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The ARGO detector readout and DAQ

Audrey Corbeil Therrien, PhD, ing.

For the ARGO collaboration

The Global Argon Dark Matter Collaboration

400 researchers from 100 institutions in 14 countries

With many thanks for support to:

CFI and NSERC (Canada)

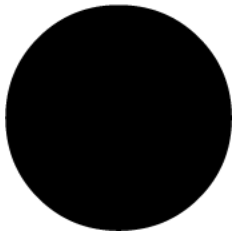
IN2P3 (France)

INFN (Italy)

STFC (UK)

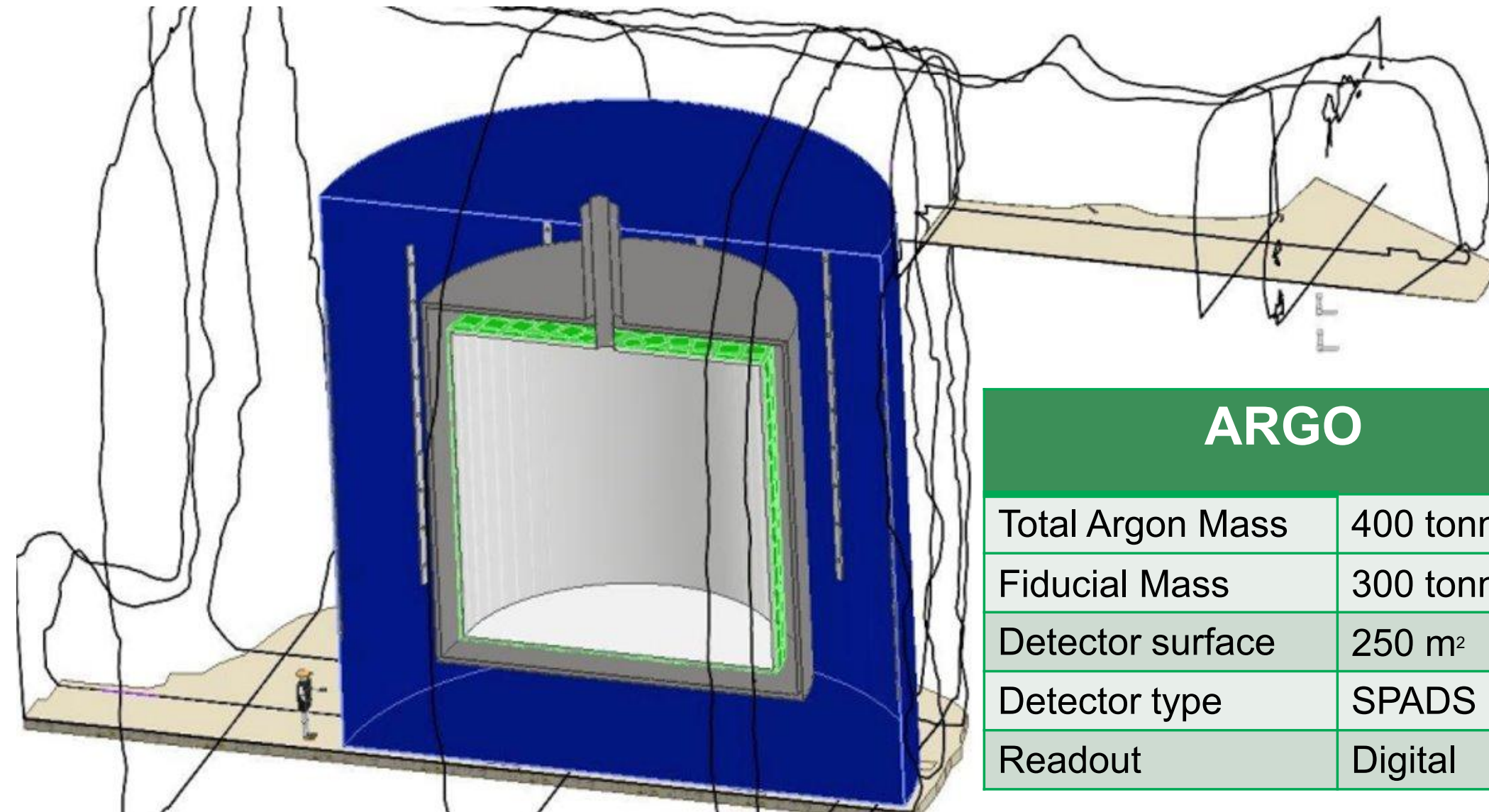
NSF and DOE (U.S.)

Poland and Spain Ministries for Science and Education



3!T

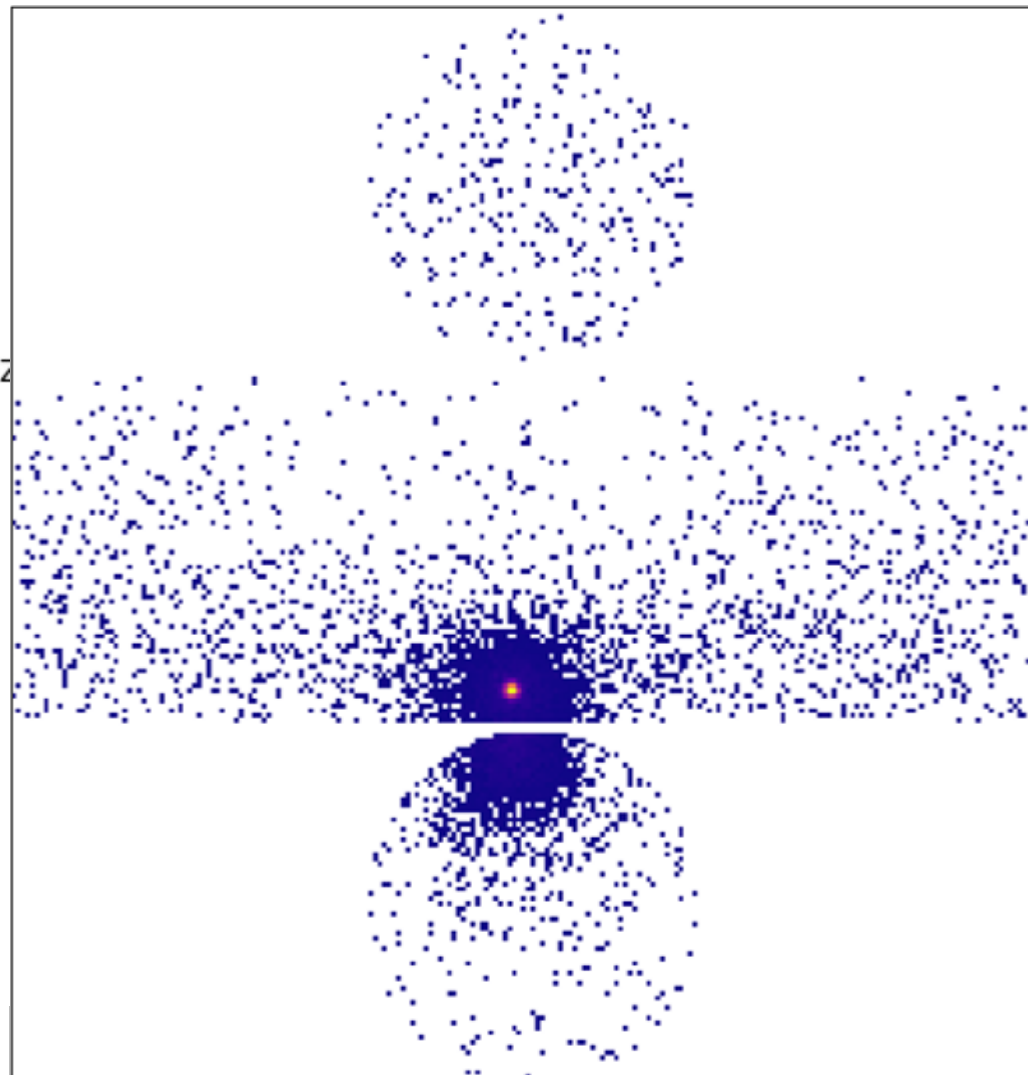
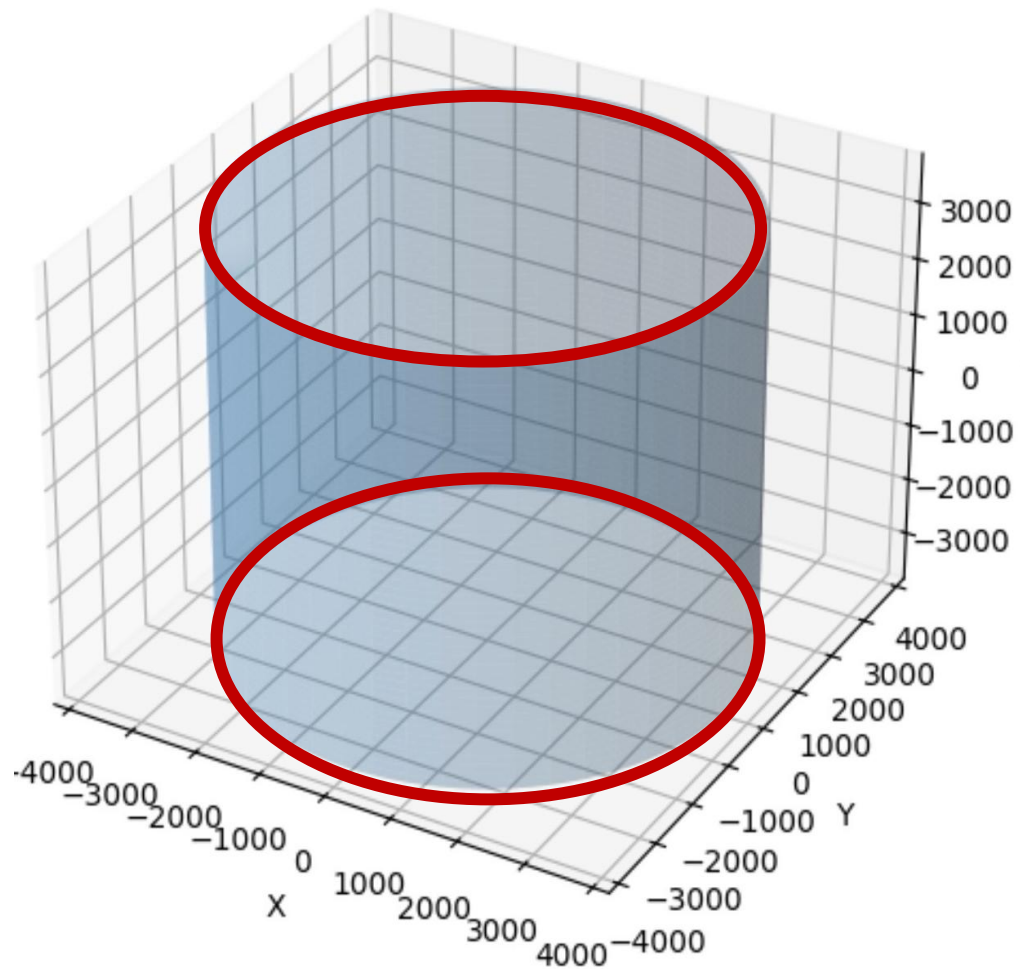
ARGO



ARGO

Total Argon Mass	400 tonnes
Fiducial Mass	300 tonnes
Detector surface	250 m ²
Detector type	SPADS
Readout	Digital

ARGO

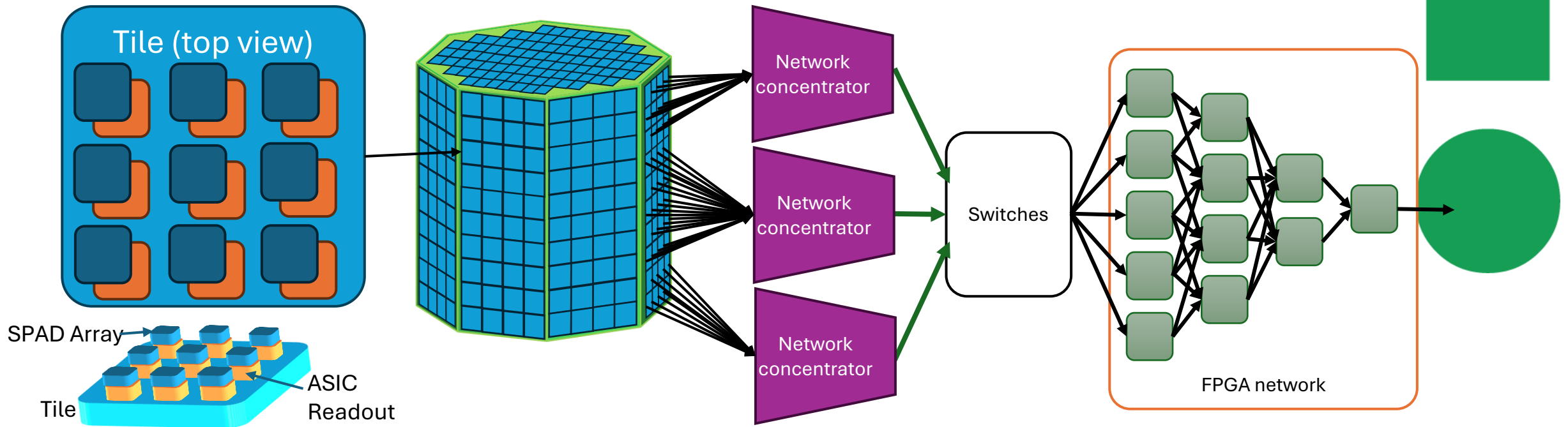


ARGO

~250 m² of detector surface

Individual detector « tile »	Number of data channels
10x10 cm ²	25 000
1x1 cm ²	2 500 000
1x1 mm ²	250 000 000

ARGO DAQ



Machine Learning and Hardware

- Machine Learning operations

- Multiplications
- Additions
- Non-linear fixed function
- Memory transactions

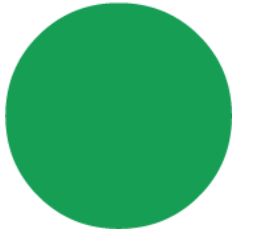
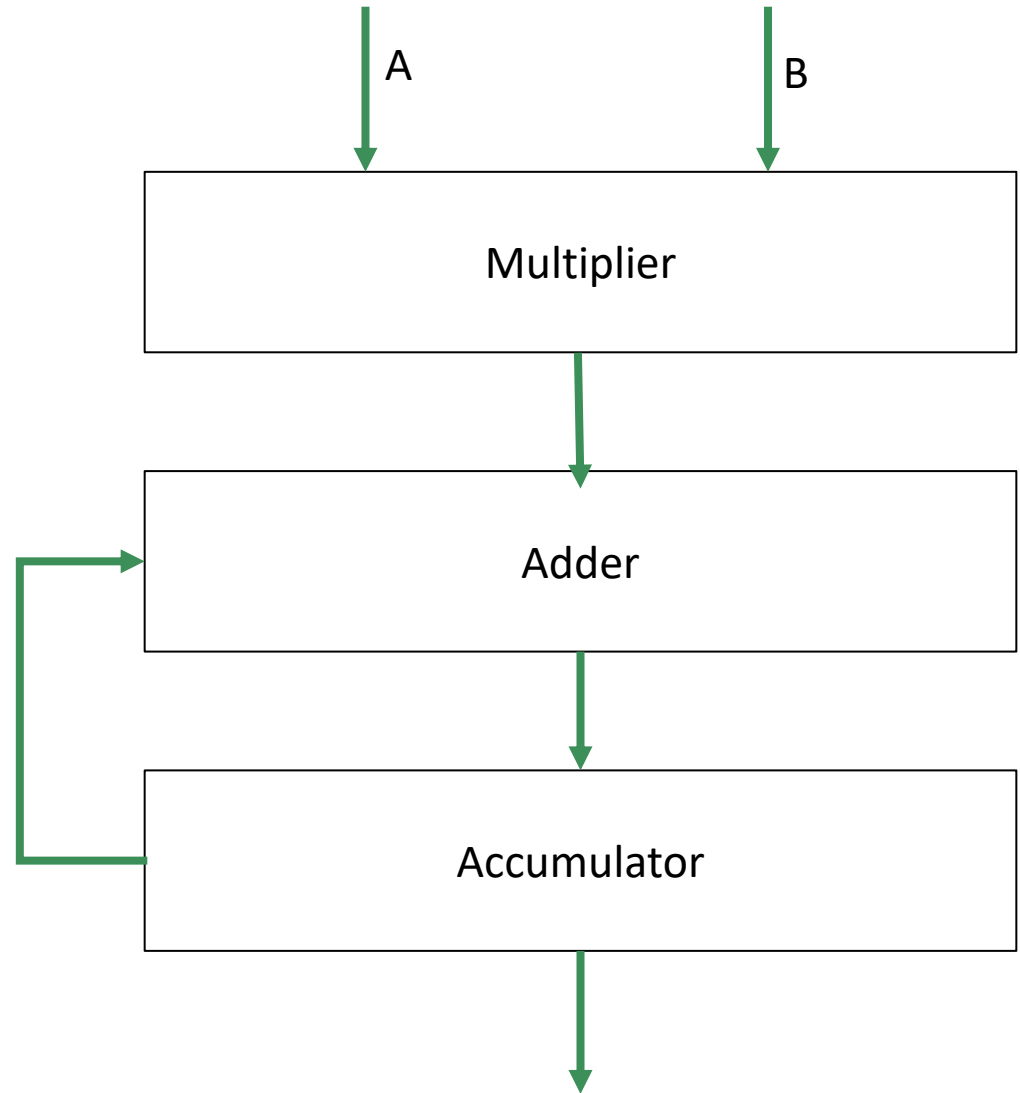
- MAC unit

- Multiply-and-accumulate

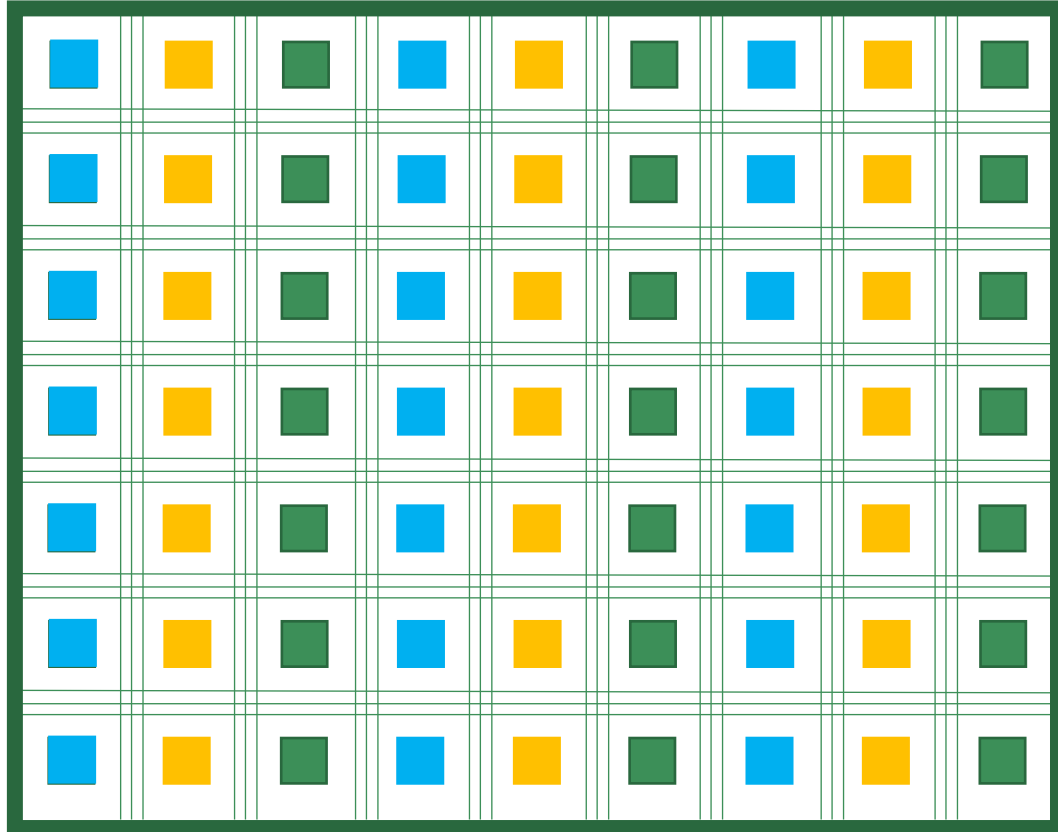
- Look-up-table

- No need to compute the function

- Data transfers



Machine Learning and FPGA



- Logic
- Memory
- Digital signal processing slices

Reconfigurable

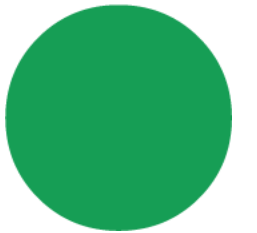
Efficient

I/O capacity

Programming

Limited clock

Limited resources



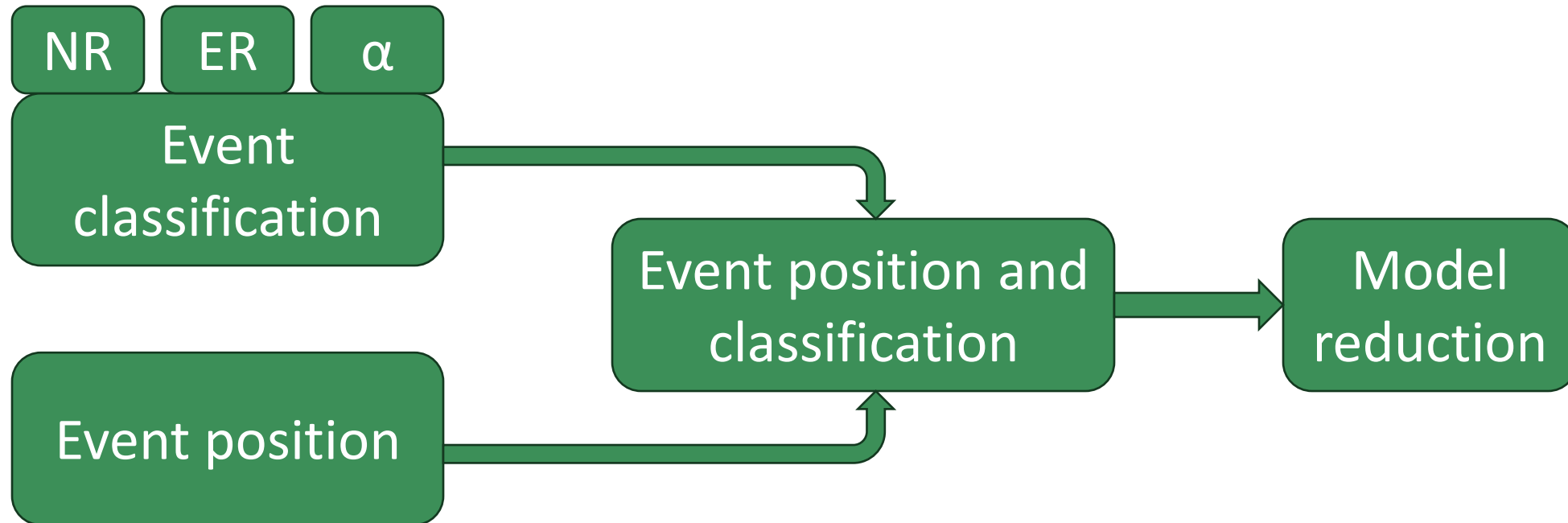
Machine Learning and Hardware

- Machine learning can analyse data using simple operations
- FPGA have several I/O
- FPGA can run ML models fully parallel and pipelined

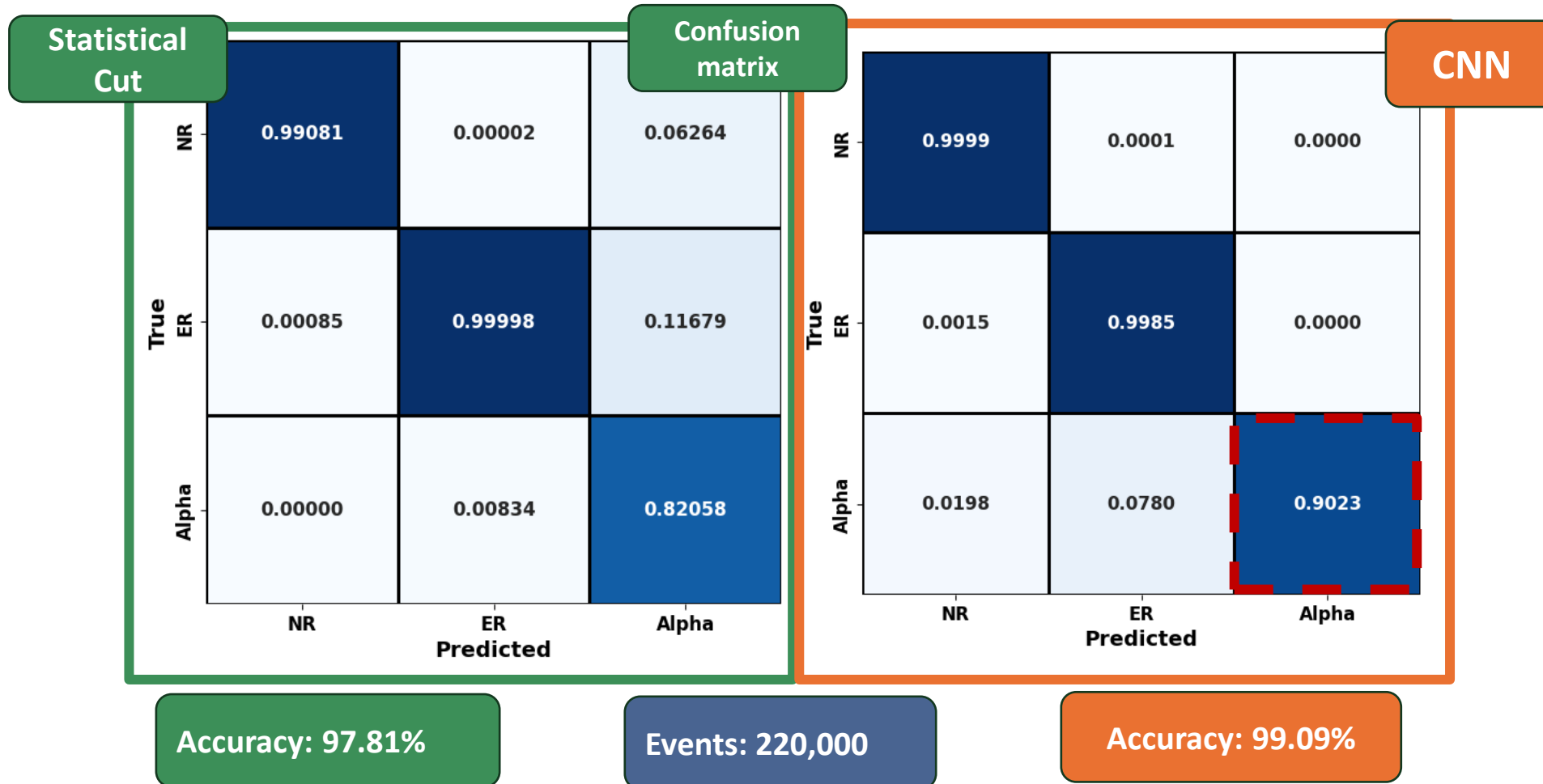
Continuous readout and analysis

Machine Learning for ARGO

Start simple, build up, squish down.

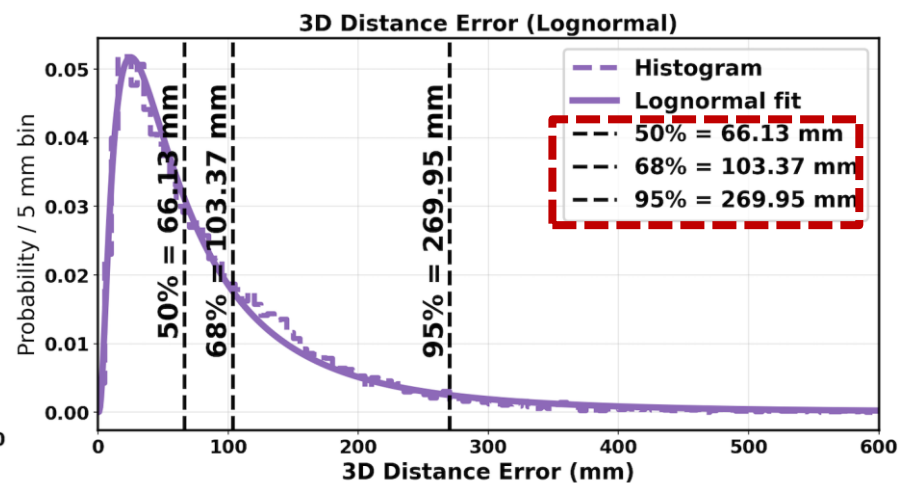
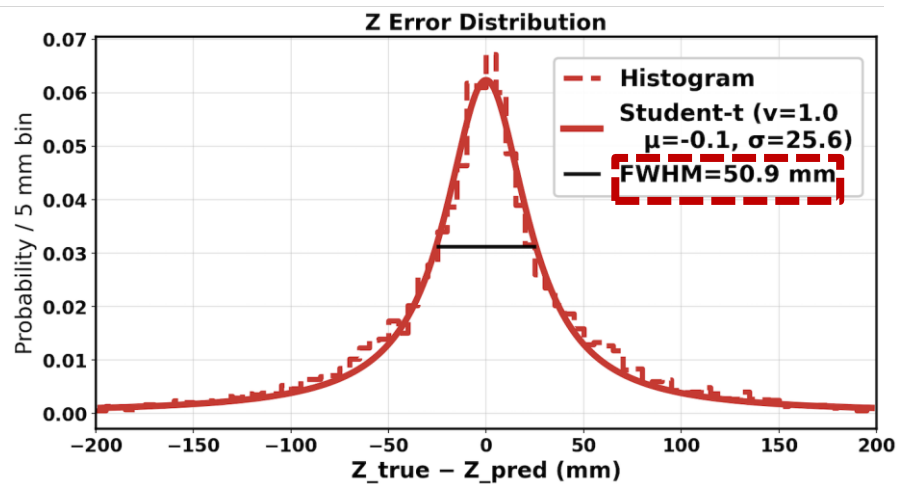
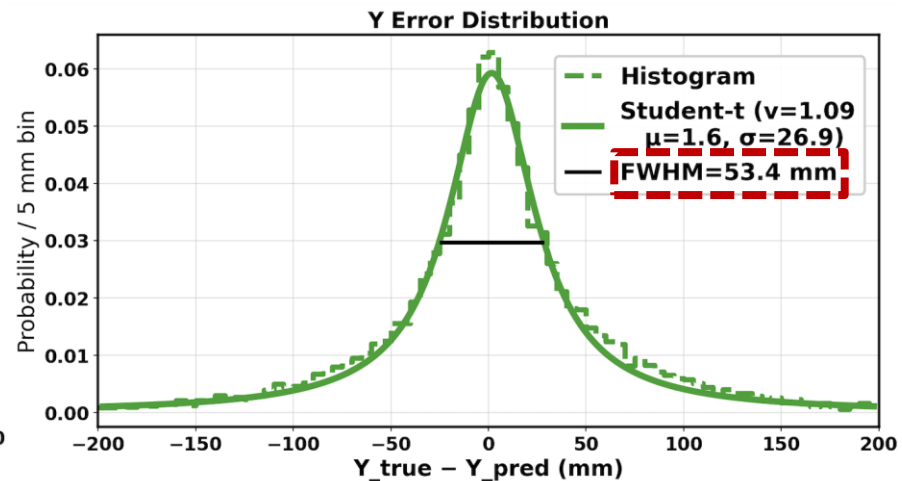
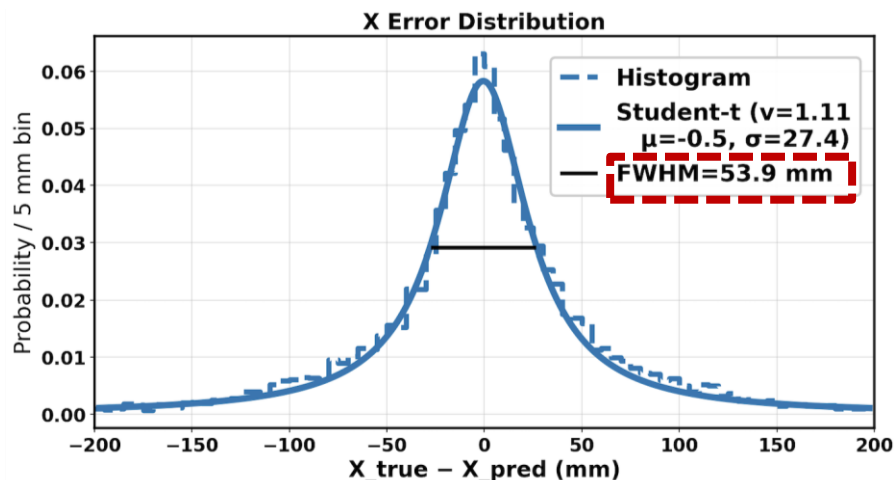


Event classification

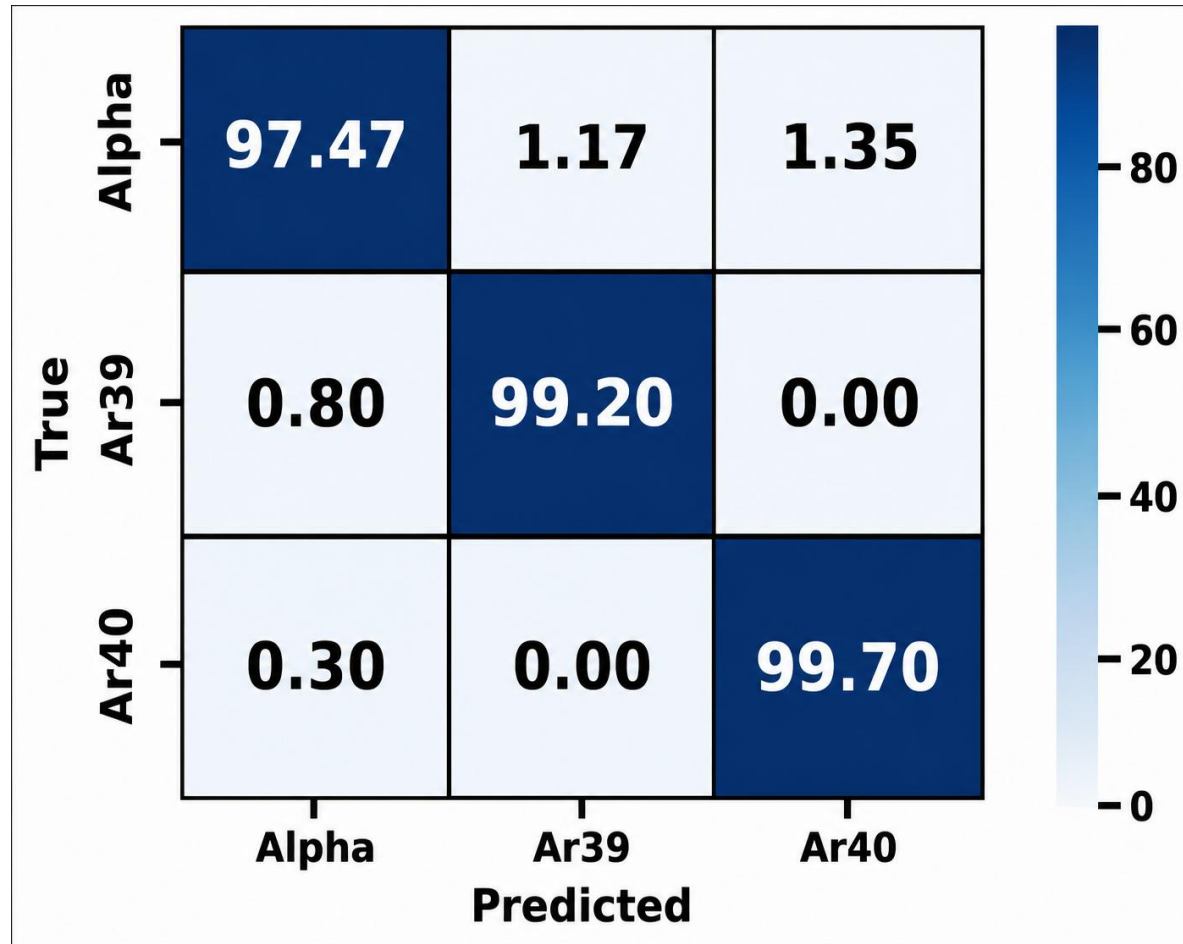


Event position

100x100 mm² tiles

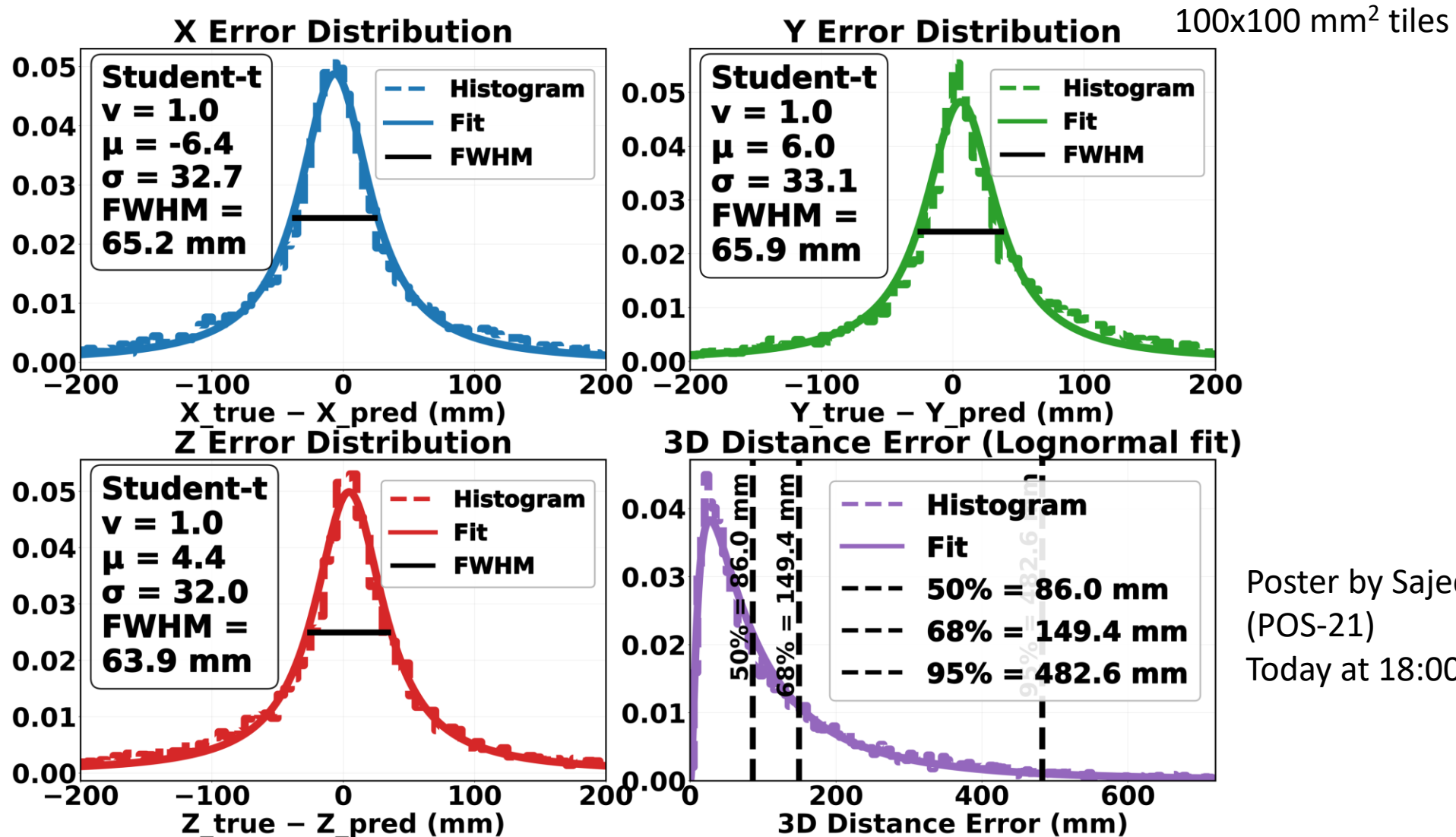


Combined model – event classification



Poster by Sajedah Esmailzadeh
(POS-21)
Today at 18:00

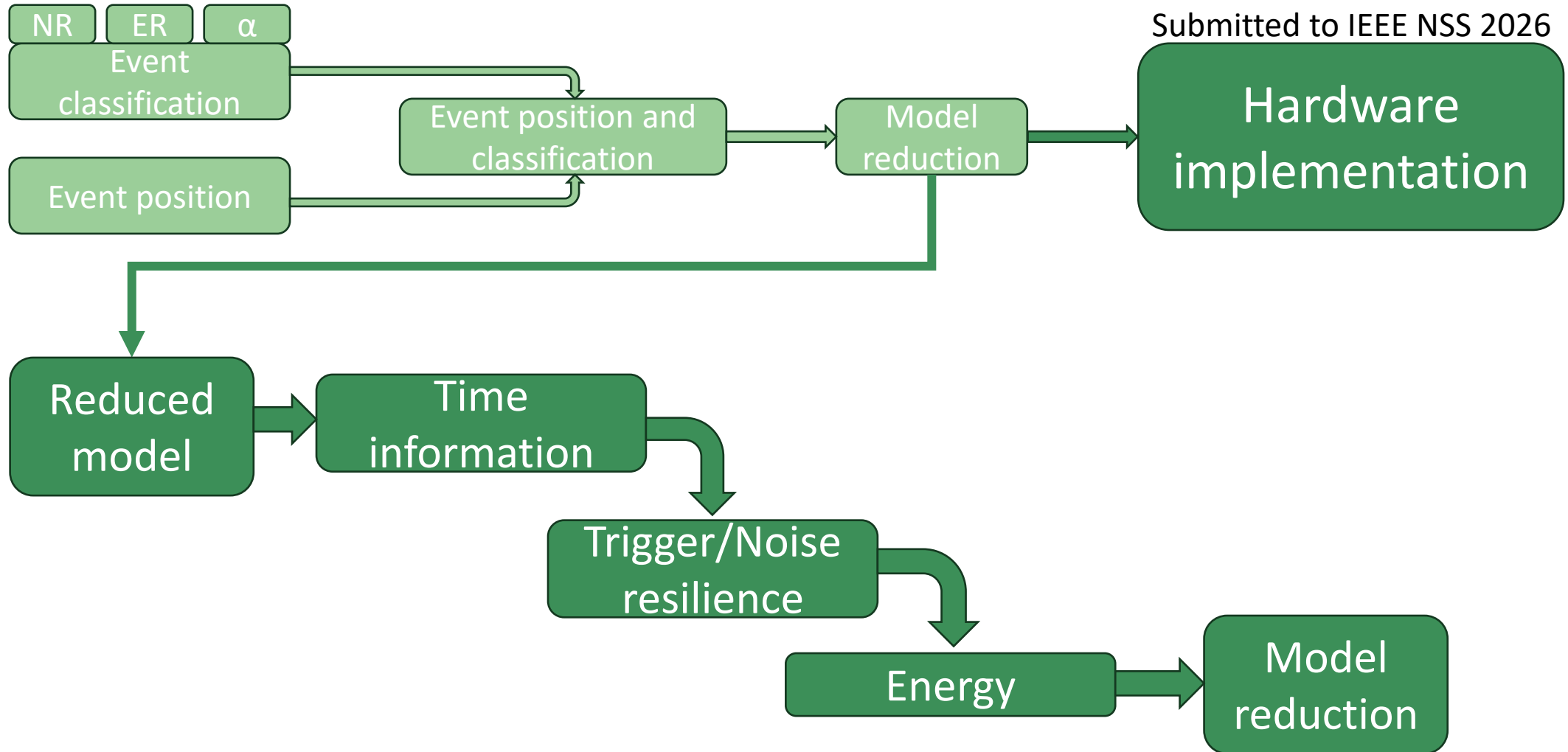
Combined model – event position



Poster by Sajedeh Esmaeilzadeh
(POS-21)

Today at 18:00

Next steps



Conclusion

ARGO pushes sensitivity to dark matter, but presents several challenges for DAQ systems

We built a single hardware aware ML model that can extract interaction type and position simultaneously

EdgeAI requires new tools and new methods to meet the requirements for experiments



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CNN and ARGO

Poster by Sajedah Esmaeilzadeh

(POS-21) Real-time Machine Learning for ARGO Data Acquisition System


Today at 18:00



Université de Sherbrooke

REAL-TIME DATA COMPRESSION USING MACHINE LEARNING MODEL FOR ARGON-BASED DARK MATTER DETECTORS

Sajedah Esmaeilzadeh, Charles-Etienne Granger, Hamza Ezzaoui Rahali, Audrey C. Therrien, 3IT, University of Sherbrooke
Kevin Gracequist, Simon Viel For the ARGO collaboration



BACKGROUND

ARGO, a liquid argon (LAr) dark matter experiment currently in the conceptual design phase by the Global Argon Dark Matter Collaboration, will search for rare dark matter interactions using a large-scale photon detection system [1] [2]

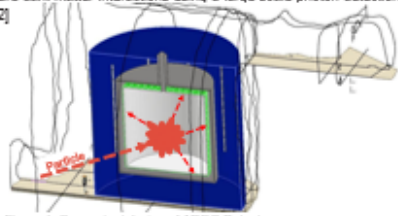


Figure 1: Conceptual design of ARGO Detector

ARGO Main Characteristics	
Start of operation	2030s
Argon mass	400 tonnes
Detector surface	200 m ²
Detector type	SPADS
Readout	Digital

Table 1: Overview of the ARGO Detector

CHALLENGES

- ARGO's large surface (200-250 m²)
- Results in millions of channels (~2-200)
- Generates large complex data
- Storage requires:
 - Extensive cabling
 - Significant power consumption
 - Immense disk space
 - Long-term costs

OBJECTIVES

To address the challenges, this project aims to:

- Preserve potential dark matter signals while rejecting most background in real time with ML models.
- Perform real-time data analysis on edge hardware before transmission and storage.

METHODS

- Generate Interactions (using Geant4):**
³⁷Ar beta decays (ER), ⁴⁰Ar (NR, WIMP-like), and alpha decays.
- Extract Features:**
 NumPE, Fprompt, time and photon hit positions
- Generate 2D Images:**
 Convert detector events into 2D photon-hit histograms by unrolling the cylindrical detector geometry (100,000 images) (Fig. 2).
- Design and Train Unified CNN:**
 Perform particle classification (NR, ER or alpha) and position reconstruction simultaneously.

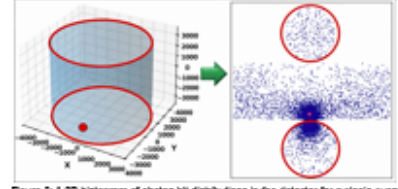


Figure 2: A 2D histogram of photon hit distributions in the detector for a single event.

Model Structure	
Task	Classification + Reconstruction
Input	Image + Fprompt
Architecture	2 Conv2D (128, 256) + 5 ResBlocks (256, 512)
Outputs	NR, ER, Surface $\alpha + (x,y,z)$
Loss Functions	Cross-Entropy + Huber
Metrics	Accuracy + FWHM
Parameters	13.6 M

Table 2: Structure of the CNN model.

RESULTS

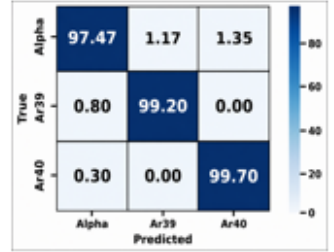


Figure 3: Confusion Matrix for CNN Classification

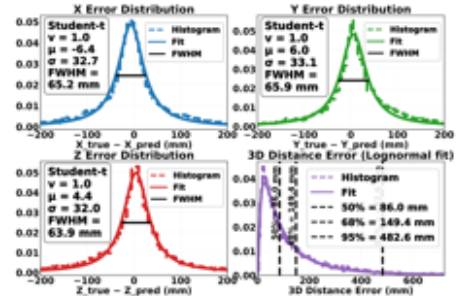



Figure 4: Position Reconstruction Error Distribution

CONCLUSION


We presented a unified CNN model for particle identification and position reconstruction in ARGO, achieving 99% classification accuracy and 80-70 mm position resolution. These results demonstrate the potential of EdgeML to reduce data volume, storage, and offline processing demand in next-generation dark matter detectors. Next, we will focus on model optimization and FPGA implementation to validate edge hardware performance.


REFERENCES

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