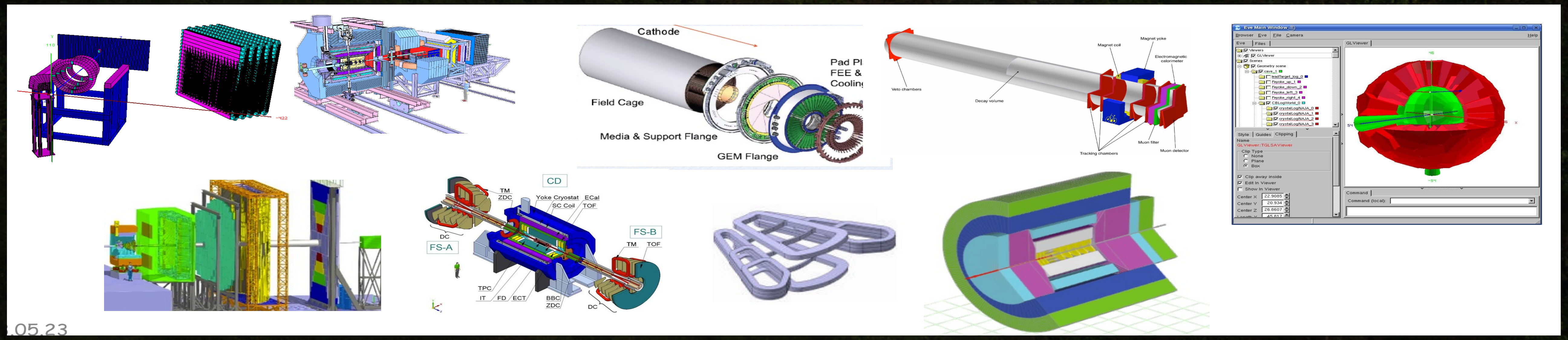
- Software framework born at CERN
- Available under (L)GPL
- Successor of PAW (fortran)
- Storage, processing, visualisation, analysis of scientific data
- Designed to cope with LHC data (>PB/yr)
- Object oriented (C++)
- Interactive usage with Cling C++ interpreter; interface to Python
- Huge community beyond HEP
- Windows, OSX, Linux, Solaris, IBM AIX; IA-32, x86-64

Mohammad Al-Turany (GSI) et al.

FAIRROOT

…since 2003



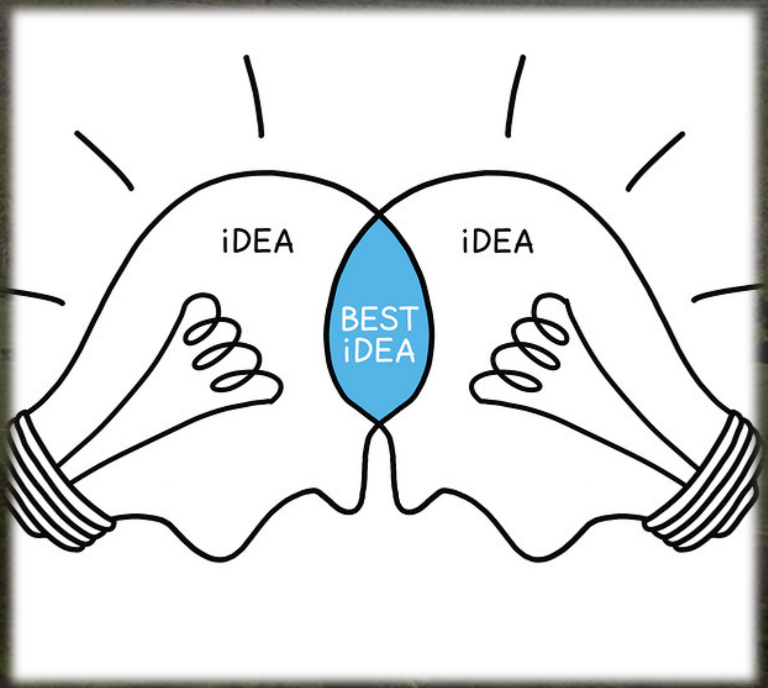


- Experiment **design**, **feasibility** MC studies, and data **analysis** of exp^s!
- Generate(d)s lots of **synergy** between different groups at FAIR and beyond
- The proven basis for successful “**federated**” computing!

Mohammad Al-Turany (GSI) et al.

Tackling online-data processing

…a *federated* spin-off

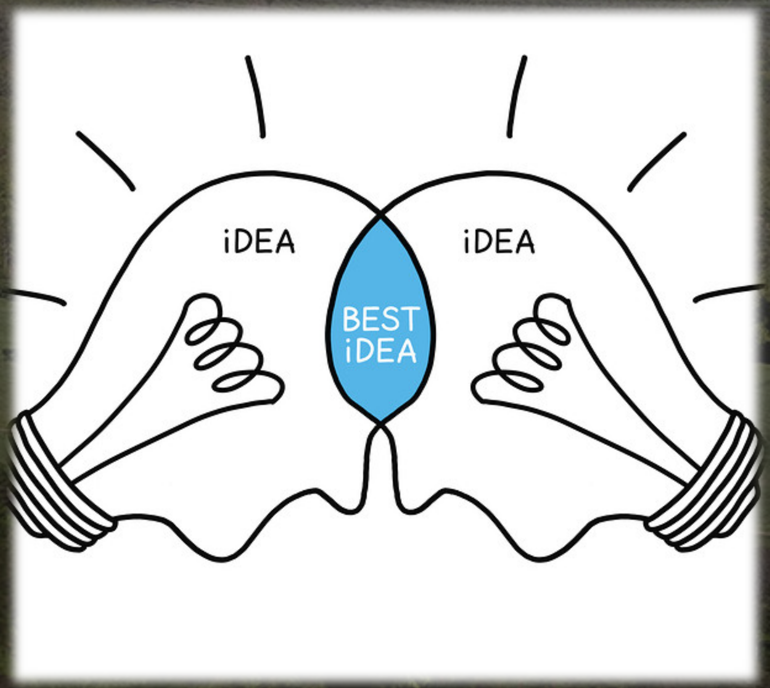


FAIR meets ALICE (CERN)

Mohammad Al-Turany (GSI) et al.

Tackling online-data processing

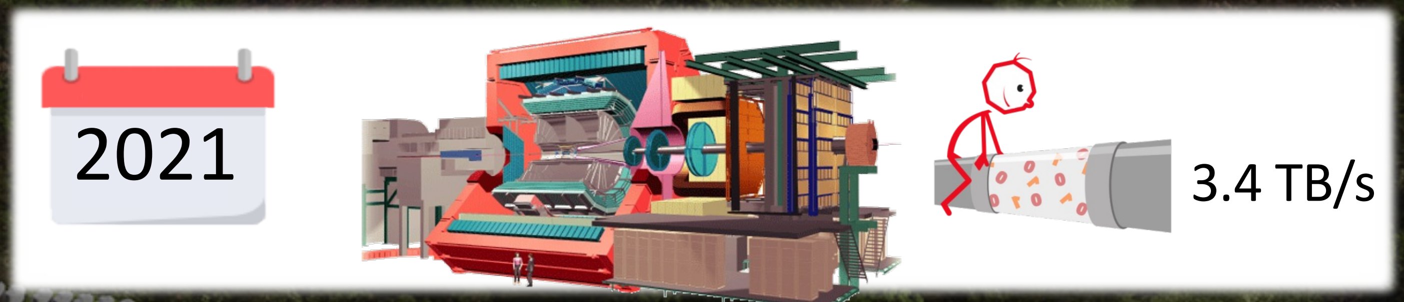
...a *federated* spin-off



FAIR meets ALICE (CERN)

ALICE O²:

- **DAQ, online & offline with one framework**



Mohammad Al-Turany (GSI) et al.

Tackling online-data processing

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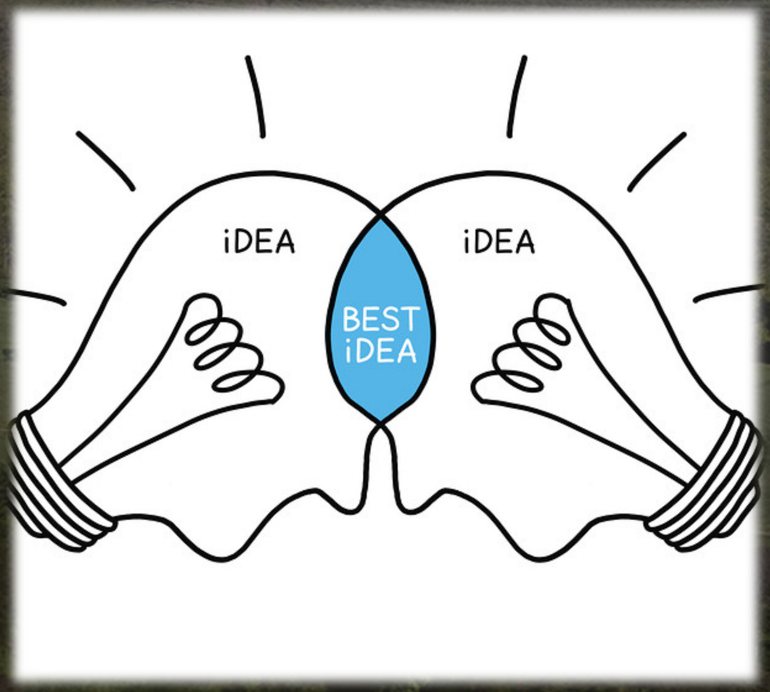


FAIR meets ALICE (CERN)

ALICE

ALICE O²:
- **DAQ, online & offline with one framework**

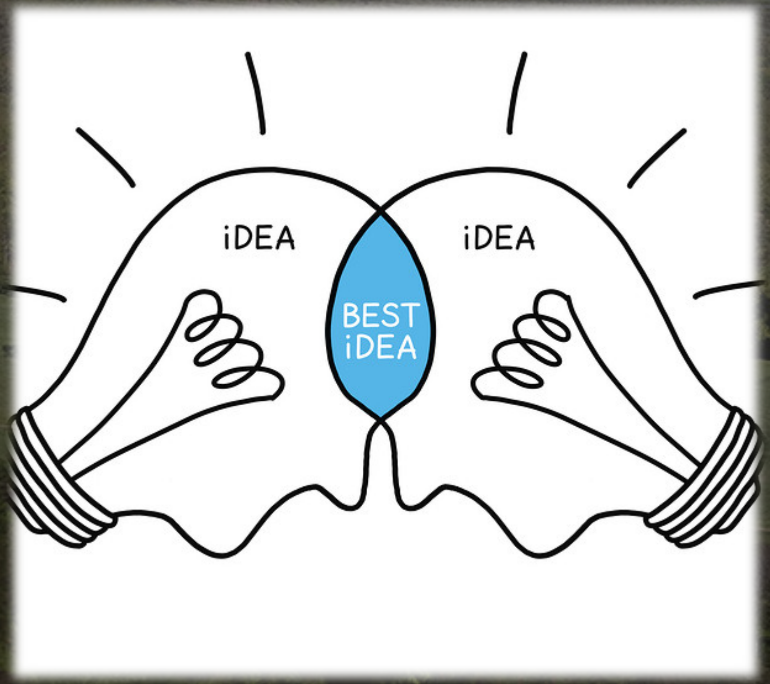
FAIR

FAIRROOT:
- **Concurrency, merging online and offline**

Mohammad Al-Turany (GSI) et al.

Tackling online-data processing

...a *federated* spin-off



FAIR meets ALICE (CERN)

ALICE O²:
- **DAQ, online & offline with one framework**

\+

FAIRROOT:
- **Concurrency, merging online and offline**

=

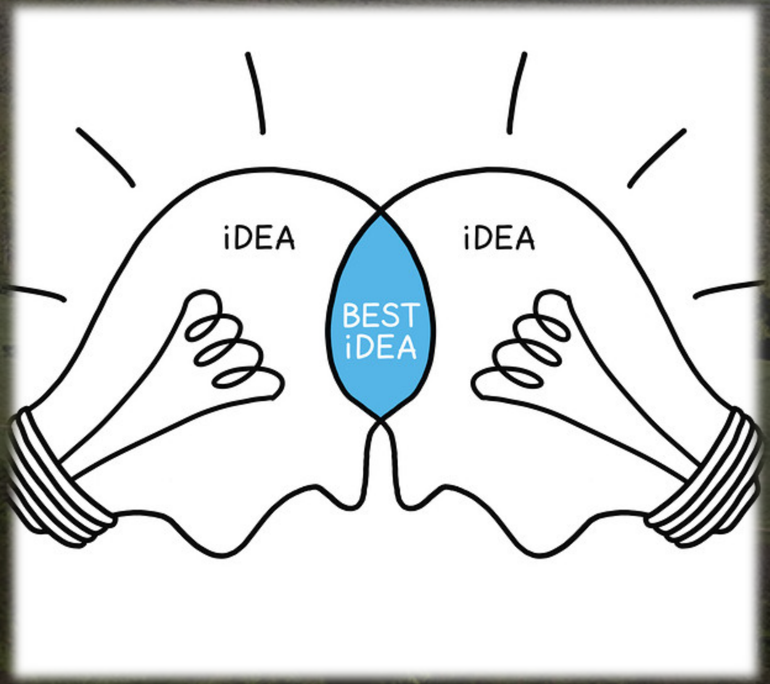
ALFA

ALFA:
- **Join forces in a combined framework!**

Mohammad Al-Turany (GSI) et al.

Tackling online-data processing

…a *federated* spin-off



FAIR meets ALICE (CERN)

- BSD sockets API
- Bindings for 30+ languages
- Lockless and Fast
- Automatic re-connection
- Multiplexed I/O

FAIRMQ:

- Based on **"actor" model** of concurrency
- Asynchronous messaging toolkit
- Broad scala of messaging pattern
- Fault tolerant, scalable, and simplified concurrency
- Commun. layer: 0MQ, shared memory, and Libfabric

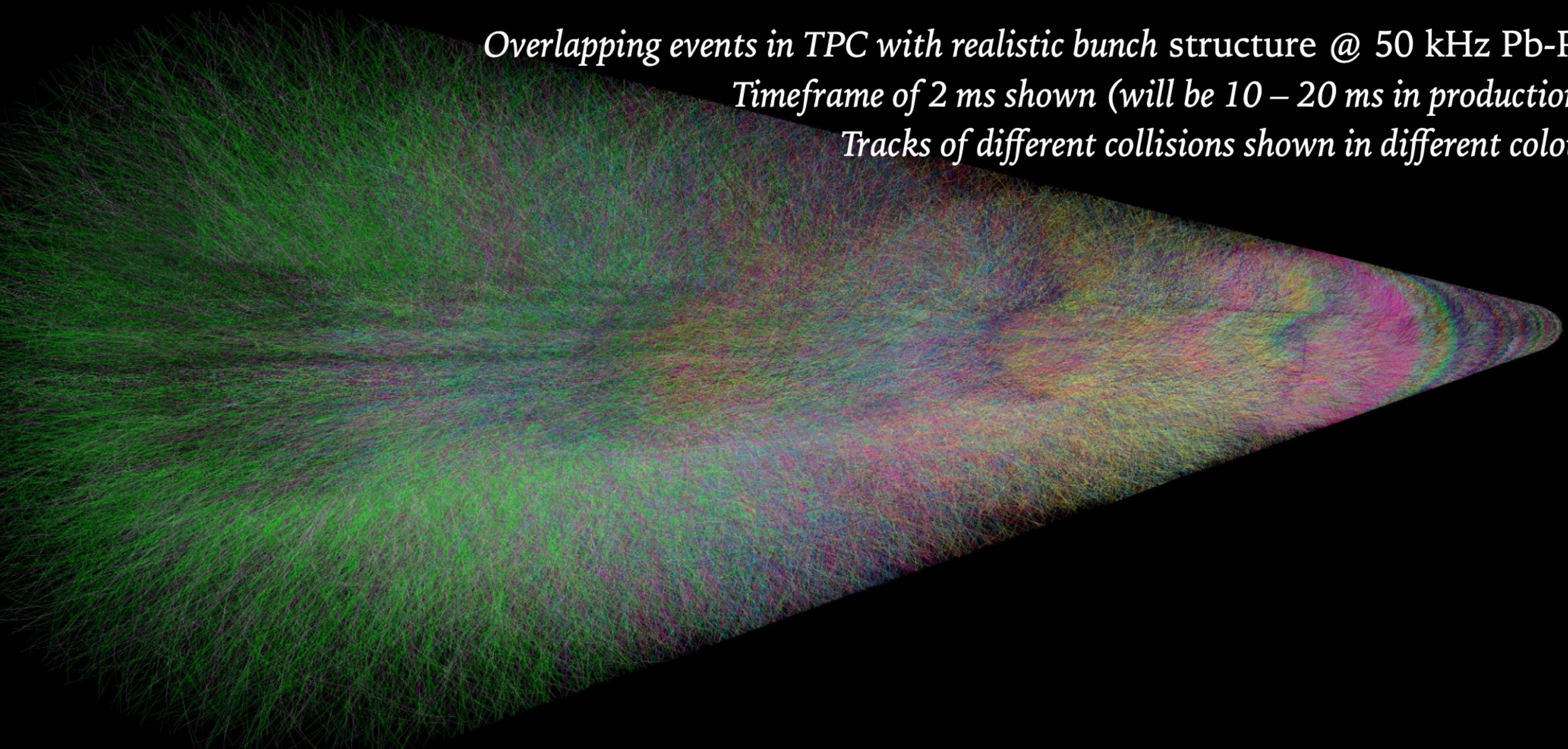
ALFA

Hewitt, Bishop, Steiger, *"A Universal Modular Actor Formalism for Artificial Intelligence"*, **1973**

David Rohr, Giulio Eulisse, ALICE

Tackling online-data processing

…a *federated* spin-off



Overlapping events in TPC with realistic bunch structure @ 50 kHz Pb-Pb

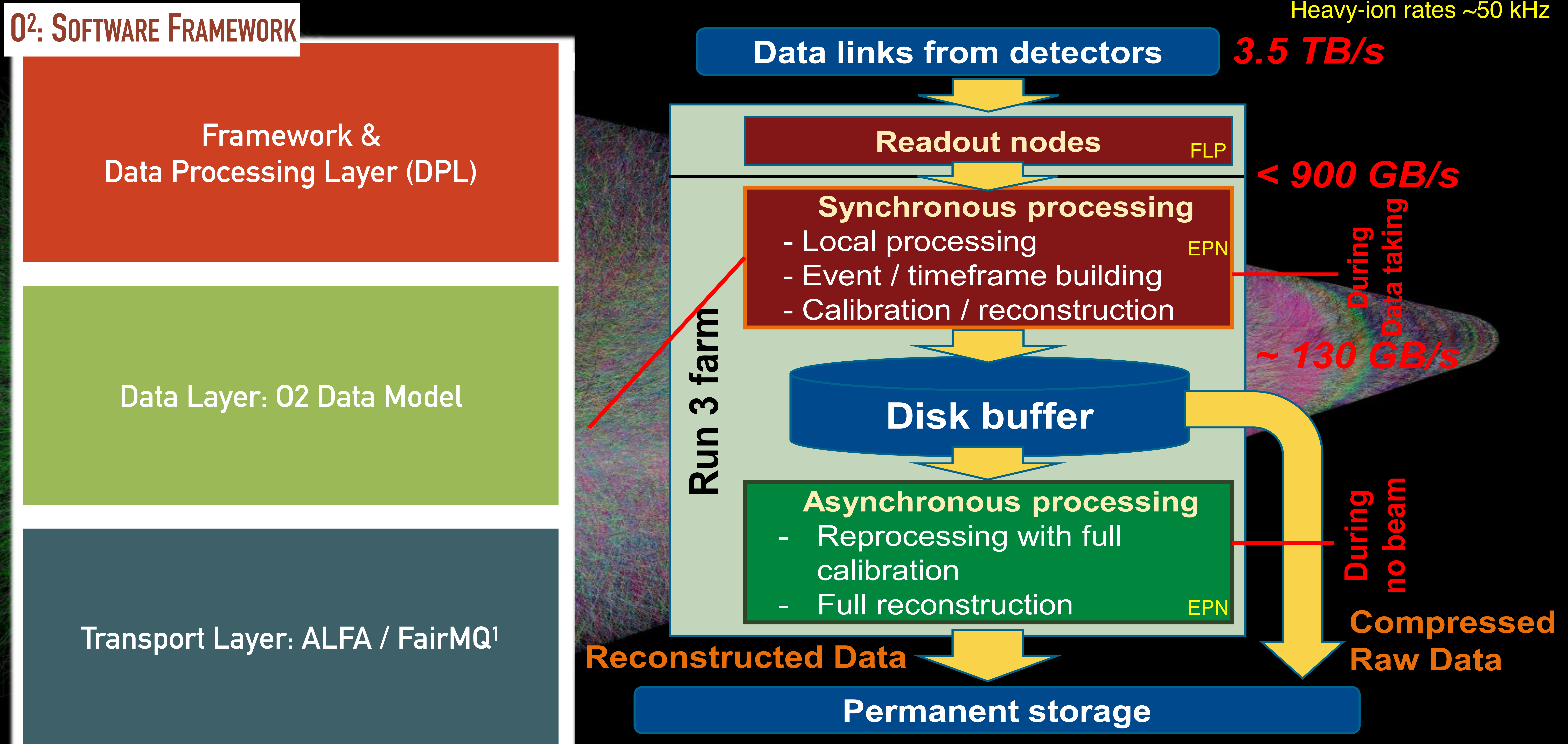
Timeframe of 2 ms shown (will be 10 – 20 ms in production)

Tracks of different collisions shown in different colour

David Rohr, Giulio Eulisse, ALICE

Tackling online-data processing

…a *federated* spin-off

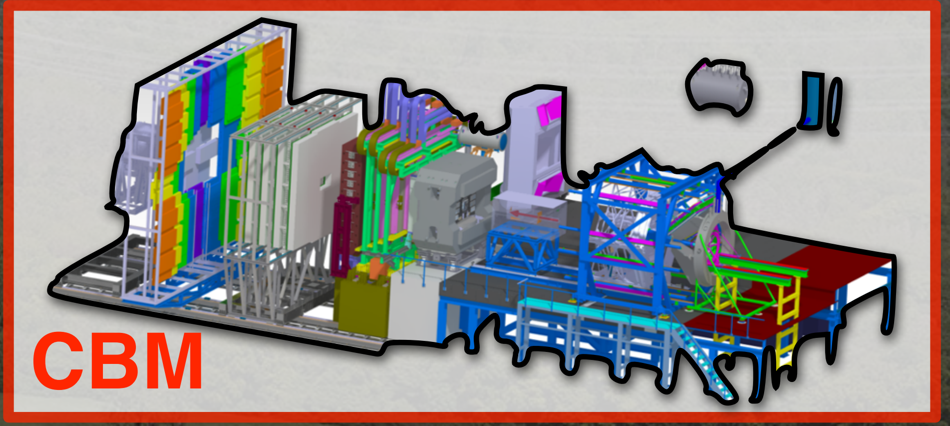


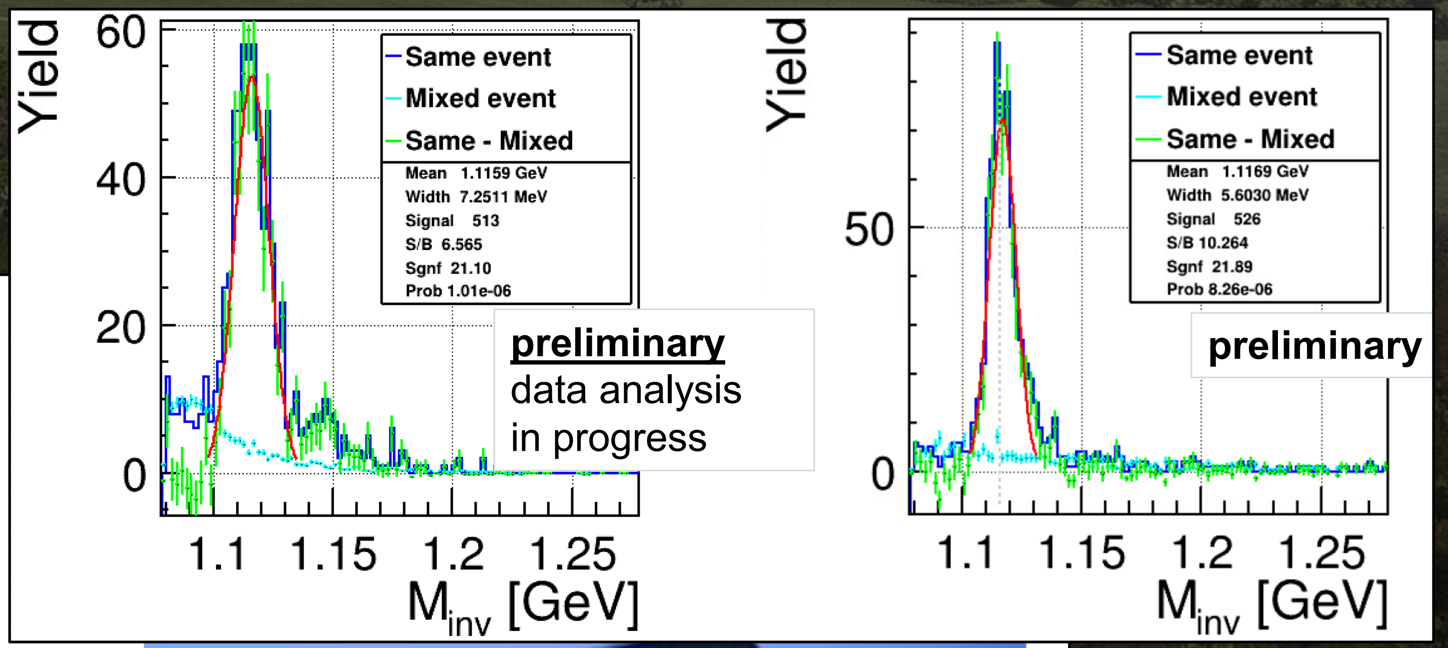
Offline and Online based on same architecture

Norbert Hermann, CBM

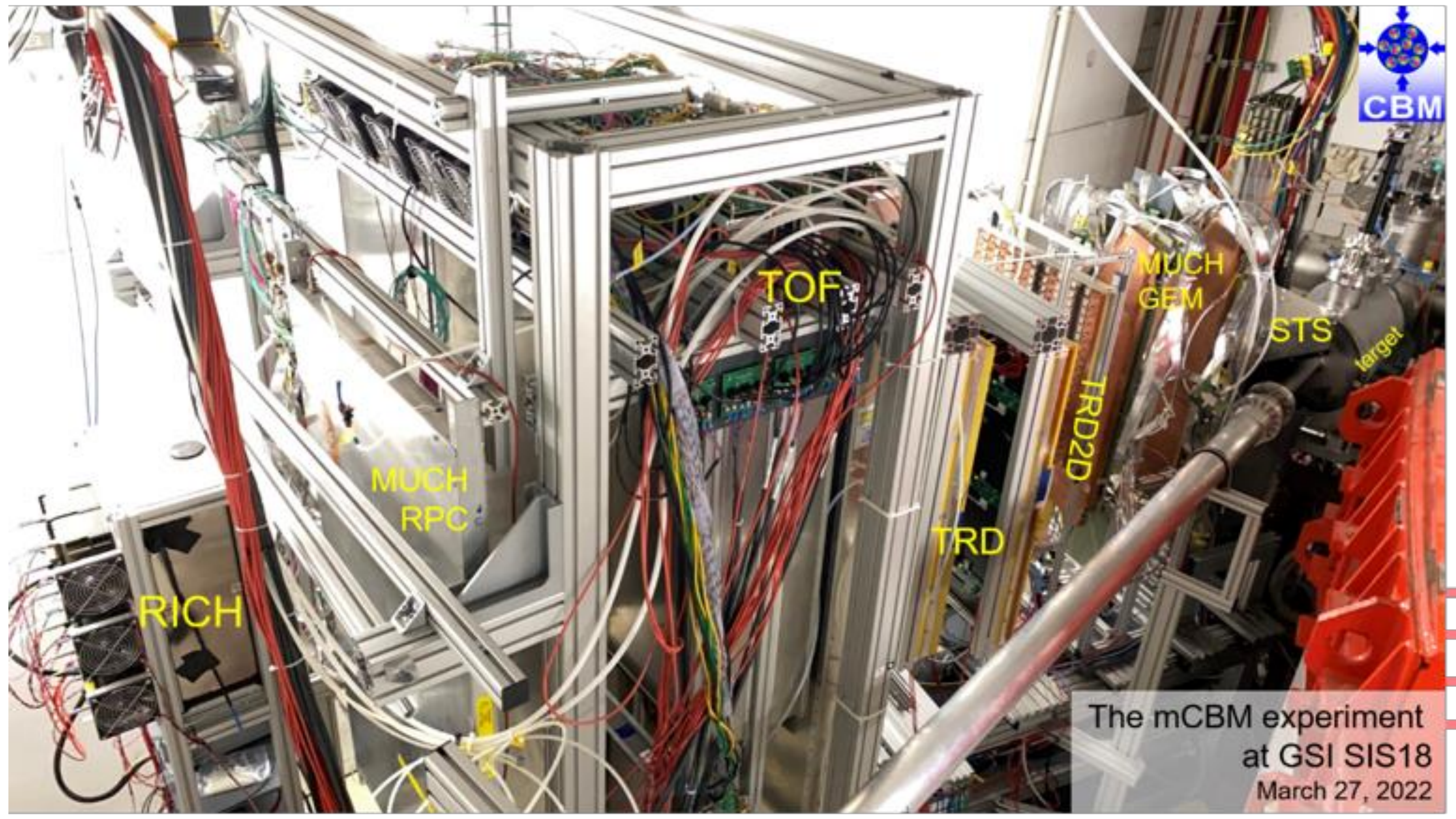
Tackling online-data processing

...a *federated* spin-off





The free-streaming CBM DAQ and data processing



optical fibers 50m

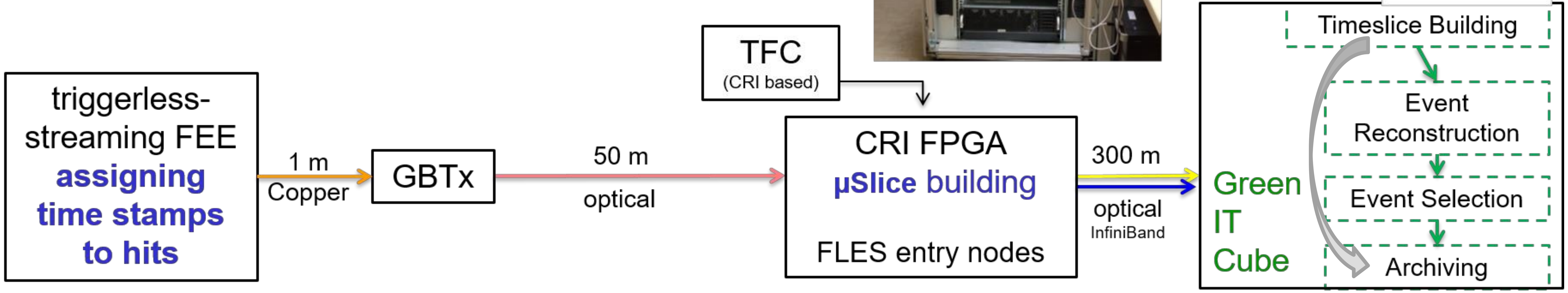
DAQ container

CRI (PCIe) @ FLES entry nodes

optical fibers 300 m

FLES processing nodes

FAIR Phase 0 Research Program



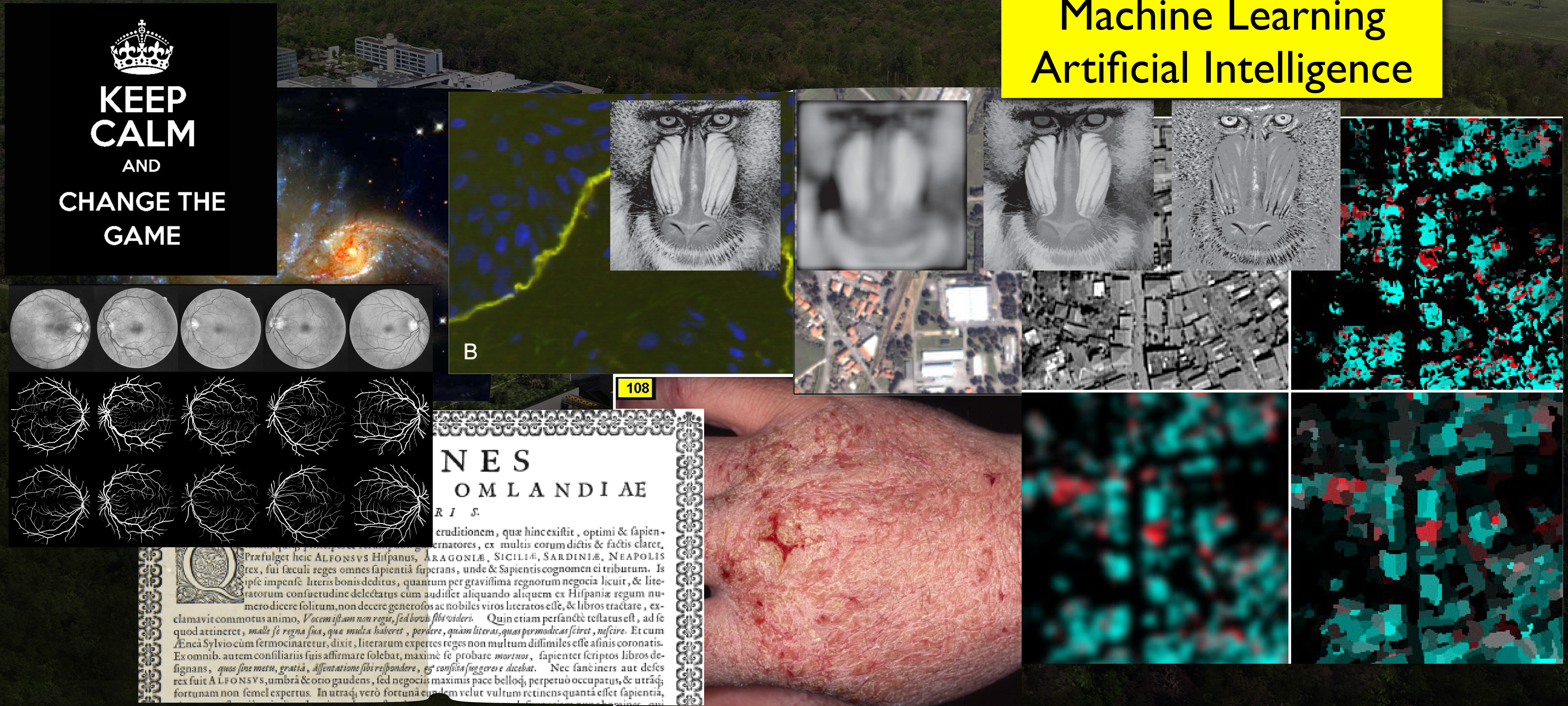
Computing developments

...getting *smarter*

Computing developments

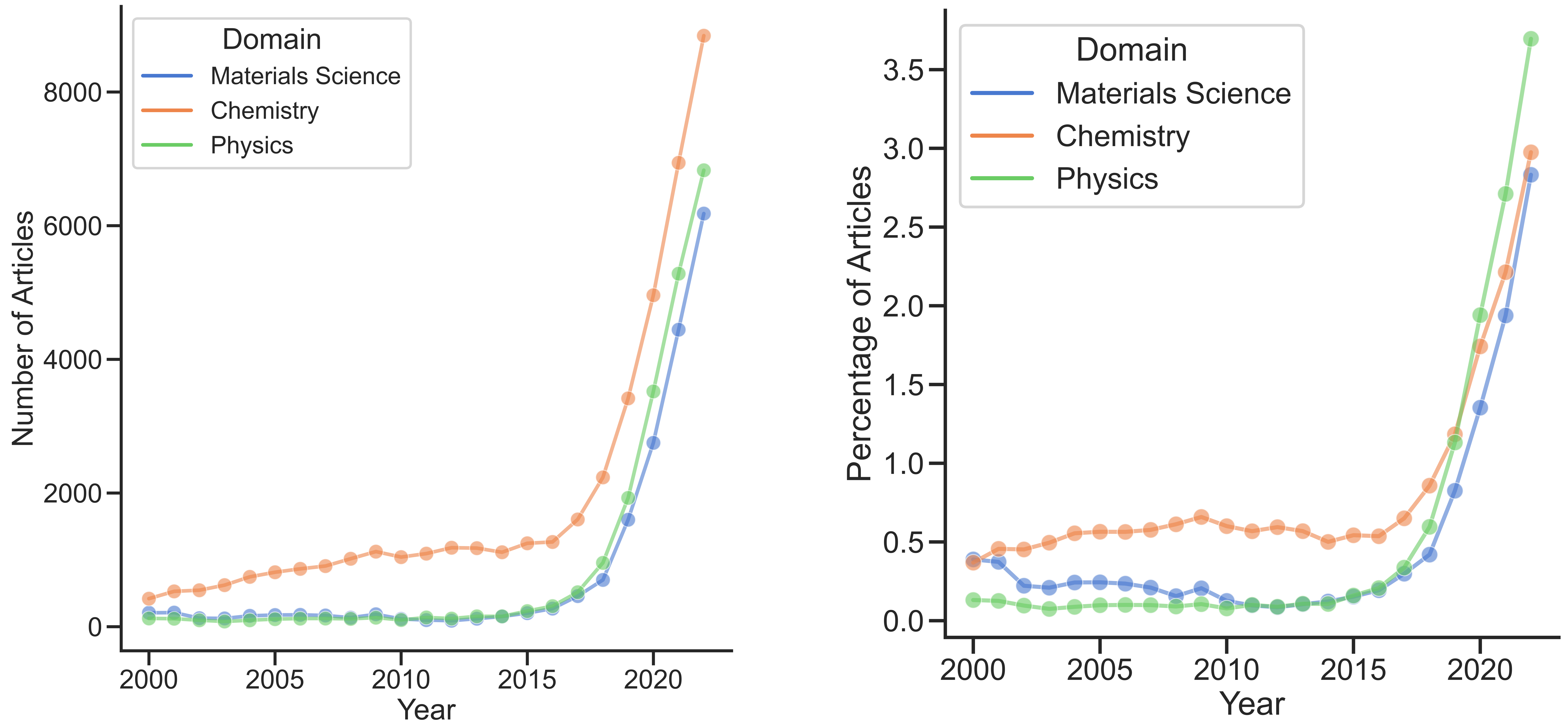
…getting *smarter*

Computer Vision
Machine Learning
Artificial Intelligence



Machine Learning & Artificial Intelligence

…has become very trendy



Ben Blaiszik, “2021 AI/ML Publication Statistics and Charts”. Zenodo, Sep. 07, 2022. doi: 10.5281/zenodo.7057437.

Machine Learning & Artificial Intelligence

...has become very trendy

hessian.AI

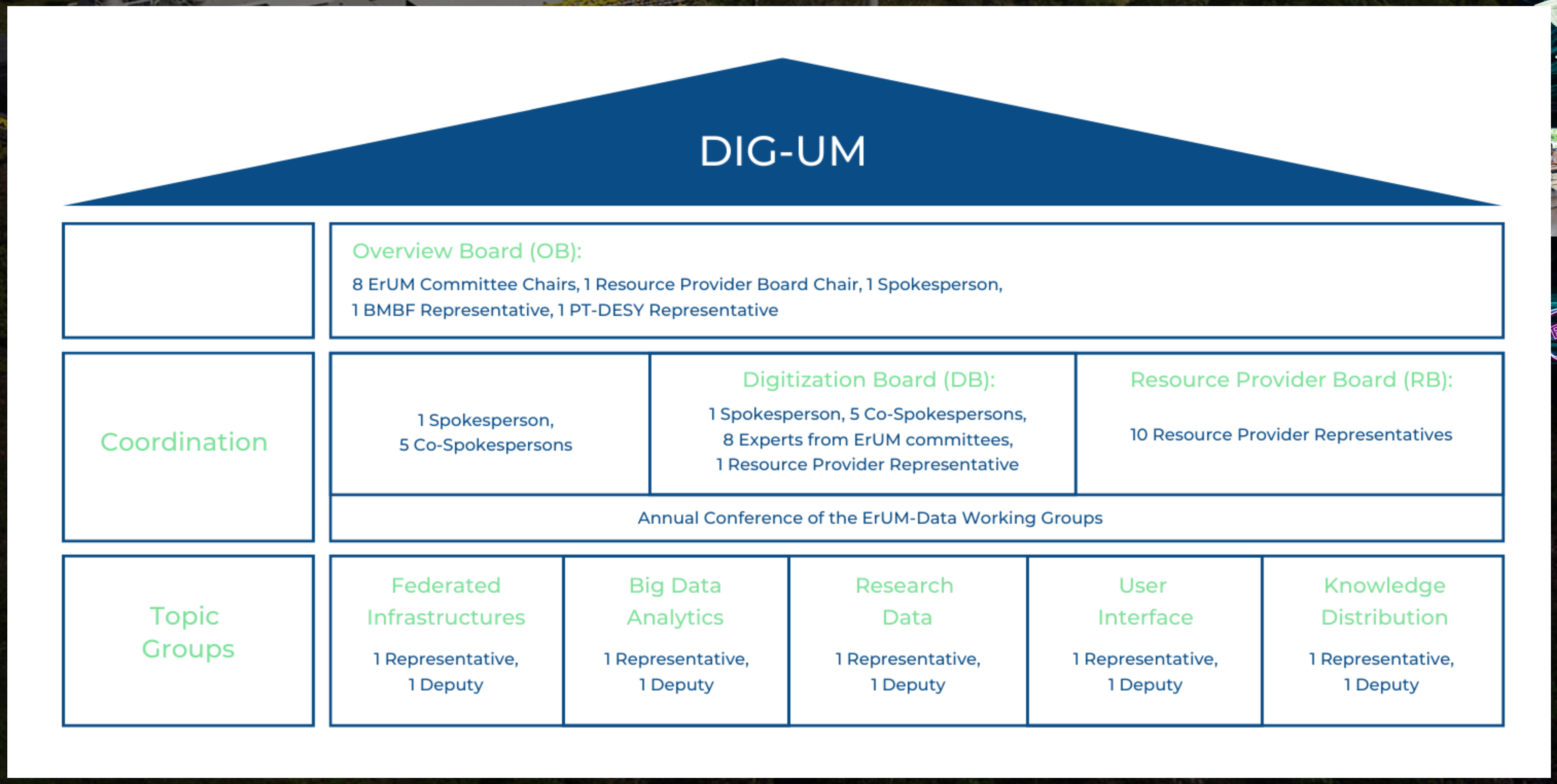
AI Innovation Lab @GSI

Machine Learning & Al ... ce

...has become very trendy

tions

hessian.AI




Machine Learning & AI ... ce

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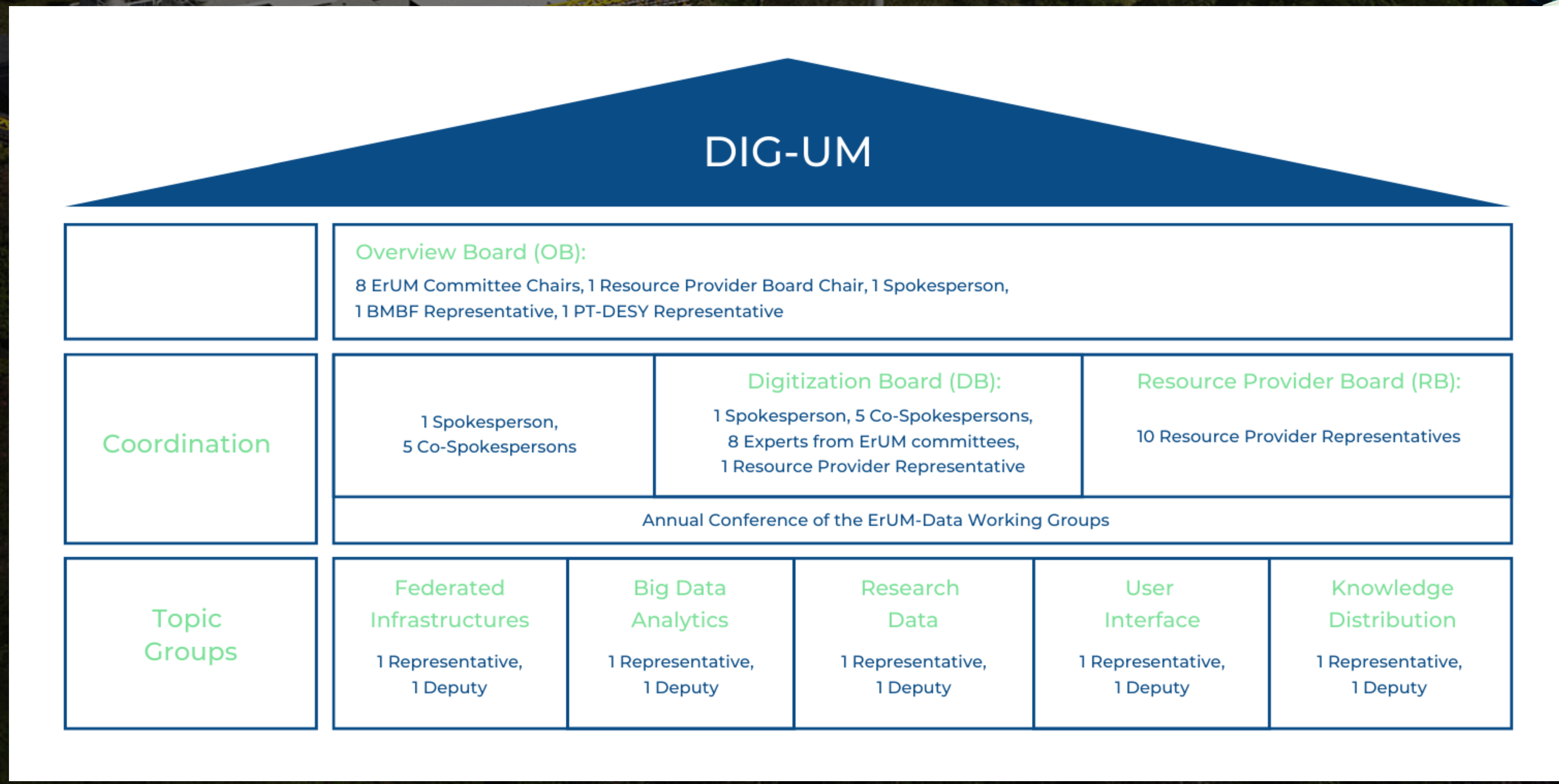
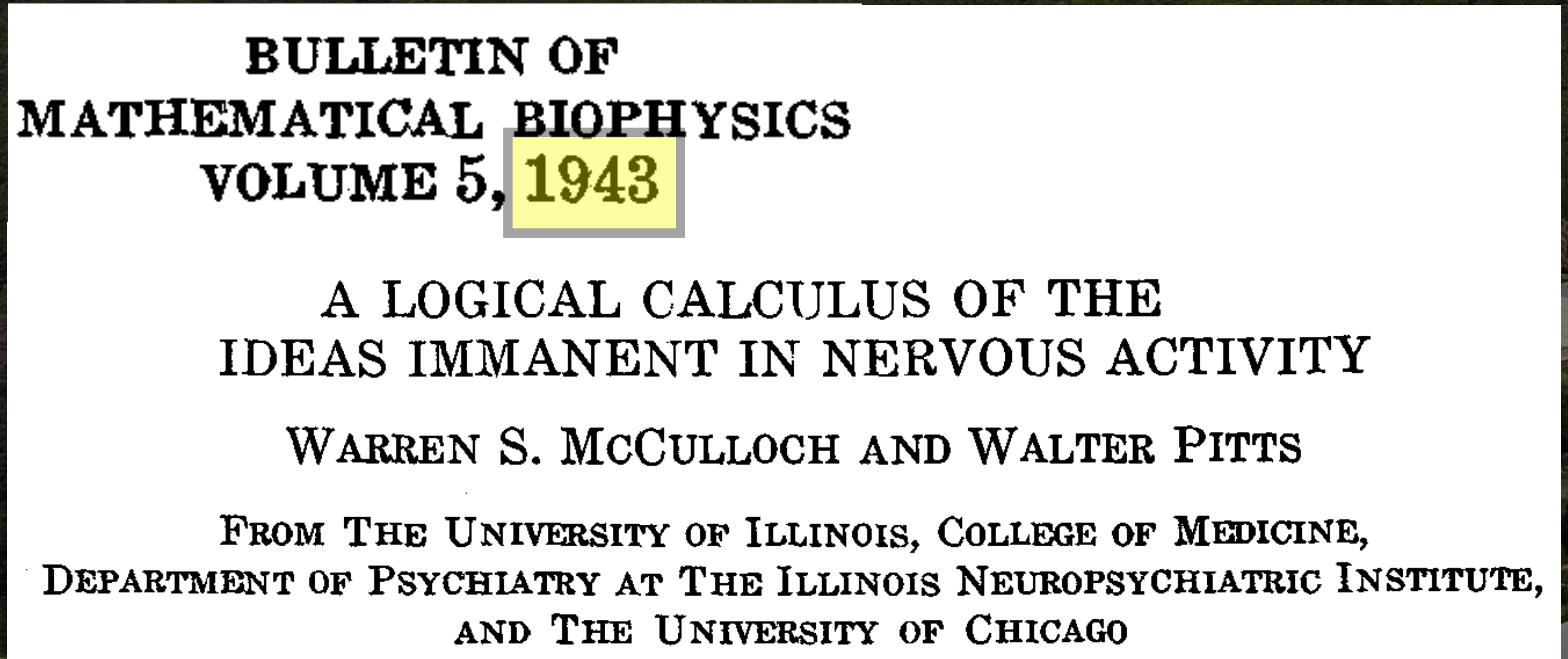


Machine Learning & Artificial Intelligence

...evolution

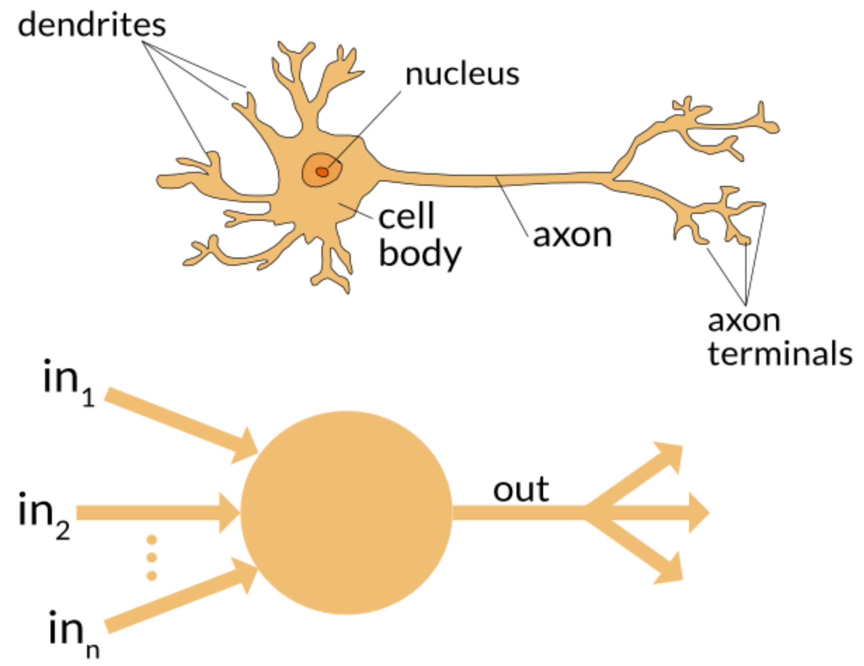


BULLETIN OF
MATHEMATICAL BIOPHYSICS
VOLUME 5, 1943

A LOGICAL CALCULUS OF THE
IDEAS IMMANENT IN NERVOUS ACTIVITY

WARREN S. MCCULLOCH AND WALTER PITTS

FROM THE UNIVERSITY OF ILLINOIS, COLLEGE OF MEDICINE,
DEPARTMENT OF PSYCHIATRY AT THE ILLINOIS NEUROPSYCHIATRIC INSTITUTE,
AND THE UNIVERSITY OF CHICAGO



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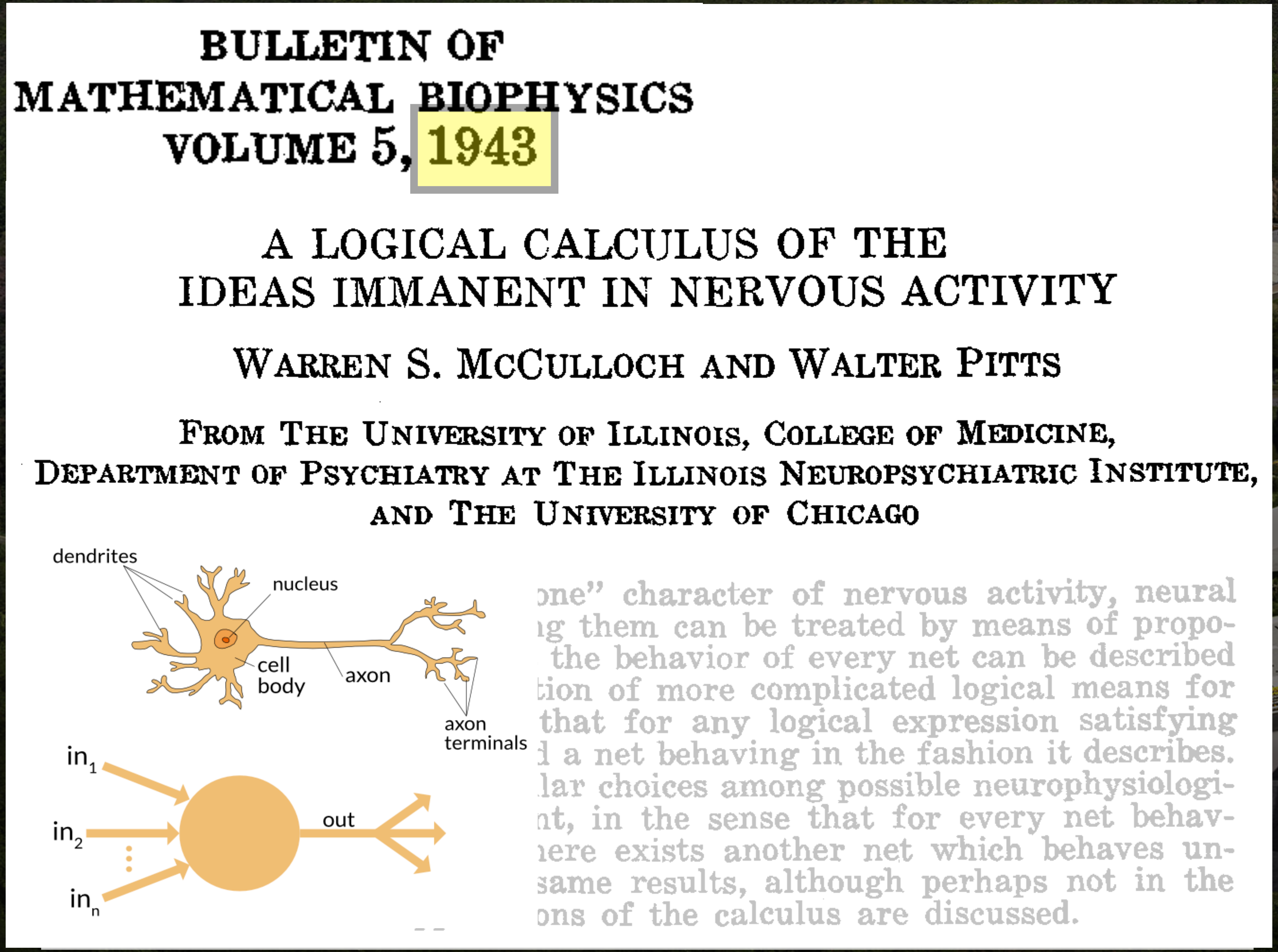
Machine Learning & Artificial Intelligence

...evolution



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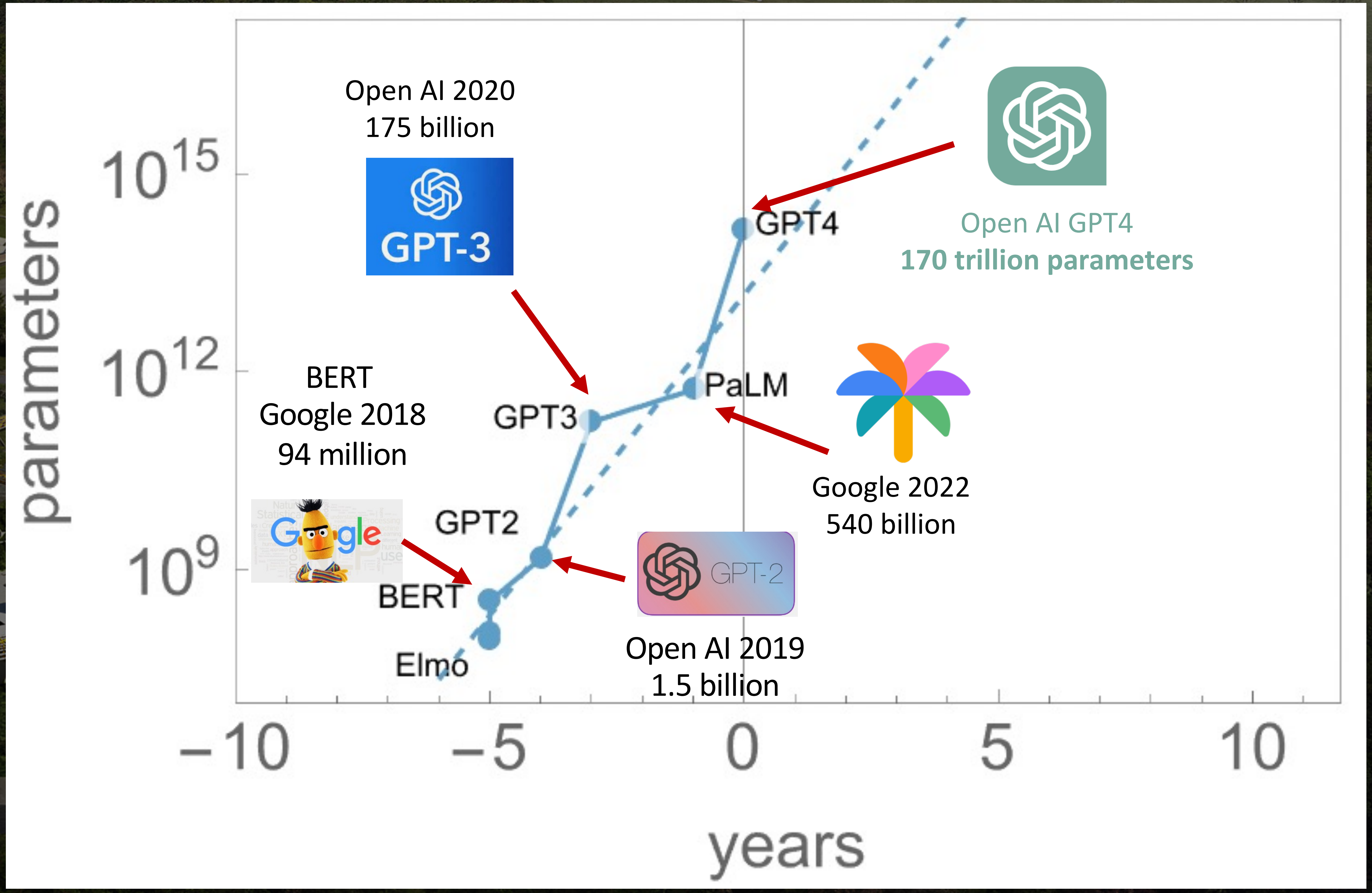
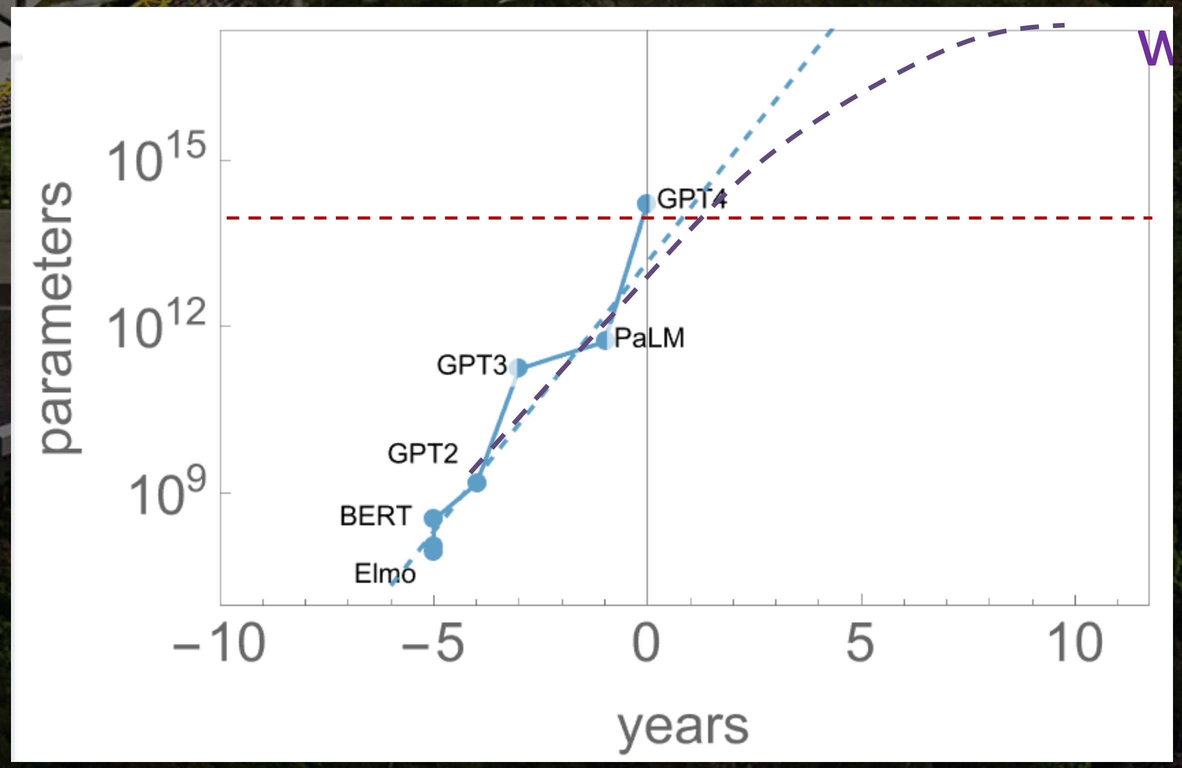


Recurrent Neural Networks (RNN) → Long Short-Term Memory Networks (LSTM) → Large Language Models (LLM) → Generative Pre-trained Transformers (GPT)

Machine Learning & Artificial Intelligence

...evolution

Matthew Schwartz, Harvard University,
EuCAIFConf Amsterdam, April/May 2024



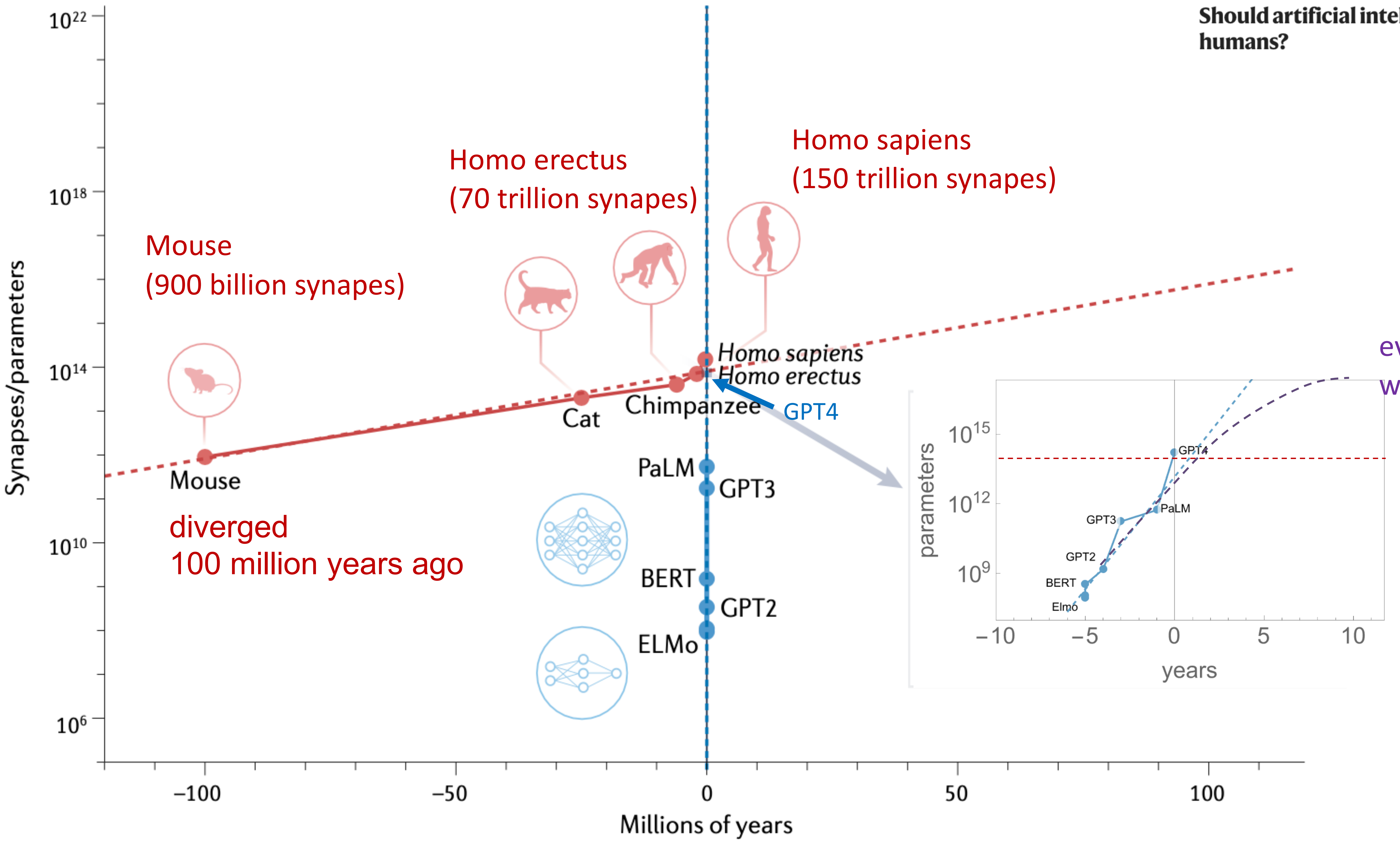
Machine Learning & Artificial Intelligence

...evolution

Matthew Schwartz, Harvard University,
EuCAIFConf Amsterdam, April/May 2024

MDS, Nature reviews physics (2022)

Should artificial intelligence be interpretable to humans?



even subexponential grown
will soon be superhuman

Machine Learning & Artificial Intelligence

…evolution

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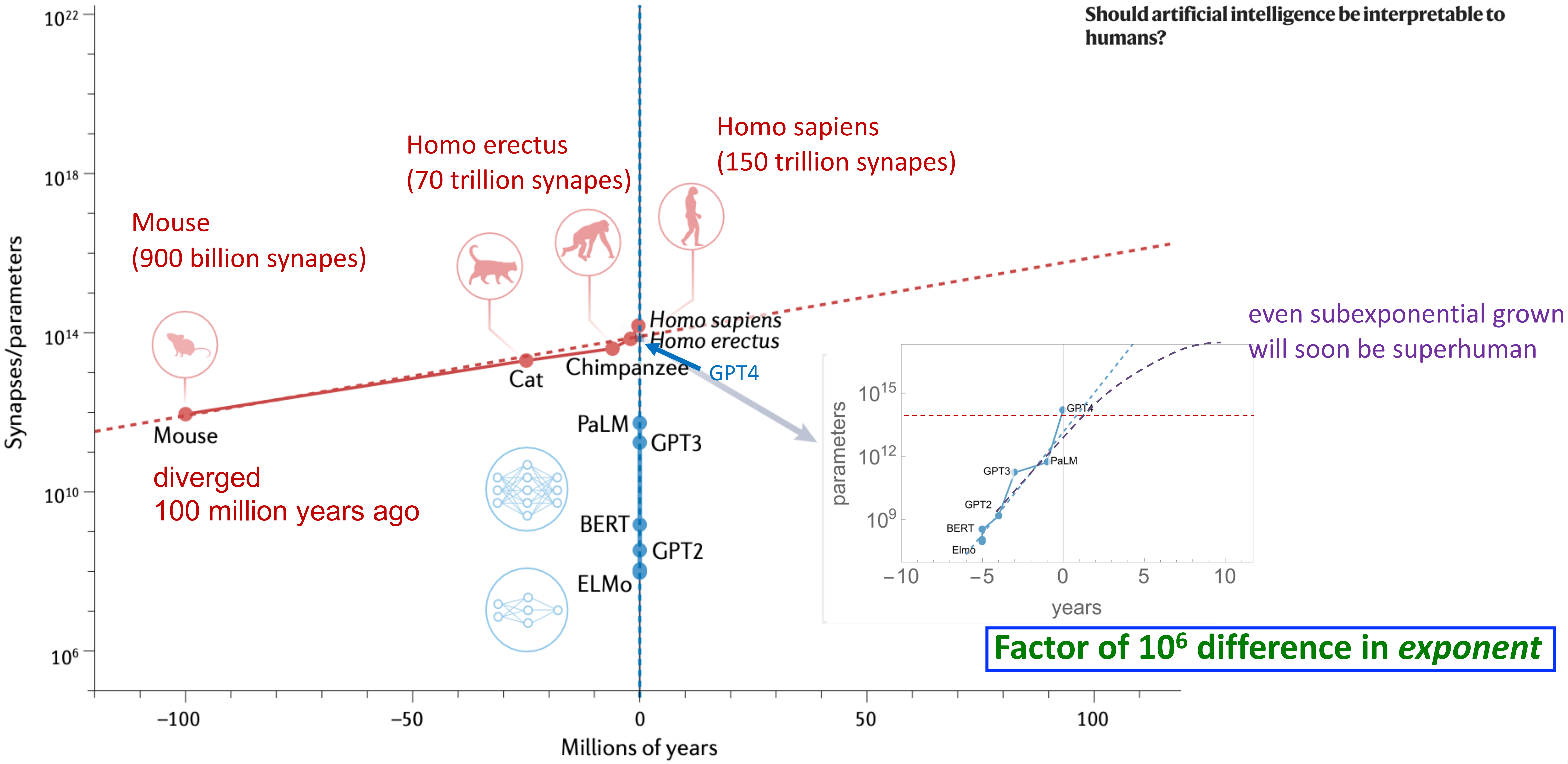
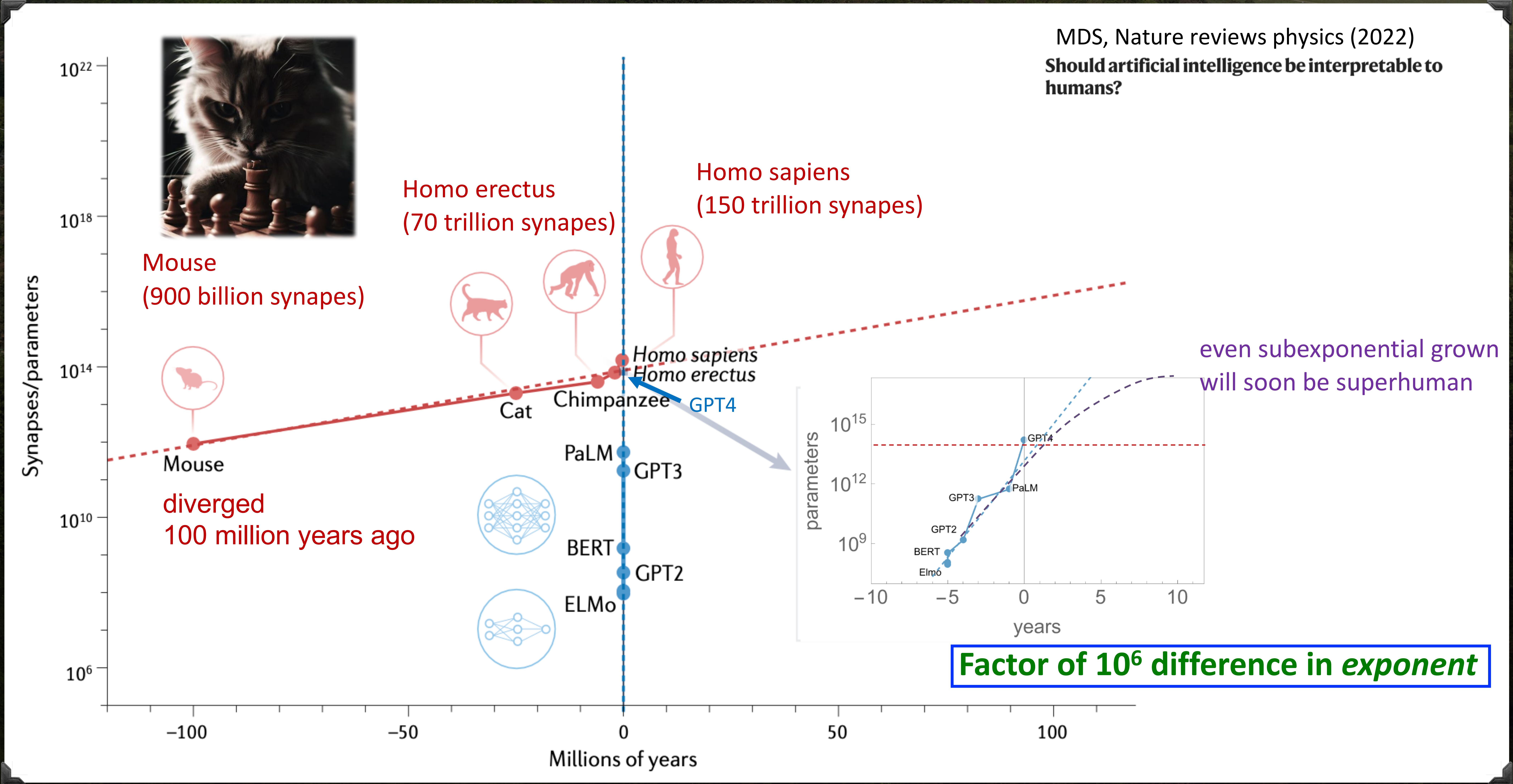


Factor of 10^6 difference in *exponent*

Machine Learning & Artificial Intelligence

…evolution

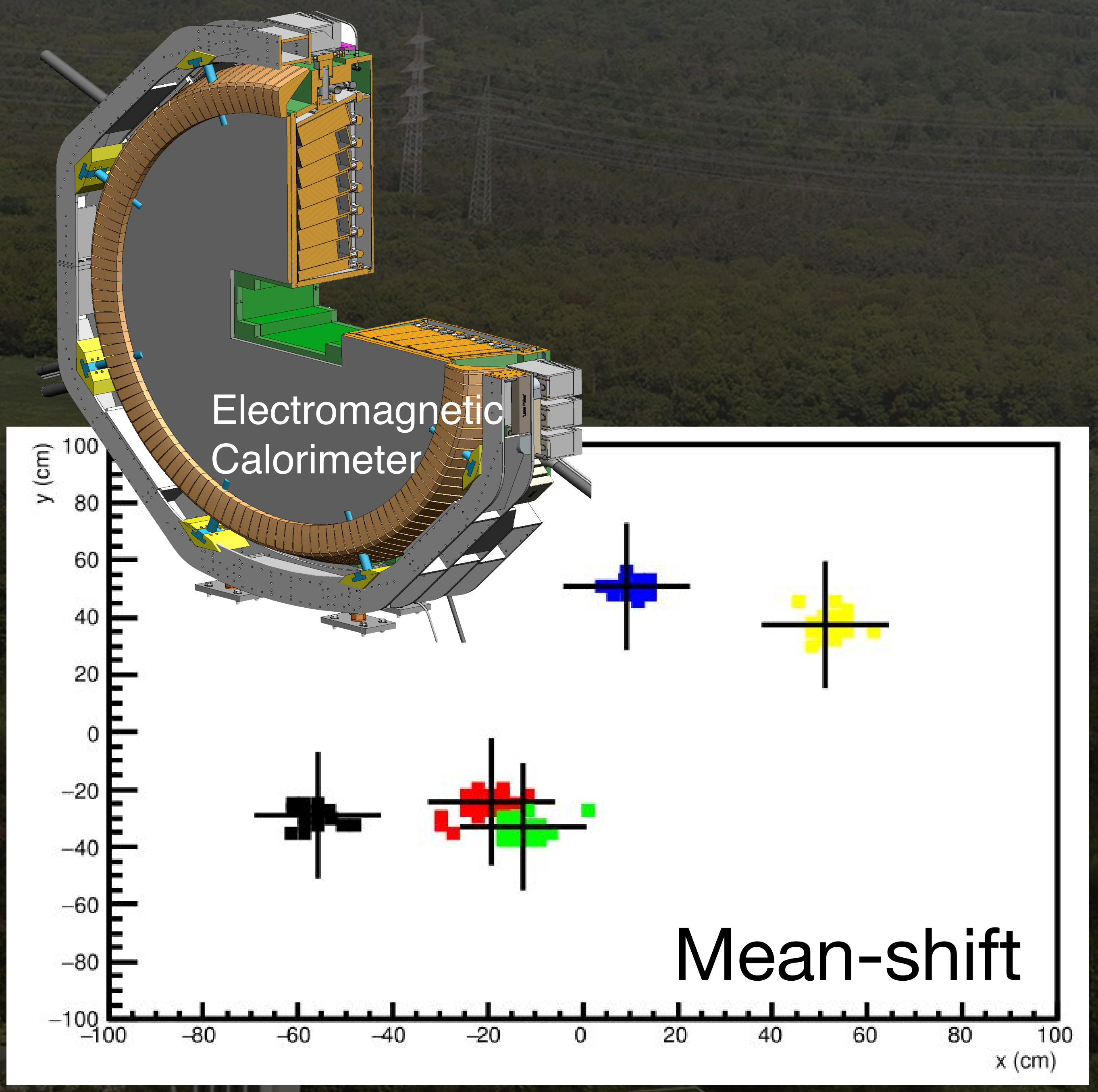
Matthew Schwartz, Harvard University,
EuCAIFConf Amsterdam, April/May 2024

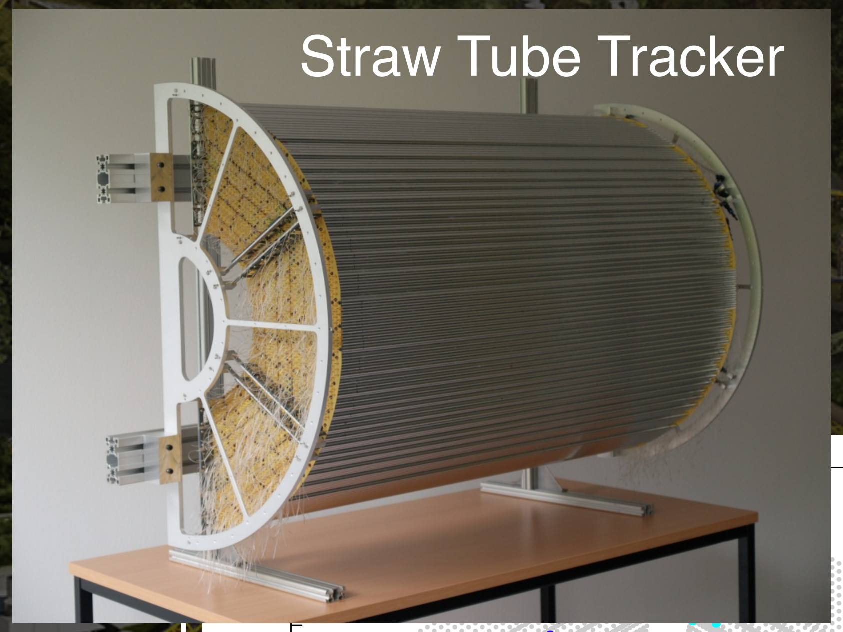


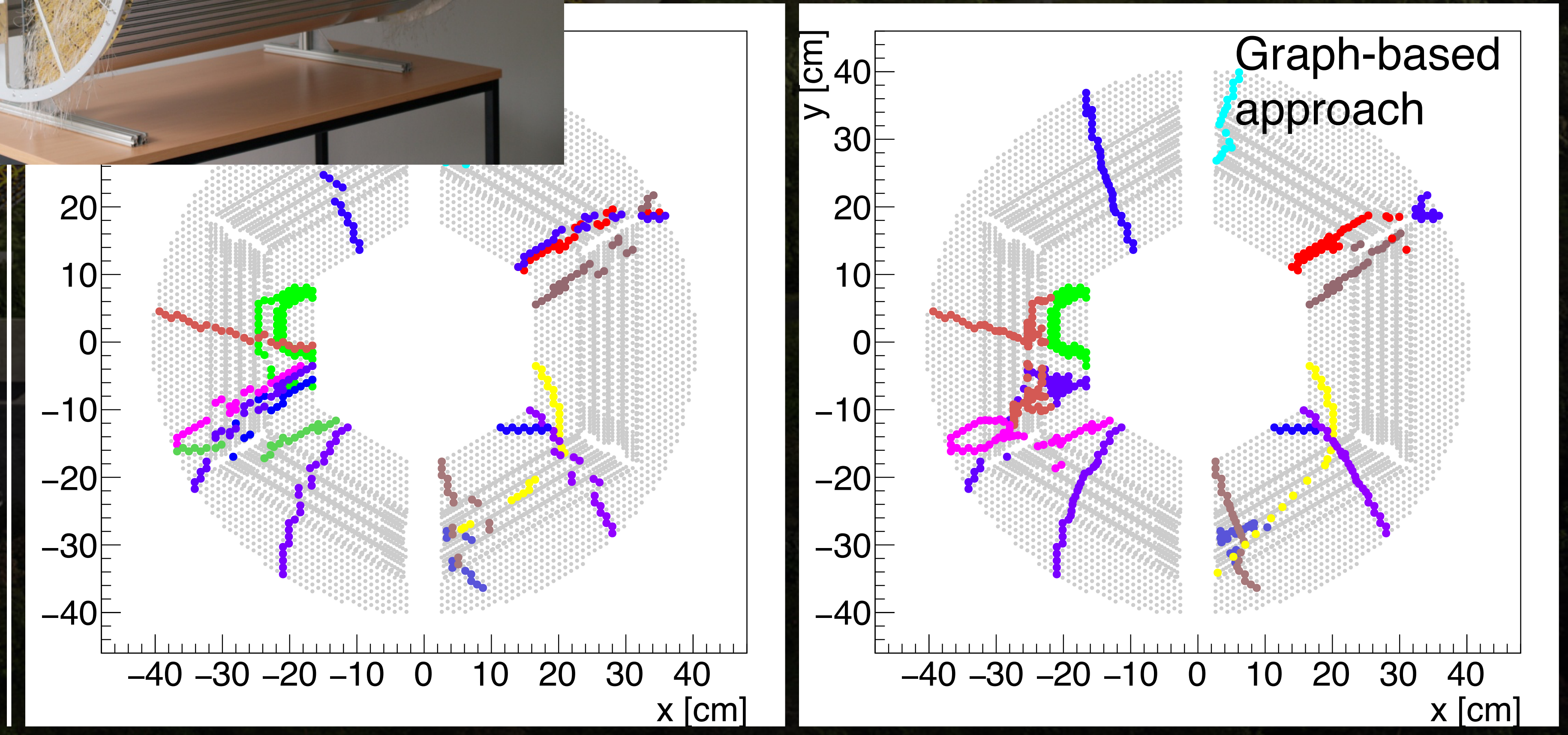
ML applications

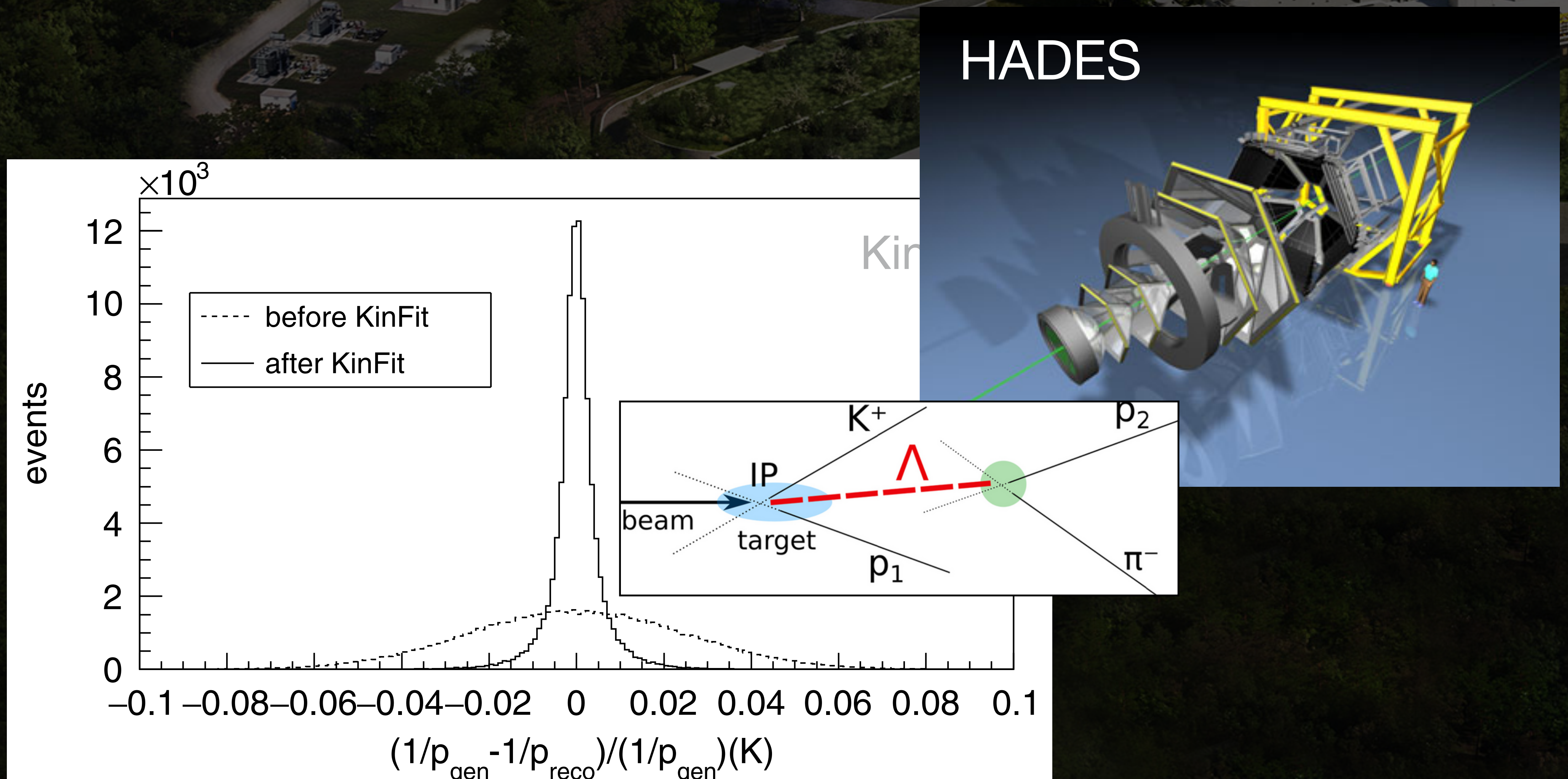
…well-established in nuclear physics

1. Classification
2. Clustering
3. Multi-parameter fits







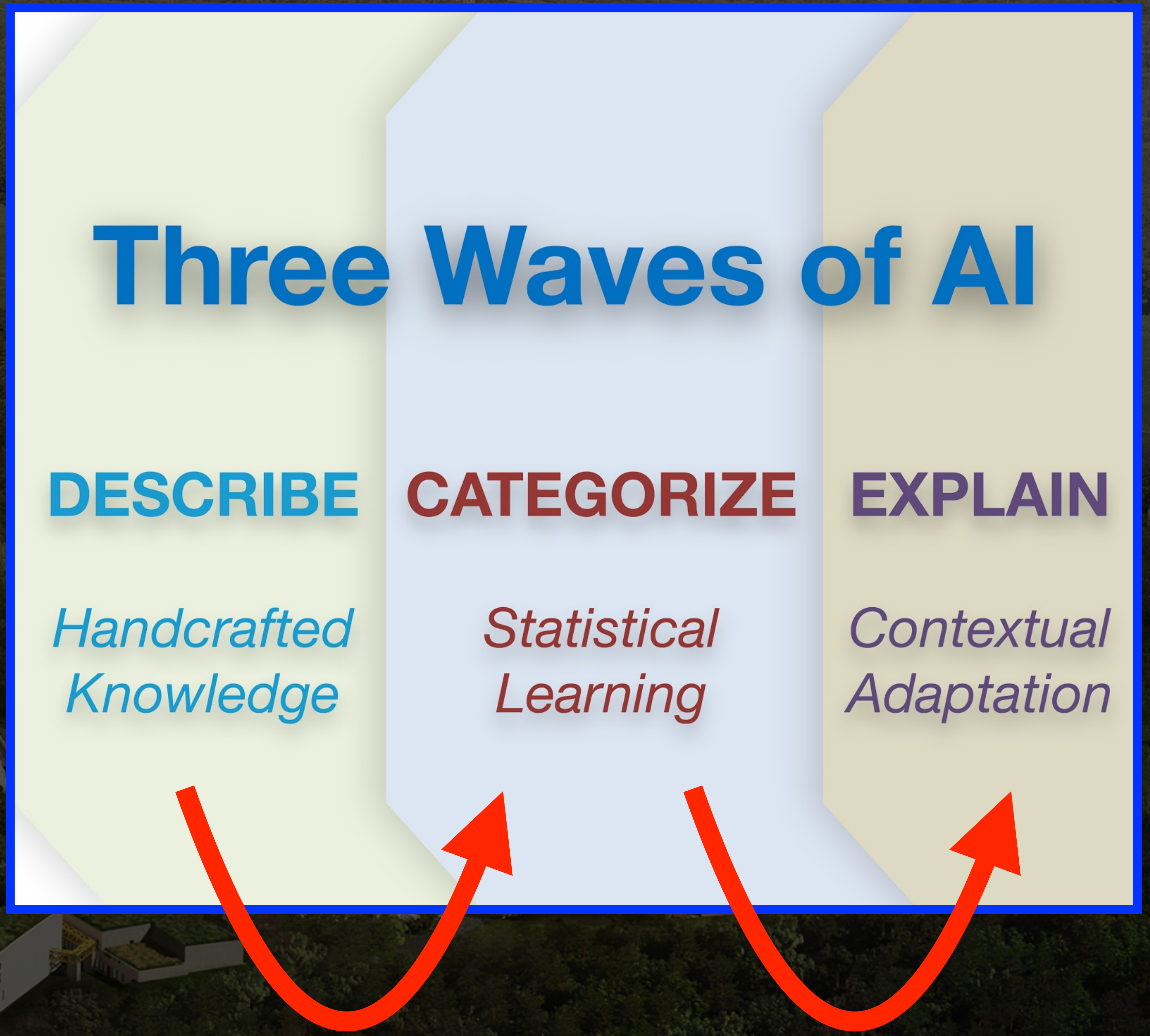


Examples: multi-variate tools, neighbour-searches, likelihood fits, Hough transforms, Kalman filters, …

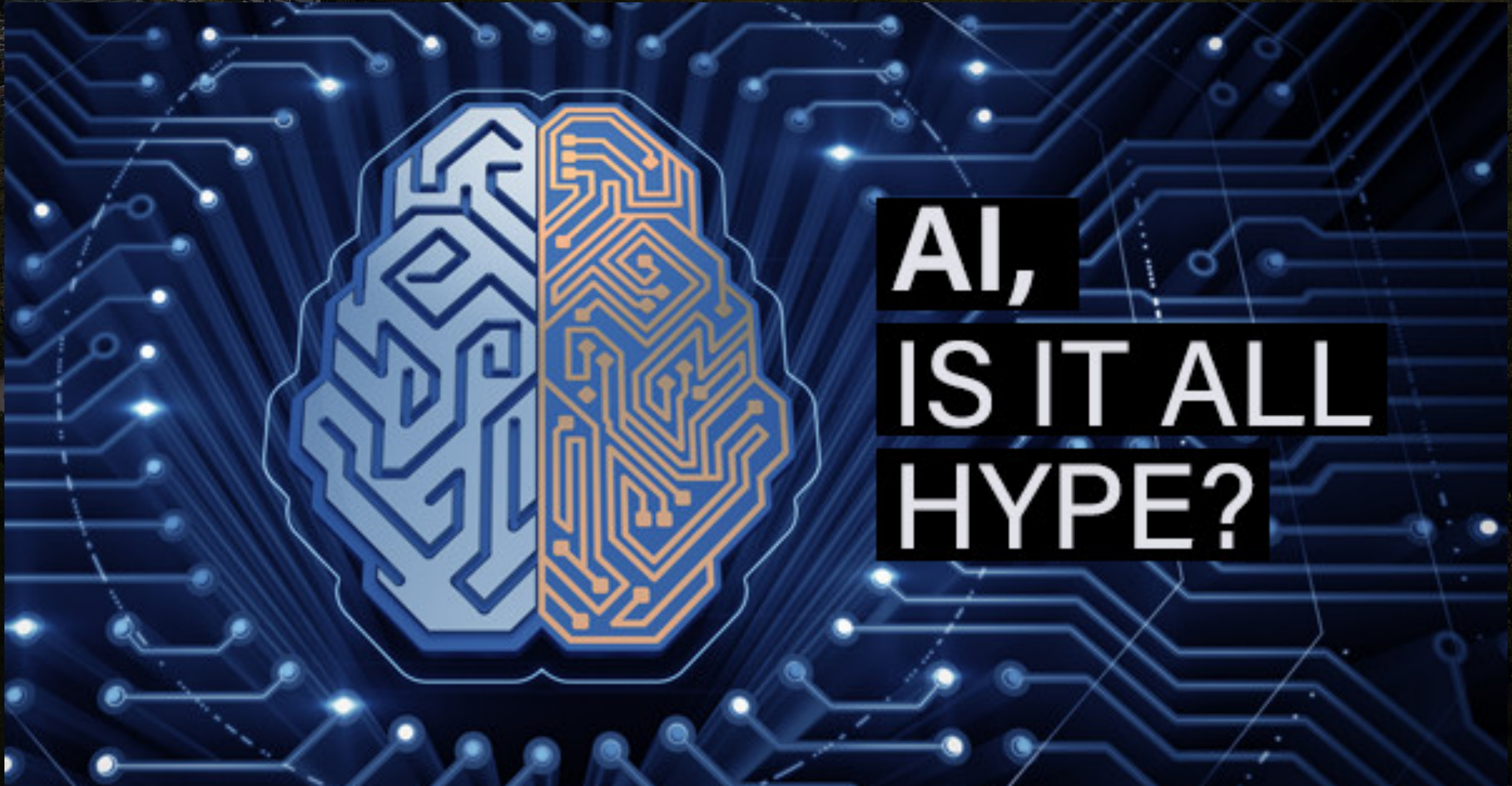
ML & AI applications

… the promises for the future

1. Model complex detector responses
2. Assist in detector design
3. Support experiment operations
4. Support real-time event selection
5. Anomaly detection
6. Enable new discoveries via data mining, etc.
7. Support data management & information preservation
8. Exploit foundation models
9. … etc.…



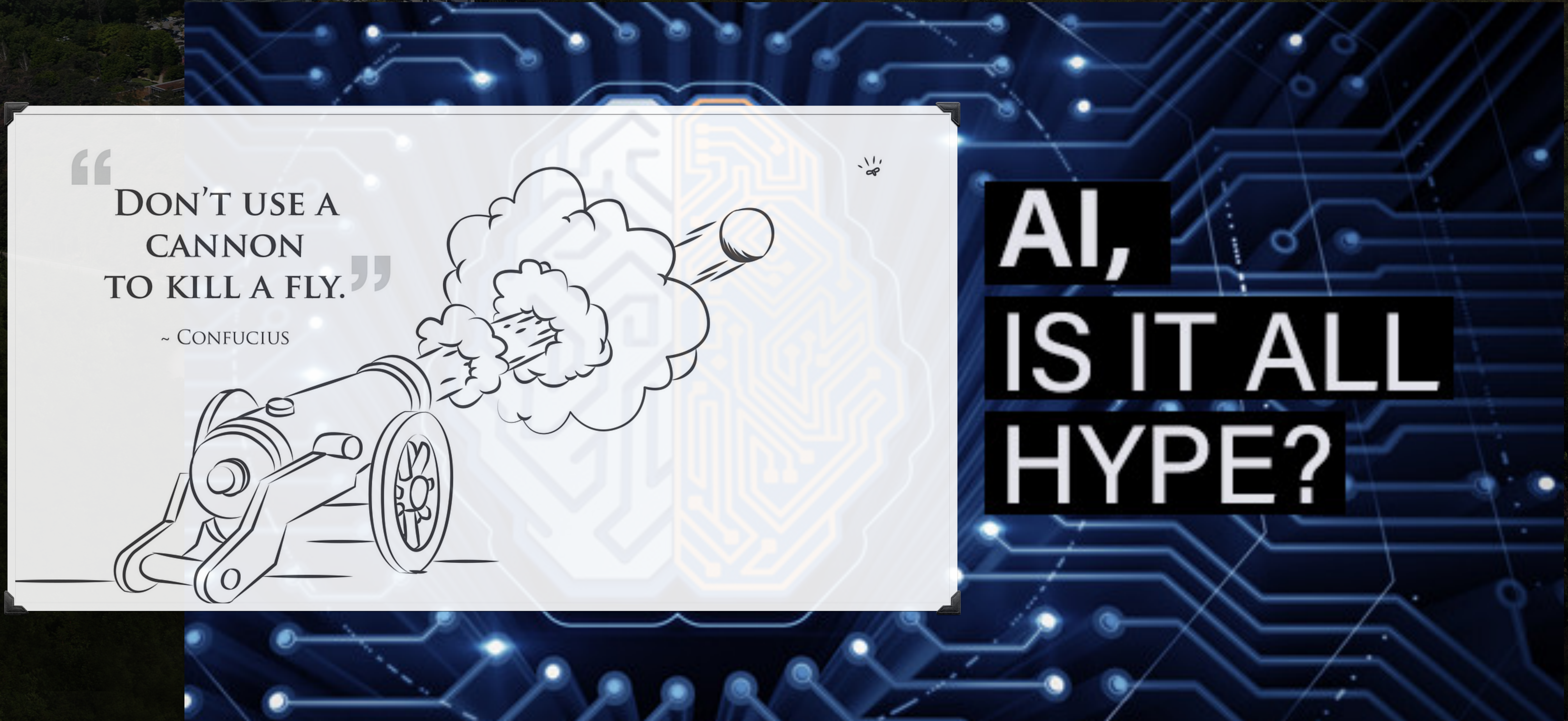
ML & AI applications
… the promises for the future



-shift

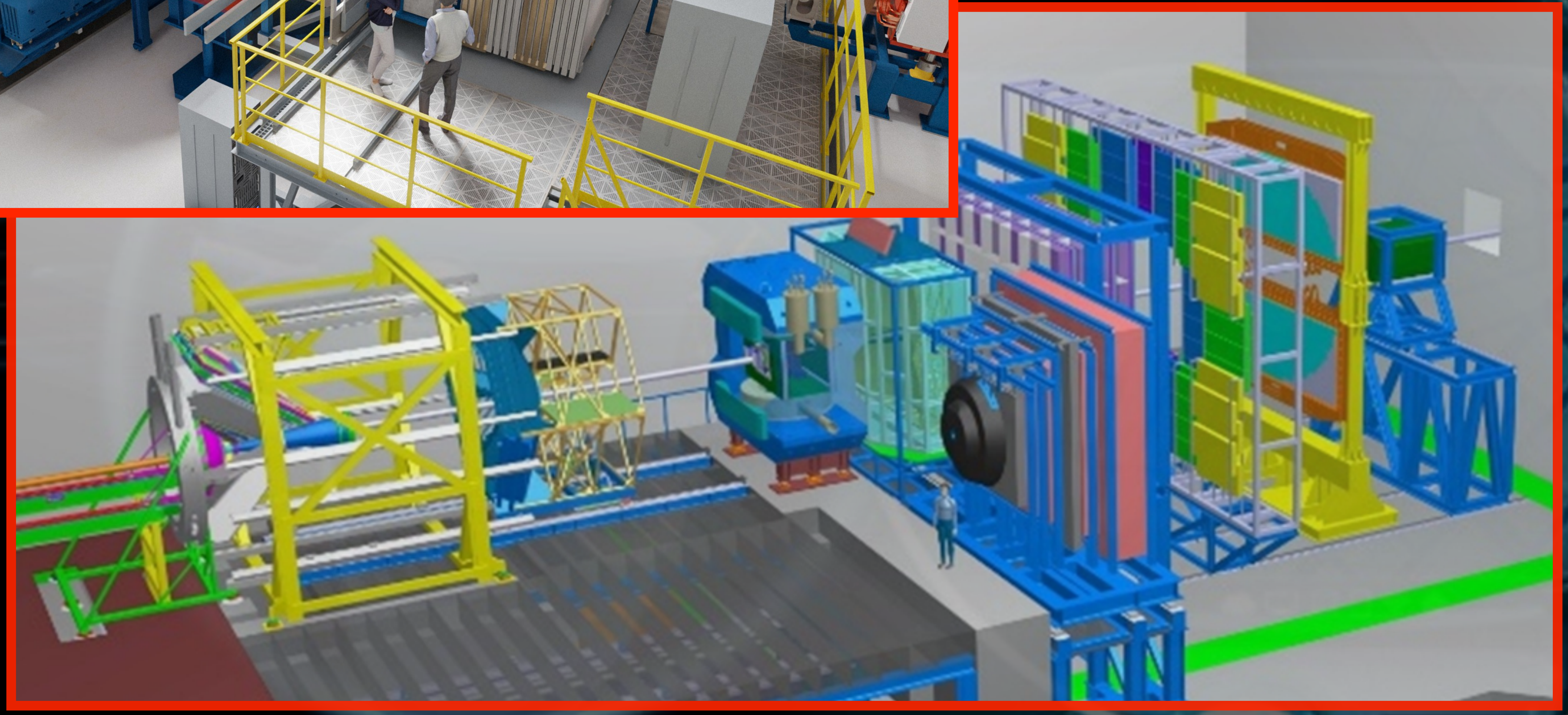
ML & AI applications

… the promises for the future

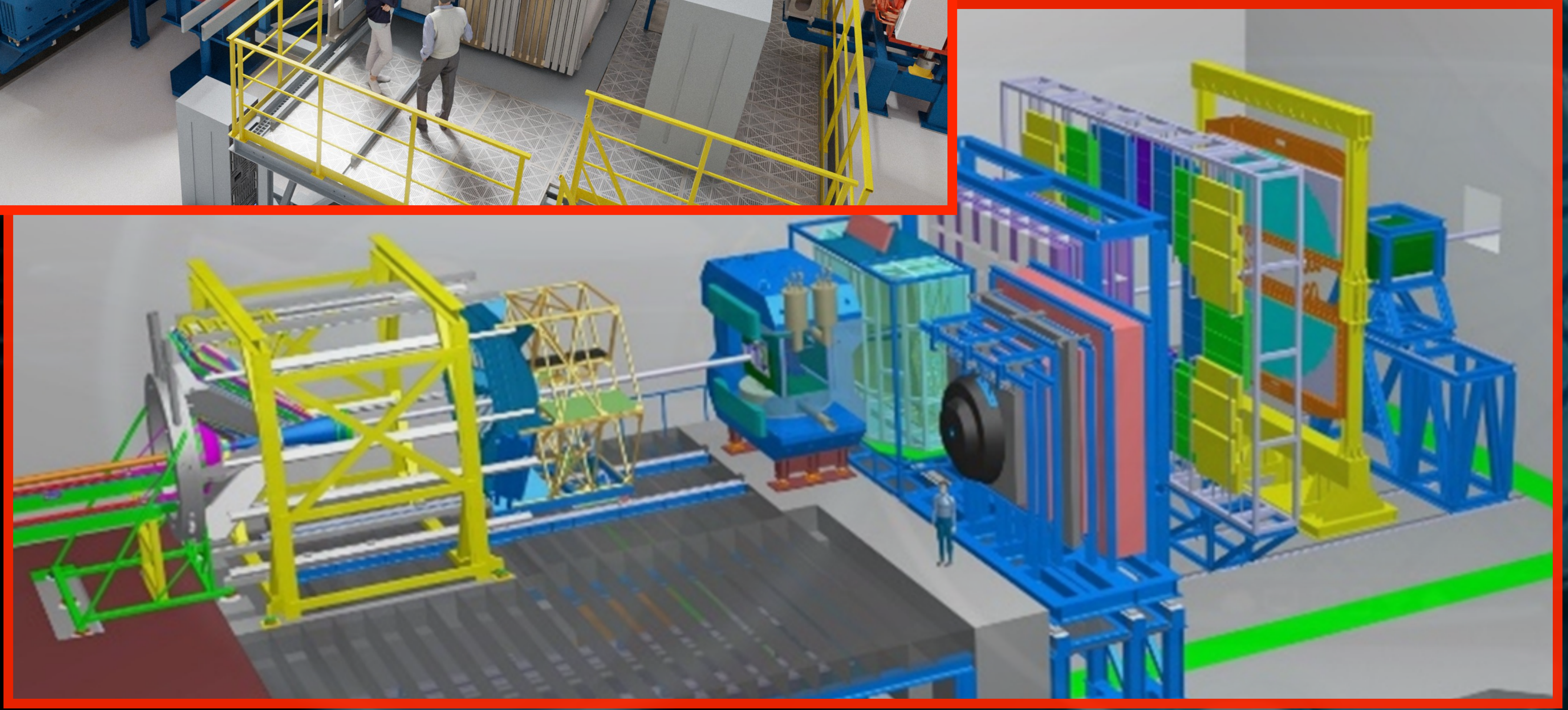


AI/ML for *stable* experiment operations

AI/ML for *stable* experiment operations

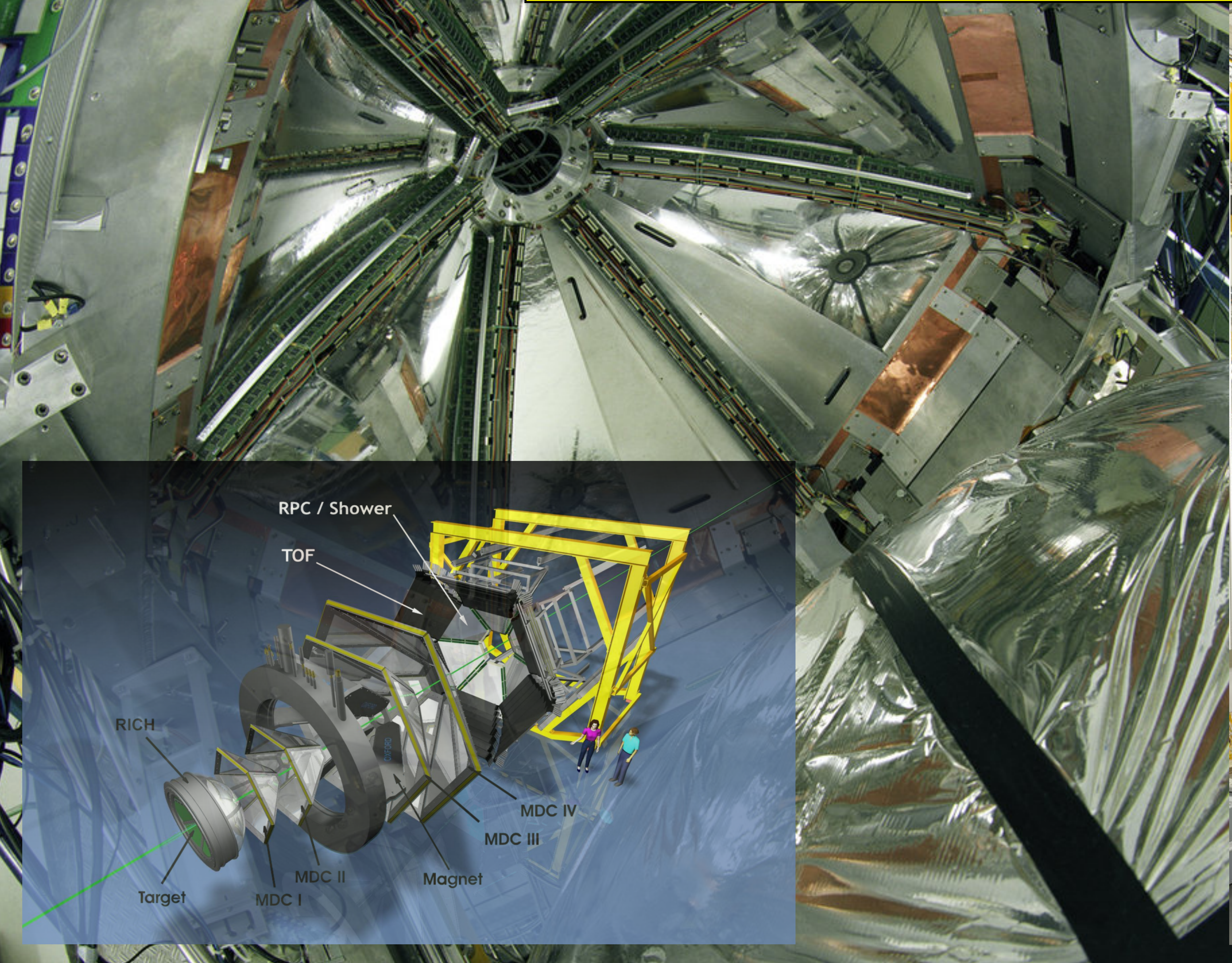


AI/ML for *stable* experiment operations



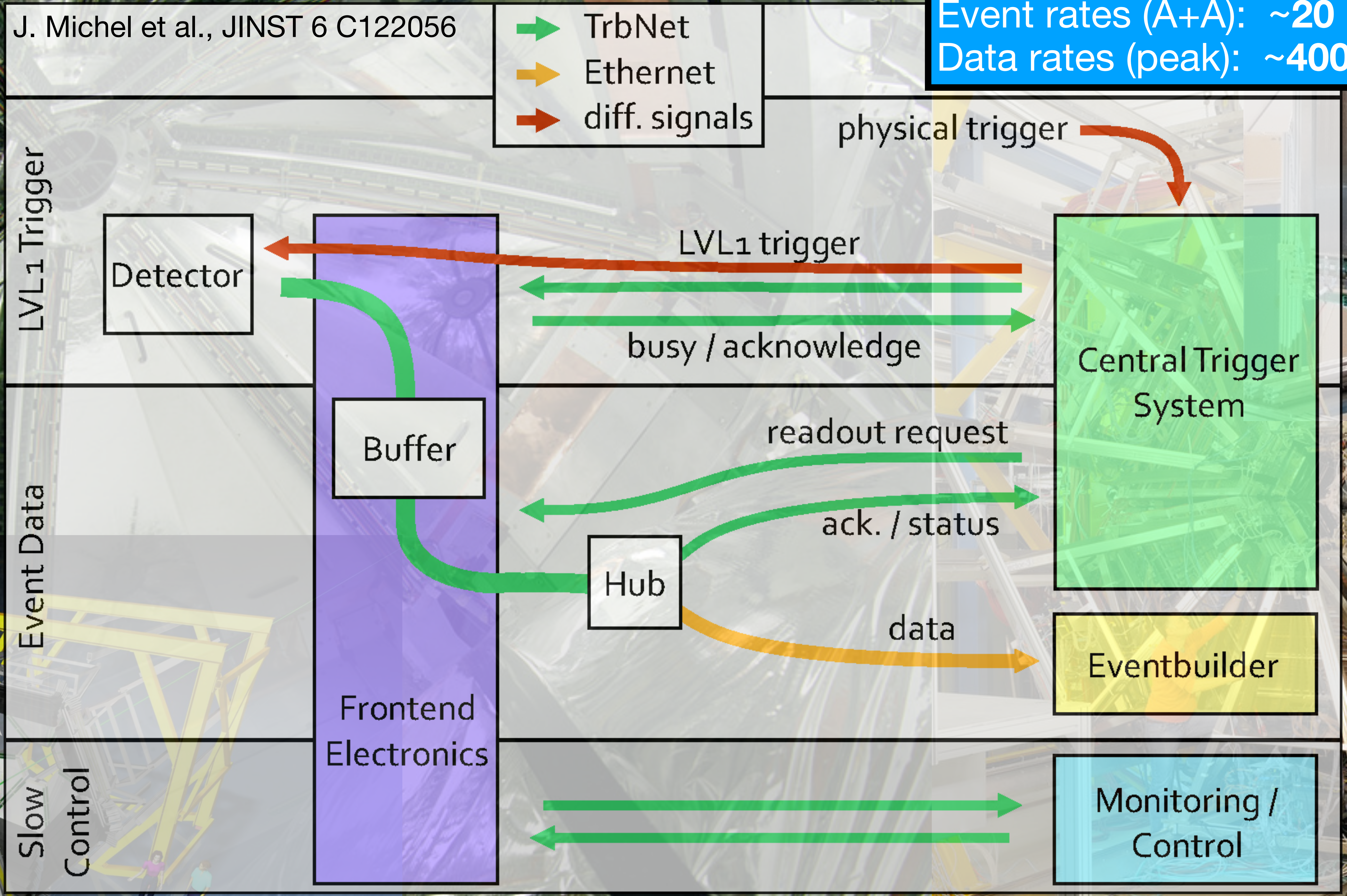
- Beams at **high intensities**, **harsh environment**, increasing #sensors + holistic, complex
- **In-situ event reconstruction** will rely on quality beam & calibrated sensors
- **High operational costs**, limited beam time, and human resources
- **High publication pressure**, spending years on calibrations etc. unacceptable
- **Remote control** has become more important (pandemic)

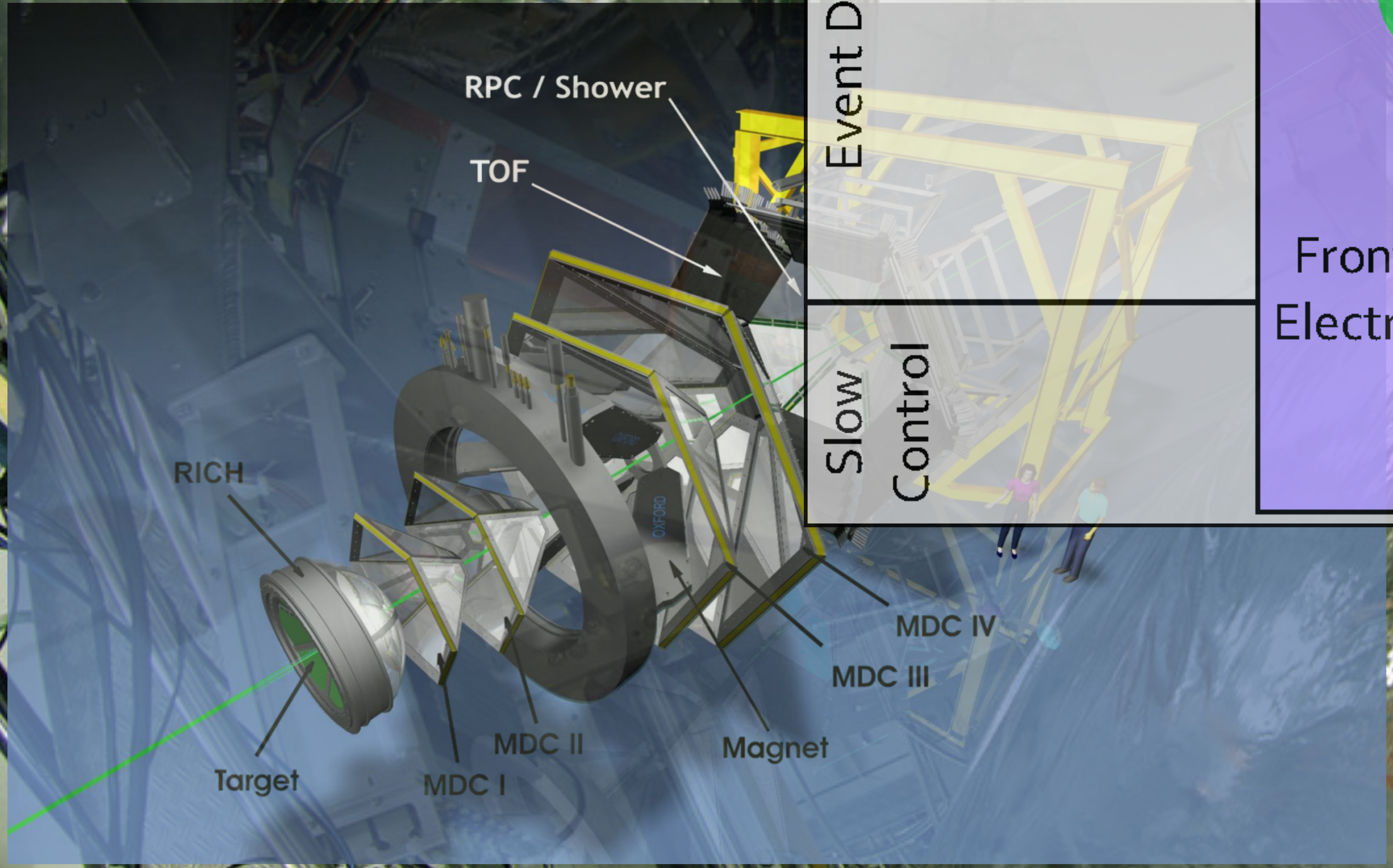
Running an experiment at GSI
(HADES @ FAIR Phase Zero)

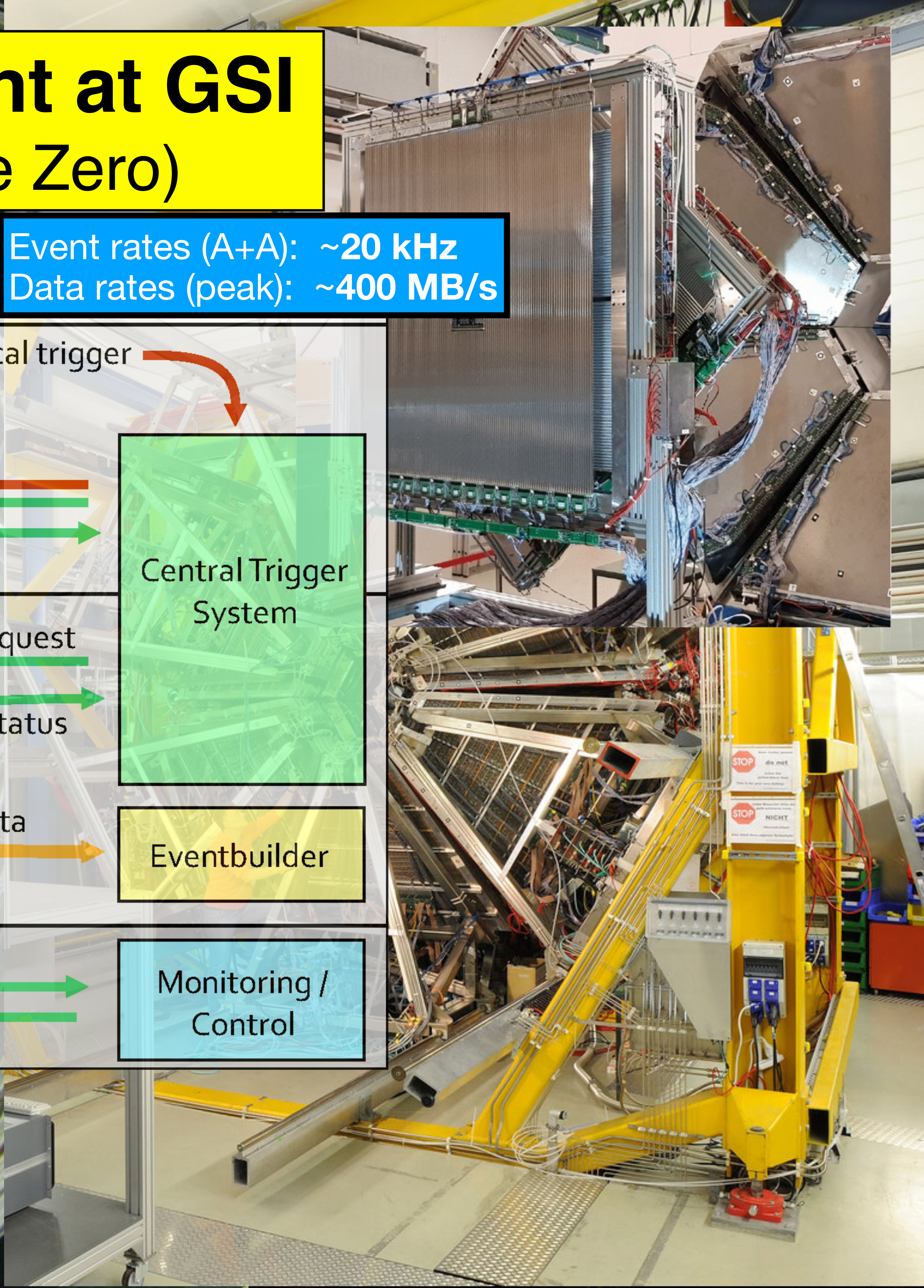


Running an experiment at GSI
(HADES @ FAIR Phase Zero)

Event rates (A+A): ~**20 kHz**
Data rates (peak): ~**400 MB/s**







Shift Start
Shift-Leader
DAQ+QA Operator
DAQ-Standby Expert
MDC Operator
RICH Operator
ECAL Operator
Forward STS Operator
Forward RPC Operator
RPC Operator
WEDNESDAY 16-FEB-2022
16:00
I. Ciepal on shift
A. Shabanov+A.Strach on shift
K. Sumara
L. Lopes
THURSDAY 17-FEB-2022
00:00
J. Rieger on shift
Tactical Overview
Wall Clock 21:47:44
Current Rate 48302
Beam Abort
Last Restart 1m55s ago
Spill Count 12
TrbNet OK
Timeouts on 1 ports
Busy 54.1%
Read-out 796MB/s
Sync OK
Spill Sum 444k (9s)
Accept. PT3 24% / 29%
Trigger Source PT2/64 PT3 PT7
Trg Ratios 1.49% / 2.67‰
Start Count 69M / 361M
PT1 Rate 947k
PT2 Rate 892k
PT3 Rate 173k
nothing
PT8 Rate 723k
Disk Level 47%
Max. CPU 33%
to see
here
Online QA
#EB running i:7, b:10 ("be")
ΔRate CTS/EB 30k/29k
Data Rate 460 MB - 17 kB
#Evt Discarded 0
#Evt w/ errors 161 (0.0%)
MBO Reinit
MBO w/o data
Temperature 51/57/58/57
Link Errors 6 Errors
Voltages 58 warnings
MDC 3 / 431 miss
RICH OK 931(-13)
TOF/RPC/FW OK 90
ECal/STT/fRPC OK 99
Hub/St/CTS OK 33
FEE Error
Trg. Inputs
Trigger
RPC Thresh
TOF Thresh
Temperature 18 - 42
LV
Temperature 22 - 33
Gas 1.6|14|103
RICH Thresh 2
ECAL 104/105 | 30-44
Start 12/12 | 28-34
iTOF 18/18 | 18-29
Hodo 2/2 | 28-29
STS 3.0/3.0/3.0/3.0
RICH HV 0.86 / 1.03 kV
ECAL HV 815/815
RPC HV 12/12
FW HV OFF
TOF HV 766/768
MDC HV 1.7/1.8/1.9/2.1
STS HV 1.7k - 1.7k
fRPC 5.4k/5u/32.0°
iTOF HV 30V / 7.5mA
Vacuum 46 / 16
SEU 9/303
Last TDC Calib 14.02. 22:04
Magnet
20.9° / 984mbar 0.96mT / 35.7%
HV Sequencer 36/36
GSI Telefonnummern
Name
HKR SIS
Strahlenschutz
Hades cave
Hades Detector Room "Edelhuette"
Hades Lower Counting Room
Hades Upper Counting Room
Hades Cave Entrance
NE5 Entrance
Cryo
Network
FRS
guest house GSI
Christian Müntz
Christian Wendisch
Erwin Schwab
Gosia Gumberidze
Jan Michel
Jerzy Pietraszko
Joachim Stroth
Jochen Markert
Jörn Adamczewski-Musch
Michael Traxler
Peter Zumbruch
Torsten Heinz
Vladimir Pechenov
Start Channel
Time [100ms]
Share of each stripe of total rate
STS Hit Rate
TOF Hit Rate
iTOF Hit Rate
HADES beam time, February 2022


Shift Start
Shift-Leader
DAQ+QA Operator
DAQ-Standby Expert
MDC Operator
RICH Operator
ECAL Operator
Forward STS Operator
Forward RPC Operator
RPC Operator
WEDNESDAY 16-FEB-2022
16:00
I. Ciepal on shift
A. Shabanov+A.St on shift
K. Sumara
L. Lopes
THURSDAY 17-FEB-2022
00:00
J. Rieger on shift
GSI Telefonnummern
Name
HKR SIS
Strahlenschutz
Hades cave
Hades Detector Room "Edelhuette"
Hades Lower Counting Room
Hades Upper Counting Room
Hades Cave Entrance
NE5 Entrance
Cryo
Network
FRS
guest house GSI
Christian Müntz
Christian Wendisch
Erwin Schwab
Gosia Gumberidze
Jan Michel
Jerzy Pietraszko
Joachim Stroth
Jochen Markert
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Time [100ms]
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STS Hit Rate
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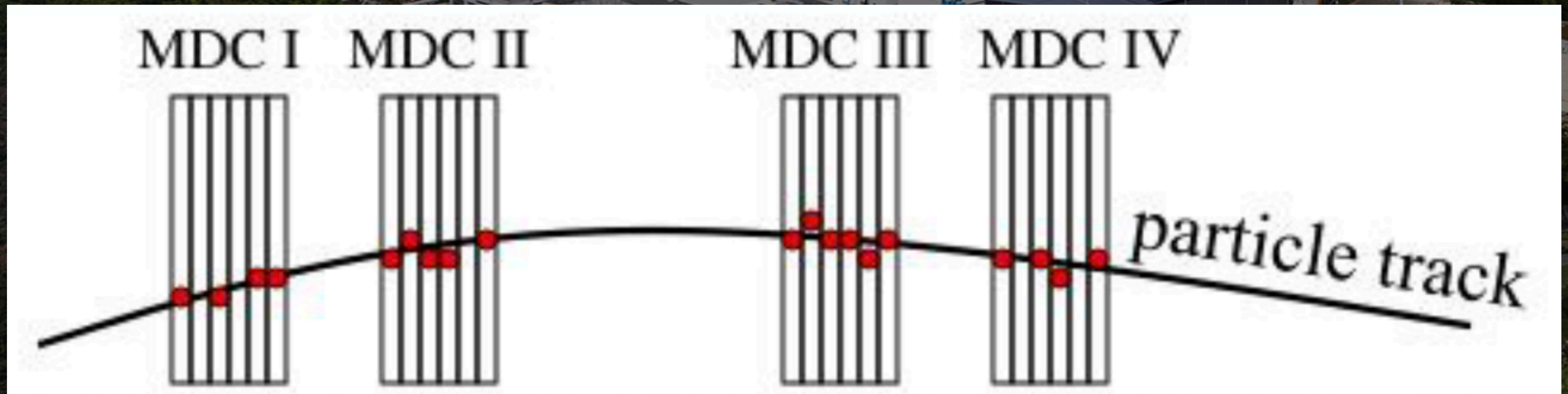
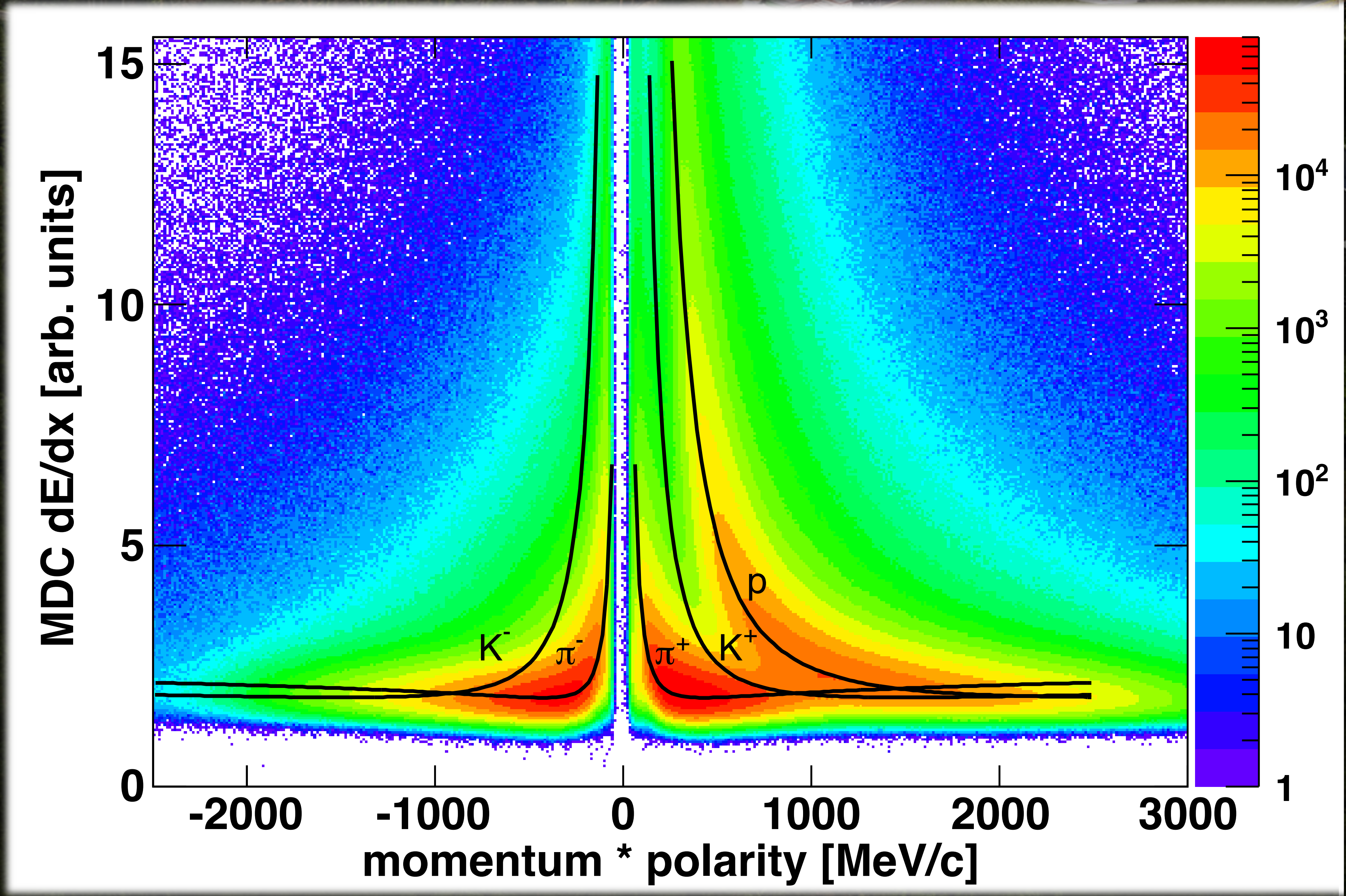
beam conditions (e.g. current)
HV/LV current
temperature (multi)
pressure
Conditions values read from existing slow controls system
sensor settings (e.g. HV)
A.I.
calibration constants
preselected and reconstructed data and Monte Carlo data

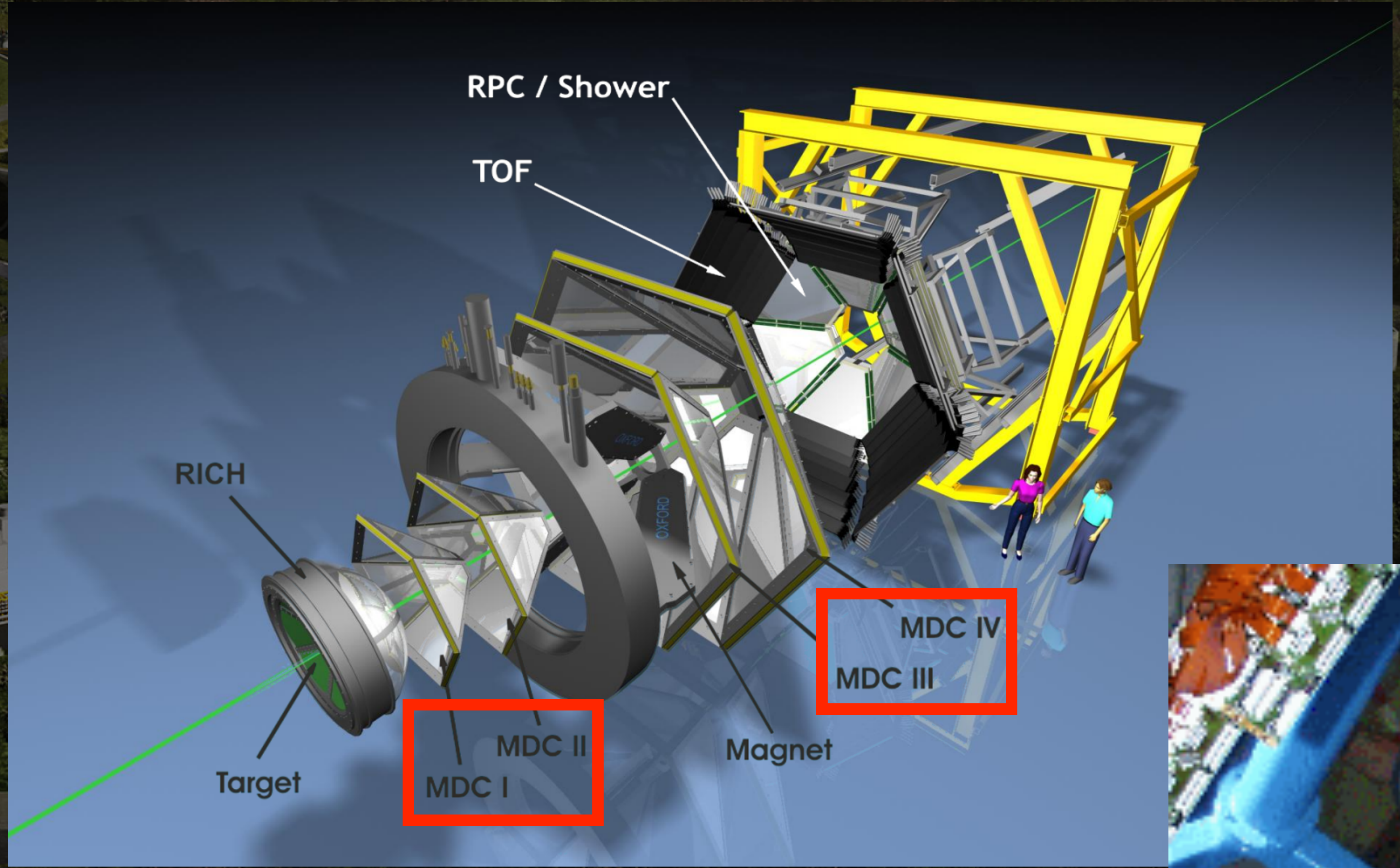
Valentin Kladov (GSI)

Real-time calibrations for FAIR

…with HADES Mini Drift Chambers (MDCs) as demonstrator case







Energy loss (*dE/dx*) depends on beam & environmental conditions

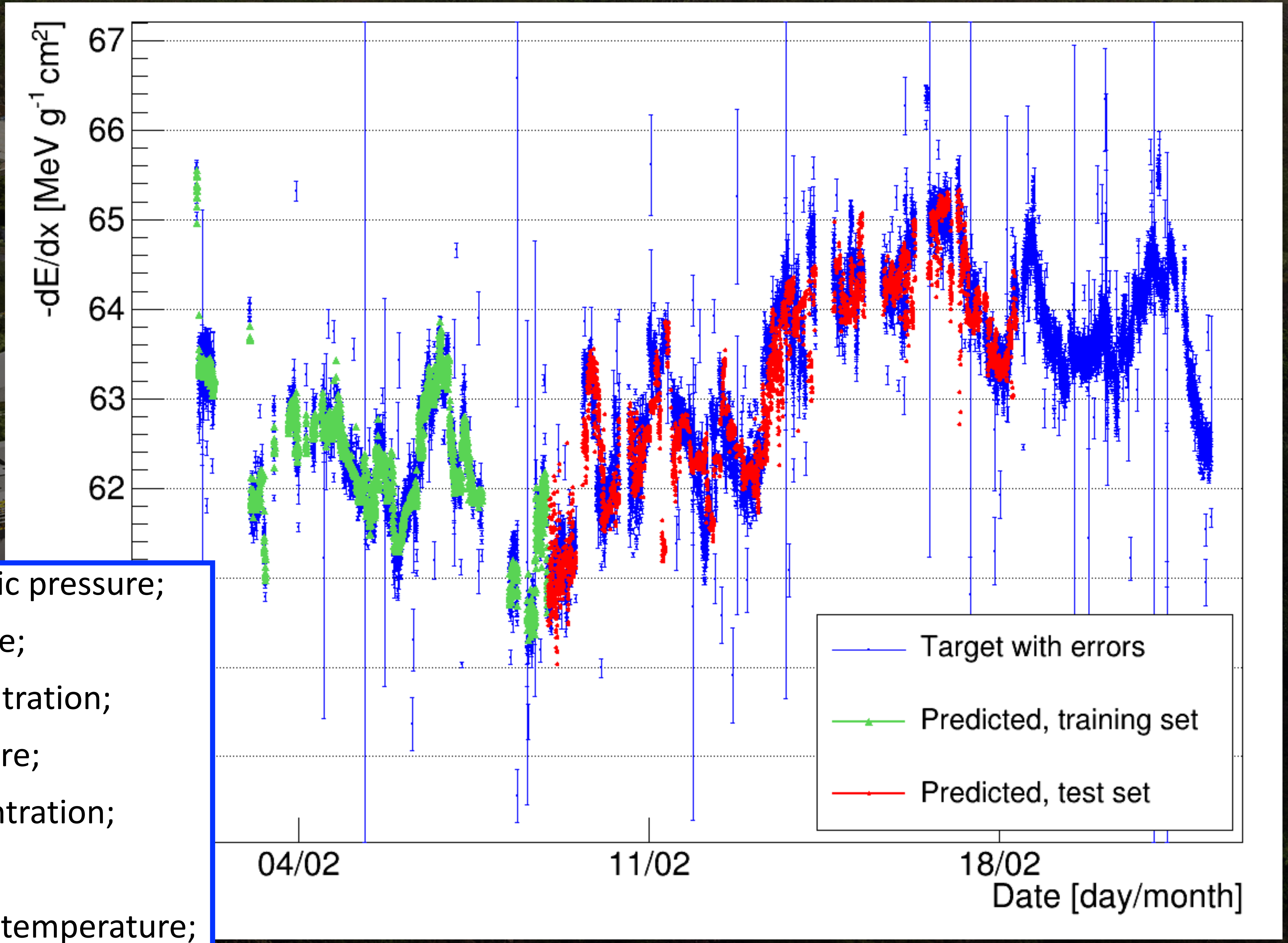
Regular calibration necessary!

Valentin Kladov (GSI)

Real-time calibrations for FAIR

…with HADES Mini Drift Chambers (MDCs) as demonstrator case

- Long short-term memory (LSTM) within in a graph convolutional network
- ~5 M parameters
- … ideal for time-sequential data with smoothness in environmental changes
- … making predictions for present conditions



- Atmospheric pressure;
- High voltage;
- CO_2 concentration;
- Overpressure;
- H_2O concentration;
- Dew Point;
- Electronics temperature;

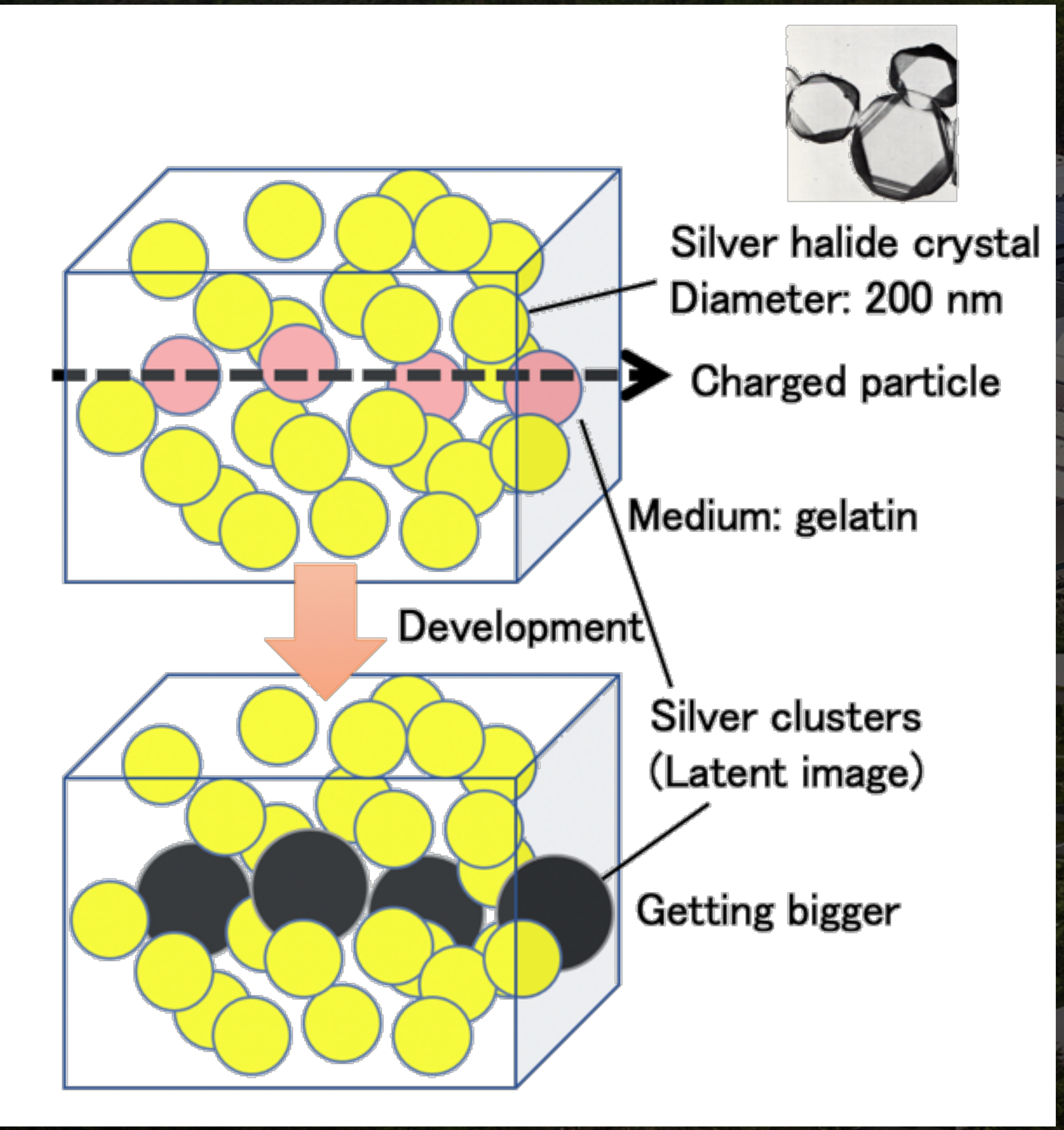
Environmental features

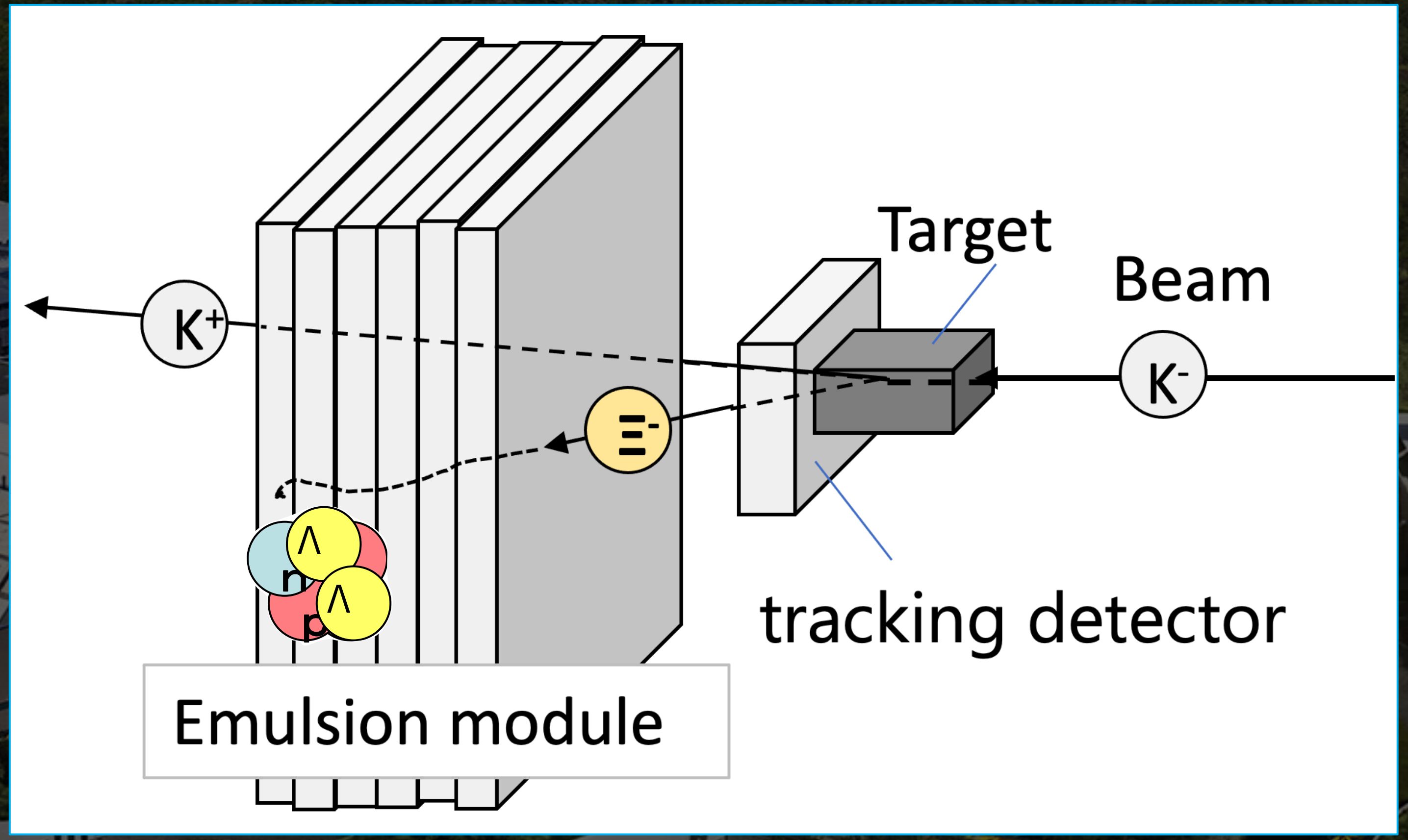
Japan **P**roton **A**ccelerator **R**esearch **C**omplex

Take Saito

Image analysis in nuclear physics

...on a massive scale!





J-PARC E07 experiment (Japan)

Nuclear Emulsion:

Charged particle tracker
with best spatial resolution!

(since 1905, Rutherford!)

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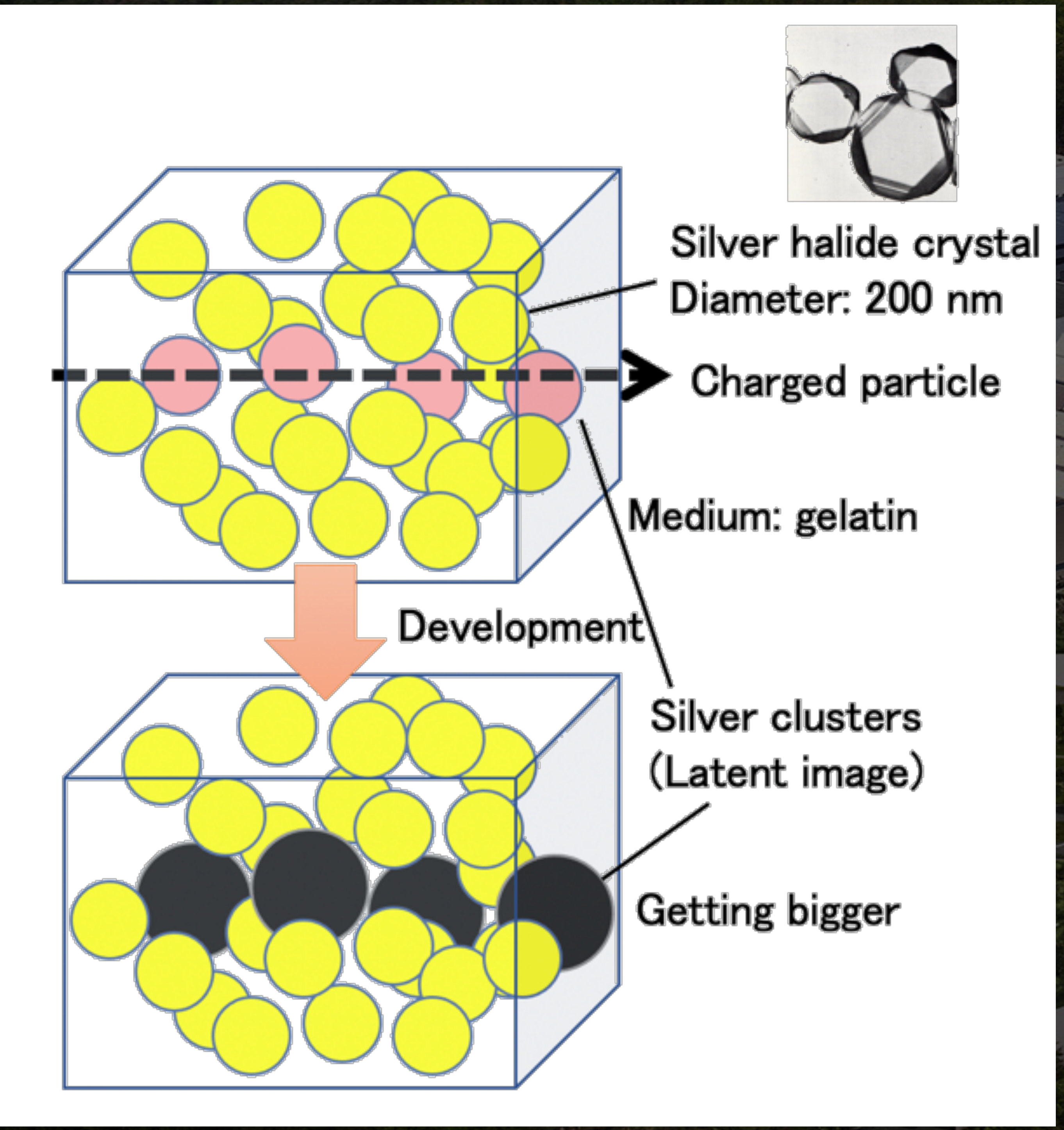

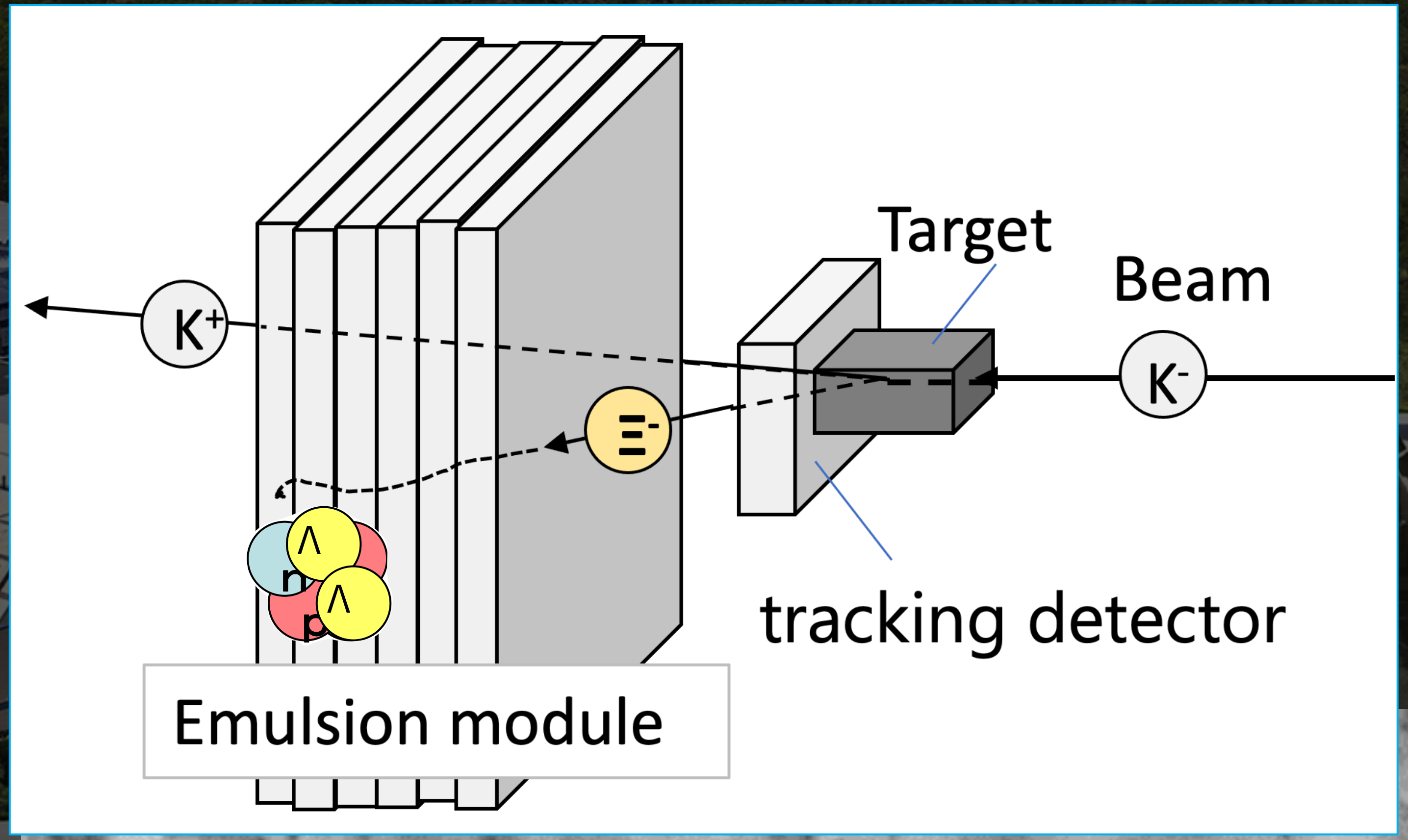

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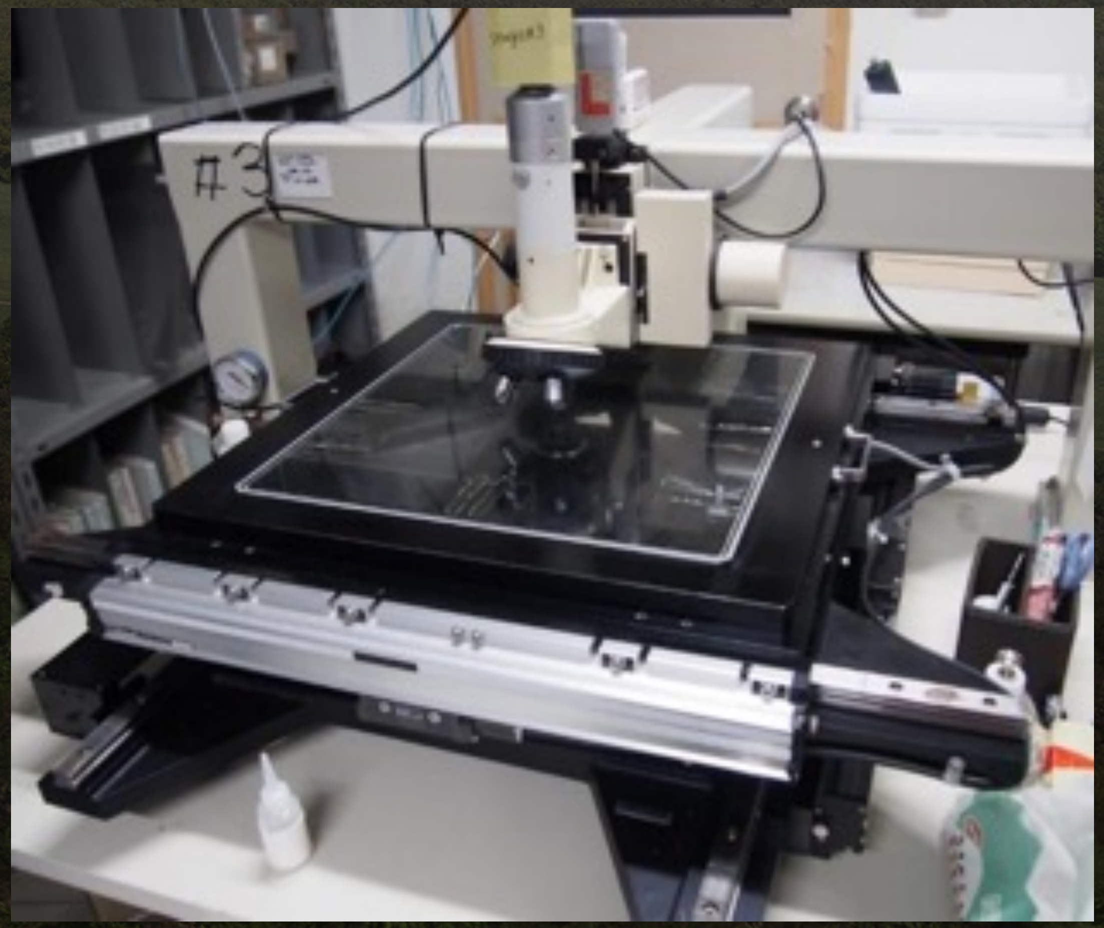

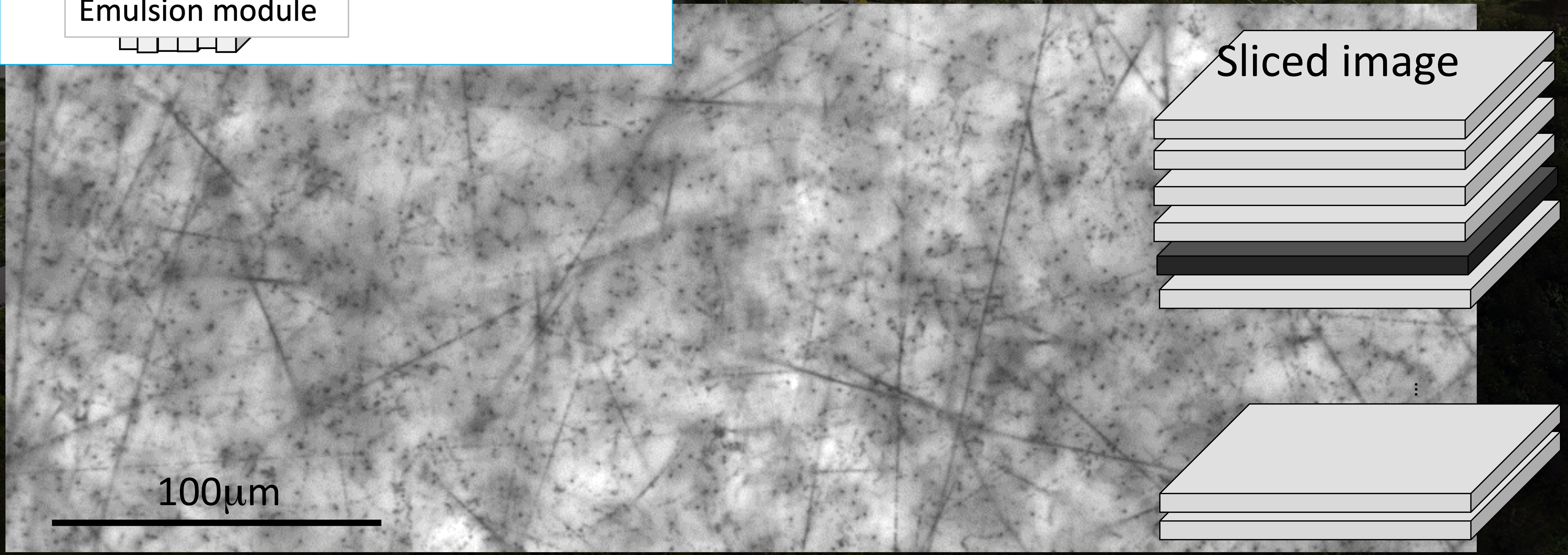

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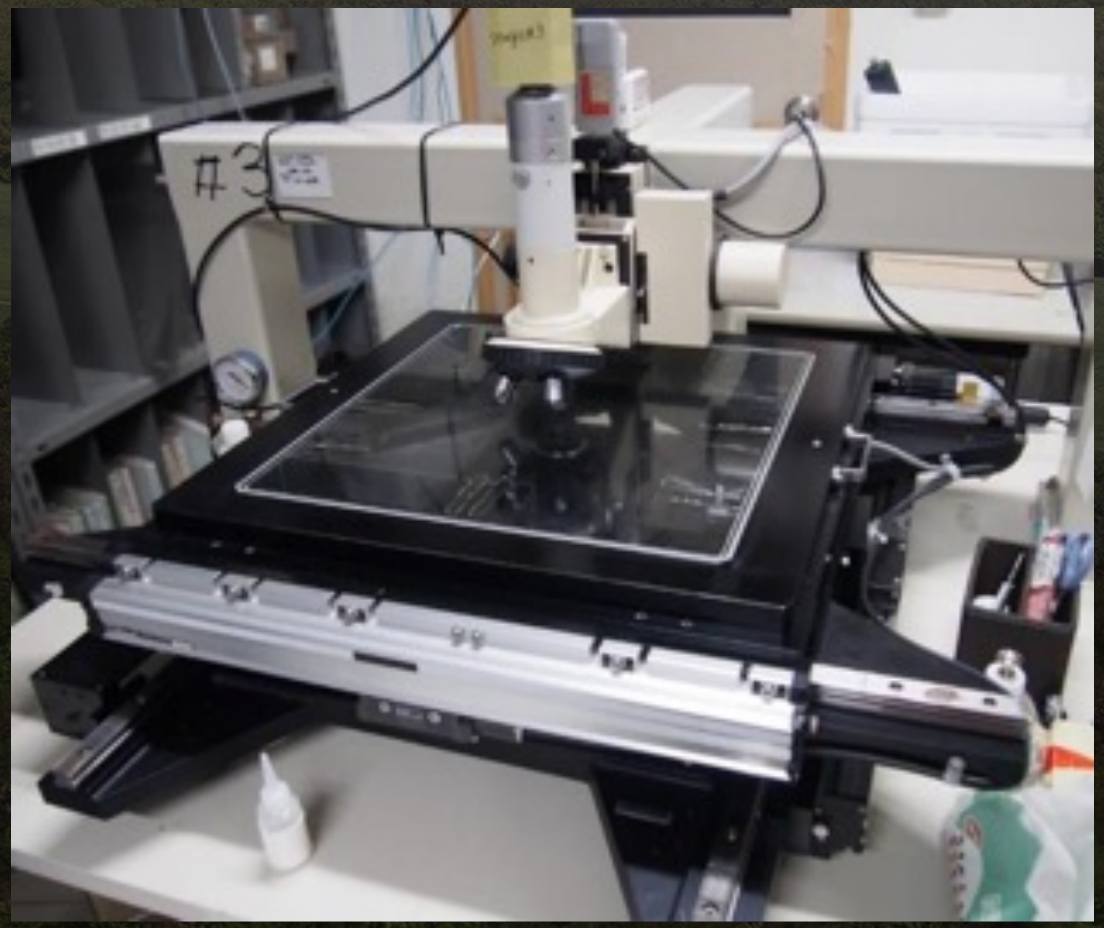

Data size:
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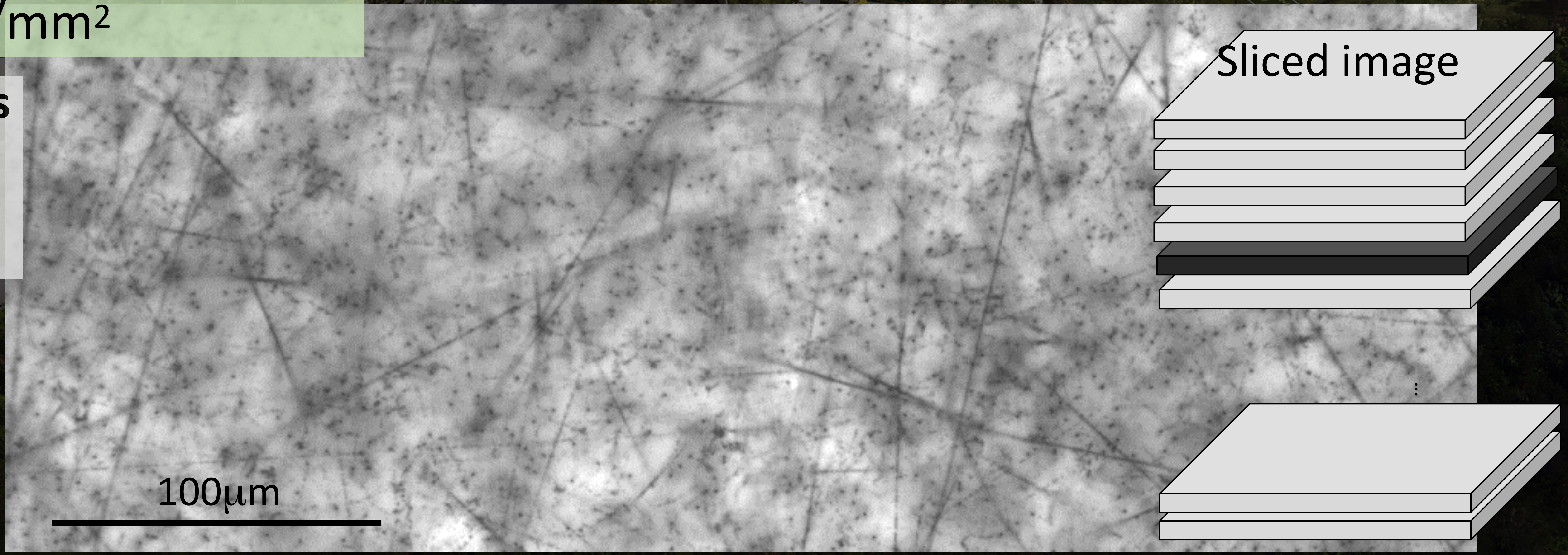
- 10^{10} images per 1000 emulsions (100 P Byte)

Number of background tracks:
- Beam tracks: $10^4/\text{mm}^2$
- Nuclear fragmentations: $10^3/\text{mm}^2$

Current equipments/techniques with visual inspections

560 years



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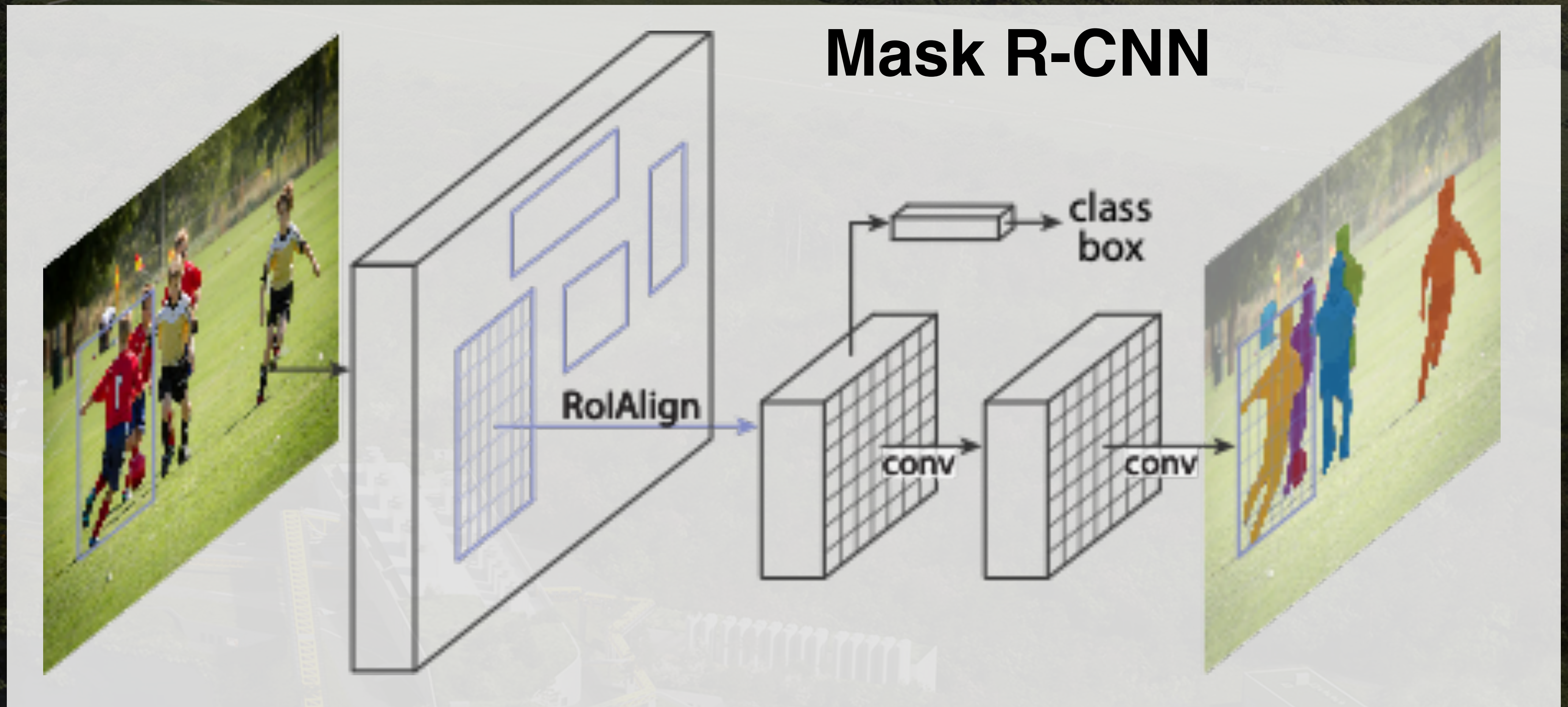

Machine Learning

Take Saito

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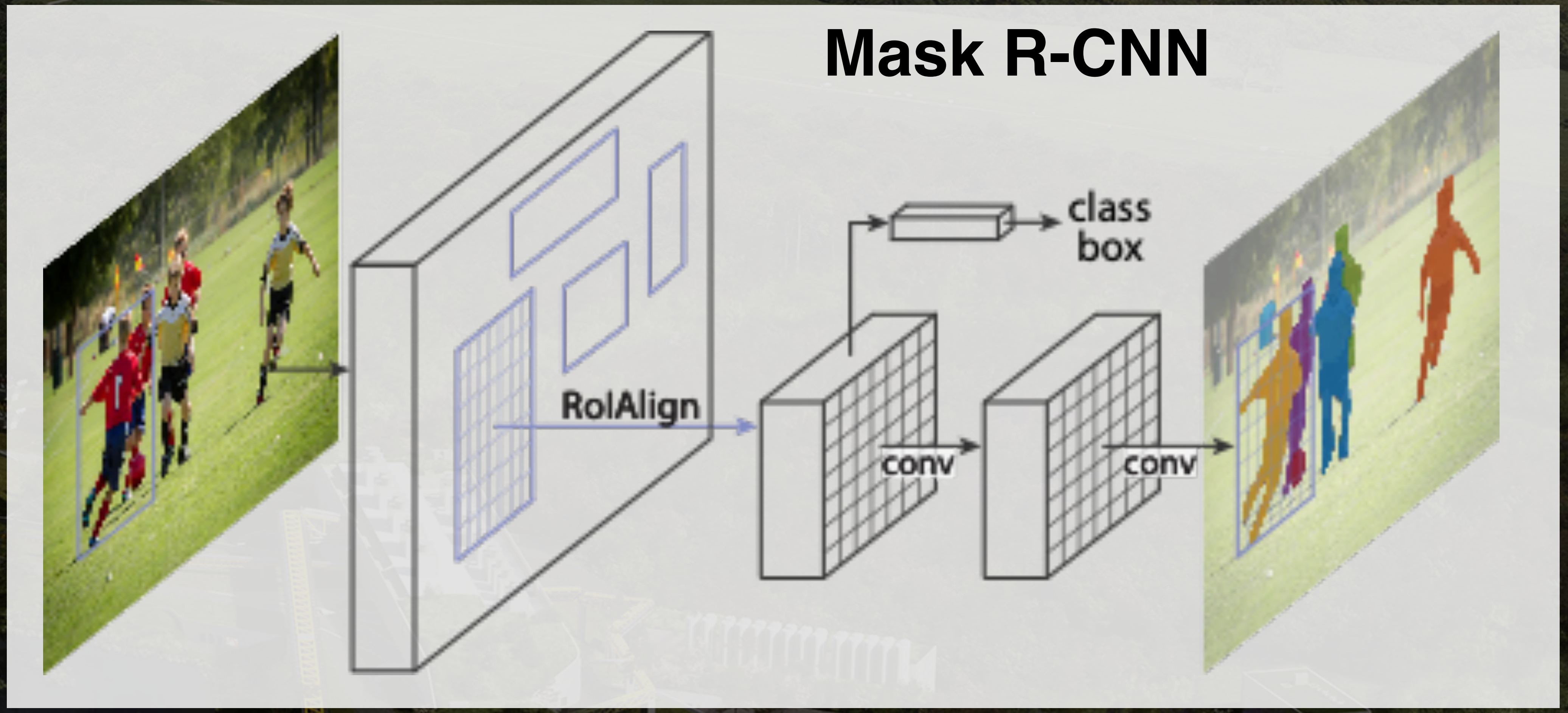
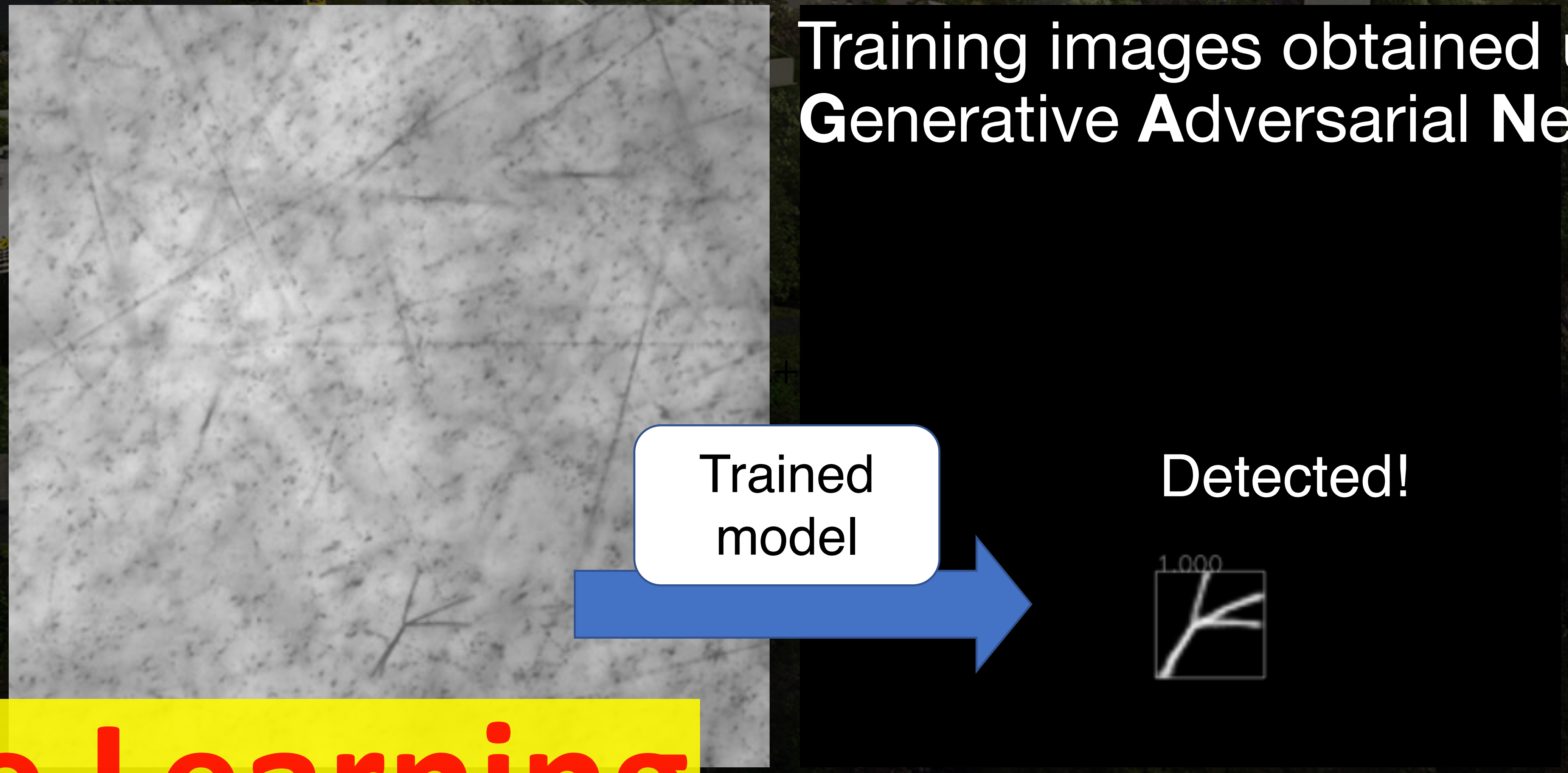


Training images obtained using **G**enerative **A**dversarial **N**etwork



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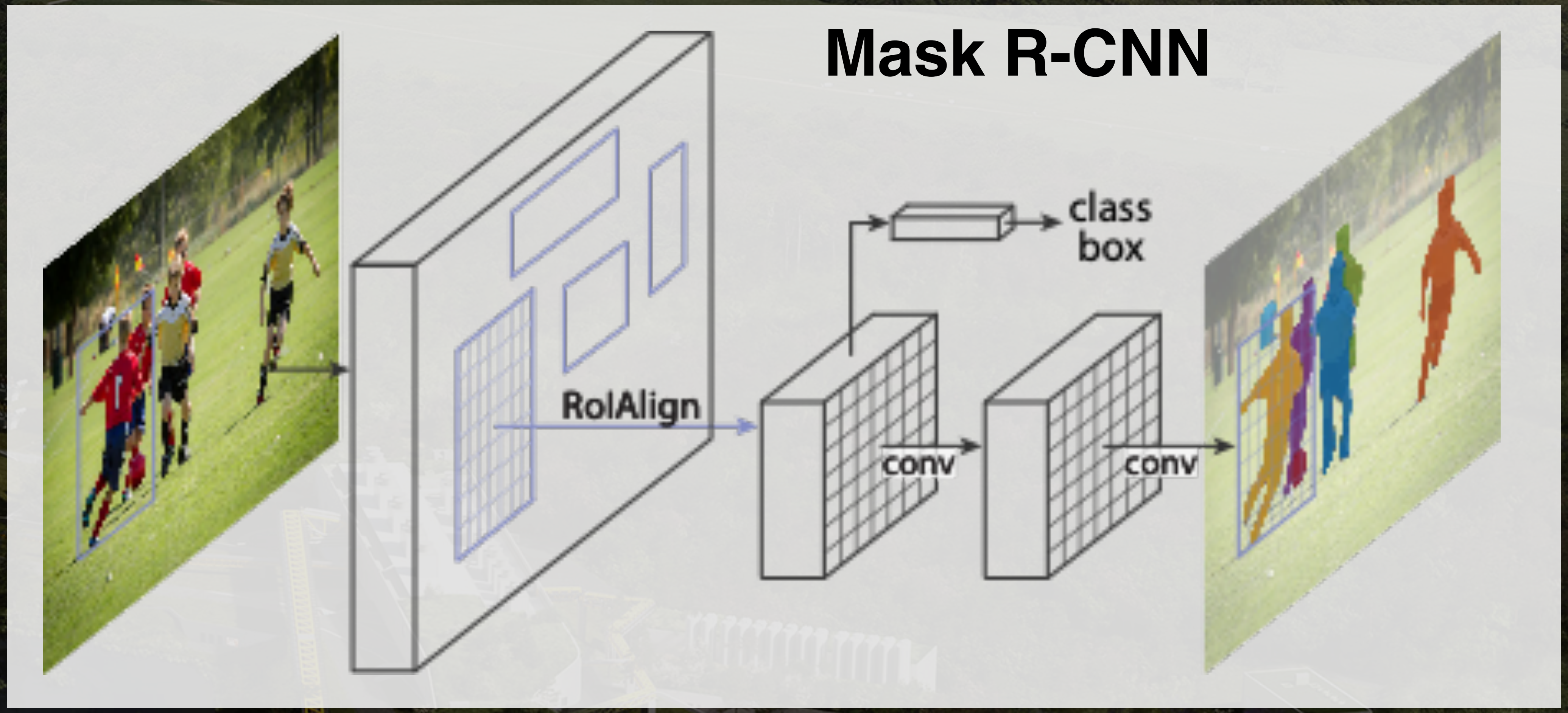

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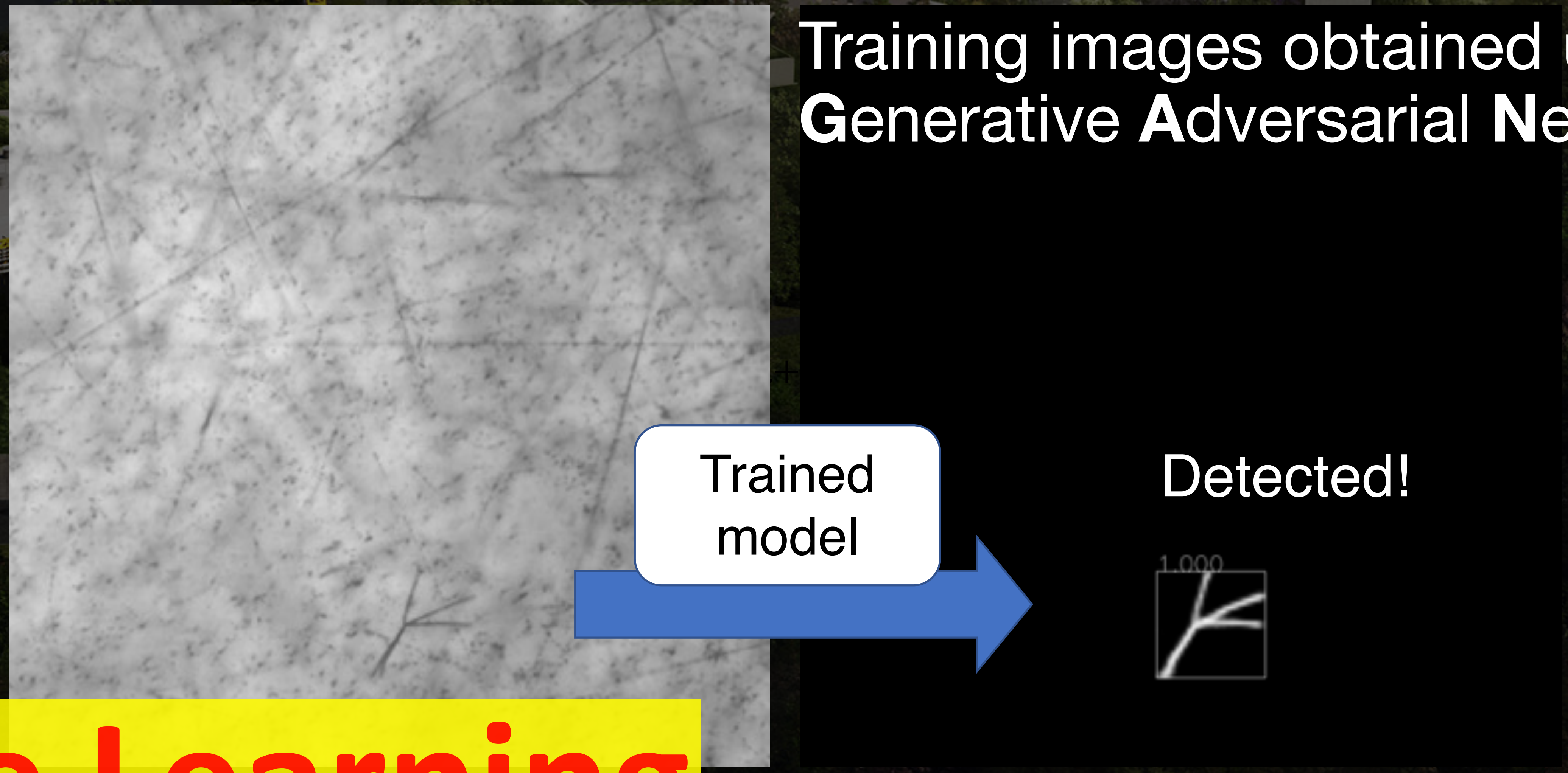

Machine Learning

3 years

TAKE AWAY

Pushing Boundaries:

Femtoscale **Research** with Large-Scale **Tech**

(in accelerator-driven “nuclear” physics)

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TAKE AWAY

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6. Its **academic values** (*e.g.* impact on scientific advances) are yet **underestimated**, but will increasingly be recognised!

Pushing Boundaries:

Femtoscale **Research** with Large-Scale **Tech**
(in accelerator-driven "nuclear" physics)

GNUradio?

1. Well integrated in accelerator/ring activities at GSI/FAIR.
2. What about its usefulness in (large-scale) experiments?
3. Follow-up the recommendation of ChatGPT?
4. Role of ML & AI?
5. Suggestions?