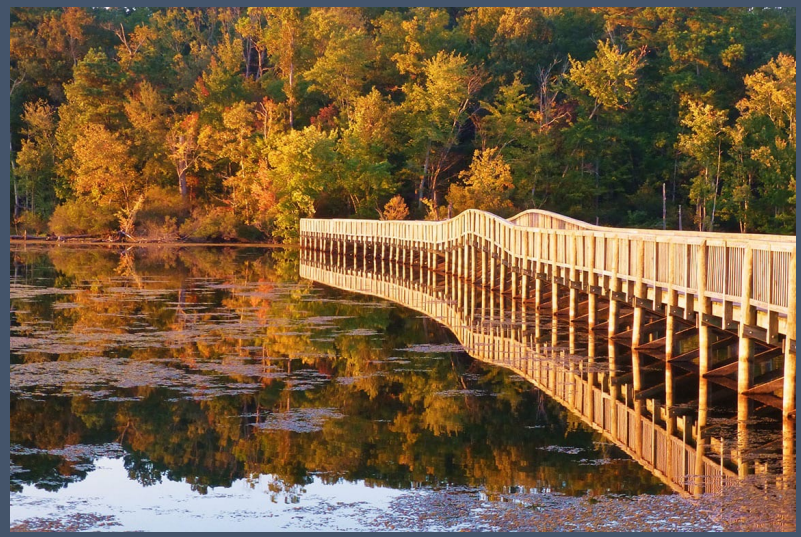
ARW 2022 Overview

Laurent S. Nadolski



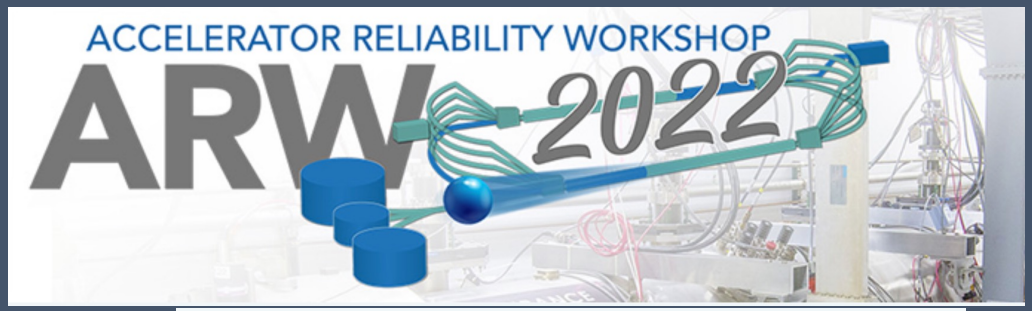
Accelerator Reliability Workshop History

2002	2009	2011	2013	2015	2017	2019	2022
ESRF Grenoble	TRIUMF Vancouver	iThemba Cape Town	Australian Synchrotron	ORNL, SNS Knoxville	SOLEIL Paris	IHEP Guangzhou	JLAB Newport News

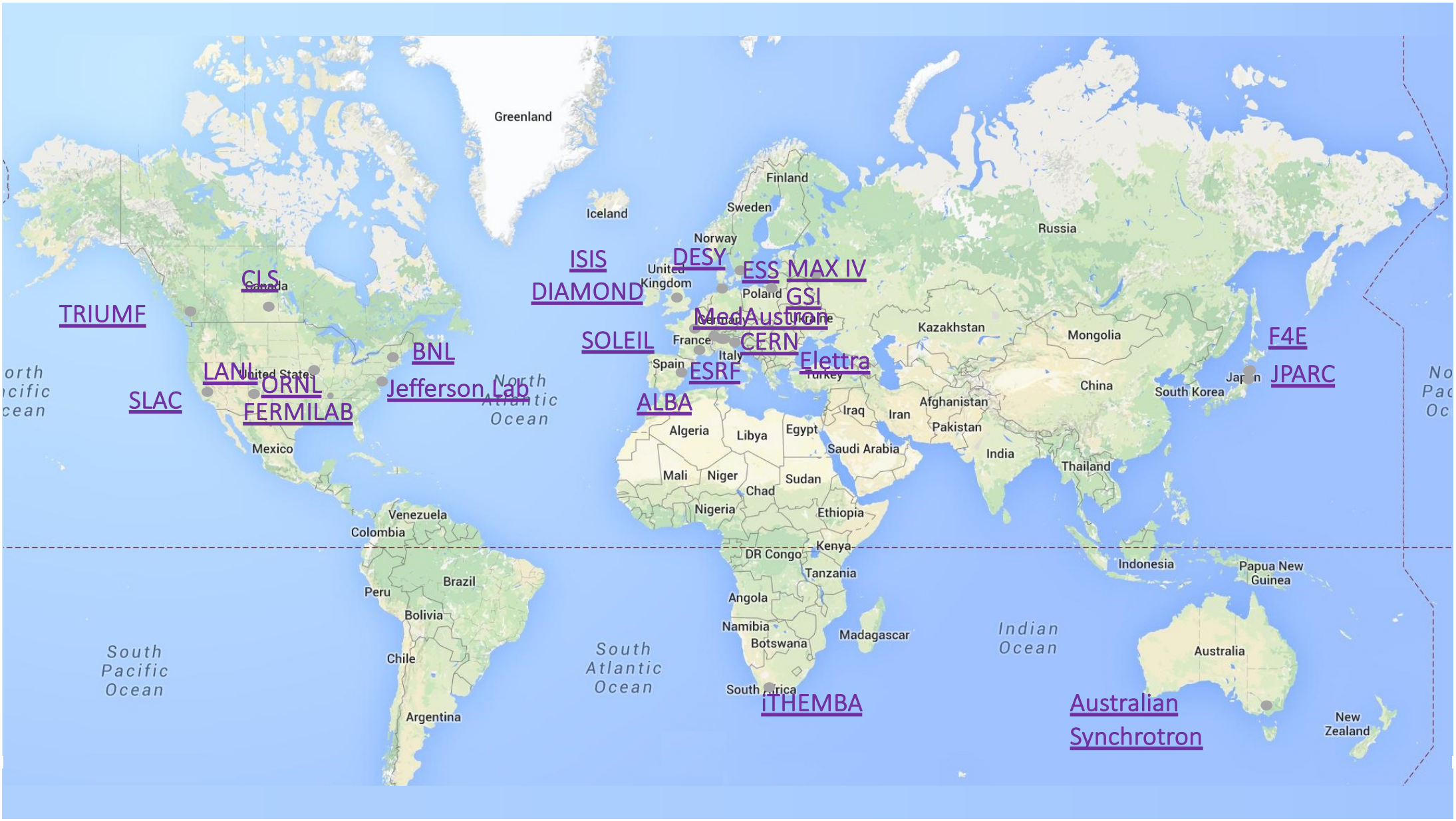
20th Anniversary ARW

112 participants, after Covid – Very good response from the community!

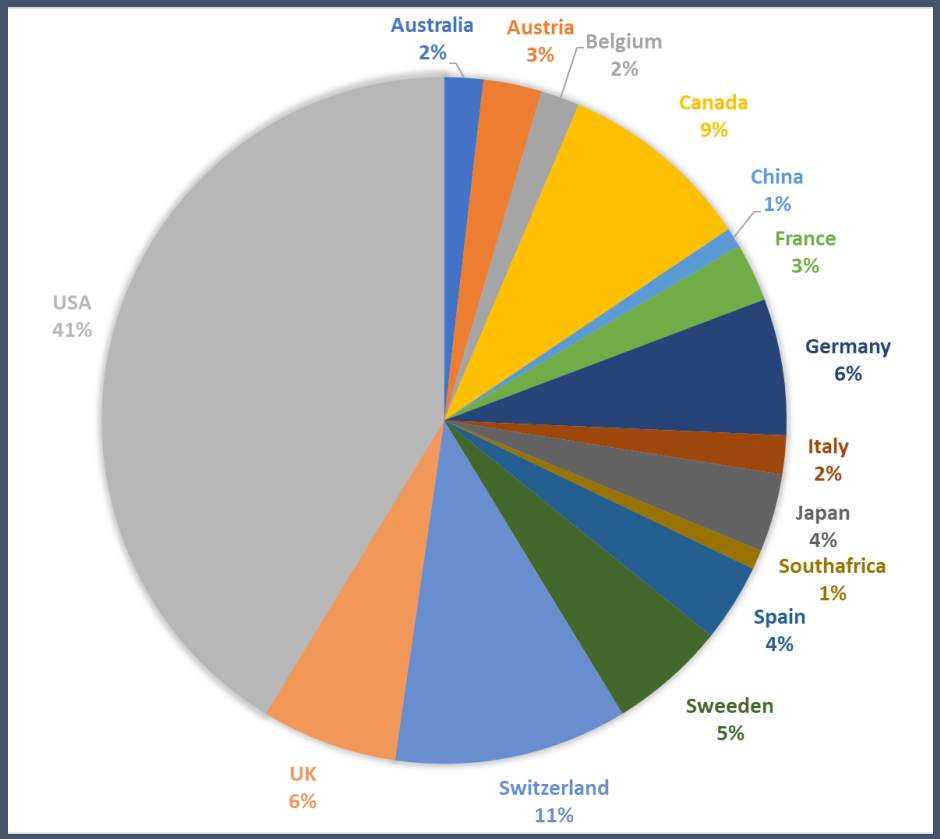
1/3 of new comers



16-21 October 2022
Marriott Newport News at City Center
US/Eastern timezone


TRIUMF
CLS
BNL
LANL
ORNL
SLAC
FERMILAB
Jefferson Lab
ISIS
DIAMOND
DESY
ESS
MAX IV
GSI
MedAustron
SOLEIL
CERN
Elettra
ESRF
ALBA
F4E
JPARC
iTHEMBA
Australian Synchrotron
Greenland
Iceland
Finland
Sweden
Norway
Russia
United Kingdom
Poland
France
Spain
Italy
Kazakhstan
Mongolia
China
South Korea
Afghanistan
Iran
Iraq
Pakistan
India
Thailand
Indonesia
Papua New Guinea
Australia
New Zealand
Mexico
Venezuela
Colombia
Brazil
Peru
Bolivia
Chile
Argentina
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
Kenya
DR Congo
Tanzania
Angola
Namibia
Botswana
Madagascar
South Africa
North Atlantic Ocean
South Pacific Ocean
South Atlantic Ocean
Indian Ocean

ARW2022 Participants



Monday, October 17, 2022

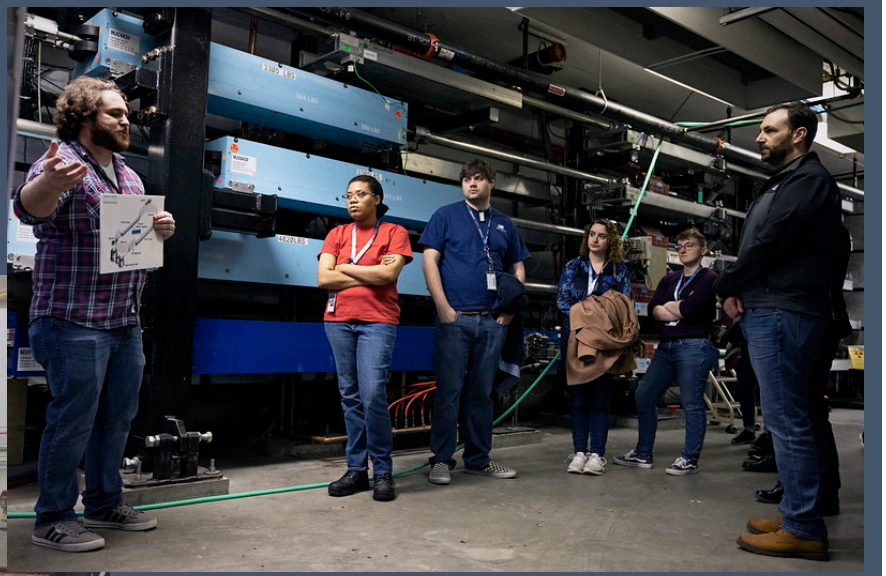
8:00	**Registration**
8:30 - 10:00	**Workshop Welcome, Introductions & Fault Tracking Panel** Chair: BAGGETT, Ken (Jefferson Lab)
8:30	**LOC/IOC Welcome** Speaker: BAGGETT, Ken (Jefferson Lab)
8:50	**ARW Introduction** Speaker: APOLLONIO, Andrea
9:15	**Fault Tracking Panel** **Speakers**: APOLLONIO, Andrea (CERN), BAGGETT, Ken (Jefferson Lab), BLACKLER, Ian (Brookhaven National Laboratory), FERNANDEZ, Ferran (ALBA synchrotron), GENGE, Kathleen (TRIUMF), GIACHINO, Rossano (CERN), PETERS, Charles (SNS)
10:00	**MORNING BREAK**
10:30 - 12:00	**Accelerator Support Systems** Chair: K. Genge
10:30	**Maintenance and Recommissioning of the LHC Cryogenic System for the Physics Run3** Speaker: FERRAND, Frédéric (CERN TE-CRG)
11:00	**Cryogenic Supply Chain Disruptions Effect on Accelerator Operations** Speaker: KISHI, David (TRIUMF)
11:30	**Operation History and Current Status of Electrical Power Conversion Equipment at the SNS** Speaker: TAN, Yugang (Oak Ridge National Laboratory)
12:00	**LUNCH BREAK**
13:30 - 15:00	**Plenary Discussion** Speakers: NEWHART, Duane (Fermi National Accelerator Laboratory), Dr NORDT, Annika (European Spallation Source ERIC)
15:00	**AFTERNOON BREAK**
15:30 - 17:00	**Maintenance & Obsolescence** Chair: L. Nadolski
15:30	**Recent Experience on LIPAc Reliability** Speakers: Dr CISMONDI, Fabio (Fusion for Energy), Mr SCANTAMBURLO, Francesco (F4E)
16:00	**Maintenance and Reliability Overview at the Canadian Light Source** Speaker: LE PIMPEC, Frederic (Canadian Lightsource)
16:30	**STAR Accelerator High Voltage Generator Driver Replacement** Speaker: Mr PANERAS, Nikolas (ANSTO)
17:00	**SESSIONS END**
18:00	IOC Meeting

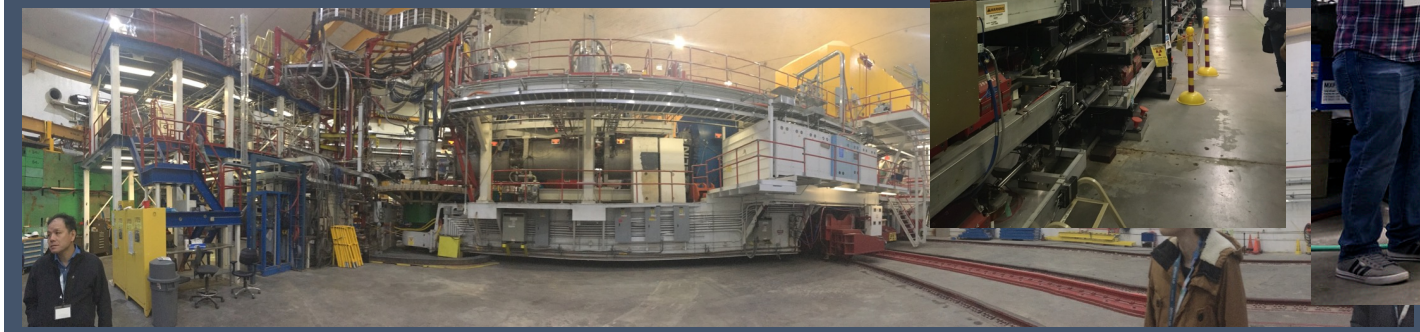
Tuesday, October 18, 2022

8:30 - 10:00	**Machine Learning & Reliability** Chair: GIACHINO, Rossano (CERN)
8:30	**Toward More Efficient Accelerator Tuning with Deep Learning** Speaker: TENNANT, Christopher (Jefferson Lab)
8:55	**Pulse-by-Pulse Classification System at CRYRING@ESR** Speaker: Dr GEITHNER, Wolfgang (GSI Helmholtzzentrum fuer Schwerionen-forschung)
9:15	**Sustainable Implementation of Machine Learning for Particle Accelerators** Speaker: MICELI, Tia (Fermilab)
9:35	**Uncertainty Aware Anomaly Detection to Predict Errant Beam Pulses and GradCAM Analysis** Speaker: RAJPUT, Kishansingh (JLab)
10:00	**MORNING BREAK**
10:30 - 12:00	**Reliability in Harsh Environments**
10:30	**Industry 4.0 Boosting Reliability in Particle Accelerators** Speaker: Dr DI CASTRO, Mario (CERN)
11:00	**Power Interruption at BNL** Speaker: TERHEIDE, Rachel (Brookhaven National Lab)
11:30	**High Power Operation of J-PARC 3 GeV Rapid Cycling Synchrotron Under High Temperature and Humidity** Speaker: YAMAMOTO, Kazami (J-PARC Center, Japan Atomic Energy Agency)
12:00	**LUNCH BREAK**
13:30 - 15:00	**Poster Sessions** Chairs: PREDDY, Doug (TRIUMF), SAMPSON, Paul (Brookhaven National Lab)
15:00	**AFTERNOON BREAK**
15:30 - 17:00	**Breakout Session**
17:00	**SESSIONS END**
18:00 - 19:30	**Scientist Walks Into a Bar** Tradition Brewery Hosted By: JLab / The Accelerator Reliability Workshop 2022—Admission is Free

Wednesday, October 19, 2022

7:00 - 8:30	**All American Breakfast Buffet**
8:30 - 10:00	**Invited Speakers** Clayton Smith and Resit Unal Chair: BAGGETT, Ken (JLab)
10:00 - 12:30	**JLab Tour**
12:30 - 13:00	**Excursion - Travel to Colonial Williamsburg & Bus Picnic Lunch**
13:00 - 17:00	**Colonial Williamsburg Excursion**
17:00 - 18:00	**Reconvene at buses and transport to James River Country Club** ***Buses leave promptly at 5:00 p.m..***
18:00 - 21:30	**Networking Reception & Banquet**
21:30 - 22:00	**Transportation back to Marriott**





Thursday, October 20, 2022

8:30 - 10:00	**Reliability of Medical Facilities** Chair: GENGE, Kathleen (TRIUMF)
8:30	**The MedAustron Ion Therapy Centre: Experiences from 6 Years of Clinical Operation** Speaker: Dr NOWAK, Sebastian (MedAustron)
8:55	**Maintenance Program of HIMAC** Speaker: KADOWAKI, Tetsuhito (Accelerator Engineering Corp.)
9:20	**Reliability of the Medical Cyclotron at BC Cancer in Vancouver** Speaker: SINGH, Baljit (BC Cancer)
9:40	**Development, Testing, and Installation of the LANSCE Isotope Production Facility Target Transfer Push Pull Chain** Speaker: KOPPI, Anthony (Los Alamos National Laboratory)
10:00	**MORNING BREAK**
10:30 - 12:00	**Predicting Failure** Chair: Dr NORDT, Annika (European Spallation Source ERIC)
10:30	**Utilizing Machine Learning to Improve Superconducting RF Cavity Linac Reliability*** Speaker: PETERS, Charles
11:00	**Prediction, Prevention and Handling of Failure at MAX IV** Speaker: NIEUWENHUIS, Rutger Arend (MAX IV Laboratory)
11:30	**RAMI Analysis of IFMIF-DONES Lithium Systems Events Important for Beam Interlocks of the 5** Speaker: Mr RUEDA PÉREZ, Juan José (University of Granada) MW Superconducting LINAC
12:00	**LUNCH BREAK**
13:30 - 15:00	**Breakout Sessions** Chairs: BAGGETT, Ken (Jefferson Lab), GIACHINO, rossano (CERN)

Thursday, October 20, 2022 (Continued)

15:00	**AFTERNOON BREAK**
15:30 - 17:00	**New & Innovative Accelerator Technology** Chair: DI CASTRO, Mario (CERN)
15:30	**A Digital Twin Application for Particle Accelerators** Speaker: SMAKULSKA, Dorota (CERN)
15:50	**Hardware Integrity Assessment of the Fast Beam Interlock System (FBIS) at ESS** Speakers: GUSTAFSSON , Johannes (ESS), WENG, Joanna (ZHAW)
16:10	**Alarm Management at the Australian Synchrotron** Speaker: DE BOOY, Jonathan (ANSTO)
16:35	**Multi-Module Based VAE to Predict HVCM Faults in the SNS Accelerator** Speaker: ALANAZI, Yasir (Old Dominion University)
17:00	**SESSIONS END**
17:30	IOC Committee Meeting & Dinner

Friday, October 21, 2022

8:30 - 10:00	**Reliable Protection Systems** Chair: CARROLL, Martin (European Spallation Source ERIC)
8:30	**Lessons Learning: Vacuum Protection for TRIUMF's Superconducting Linear Accelerator (SCLinac)** Speaker: ANGUS, Tiffany (TRIUMF)
9:00	**Equipment Protection System Checks at ALBA** Speaker: FERNANDEZ, Ferran (ALBA synchrotron)
9:30	**Beam Abort System for the SLS 2.0** Speaker: ARMBORST, Felix (Paul Scherrer Institute (PSI))
10:00	**MORNING BREAK**
10:30 - 12:00	**Reliability Consideration During Commission or Machine Upgrade** Chair: BAGGETT, Ken (Jefferson Lab)
10:30	**An Overview of Power Supply System of the EBS** Speaker: GOUDARD, Olivier (ESRF)
11:00	**Considerations on the Reliability of FAIR** Speaker: Dr REIMANN, Stephan (GSI/FAIR)
11:30	**Reliability of Proton Superconducting Linacs: SNS Case Study and Perspective on Future Machines** Speaker: GENG, Rongli (Oak Ridge National Laboratory)
12:00 - 13:00	**LOC/IOC Closing Remarks, Workshop Highlights & Next Workshop**
13:00	**WORKSHOP ADJOURNS**

4 Breakout sessions

- Fault tracking
- Software Reliability (formal methods, peer reviews, PLCverif, etc.)
- Inflation in cost and supply chain times and impact on machine reliability and availability
- Machine Learning

Inflation Cost

- Long delay, lead time
  - FPGA (1.5y)
- Quotation
  - valid for a single day (price of the day),
  - Valid for a time period shorter that the time for purchasing policy in the laboratory
- Buying on Ebay, online broker
- Redesign electronic board with available electronic components
- Downgraded performance ?
- Extension of the lifetime
- Diversification an increase of the number of suppliers
- Standardization between labs
- Education and training about Risk Management
- Spending more time and effort for sustainable design and operation

Many in-house developed tools

Fault tracking...a popular topic

Community willing to share experience

Convergence of operations and equipment experts viewpoints

Statistics – to what extent are they used by management to drive investments?

World-wide shortage of supplies – how to manage them? What is the impact?

Complex cryogenic systems, a vital infrastructure

A high-impact system – preventive maintenance is key

Continuous upgrade of power supplies to increase availability

Liquid Helium Supply Challenges

In 2022, TRIUMF was restricted to 75% of what we ordered in 2021

- Reduce consumption
- Improve measurement system along the distribution system
- Education and Training of the Cryo staff and users
- Closed circuit System (<10% consumptions)
- Recovery System for GHe (goal: >80%)
- Low consumption Design
- Increase the storage capacity (GHe, LHe)

Maintenance and Obsolescence, L. Nadolski

"Whatever complicated system/tool/process is in place, make sure that the staff dominates it and not the other way around"

Database for the assets management (lifecycle tracking, spare part management and maintenance record)

"Temporary *fixes* become permanent problems"

"Lacking of specifications will lead to vexations"

Sustainable machine learning: data management, model management, deployment

Lots of great work in different facilities, a very promising start!

How to make the transition to operational tools?

Interest to develop a ML network across facilities

Machine Learning (I)

- Uncertainty Aware Anomaly Detection to Predict Errant Beam Pulses and GradCAM Analysis

- Uncertainty Quantification (UQ)
  - How to make DL more reliable ?
  - How to know the confidence of an output ?
  - Surrogate Model, Gradient Class Activation Mapping (GradCAM), SNN (Siamese Neural Network), Deep Gaussian Process Approximation (DGPA)
- Classification, Confusion Matrix

- Tuning with DL: using Graph Neural Network (GNN), latent space

- Using ML in automating processes
  - Using best practice from the industry world

Machine Learning (II)

- Major discussion points
  - Use cases with a potential added value of ML
    - System Hidden variables
    - High degree of freedom system
    - Speed-up process

  - Assisting (supporting) and automation, the operation, the measurement
    → augmented operation
  - Permanent Resources in ML experts
  - Guidance
  - Training
  - Difficult step to go from the Proof-of-Concept to Operation
  - Maintability of ML applications
  - Use of Digital Twin
  - Identifiying right use case for learning: from simple to complex problem to solve

Robotics for harsh environments, custom solutions

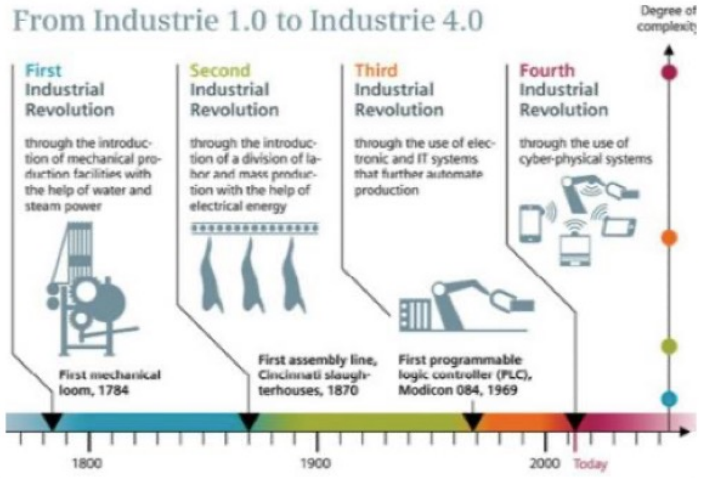
Open hardware platform for collaboration

Effect of atmospheric conditions on performance: cost effectiveness of system upgrades to be demonstrated and compared to alternative solutions (e.g. temporary power reduction)

How to deal with electrical network perturbations, importance of UPS coverage

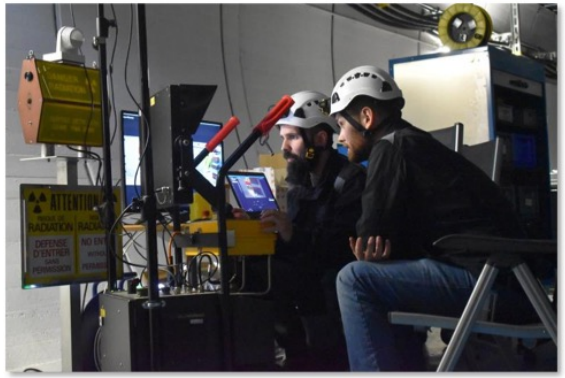
Current industrial revolution

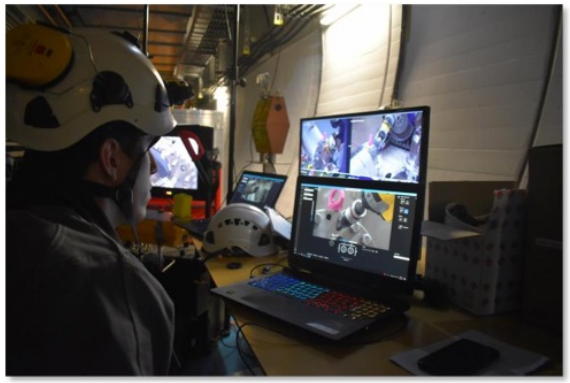
- **Industry 4.0**
  - ✓ Cyber-physical transformation of manufacturing
  - ✓ Internet of things (IoT)
  - ✓ Artificial intelligence
  - ✓ Diffuse signals
  - ✓ Sensor fusion
  - ✓ DATA
  - ✓ Robots
  - ✓ Assisting people and machinery to execute their tasks maximizing efficiency



Robotics technologies are mainly used for:

- Remote maintenance for **safety and machine availability increase**
- Environmental measurements, maintenance/tele-operation and inspection in dangerous areas
  - ✓ **Taking data in harsh environment, used also for reliability study!**
- Human intervention procedures preparation
- Quality assurance
- Post-mortem analysis/inspection of radioactive devices
- Reconnaissance, search and rescue
- And others…





Moving to Smart IoT Accelerators

- **Industry 4.0 Boosting Reliability in Particle Accelerators**
  - **Use of IoTs**
  - **Data driven reliability**
  - **Robotics and AI**

  - **From wired based to wireless based infrastructure**
  - Industry is moving towards wireless technologies for:
    - Asset management and tracking
    - Production and machine monitoring, maintenance and improvement
    - Interconnected supply chains

- Ground
- Tunnel applications

- The impact on:
  - Costs reduction
  - Higher efficiency
  - Data consistency

Radiation tolerant IoT hardware platform developed at CERN

Preventive maintenance for complex systems: not always the solution! Condition-based maintenance is the future (?)

Mission-critical systems: formal studies are mandatory, involving hardware and software

Is our Maintenance Policy Well Adapted to Light Sources?

IEEE Access

IEEE POWER & ENERGY SOCIETY SECTION

Received February 18, 2022, accepted April 30, 2022, date of publication May 4, 2022, date of current version May 19, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3172697

Power System Reliability and Maintenance Evolution: A Critical Review and Future Perspectives

MANUEL S. ALVAREZ-ALVARADO[1], (Member, IEEE), DANIEL L. DONALDSON[2], (Member, IEEE), ANGEL A. RECALDE[1], (Member, IEEE), HOLGUER H. NORIEGA[1], (Member, IEEE), ZAFAR A. KHAN[3], (Senior Member, IEEE), WASHINGTON VELASQUEZ[1], (Senior Member, IEEE), AND CARLOS D. RODRÍGUEZ-GALLEGOS[4], (Senior Member, IEEE)

[1]Faculty of Electrical and Computer Engineering, Escuela Superior Politécnica del Litoral (ESPOL), Guayaquil 090112, Ecuador
[2]Department of Electronics, Electrical and Systems Engineering, University of Birmingham, Birmingham B15 2TT, U.K.
[3]Department of Electrical Engineering, Mirpur University of Science and Technology, Mirpur, Azad Jammu and Kashmir 10250, Pakistan
[4]Solar Energy Research Institute of Singapore (SERIS), National University of Singapore (NUS), Singapore 117574

Corresponding author: Manuel S. Alvarez-Alvarado (manalva@espol.edu.ec)

This work was supported by the Decanato de Investigación from the Escuela Superior Politécnica del Litoral (ESPOL).

Enlightening talk by Prof. Resit Unal (Univ. Old Dominion, USA)

Random errors are not impacted by preventive maintenance
Complex system are more sensitive to random failure and less to wear-out failure

Power System Reliability and Maintenance Evolution:

A Critical Review & Future Perspectives, M.S. Alvarez-Alvarado et al. (2022)

Paper presents a comprehensive review of advances in maintenance strategies and system reliability for power systems (PS).

It details existing approaches for PS maintenance planning, and provides definitions, models, methods, and maintenance policies.

286 References provided.

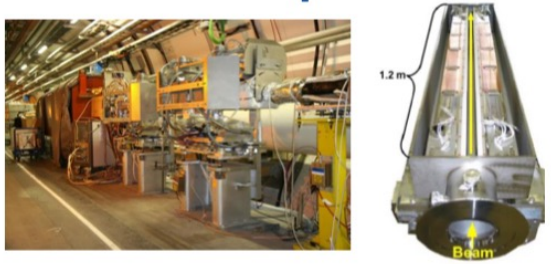
From Preventive to predictive maintenance
Data based maintenance: **on-condition maintenance** or CBM (Condition Based Maintenance) / P-F Curve

- Maintenance evolved into Asset Management. It consists in determining the best moment to maintain assets based on operating data.
- Reliability Based Smart Maintenance (RBSM) model.

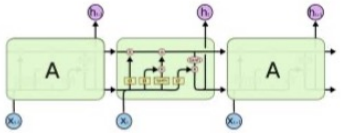
From corrective and preventive to predictive maintenance

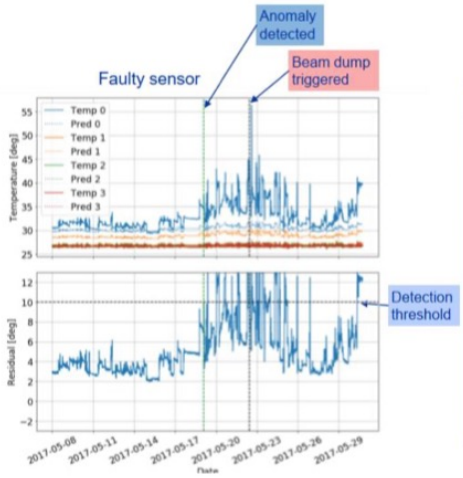
LHC Collimators Jaws temperature Maintenance over the last years

- **Corrective maintenance** during unplanned downtime could have huge impact on accelerators
  - ✓ Unavailability, cost of the operation, needs for backup solutions etc.
- **Preventive maintenance** to improve reliability
  - ✓ High cost
- **Predictive maintenance** could help in reducing the corrective maintenance probability optimizing the preventive maintenance
  - ✓ Example done at CERN for on predictive maintenance algorithms run on interlocked LHC Collimators jaws temperature signals monitored in real time → Anomaly detection
  - ✓ Machine learning LSTM model (RNN)



LHC Collimators and view of inside/jaws





Data Set	tuning	2018
Total Samples	42	**79**
True Positives	21	**23**
True Negatives	20	**52**
False Positives	1	**4**
False Negatives	0	**0**
F-1 Score	0.98	**0.92**
Mean time detection to event [h]	13.73	**3.19**
Accuracy	97.60%	**94.90%**

Courtesy of L. Serio, CERN

Accelerators are different but all have stringent quality management guidelines

Root-cause analysis for recurring issues, advanced diagnostics

Knowledge sharing in action - Japan has formed a group with members from all treatment facilities to improve machine reliability

Maintainability improvements: move to industrial solutions

Towards implementation of ML models into operational settings

Dedicated machine learning resources + domain experts required

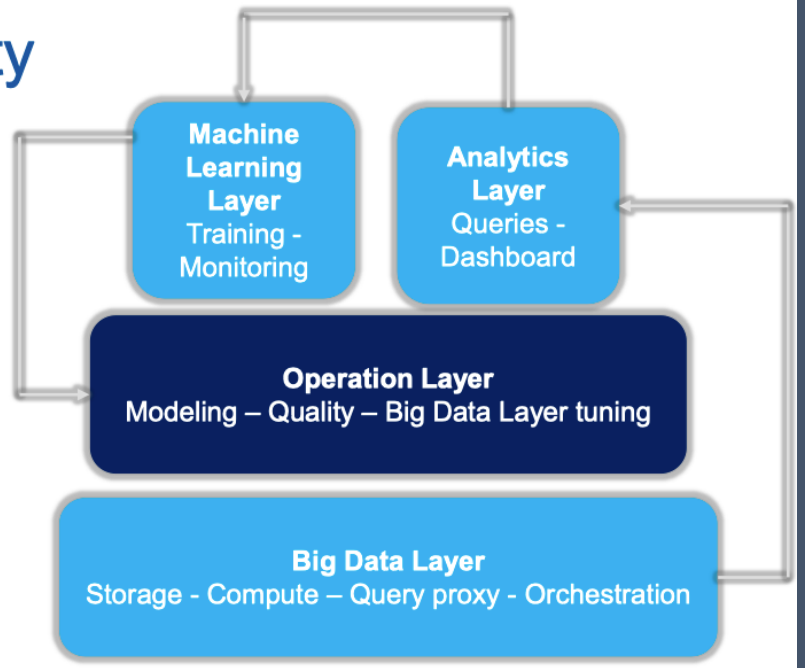
Predicting, preventing and handling failures: from occurrence to recovery of operational conditions

“Don’t shy away from making applications in-house and automating procedures”

Reliability before design: formal RAMI studies to verify compliance to targets

Data driven reliability and data quality

- To understand how to execute, maintain and improve machines, **data are needed**
  - ✓ Key aspect is to put together data scientist, developers and equipment experts → cross functional learning
- Predictive analytic model of machine components could be extrapolated from data
  - ✓ Failures could be anticipated, feedbacks for operation and quality
- Every year, poor/bad data quality costs to organizations an average of $13 millions
  - ✓ Right data / data quality is needed → Data reliability engineering (DRE) approach to data quality is needed. **Treating data quality like an engineering problem**



Data stack based on Bigeye solutions

Question could be: how much money will it cost?

Answer could be: how much money could be saved in prospective?

It's not only about money, about SAFETY.

New and innovative accelerator technology, M. Di Castro

Digital twins: a powerful tool for equipment design, operations, safety

Formal approach for integrity assessment of Beam Interlock System

Alarm system: an effective tool to support operations

Anomaly detection for High Converter Modulators using ML

Digital twins are dynamic: hybrid approach mixing Physical model / simulation data and Measurement data (deep learning)

Necessity of checks due to new devices, maintenance, upgrades

Fast, fail-safe, reliable, while avoiding false interlocks

Potential impact of vacuum failures on accelerator operation

Reliability considerations during commissioning and upgrade, K. Bagget

MTBF improvement thanks to SW and HW upgrades + hot swappable systems

A bright future for SRF based high power hadron machines

Beam energy required by ADS-class machine achievable with existing SRF technology

New machines: reliability considerations already during design phase (quality, standardization, maintainability)

Proceedings:

ARW 2022 :
https://indico.jlab.org/event/495/timetable/

Machine Learning November 2022:
https://indico.bnl.gov/event/16158/timetable/#20221101

Acknowledgement: Rossano Giachino

Workshops to Come

- **WAO 2023**
  - 10 – 15 September 2023 Japan.
    Epochal Tsukuba International Congress Center
  - http://wao2023.kek.jp/

- **ARW 2024**
  - Lund, Sweden. Hosted by MAX IV and European Spallation Source

MAX IV

ESS