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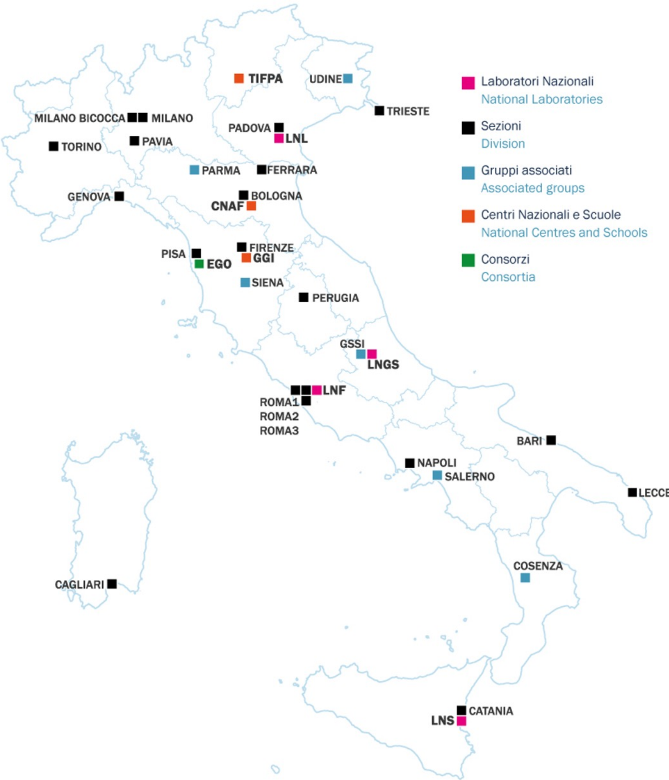
Luca Giommi
Istituto Nazionale di Fisica Nucleare
CNAF

The ML_INFN Initiative

INFN CNAF | ml INFN | INFN CLOUD | ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

INFN Research and structures



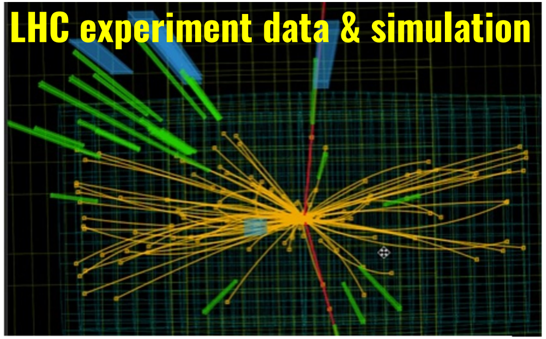
216 activities distributed in 33 structures (labs, groups and divisions)

CSN1	**Particle Physics**	17 experiments
CSN2	**Astroparticle Physics**	45 experiments
CSN3	**Nuclear Physics**	23 experiments
CSN4	**Theoretical Physics**	35 initiatives
CSN5	**Technological Research**	96 experiments

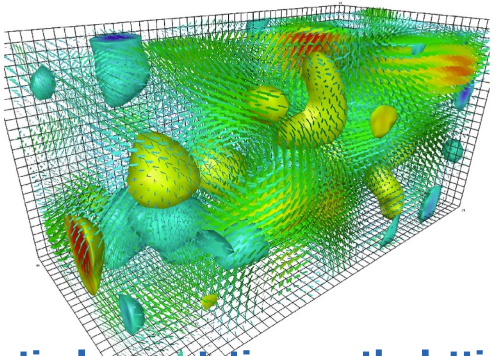
Machine Learning applications in INFN

Most of the experiments and initiatives produce, analyse or process digital data.

Enthusiasm on the modern data processing technologies!

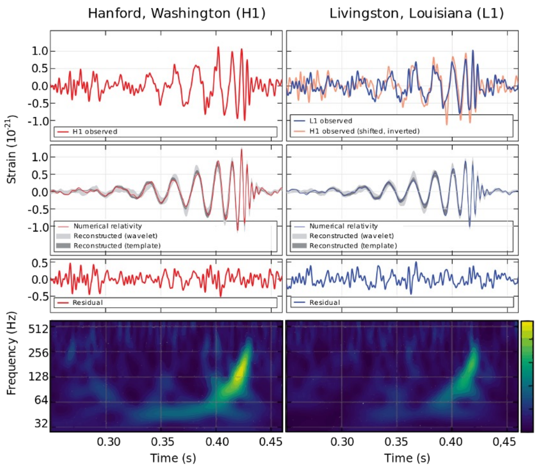


LHC experiment data & simulation

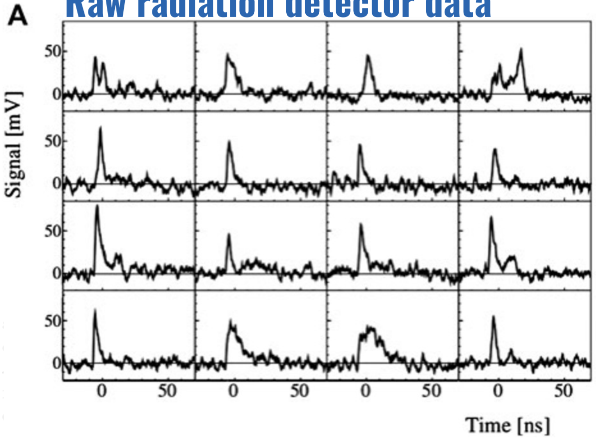


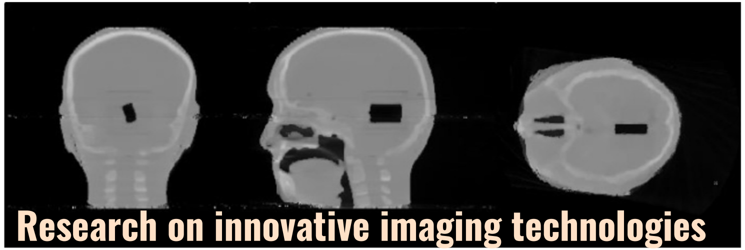
Theoretical computations on the lattice

Gravitational wave detection



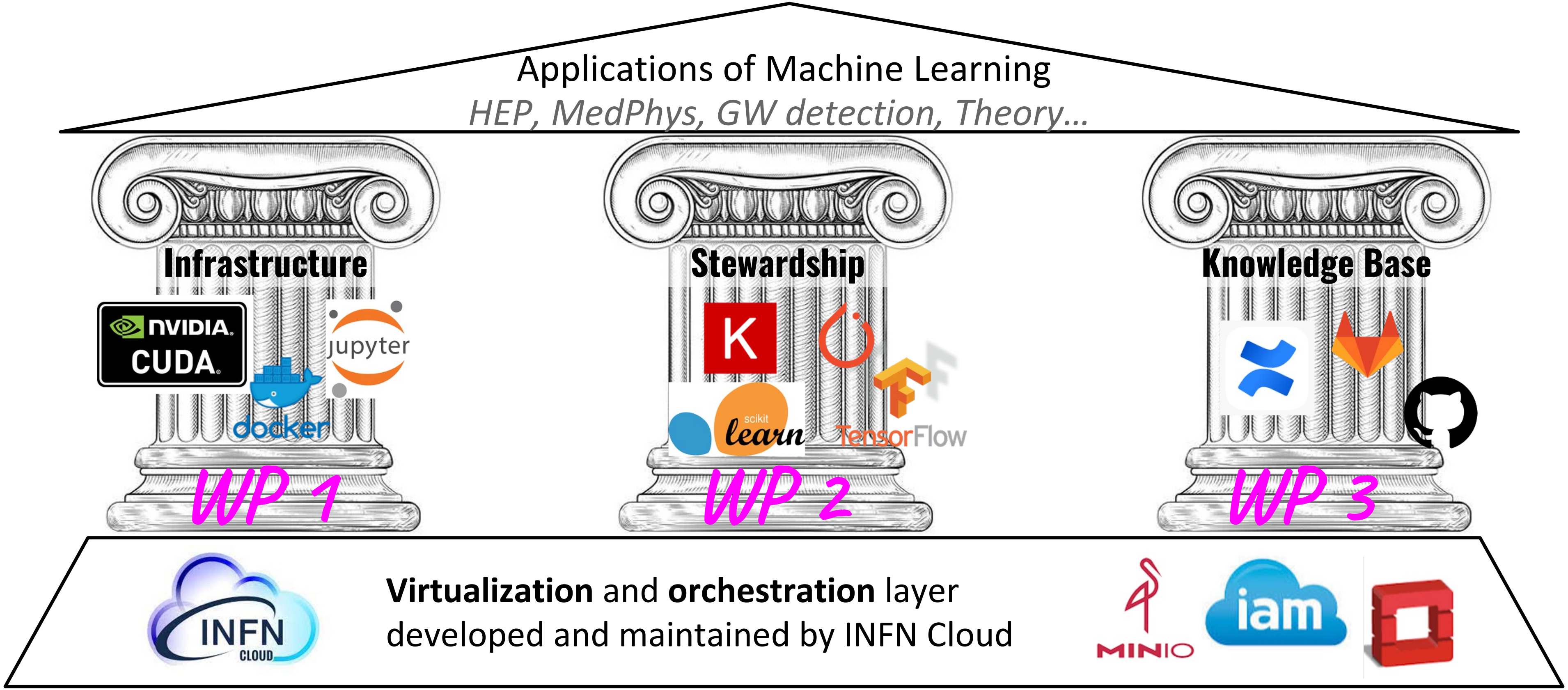
Raw radiation detector data





Research on innovative imaging technologies

ML_INFN: The structure of the project



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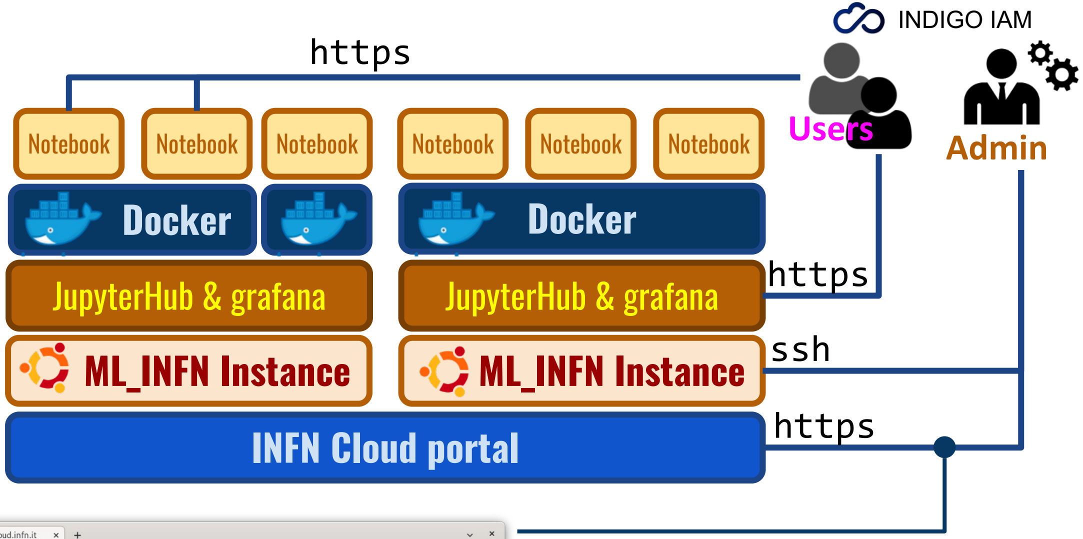
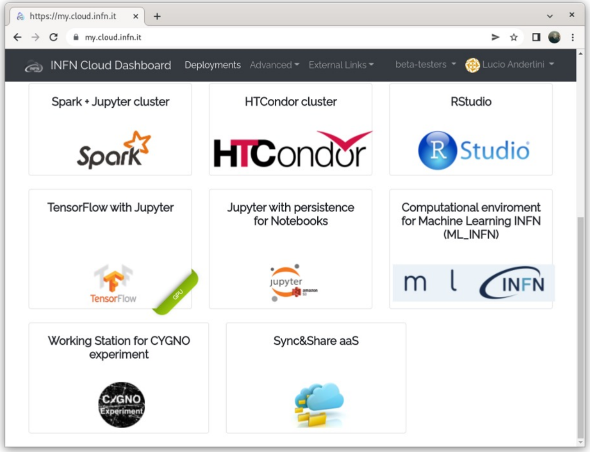
WP1. The infrastructure

INFN Cloud

ML_INFN is built on top of **INFN Cloud**: a data-lake centric, heterogeneous federated Cloud infrastructure spanning over multiple sites across Italy, providing an extensible portfolio of solutions tailored to **multidisciplinary scientific communities**.





See also...

Talks: Fanzago, Marcon, Mazzitelli

Poster: Michelotto, Sinisi

Federated bare-metal resources

1× SuperMicro + 1× E4 servers:

- 1.8 TB RAM
- 64-128 CPU cores
- 36 TB local storage (NVMe)
- 8× **Tesla T4** GPUs
- 5× **RTX 5000** GPUs
- 1× **A30** GPU
- 1× **A100** GPU, served as 7 independent MIG slices
- 10 GbE connection to CNAF resources

Federated to CNAF OpenStack and INFN Cloud

Storage solutions

CERN experiments data, contained in INFN Tier-1 storage, are remotely accessed via NFS

Hypervisors integrate Ceph to manage persistent virtual volumes accessed from the VM via POSIX

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WP2. Stewardship

Machine Learning hackathons: *Base and Advanced level*

To foster the adoption of machine learning tools and techniques in INFN community, we organize events to discuss ML algorithm with the time to look at (and hack) the code.

Starting-level Hackathons

Jun 2021, Dec 2021, Jun 2023

- **online events** with no fee
- up to **60 participants**
- **1 tutor per 5 participants**
- INFN Cloud **CPUs** with shared filesystem

Advanced Hackathons

Nov 2022

- **in-person events**
- up to **30 participants**
- **(almost) 1 tutor per participant**
- INFN Cloud **GPUs** with shared filesystem

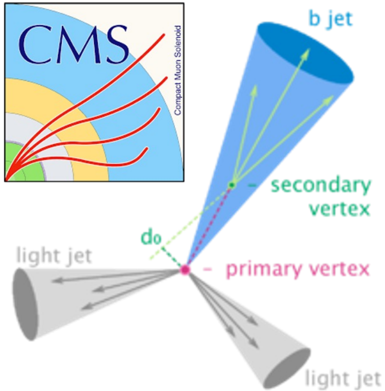
Base hackathon: *Lecture Program*

Day 1	*Day 2*	*Day 3*
Lectures **Theoretical introduction to ML**	Hands-on **Neural Networks**	Hackathon **Exercises with tutors *continuous support***
Lectures **Cloud and Cloud Resources**	Seminars **Deep Neural Network Applications to INFN research**	
Lunch break		
Hands-on **Numpy, Pandas and Keras**	Hands-on **Exercises with tutors *on demand***	Closure **Reports from the students**

Hackathon use cases: *10 groups, one tutor per group*

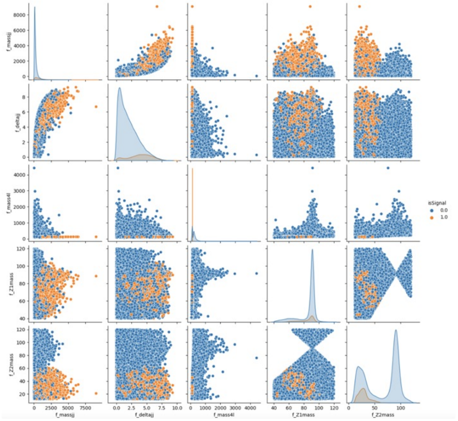
Jet b-tagging at CMS

Recurrent Neural Networks with LSTM



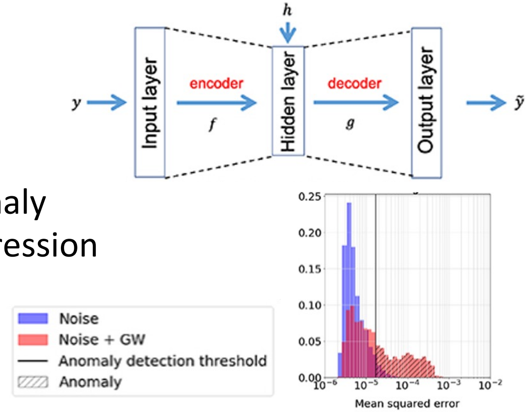
Higgs searches at CMS

Deep Neural Networks and Advanced Keras



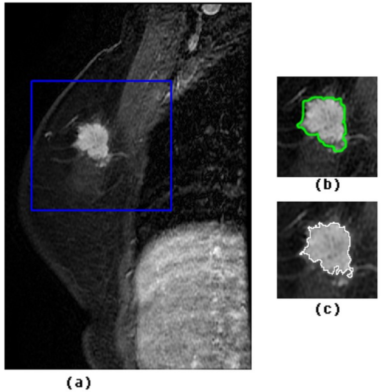
Gravitational Waves with Virgo

Autoencoders, anomaly detection and compression



Segmentation of CT scans

Convolutional Neural Networks
Handling 2D and 3D datasets



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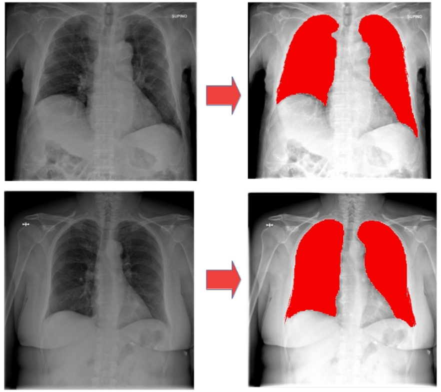
Advanced hackathon: *Lecture Program*

Day 1	Day 2	Day 3	Day 4
	Lectures **Advanced Models** (U-Nets, GANs, NFs, …)	Lectures **Advanced Models** (Transformers, GNNs)	Lectures **Ongoing R&Ds in Machine Learning** (FPGAs, HPO, …)
	Hands-on **Beyond Keras** (Coding lower-level ops)	Lectures **Explainability**	Hands-on **BondMachine** Compiling NN in VHDL
Lunch break			
Lectures **Cloud Infrastructure and High Performance Computing**	Hackathon **Exercises with tutors *continuous support***	Hackathon **Exercises with tutors *continuous support***	

Advanced hackathon use cases

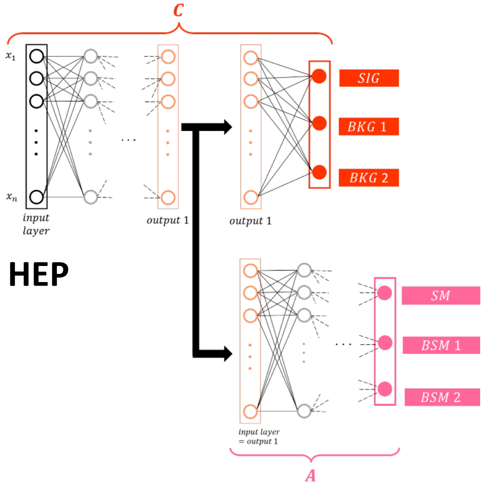
Lung Segmentation with U-Nets

U-Nets, custom loss, custom data loaders

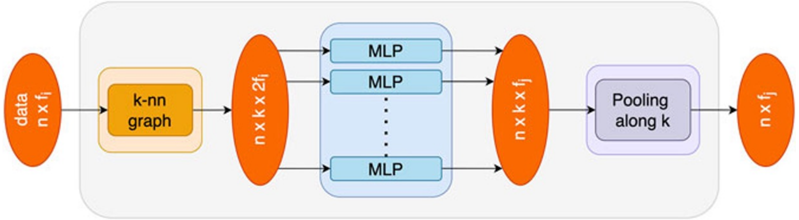


Domain Adaptation in HEP

Adversarial Training, Gradient Tape

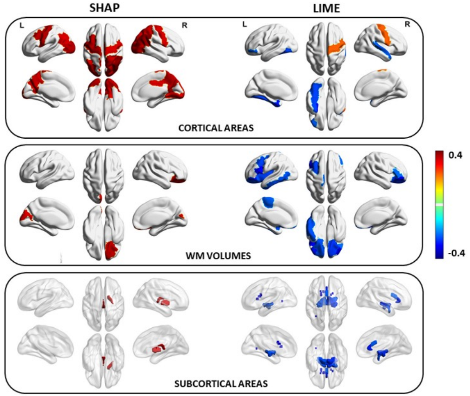


GNN and Transformers in HEP
Application to Jet Tagging



Explainability

Shapley and GradCAM



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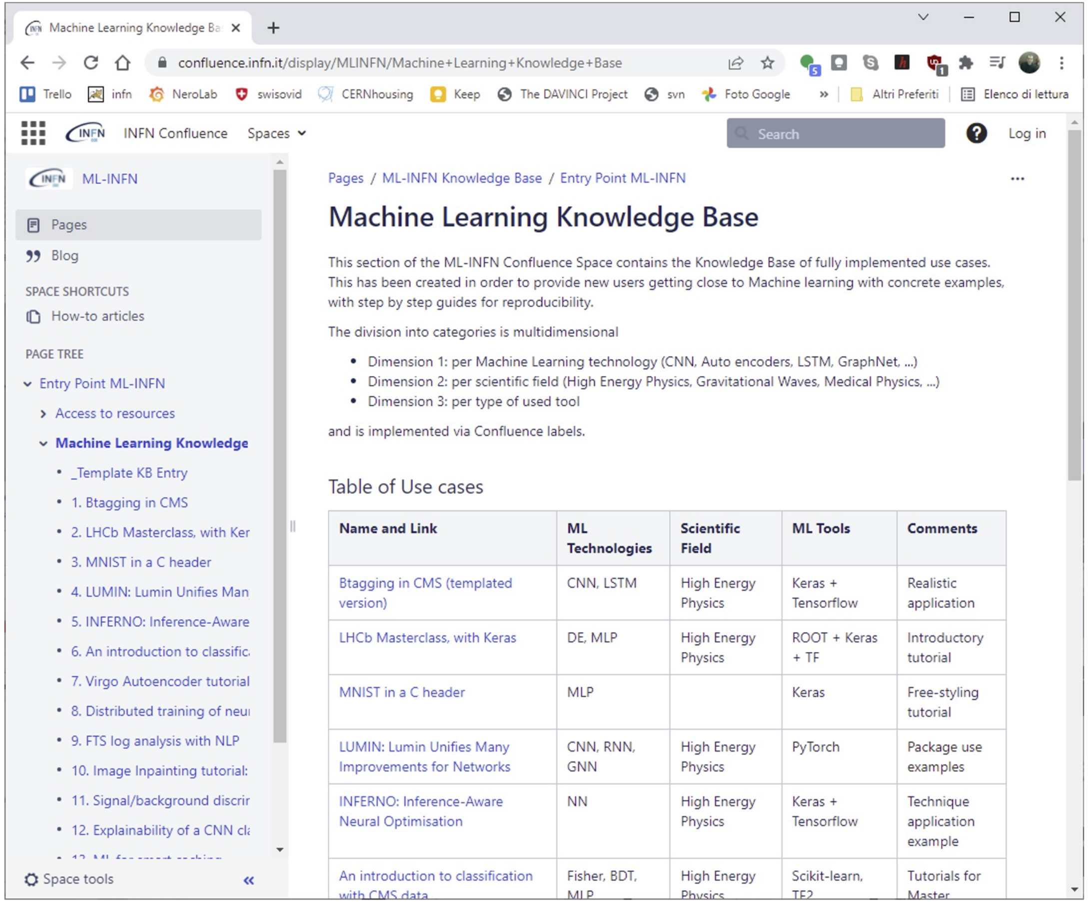
WP3. The Knowledge Base

Confluence Knowledge Base

Atlassian Confluence was used to build a **Knowledge Base** reporting several machine-learning use cases, including those discussed at the hackathon.

Each entry includes:

- Runnable **example** as a jupyter notebook or a git repository
- **Contact information** of one or more experts



Seminars organized in 2023

1) Improving parametric neural networks for high-energy physics (and beyond)
2) Cell counting with cell-ResUnet
3) A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme
4) Deep-learning emulators and hierarchical Bayesian inference: application to gravitational-wave astronomy
5) New Physics Learning Machine (NPLM): a tool for statistical anomalies detection in presence of systematic uncertainties
6) Machine Learning as a Service for High Energy Physics (MLaaS4HEP): a service for ML-based data analyses
7) Ante-hoc explainability methods: the ProtoPNet architecture and its application on DBT images

Publications

Measuring Analytic Gradients of General Quantum Evolution with the Stochastic Parameter Shift Rule **WOS:000613656700001** | **10.22331/q-2021-01-25-386** |	**QUANTUM-AUSTRIA**	2021
The novel Mechanical Ventilator Milano for the COVID-19 pandemic **WOS:000632649400001** | **10.1063/5.0044445** |	**PHYS FLUIDS**	2021
How to enhance quantum generative adversarial learning of noisy information **WOS:000655340700001** | **10.1088/1367-2630/abf798** |	**NEW J PHYS**	2021
Deep learning method for TomoTherapy Hi-Art: prediction three-dimensional dose distribution **WOS:000709667204219** | |	**RADIOTHER ONCOL**	2021
Model compression and simplification pipelines for fast deep neural network inference in FPGAs in HEP **WOS:000714374500003** | **10.1140/epjc/s10052-021-09770-w** |	**EUR PHYS J C**	2021
Generalization in Quantum Machine Learning: A Quantum Information Standpoint **WOS:000718152600001** | **10.1103/PRXQuantum.2.040321** |	**PRX QUANTUM**	2021
Model compression and simplification pipelines for fast deep neural network inference in FPGAs in HEP (vol 81, 969, 2021) **WOS:000726095200001** | **10.1140/epjc/s10052-021-09875-2** |	**EUR PHYS J C**	2021
Calorimetric Measurement of Multi-TeV Muons via Deep Regression **WOS:000749246700002** | **10.1140/epjc/s10052-022-09993-5** |	**EUR PHYS J C**	2022
A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme **WOS:000770368300012** | **10.1088/1748-0221/17/02/P02018** |	**J INSTRUM**	2022
Tau Lepton Identification With Graph Neural Networks at Future Electron-Positron Colliders **WOS:000836356800001** | **10.3389/fphy.2022.909205** |	**FRONT PHYS-LAUSANNE**	2022
Applications of artificial intelligence in stereotactic body radiation therapy **WOS:000837374300001** | **10.1088/1361-6560/ac7e18** |	**PHYS MED BIOL**	2022
Model independent measurements of standard model cross sections with domain adaptation **WOS:000869847800002** | **10.1140/epjc/s10052-022-10871-3** |	**EUR PHYS J C**	2022
Robust quantum classifiers via NISQ adversarial learning **WOS:000890324500009** | **10.1038/s43588-022-00359-1** |	**NAT COMPUT SCI**	2022
Toward artificial-intelligence assisted design of experiments **WOS:000908434600001** | **10.1016/j.nima.2022.167873** |	**NUCL INSTRUM METH A**	2023
Hyperparameter Optimisation of Artificial Intelligence for Digital REStoration of Cultural Heritages (AIRES-CH) Models **WOS:000916462800007** | **10.1007/978-3-031-10536-4_7** |	**LECT NOTES COMPUT SC**	2022

Summary

The ML_INFN initiative has been providing many INFN experiments with the hardware and the knowledge base to assess the potential **benefit of machine learning to their research** for three years.

The **ML_INFN** project relies on **INFN Cloud** solutions and it federates resources optimized for ML performance in interactive and batch-like usage patterns (high-end professional GPUs, NVMe disks, many-core high-RAM systems)

A series of national training events (***machine learning hackathons***) and a collection of tutorials and real applications within the INFN community (***knowledge base***) contribute to building **a network of experienced and enthusiast machine learning practitioners**, lowering the skill gap to benefit from machine learning developments.

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Thanks for the attention
Questions?

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Backup

The numbers of ML_INFN

12 INFN **structures** involved in the developments, training activities and hackathons

79 **researchers** devoting a fraction of their time to promote ML techniques for research

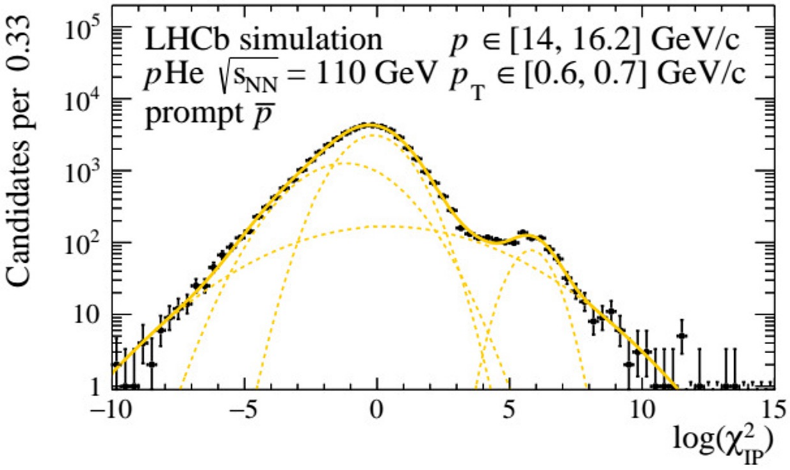
14 professional **GPUs** made available and accessible through the INFN Cloud Interface

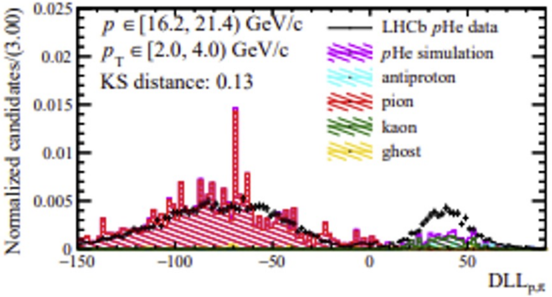
143 **participants** to the **hackathons**, ranging from students to permanent staff members

Stories of success [1]: *building template models for LHCb*

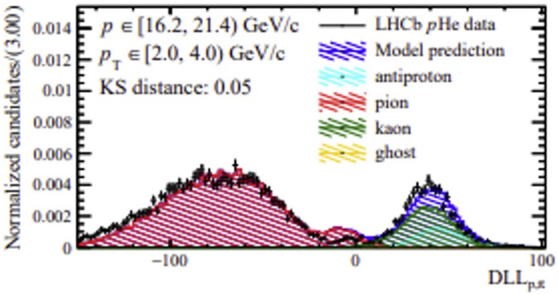
ML_INFN infrastructure was used to develop a model for the Particle Identification response of the LHCb detector as a Gaussian-Mixture model.

With Gaussian parameters inferred with a Deep Neural Network.





Traditional method based on reweighted MC



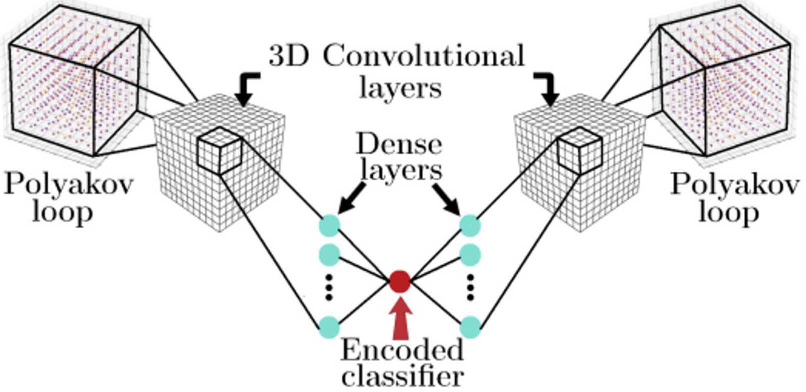
Deep Learning model

S. Mariani *et al*, *"A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme"*, JINST 17 (2022) P02018

Public repository **PID4SMOG**

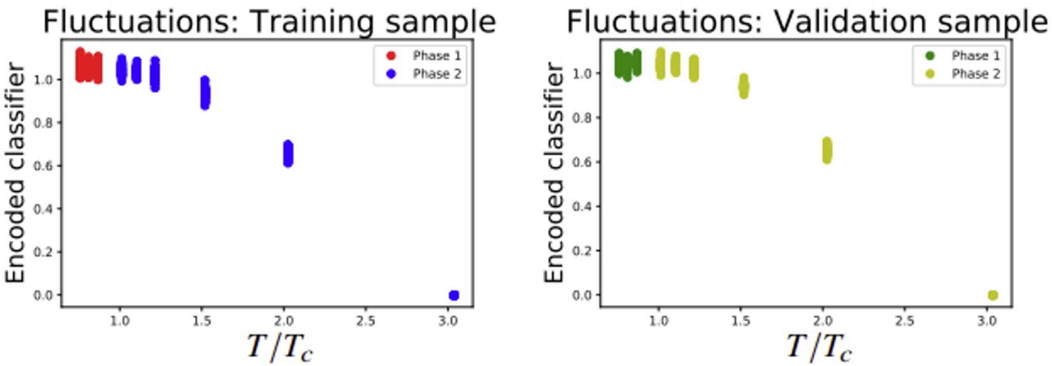
Stories of success [2]: *studying LQCD with CNNs*

A Deep Neural Network is trained in a semi-supervised manner to define an effective order-parameter for Gauge theory where a real order-parameter is not defined.



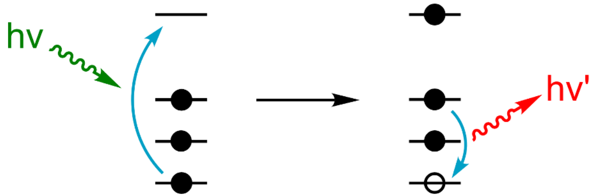
The study was made possible thanks to the GPUs provided by the ML_INFN initiative.

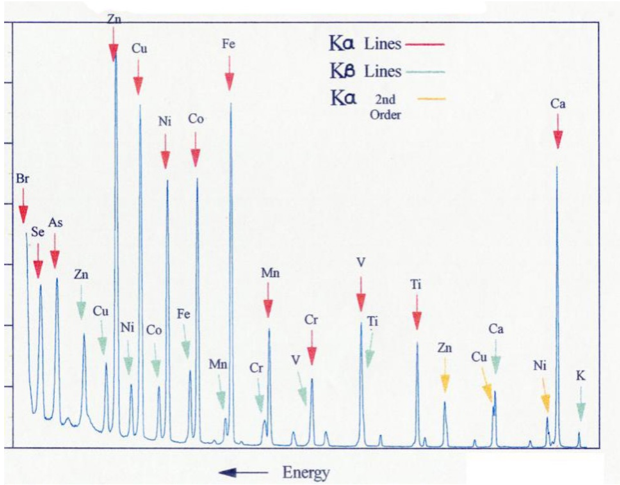
A. Palermo, M.P. Lombardo *et al.*
"Machine learning approaches to the QCD transition", Proceeding of LATTICE21



Stories of success [3]: *X-rays to visible colors for CH*

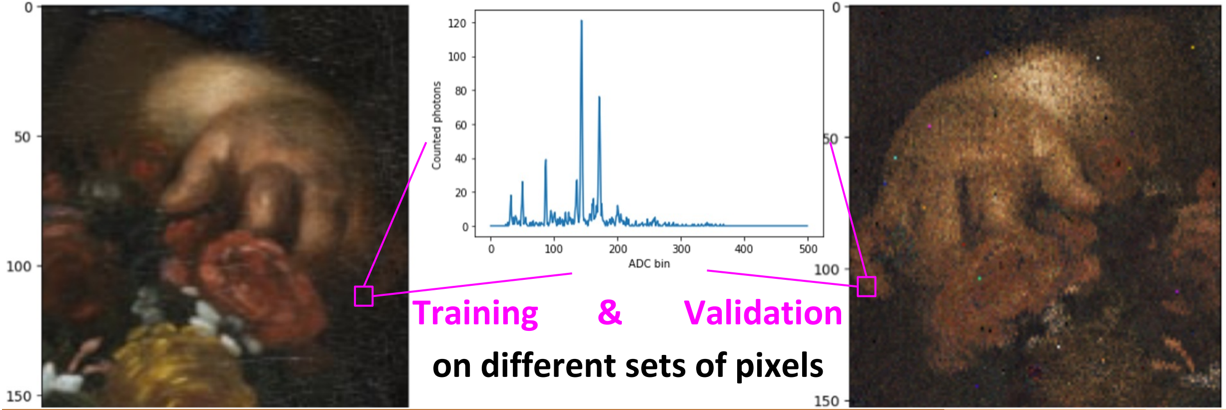
X-ray fluorescence spectroscopy widely used for Heritage Conservation and non-invasive probe of pictorial artworks.





INFN CHNet
Istituto Nazionale di Fisica Nucleare
Cultural Heritage Network

EOSC-Pillar
Coordination and Harmonisation of National &Thematic Initiatives to support EOSC



Deep Neural Network models are trained to reconstruct the image from the XRF scan of the pixels.

Public repository
Hackathon tutorial