EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

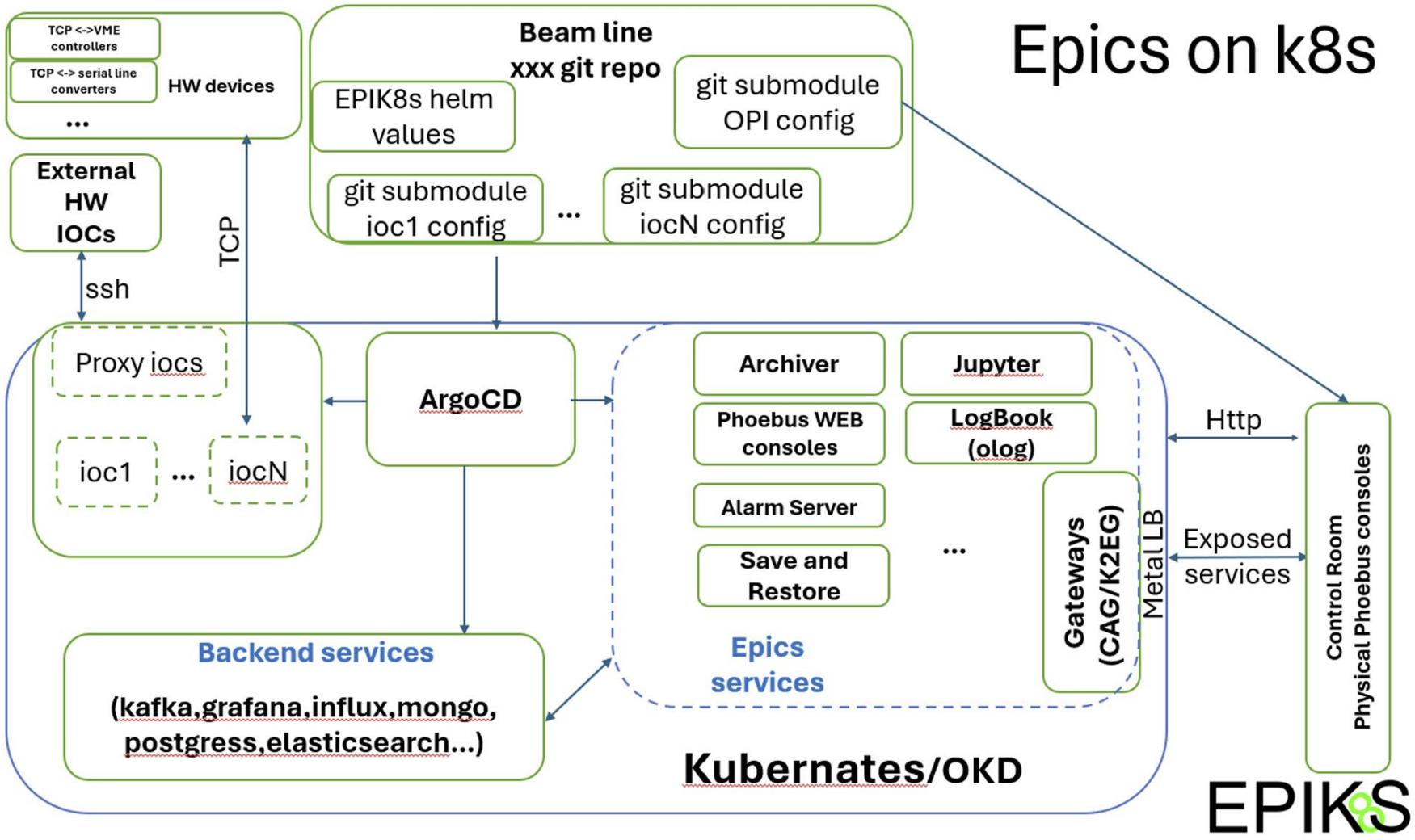
EuPRAXIA

Control system and Functional Safety

Stefano Pioli on behalf of INFN-LNF Control System Group

Funded by the
European Union

LNF EPICS on Kubernates migration



- SPARC
- FLAME
- TEX
- ELI/SSRIP
- LINAC/BTF

Courtesy of A. Michelotti

Control system integration status

RF
ScandiNova modulators
LiberaLLRF systems
Klystron-Loop feedback
Phase Shifter

Timing
MRF distributed system

TDR Technical readiness 90%

Vacuum
Ion pumps
Getter pumps
Scroll pumps
Turbo pumps
Vacuum valves

Cooling
Chillers
Cooling-plant
Thermo couple

Laser
Transfer line cameras
Mirror motors
Shutters

Functional safety
Personnel Safety
Machine Protection
Intra-pulse interlocks
Beam Loss Monitors

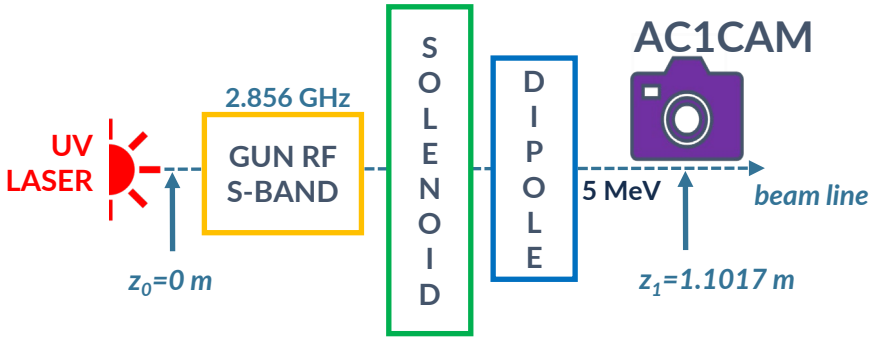
Magnet
Power supplies

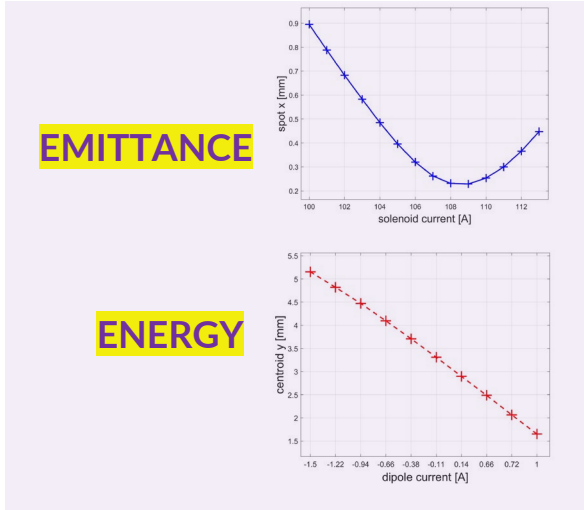
Diagnostics
Cameras
Flag Motors
Flag bulbs
Current Monitor
Faraday cups
BPMs
Cavity BPMs

Virtual Diagnostics

Funded by the European Union

The neural networks designed are aimed at **predicting ASTRA simulation (Digital Twin) of the SPARC particle beam spot size** on AC1CAM and then to perform virtual emittance and energy measurements.





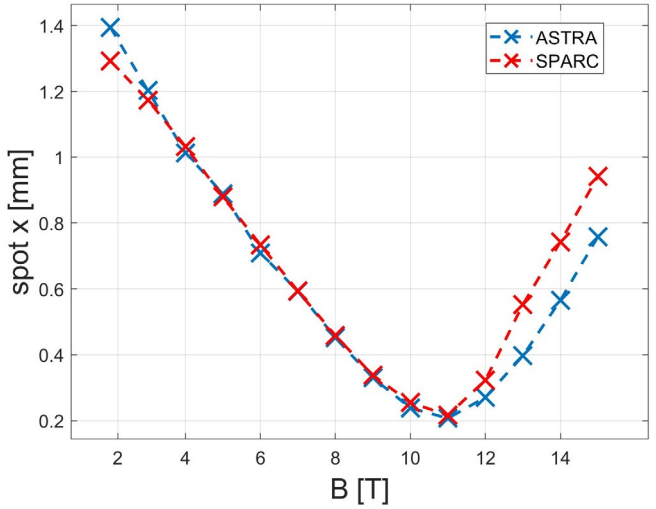
NEURAL NETWORK → VIRTUAL MEASUREMENTS

Funded by the European Union

DATASET COSTRUCTION

The training dataset consists of **ASTRA simulations:** one simulation contents 10000 samples, which they represent the position of 10000 particles on the AC1CAM, changing the following six machine parameters. To evaluate the **ASTRA** reliability, the simulator is **aligned with SPARC accelerator** using emittance measurements.

Parameter
laser pulse [ps]
laser spot [mm]
charge q [pC]
accelerating field [MV/m]
solenoid field [T]
dipole current [A]

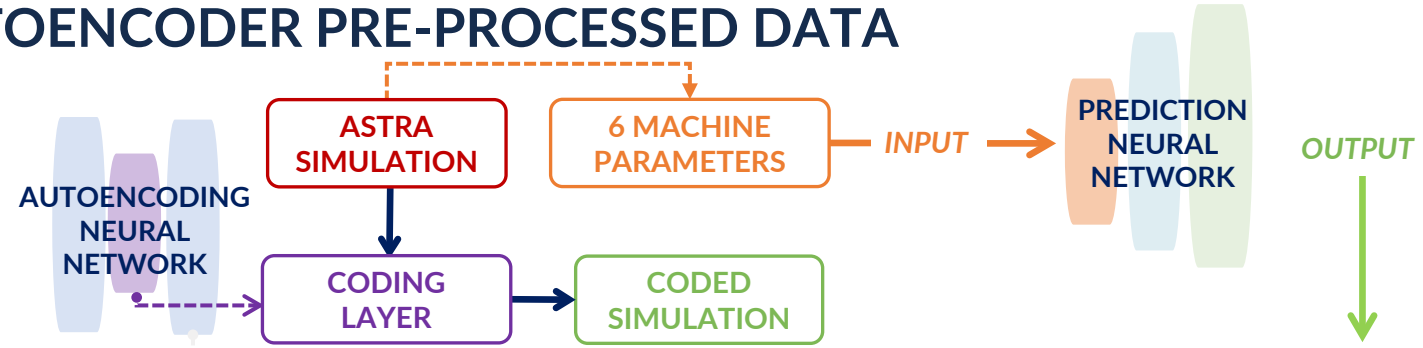


The simulations are pre-processed using an **autoencoding neural network** and **PCA** techniques to reduce the dimensionality of the training dataset.

Virtual Diagnostics

Funded by the European Union

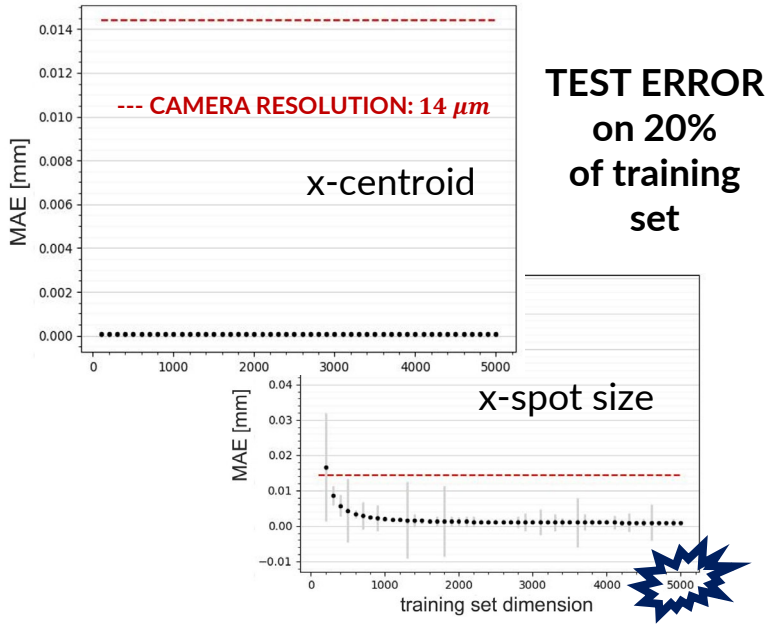
AUTOENCODER PRE-PROCESSED DATA



ERROR METRIC: MAE

$$\sigma_{MAE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(MAE - \overline{MAE})^2} < 14\ \mu m$$

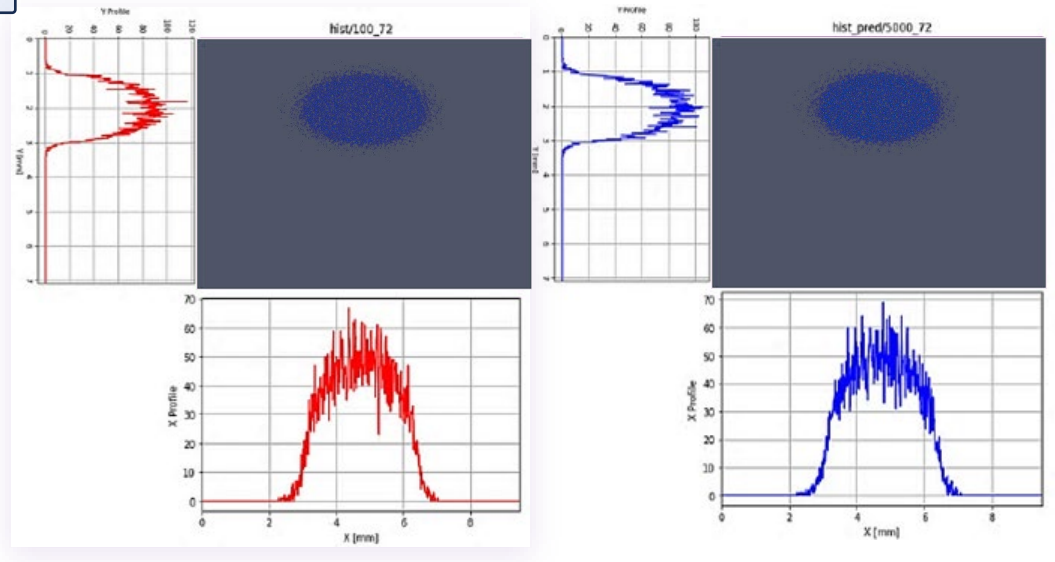
Error below camera resolution



TEST ERROR on 20% of training set

SIMULATION

PREDICTION



Few samples are necessary to train model

Virtual Diagnostics

EMITTANCE - ENERGY MEASUREMENTS

Paper: «Design of Machine Learning-Based Algorithms for Virtualized Diagnostic on SPARC_LAB Accelerator" – G. Latini et al. - *Photonics* 2024, *11*(6), 516;

$\Delta x\ [\mu m]^*$

AUTOENCODER	PCA
0.7	1.6

CAMERA RESOLUTION: 14 μm

**ref. minimum beam waist*

PREDICTED SPOT

$CF_d = 0.00072475$ [T/A]

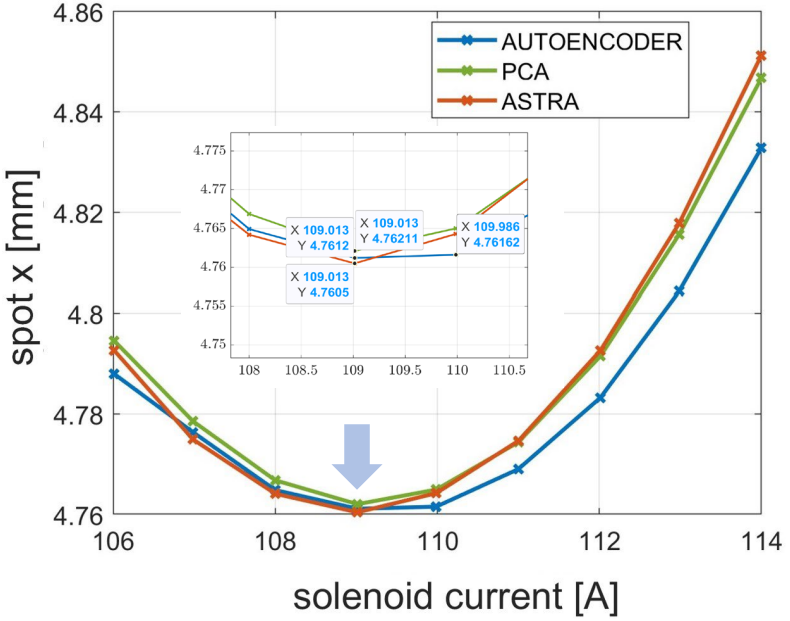
$CF_s = 0.00246667$ [T/A]

m^*

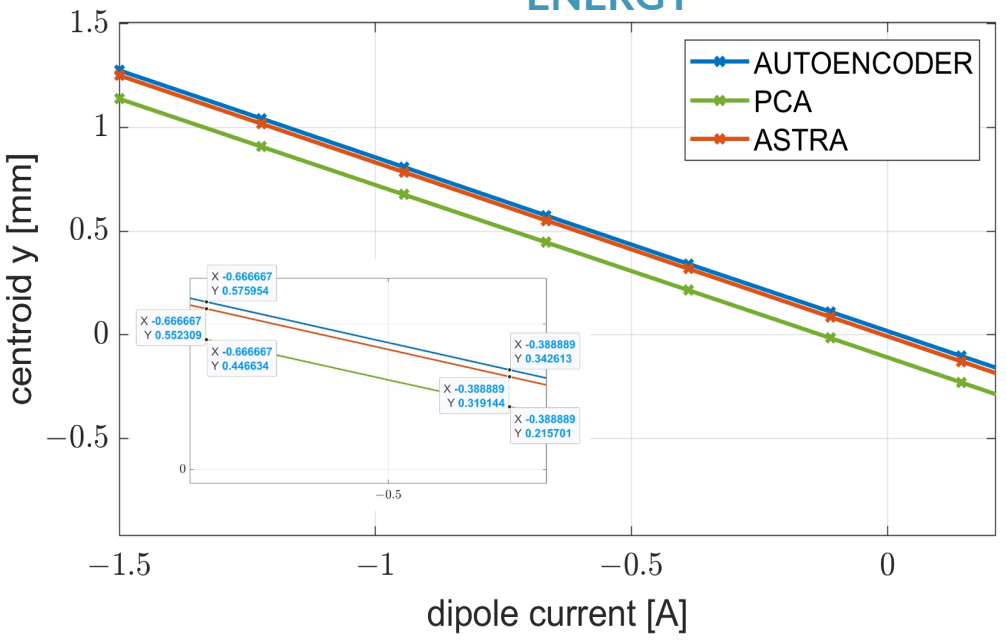
$(m_{ASTRA} = -0.8214)$

AUTOENCODER	PCA
-0.8214	-0.8214

EMITTANCE



ENERGY



Machine Protection

FPGA distributed system

Hardwired interlock:

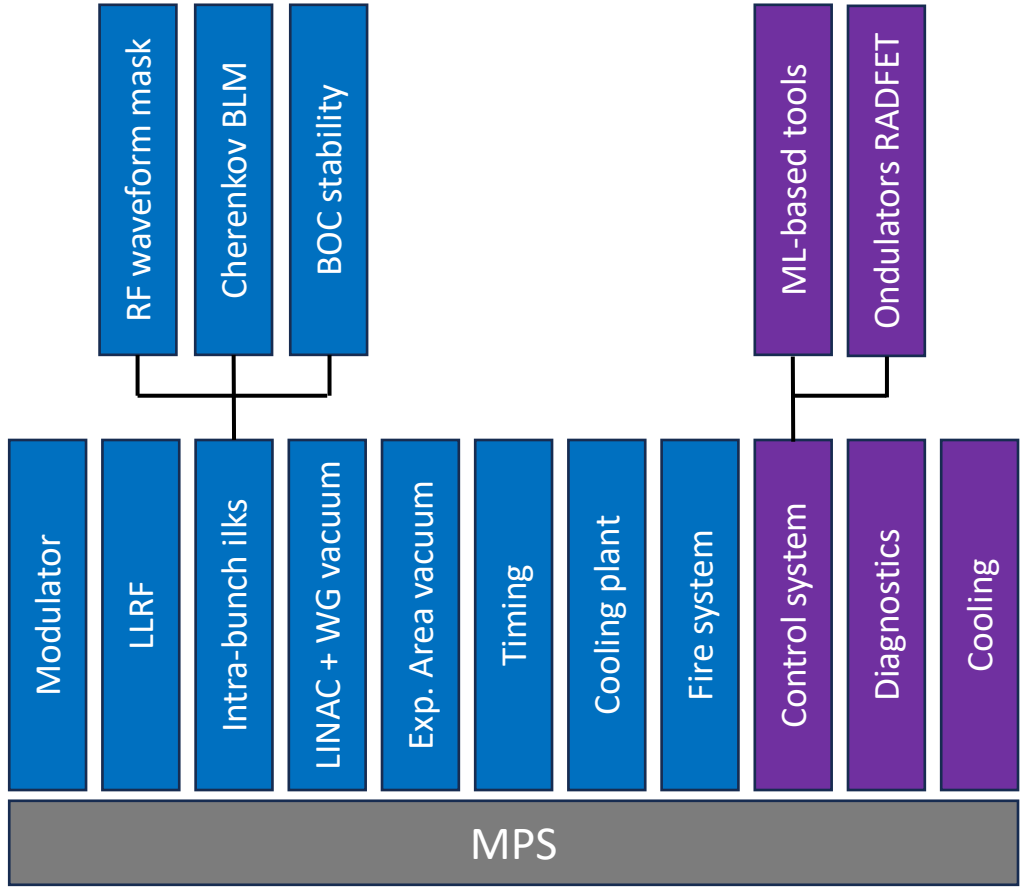
- RF Modulators
- LLRF systems
- Intra-bunch feedback:
  - RF waveform mask
  - Cherenkov Beam Loss Monitors
  - BOC temperature stability
- LINAC + waveguide vacuum system
- Vacuum Regions Valve
- Experimental area pre-vacuum system
- Timing system
- Cooling Plant
- Fire system

Tested @400Hz

EPICS IOC

Software interlock:

- ML-based vacuum anomaly detection
- ML-based RF breakdown forecasting
- EPICS IOCs heartbeat
- Temperature probes
- Toroids-based Beam Loss Monitors
- Ondulator area dose monitoring (RADFET)



Safety life-cycle assessment based on statistical methods allow the estimation of the mean time between failure (MTBF), system reliability and availability and compliance with:

- IEC-61508 standard on “Functional Safety”

Personnel Safety

Funded by the European Union

System capabilities:

- FPGA SIL-2 safety level
- Real-Time intervention up to 10kHz
- Dual Modular Redundancy
- Scalable and distributed design
- Fail-safe and fool-proof design

- Interface with:
  - Search/emergency buttons
  - Gates
  - IR light gates (under test @TEX)
  - Lamp signaling
  - Ionization chambers

Functional Safety
TDR Technical readiness 90%

IR gates @TEX

Safety life-cycle assessment based on statistical methods allow the estimation of the mean time between failure (MTBF), system reliability and availability and compliance with:

- IEC-61508 standard on “Functional Safety”
- NCRP reports 88 on “Radiation Alarms and Access Control Systems”
- ANSI reports 43.1 on “Radiation Safety for the Design and Operation of Particle Accelerator”

(Wo)Men Power

Funded by the European Union

In last year Control System group finally increased men power from 3 to 5 FTEs!

New resources from PNRR projects to be involved for EuPRAXIA control system and functional safety development.

Giulia currently involved in **Rome Technopole**

Main tasks:

- Machine Learning tools
- Functional safety FPGA-based systems for hardwired interlocks
- Intra-pulse feedback integration

Valentina currently involved in **EuAPS**

Main tasks:

- EPICS device integration
- CSS-Phoebus Engineered and User Interfaces development

EuPRAXIA-PP Consortium

Coordinator

INFN
Istituto Nazionale di Fisica Nucleare

Consiglio Nazionale delle Ricerche

Elettra Sincrotrone Trieste

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

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Università di Roma

Università di Roma
Tor Vergata

Imperial College London

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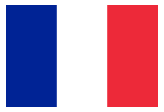
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

JÜLICH Forschungszentrum

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN



Amplitude

cea

cnrs

THALES

eli

IFT TÉCNICO LISBOA

ALBA

CLPU CENTRO DE LÁSERES PULSADOS

Empa
Materials Science and Technology

EPFL

PAUL SCHERRER INSTITUT PSI

THE HEBREW UNIVERSITY OF JERUSALEM

IASA

PÉCSI TUDOMÁNYEGYETEM
UNIVERSITY OF PÉCS

SZTE
UNIVERSITY OF SZEGED

WIGNER

THE UNIVERSITY OF CALIFORNIA UCLA

Acknowledgements

- EuPRAXIA Preparatory Phase

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101079773. It is supported by in-kind contributions by its partners and by additional funding from UK and Switzerland.

- EuPRAXIA Doctoral Network

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement no. 101073480 and the UKRI guarantee funds.

- EuAPS

This publication has been made with the co-funding of European Union Next Generation EU.