

A Few Collisions between Particle Physics & Machine Learning

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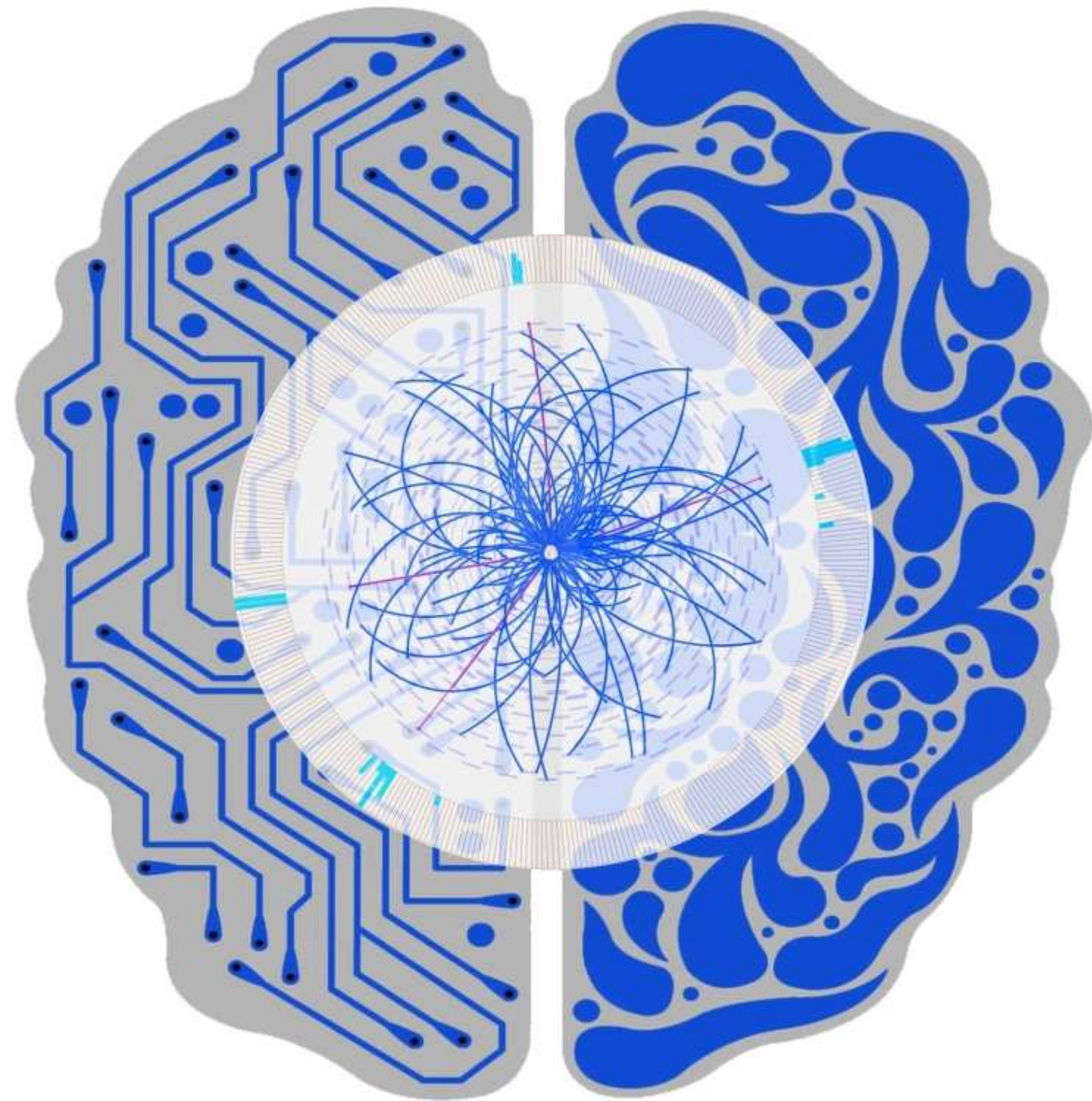
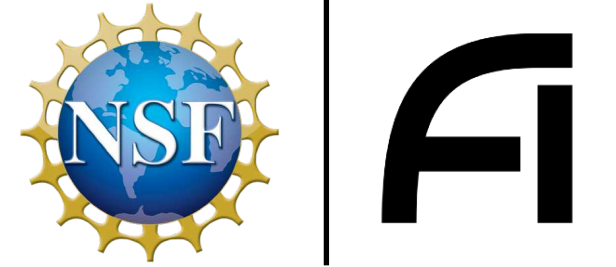
The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI /ai-fai/ iaifi.org)



AI

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

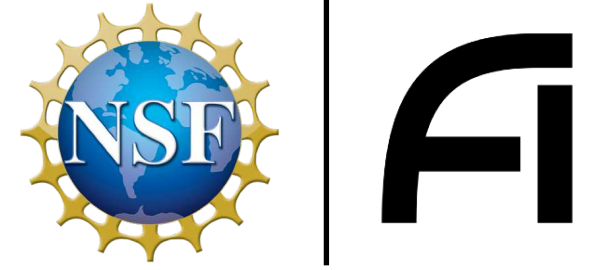
AI²: Ab Initio Artificial Intelligence



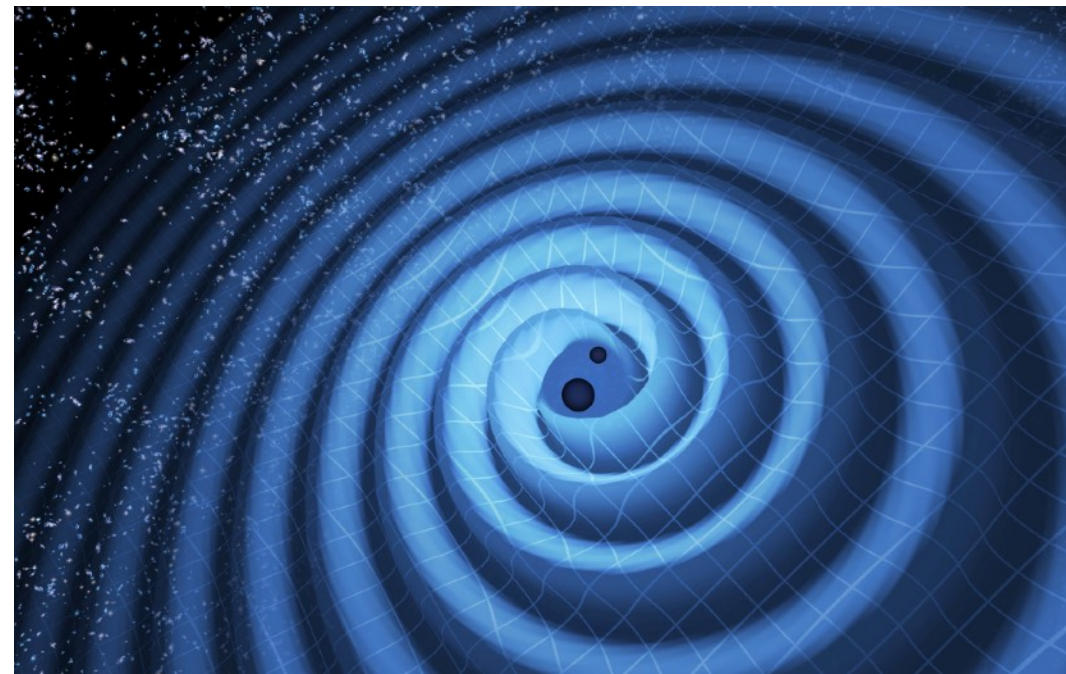
Machine learning that incorporates first principles, best practices, and domain knowledge from fundamental physics

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

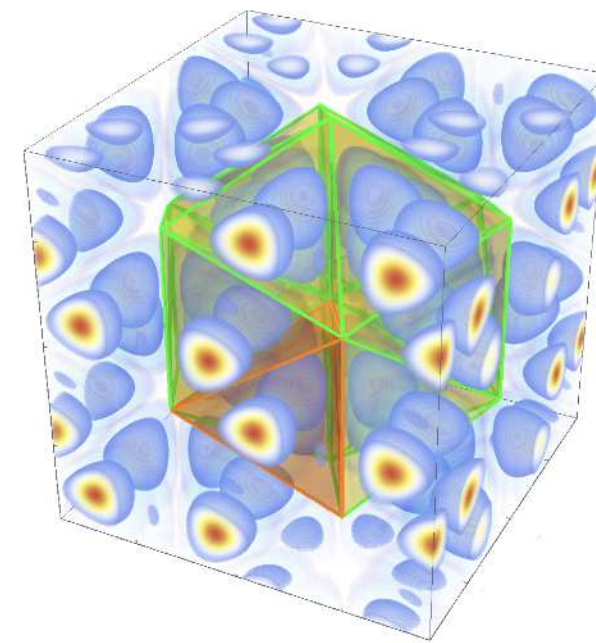
Artificial Intelligence \Leftrightarrow Fundamental Physics



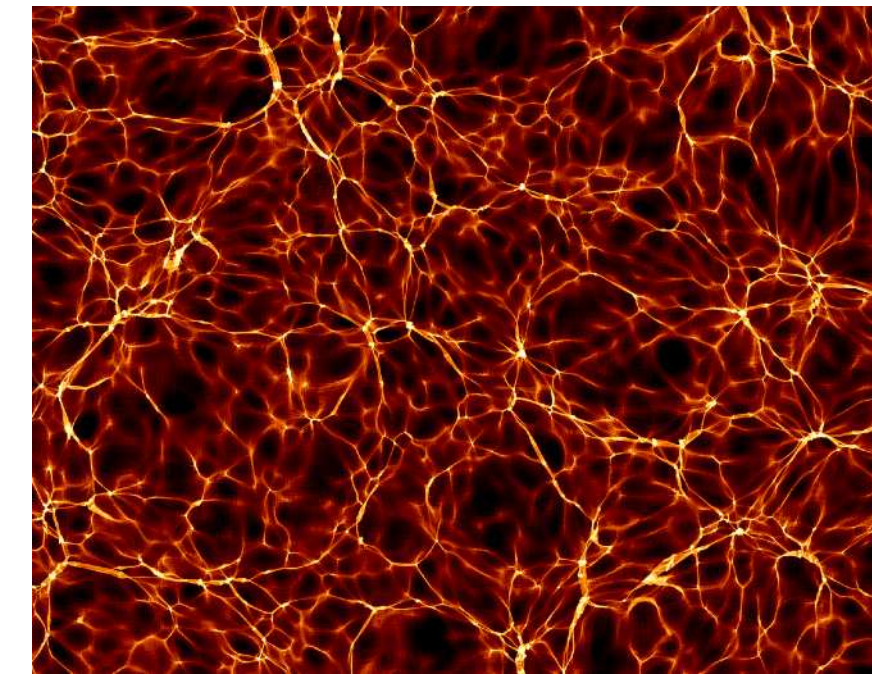
Gravitational Waves



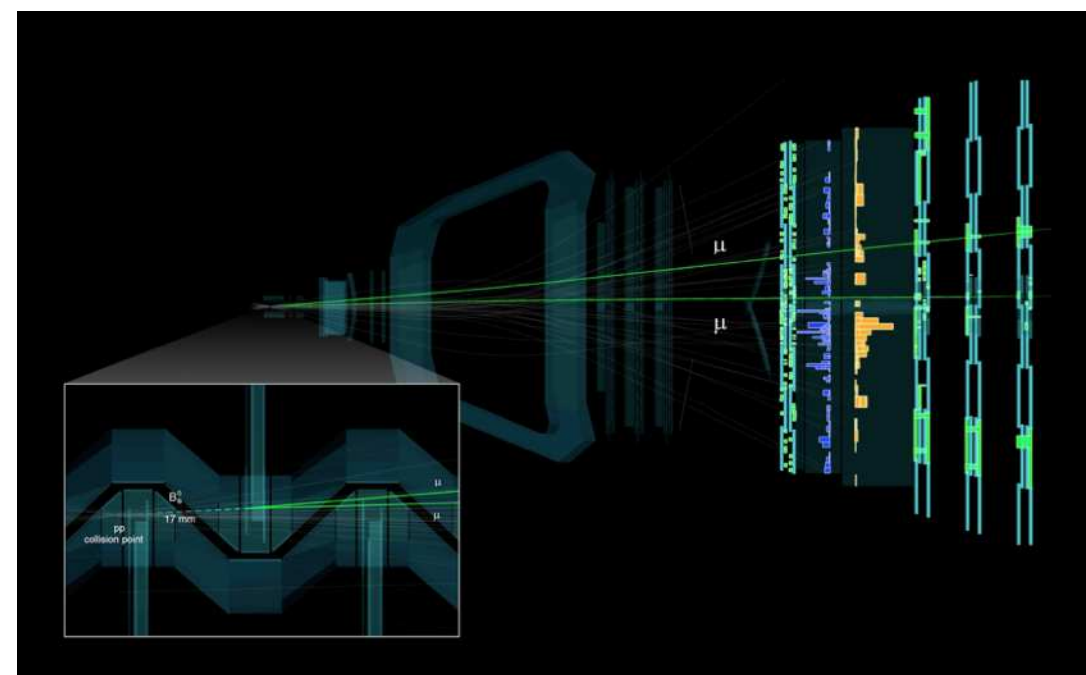
Nuclear Physics



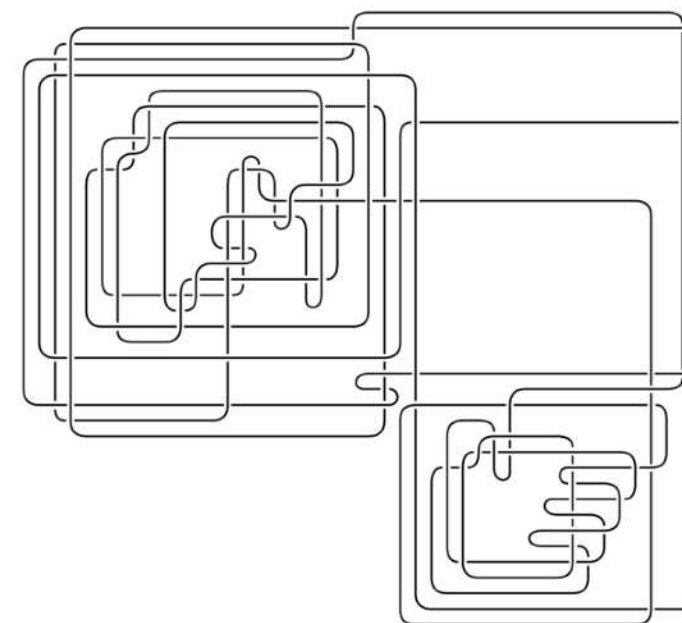
Dark Matter



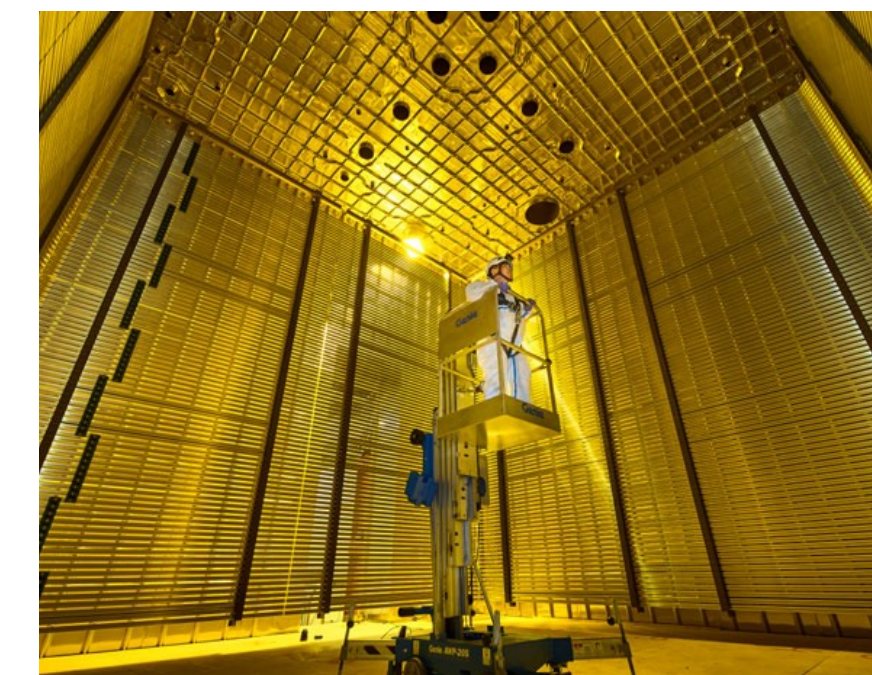
Particle Colliders



Mathematical Physics



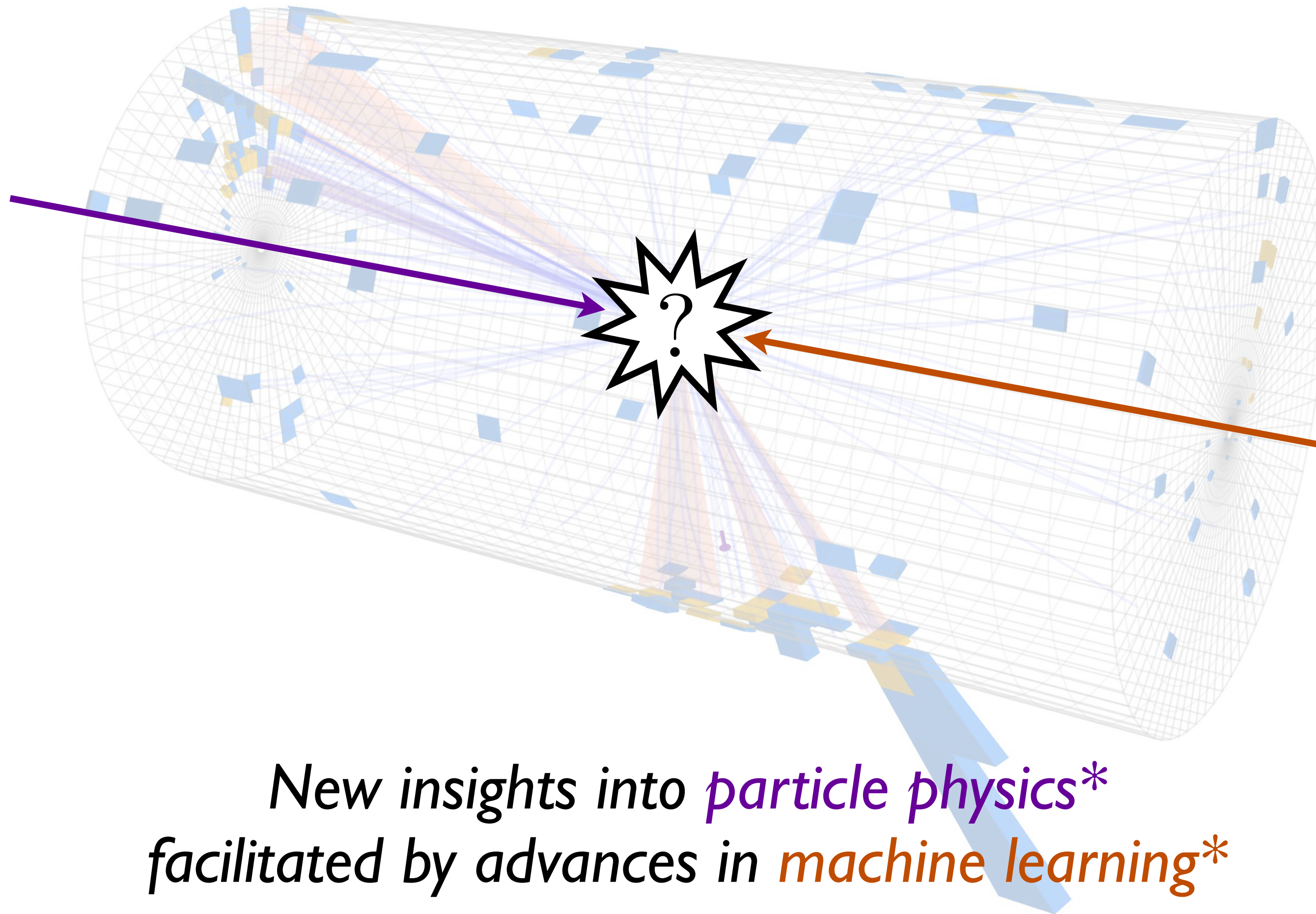
Neutrino Detection



...

“Collision Course”

Theoretical
High Energy
Physics

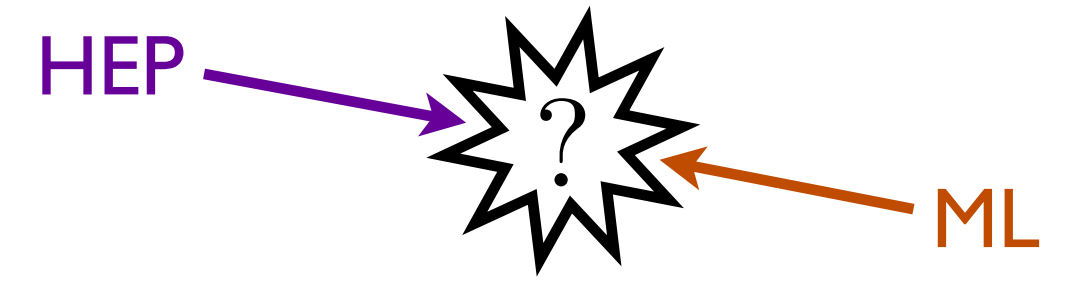


Mathematics,
Statistics,
Computer Science

*New insights into **particle physics***
facilitated by advances in **machine learning****

[e.g. [Harvard Physics Colloquium](#), November 2020]

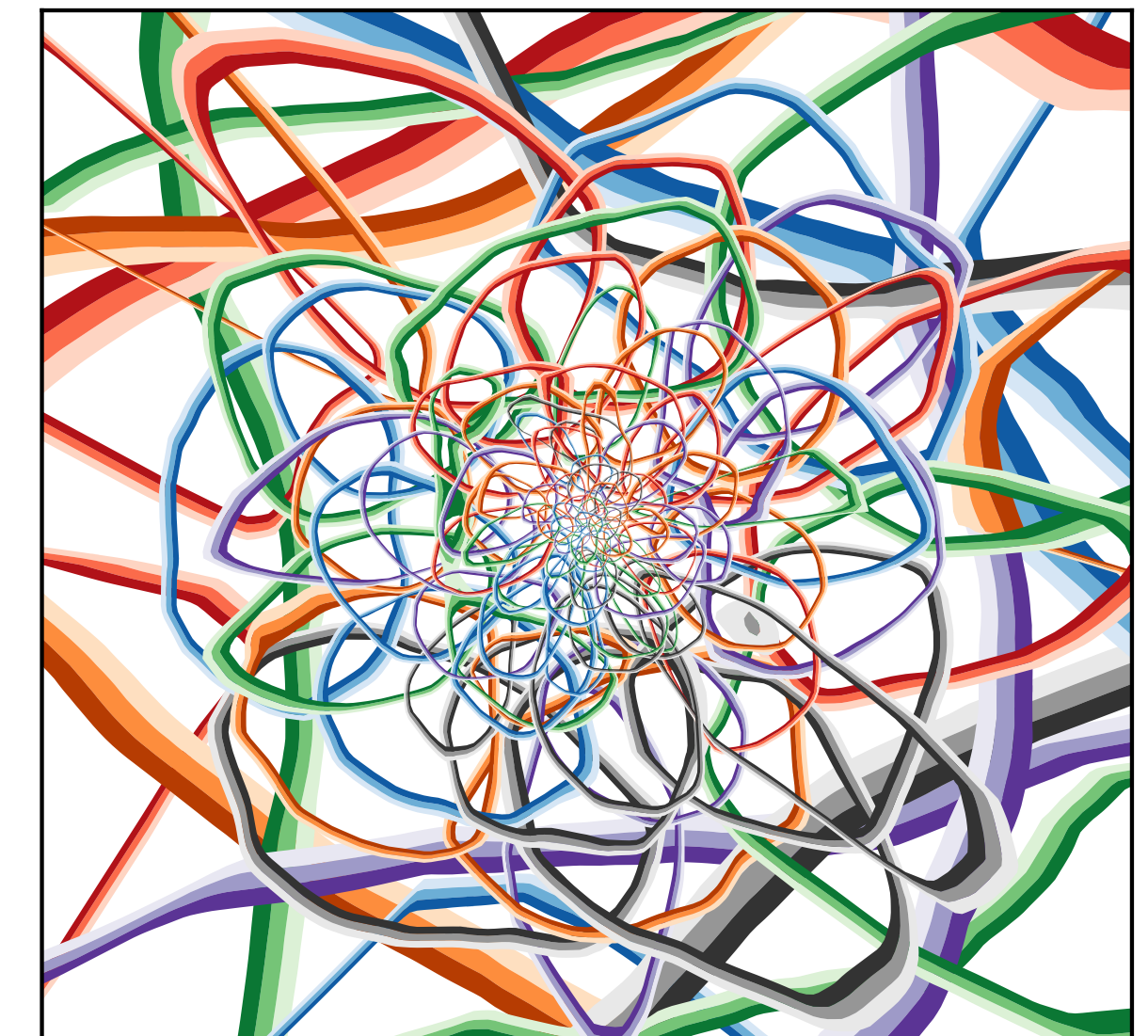
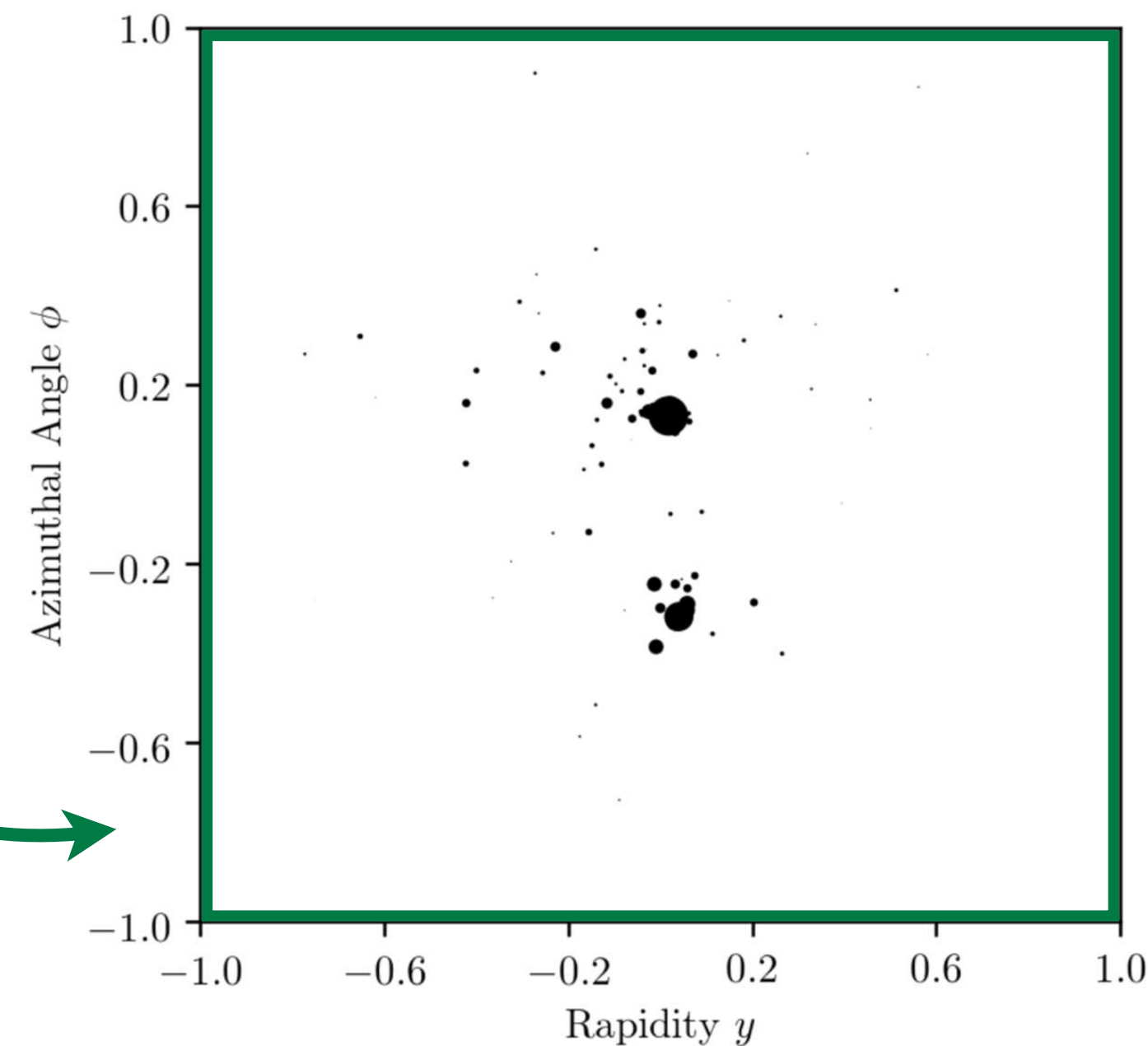
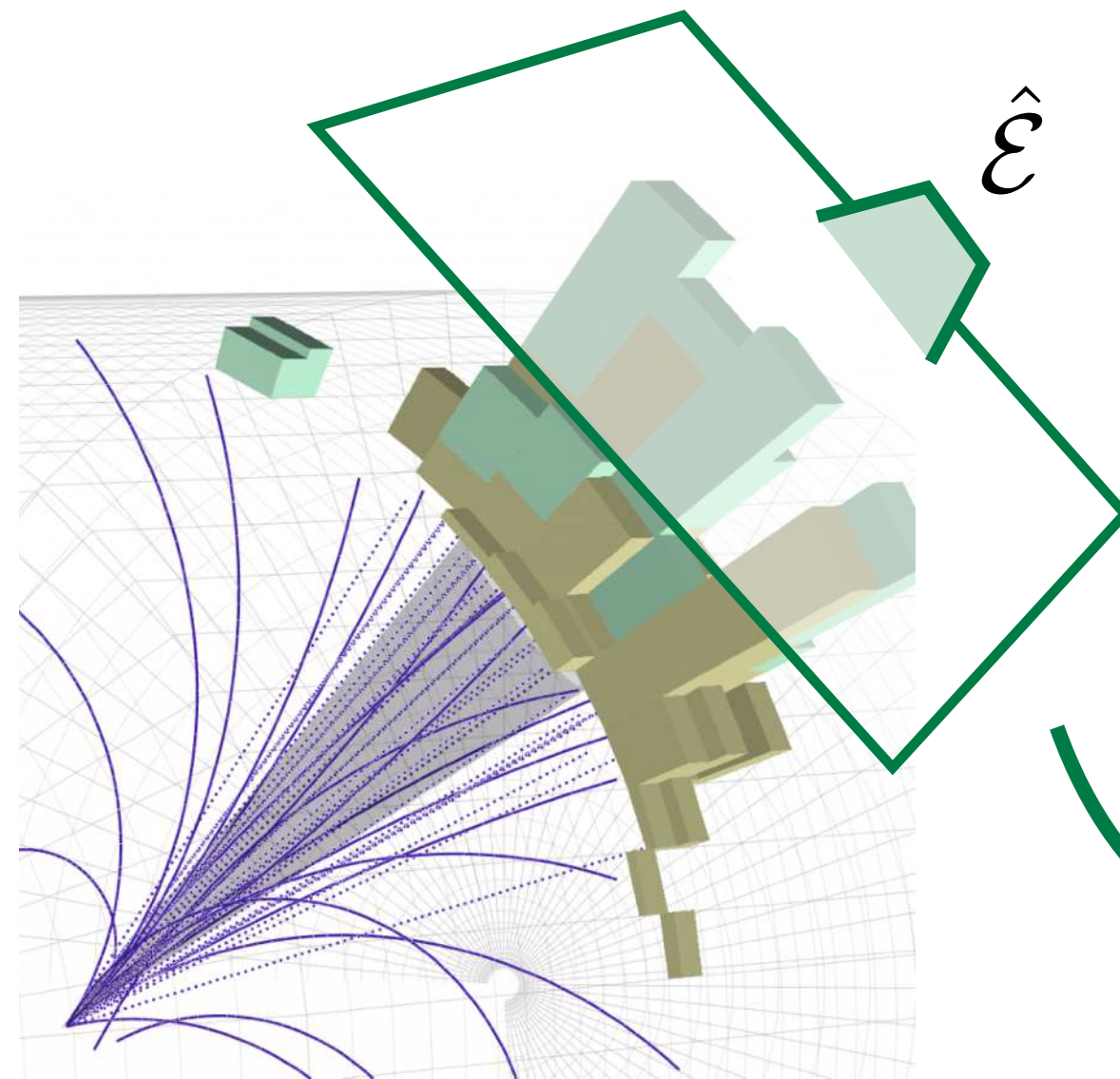
Energy Flow Networks



Collider events consist of “point clouds” of particles...

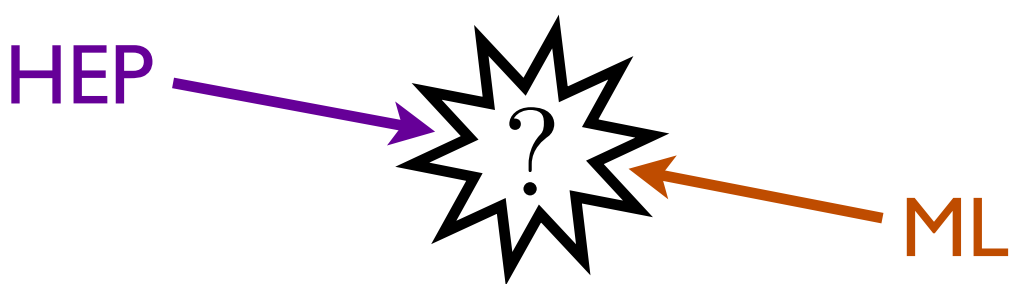
...but only “energy flow” is robust in perturbative QFT...

...inspiring network architectures for weighted point clouds



[Komiske, Metodiev, JDT, [JHEP 2019](#); see also Komiske, Metodiev, JDT, [JHEP 2018](#), [PRD 2020](#); special case of Zaheer, Kottur, Ravanbakhsh, Poczos, Salakhutdinov, Smola, [NIPS 2017](#)]

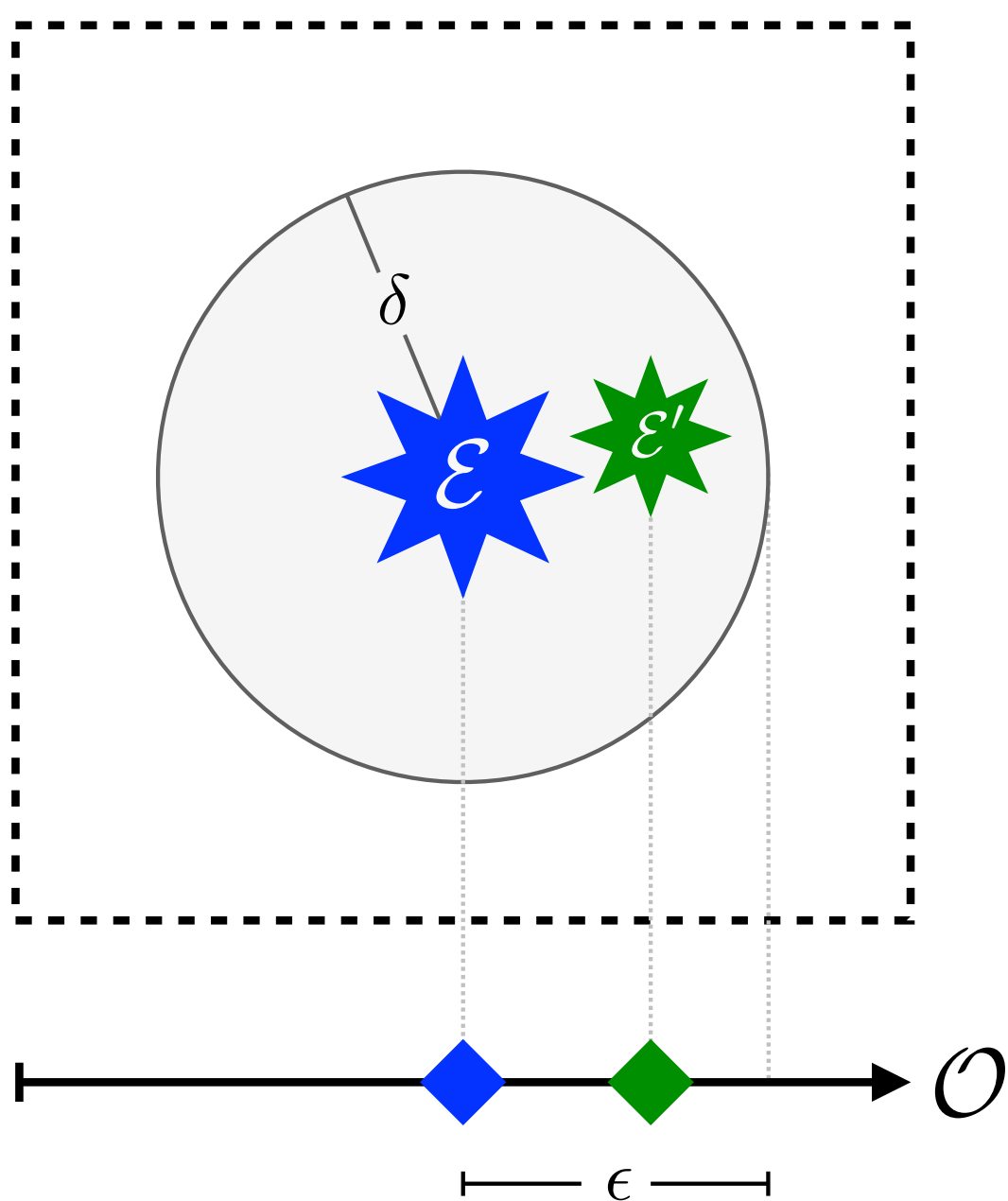
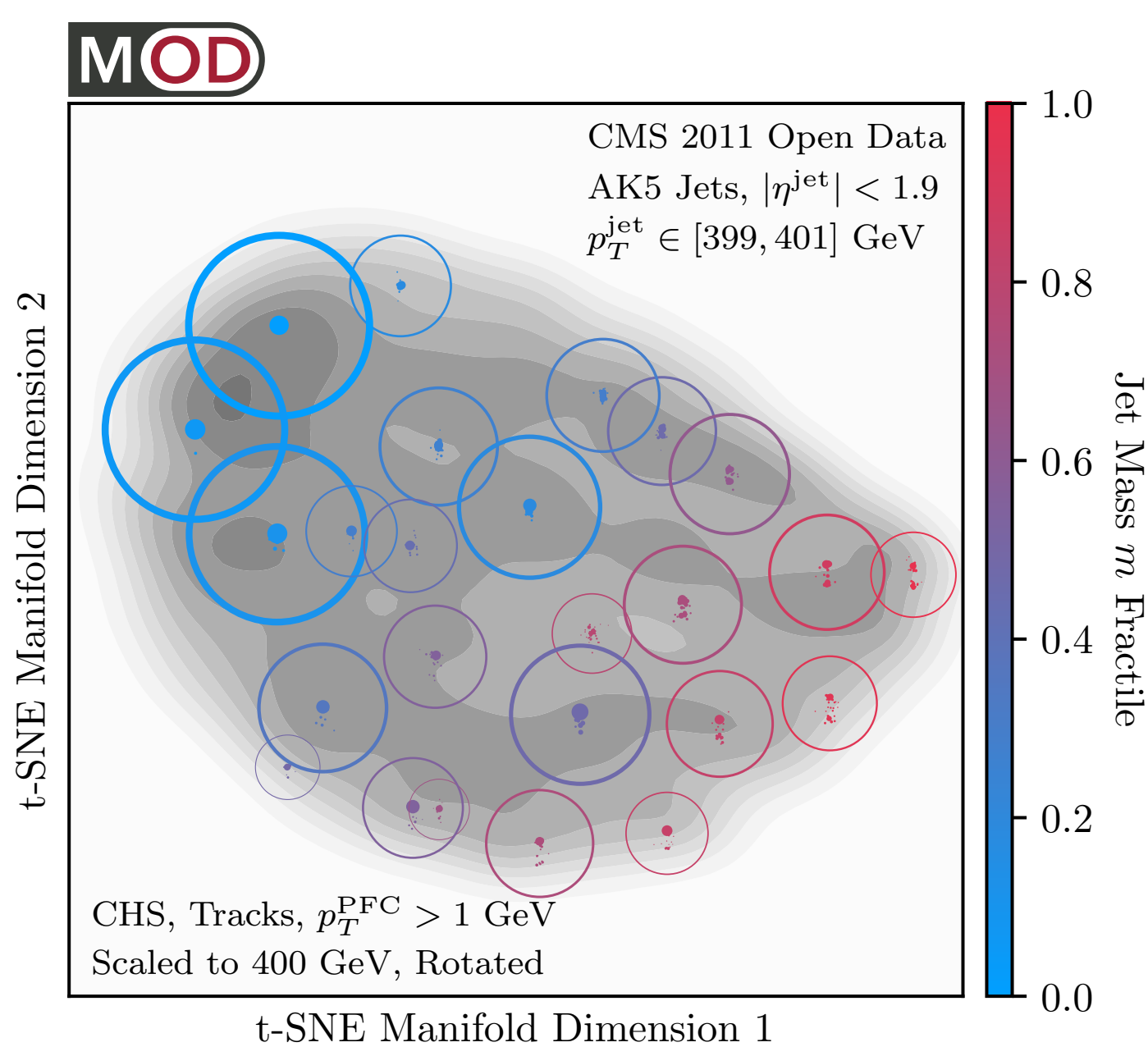
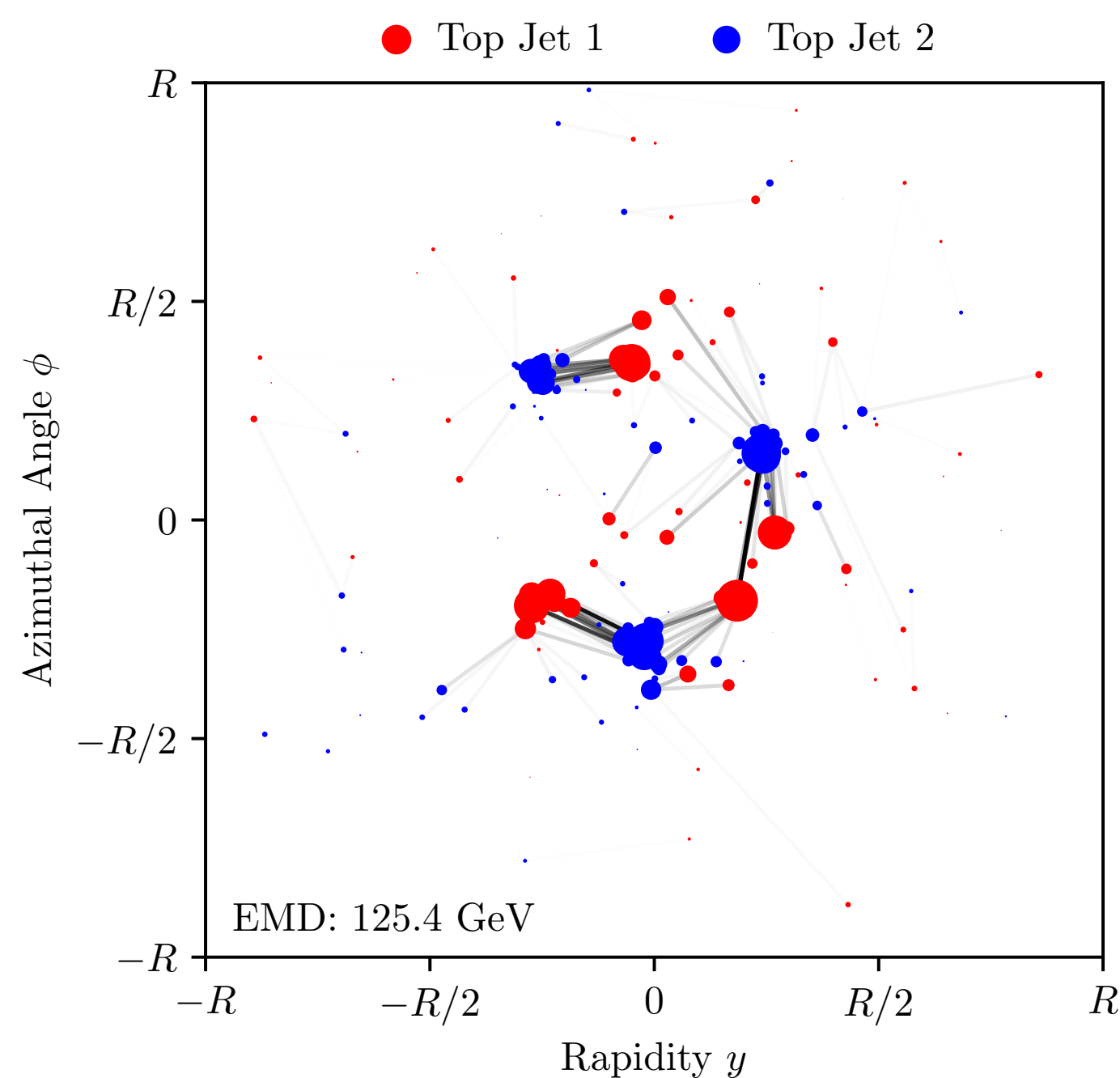
Energy Mover's Distance



Optimal transport plan
between energy flows...

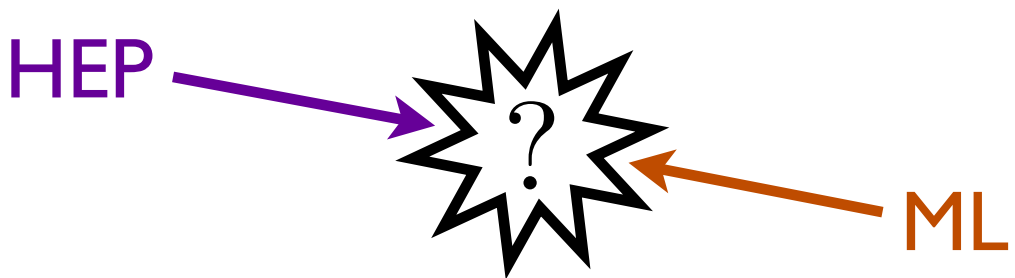
...defines a metric space
for collider events...

...yielding precise criteria
for calculability in QFT

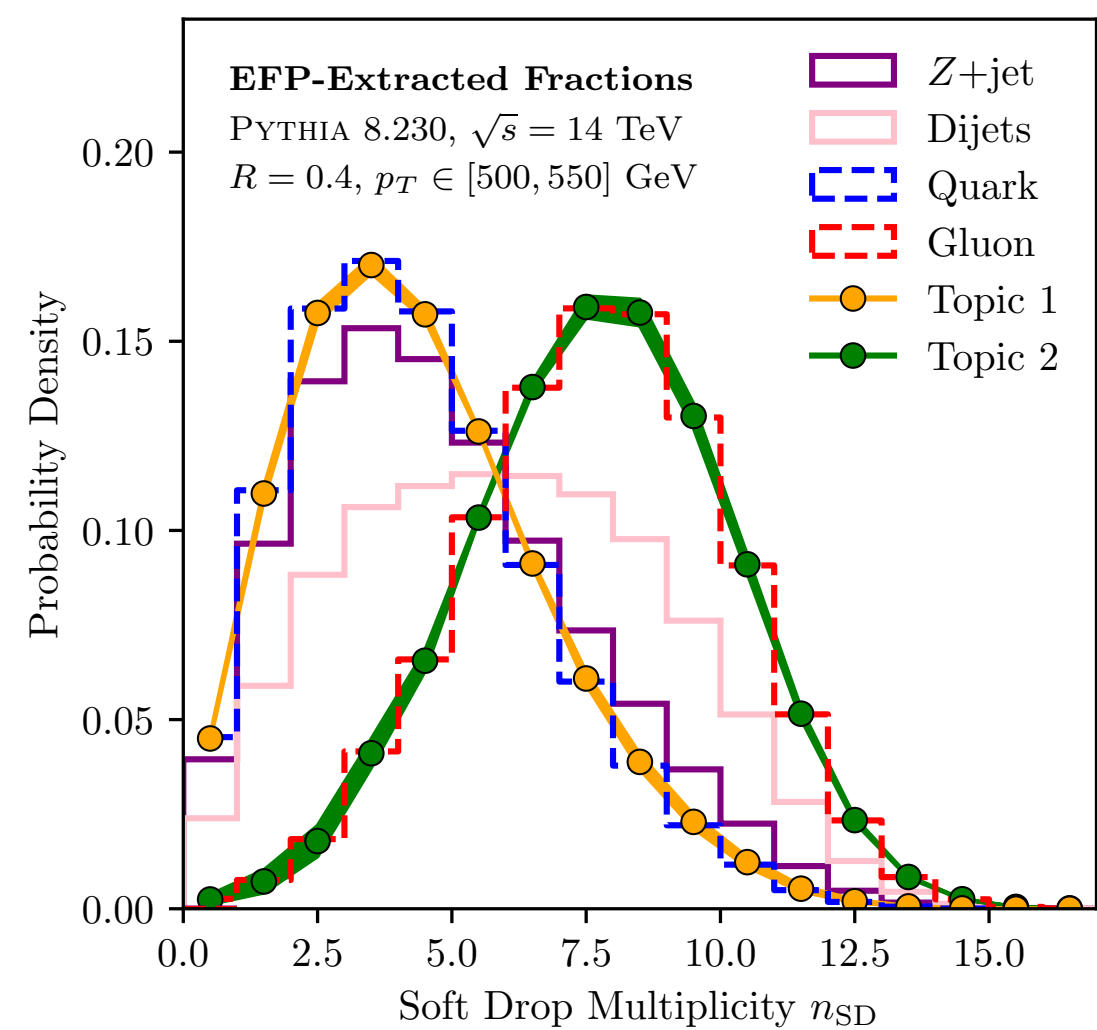


[Komiske, Metodiev, JDT, [PRL 2019](#); Komiske, Mastandrea, Metodiev, Naik, JDT, [PRD 2020](#); Komiske, Metodiev, JDT, [JHEP 2020](#); see also Cesarotti, JDT, [JHEP 2020](#); based on Peleg, Werman, Rom, [IEEE 1989](#); Rubner, Tomasi, Guibas, [ICCV 1998](#), [ICJV 2000](#); Pele, Werman, [ECCV 2008](#); Pele Taskar, [GSI 2013](#)]

More Collisions...

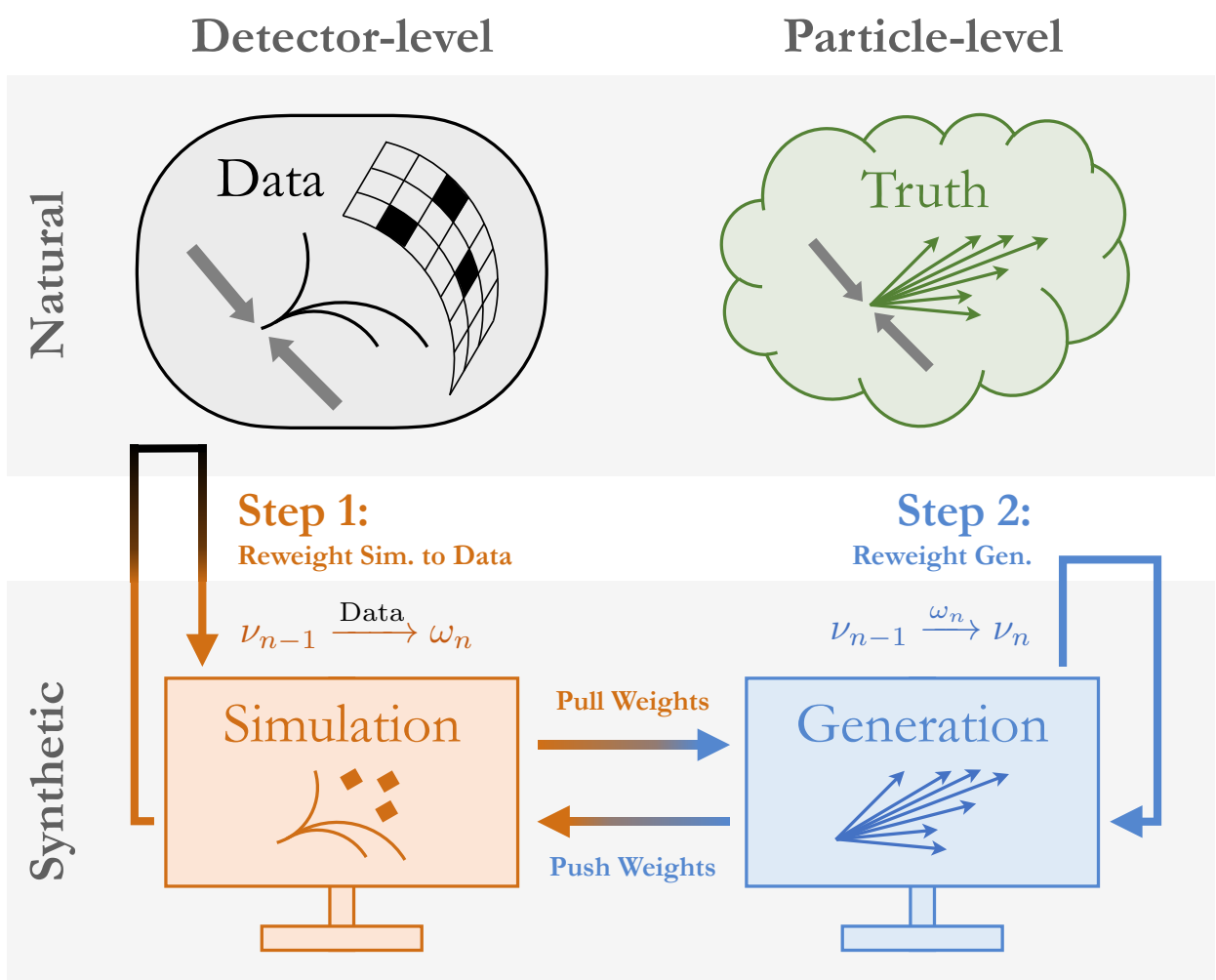


Quark/Gluon Jets via Blind Source Separation



[Komiske, Metodiev, JDT, JHEP 2018;
 Brewer, JDT, Turner; PRC 2021]

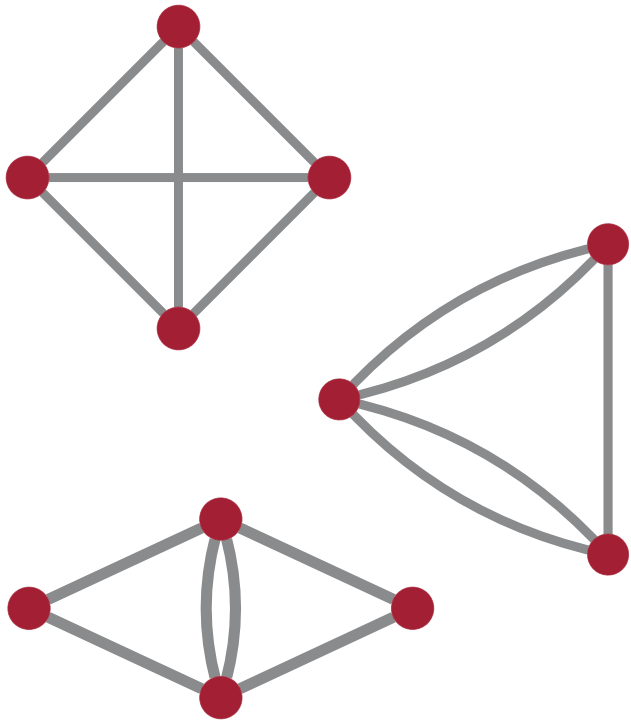
Detector Unfolding via Point Cloud Learning



[Andreassen, Komiske, Metodiev, Nachman, JDT, PRL 2020;
 see also Nachman, JDT, PRD 2020]

Kinematic Decomposition via Graph Theory

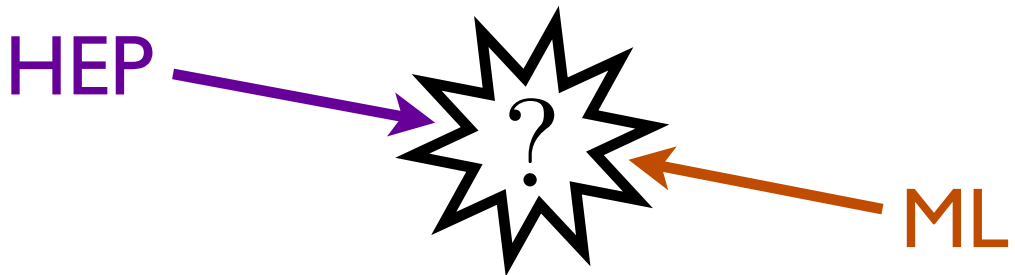
Edges d	Leafless Multigraphs	
	Connected	All
	A307317	A307316
1	0	0
2	1	1
3	2	2
4	4	5
5	9	11
6	26	34
7	68	87
8	217	279
9	718	897
10	2 553	3 129
11	9 574	11 458
12	38 005	44 576
13	157 306	181 071
14	679 682	770 237
15	3 047 699	3 407 332
16	14 150 278	15 641 159



[Komiske, Metodiev, JDT, JHEP 2018, PRD 2020]

Lots of Code!

energyflow.network



EnergyFlow

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GETTING STARTED

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Welcome to EnergyFlow

Features

EnergyFlow is a Python package containing a suite of particle physics tools:

- Energy Flow Polynomials:** EFPs are a collection of jet substructure observables which form a complete linear basis of IRC-safe observables. EnergyFlow provides tools to compute EFPs on events for several energy and angular measures as well as custom measures.
- Energy Flow Networks:** EFNs are infrared- and collinear-safe models designed for learning from collider events as unordered, variable-length sets of particles. EnergyFlow contains customizable Keras implementations of EFNs. Available from version `0.10.0` onward.

[Komiske, Metodiev, <http://energyflow.network>]



+ ...