

# Welcome to IAIFI @ MIT Physics!

Jesse Thaler

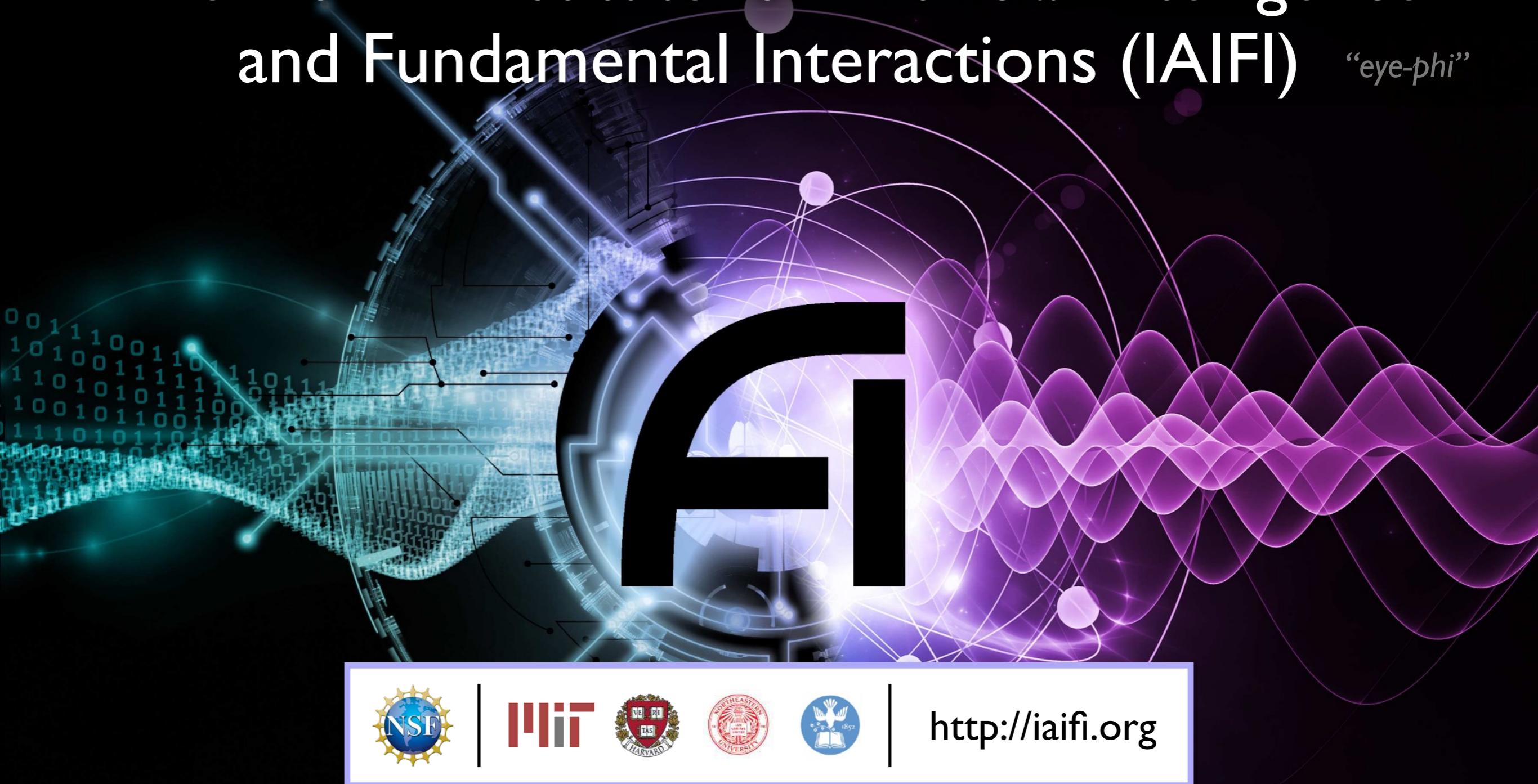
*IAIFI Director*



*Warrior-Scholar Project Open House — July 21, 2021*

# The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI)

“eye-phi”



<http://iaifi.org>

*Advance physics knowledge — from the smallest building blocks of nature  
to the largest structures in the universe — and galvanize AI research innovation*

[MIT News Announcement]

# The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI) “eye-phi”

Boston Area: **Critical Mass** for Transformative Research  
at the Intersection of **Physics** and **AI**



Pulkit Agrawal  
Lisa Barsotti  
Isaac Chuang  
William Detmold  
Bill Freeman  
Philip Harris  
Kerstin Perez  
Alexander Rakhlin

Phiala Shanahan  
Tracy Slatyer  
Marin Soljacic  
Justin Solomon  
Washington Taylor  
Max Tegmark  
Jesse Thaler  
Mike Williams



Demba Ba  
Edo Berger  
Cora Dvorkin  
Daniel Eisenstein  
Doug Finkbeiner  
Matthew Schwartz  
Yaron Singer  
Todd Zickler



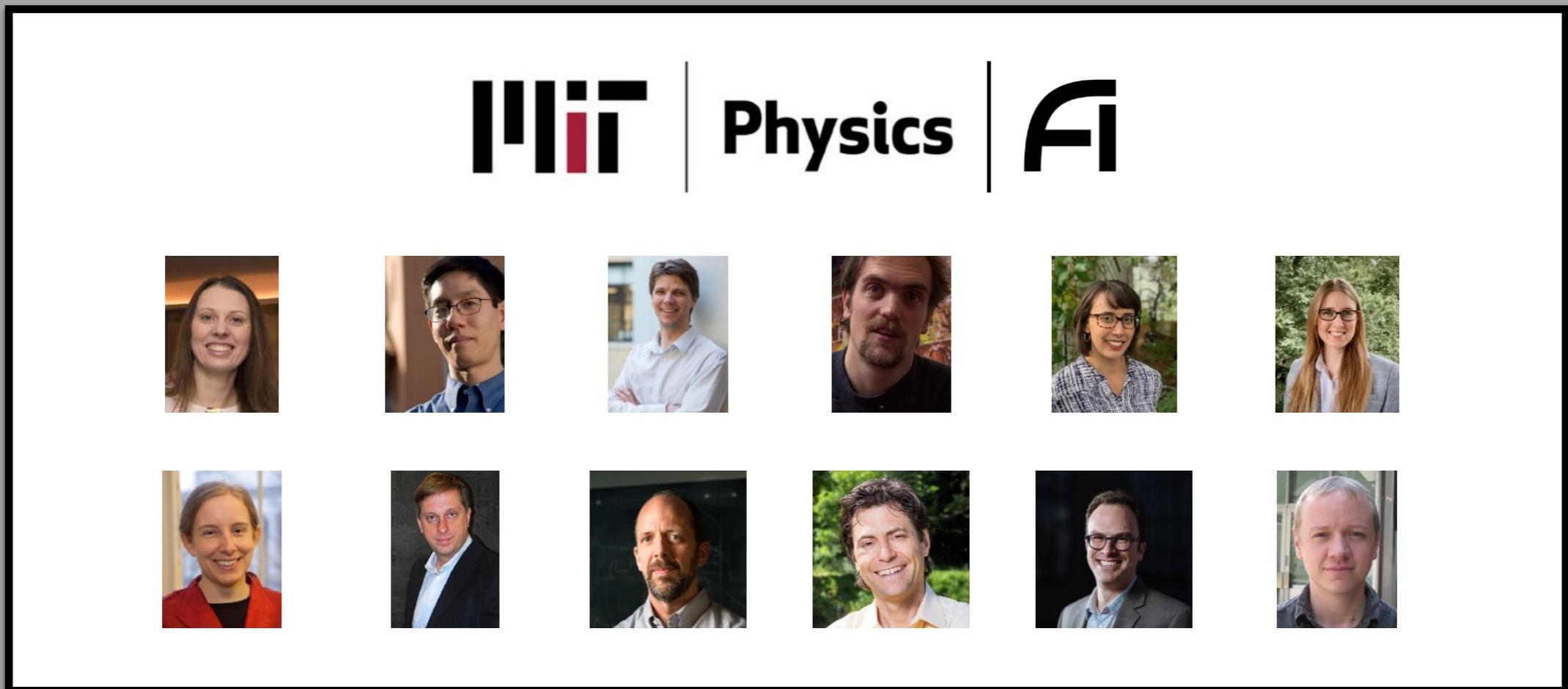
James Halverson  
Brent Nelson  
  
  
Taritree Wongjirad

Cultivate Early-Career Talent with Cross-Disciplinary Expertise

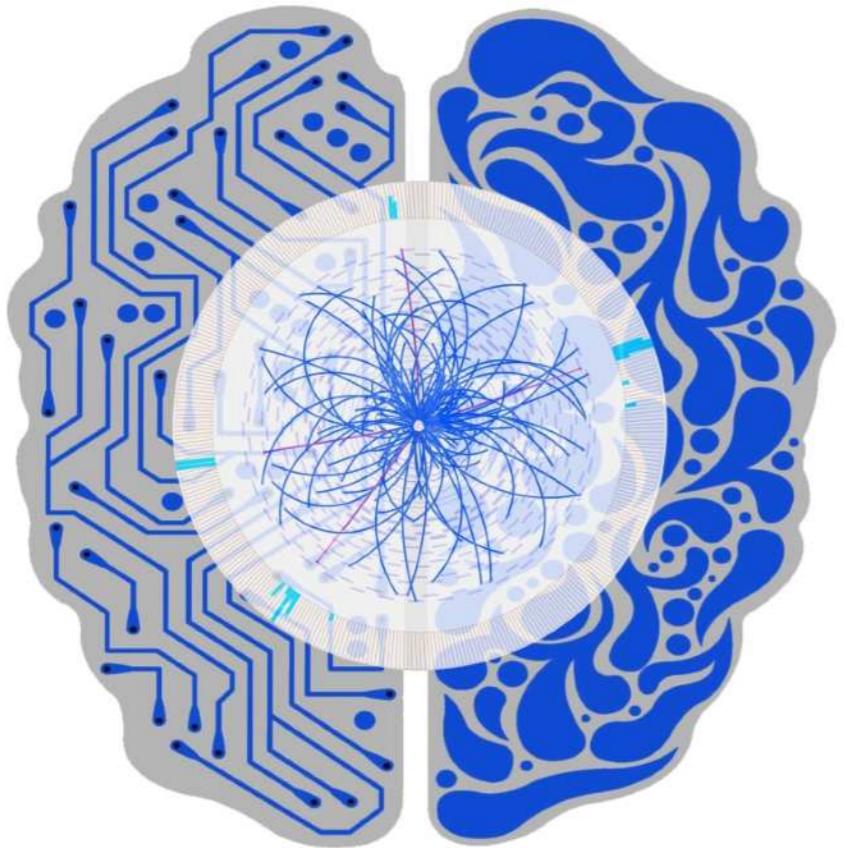
# The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI)

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Cultivate Early-Career Talent with Cross-Disciplinary Expertise



*Can we teach a machine  
to “think” like a physicist?*

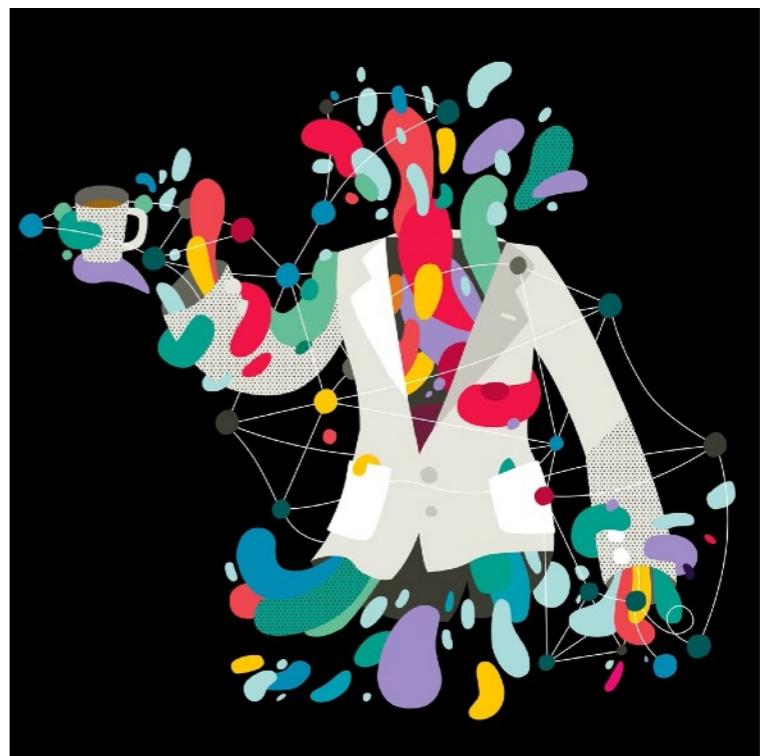
The New York Times



By Dennis Overbye

Nov. 23, 2020

Can a Computer Devise a Theory of Everything?



# AI<sup>2</sup>: Ab Initio Artificial Intelligence



*Machine learning that incorporates  
first principles, best practices, and domain knowledge  
from fundamental physics*

*Symmetries, conservation laws, scaling relations, limiting behaviors, locality, causality,  
unitarity, gauge invariance, entropy, least action, factorization, unit tests,  
exactness, systematic uncertainties, reproducibility, verifiability, ...*

# Deep Learning

*E.g. Inpainting*

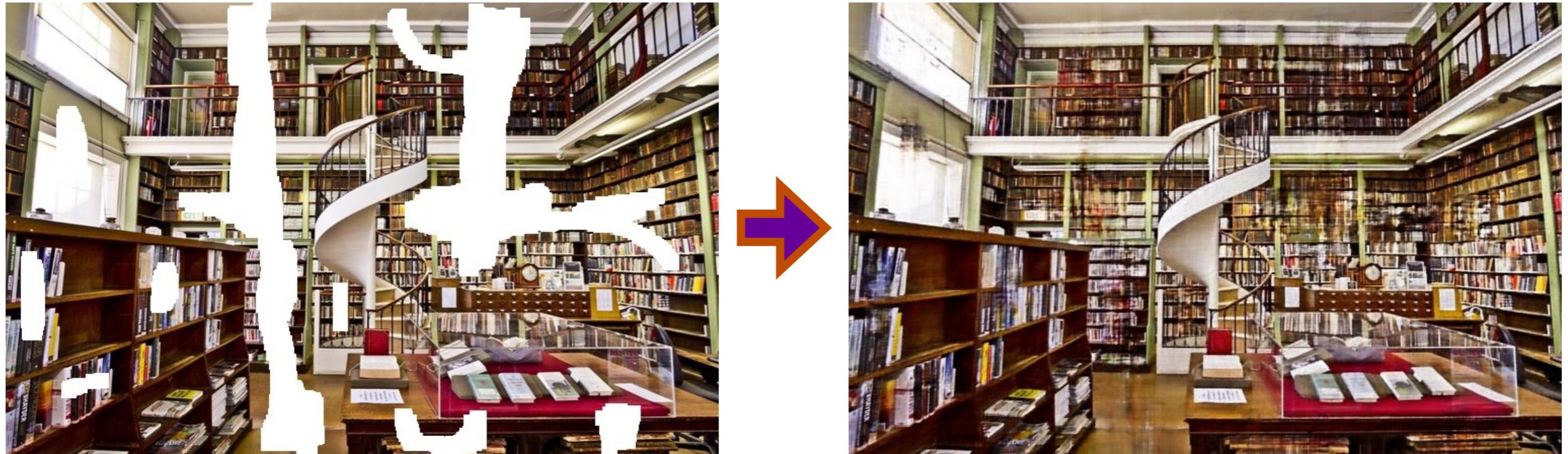


increased computational power and large data sets

[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

# Deep Learning meets Deep Thinking

E.g. *Inpainting*



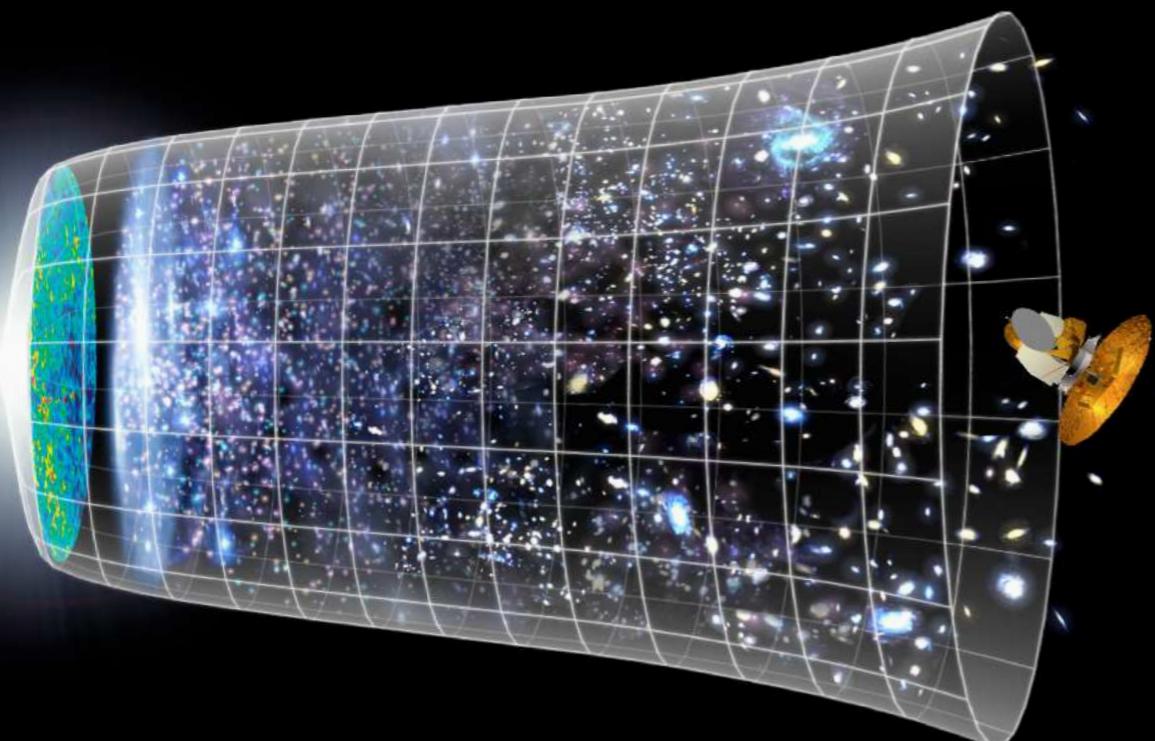
Using randomly initialized neural network (!)

Progress made by understanding the structure of problems  
(not just increased computational power and large data sets)

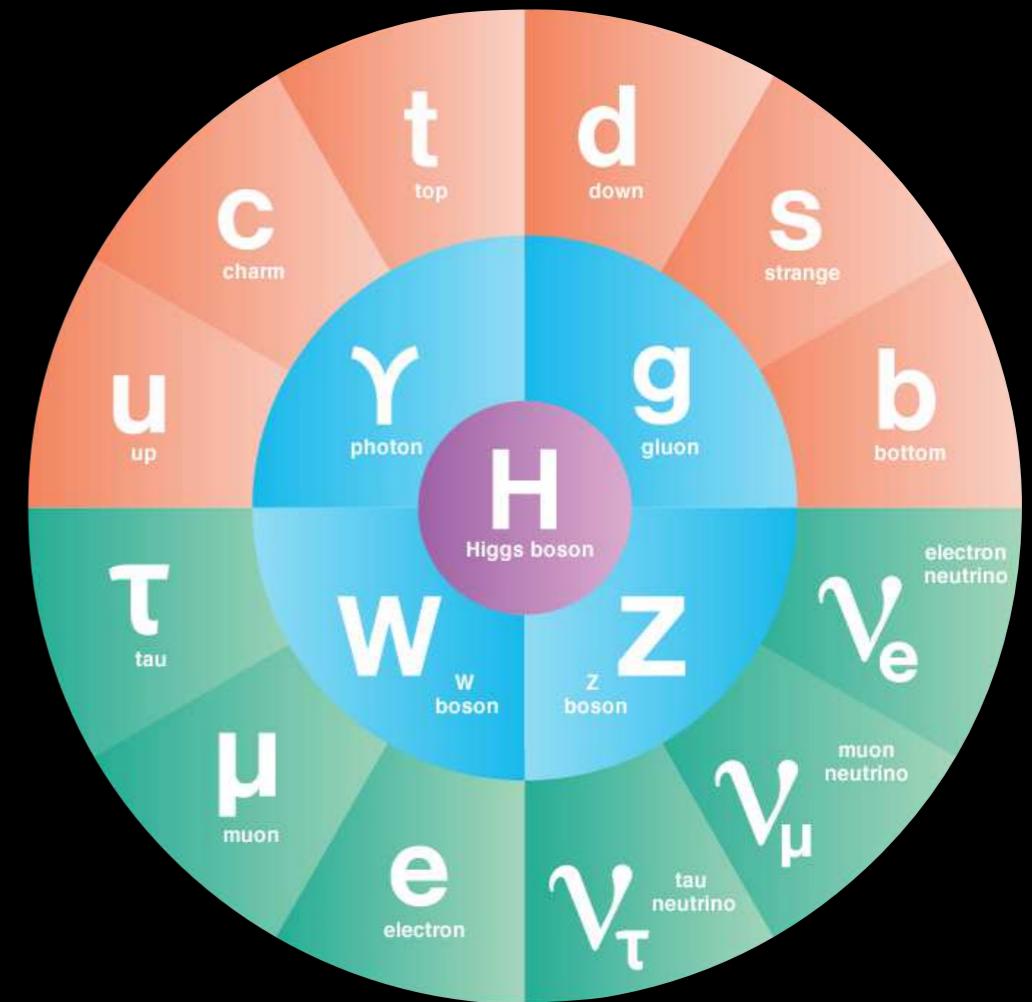
[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

# Pillars of Fundamental Physics

## Big Bang Cosmology



## Standard Model

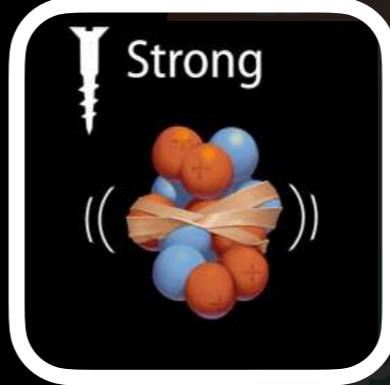
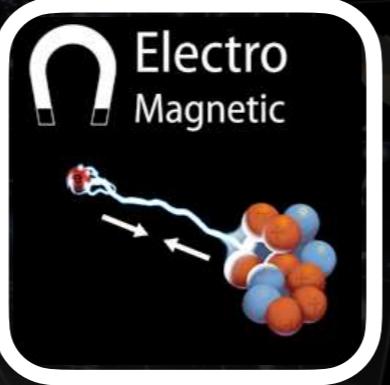


# Pillars of Fundamental Physics

Big Bang Cosmology

Standard Model

## Triumphs of Human Intelligence

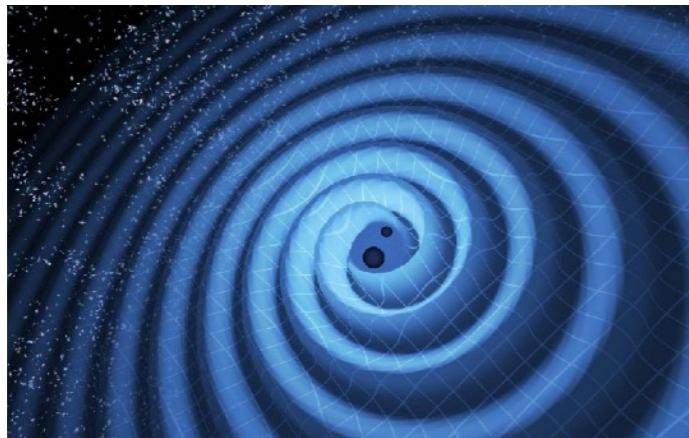


My research focus

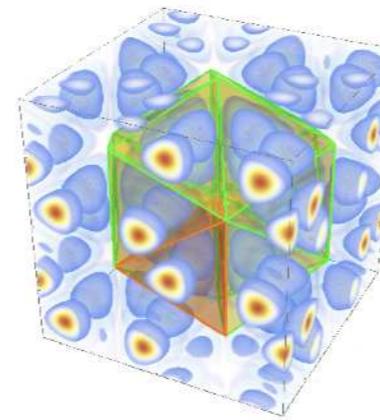
# *Artificial Intelligence $\Leftrightarrow$ Fundamental Interactions*



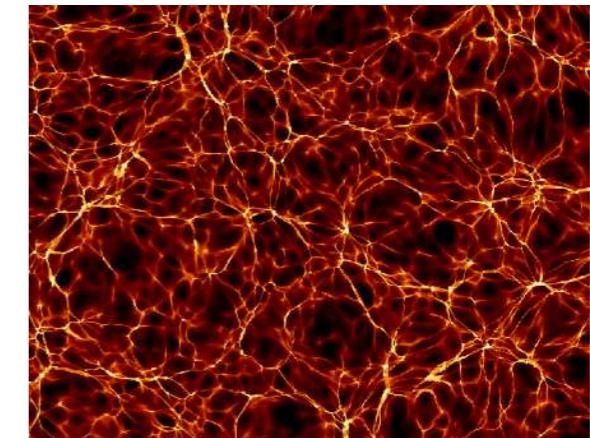
*Gravitational Waves*



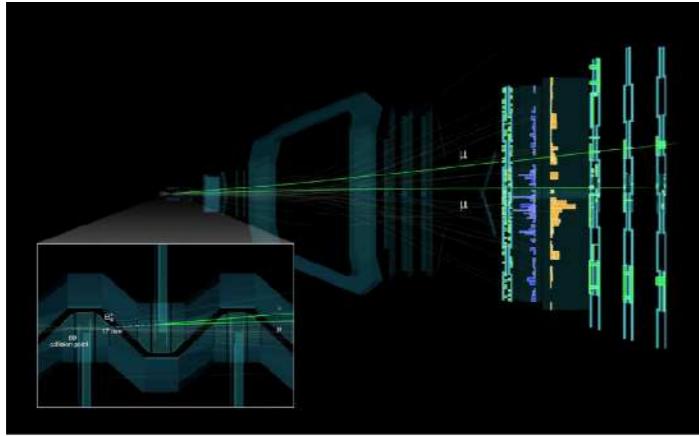
*Nuclear Physics*



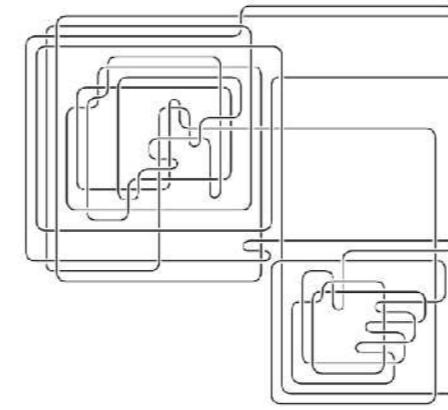
*Dark Matter*



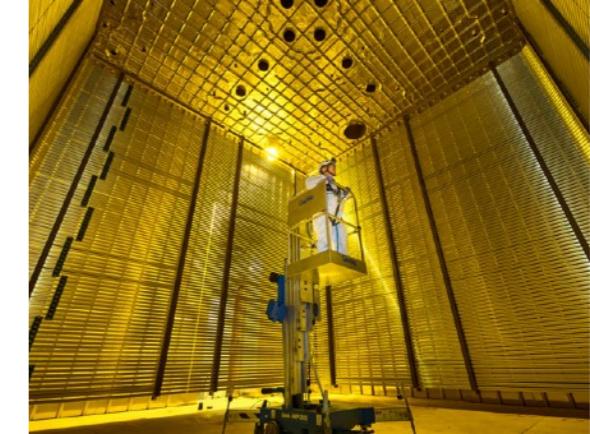
*Particle Colliders*



*Mathematical Physics*



*Neutrino Detection*



...

*Rich data sets involving deep physics principles with exciting discovery opportunities*

[<http://iaifi.org>]

# New! PhD in Physics, Statistics & Data Science

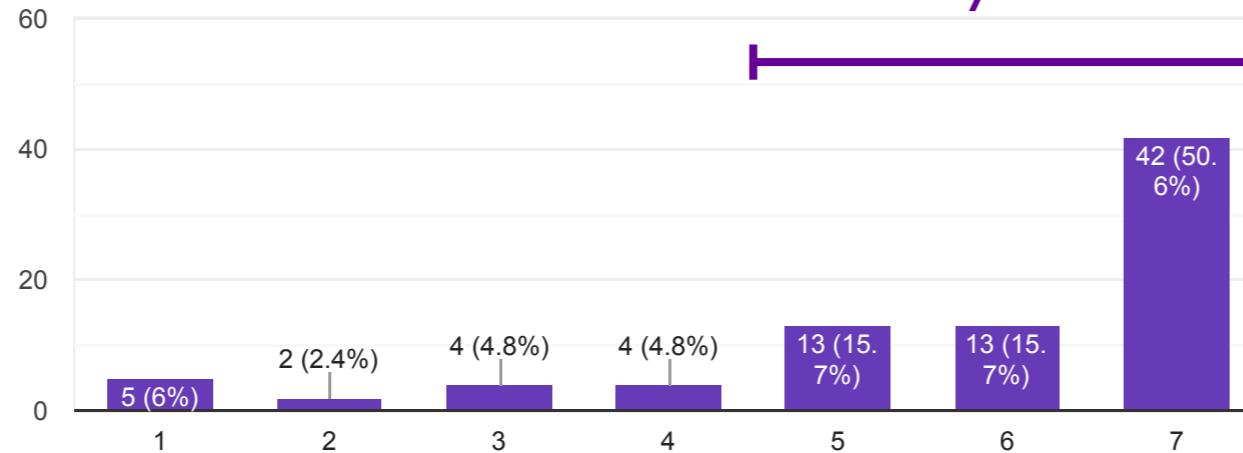
$\approx$  Physics PhD + 4 courses (probability, statistics, computation, data analysis)



How interested would you be in submitting and defending a PhD thesis that uses statistical methods in a substantial way?

83 responses

$\approx$ 30% of all Physics students (!)



Respondent #11: "I think ML is the most important thing happening in the world right now and should be incorporated into any STEM degree."



Congratulations,  
Dr. Constantin Weisser!  
(March 30, 2021)

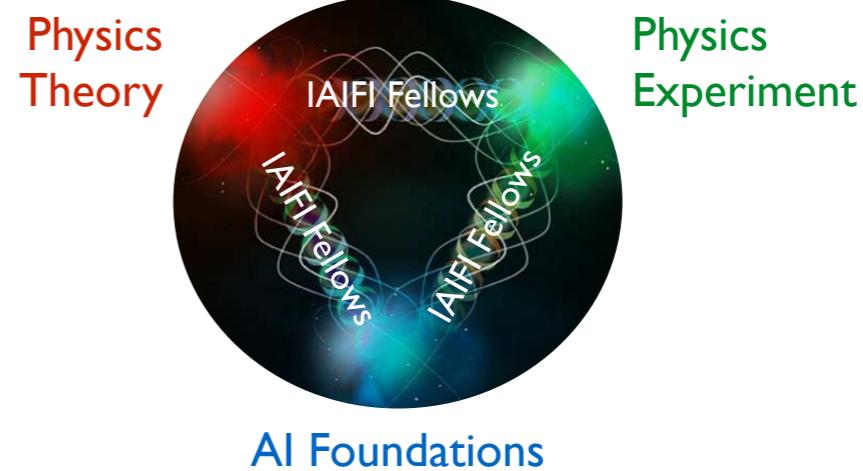
[<https://physics.mit.edu/academic-programs/graduate-students/psds-phd/>]

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to the largest structures in the universe — and galvanize AI research innovation*

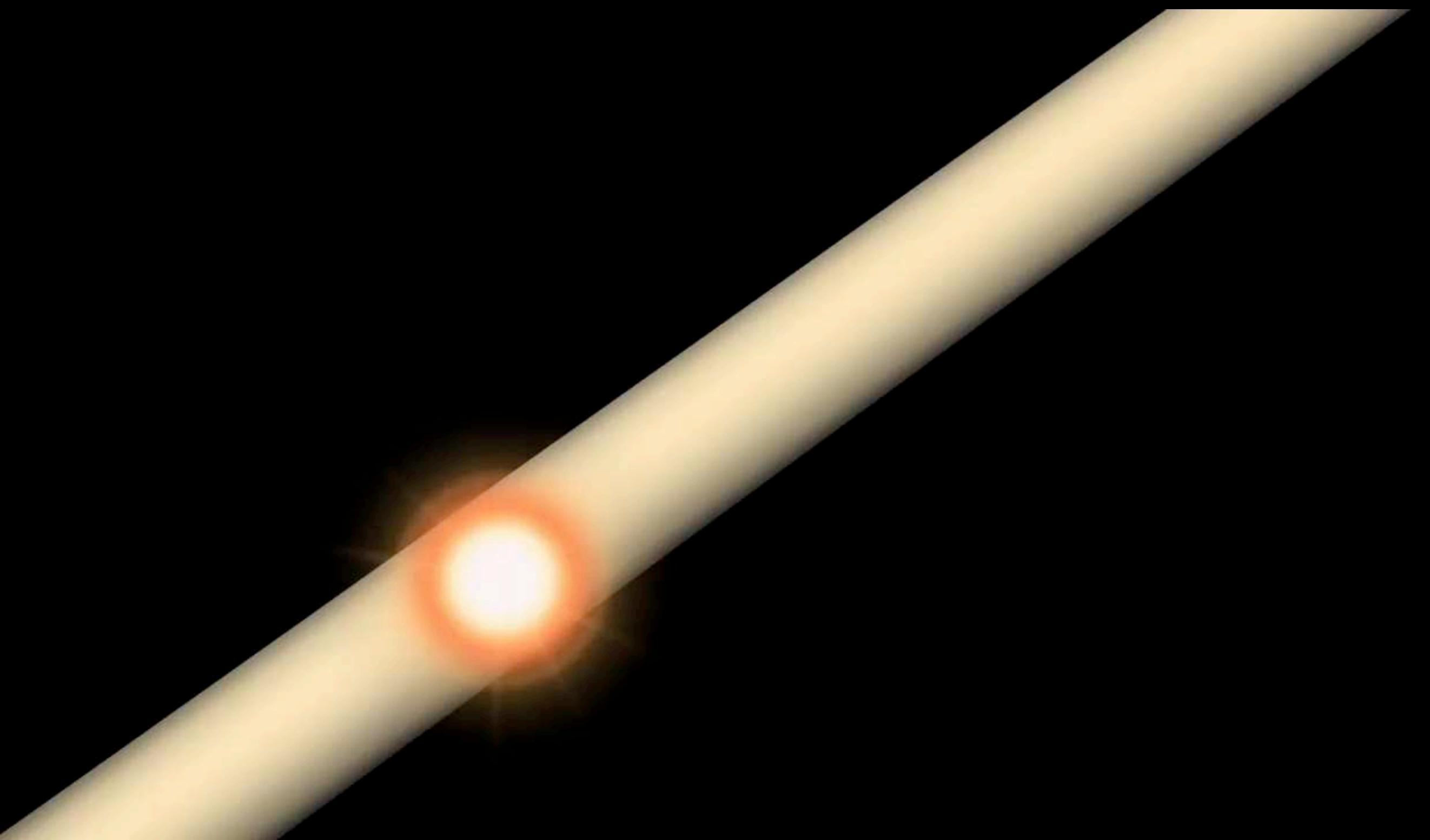


<http://iaifi.org/>

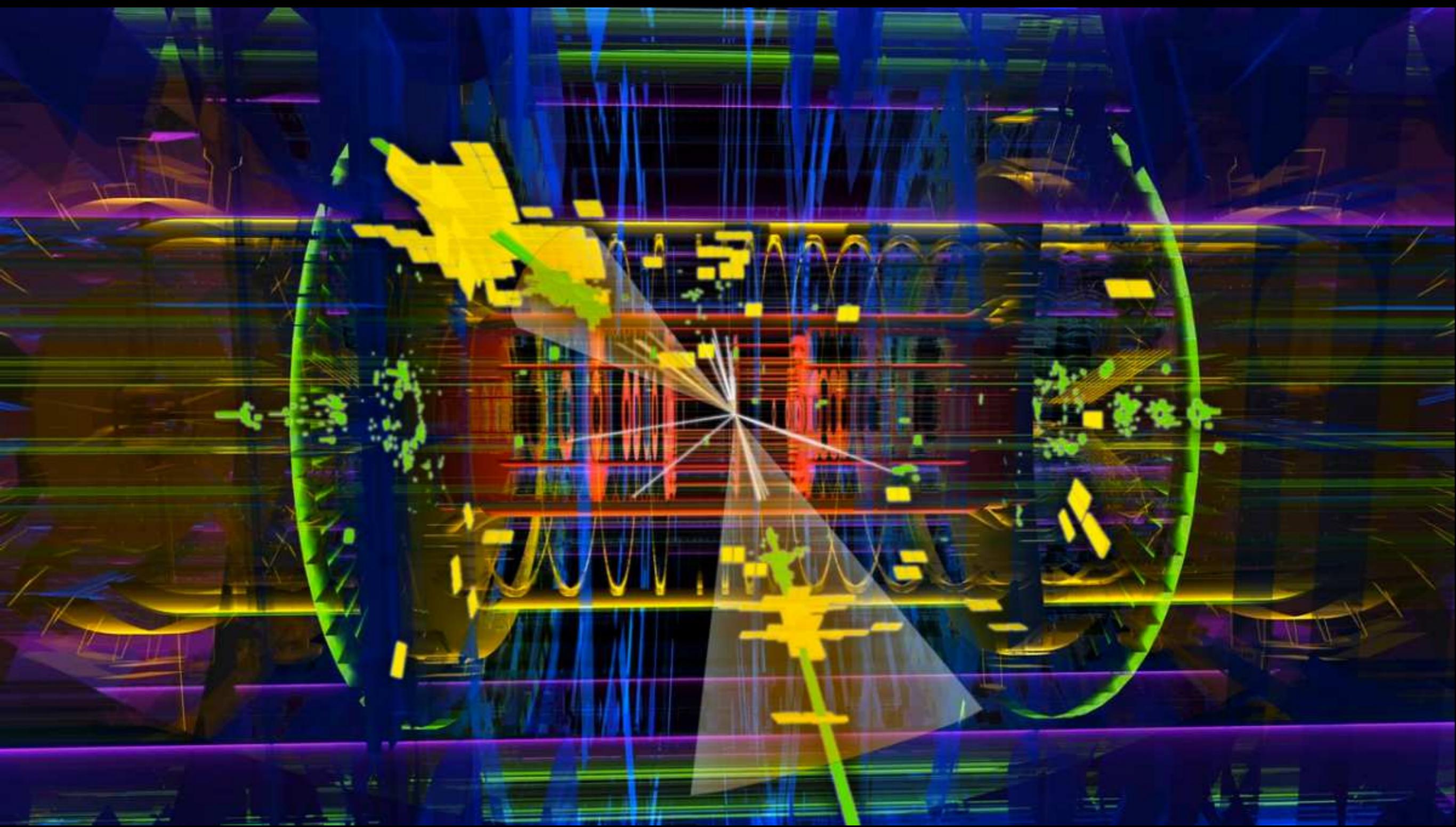


*If you are interested in rich data sets involving  
deep physics principles and exciting discovery opportunities,  
consider pursuing a STEM degree in Physics + AI!*

**“So what do you do in your research?”**

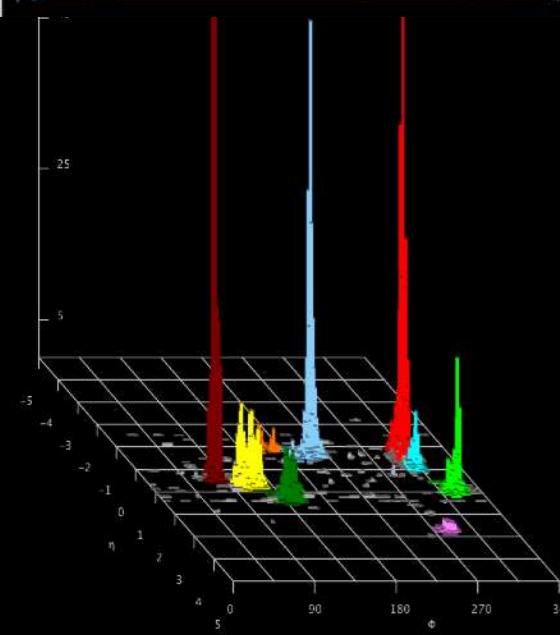
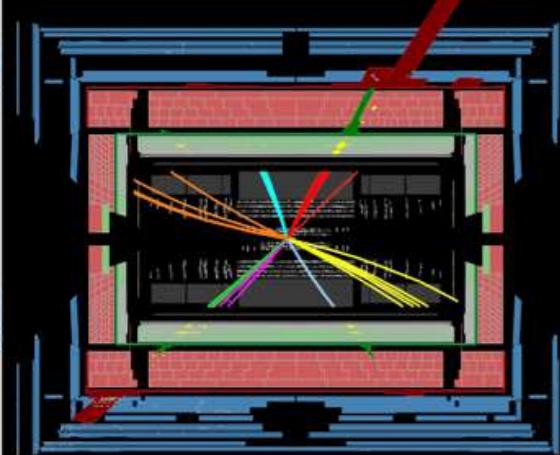




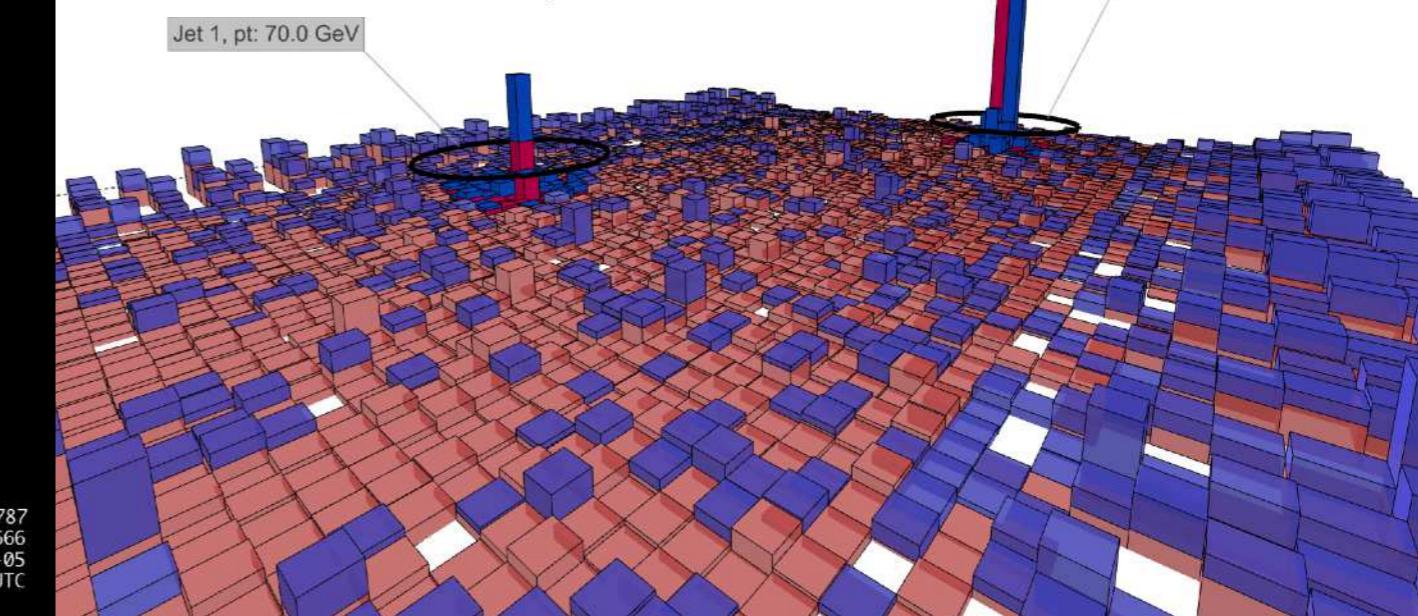
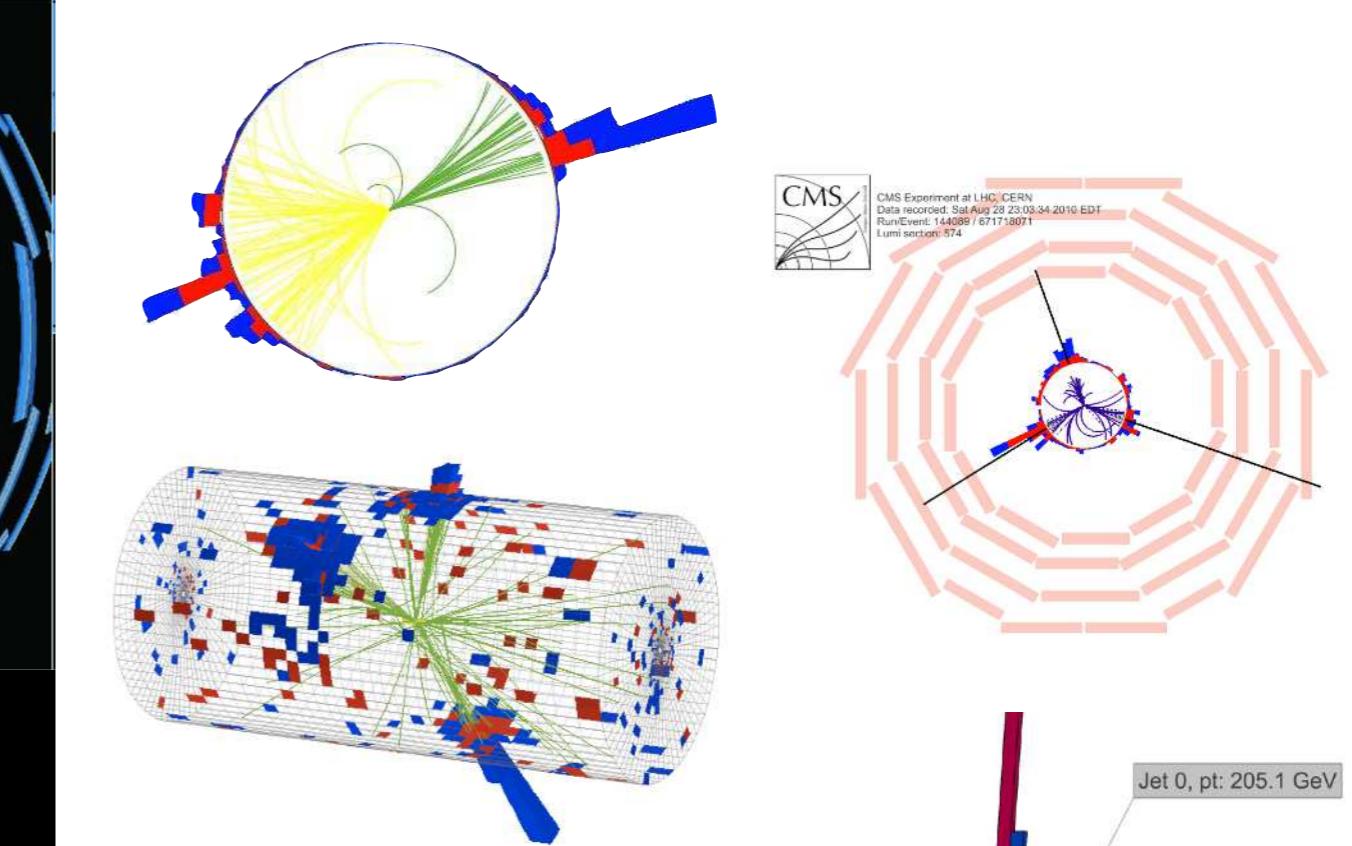
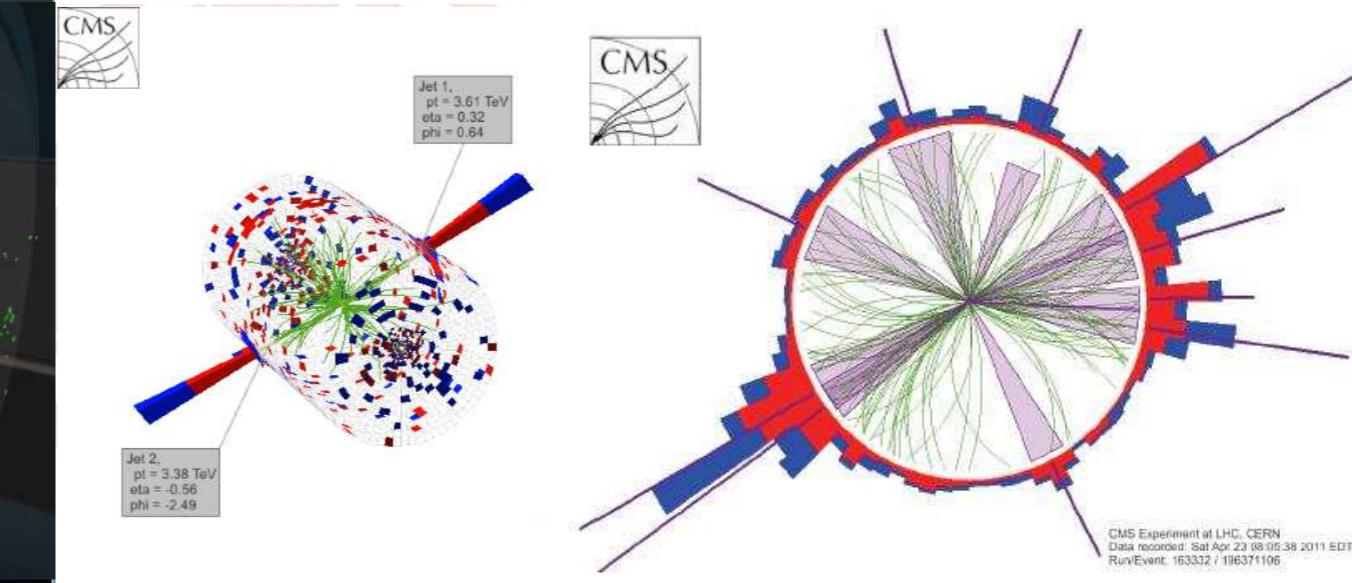
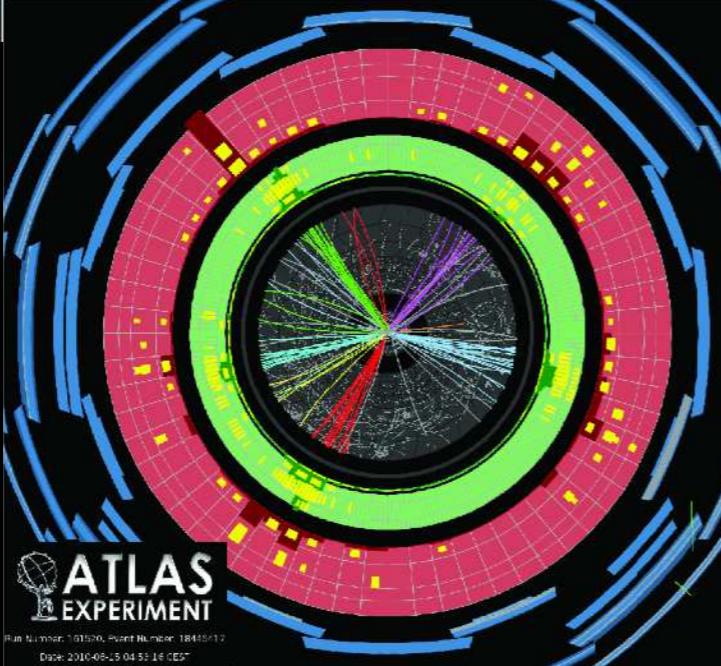
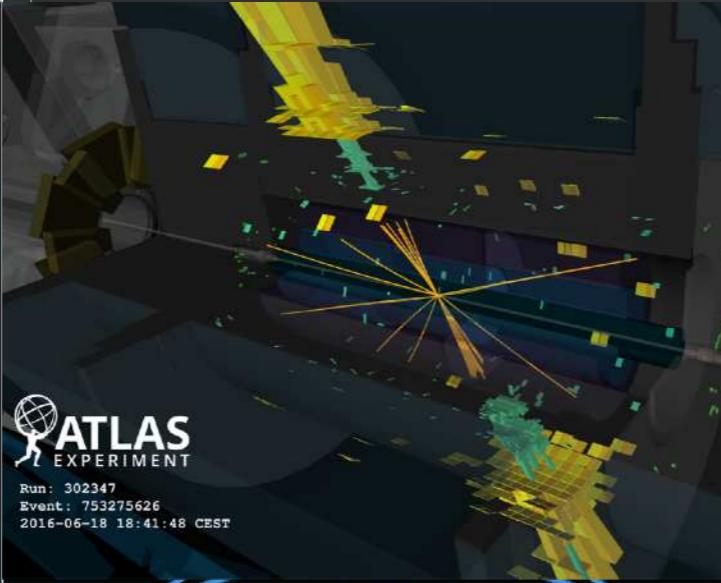
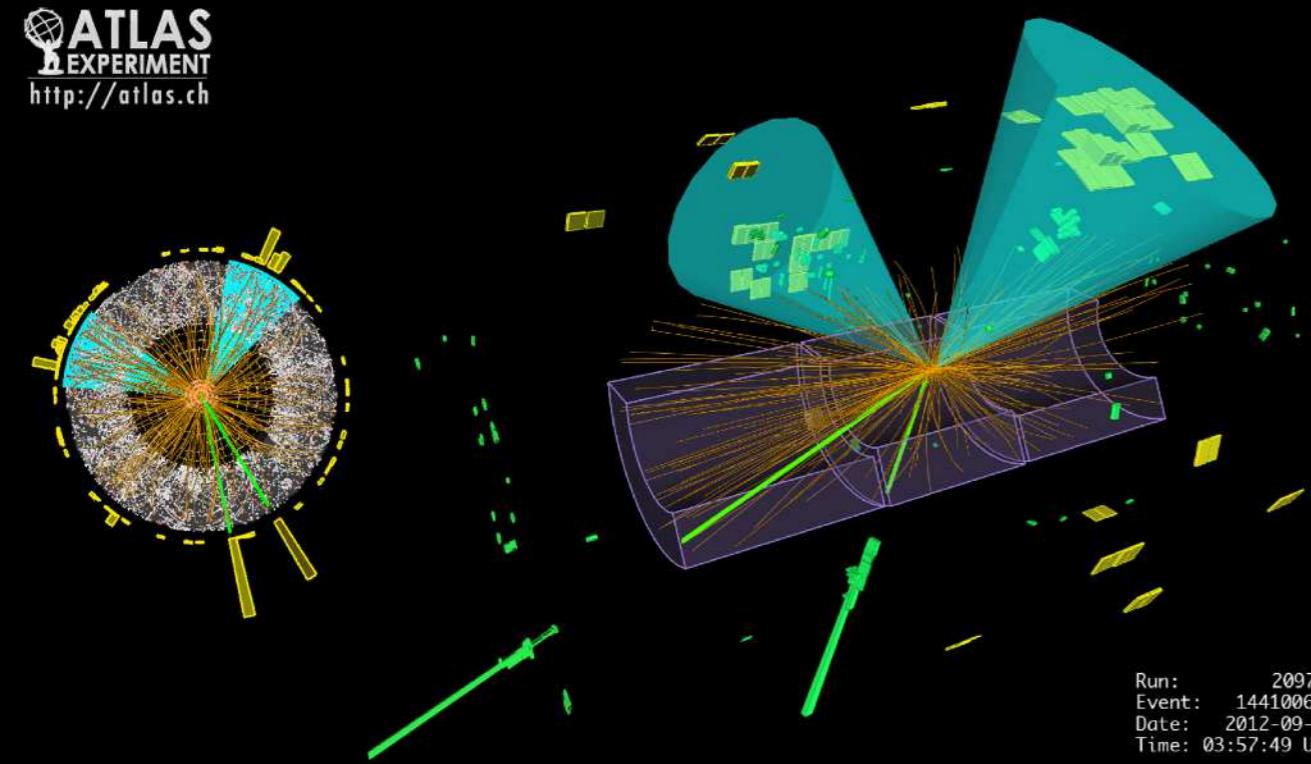


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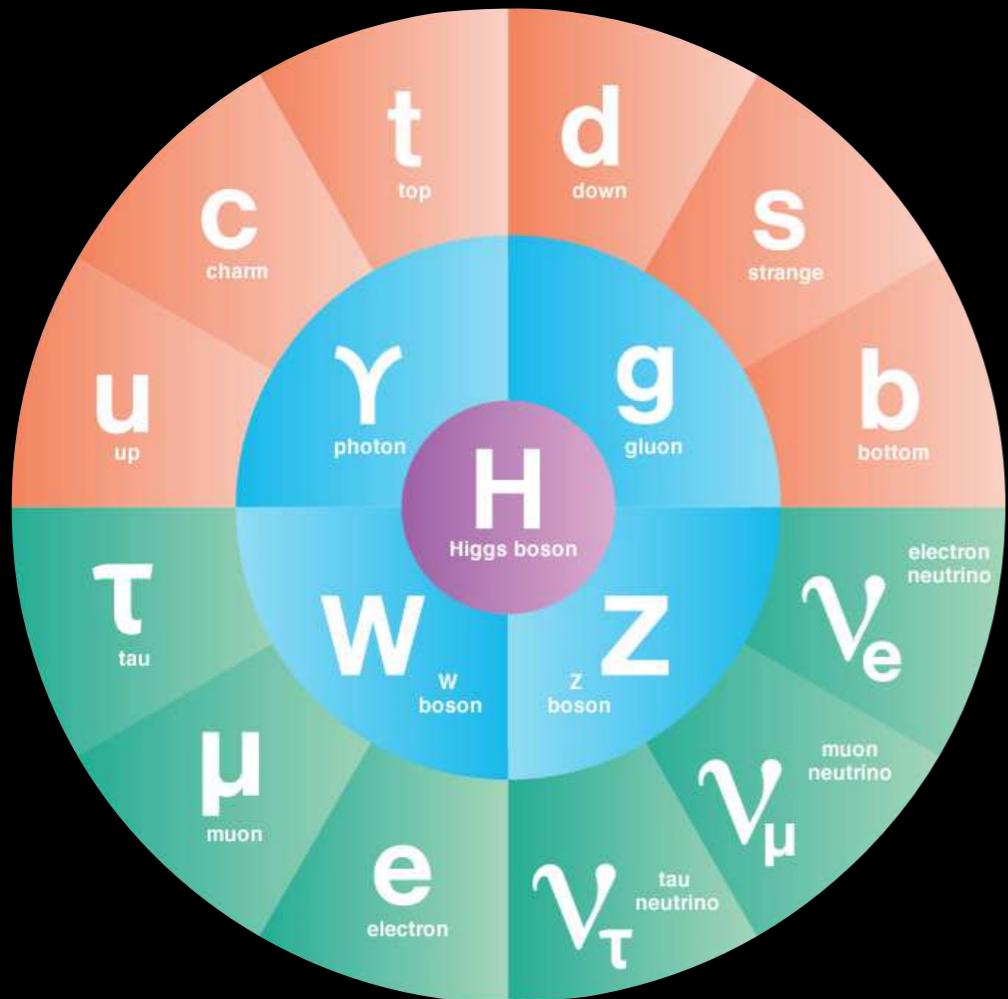
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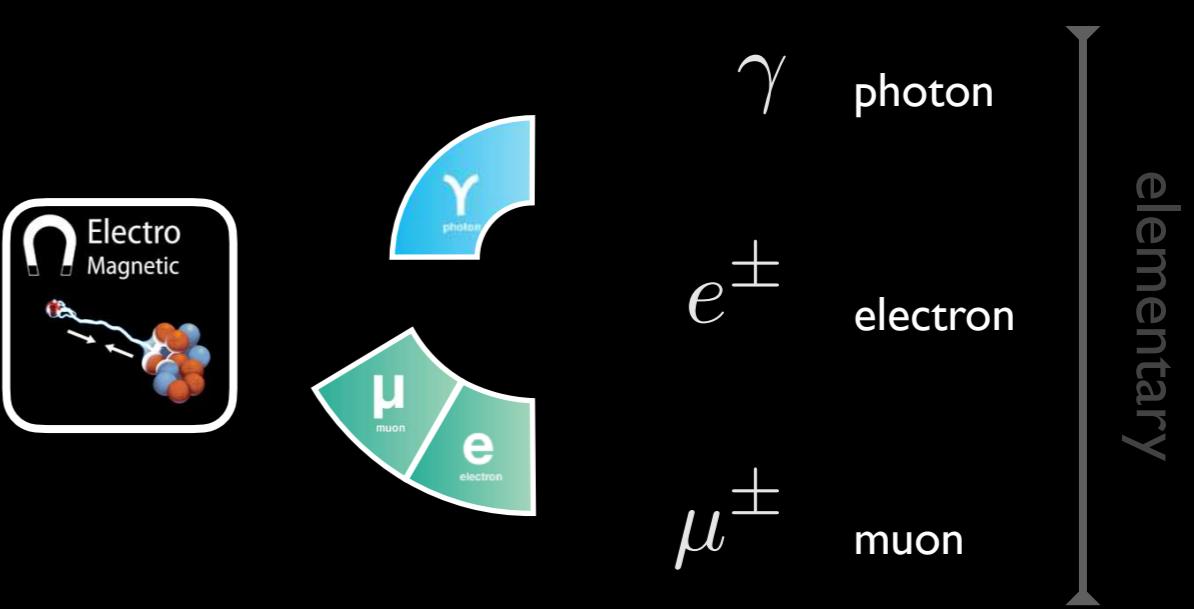
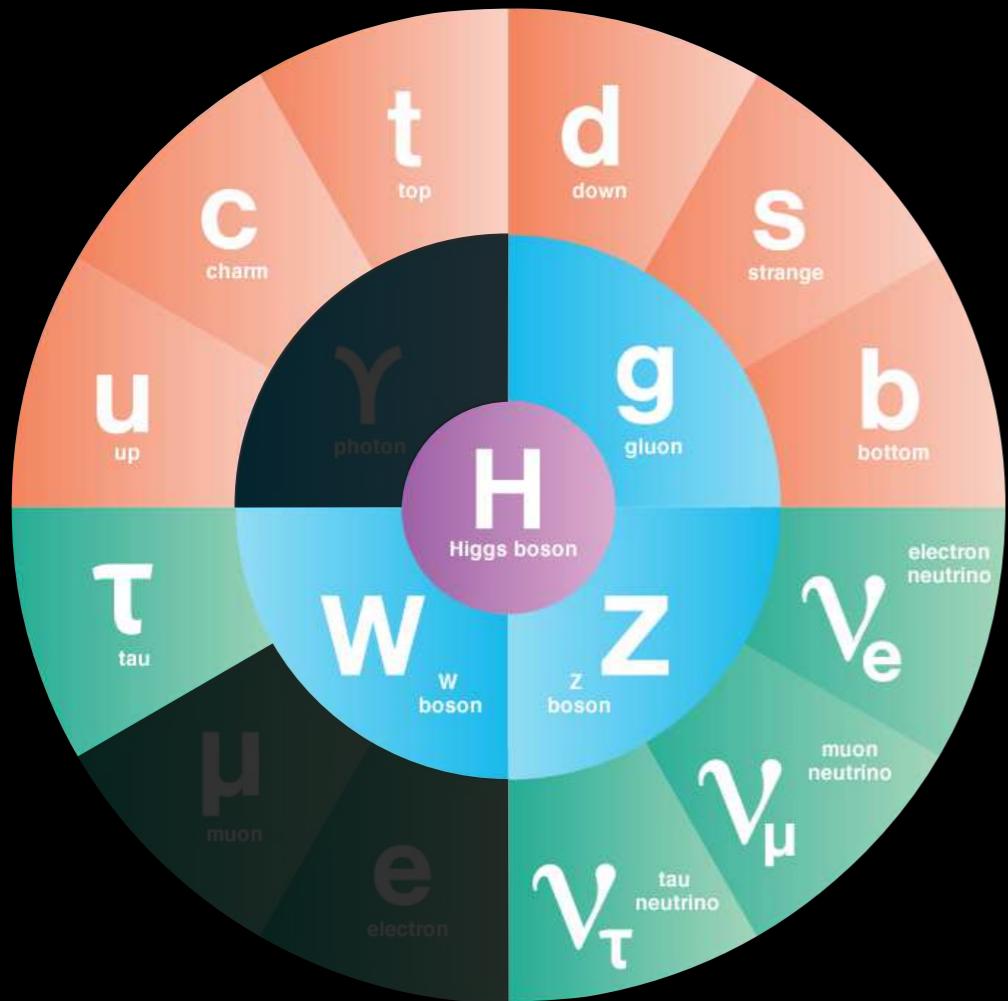
**ATLAS**  
EXPERIMENT  
<http://atlas.ch>



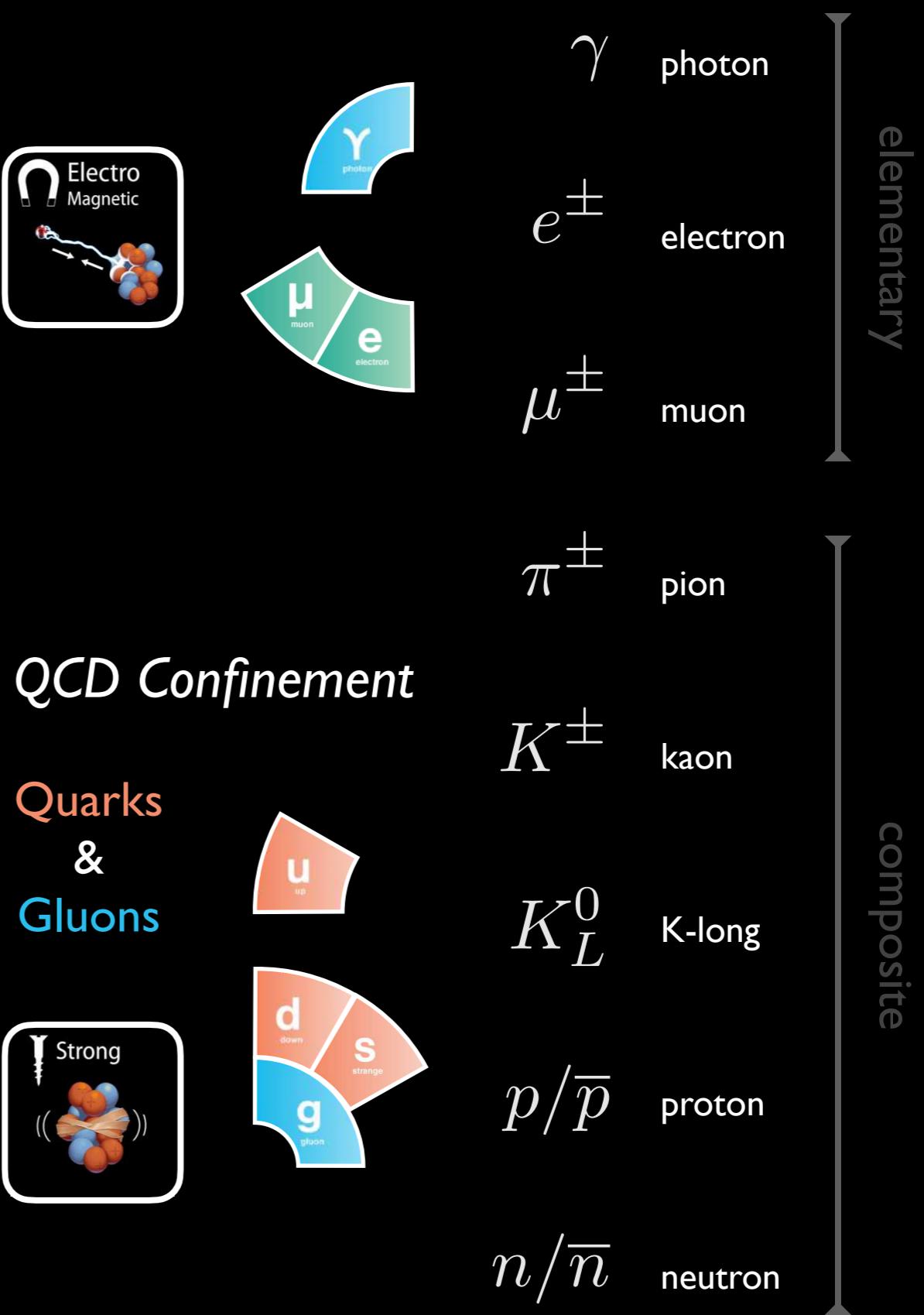
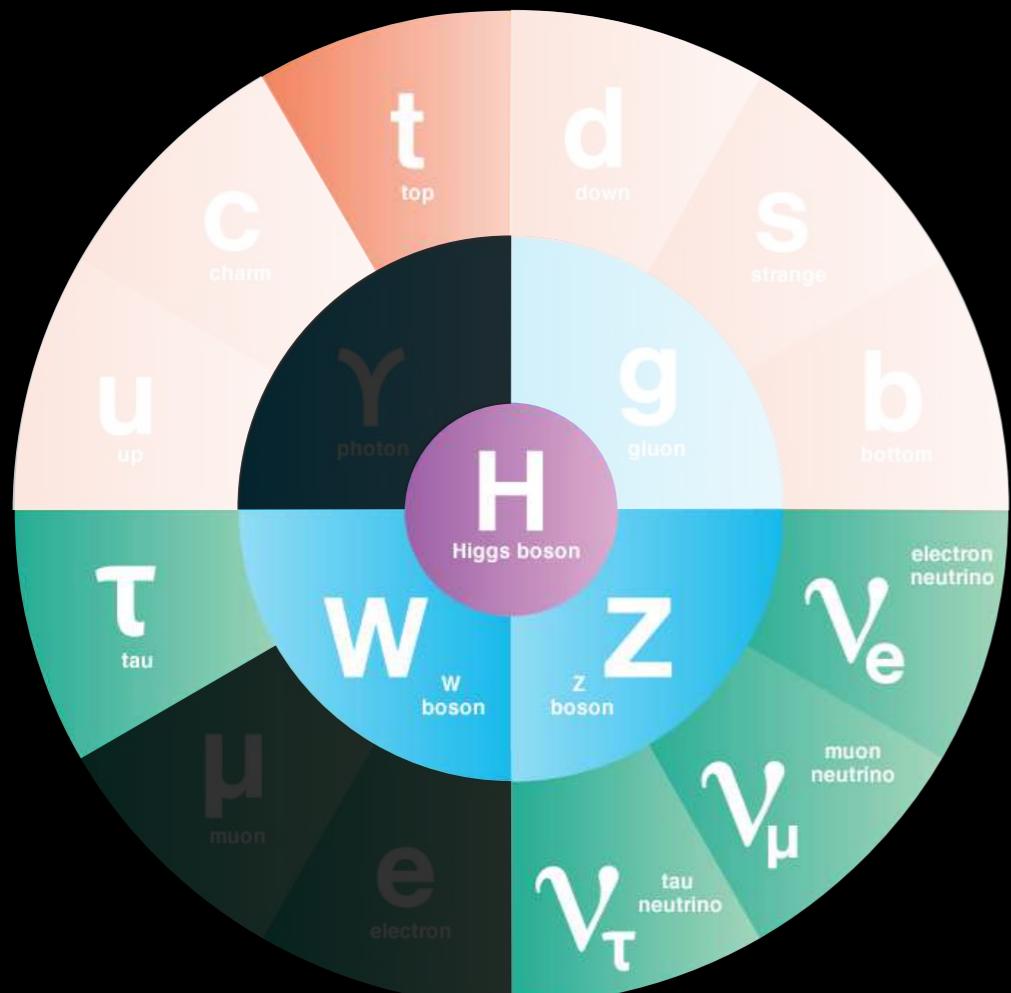
# Particle Physics 101



# Particle Physics 101



# Particle Physics 101



T E H M



$\gamma$

photon



$e^+$

electron



$\mu^+$

muon



$\pi^+$

pion



$K^+$

kaon



$K_L^0$

K-long



$p/\bar{p}$

proton



$n/\bar{n}$

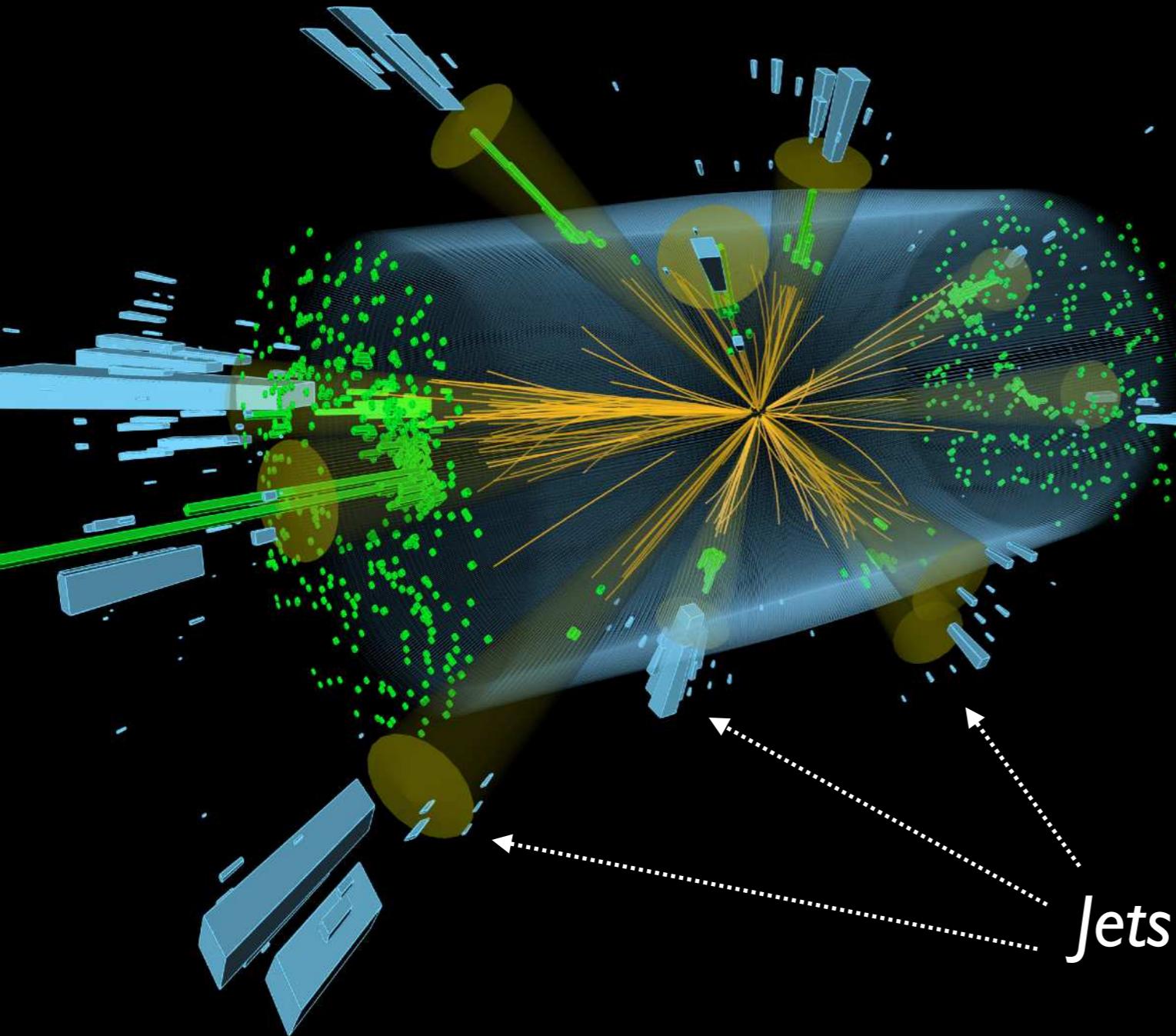
neutron

elementary

composite

# Collider Event

Every 25 nanoseconds at the LHC



T E H M



$\gamma$

photon



$e^+$

electron



$\mu^+$

muon



$\pi^+$

pion



$K^+$

kaon



$K_L^0$

K-long



$p/\bar{p}$

proton



$n/\bar{n}$

neutron

elementary

composite

# Point Cloud

## Collection of points in space



[Popular Science, 2013]

# Principles of Fundamental Physics

*Robustness of Energy Flow*

[Komiske, Metodiev, JDT, JHEP 2018]



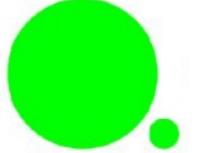
Patrick Komiske



Eric Metodiev



SF



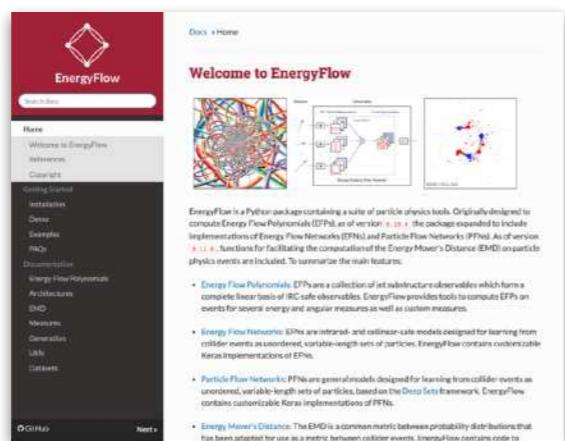
**Power of Artificial Intelligence**

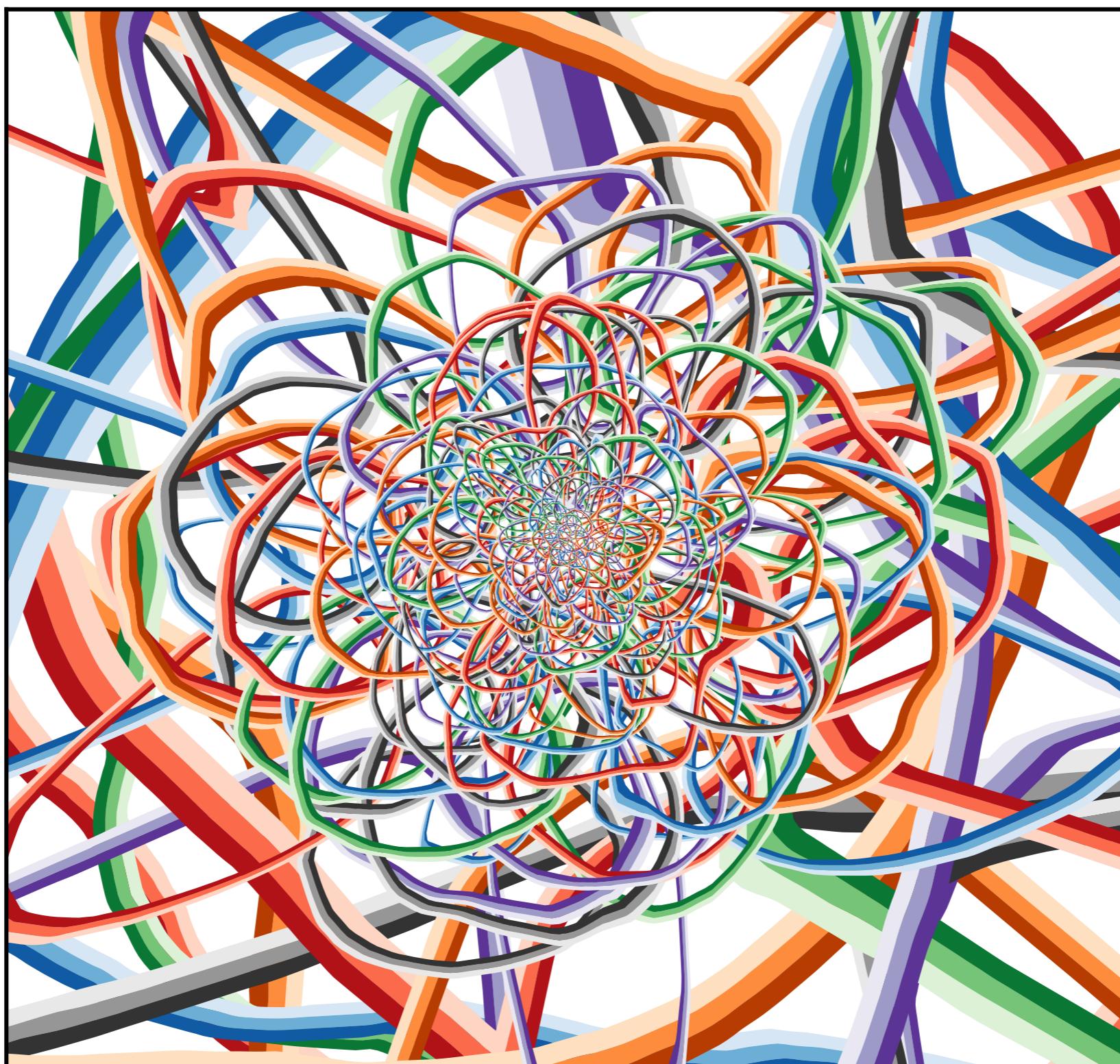
*Point Cloud Learning*

[Zaheer, Kottur, Ravanbakhsh, Poczos, Salakhutdinov, Smola, NIPS 2017]

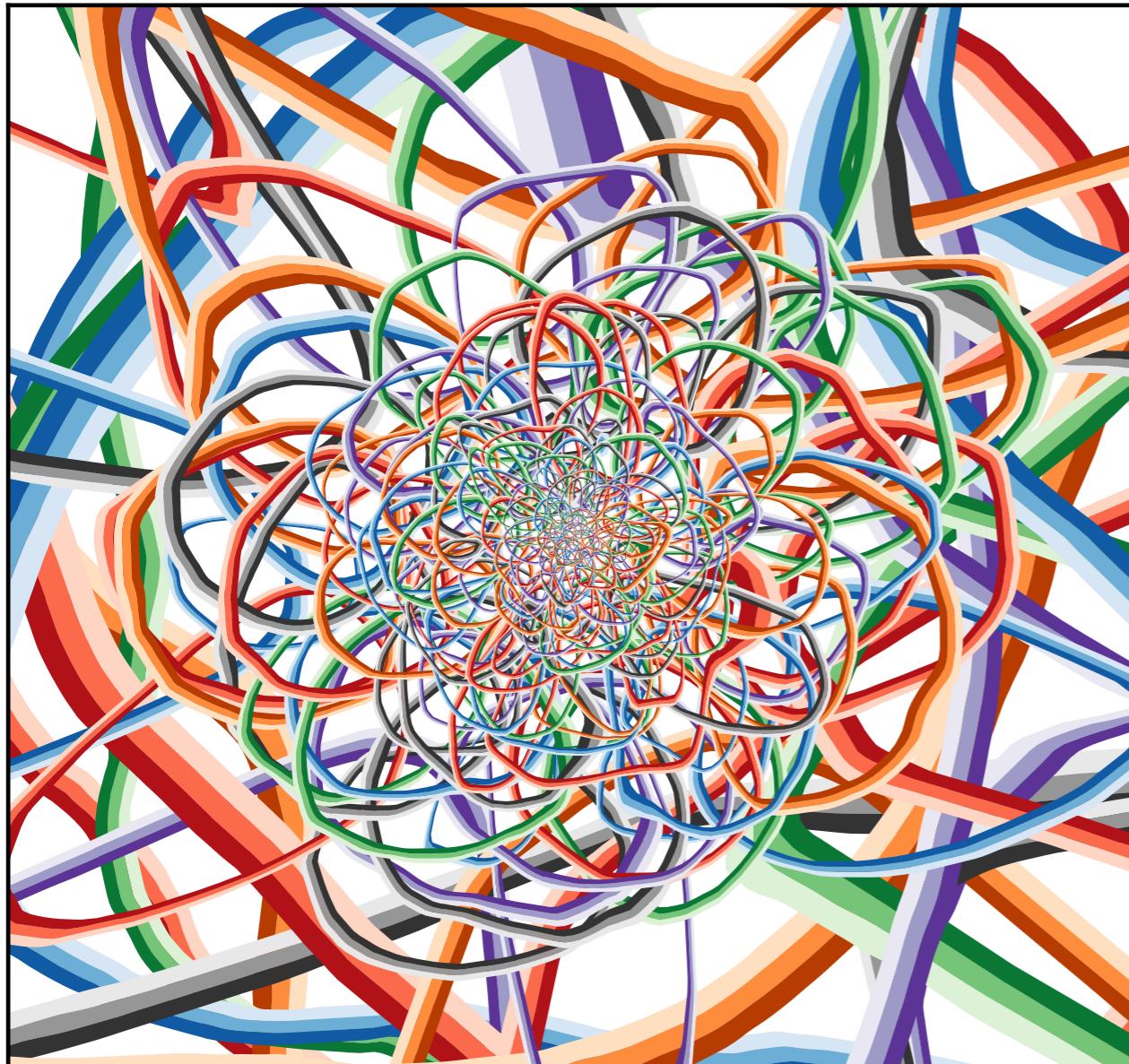
# Energy Flow Networks

<https://energyflow.network/>  
[Komiske, Metodiev, JDT, JHEP 2019]





[Komiske, Metodiev, JDT, JHEP 2019]



“Hello, World!” of Jets:

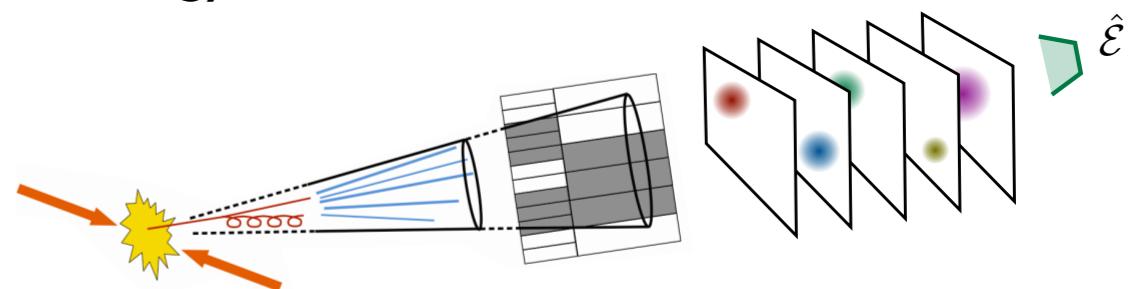
Quark 

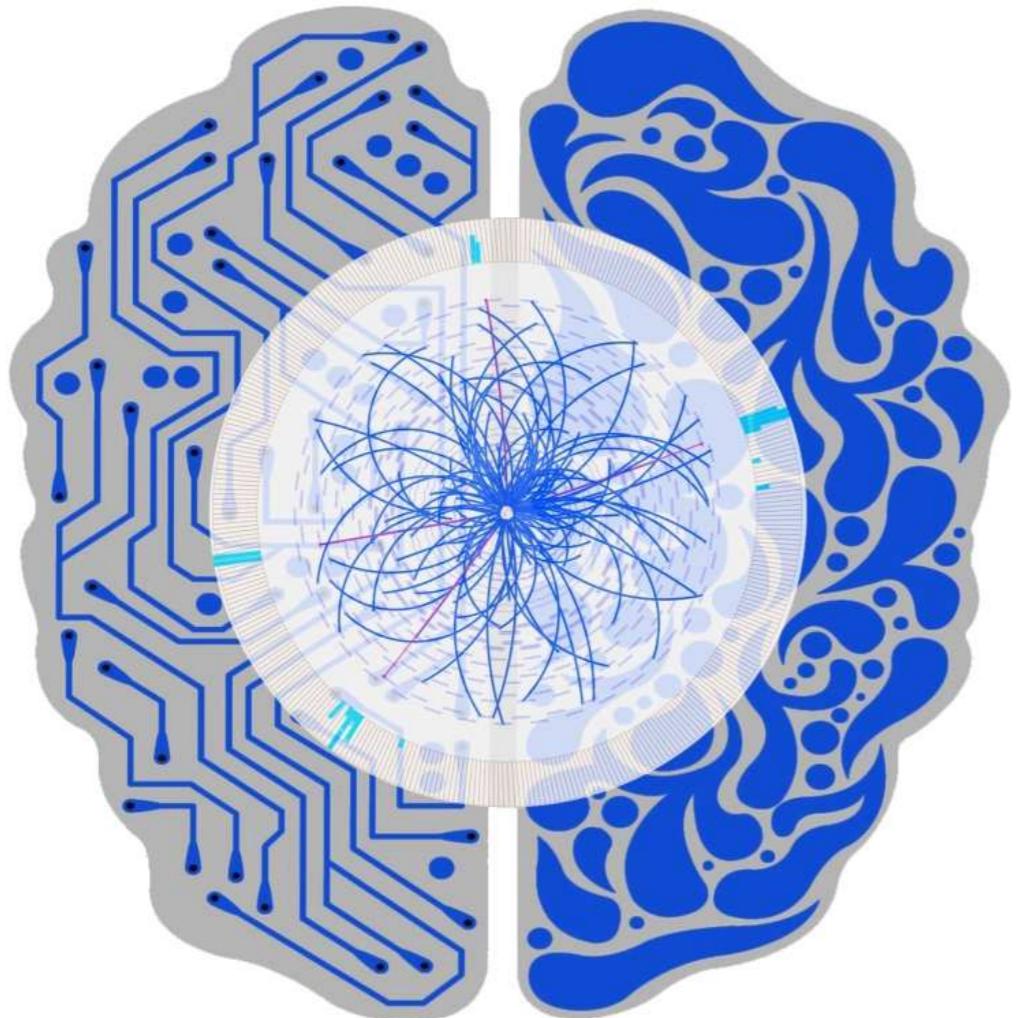
vs. Gluon 

Energy Flow Network:

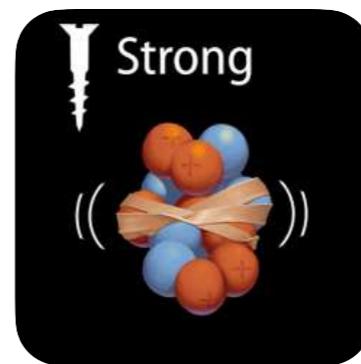
$$S(\mathcal{J}) = F(V_1, V_2, \dots, V_\ell) \quad V_a(\mathcal{J}) = \sum_{i \in \mathcal{J}} E_i \Phi_a(\hat{n}_i)$$

Strategy for Verification:





*We taught a machine to  
“think” like a physicist...*



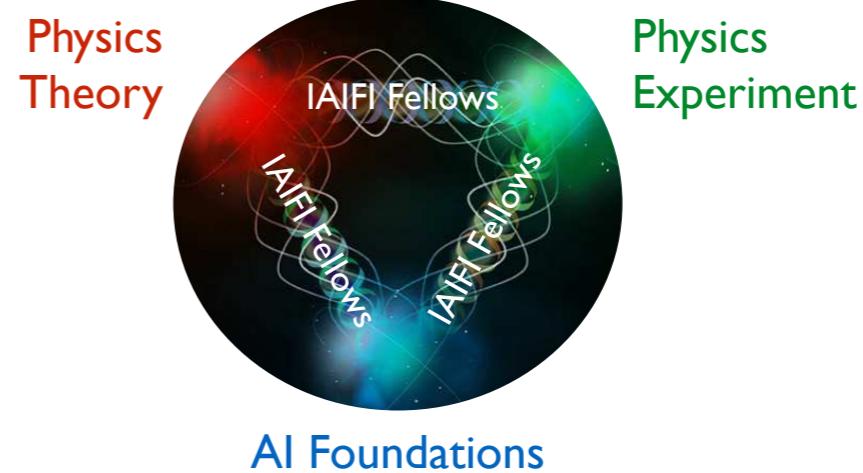
*...and it learned fractal  
structure of strong force!*

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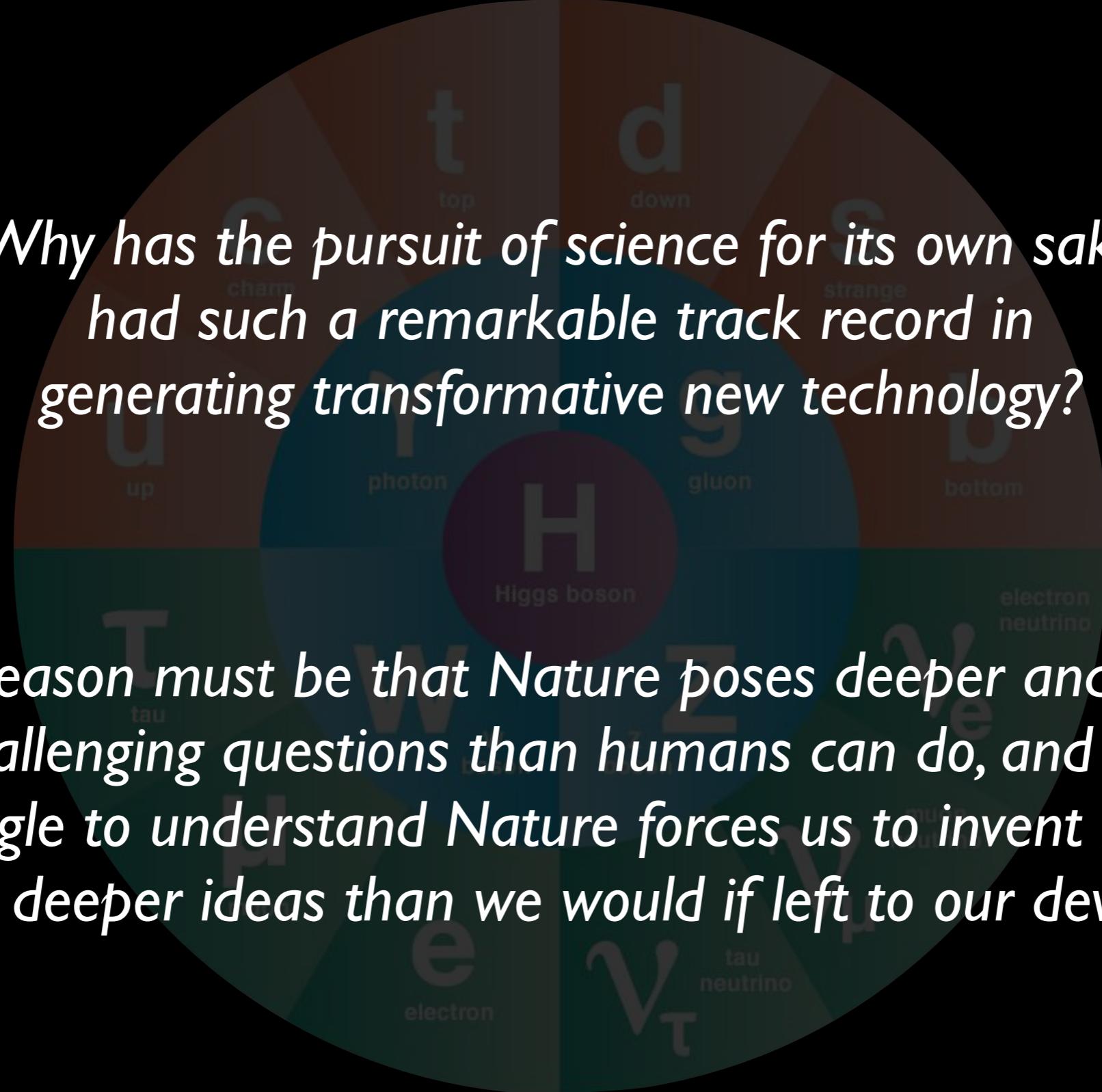
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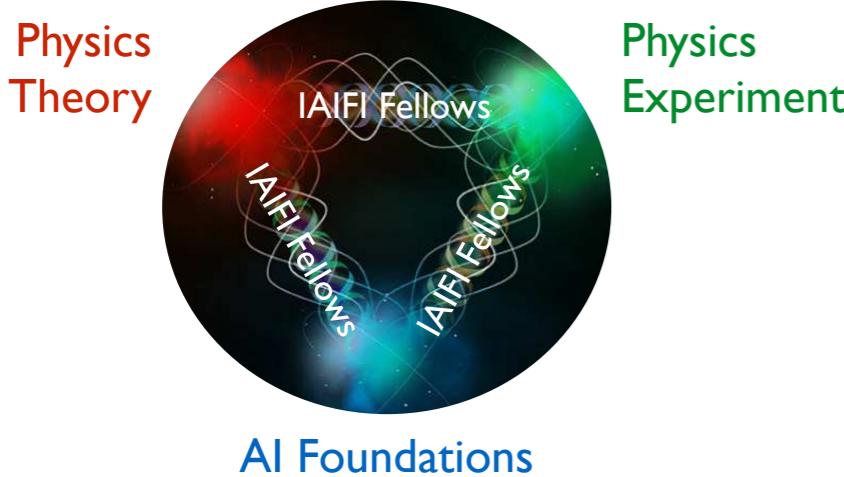
*Why has the pursuit of science for its own sake had such a remarkable track record in generating transformative new technology?*

*The reason must be that Nature poses deeper and more challenging questions than humans can do, and the struggle to understand Nature forces us to invent better and deeper ideas than we would if left to our devices.*

[David Gross (2004 Nobel Laureate in Physics), IJMPA 2016]

## AI<sup>2</sup> for Theoretical Physics

Standard Model of Nuclear & Particle Physics  
String Theory & Physical Mathematics  
Astroparticle Physics  
Automated Discovery of Physics Models



## AI<sup>2</sup> for Experimental Physics

Particle Physics Experiments  
Gravitational Wave Interferometry  
(Multi-Messenger) Astrophysics

## AI<sup>2</sup> for Foundational AI

Symmetries & Invariance  
Speeding up Control & Inference  
Physics-Informed Architectures  
Neural Networks Theory