M4CAST

an emerging national collaborative effort for IA applications to accelerators physics and technologies

by Adnan GHRIBI *on behalf of the M4CAST collaboration* (IRFU/GANIL)

on 2023, April 11th

Journée Modélisation LWFA du GdR APPEL

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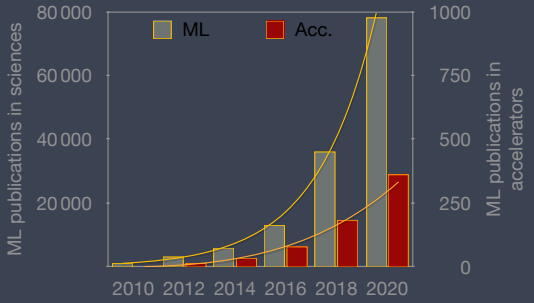
* Artificial Intelligence has penetrated almost all scientific disciplines ;
* For accelerator physics, an important dynamic has risen in the US ;
  Opportunities in Machine Learning for Particle Accelerators, A. Edelen et al.
* Others are slowly merging in France and in Europe ;
* Data and calculation infrastructures also follow a fast development pace.



Number of published ML articles in sciences and for accelerators - ArXiv + Google Scholar.

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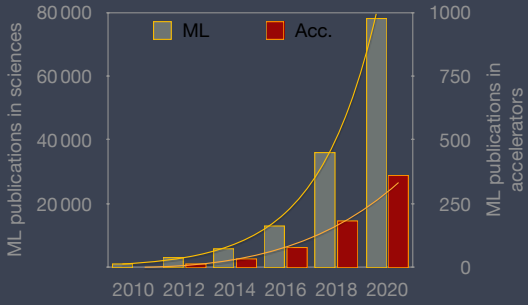

Number of published ML articles in sciences and for accelerators - ArXiv + Google Scholar.

⇒ However, we lack synergy and organisation to foster these new developments.

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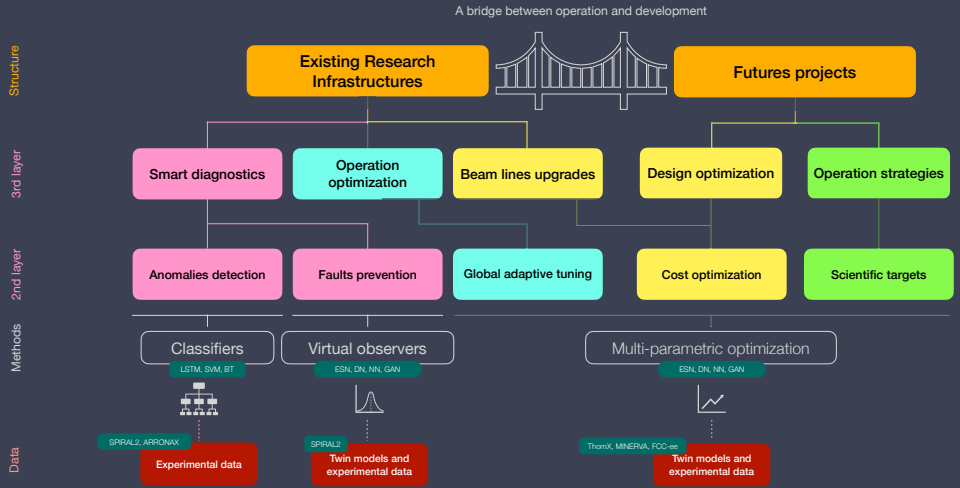
Bridging isolated islands



» Purpose, ways and methods

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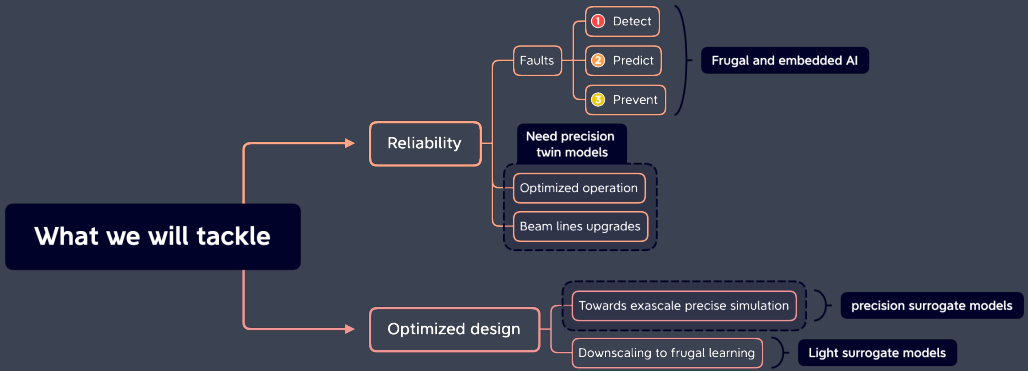

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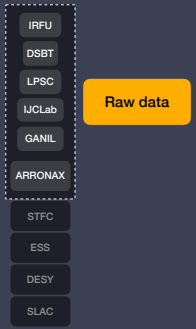

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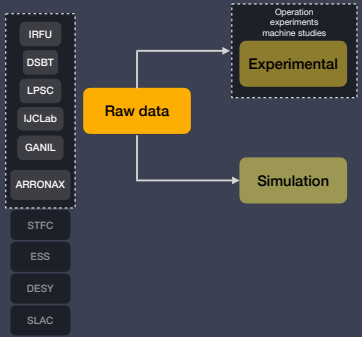

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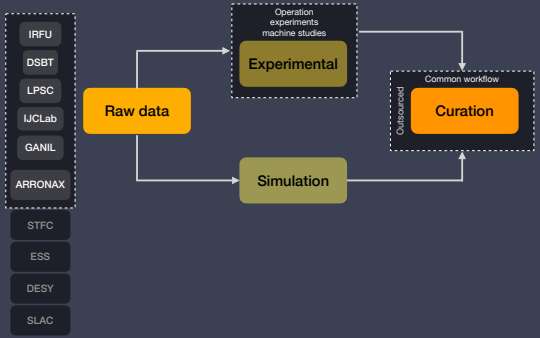

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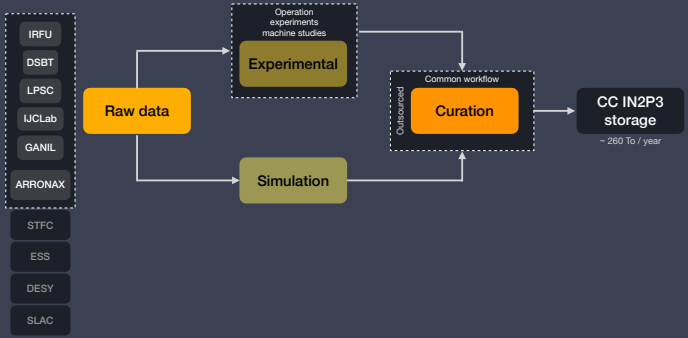

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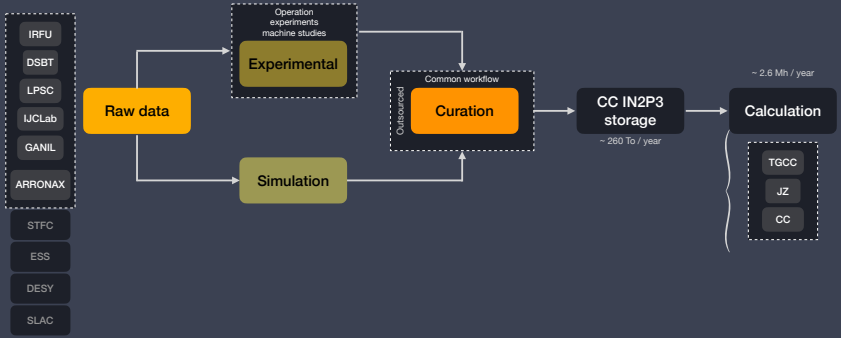

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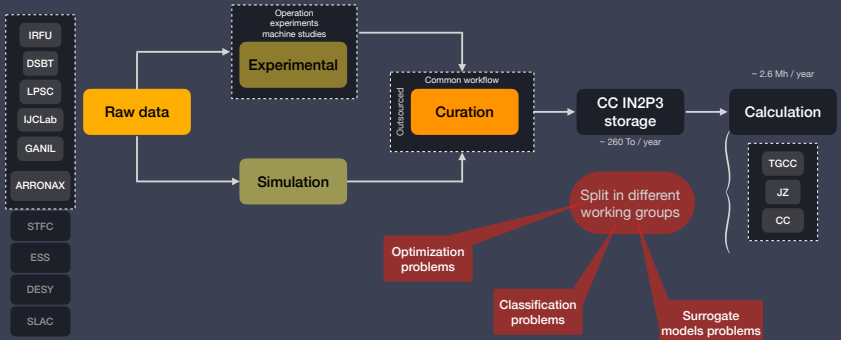

» Purpose, ways and methods

Applicability

- Applicable methods to different accelerator technologies :
  - High power LINACs (ex. ADS) ;
  - Cyclotrons/Synchrotrons ;
  - Laser wakefield acceleration (LWFA).
- For different particle acceleration (protons, heavy ions, electrons) ;
- Crossing the barrier between Operation and Design.

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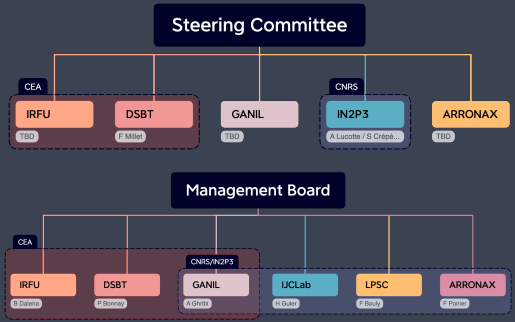
National

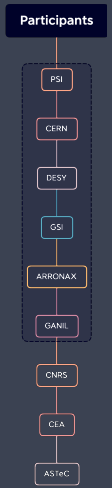
Framework agreement, including appendices :

* Structure (Steering committee and management board) ;
* Scientific program ;
* Data and software policy (including FAIRness) ;
* Ethical charter.



» Organization

Organizing a European synergy



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- Support for EU projects (one project engineer + 10 k€for expanses)
- Crossing students studies through methods ;
  ⇒ 3 PhDs and 3 internships ongoing ;
  ⇒ 2 PhDs planned for next year.

» Resources

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* Outsource the first layer curation workflow with a shared/common output (meta)data structure ;
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* One data contact person / institute ; Asking ⇒ Involved partners.

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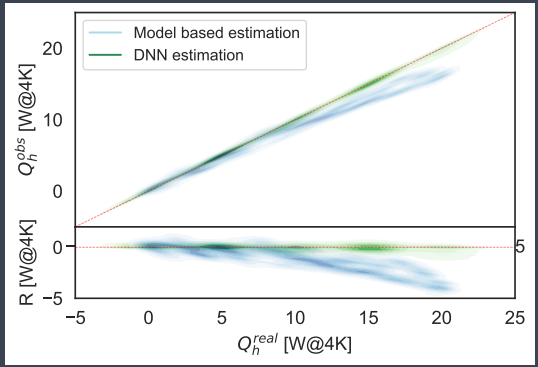
GANIL

Anomaly detection and virtual observers

Metrics	SVM	LSTM
Accuracy	0.98	0.93
Precision	0.97	0.88
Recall	0.99	0.98
F_1 score	0.98	0.93

Performance index comparison between SVM [1] and LSTM [2] for valves anomaly detection with models generated data [Vassal et al. Frontiers (2022)].



Density destribution of predictors and residuals for model based and DNN based observers.[Ghribi et al. (2022)]

. [1] Support Vector Machines
. [2] Long Short Term Memory Networks

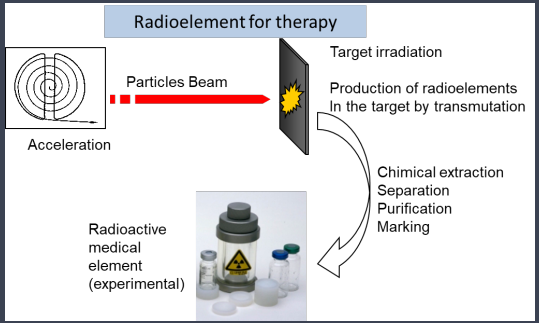
» Ongoing Work

ARRONAX

Data mining and anomaly detection/classification

Detection of outliers for radio-isotope production

* Regular and stable production over several days ;



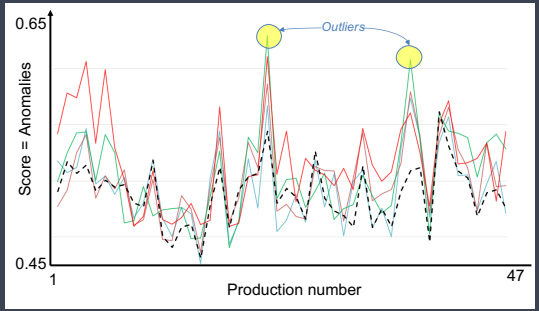
» Ongoing Work

ARRONAX

Data mining and anomaly detection/classification

Detection of outliers for radio-isotope production

- Regular and stable production over several days ;
- Exploring several approaches for clustering (DBSCAN, Isolation Forest) and detection robustness ;
- identification and classification of outliers.



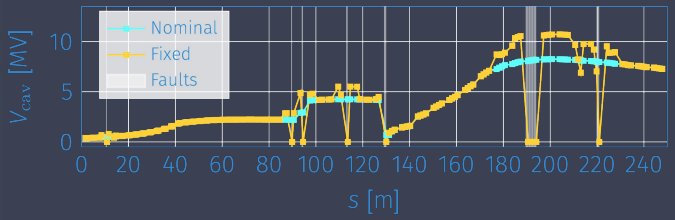
Isolation Forest anomaly detection for different variables dimension reduction (Credit : F. Poirier).

» Ongoing Work

LPSC

Multi-objective optimisation for fault compensation

- LightWin : a tool to find compensation settings for RF cavity failures in LINACs
- multi-objective optimisation problem :
  - at least 8 variables : amplitude and phase of compensating cavities ;
  - at least 6 objectives : ΔW_{kin}, $\Delta\phi$, beam parameters,
- currently using least-squares (not adapted, looking into genetic algorithm, PSO and ML techniques . . .)



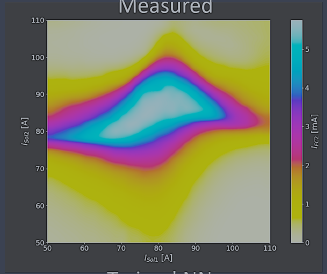
MYRRHA LINAC, 10 faults distributed along the accelerator (Credit : A. Plaçais ; F. Bouly)

» Ongoing work

PhD - Model of a LINAC injector with ANN

LPSC

- RNN Model LEBT (+RFQ)
  - 3 hidden layers with 64 neurones
- Training w. measured ($\sim 10^4$) and simulated (beam dynamic code) data
- (Predictor not fully terminated)
- Also studied : on-line tuning of A LEBT : PSO algorithm "plugged" on the control system



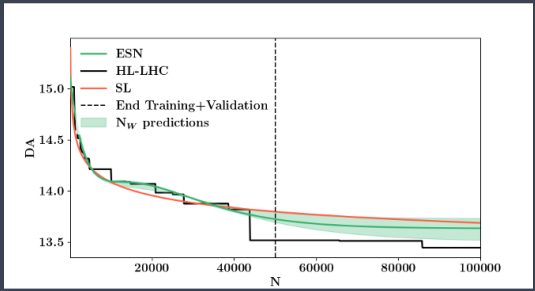
Transmission Map in the MYRRHA LEBT.[M. Debongnie, Phd Thesis (2021).]

» Ongoing Work

IRFU

Dynamic Aperture prediction with Echo State Networks

* Reservoir of Neurons for Dynamic Aperture prediction
* Applications to HL-LHC and FCC-ee
* Planned PhD



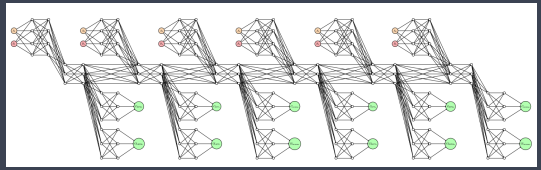
Dynamic aperture estimation with echo state networks (Credit : B. Dalena)

» Ongoing Work

Surrogate models

IJClab

* Physics constrained neuro-morphic type design
* Allows to make precise fast simulations of a LINAC
* ThomX and other industry applications
* Ongoing PhD thesis



LINAC net model for ThomX (Credit : E. Goutière, Hayg Guler)

» Ongoing Work

Other ...

IRFU, DESY, GSI, La Sapienza

* Improving current simulation tools
  * GPU acceleration
  * Multi-parametric scans
* Optimized design of future accelerators
  * Robustness to imprefections
  * Crossing multiple projects FCC-ee, Petra IV, ...

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- M4CAST : an emerging collaborative effort around IA for accelerators concentrating on data/methods sharing ;
- Integrates within a new European dynamic around IA for accelerators ;
- Bridges existing and future projects as well as reliability and optimization, R&D and operation, ... ;
- Data curation and calculation resources is an issue we need to overcome.

Questions ?

Thank you !