

Collision Course

Artificial Intelligence meets Fundamental Physics

Jesse Thaler

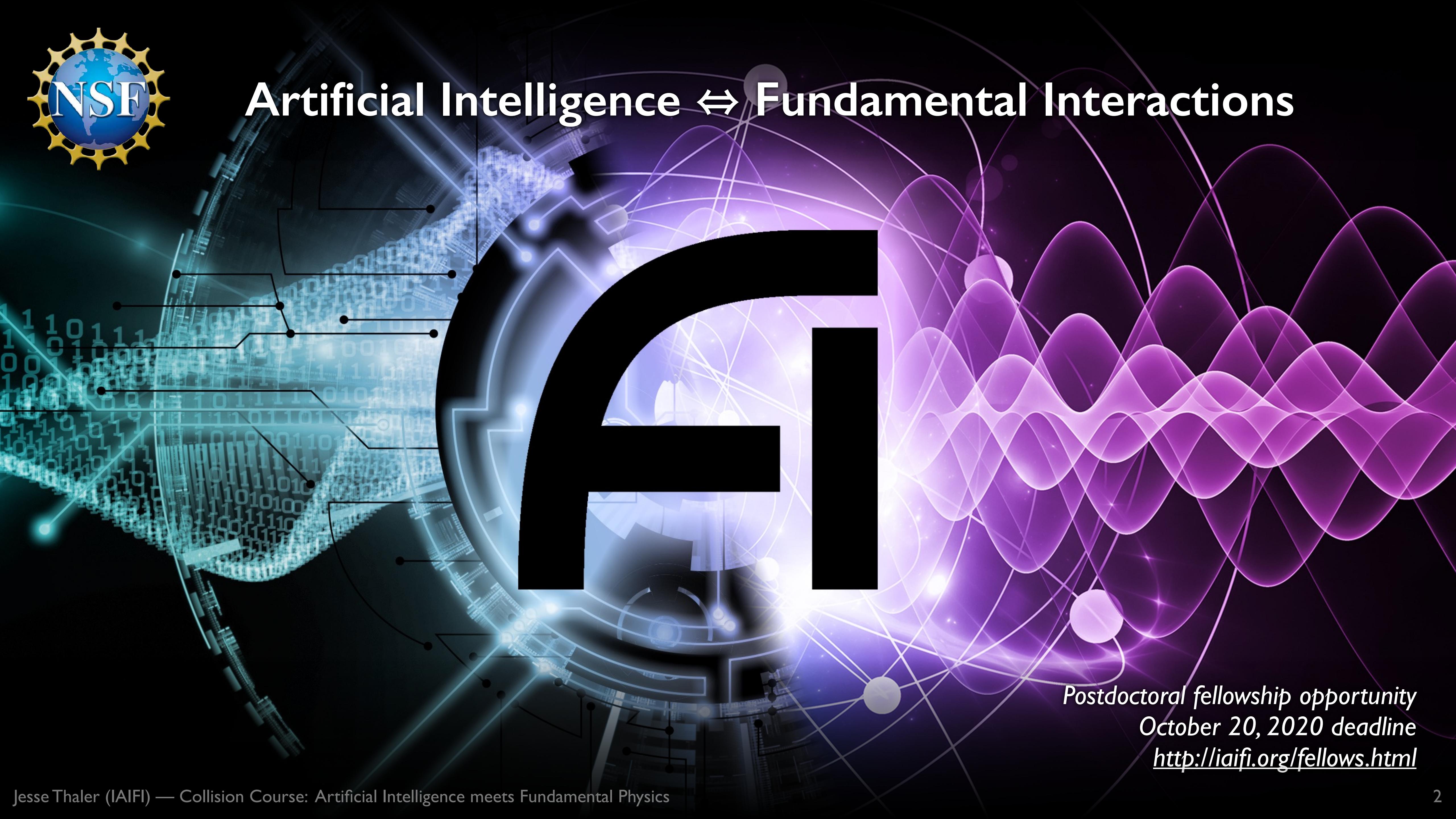
Director, NSF AI Institute for Artificial Intelligence and Fundamental Interactions



Tommy Flowers Network Conference — October 16, 2020

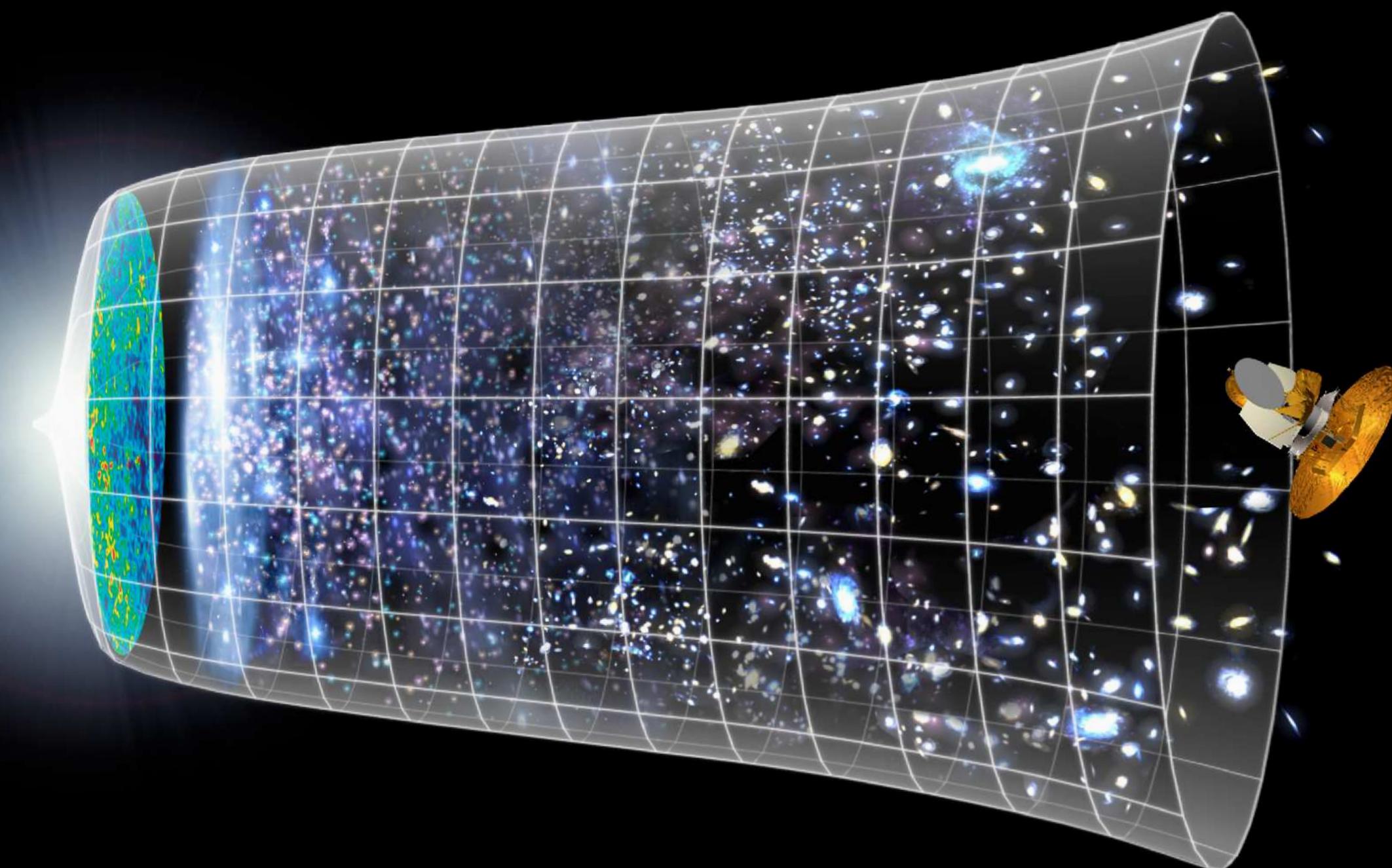


Artificial Intelligence \leftrightarrow Fundamental Interactions

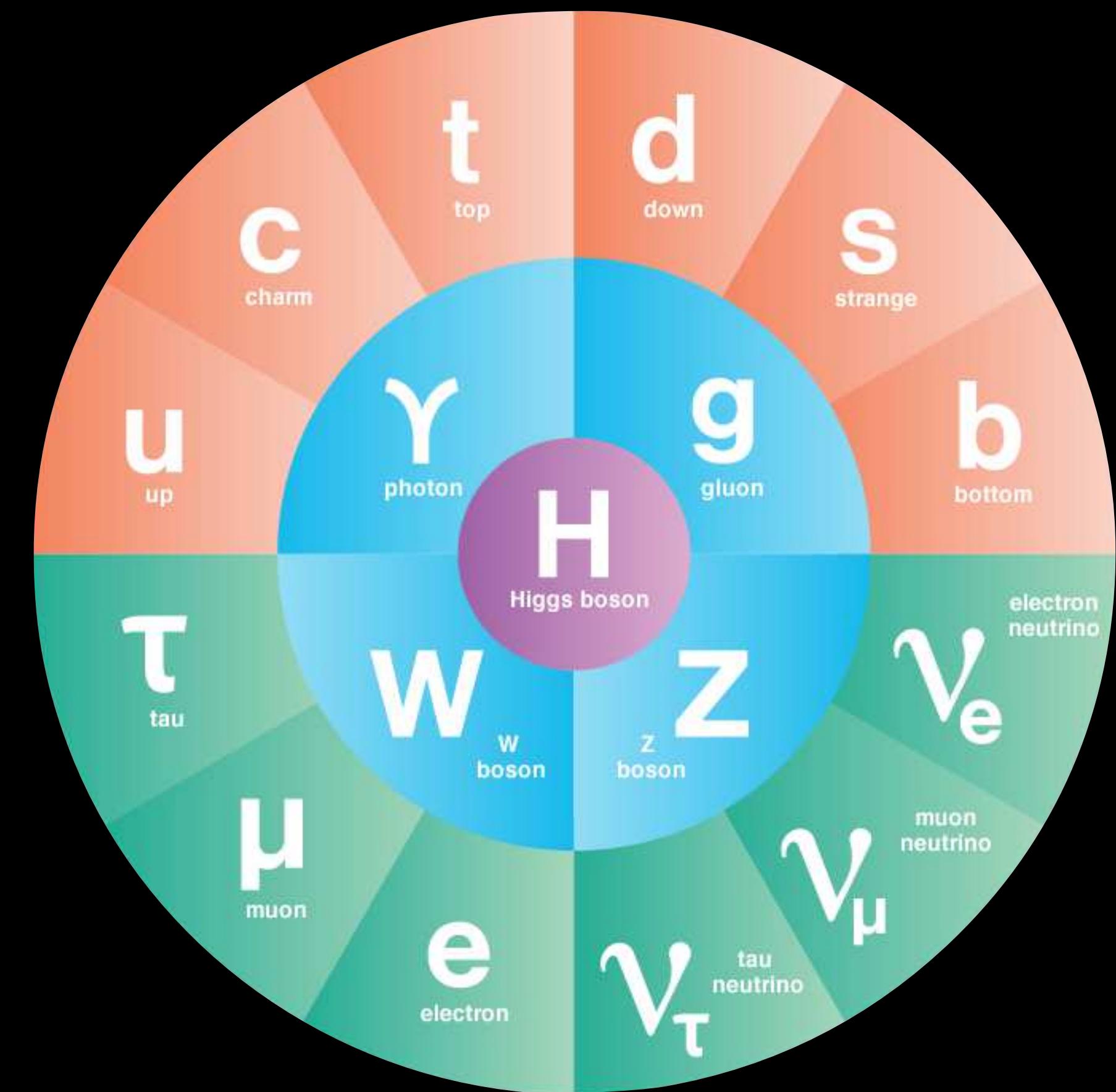


*Postdoctoral fellowship opportunity
October 20, 2020 deadline
<http://iaifi.org/fellows.html>*

Big Bang Cosmology



Standard Model



Big Bang Cosmology

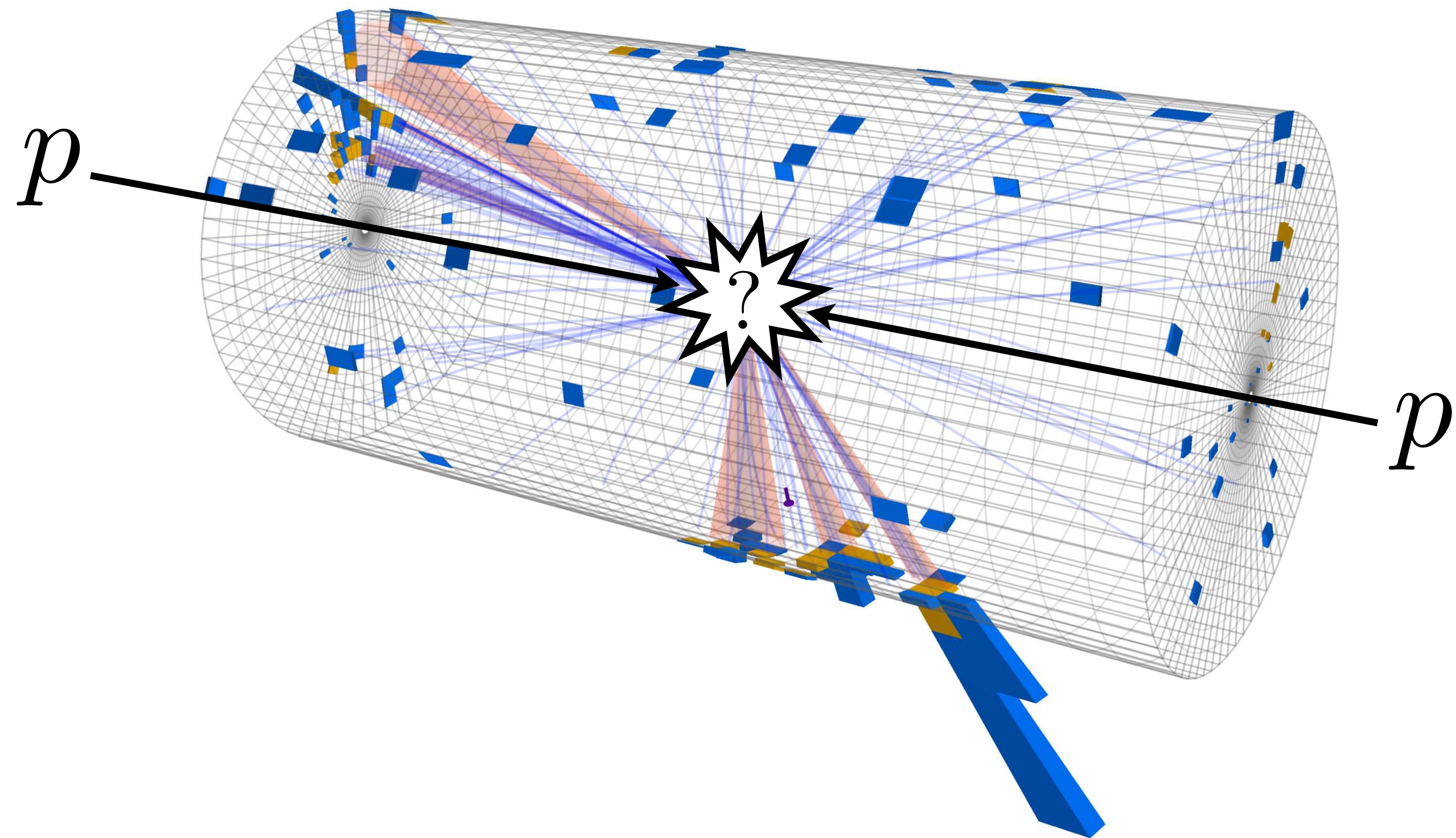
Standard Model

Pillars of Fundamental Physics

Triumphs of Human Intelligence

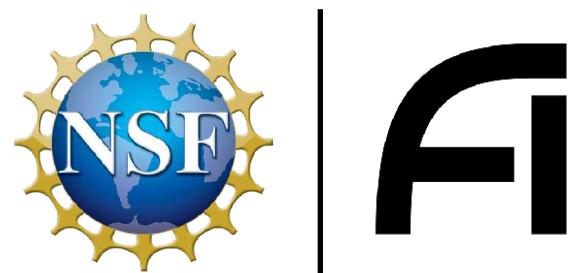
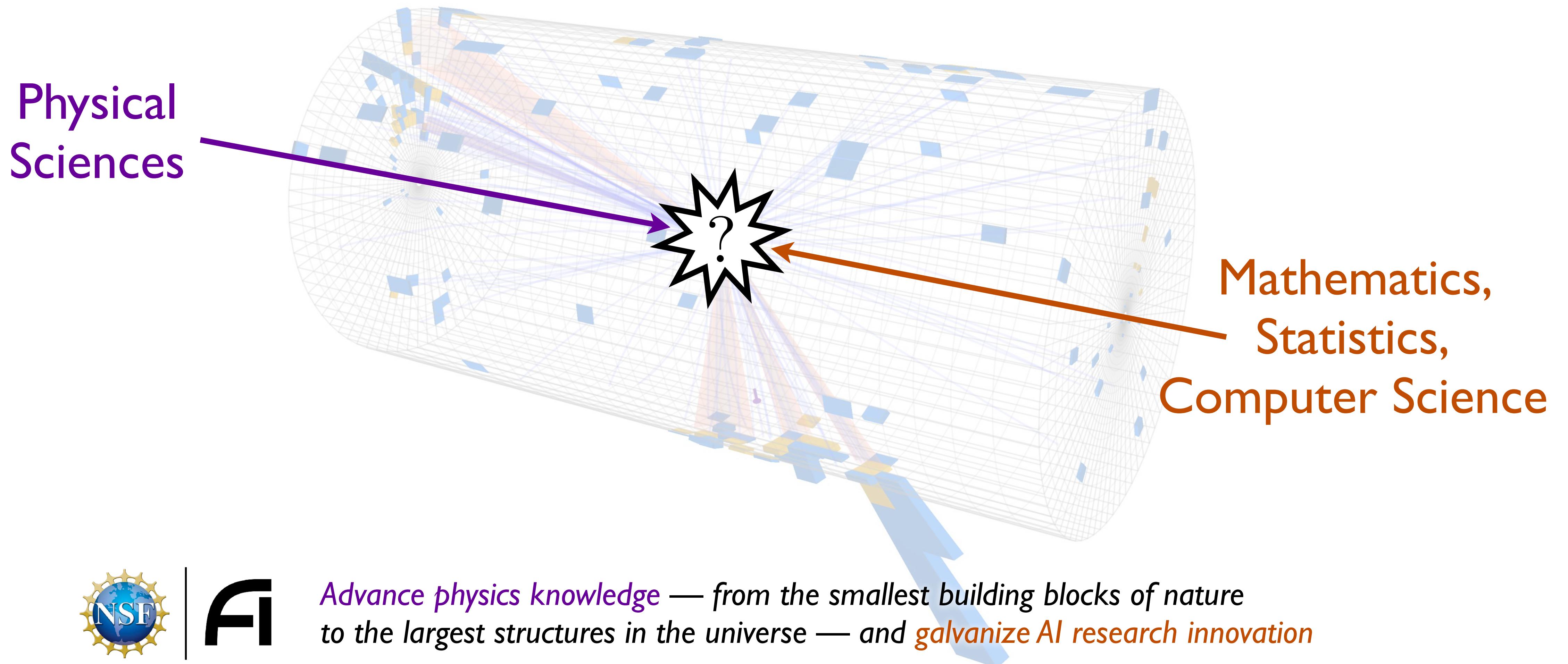


“Collision Course”

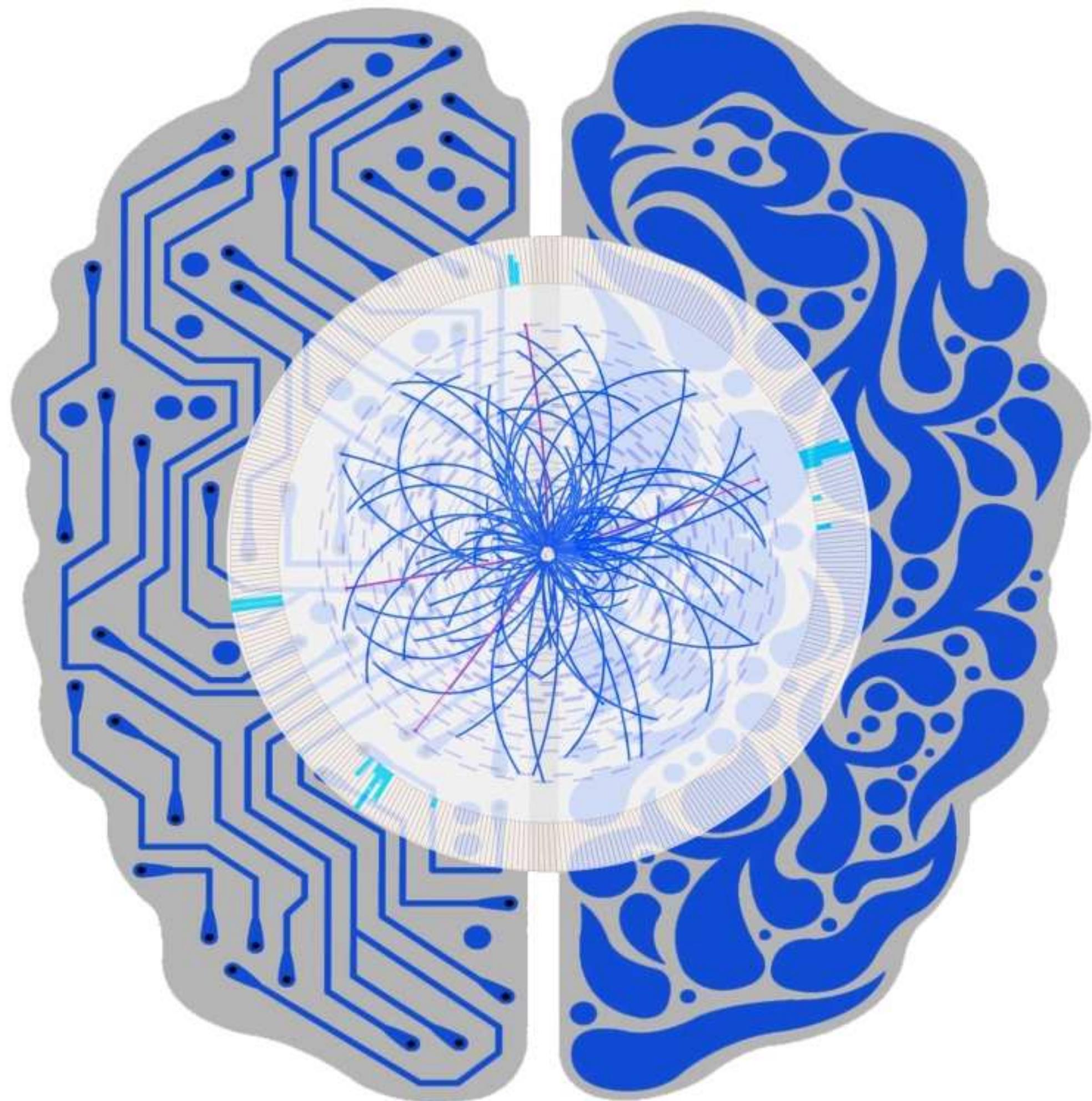


[CMS Detector at the Large Hadron Collider]

“Collision Course”



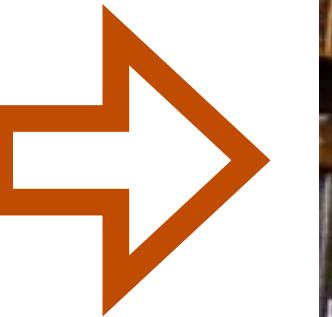
*Advance physics knowledge — from the smallest building blocks of nature
to the largest structures in the universe — and galvanize AI research innovation*



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

(Have you ever tried to reason with a toddler?)

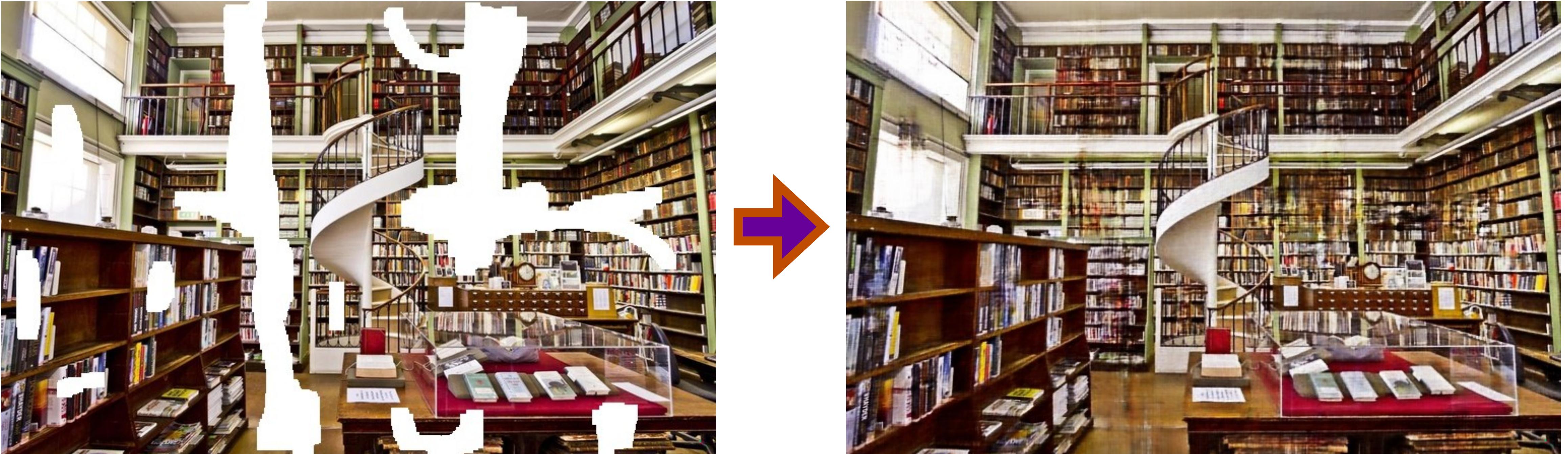
Deep Learning



Large data sets, increased computational power

[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

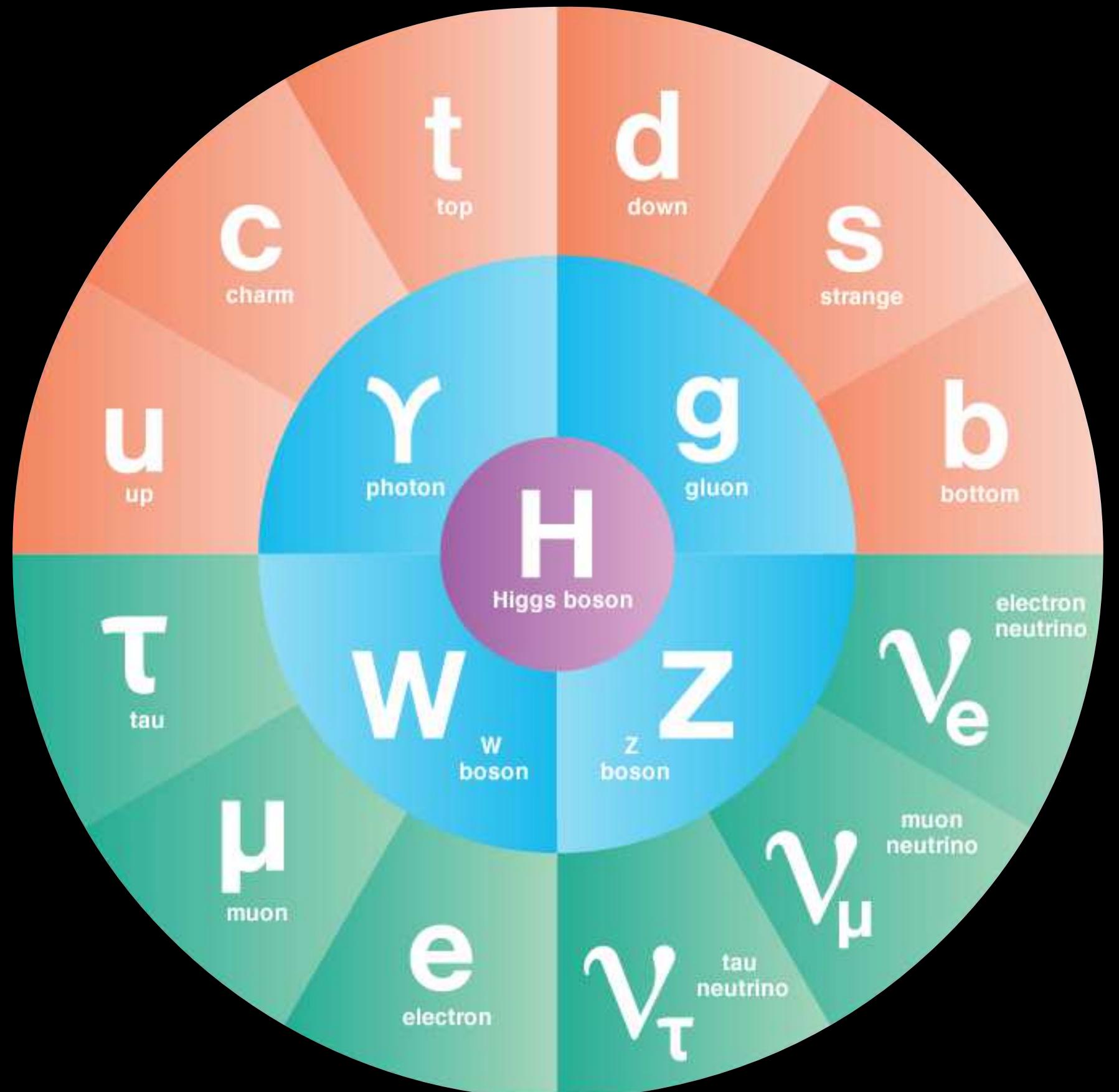
Deep Learning meets Deep Thinking



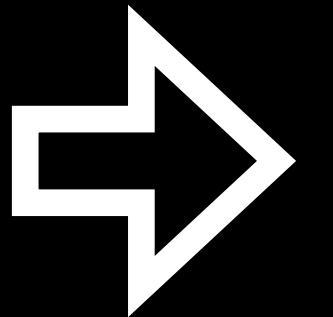
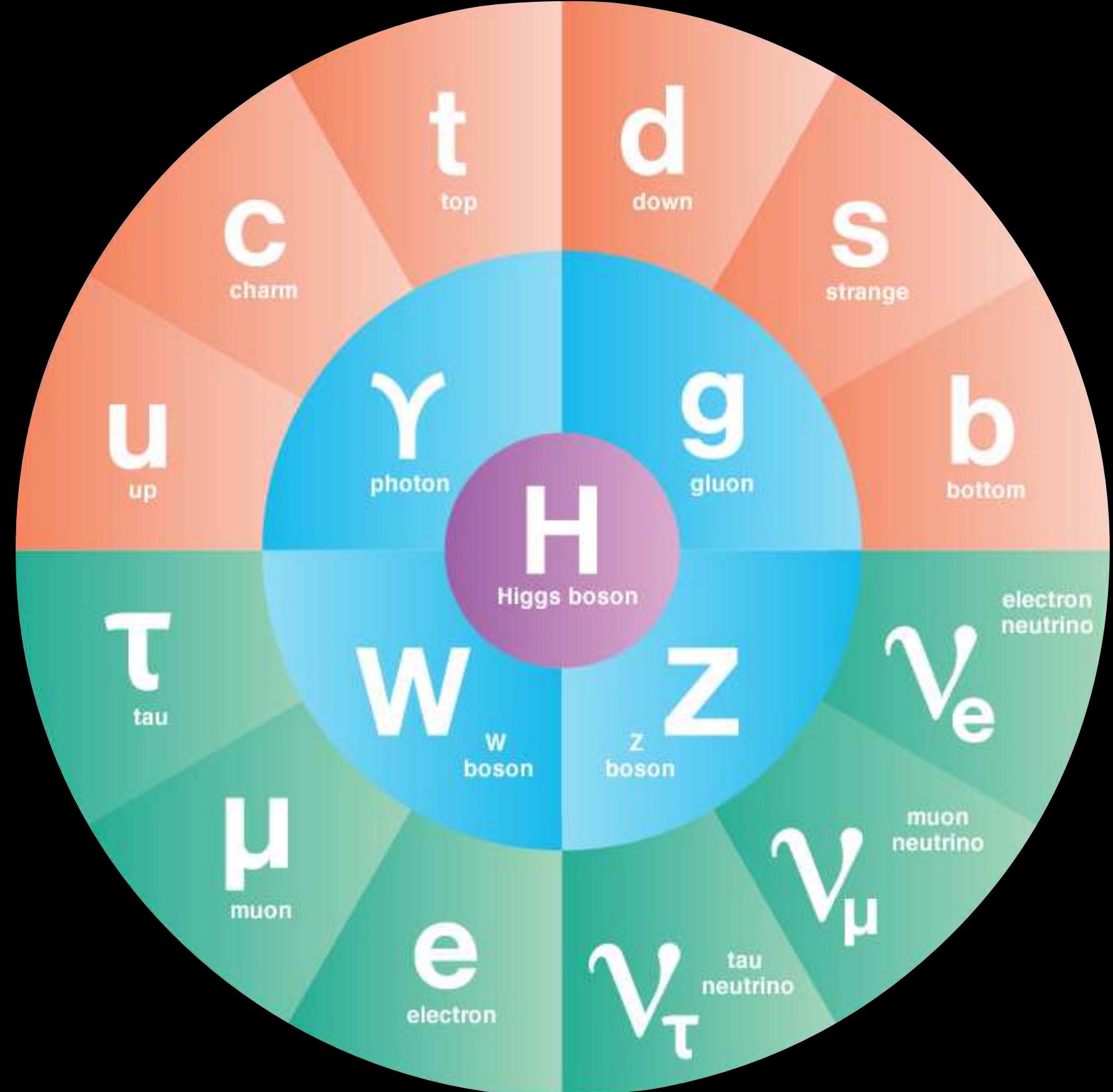
Large data sets, increased computational power, and understanding structure of problems

[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

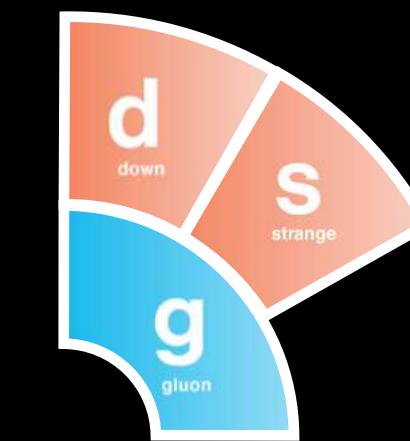
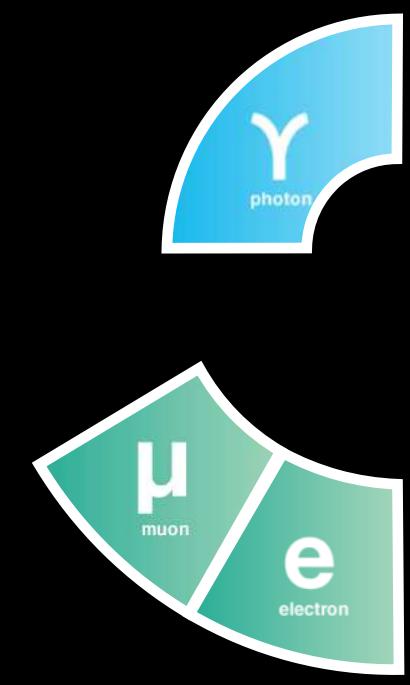
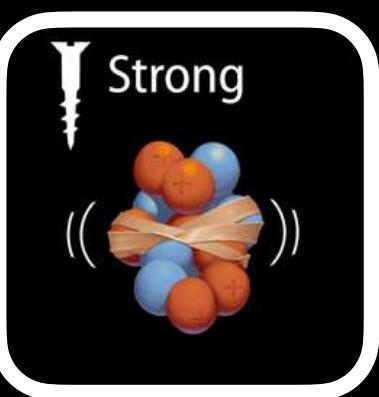
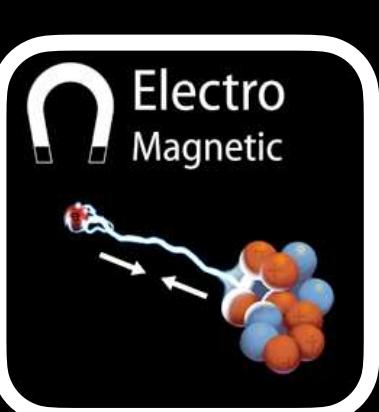
Particle Physics 101



Particle Physics 101



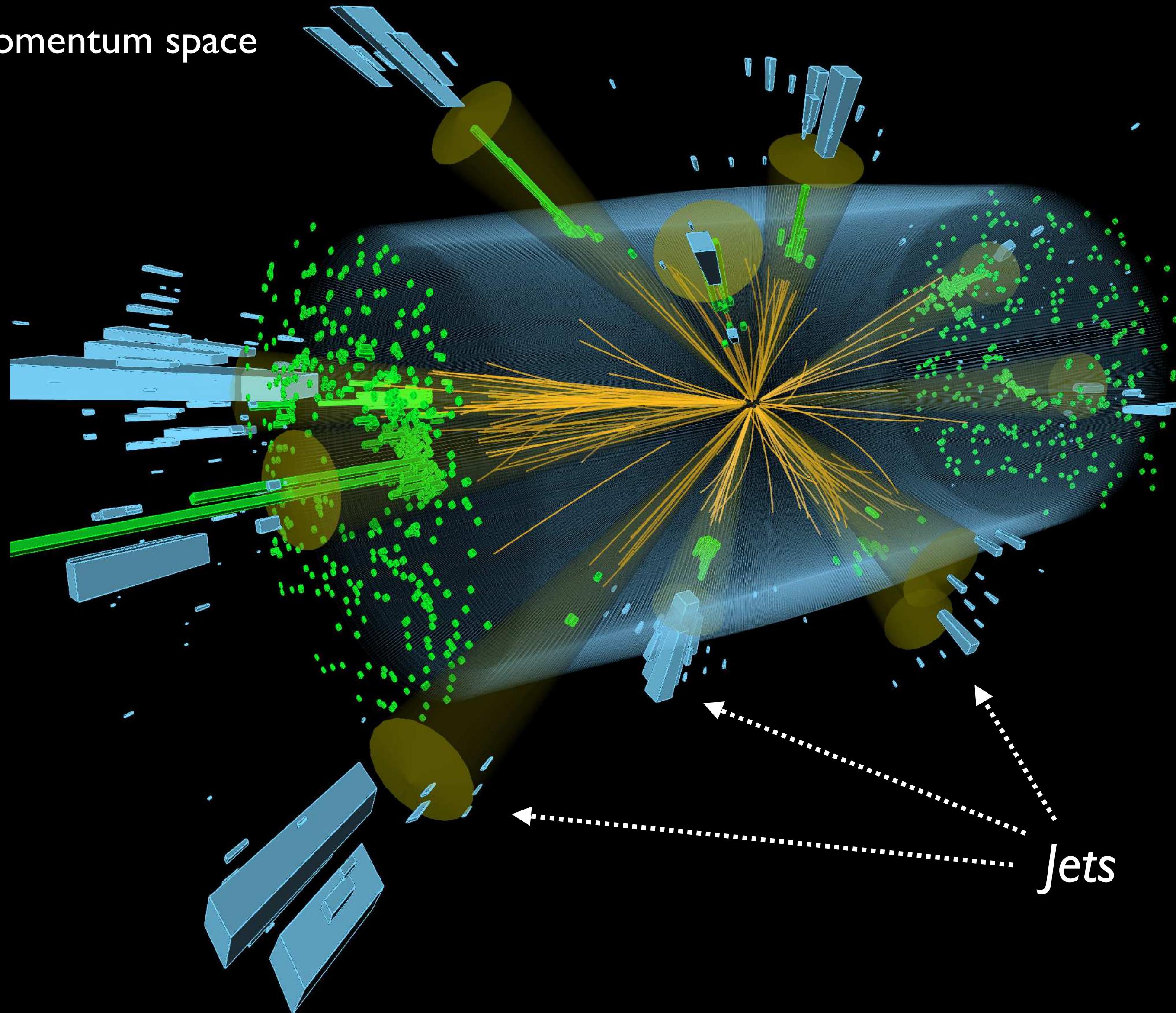
Quarks & Gluons



γ	photon
e^\pm	electron
μ^\pm	muon
π^\pm	pion
K^\pm	kaon
K^0_L	K-long
p/\bar{p}	proton
n/\bar{n}	neutron

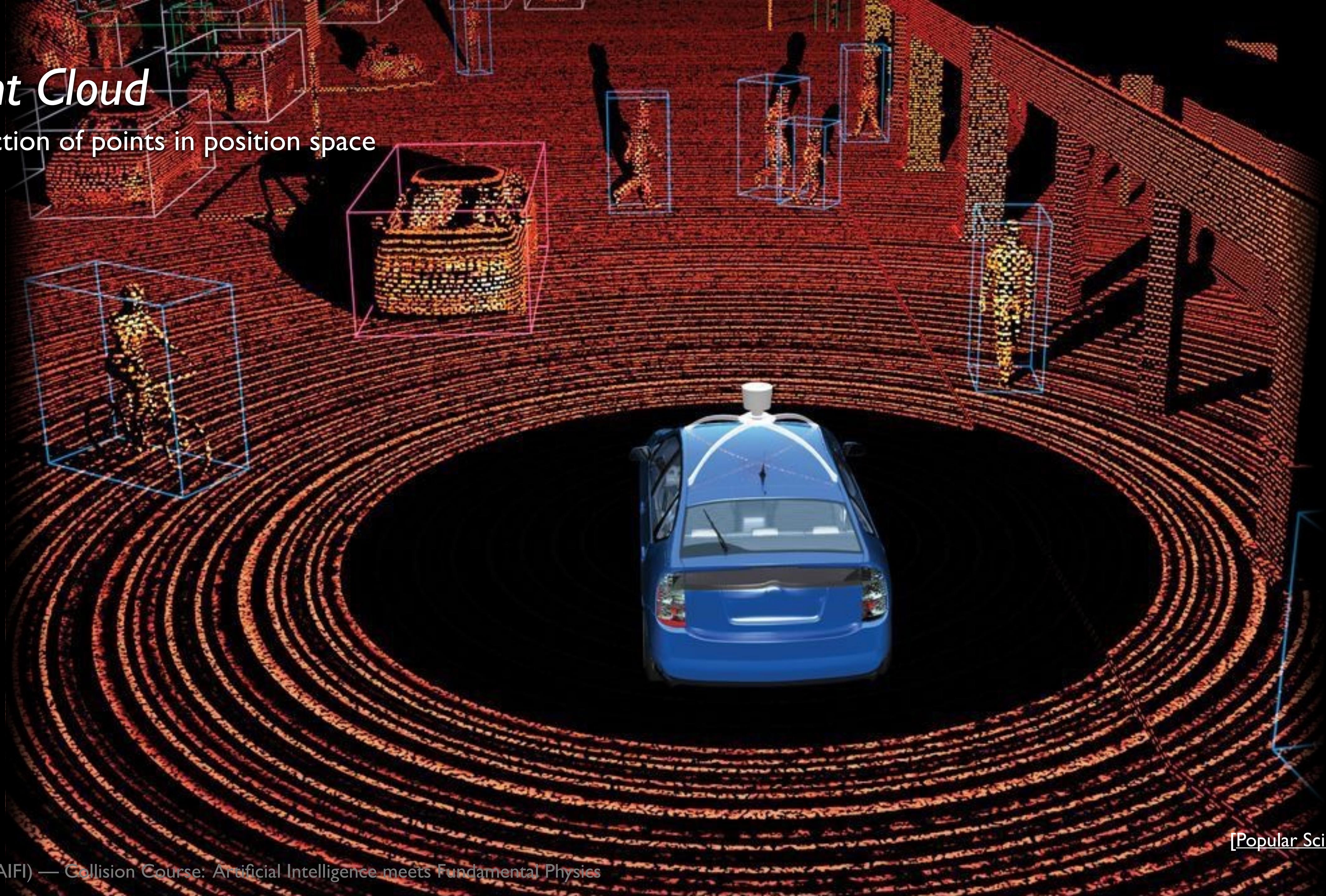
Collider Event

Collection of points in momentum space

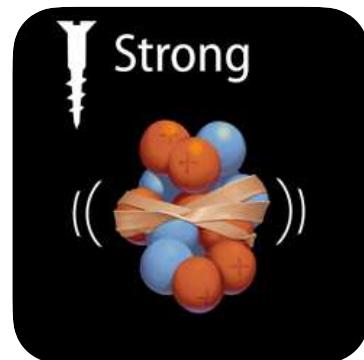


Point Cloud

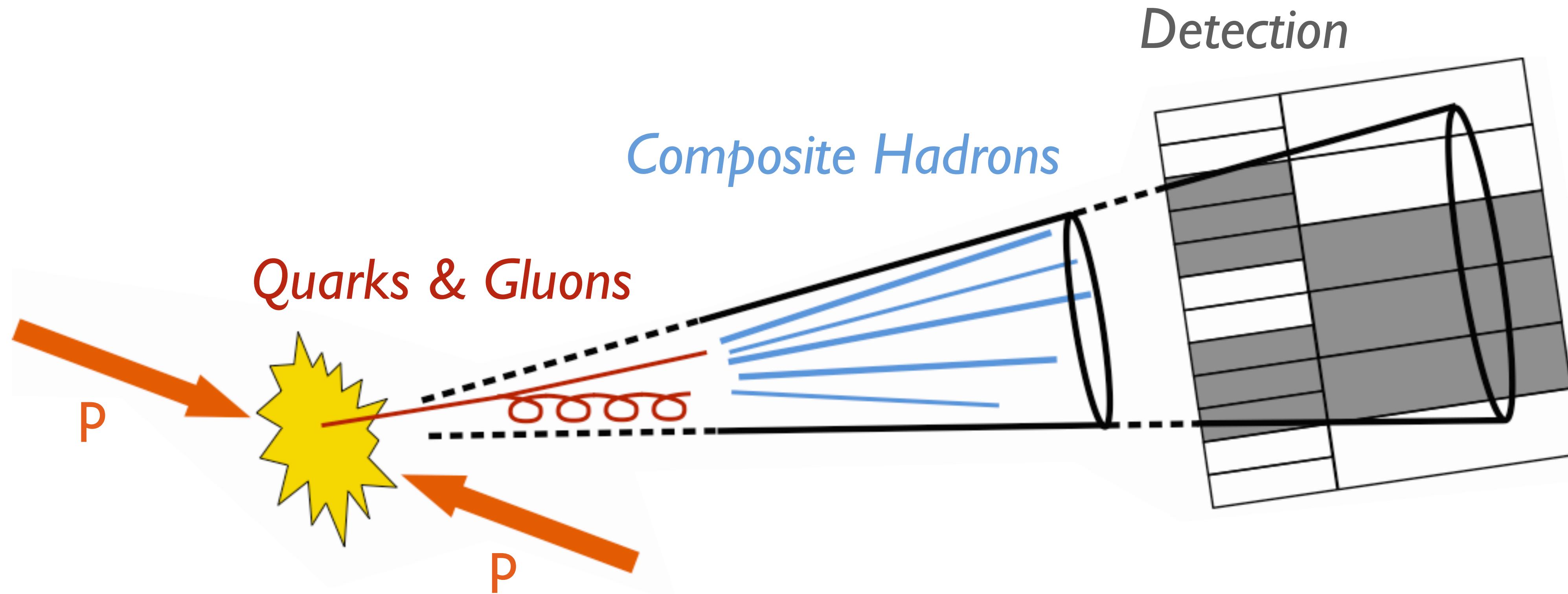
Collection of points in position space

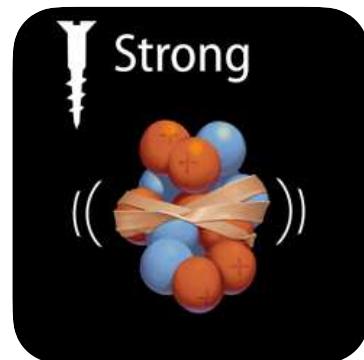


[Popular Science, 2013]



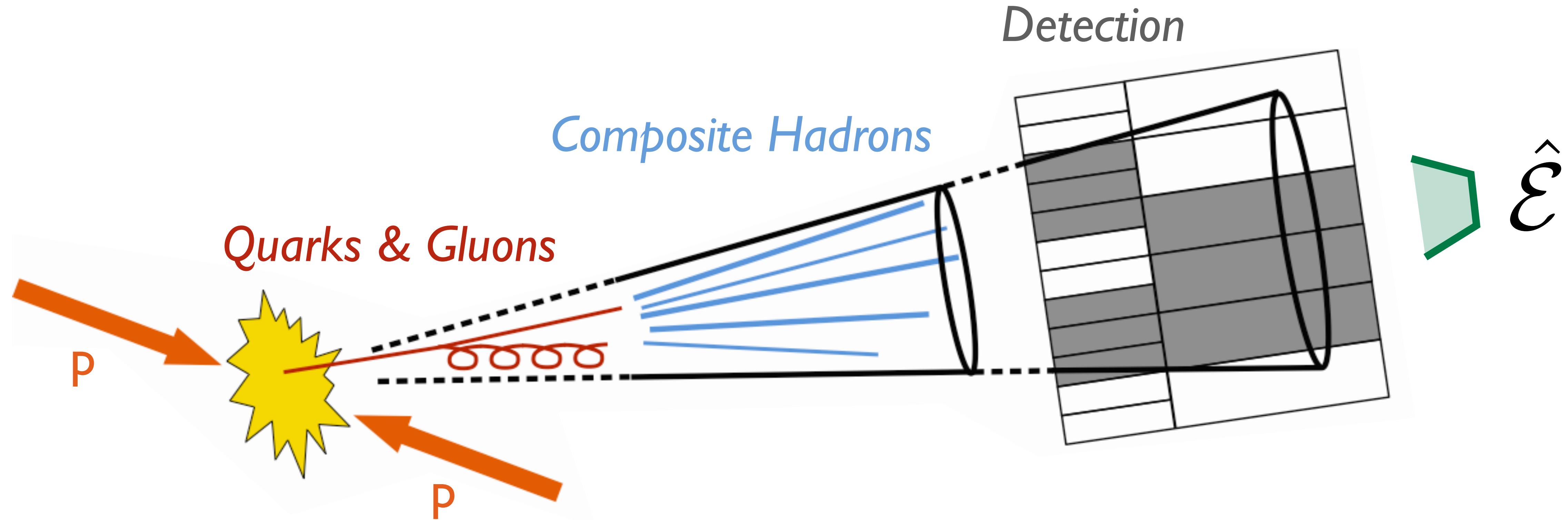
Dynamics of Jet Formation





Dynamics of Jet Formation

Theory



“Energy Flow”
Robust to hadronization and detection

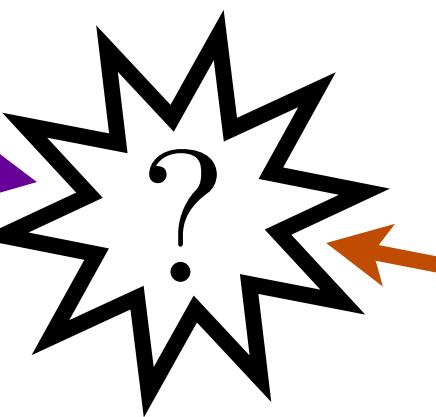
$$\hat{\mathcal{E}} \simeq \lim_{t \rightarrow \infty} \hat{n}_i T^{0i}(t, vt\hat{n})$$

[Sveshnikov, Tkachov, PLB 1996]

Principles of Fundamental Physics

Robustness of Energy Flow

[Komiske, Metodiev, JDT, [JHEP 2018](#)]



Power of Artificial Intelligence

Point Cloud Learning

[Zaheer, Kottur, Ravanbakhsh, Poczos,
Salakhutdinov, Smola, [NIPS 2017](#)]

Principles of Fundamental Physics

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Patrick Komiske



Eric Metodiev



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Principles of Fundamental Physics

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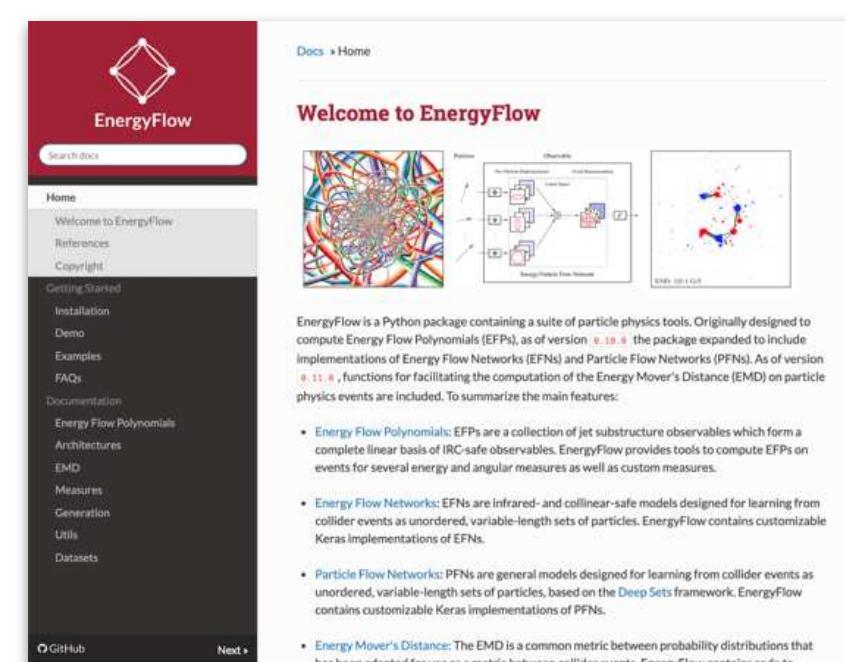
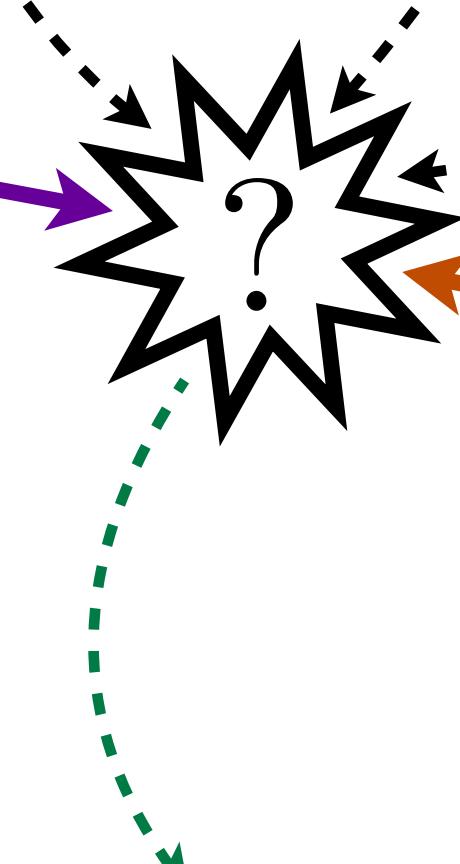


Patrick Komiske

Eric Metodiev



SF



Energy Flow Networks

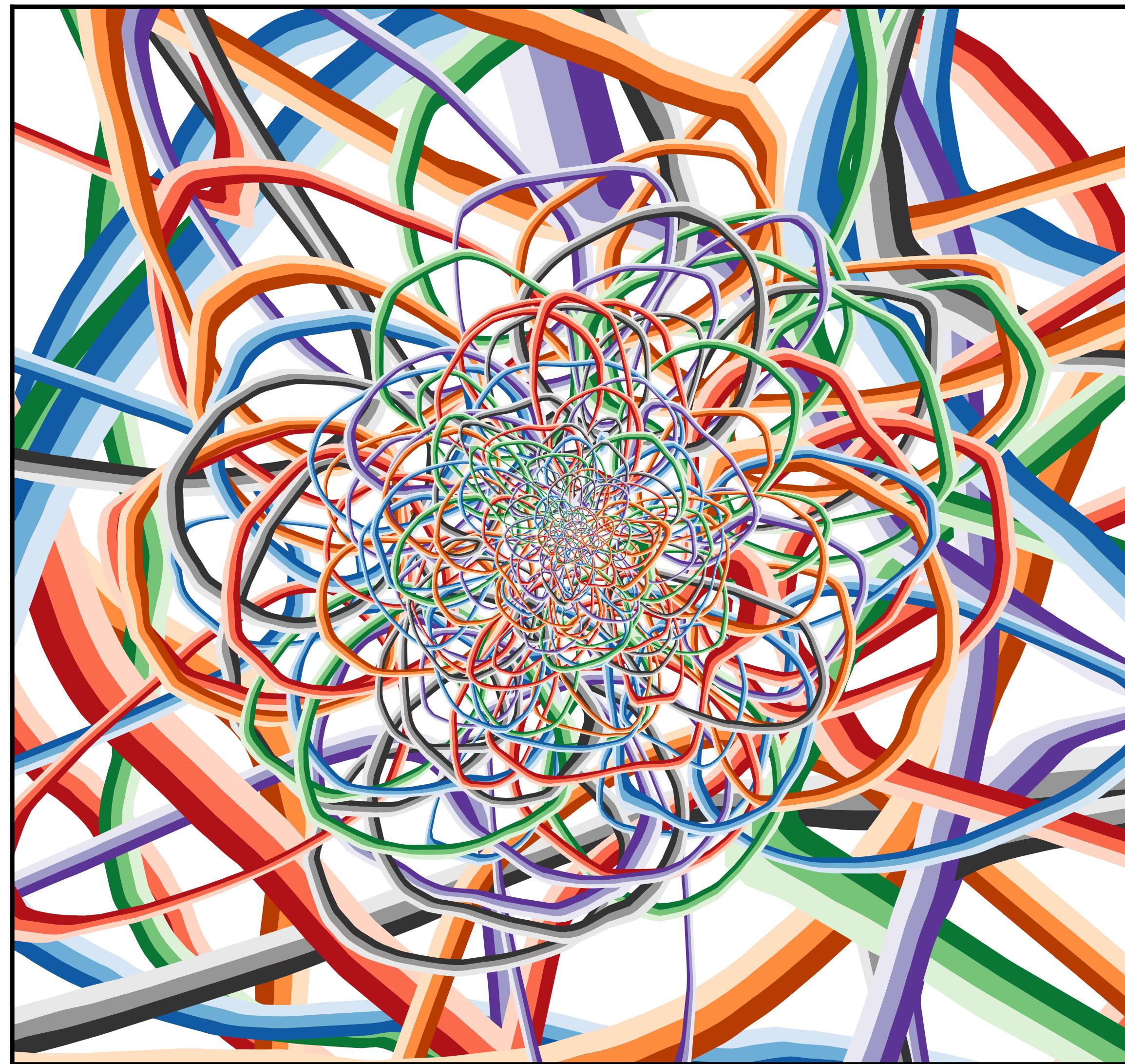
<https://energyflow.network/>

[Komiske, Metodiev, JDT, JHEP 2019]

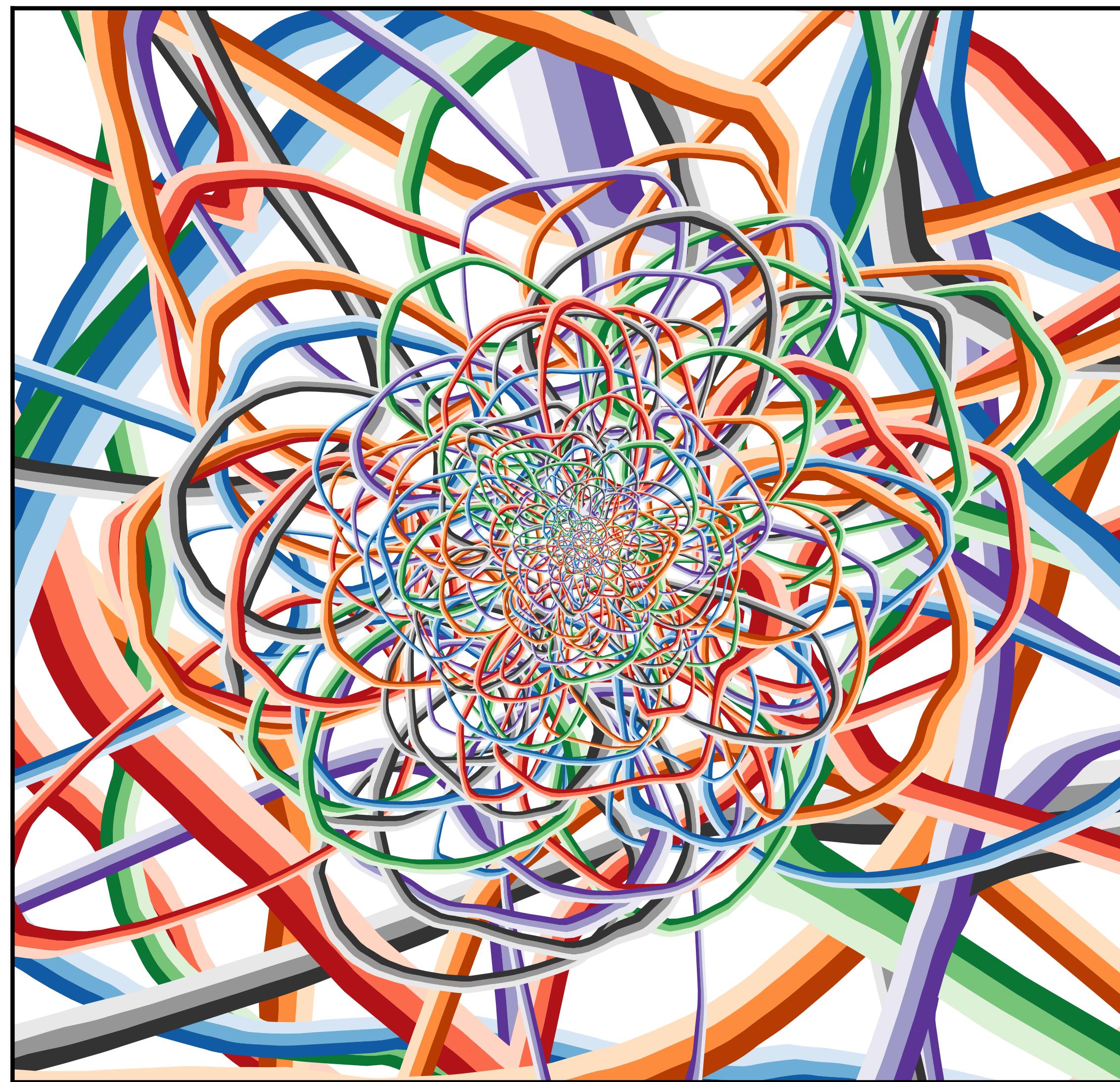
Power of Artificial Intelligence

Point Cloud Learning

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

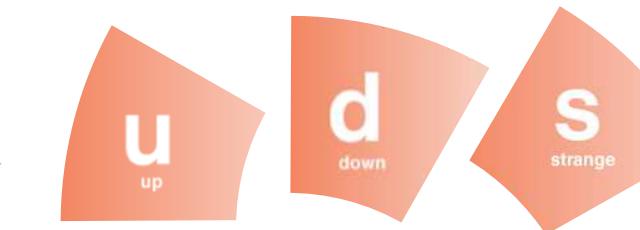


[Komiske, Metodiev, JDT, JHEP 2019]



“Hello, World!” of Jets:

Quark



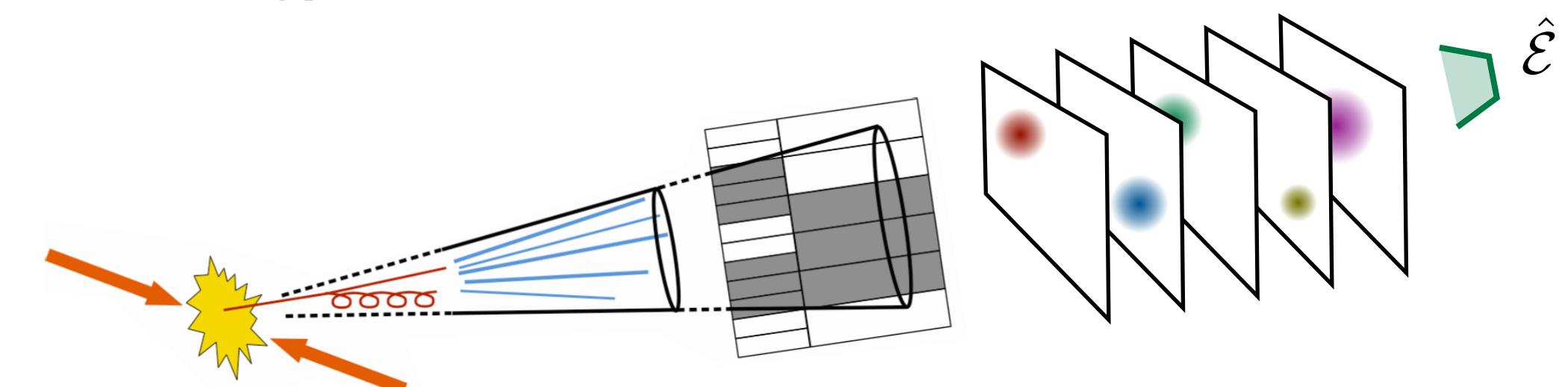
vs. Gluon



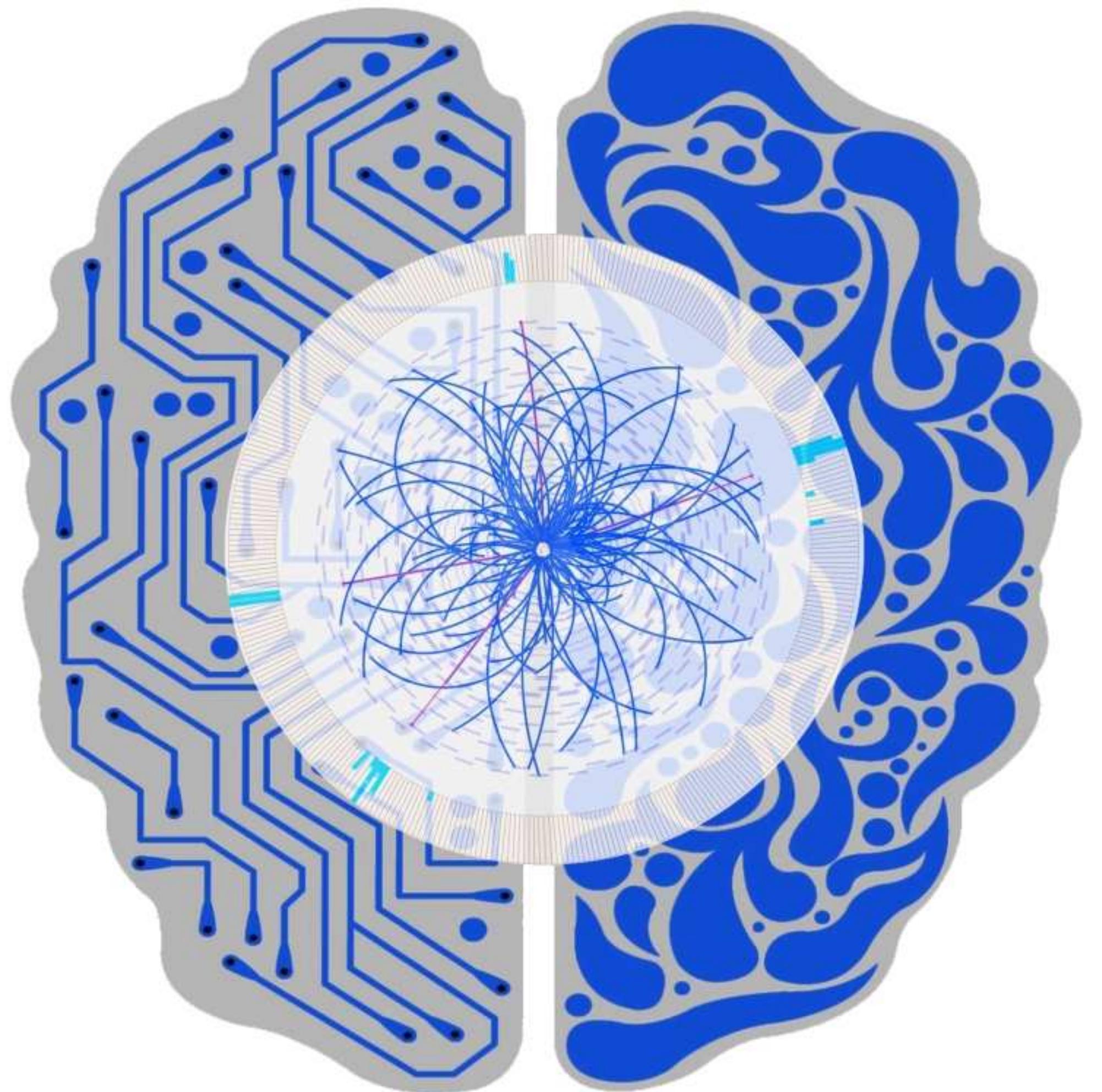
Energy Flow Network:

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

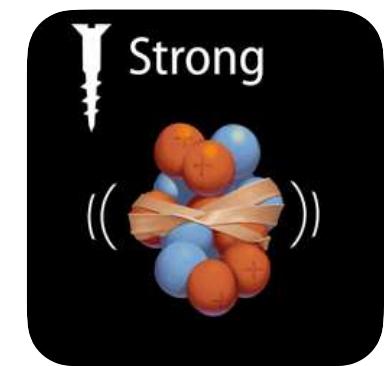
Strategy for Verification:



[Komiske, Metodiev, JDT, JHEP 2019]

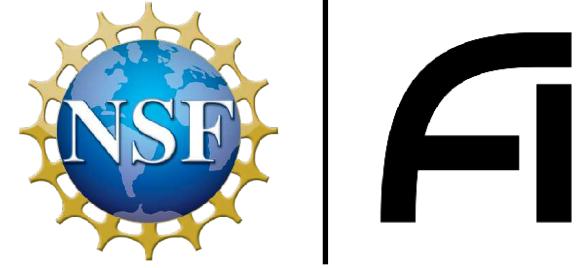


*We taught a machine to
“think” like a physicist...*

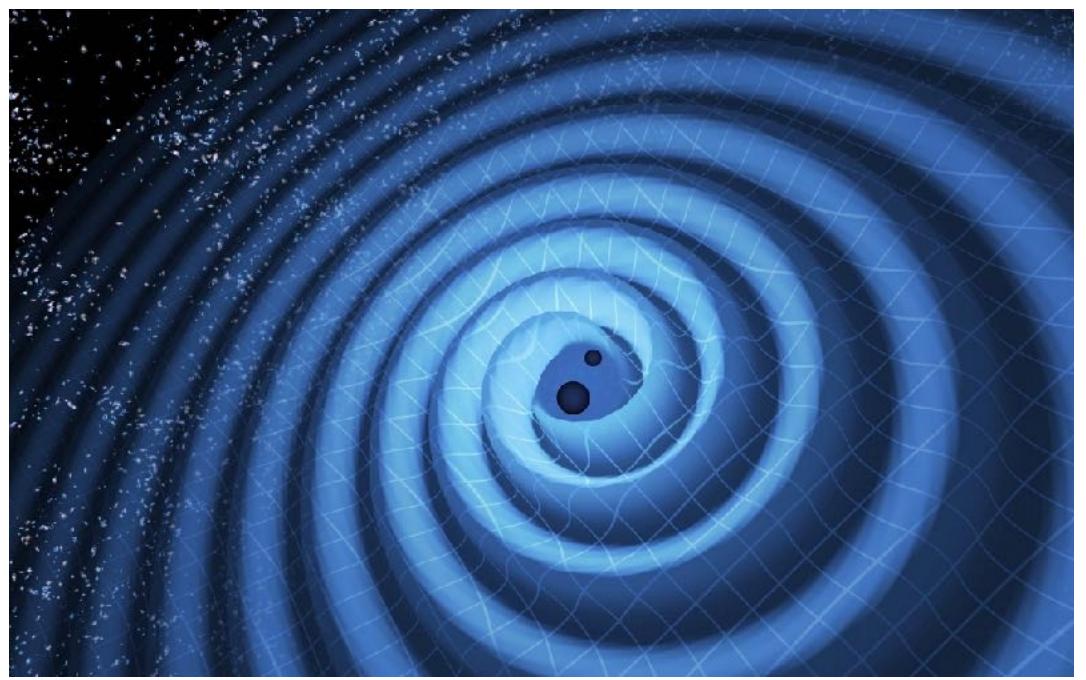


*...and it learned fractal
structure of strong force!*

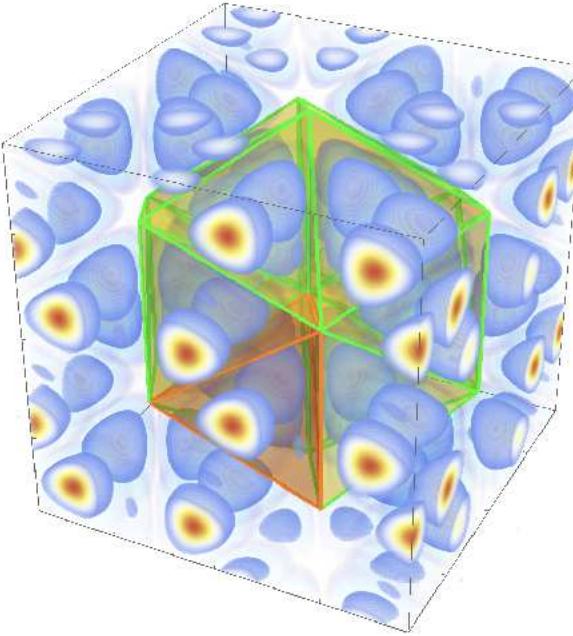
Artificial Intelligence \leftrightarrow Fundamental Physics



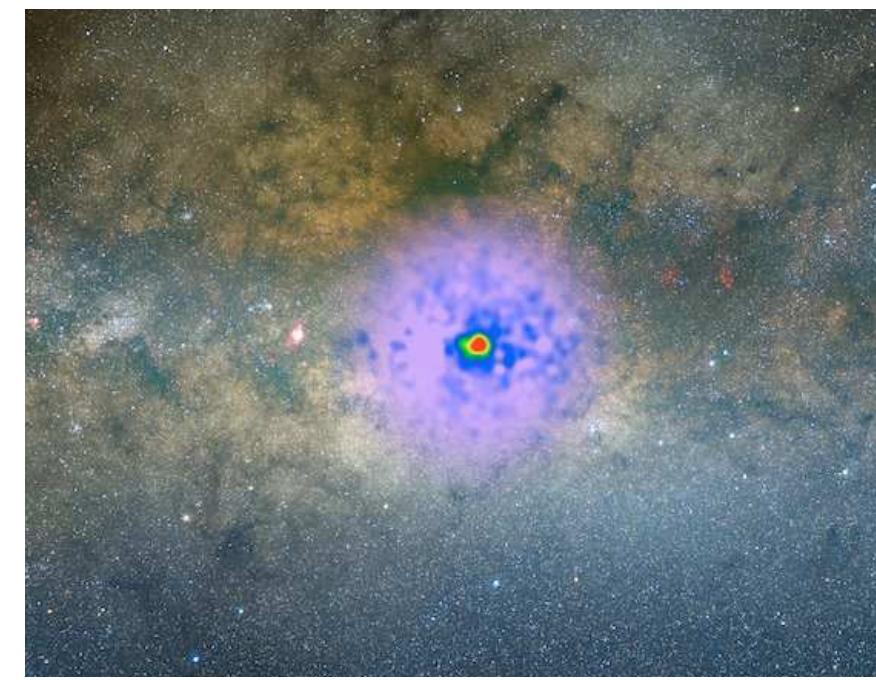
Gravitational Waves



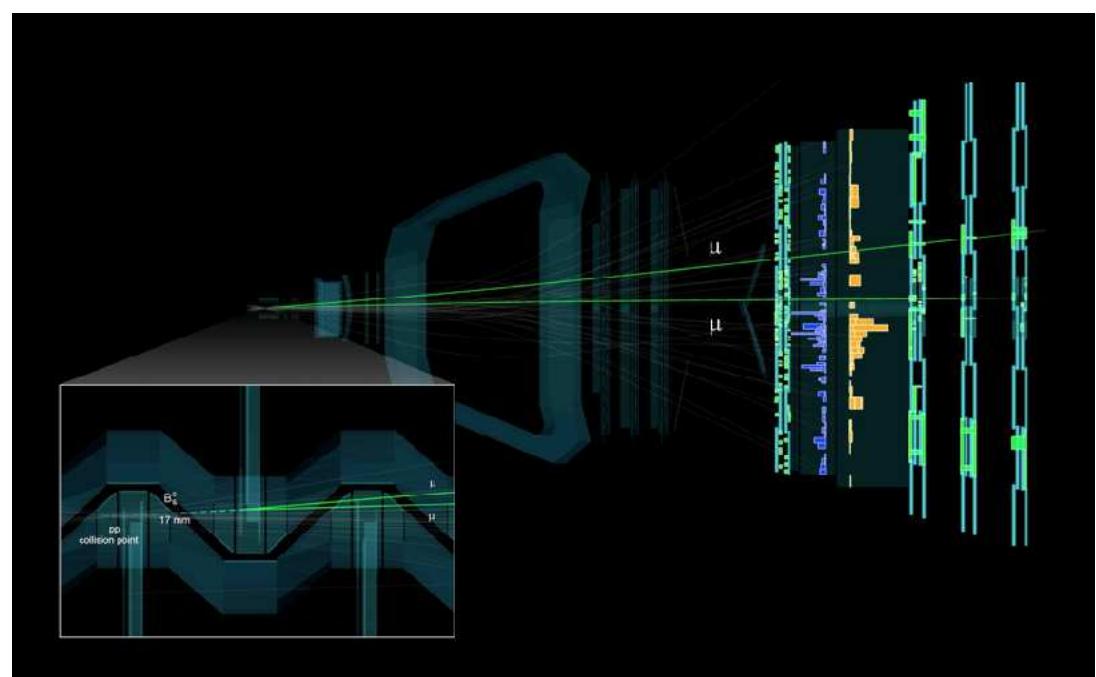
Nuclear Physics



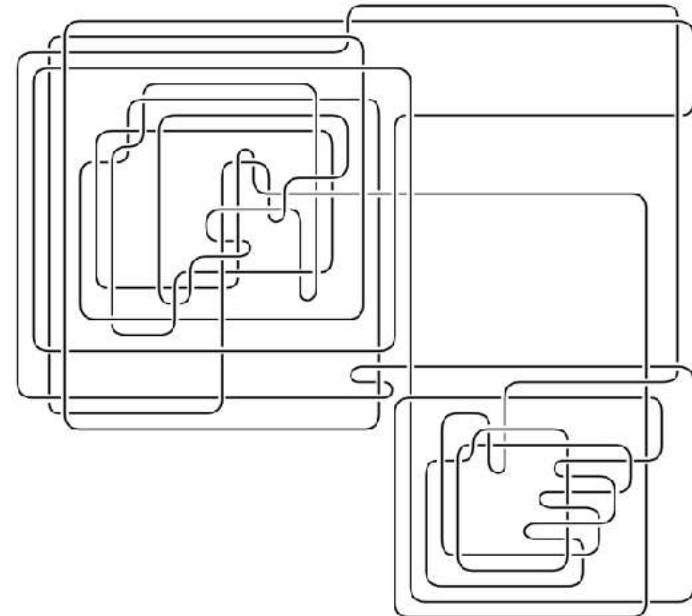
Astrophysics



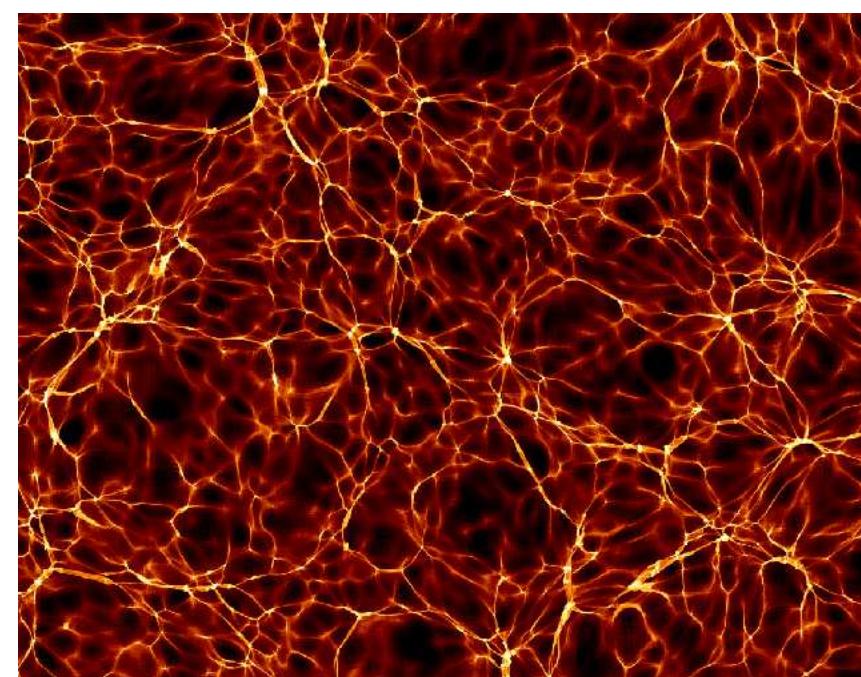
Particle Colliders



Mathematical Physics



Dark Matter



...

[\[iaifi.org\]](http://iaifi.org)



What principles and strategies from physics could be incorporated into your research in data science and AI?

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

Collision Course

Artificial Intelligence meets Fundamental Physics

Jesse Thaler

Director, NSF AI Institute for Artificial Intelligence and Fundamental Interactions

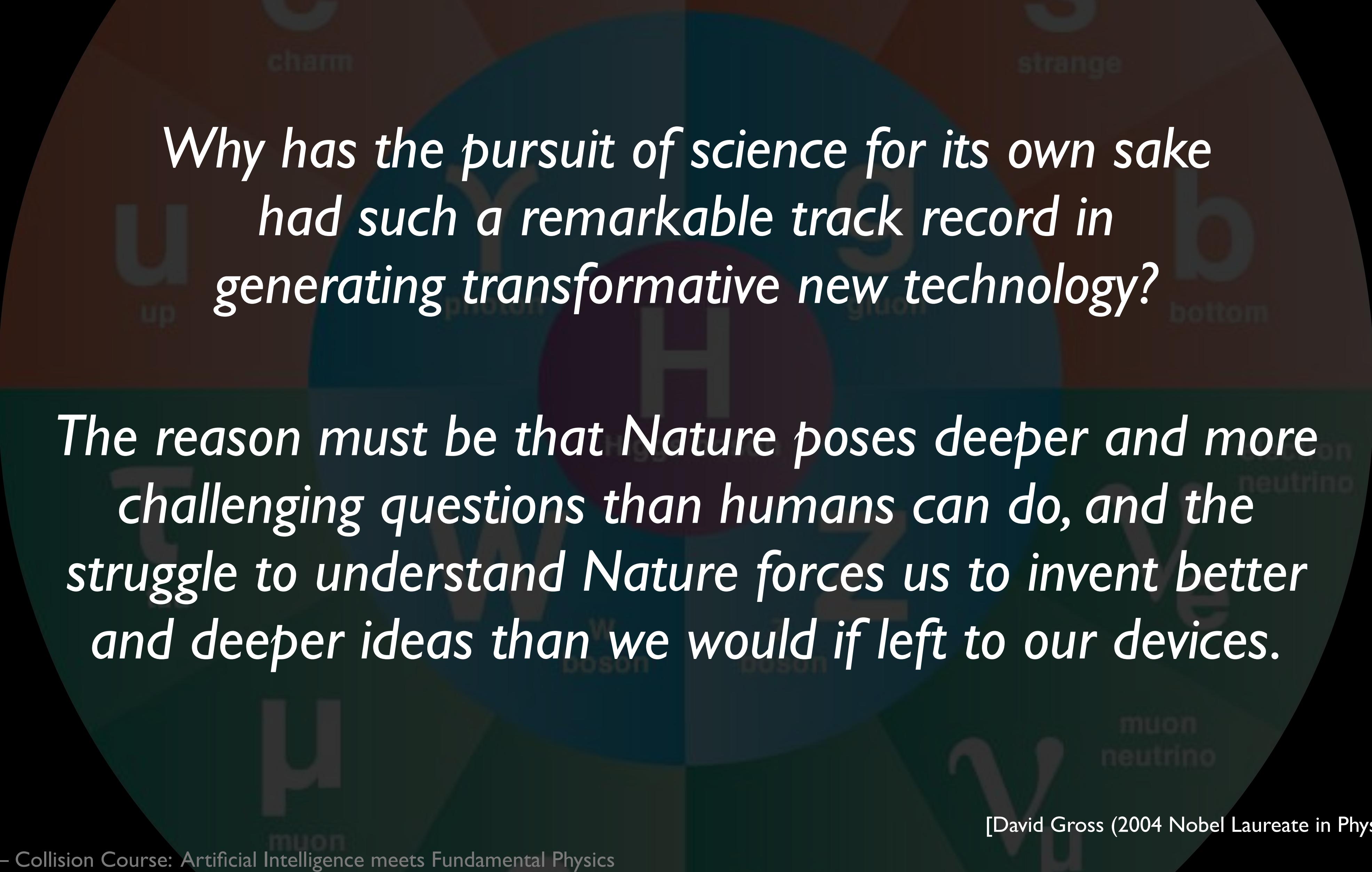


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Backup Slides

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

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



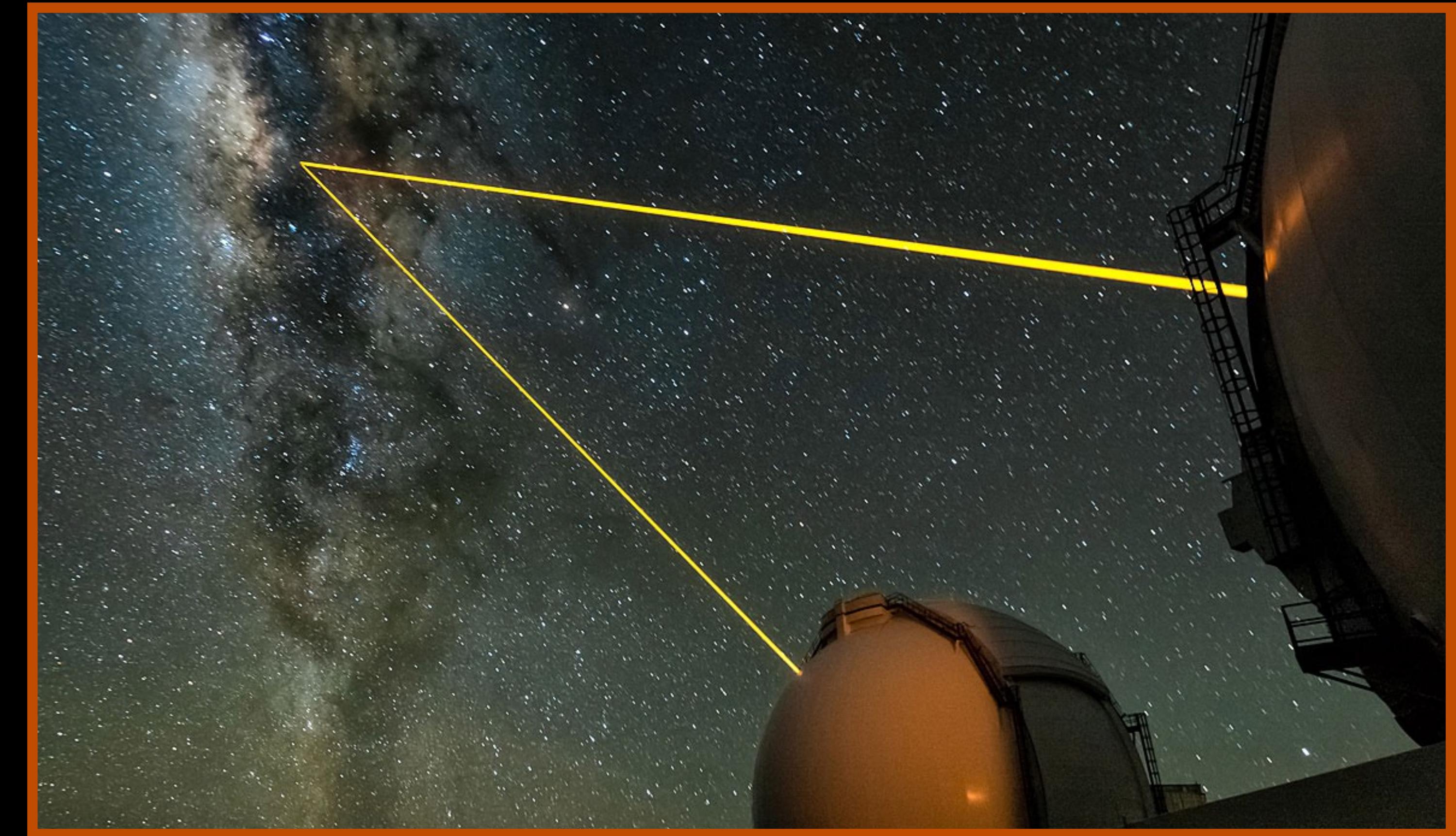
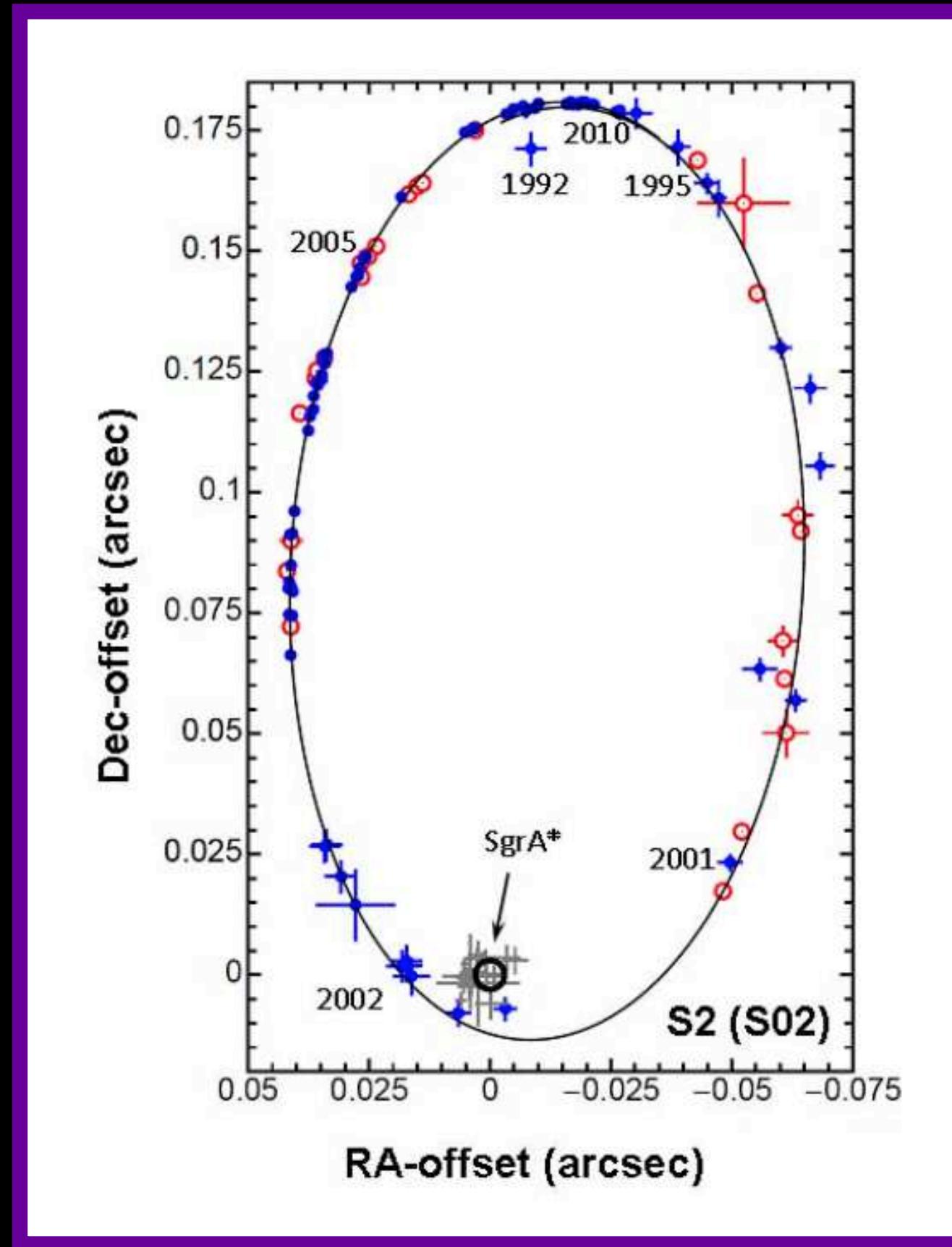
Why has the pursuit of science for its own sake had such a remarkable track record in generating transformative new technology?

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]



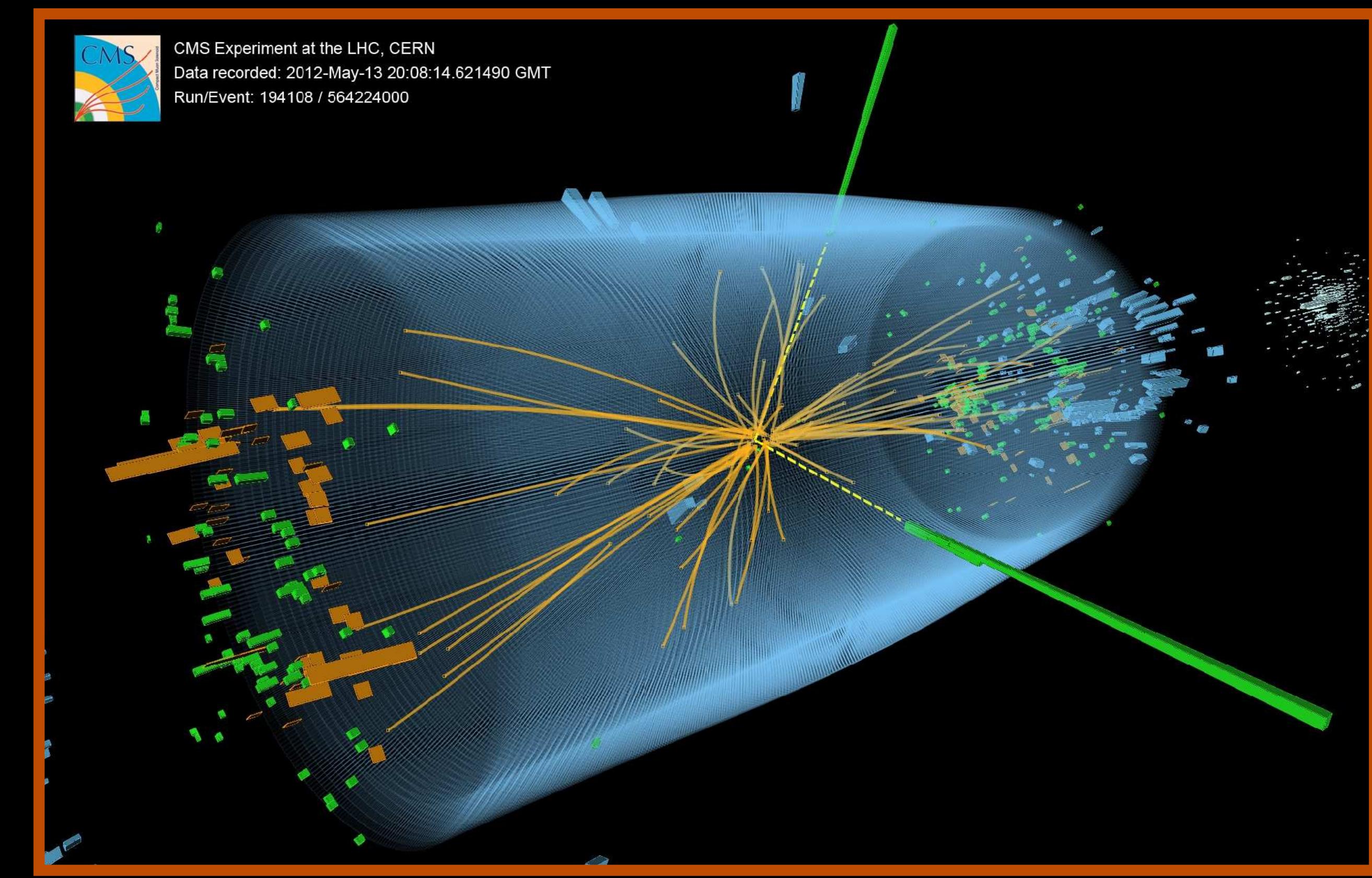
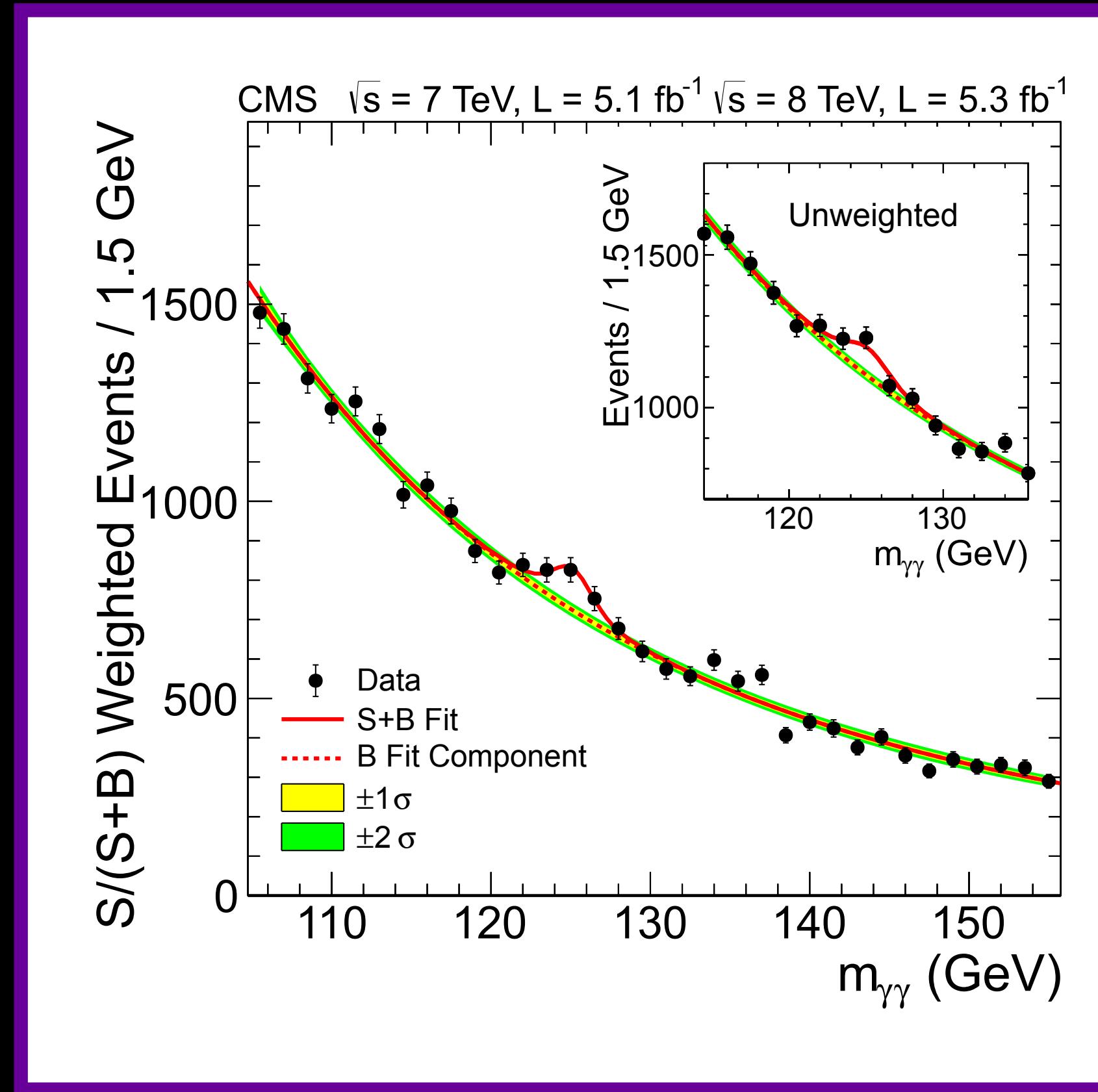
Sagittarius A*: Supermassive Black Hole in Heart of our Galaxy



[2020 Nobel Prize in Physics: Penrose, Genzel, Ghez]



Higgs Boson: Fundamental Particle at Heart of Standard Model



[2013 Nobel Prize in Physics: Englert, Higgs]