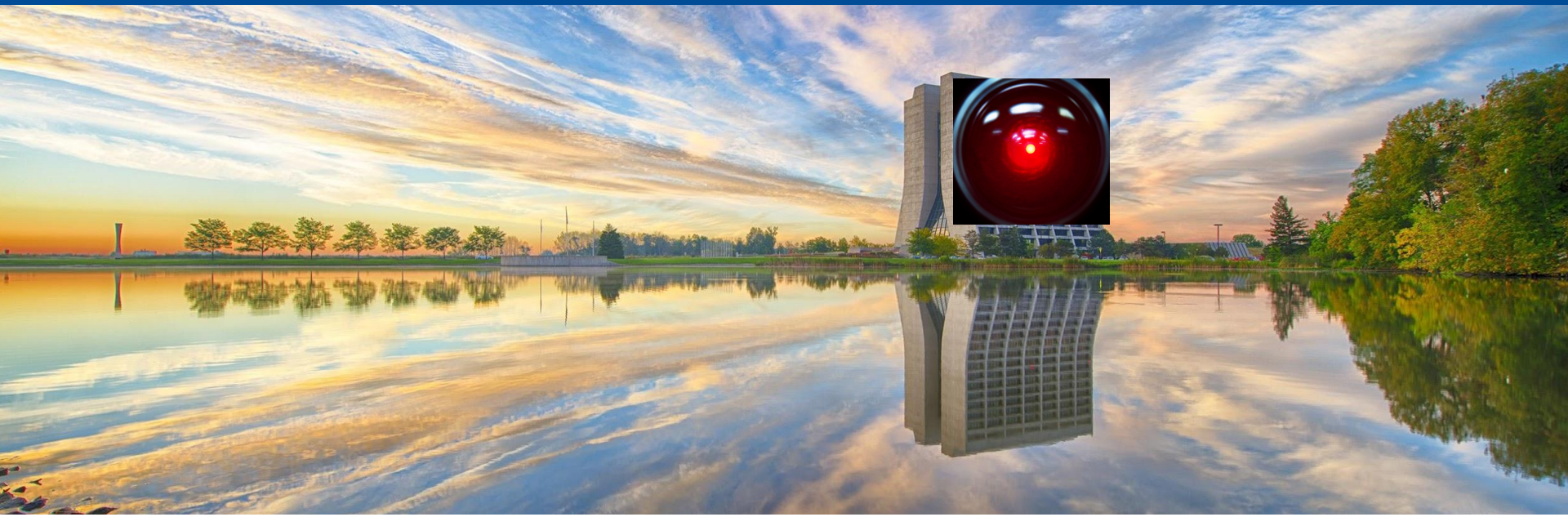
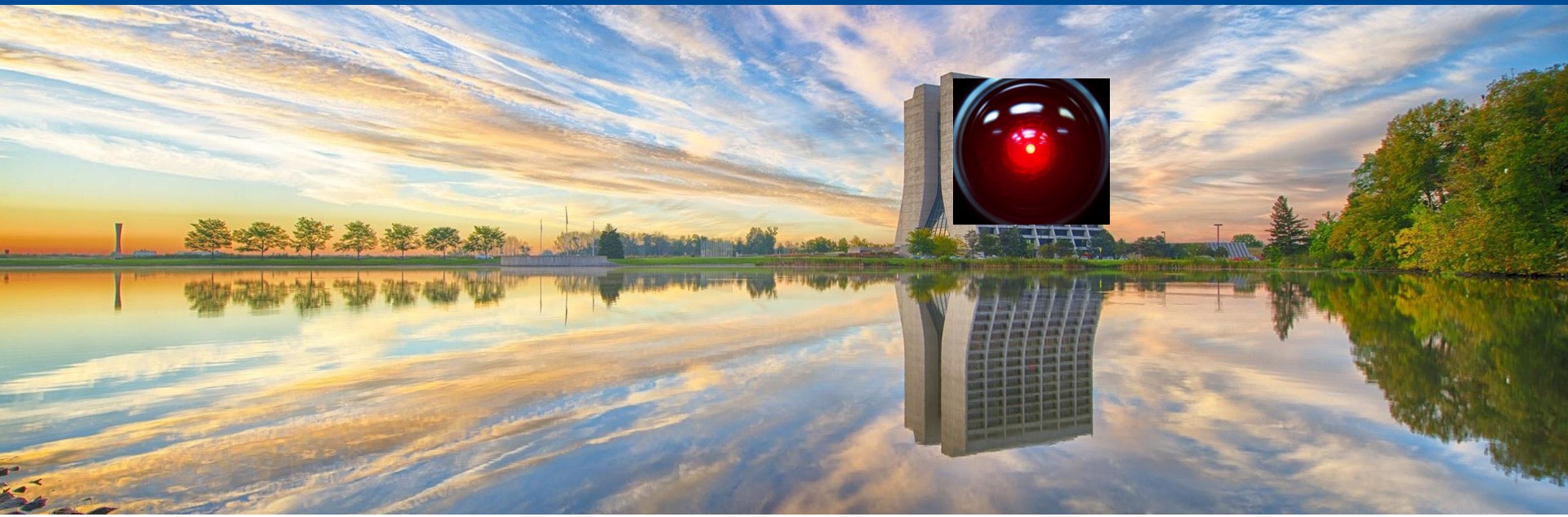


Artificial Intelligence at Fermilab

João Caldeira

Fermilab Users Meeting

12 June 2019



Wilson HAL 9000?

João Caldeira

Fermilab Users Meeting

12 June 2019

What is Artificial Intelligence?

Artificial Intelligence (AI) or *Machine Learning* (ML):

- Algorithms for which rules are not given, but inferred from data

- Power and usage grew enormously in the last decade

- This is due to more powerful computers (GPU -- graphical processing units) and some recently discovered techniques

AI in physics?

AI has had a place in physics for many years

PHYSICAL REVIEW D **78,** 012005 (2008)

Evidence for production of single top quarks

We present first evidence for the production of single top quarks in the D0 detector at the Fermilab Tevatron $p\bar{p}$ collider. The standard model predicts that the electroweak interaction can produce a top

such as W + jets and $t\bar{t}$ events, which we separate from the expected signals using three multivariate analysis techniques: boosted decision trees, Bayesian neural networks, and matrix-element calculations. A

Similar systems used in Higgs discovery

Recent progress in AI

“Deep learning” has enabled many developments

Recent progress in AI

"Deep learning" has enabled many developments

- Games

Go

Starcraft

Fermilab

Recent progress in AI

"Deep learning" has enabled many developments

- Games
- Self-driving cars

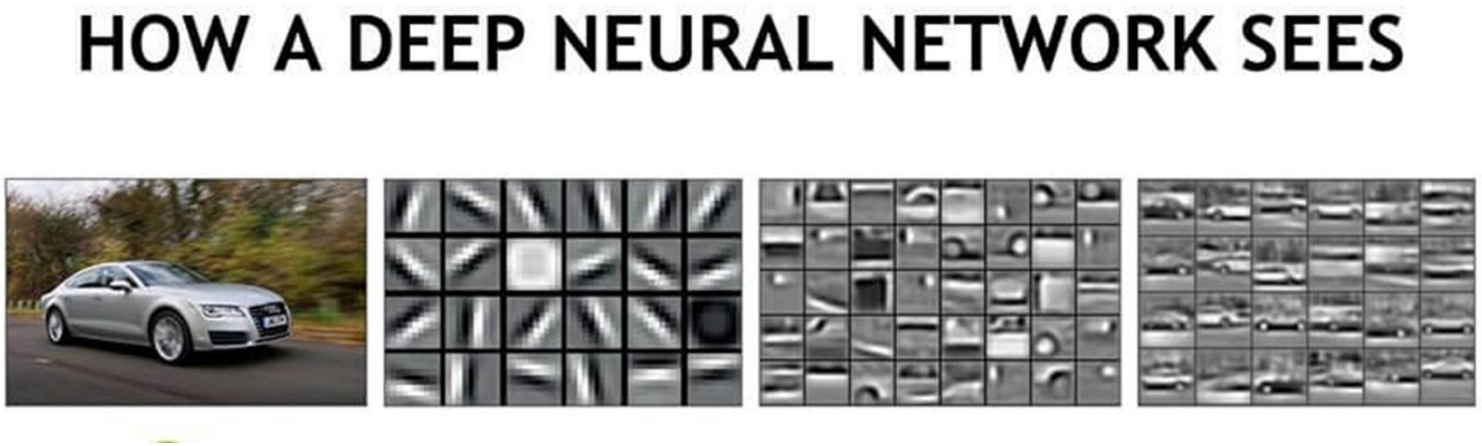
Recent progress in AI

"Deep learning" has enabled many developments

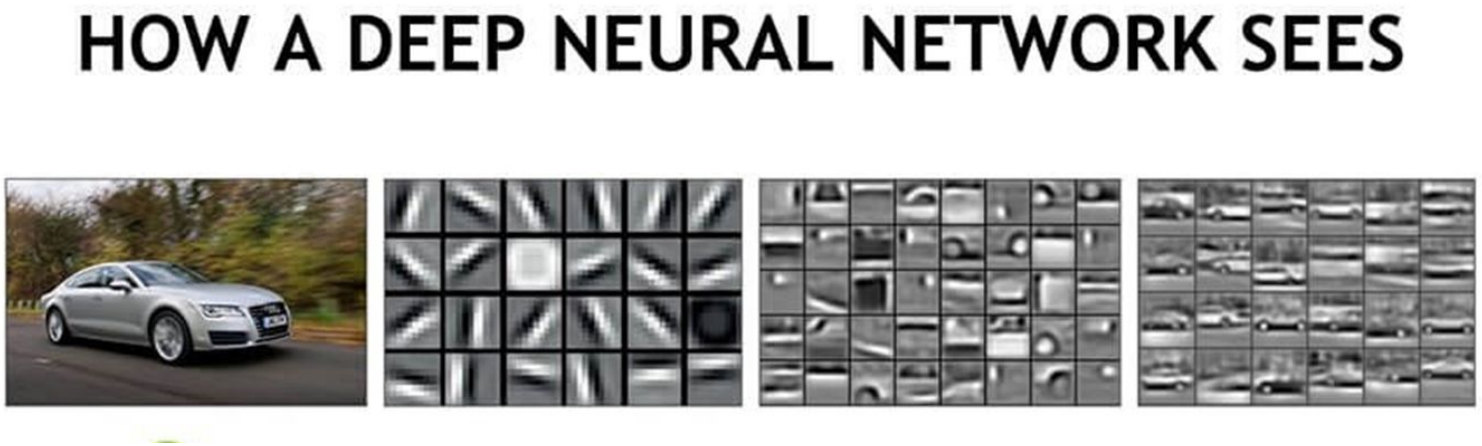
- Games
- Self-driving cars
- Language translation
- Generating new samples

www.thispersondoesnotexist.com

But what is Deep Learning?



But what is Deep Learning?

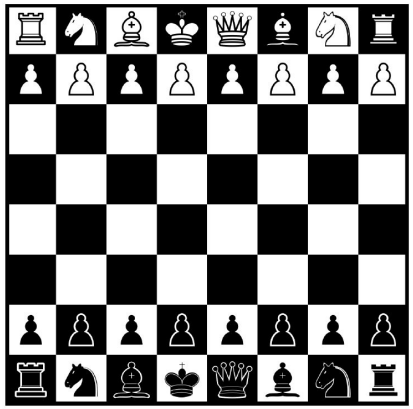


Features get more and more complex as we move forward in the neural network.

To learn more: [Andrew Ng's coursera ML course]

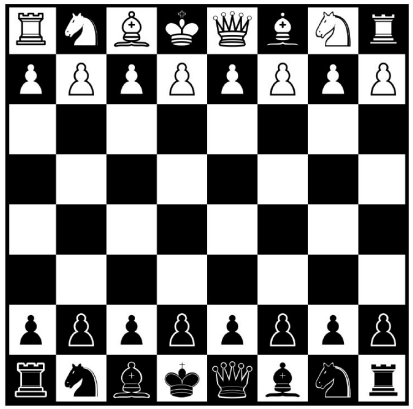
AI for science: an analogy

Hard problem: chess



AI for science: an analogy

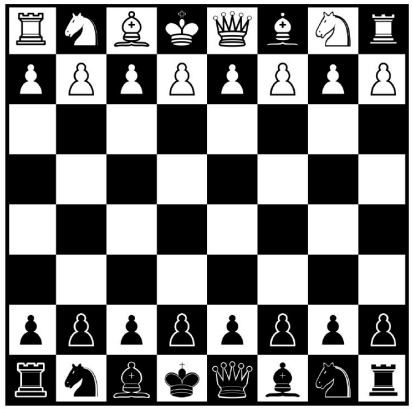
Hard problem: chess



Solution: rule-based system based on human knowledge

AI for science: an analogy

Hard problem: chess

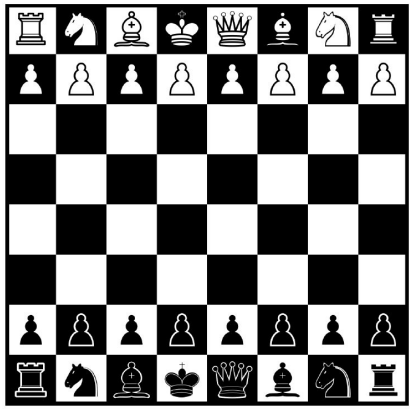


Solution: rule-based system based on human knowledge

Harder problem: go

AI for science: an analogy

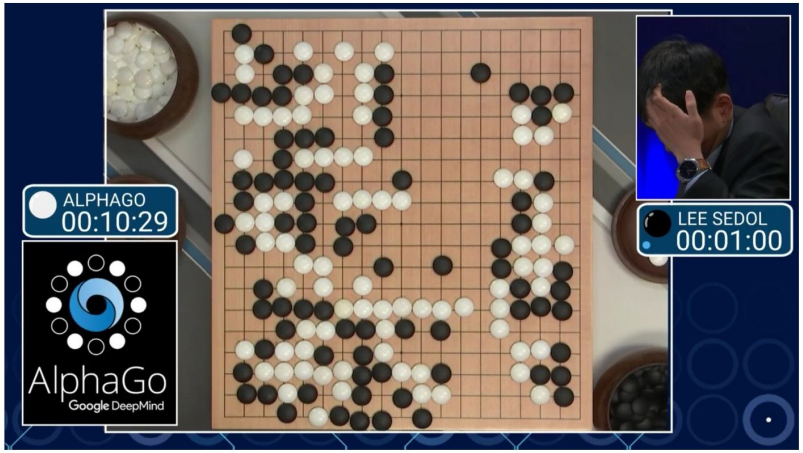
Hard problem: chess



Solution: rule-based system based on human knowledge

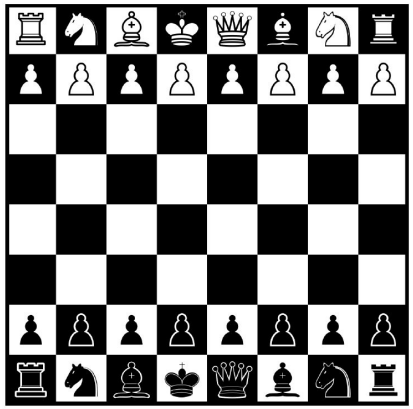
Harder problem: go

Solution: deep learning



AI for science: an analogy

Hard problem: chess



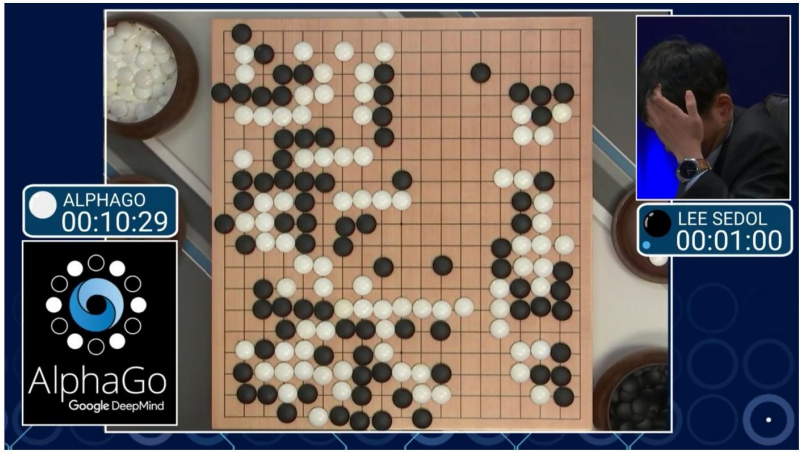
Discovery in past & current instruments

Solution: rule-based system based on human knowledge

Harder problem: Go

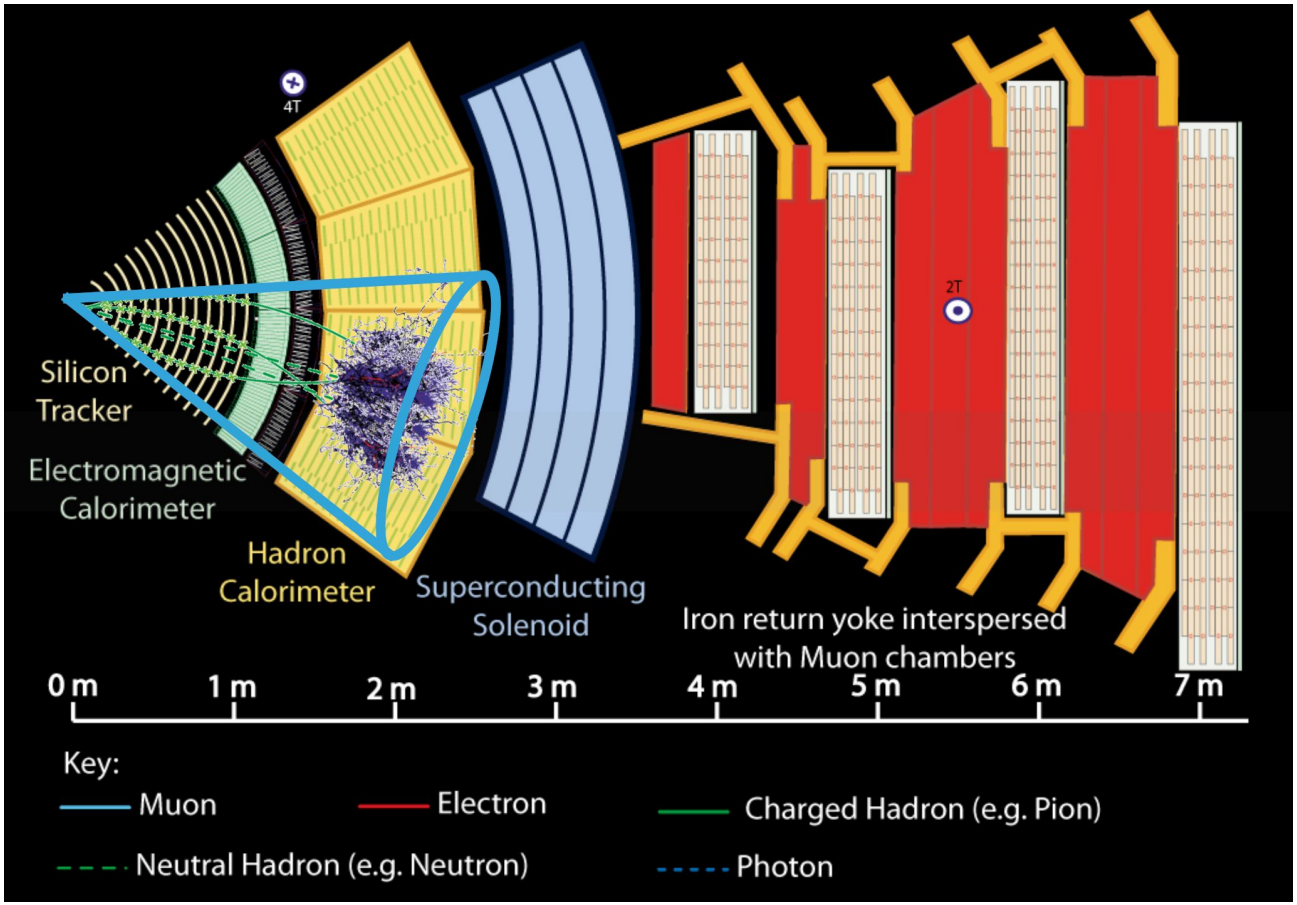
Discovery in current & future instruments

Solution: deep learning



AI for CMS

Quarks and gluons interact via strong force and are never seen in isolation: *jets* of hadrons, measure to test Standard Model



AI for CMS: well-established

Identify jets from images: arXiv:1511.05190,

Quark/gluon discrimination: arXiv:1612.01551,

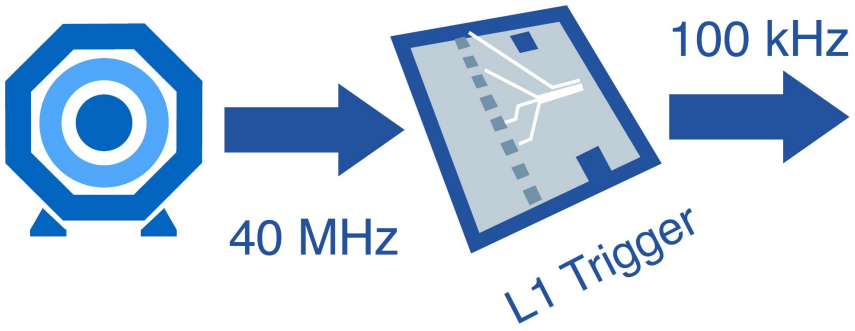
Particle tracking: HEP.TrkX,
arXiv:1810.06111,

Fast inference on FPGA: JINST 13 P07027,
arXiv:1904.08986.

Deep learning works well

JINST 13 P07027
arXiv:1904.08986

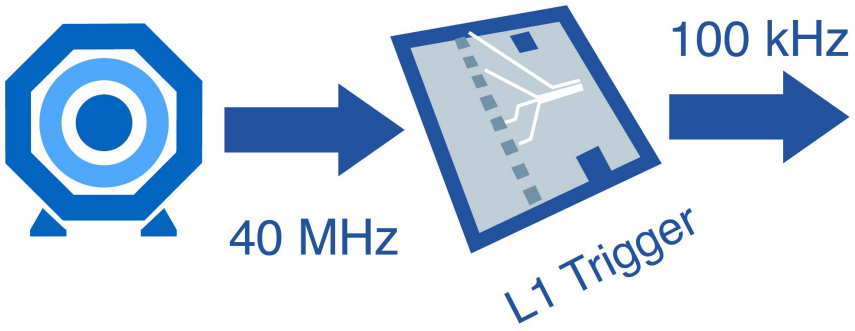
But decisions have to be *fast*

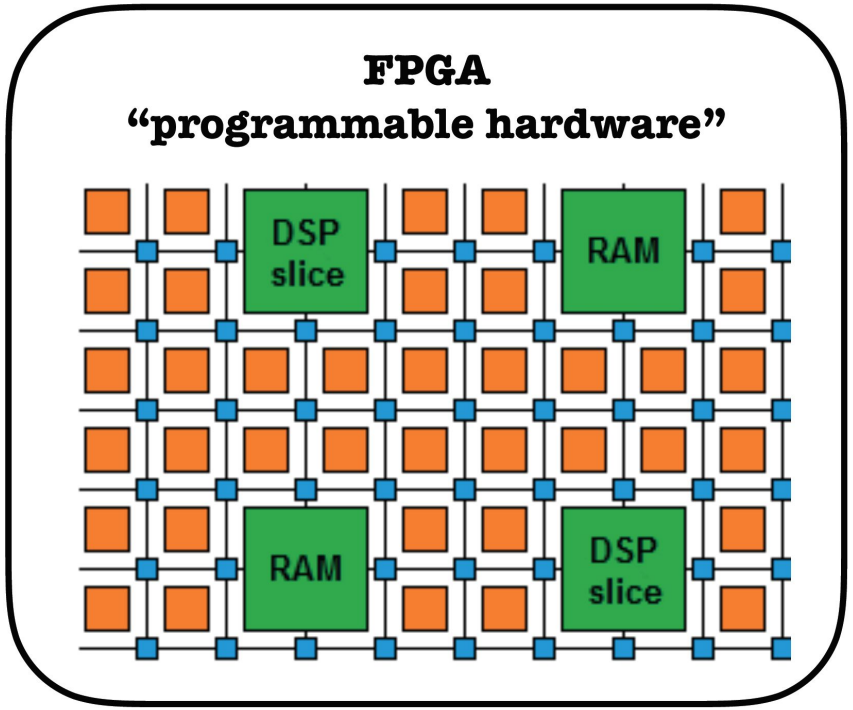


Deep learning works well

JINST 13 P07027
arXiv:1904.08986

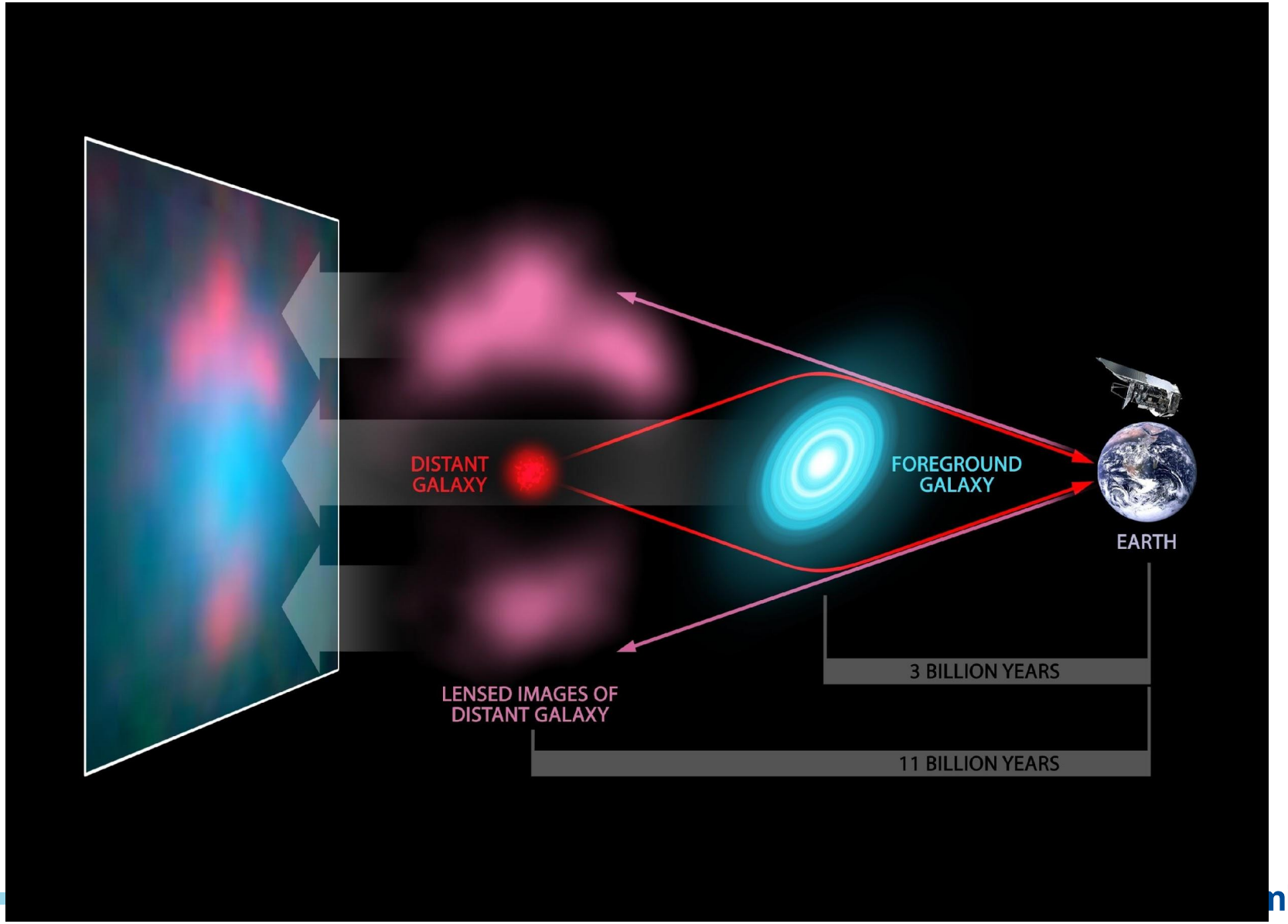
But decisions have to be *fast*

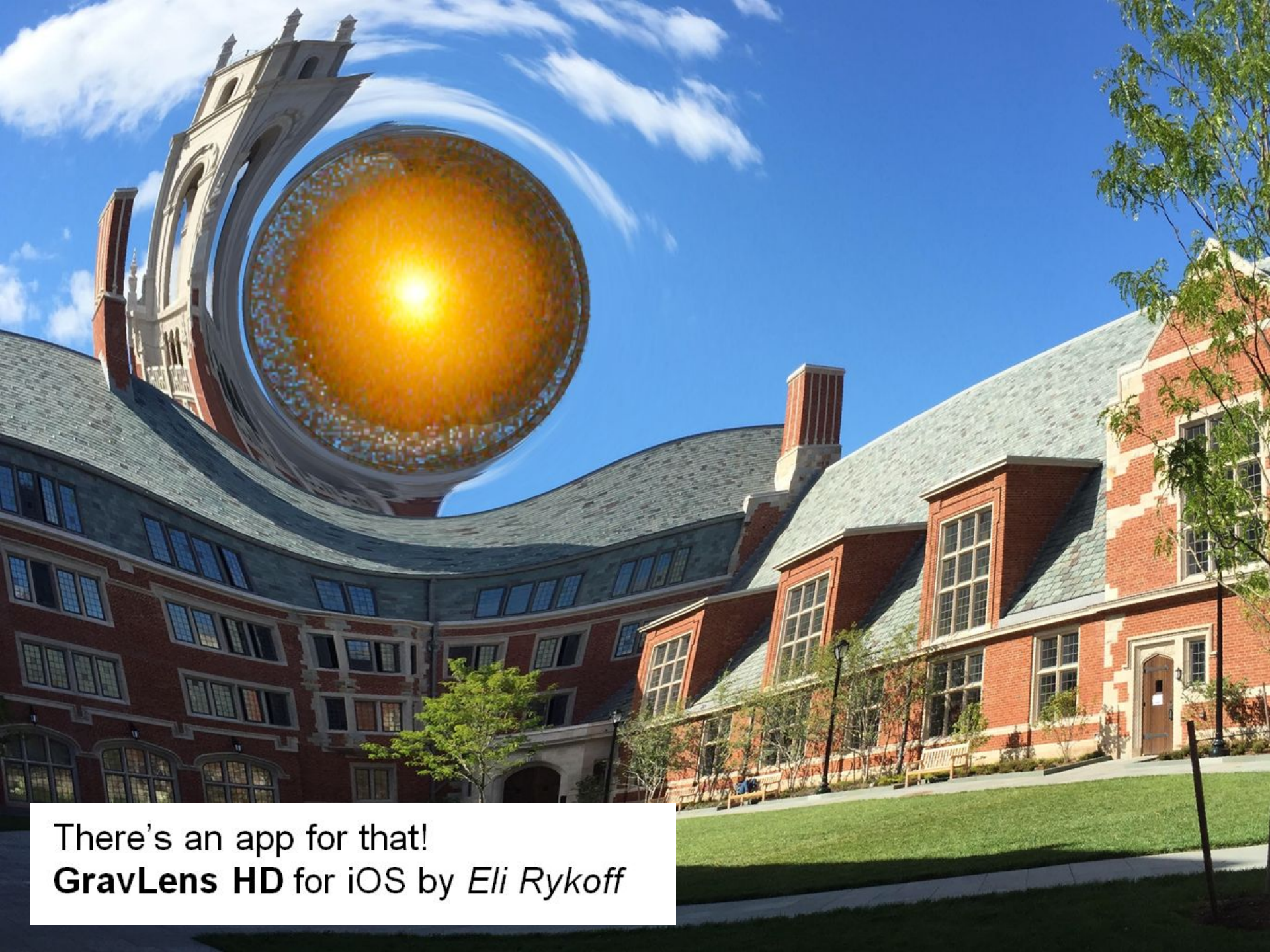




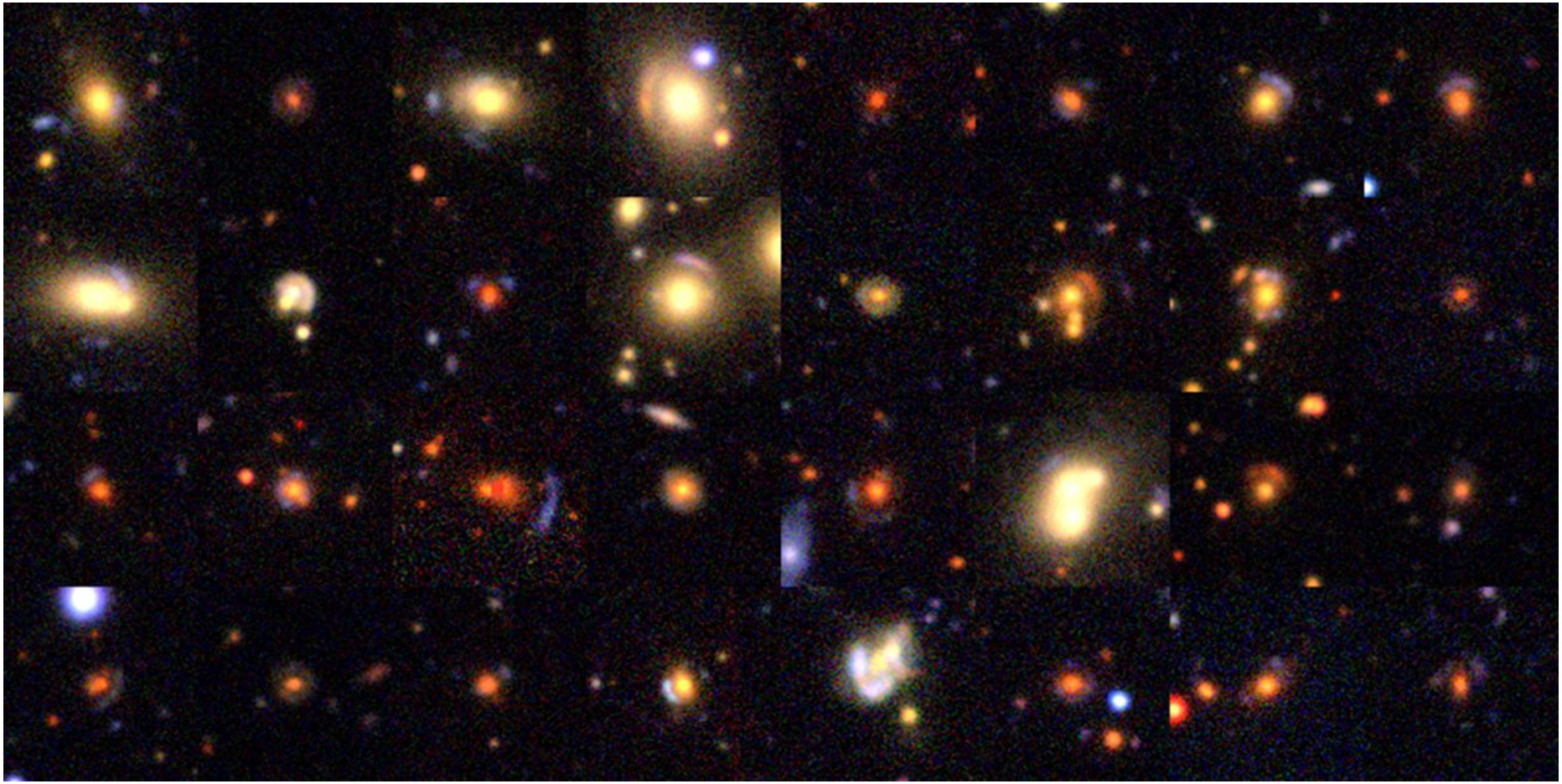
Developed automated tools to translate AI into firmware; Inference of networks with 1000s of parameters to run in < 100 ns!

Cosmic frontier: finding & measuring strong lenses




There’s an app for that!
GravLens HD for iOS by *Eli Rykoff*

Lenses discovered in the Dark Energy Survey



MNRAS 484 5330

A Shifting Paradigm

Lens type

Sample	Galaxy	Quasar	SNe
Today (all)	1000	<50	2
DES	2,000	120	5
LSST	120,000	8,000	120
Euclid	170,000	-	-

ApJ 827 51; ApJ 811 20; ApJ 677 1046; MNRAS 405 2579

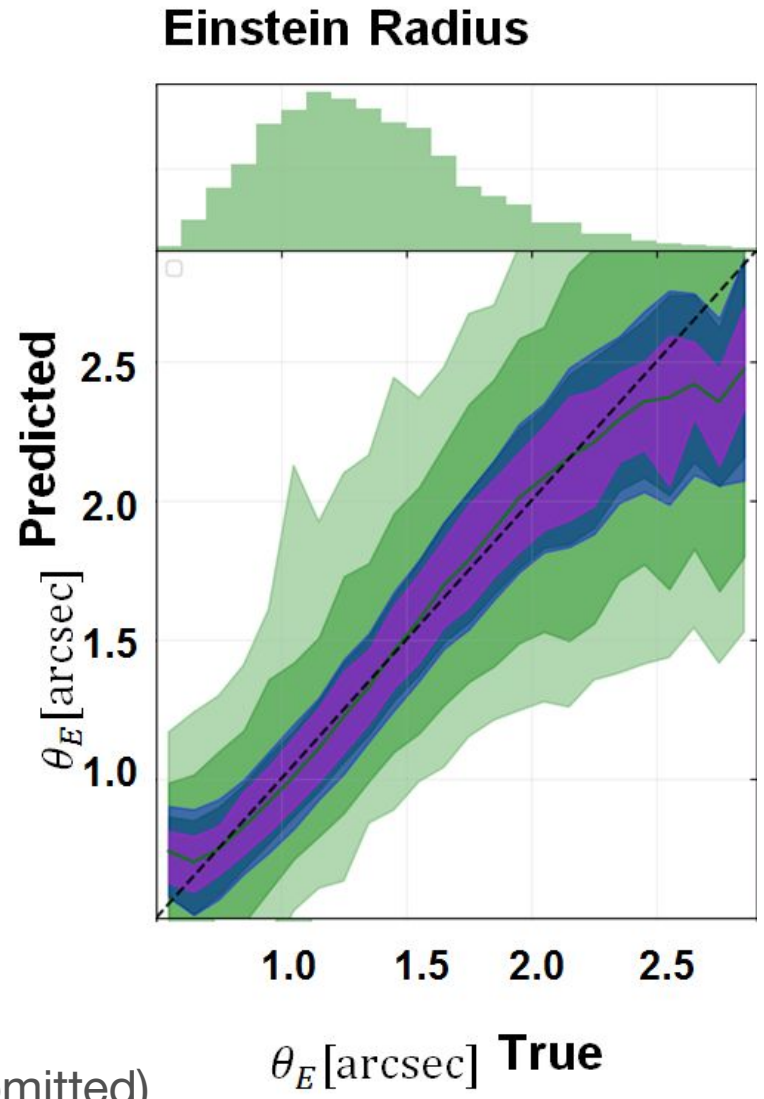
Predicting strong lens parameters

Can we not only find lenses, but also measure the relevant parameters?

And more importantly, can we measure uncertainties?

: statistical error

: model error



De Bom, Poh, Nord (submitted)

Predicting strong lens parameters

Can we not only find lenses, but also measure the relevant parameters?

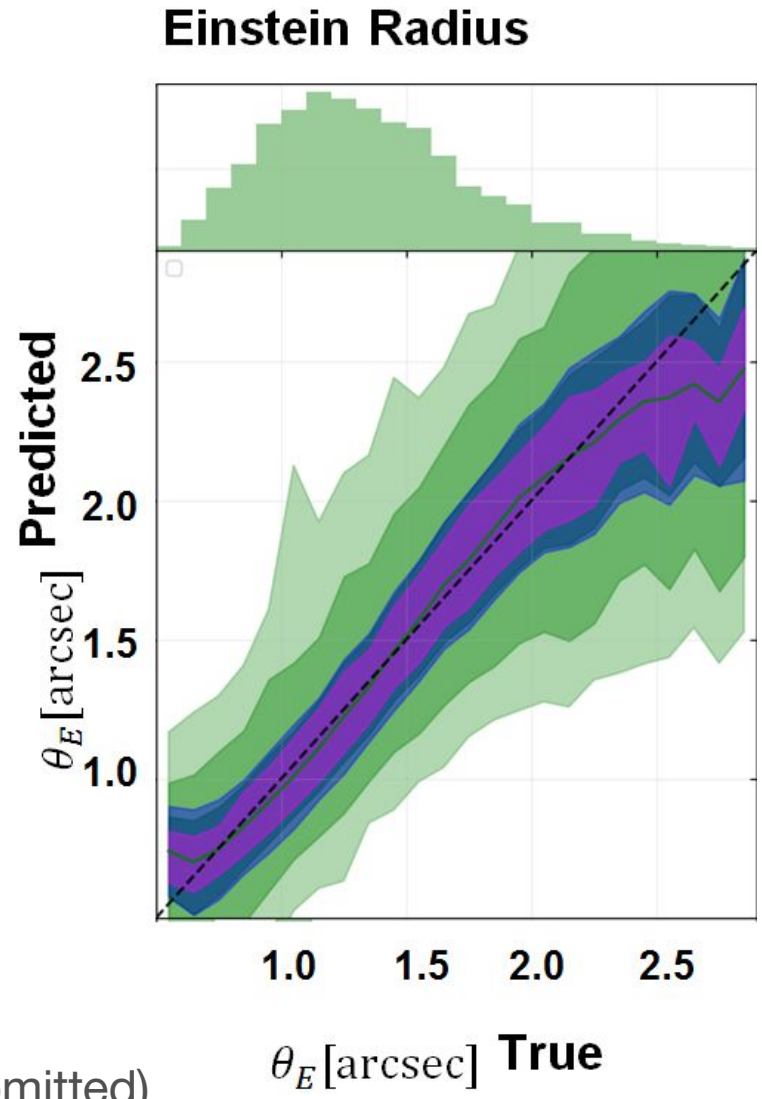
And more importantly, can we measure uncertainties?

: statistical error

: model error

See also CMB lensing reconstruction: arXiv:1810.01483, blog (and poster outside)

De Bom, Poh, Nord (submitted)



AI for neutrino experiments

Identify particles from tracks in MicroBooNE: PRD 99 092001, arXiv:1903.05663,

Similar techniques being developed in MINERvA,

Reducing simulation model bias in MINERvA: JINST 13 P11020,

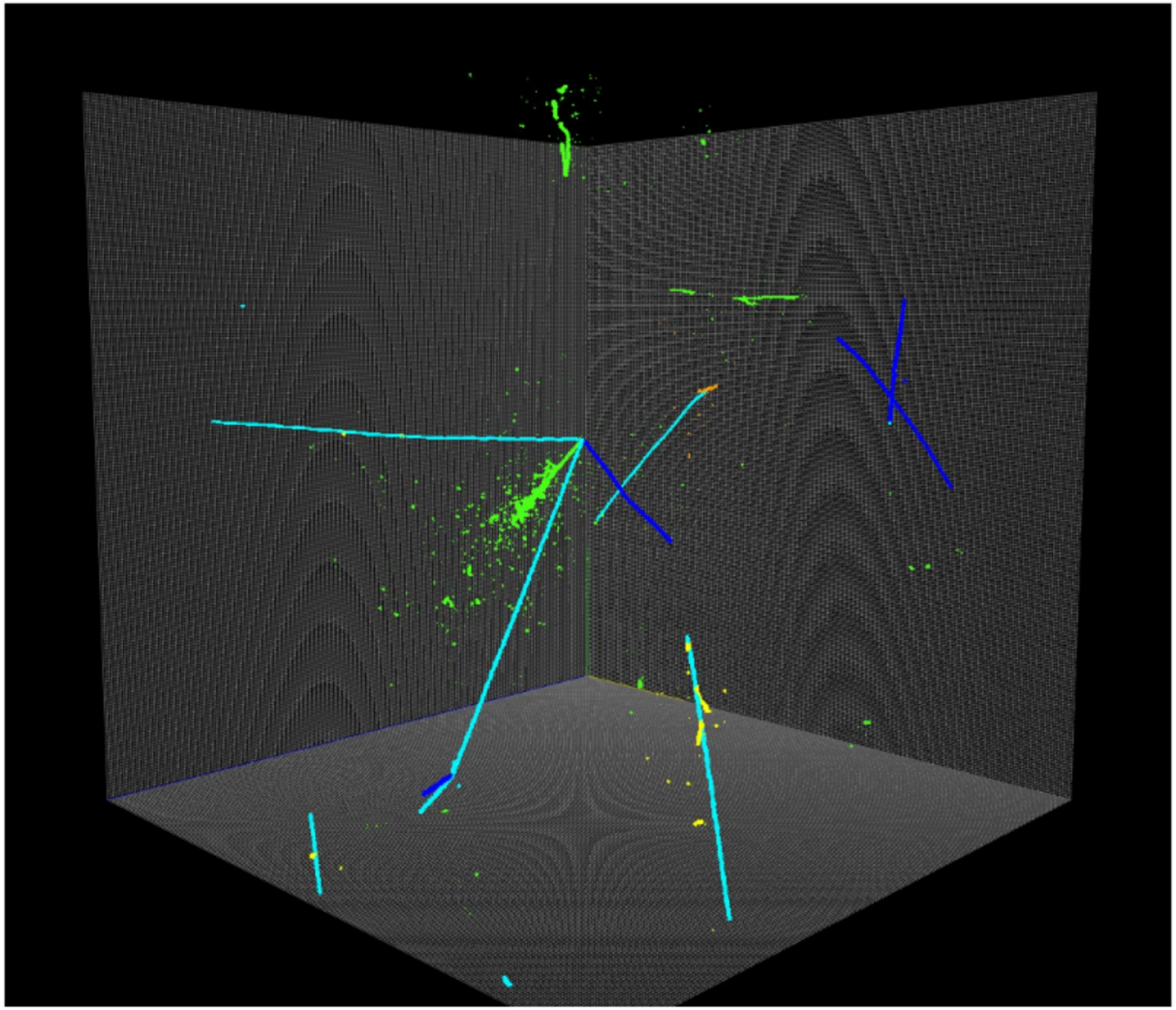
NOvA event classifier: JINST 11 P09001,

NOvA energy estimator: PRD 99 012011.

AI for neutrinos: MicroBooNE

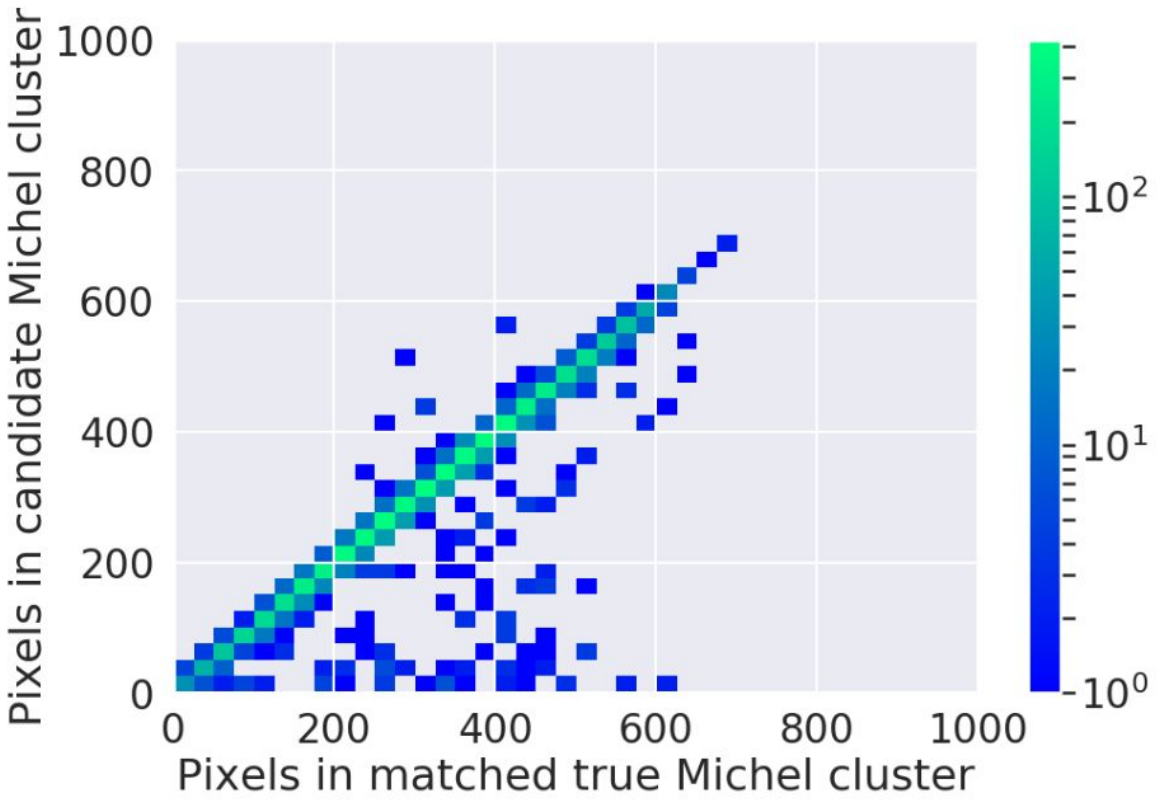
Analyze and identify particle tracks in Liquid Argon Time Projection Chambers or LArTPC.

Need adaptation for sparse data!



MicroBooNE results (simulation)

arXiv:1903.05663



91.8% of reconstructions have purity and efficiency > 95%

vs

Other methods: 80-90% purity, 2% efficiency

AI for neutrinos: MINERvA

Can we adapt MicroBooNE code infrastructure?

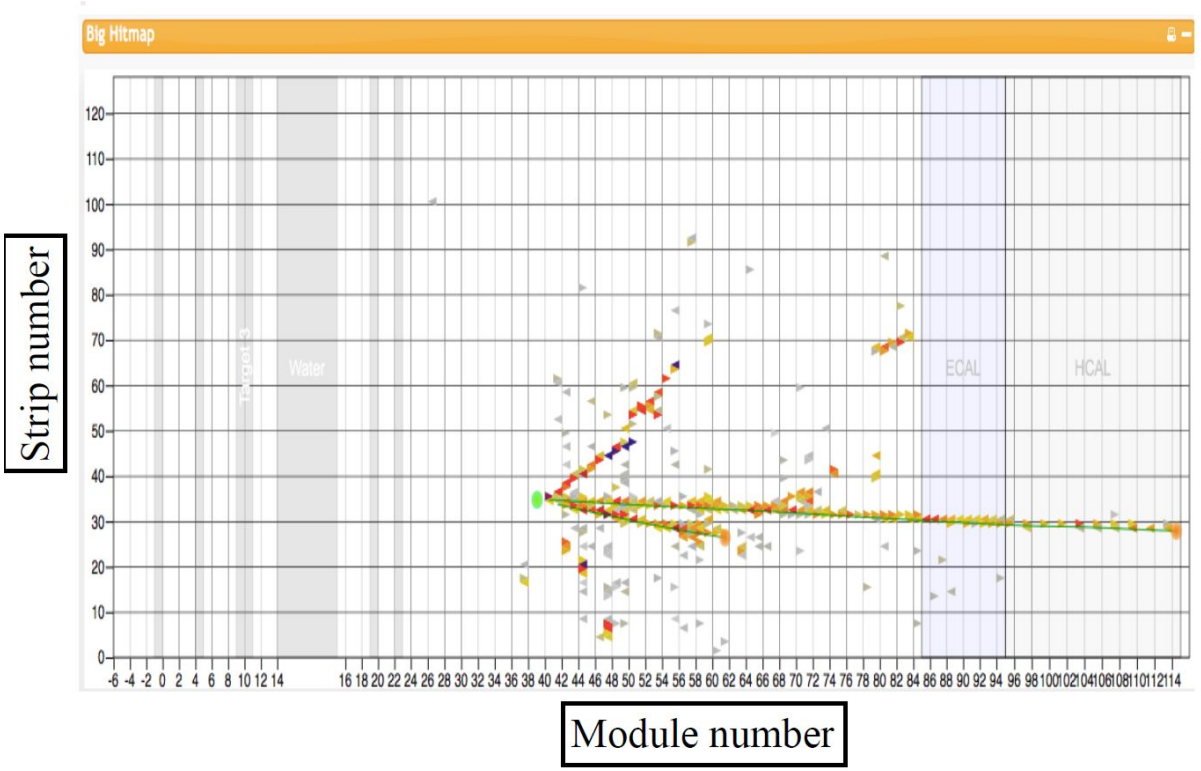
- Different detector (plastic scintillator), higher energy
- This means messier events

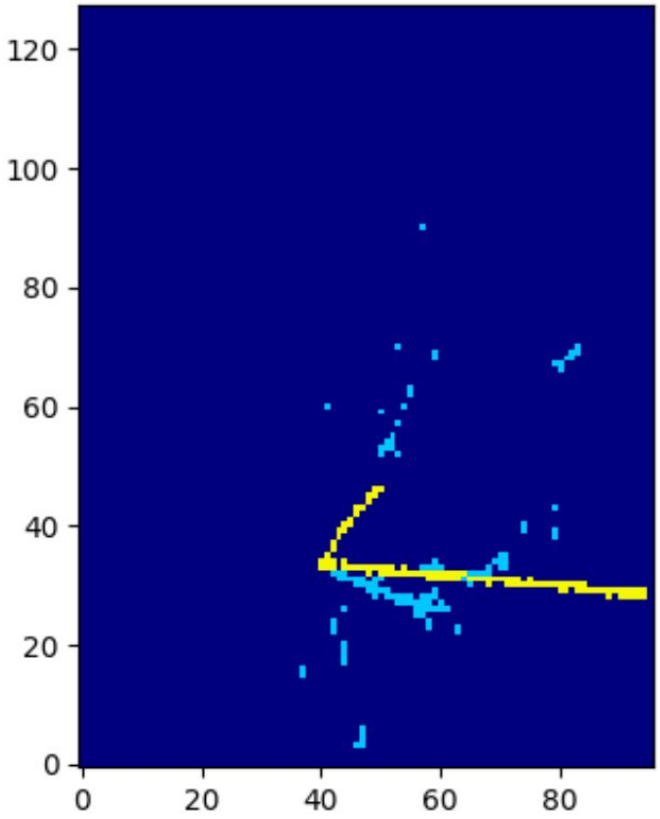
AI for neutrinos: MINERvA

in progress (sims)

Can we adapt MicroBooNE code infrastructure?

- Different detector (plastic scintillator), higher energy
- This means messier events

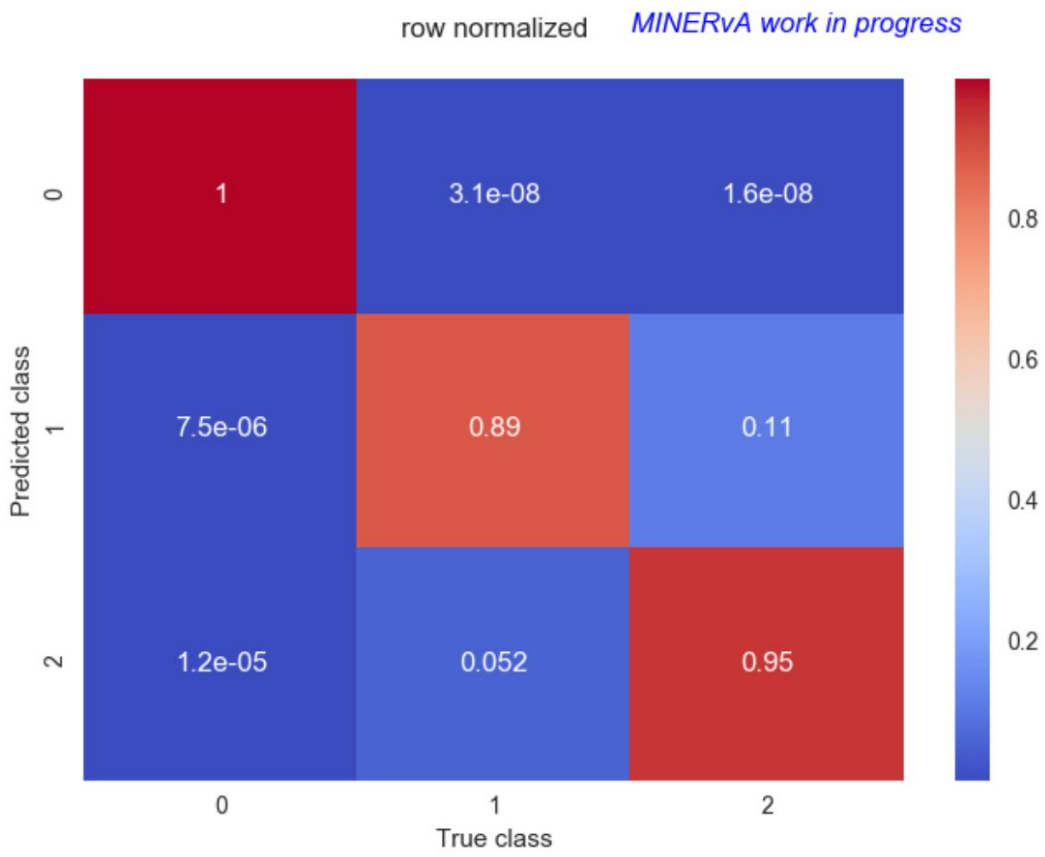




Fermilab

AI for neutrinos: MINERvA

in progress (sims)

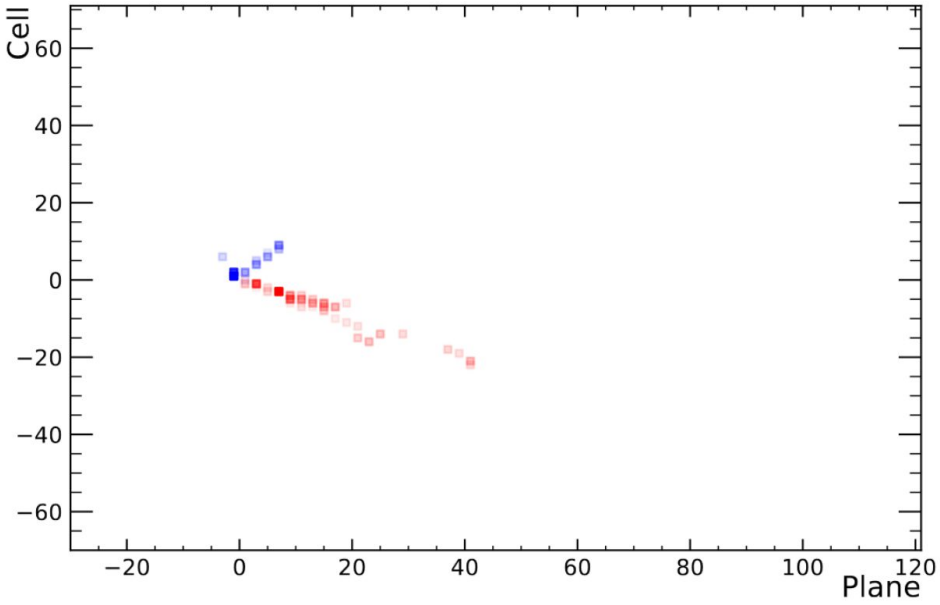


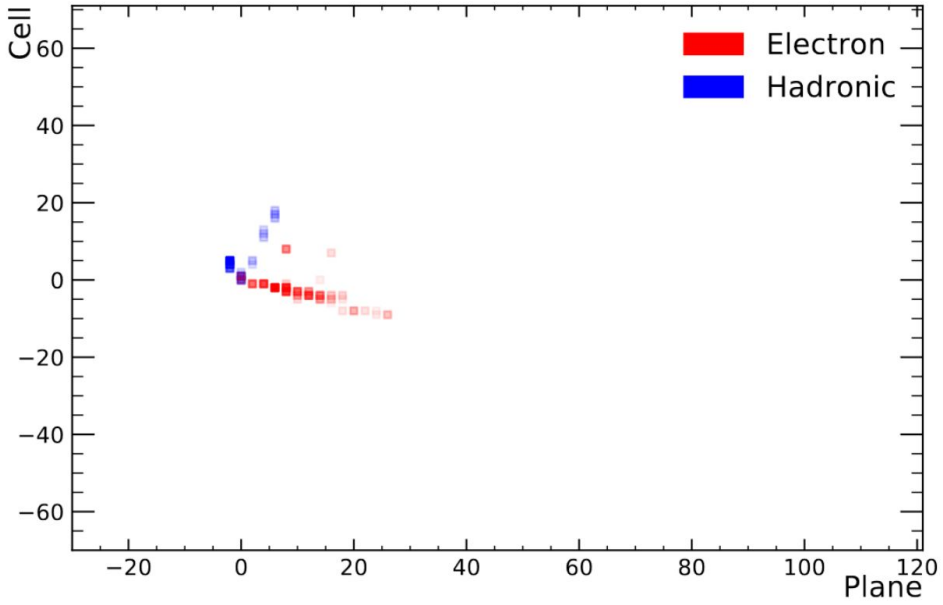
Class	Diagonal value from row normalized matrix
0	0.99
1 (EM-like)	0.89
2(Non-EM like)	0.95

AI for neutrinos: NOvA

PRD 99 012011

Liquid scintillator detector. Reconstruct event energy:



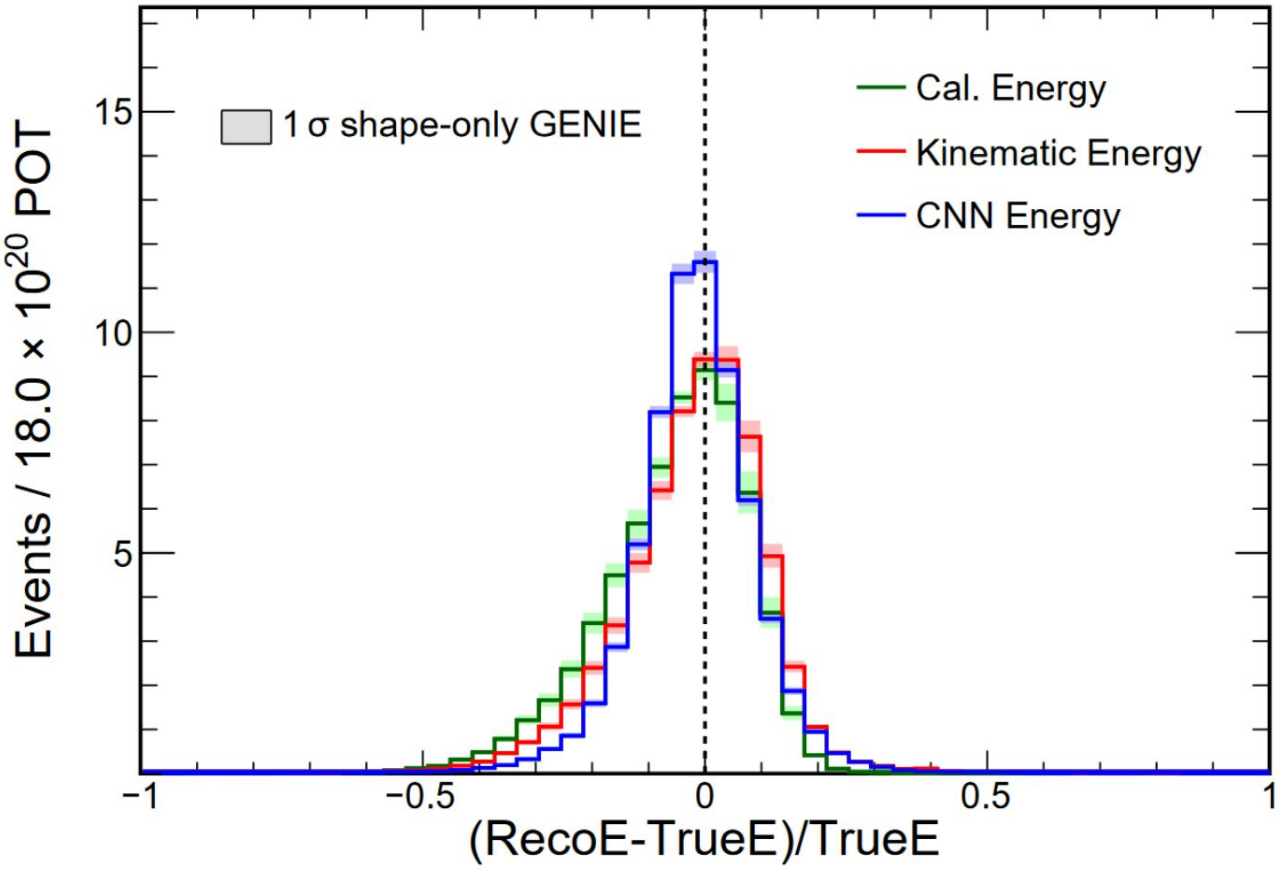


Can a neural network, just from these images, return the energy of the original neutrino and of the electron shower?

AI for neutrinos: NOvA

PRD 99 012011

Better performance than with previous kinematic methods! (on sims)



Fermilab

Outlook

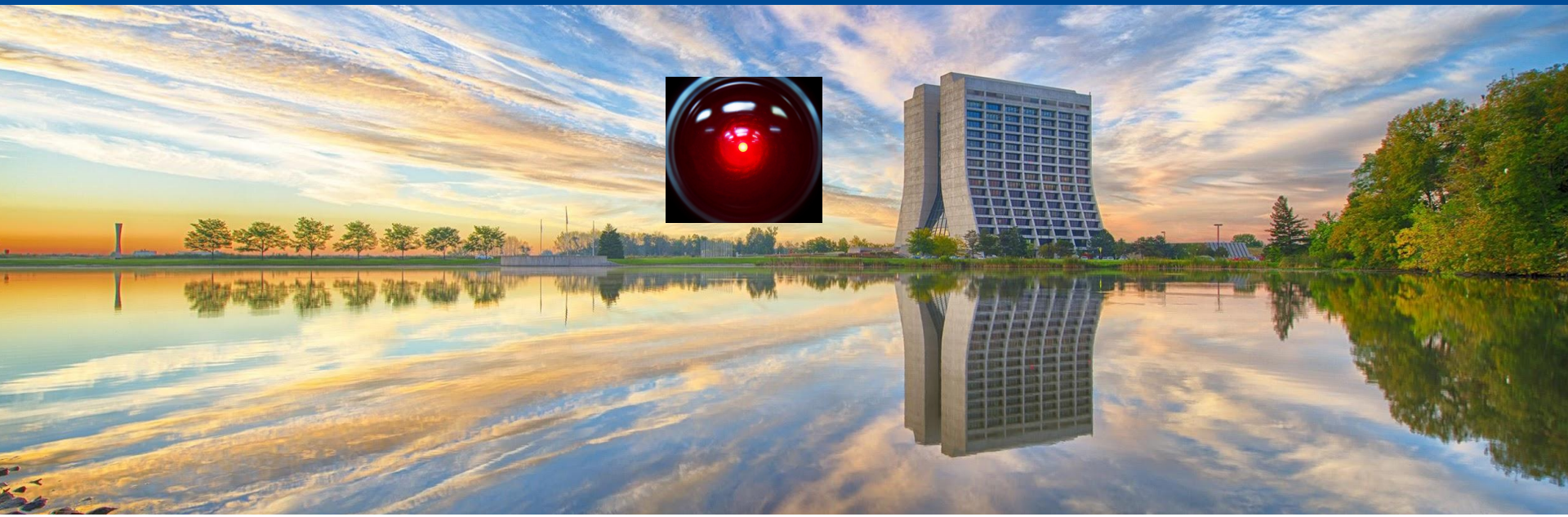
Nature 560 41

- Machine learning is an exciting and crucial toolset whose utility is just starting to be explored

- Often extreme computing challenges in physics experiments need AI tools to succeed

- Needed tools on the science side can also drive development in AI! (eg, uncertainty quantification)

- What is the bottleneck in your work, and can AI help you?



Wilson Hall + HAL 9000!

João Caldeira

Fermilab Users Meeting

12 June 2019