

Artificial Intelligence meets Fundamental Physics

Jesse Thaler

Director, NSF AI Institute for Artificial Intelligence and Fundamental Interactions



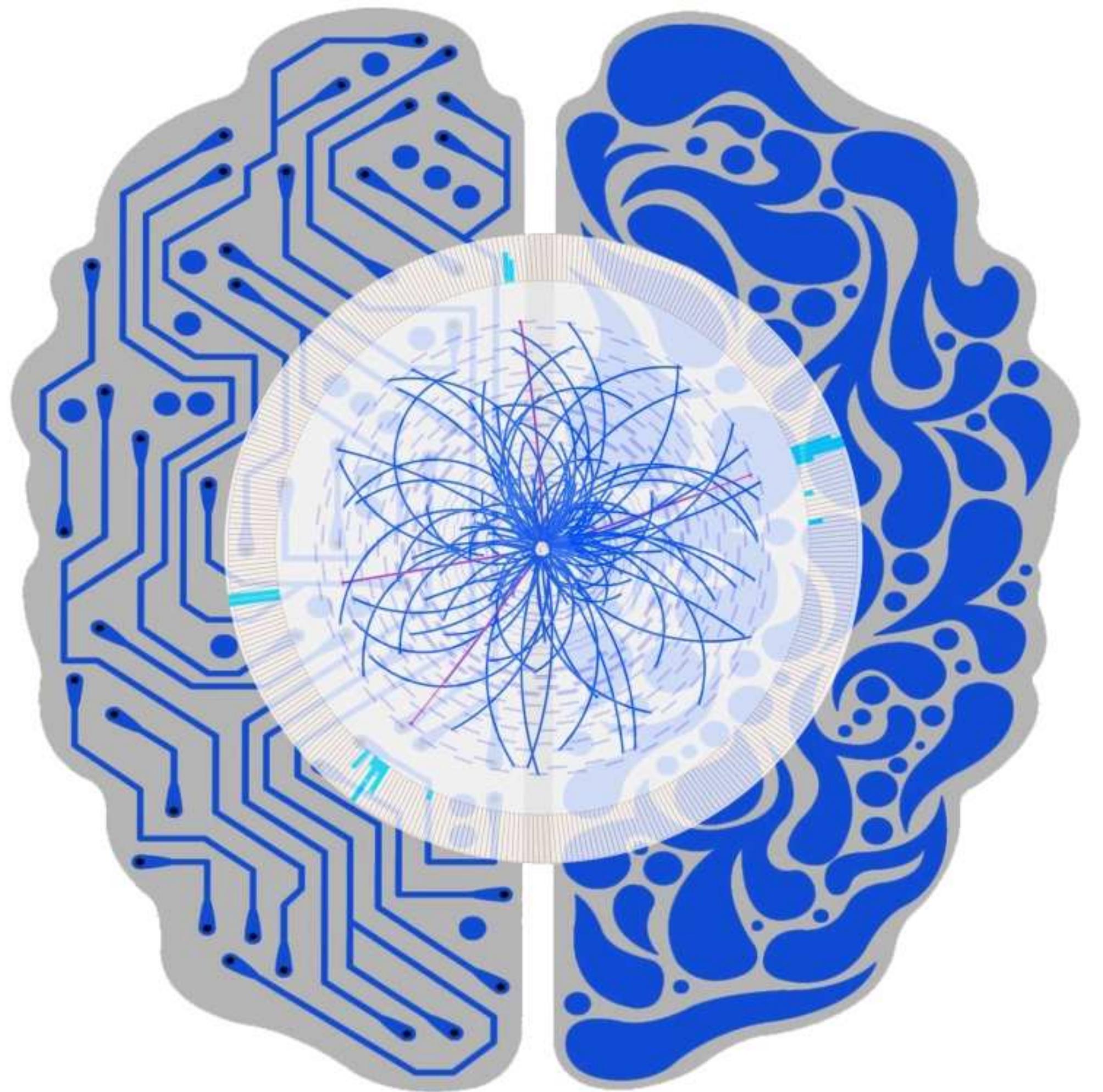
EmTech Digital Inside Track — March 23, 2021



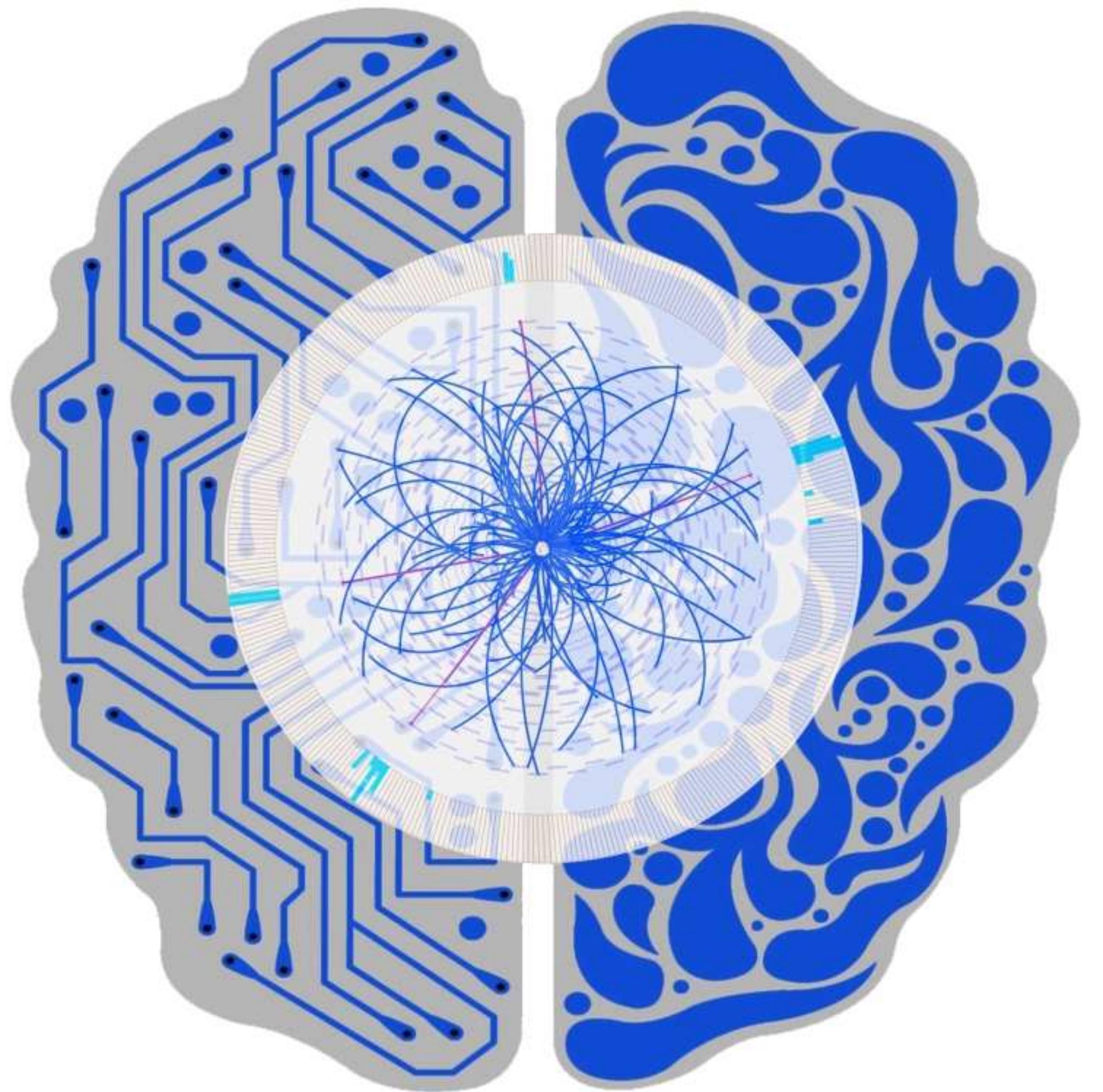
The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI /ai-fai/ iaifi.org)



*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?*



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to “think” like a physicist?*

The New York Times

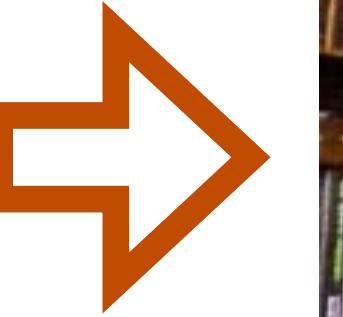


By Dennis Overbye

Nov. 23, 2020

Can a Computer Devise a Theory of Everything?

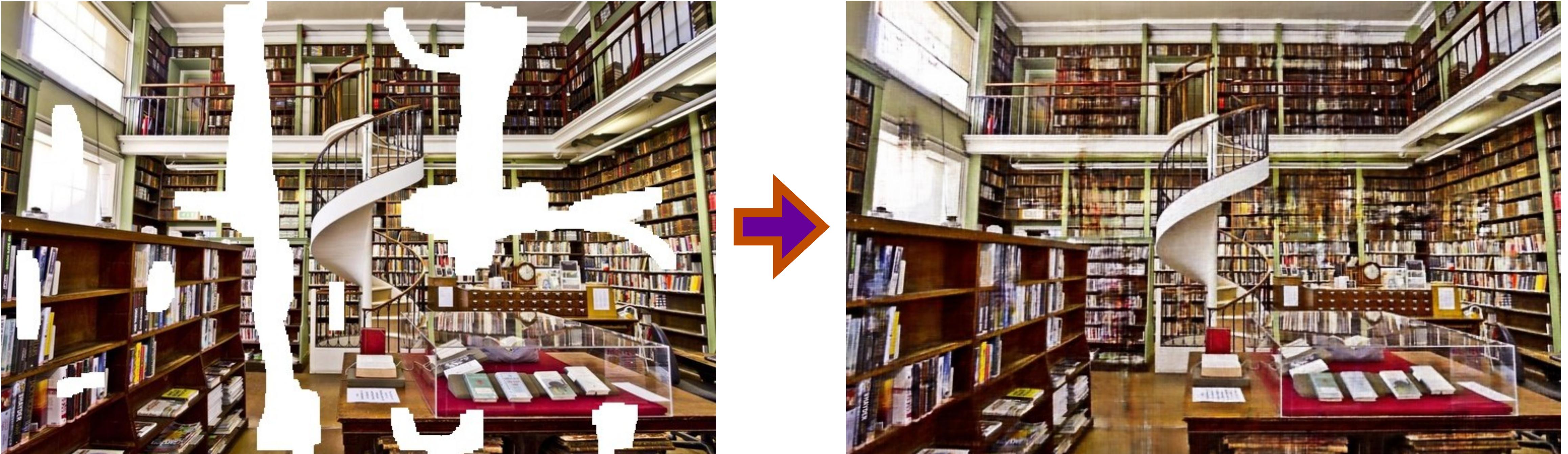
Deep Learning



Large data sets, increased computational power

[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

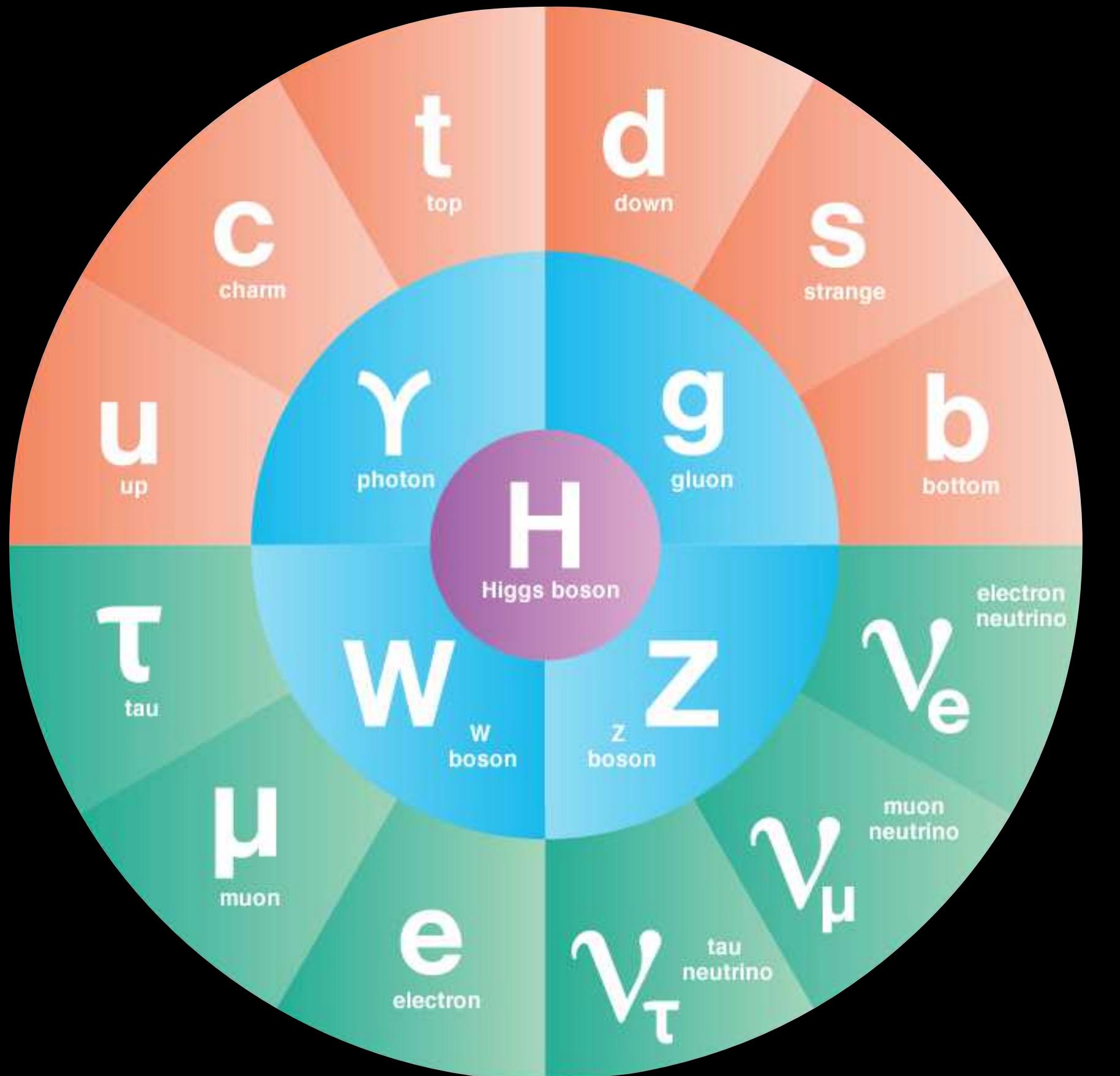
Deep Learning meets Deep Thinking



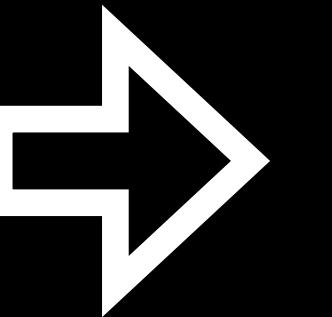
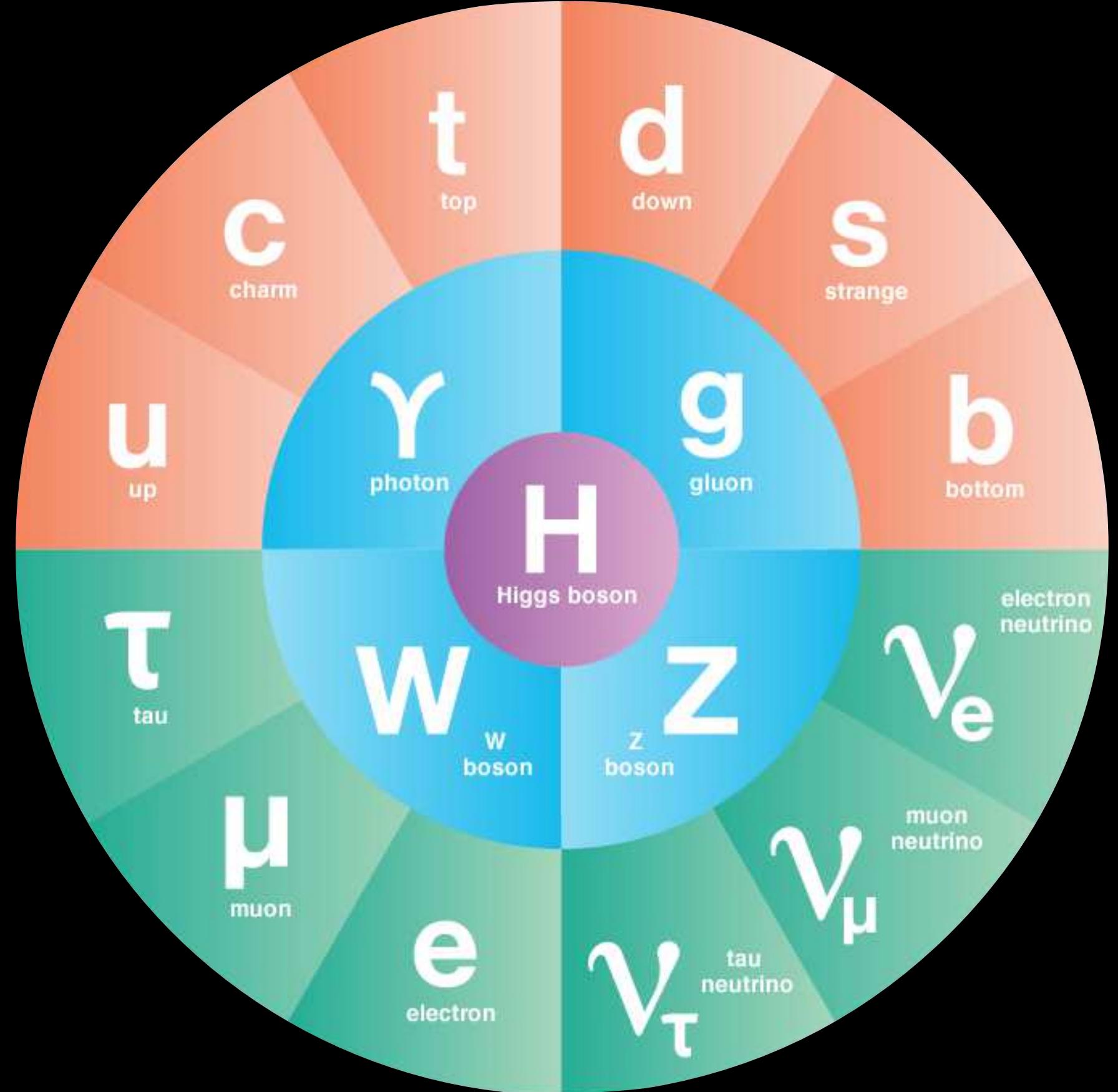
Large data sets, increased computational power, and understanding structure of problems

[Ulyanov, Vedaldi, Lempitsky, CVPR 2018]

Standard Model of Particle Physics



Standard Model of Particle Physics



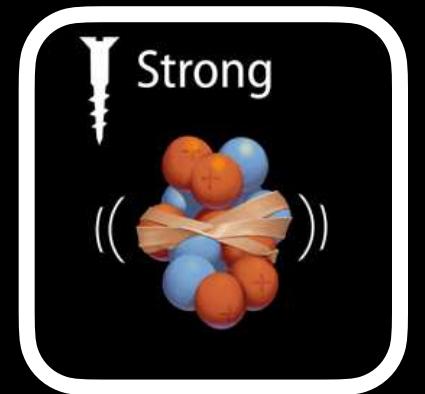
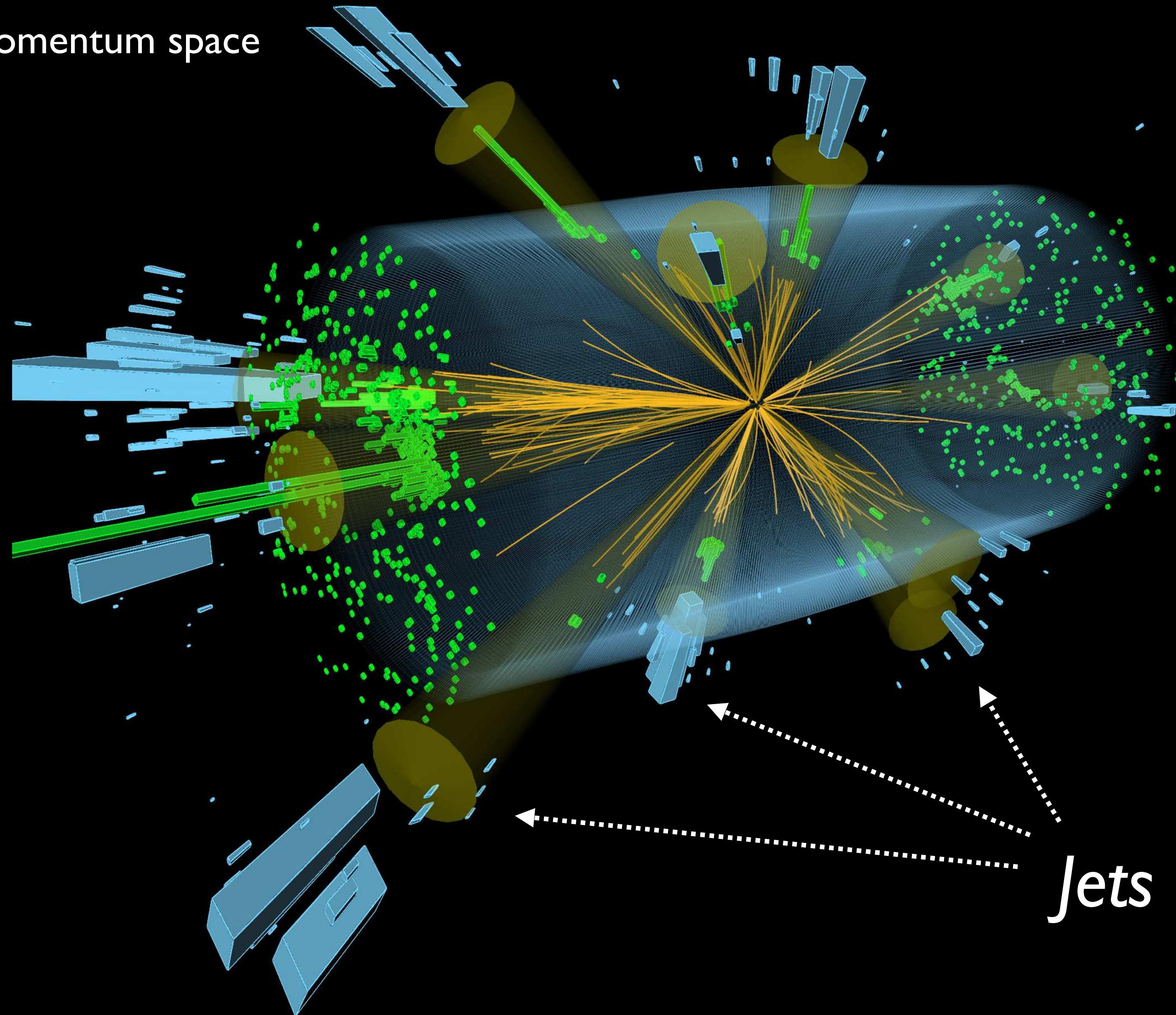
Quarks & Gluons



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

Collider Event

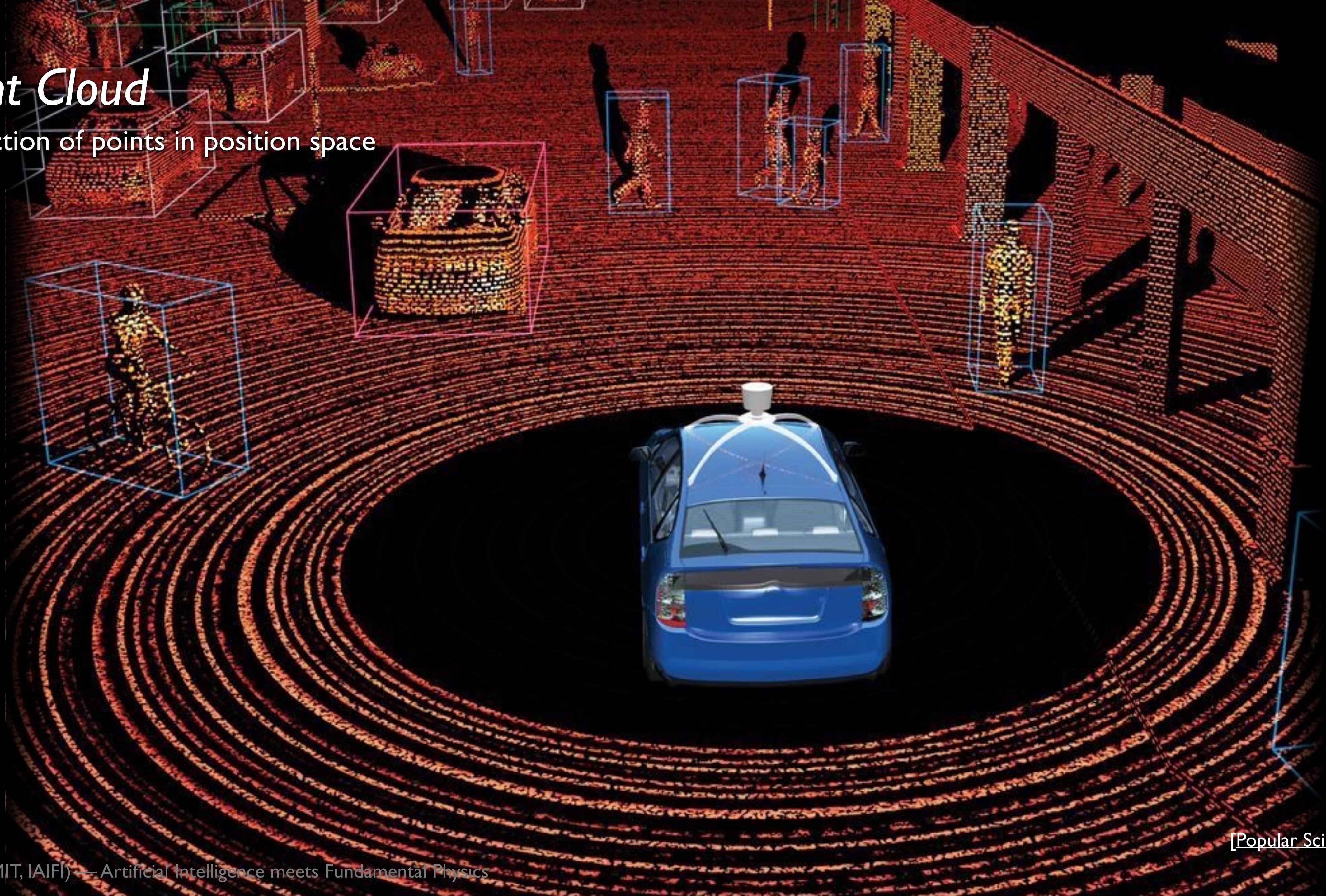
Collection of points in momentum space



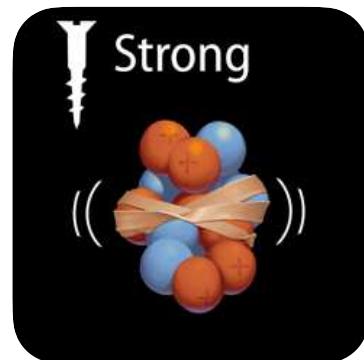
Manifestation
of
Quarks & Gluons

Point Cloud

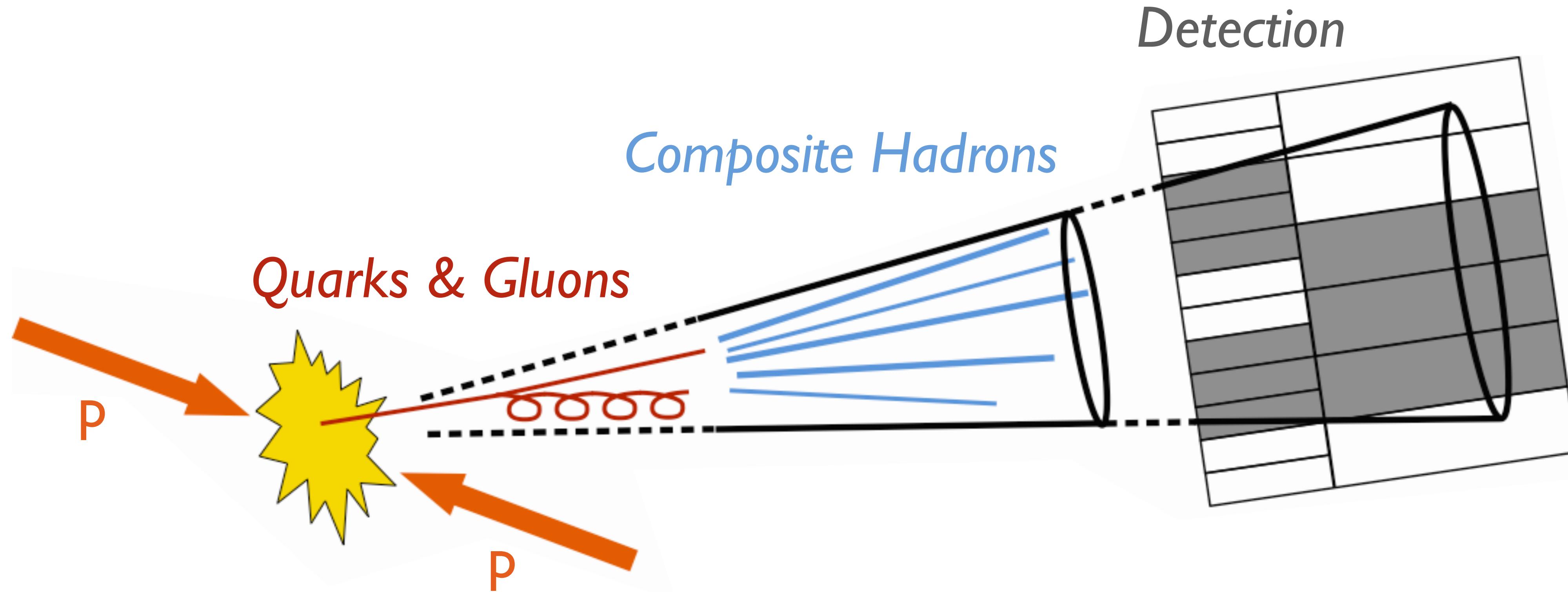
Collection of points in position space

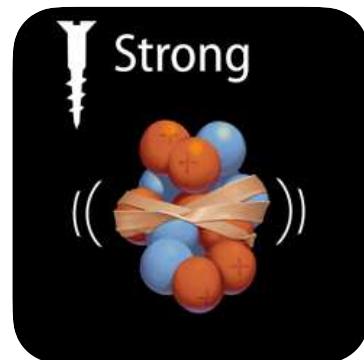


[Popular Science, 2013]



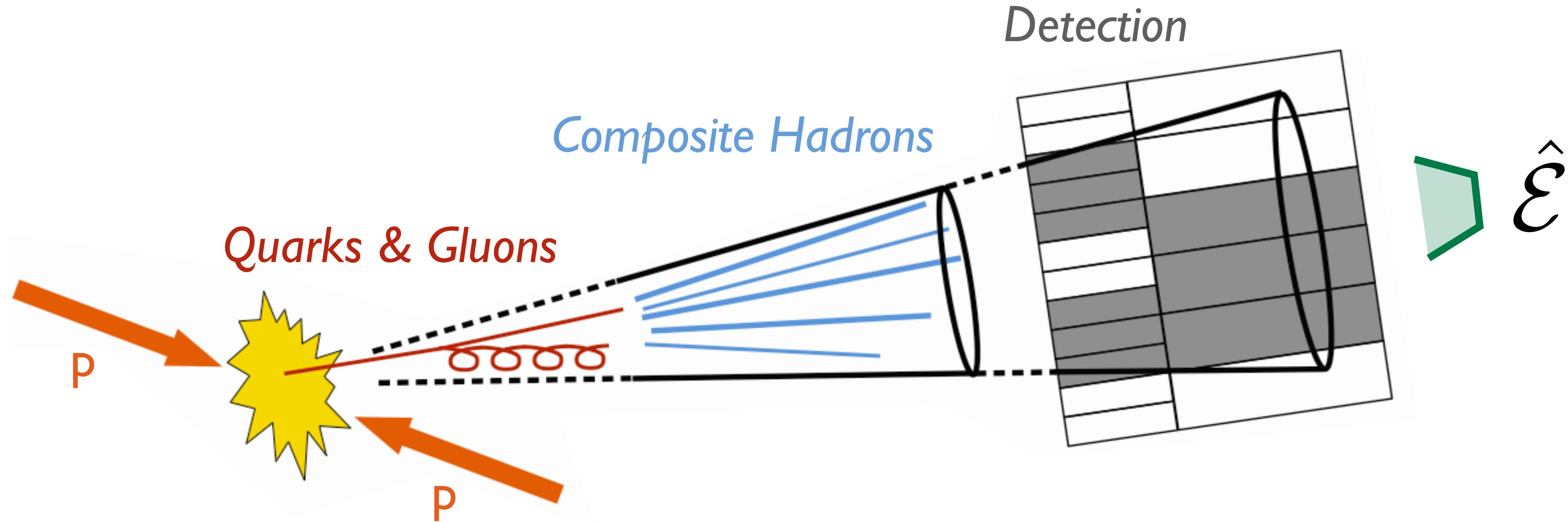
Dynamics of Jet Formation





Dynamics of Jet Formation

Theory



“*Energy Flow*”
Robust to hadronization and detection

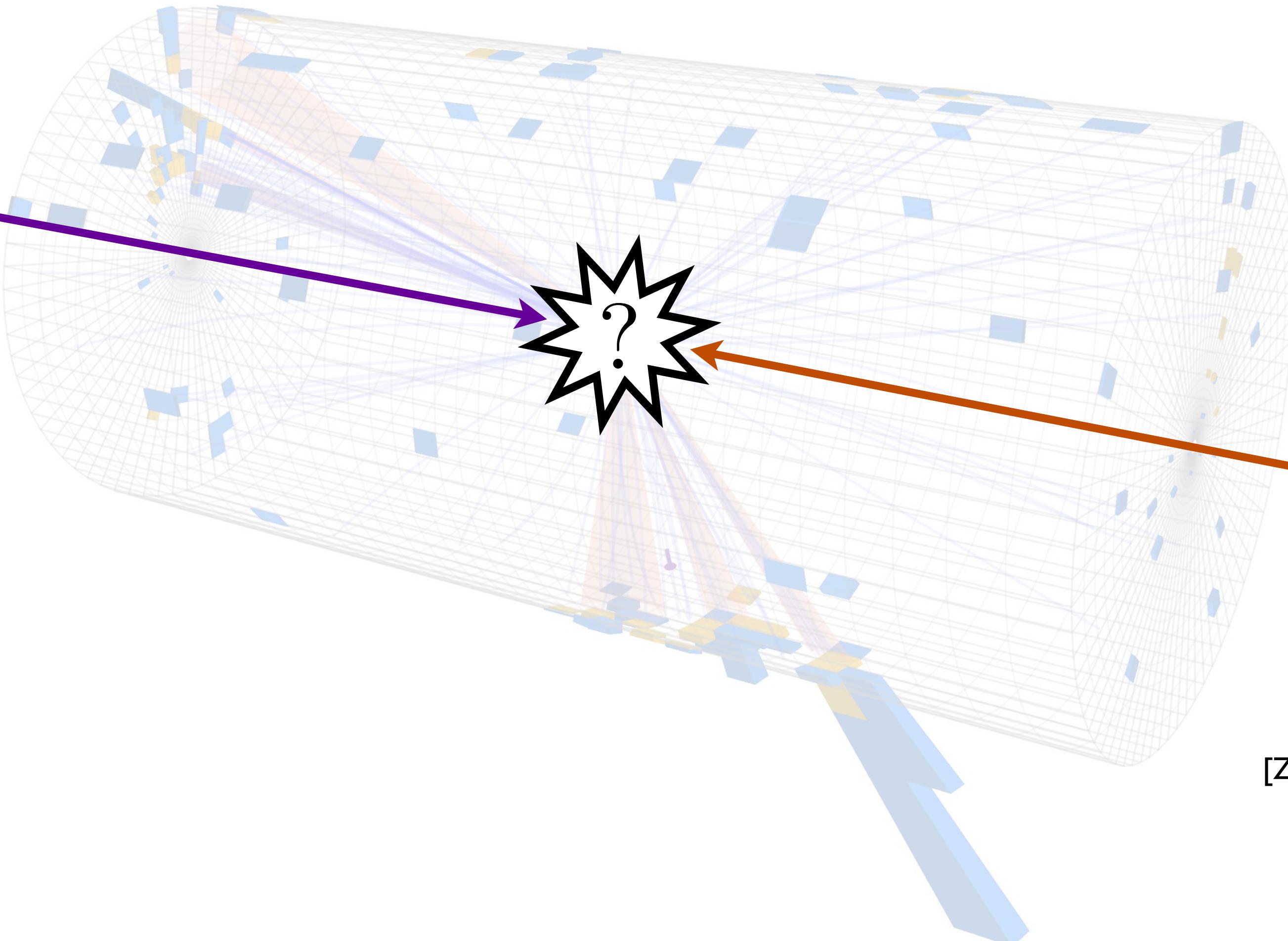
$$\hat{\mathcal{E}} \simeq \lim_{t \rightarrow \infty} \hat{n}_i T^{0i}(t, vt\hat{n})$$

[Sveshnikov, Tkachov, PLB 1996]

Principles of Fundamental Physics

Robustness of Energy Flow

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



Power of Artificial Intelligence

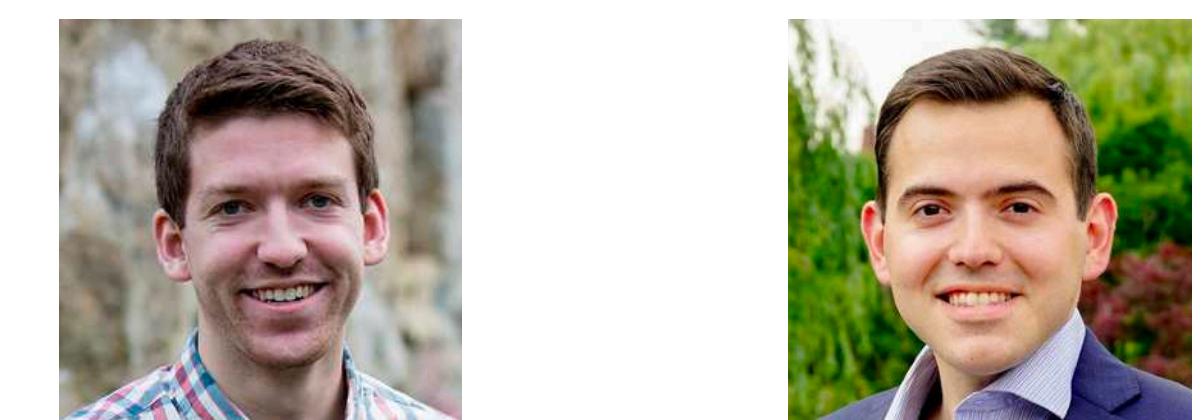
Point Cloud Learning

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

Principles of Fundamental Physics

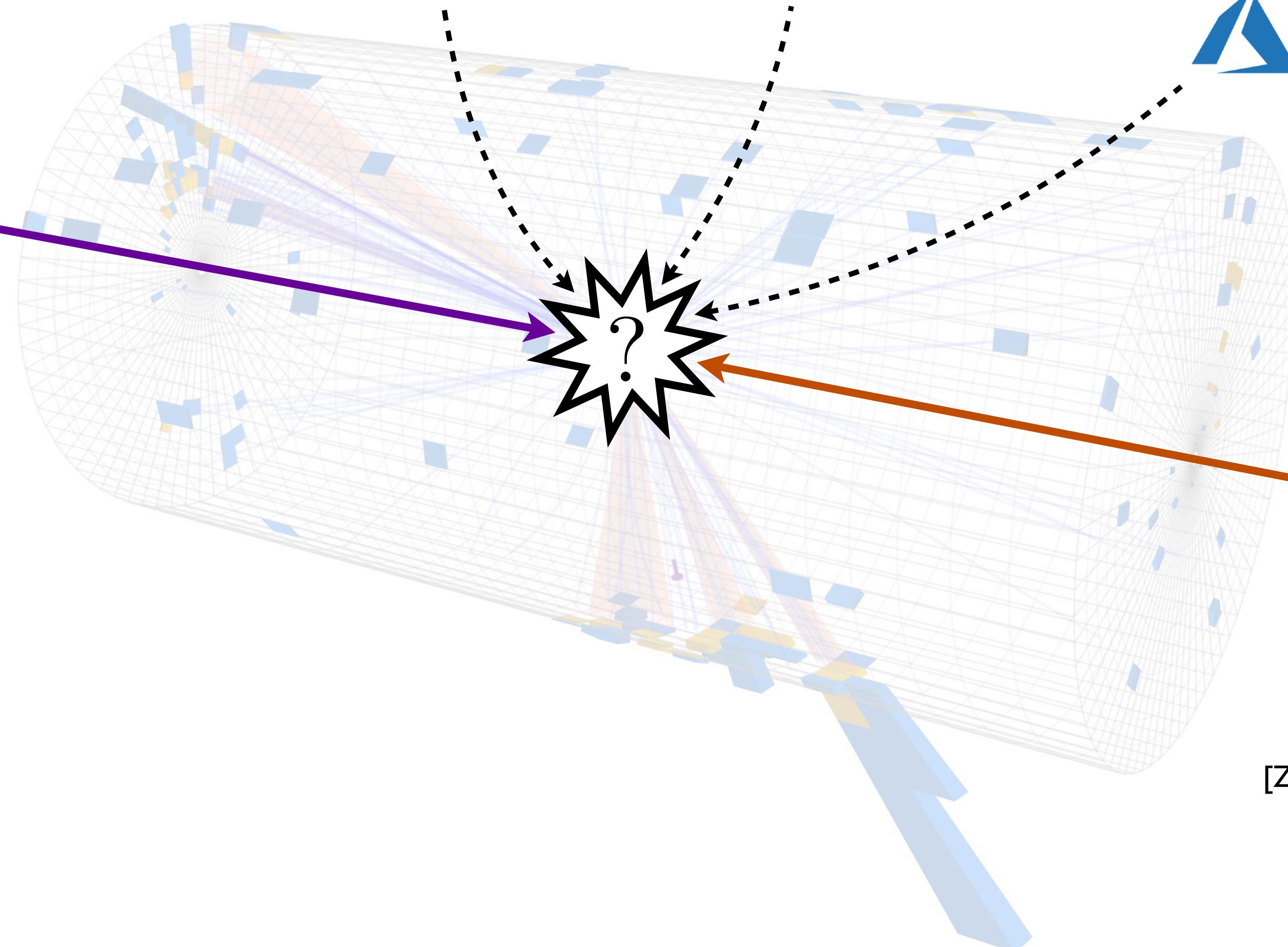
Robustness of Energy Flow

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



Patrick Komiske

Eric Metodiev



Power of Artificial Intelligence

Point Cloud Learning

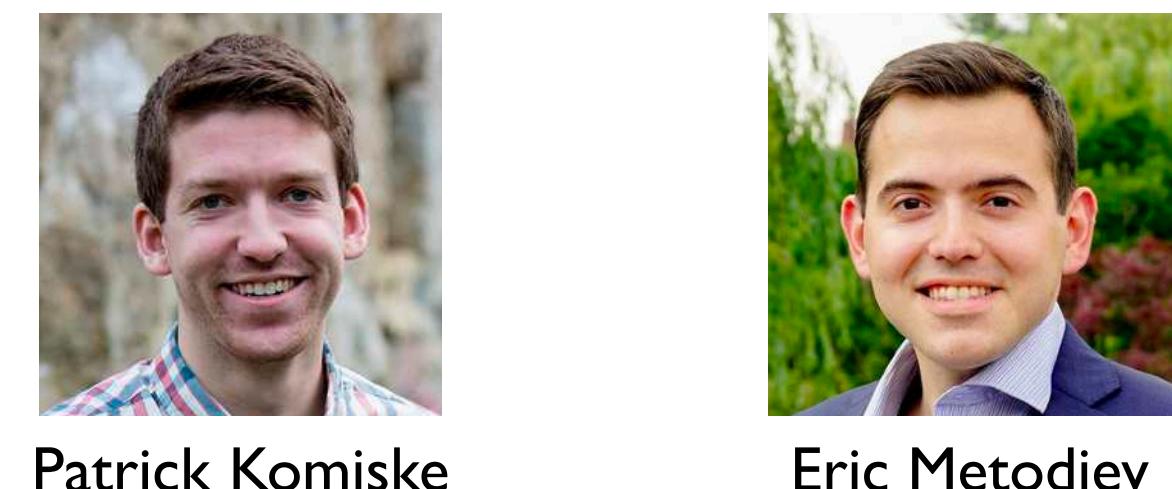
[Zaheer, Kottur, Ravanbakhsh, Poczos, Salakhutdinov, Smola, [NIPS 2017](#)]



Principles of Fundamental Physics

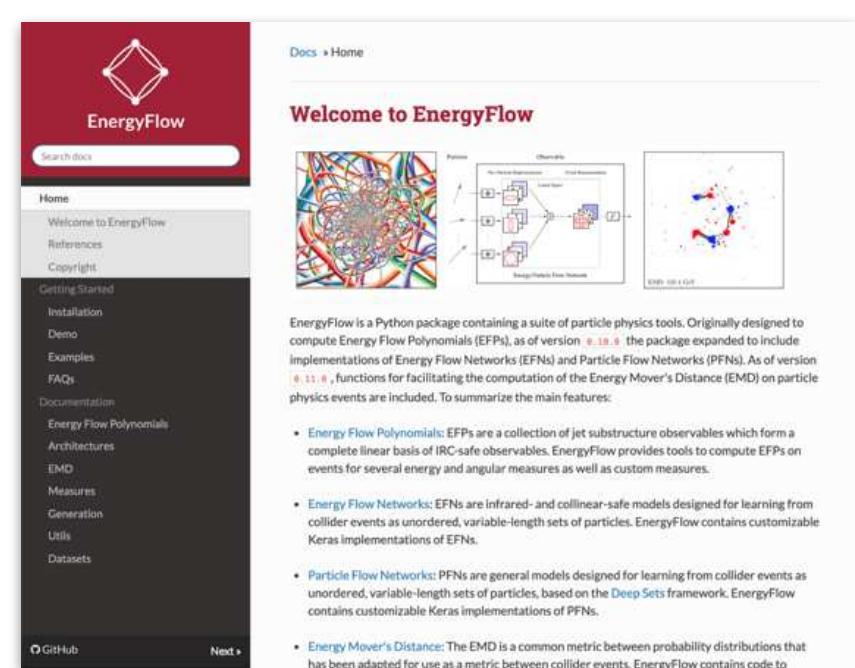
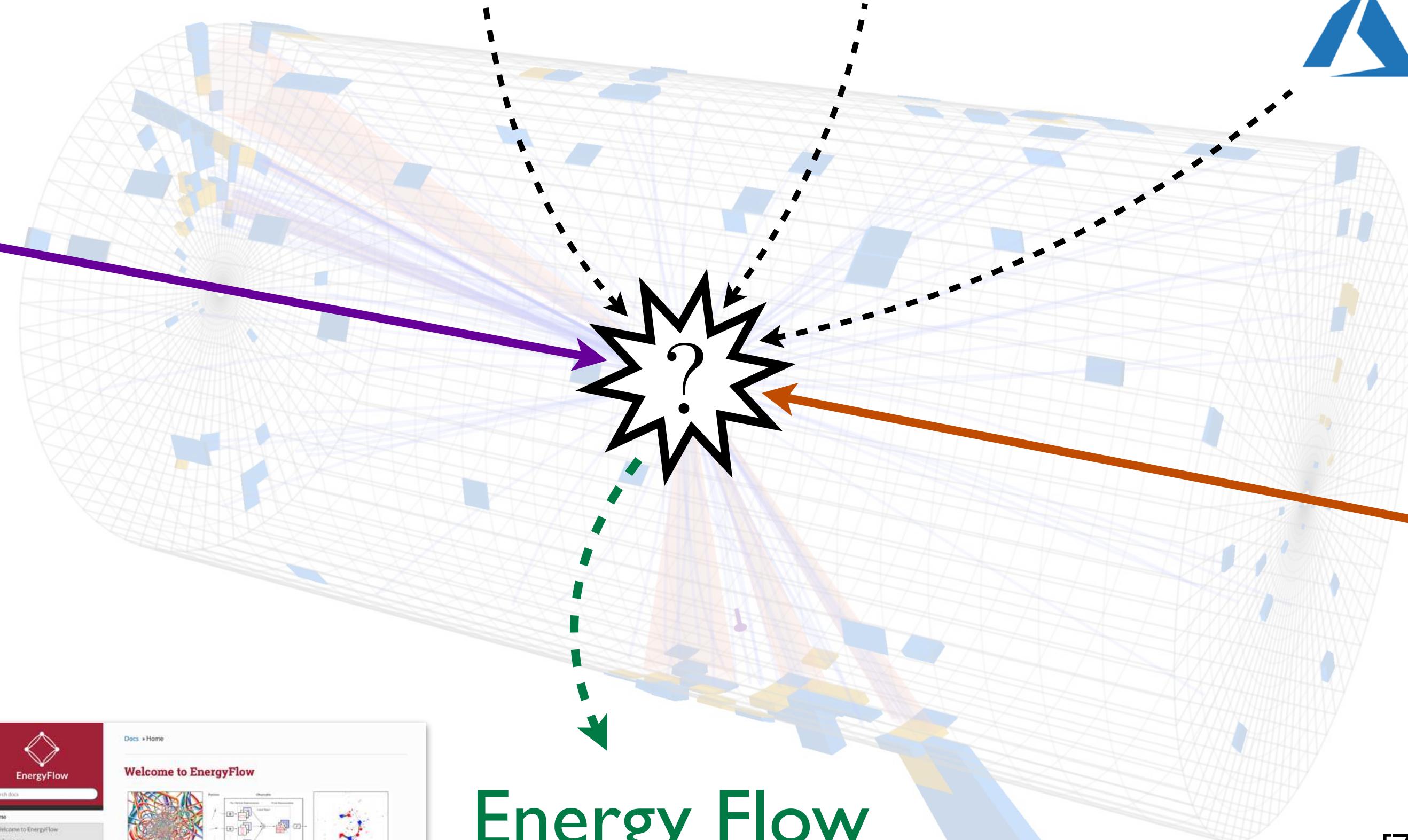
Robustness of Energy Flow

[Komiske, Metodiev, JDT, JHEP 2018]



Patrick Komiske

Eric Metodiev



Energy Flow Networks

<https://energyflow.network/>

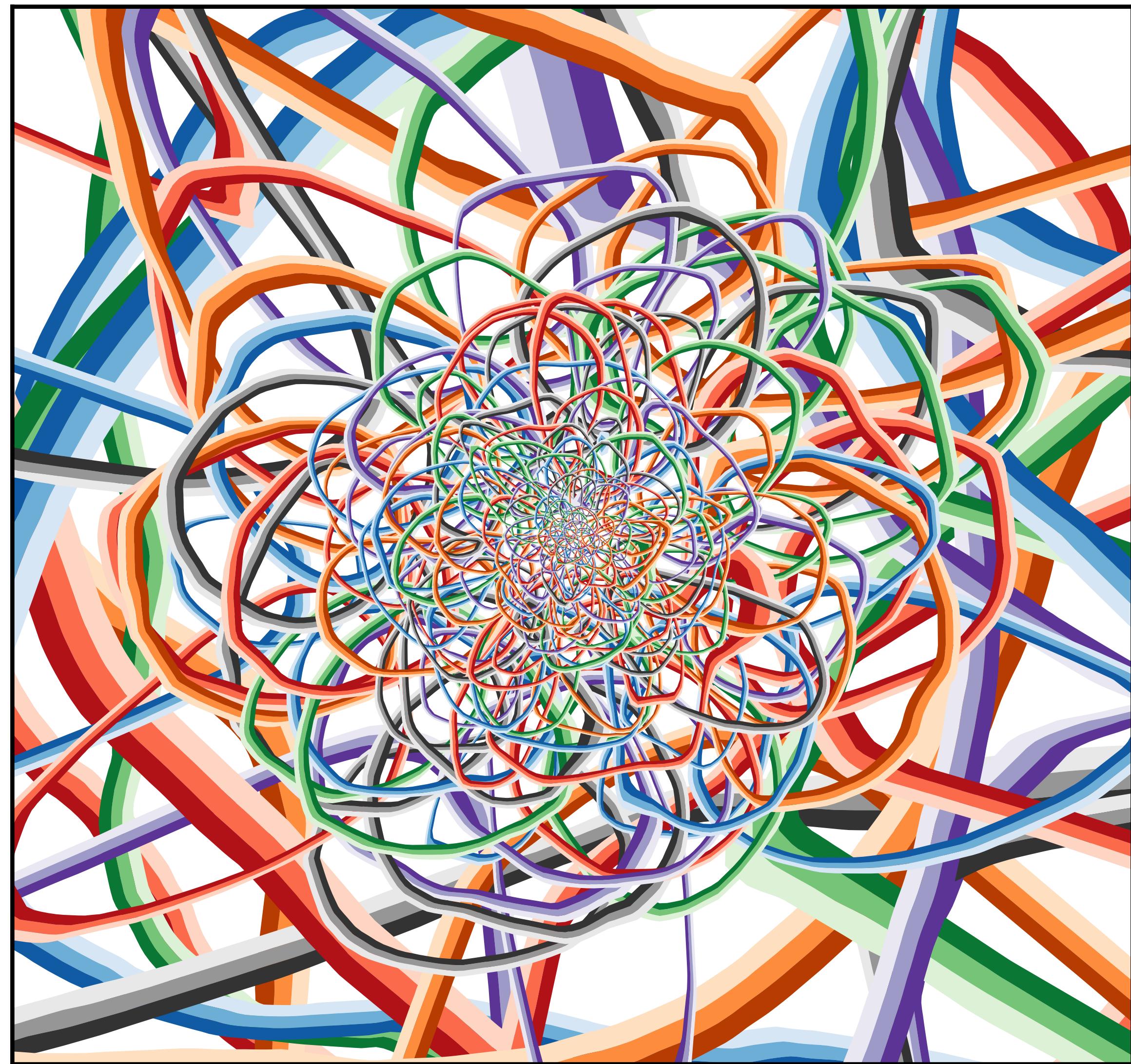
[Komiske, Metodiev, JDT, JHEP 2019]



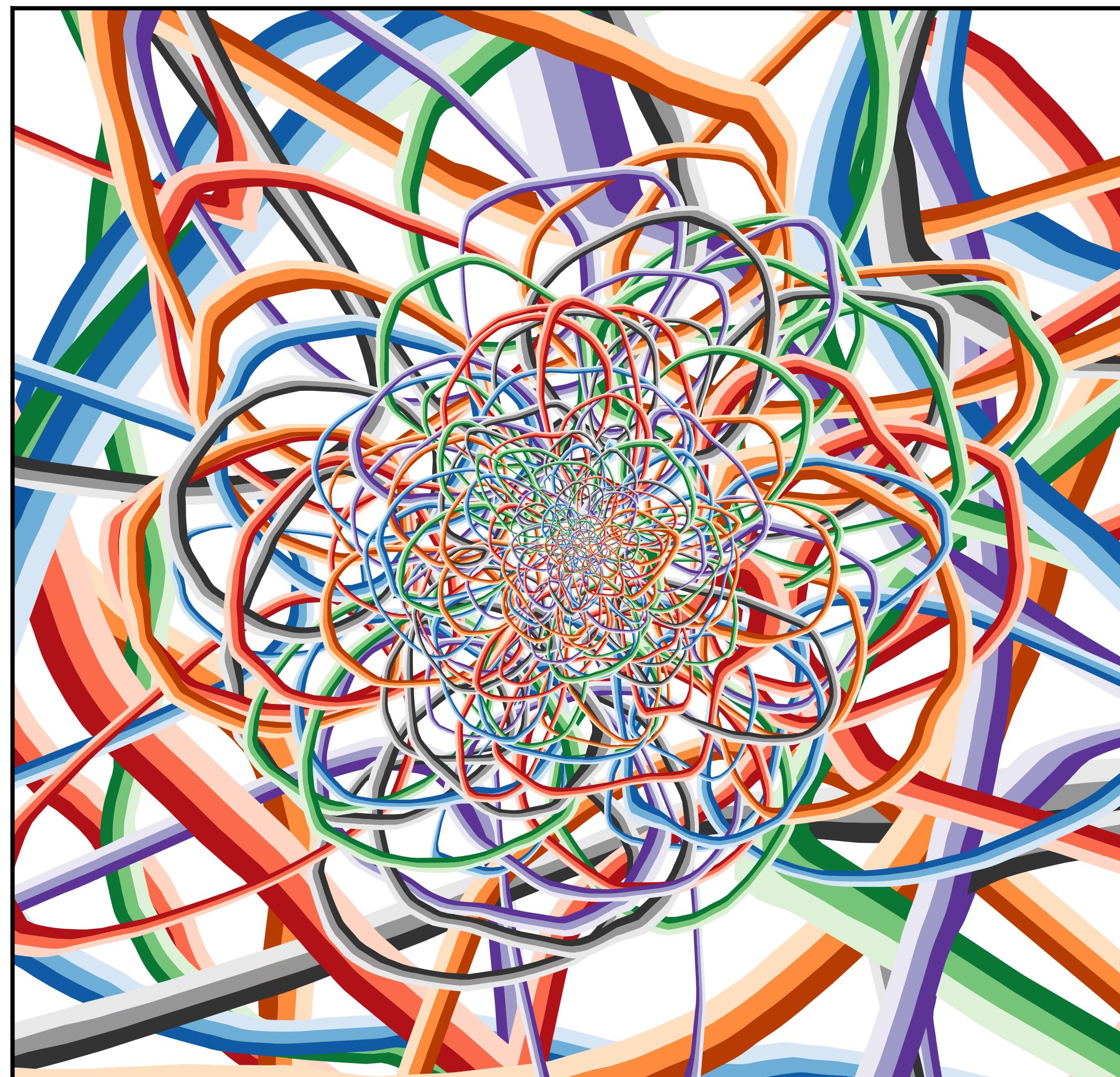
Power of Artificial Intelligence

Point Cloud Learning

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



[Komiske, Metodiev, JDT, JHEP 2019]



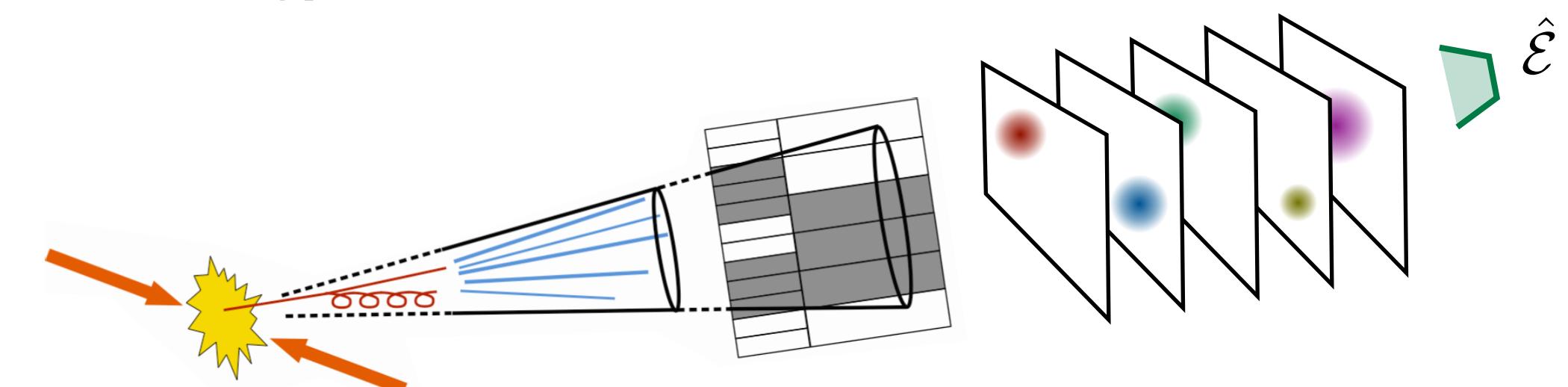
“Hello, World!” of Jets:

Quark vs. Gluon

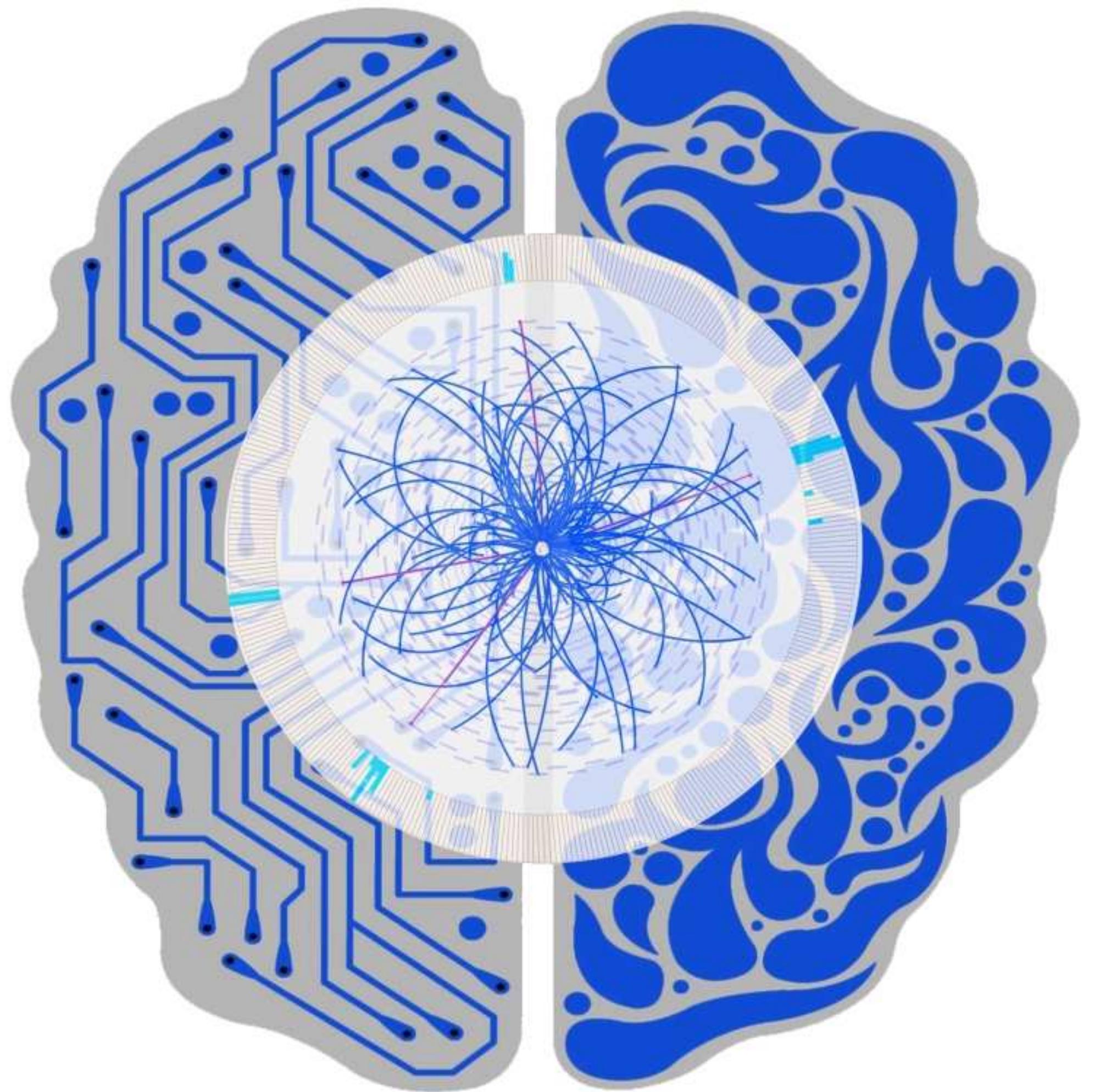
Energy Flow Network:

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

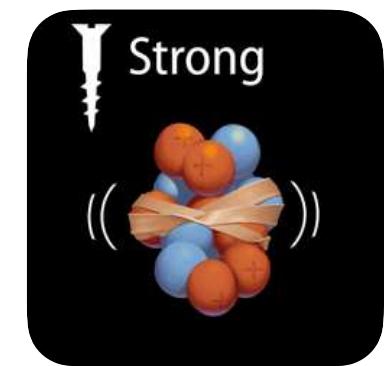
Strategy for Verification:



[Komiske, Metodiev, JDT, JHEP 2019]

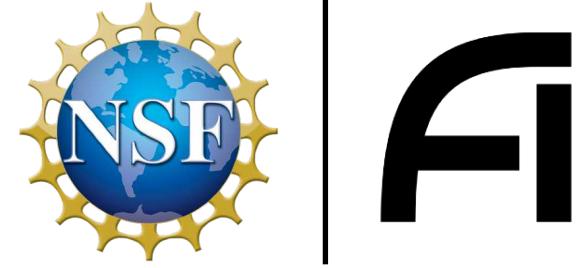


*We taught a machine to
“think” like a physicist...*

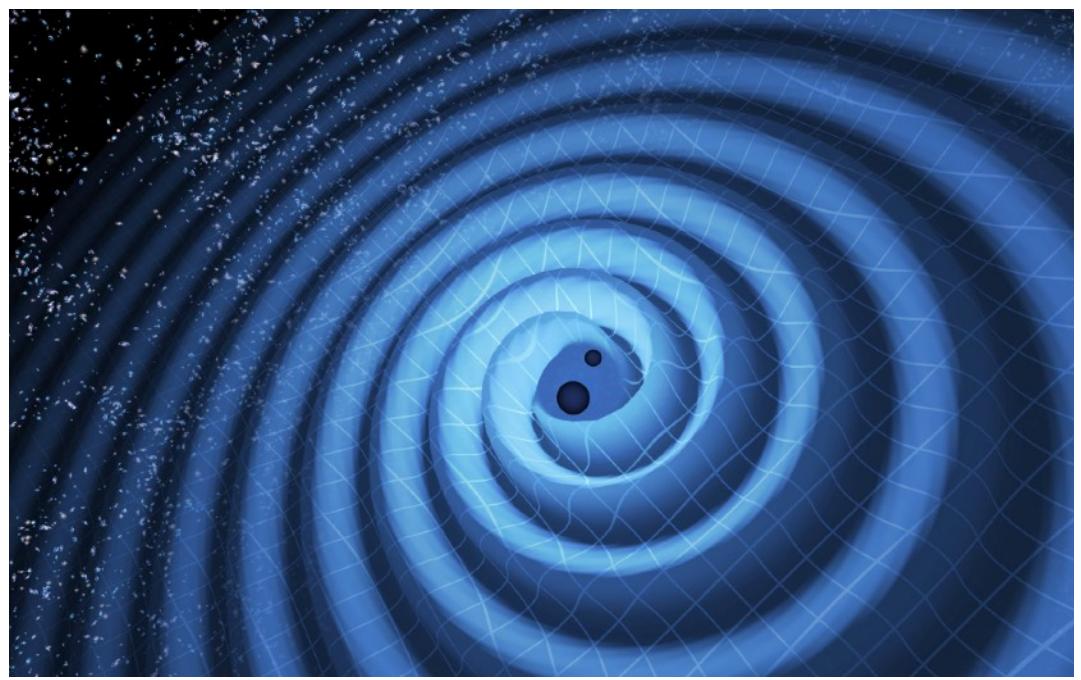


*...and it learned fractal
structure of strong force!*

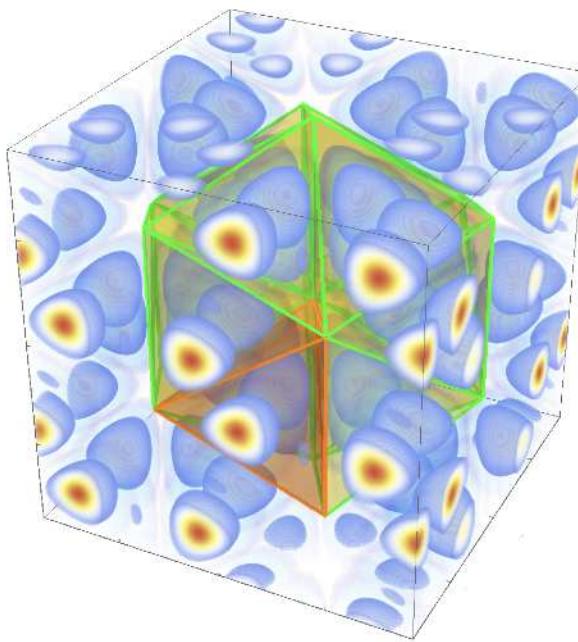
Artificial Intelligence \leftrightarrow Fundamental Physics



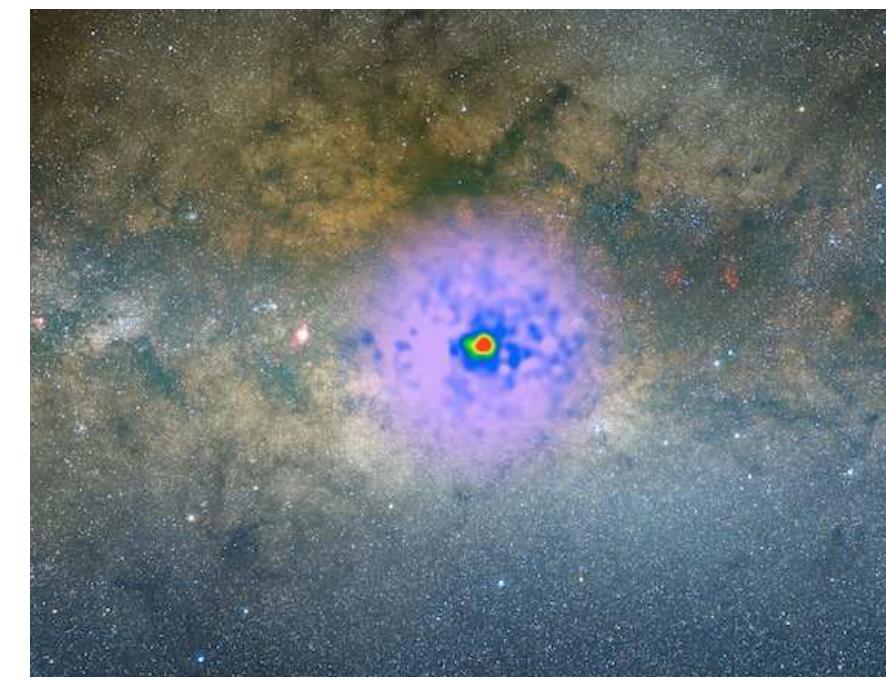
Gravitational Waves



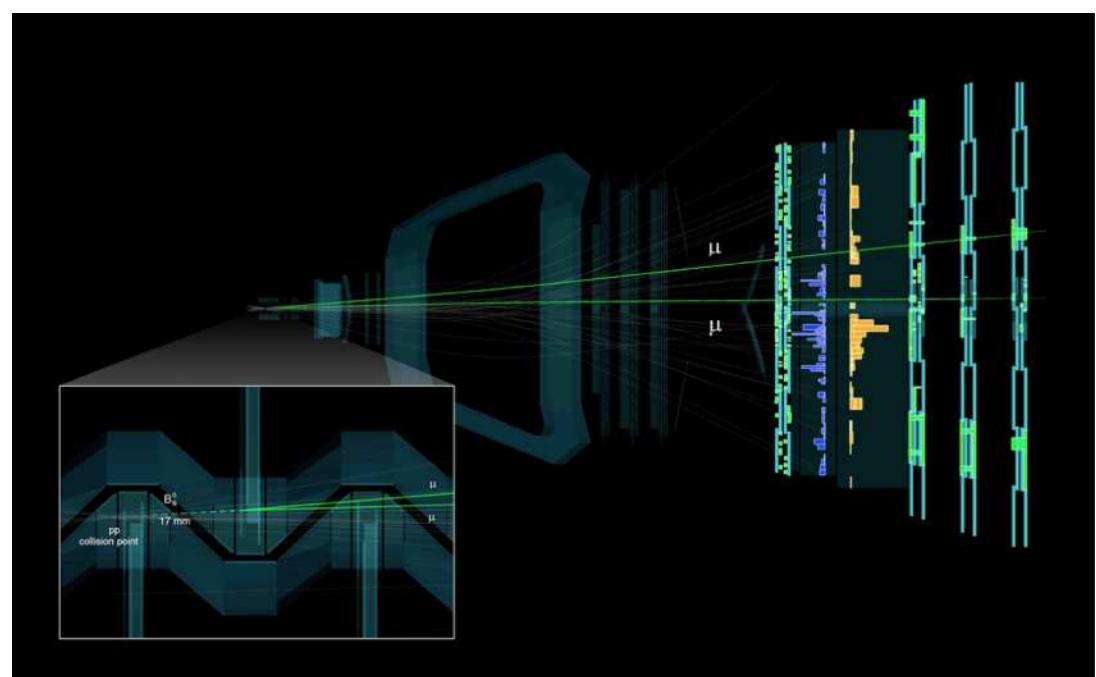
Nuclear Physics



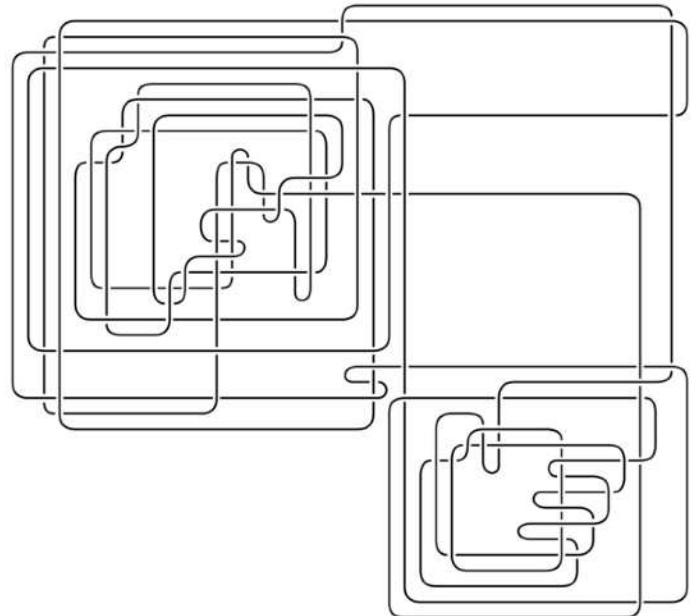
Astrophysics



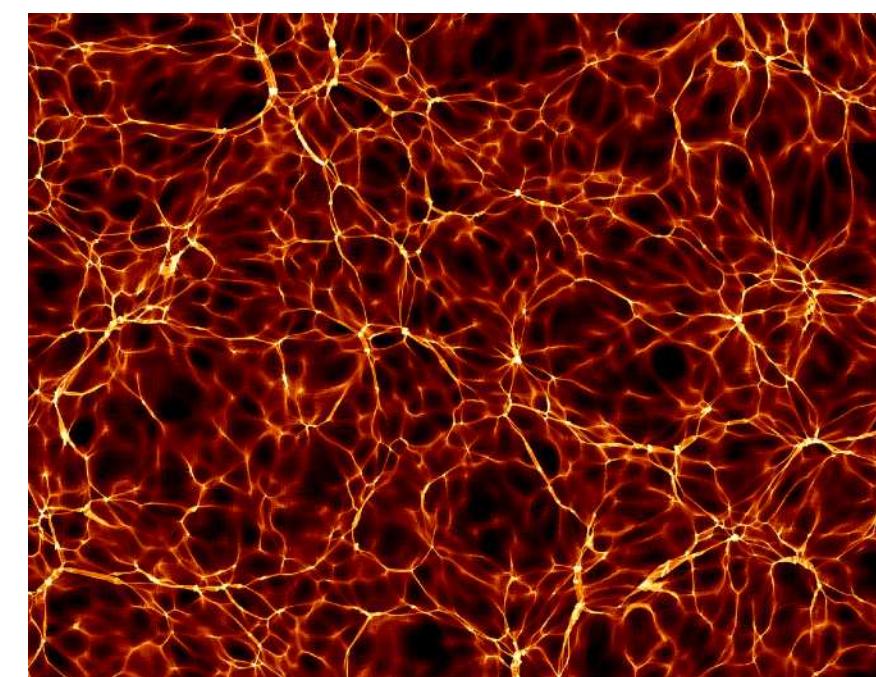
Particle Colliders



Mathematical Physics

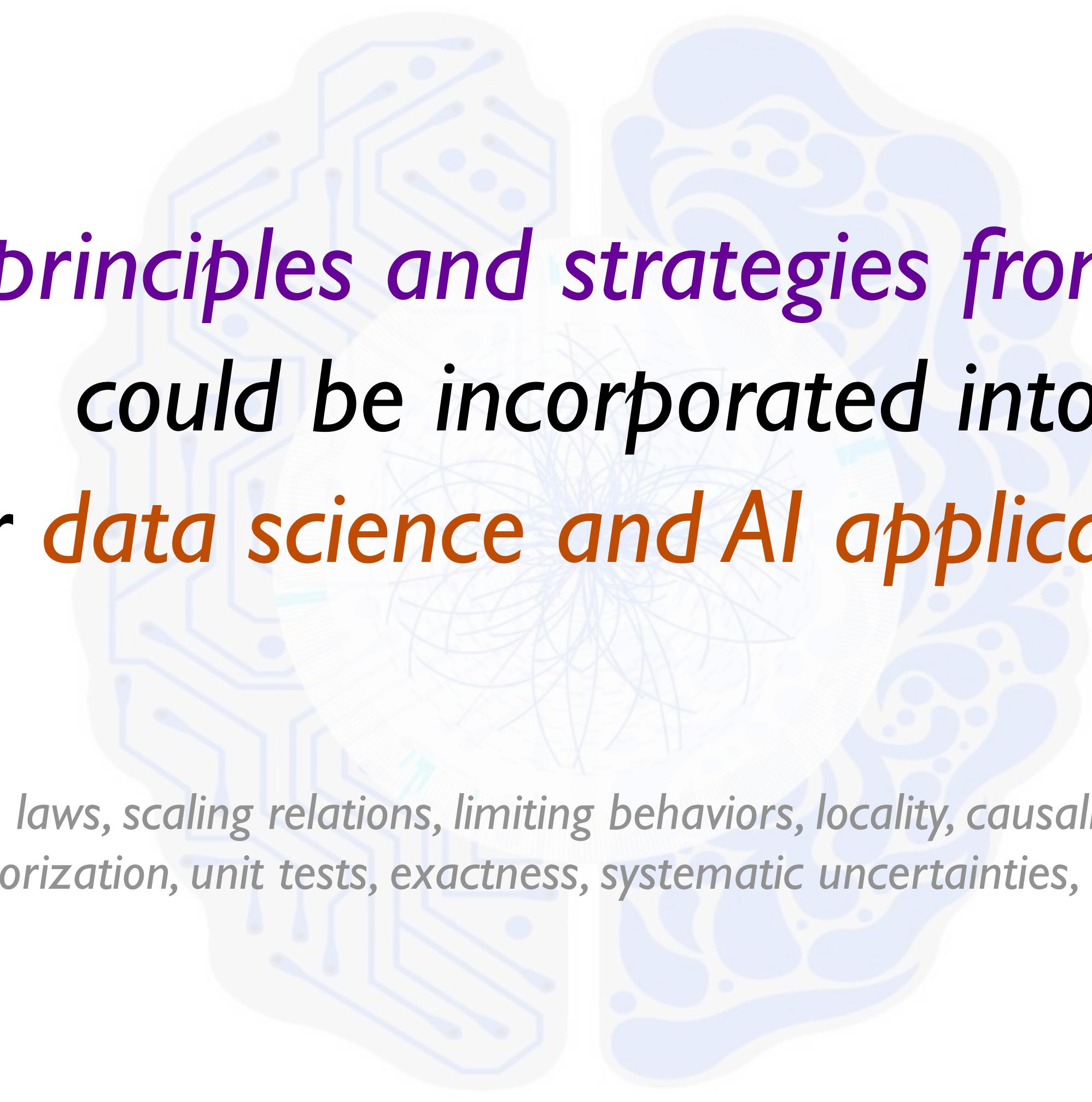


Dark Matter



...

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



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

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

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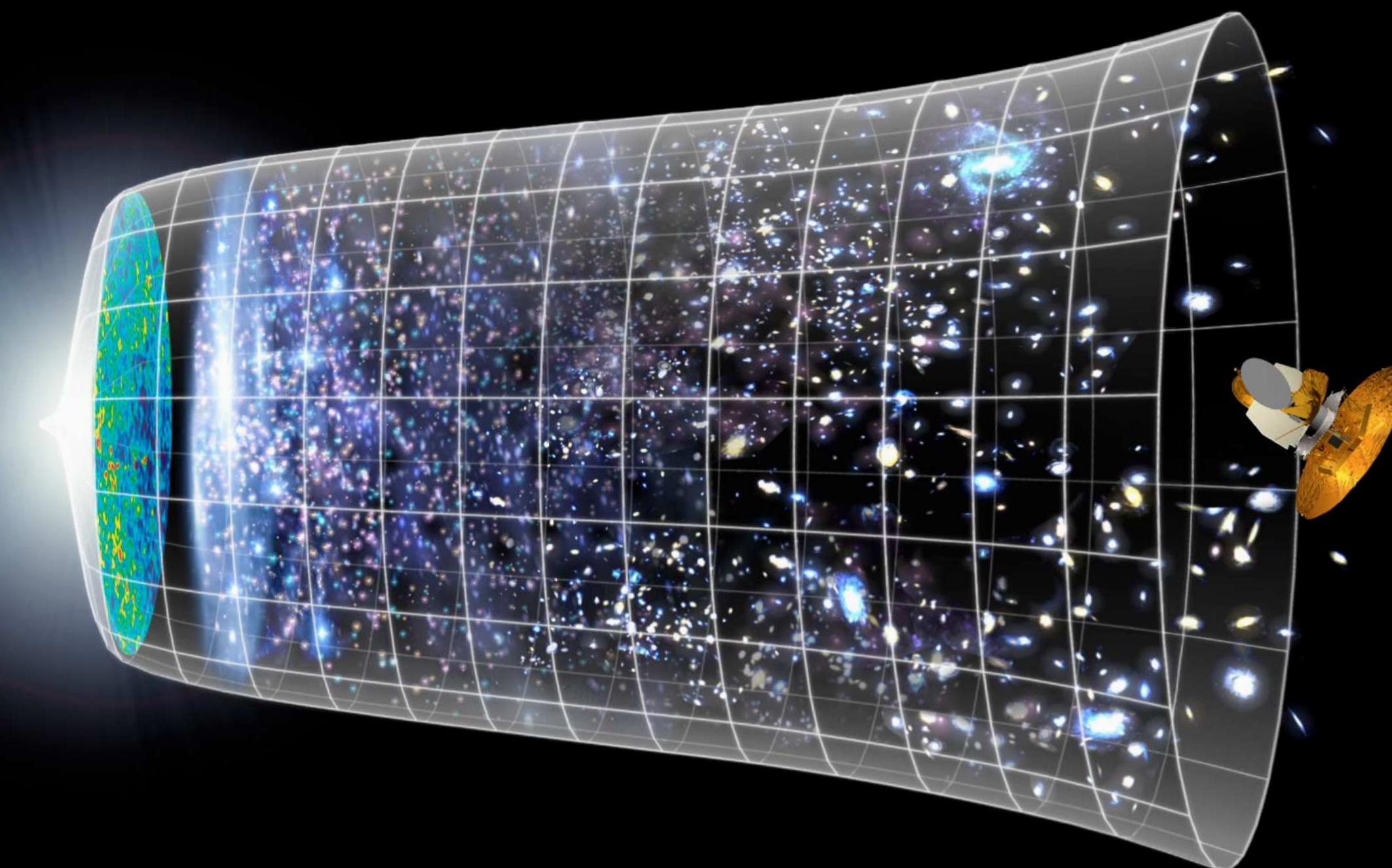
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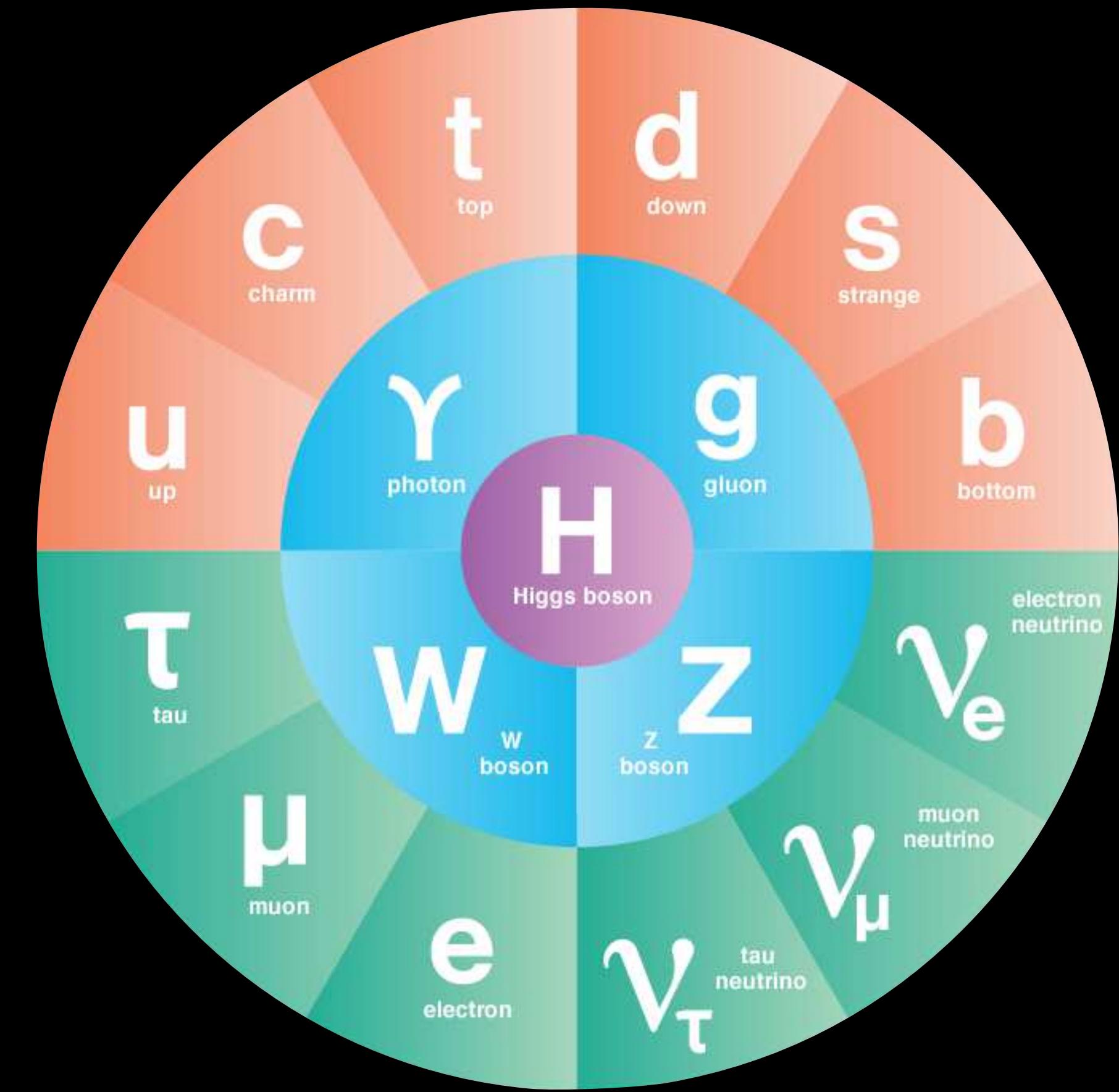
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Backup Slides

Big Bang Cosmology



Standard Model

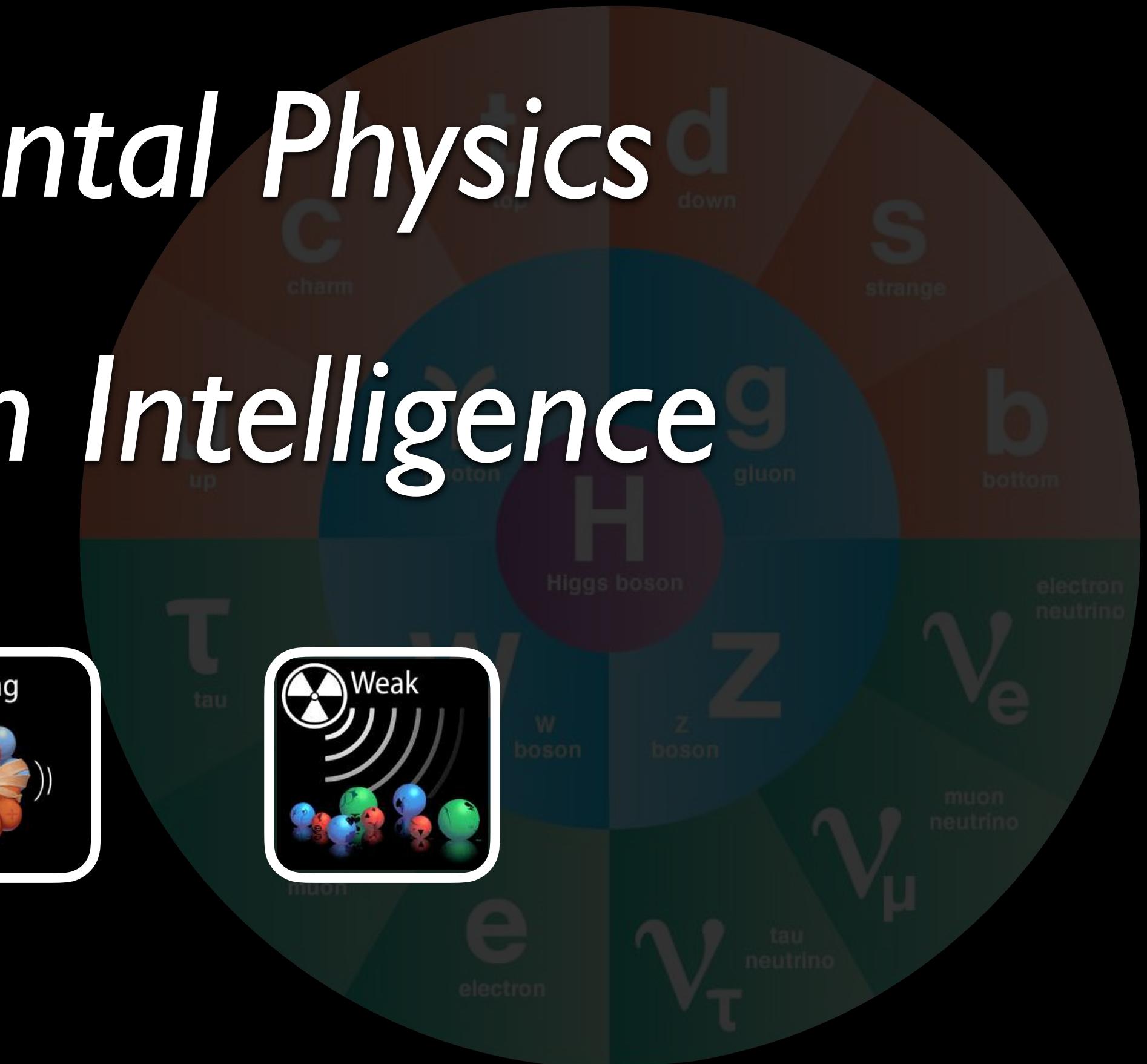
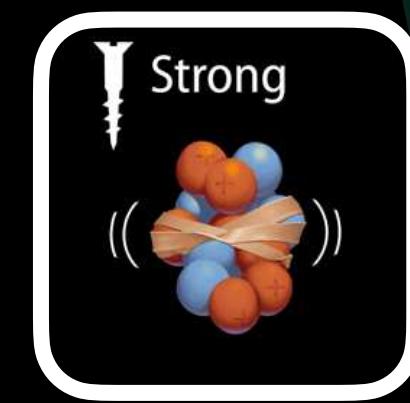
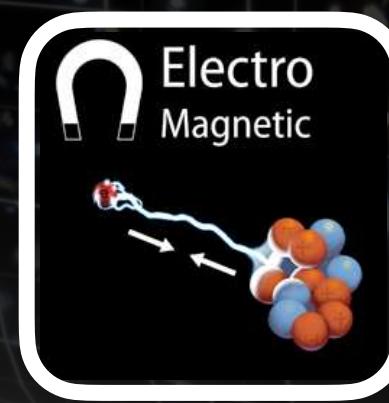


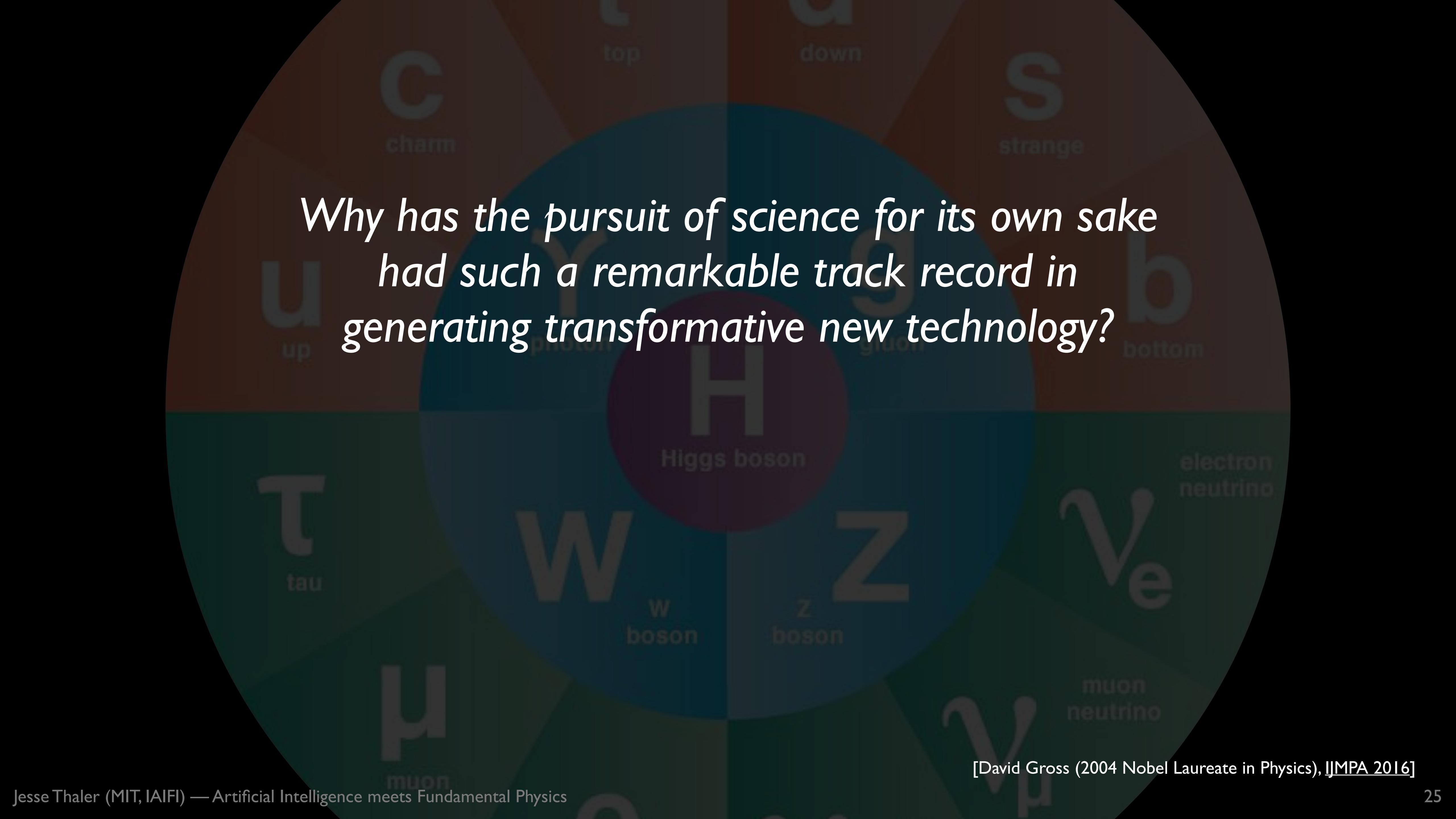
Big Bang Cosmology

Standard Model

Pillars of Fundamental Physics

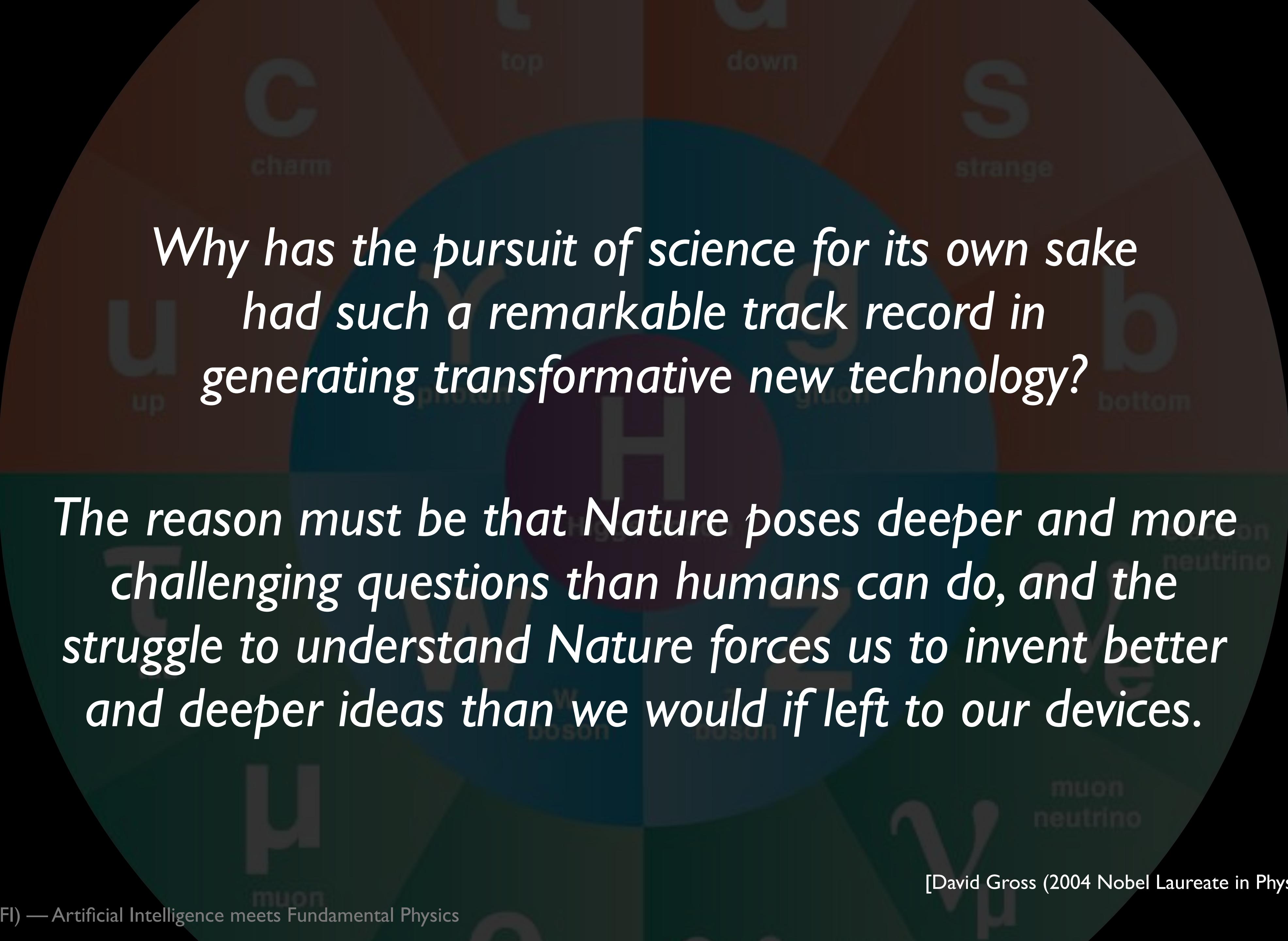
Triumphs of Human Intelligence





*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]