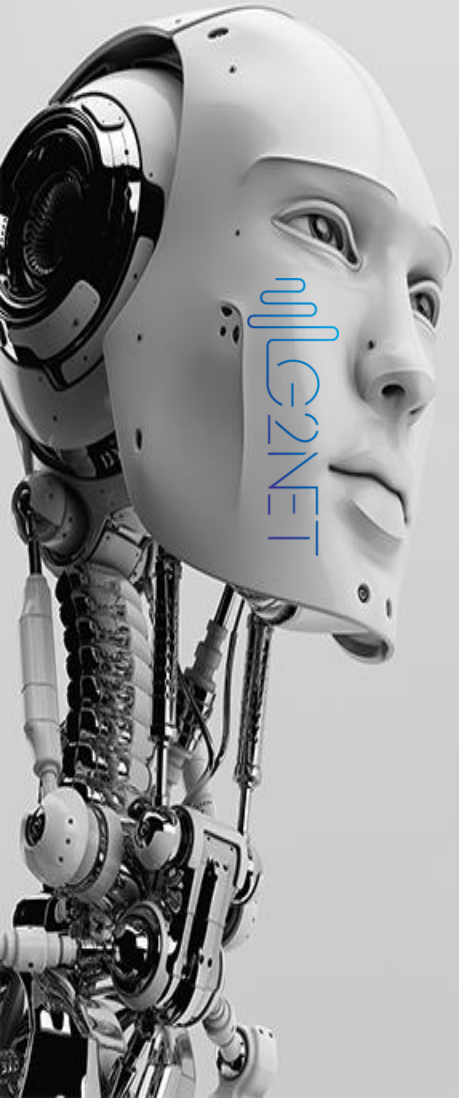


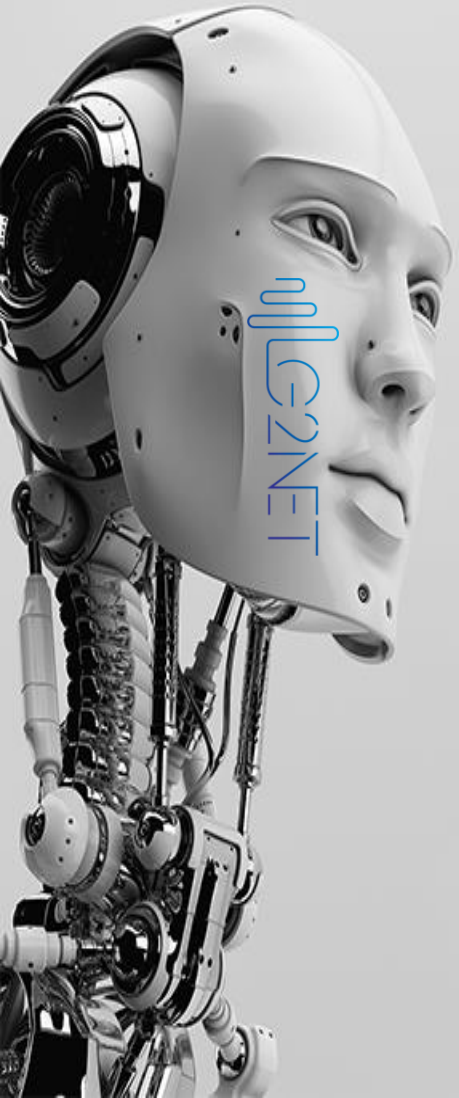
Introduction to WG3

Machine learning for noise cancellation and GW detector control

Jan Harms

Gran Sasso Science Institute

WG3 Organization



WG leader
Jan Harms (jan.harms@gssi.it)

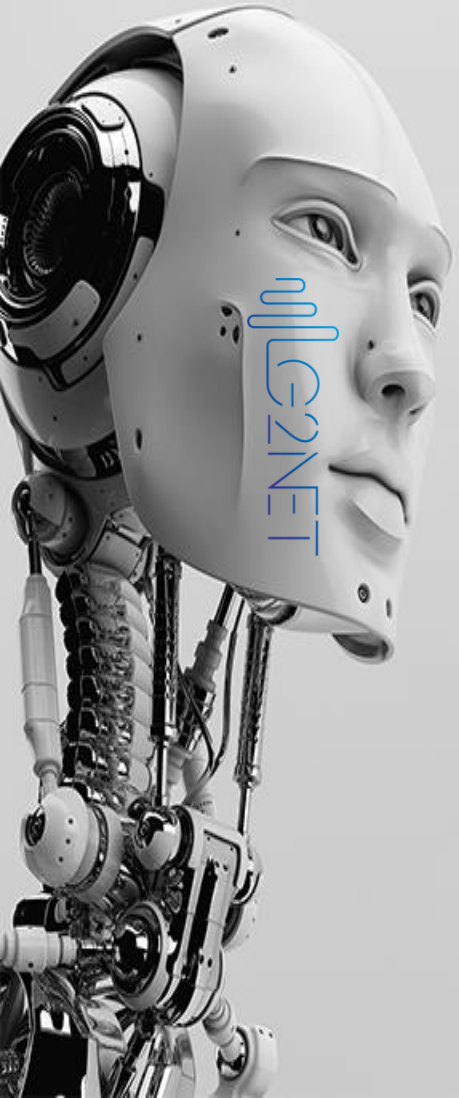
WG co-leader
Luca Longo (luca.longo@dit.ie)

International expert partner
Gabriele Vajente

Monthly telecons every first Tuesday at 5pm CET

Subscribe to mailing list at
http://mail.ego-gw.it/mailman/listinfo/Wg3-g2net

Current WG3 Composition



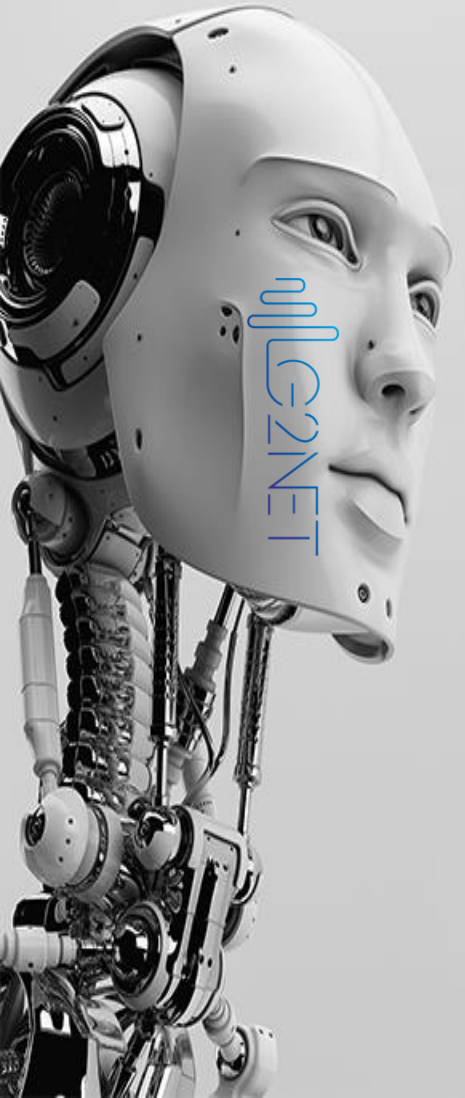
29 members of which

- 8 are passive listeners or management
- 5 PhD students (physics and CS)
- 8 postdocs/senior in CS or robotics
- 8 postdocs/senior in GW physics

Interesting synergies to be expected from GW/CS mergers.

Interaction with hand-picked external experts will be very beneficial.

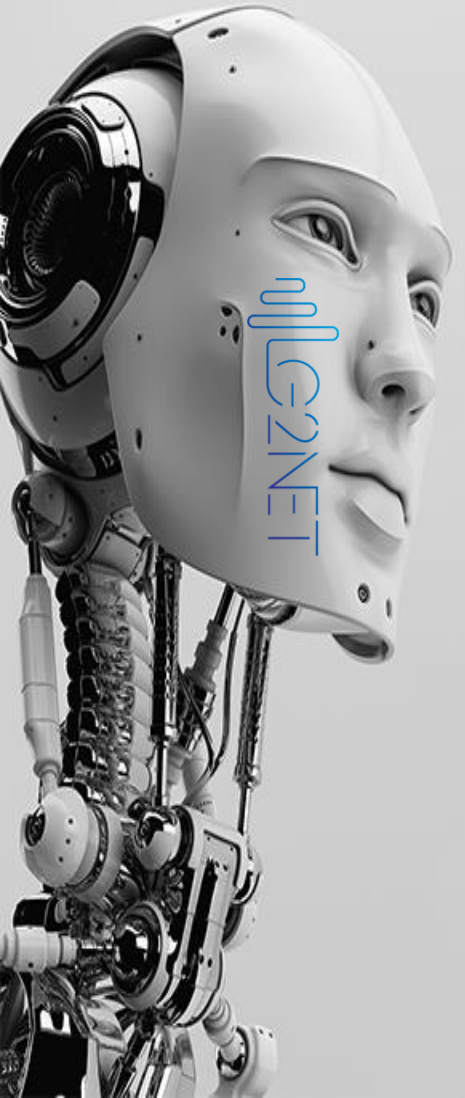
Motivation



Solve problems and fulfill a utopia

Case study: AlphaZero plays Chess and Go like a virtuoso, not as one would expect from a computer. It is not crunching numbers nearly as much as other computer programs. It does so without being able to explain its strategies to human beings, and especially in the case of Go, humans do not really understand why its strategies are so effective.

Status of the Game



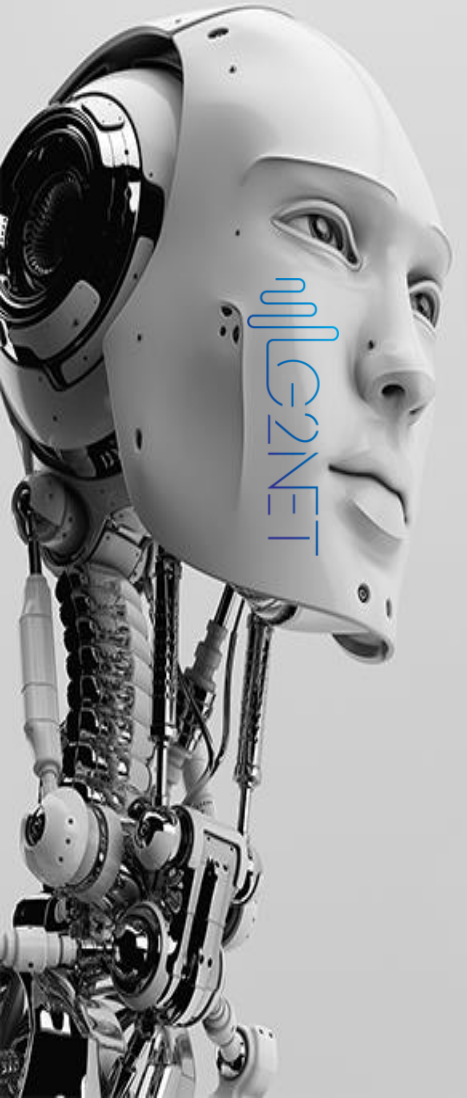
1. It is a long way until ML will have taken over, and there are above all hardware challenges in addition to creating the appropriate software.
2. To get there, we will have to demonstrate in little steps that ML is worthwhile.
3. Currently, we are behind state-of-the-art in terms of software development, we have no generic approach to implement machine learning for interferometer control, and we are not making full use of hardware capabilities.

The Three ML Categories

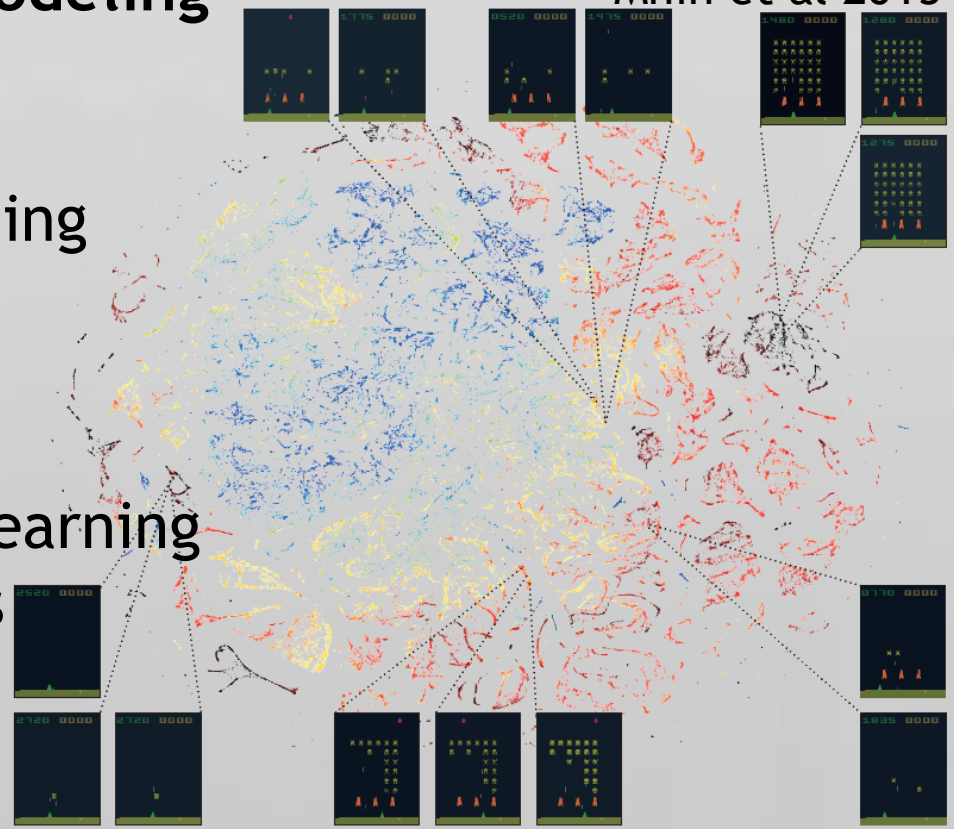
Unsupervised learning
- **Visualization**
  (clustering, dimensionality reduction)
- **Generative modeling**
- **Clustering**

Supervised learning
- Classification
- **Regression**

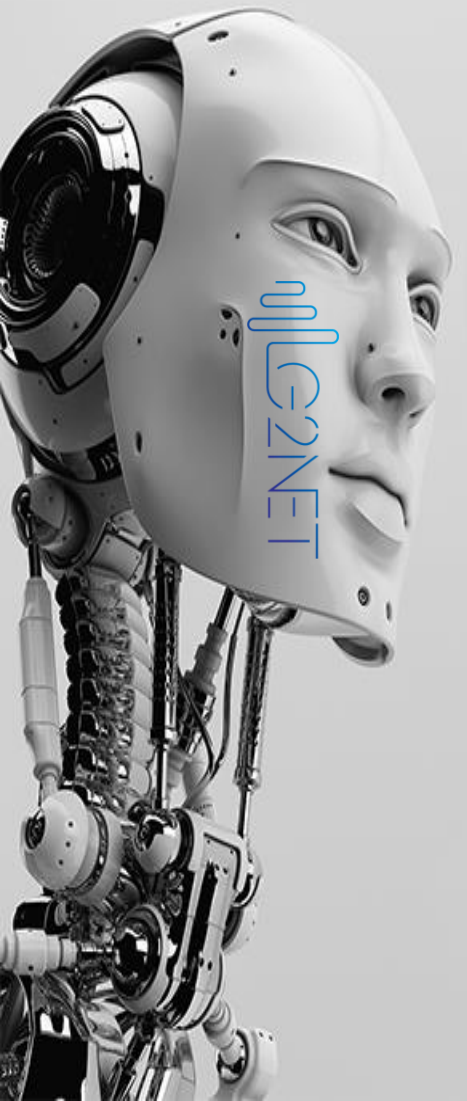
Reinforcement learning
- Playing games
- **Control**



Mnih et al 2015



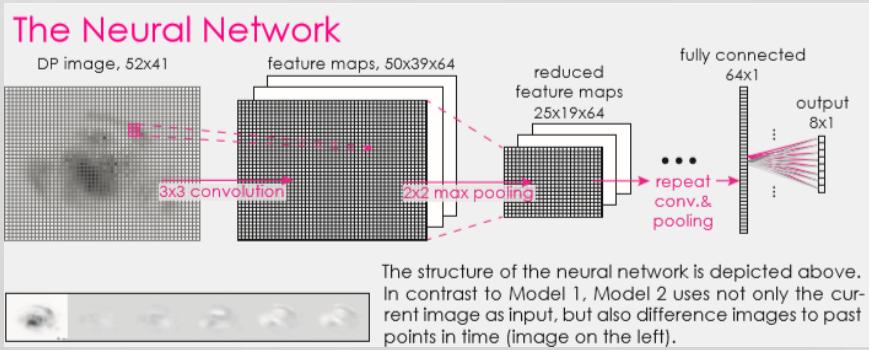
Sophisticated Example of Noise Cancellation



1. Train a policy NN (a NN that takes the past N samples of input channels and outputs the value subtracted from the next sample) with supervised learning
2. Train a value NN from the pre-computed policy NN
3. Use this, for example, as a starting point for a so-called actor-critic reinforcement-learning algorithm, which could further improve cancellation

Past and Current Work I

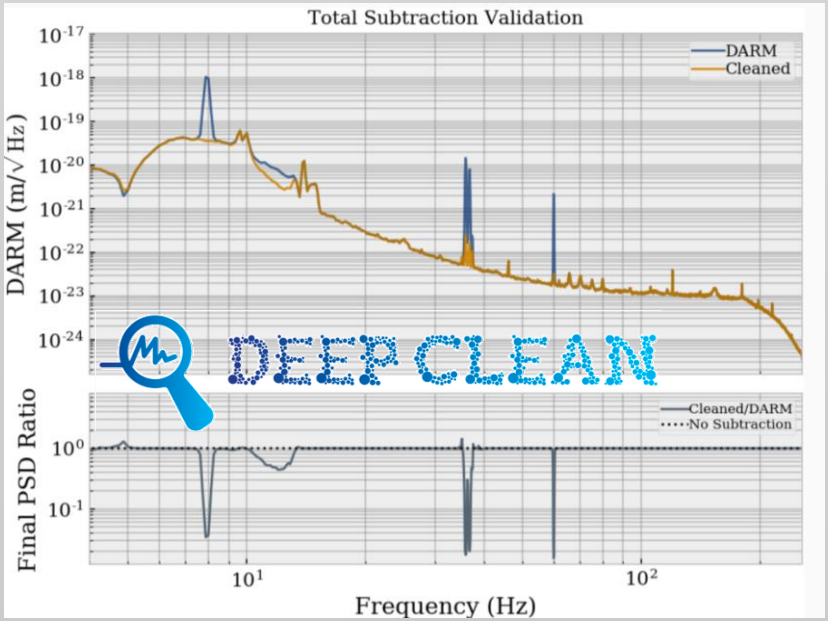
Adaptive optics (H Wittel at GEO600):



Parameters	Model 1 (immediate)	Model 2 (with past)
Training data set	8 minutes of video (25Hz) & WFS error signals	
Input data	single image (current time)	6 images (current + past)
Input size	52 x 41 px	312 x 41 px
# of free parameters	53.5 k	256 k
Training time on CPU*	1.3 h	8 h
Training time on GPU**	8 min	30 min
Inference time per step**	220 µs	1 ms

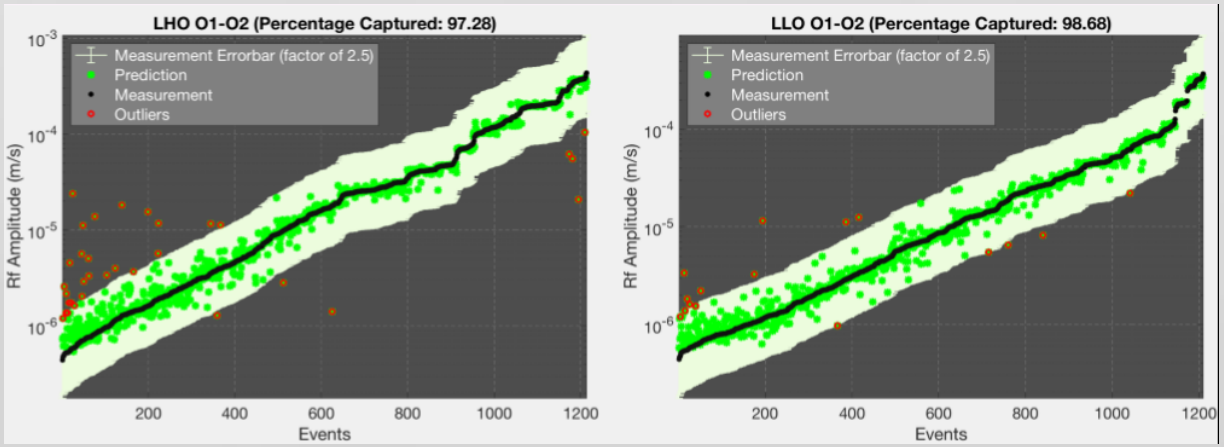
* Intel Core i7-7600U / ** Nvidia Quadro M2000M

Noise cancellation with nonlinear couplings (G Vajente et al):

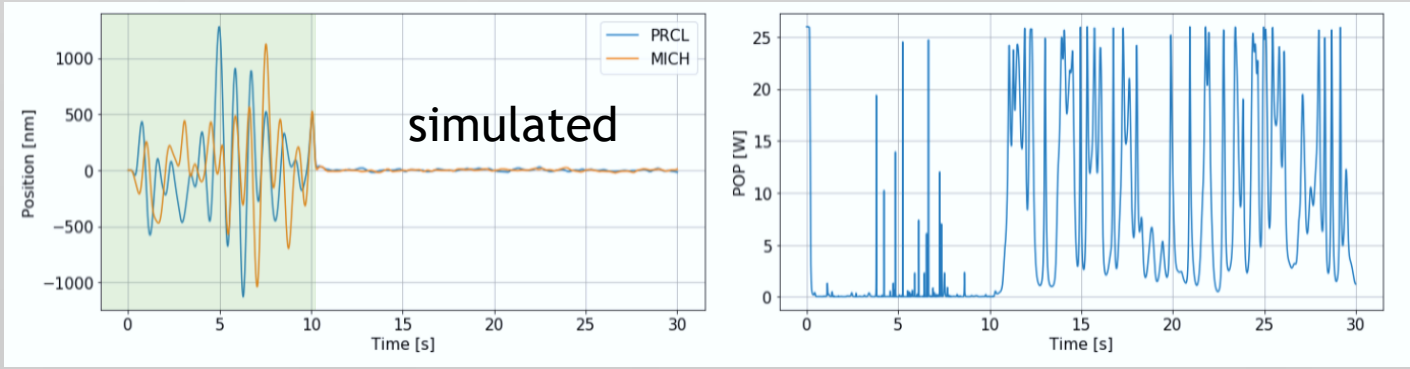


Past and Current Work II

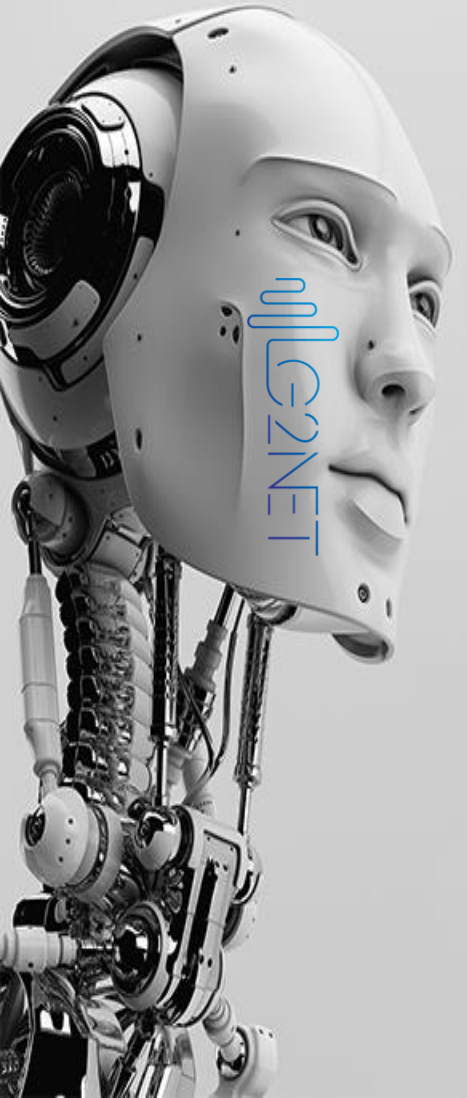
Real-time, earthquake-amplitude prediction (Mukund et al):



Lock acquisition with state estimation (G Vajente et al):

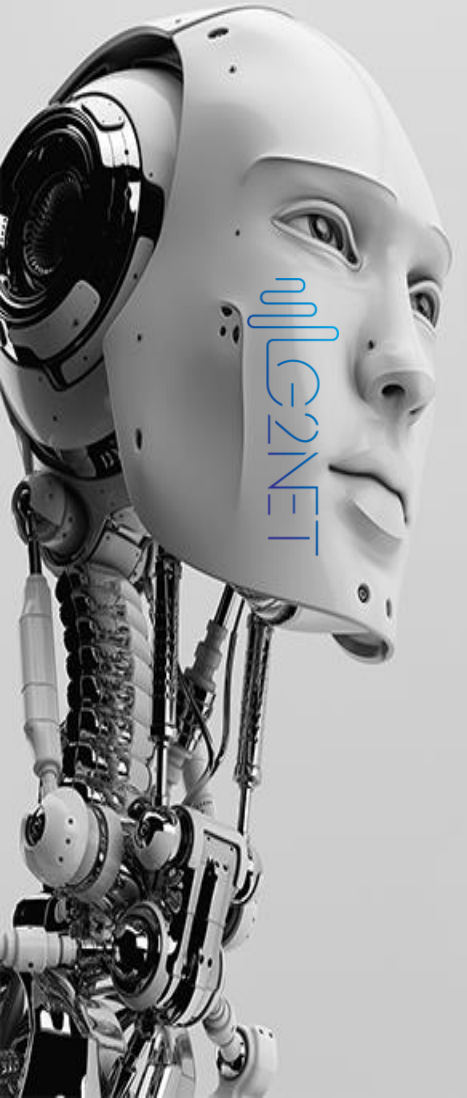


The Utopia



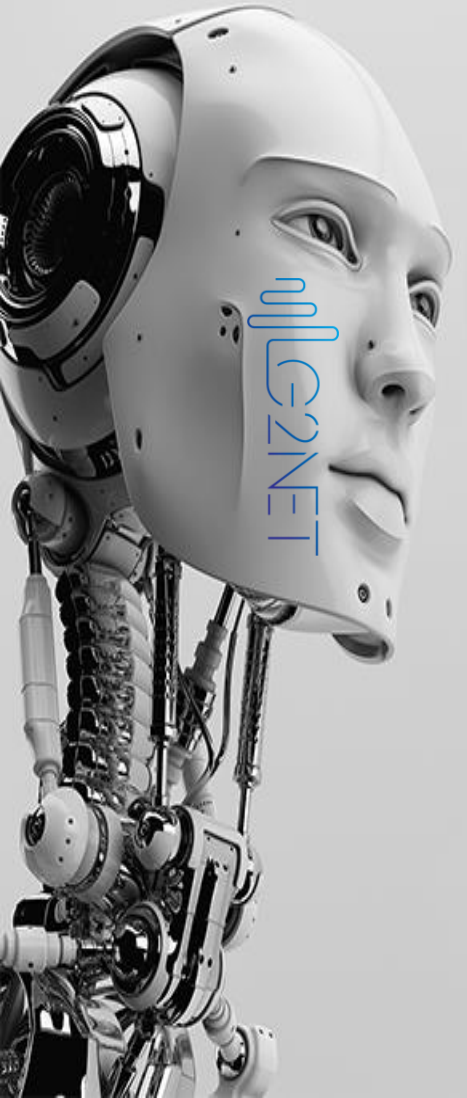
1. Interferometer control will be entirely left to an AI achieving near optimal performance in terms of duty cycle and sensitivity
2. AI will adjust controls to hardware changes (requires real-time analysis of all relevant channels)
3. AI will report to the commissioners, which part of the hardware causes the main limitations in terms of duty cycle and sensitivity

What Can We Actually Achieve in CA17137?



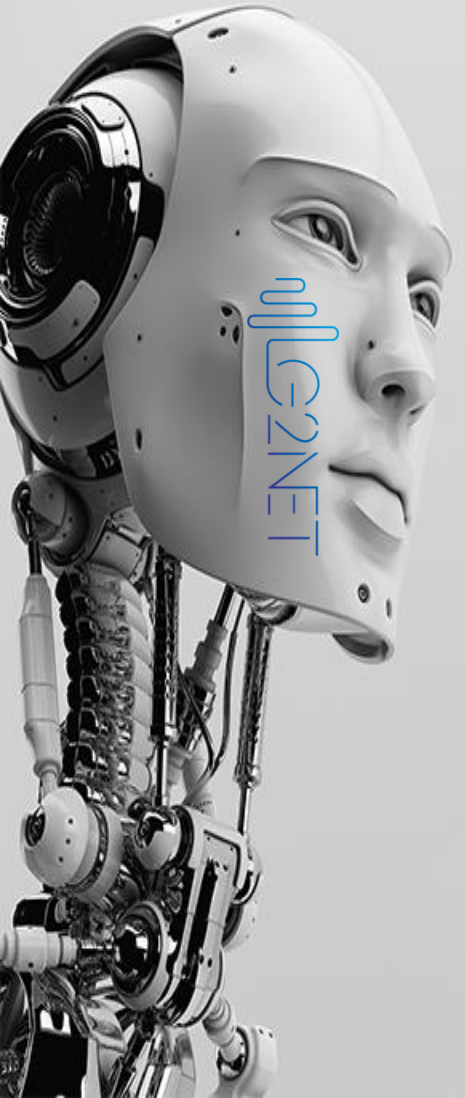
1. Convincing demonstrations in simulations
2. Improved feed-forward noise cancellation in systems with non-linear couplings, non-stationary noise, or time-variant systems
3. Implementation of ML controls in prototypes and dedicated lab experiments to solve specific problems
4. Introducing ML experts in commissioning teams

What Do We Need to Make WG3 a Success?



1. Young scientists at the right places (in terms of facilities and supervisors) dedicating significant time to WG3 projects
2. Support from lab leaders to offer opportunities to implement and test ML algorithms
3. Exchange with external experts

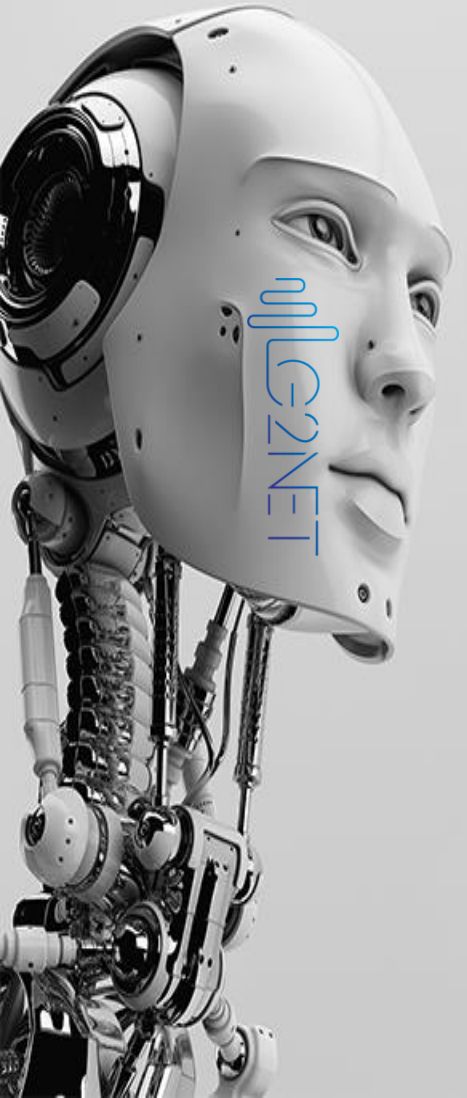
Two Approaches



Bird's view: take most powerful ML algorithms and see where you can apply them to detector controls problems

Bug's view: choose your favorite controls problem and try to solve it with a less complicated ML algorithm

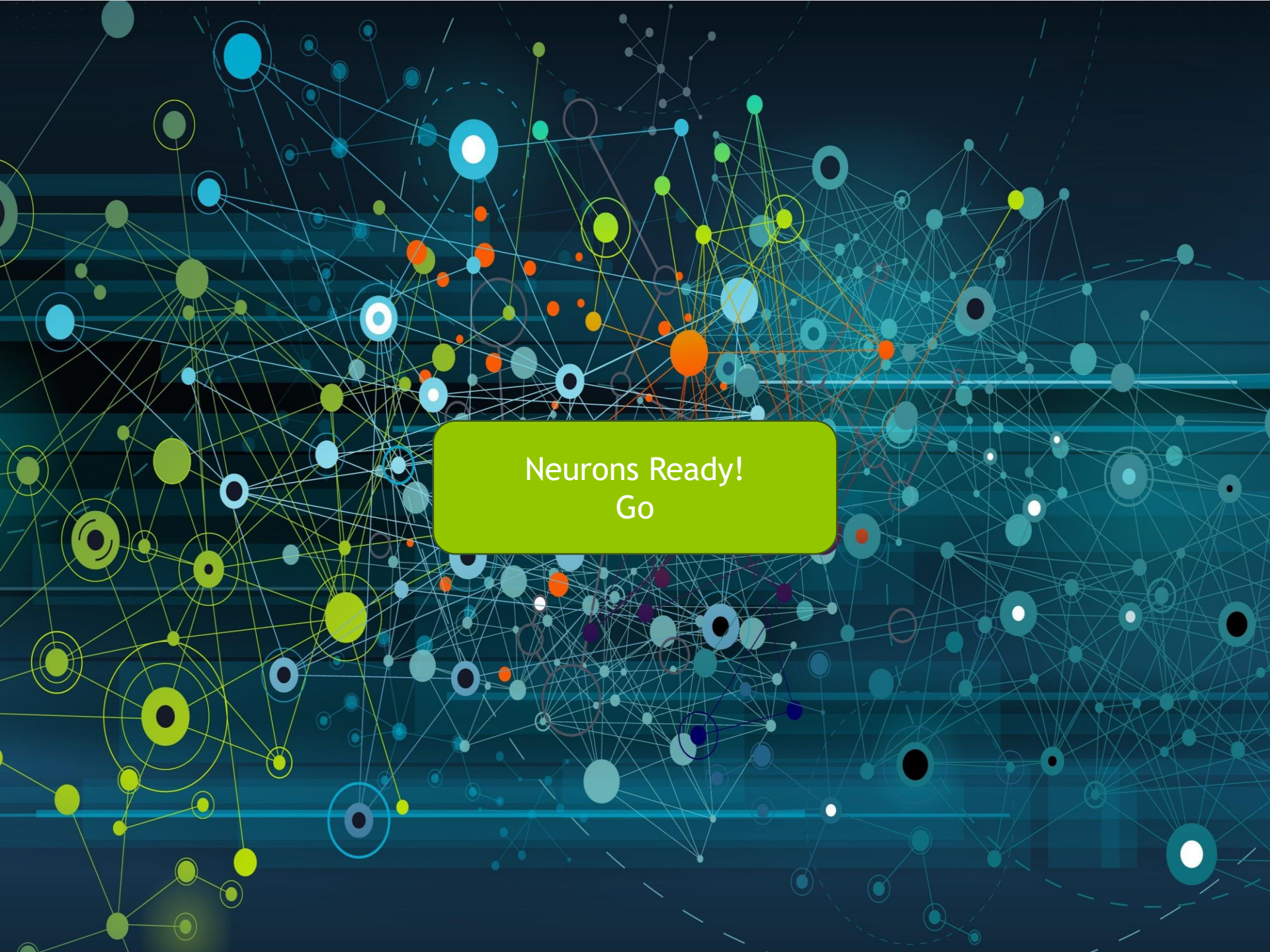
Machine-Learning Benefits



Publications for young scientists (also) working in commissioning.

Connecting our research to interests of private industry.

ML is one way to solve certain problems in detector commissioning.


Neurons Ready!
Go