A Few Collisions between Particle Physics & Machine Learning

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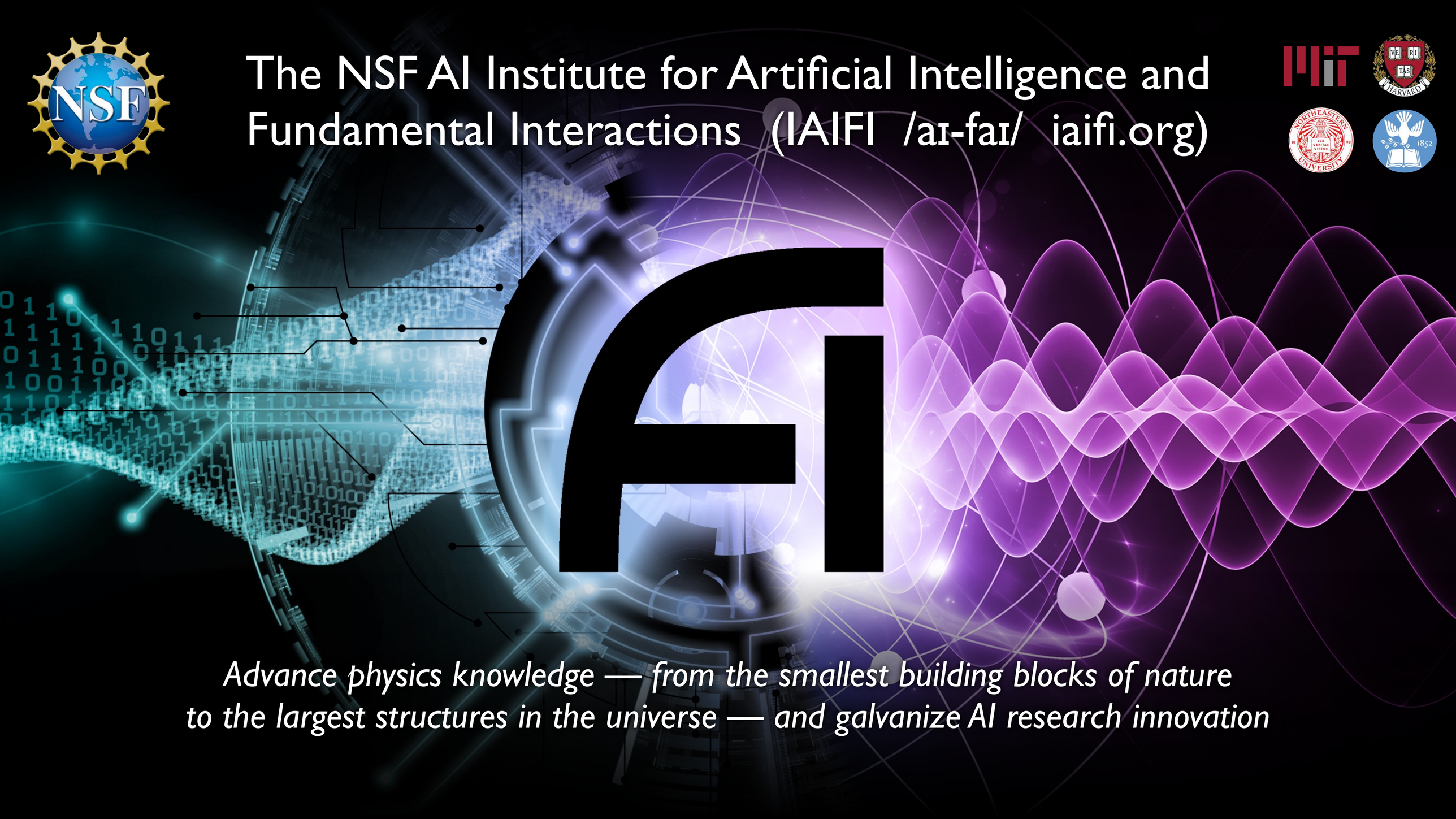
STAMPS Group Meeting, CMU — June 25, 2021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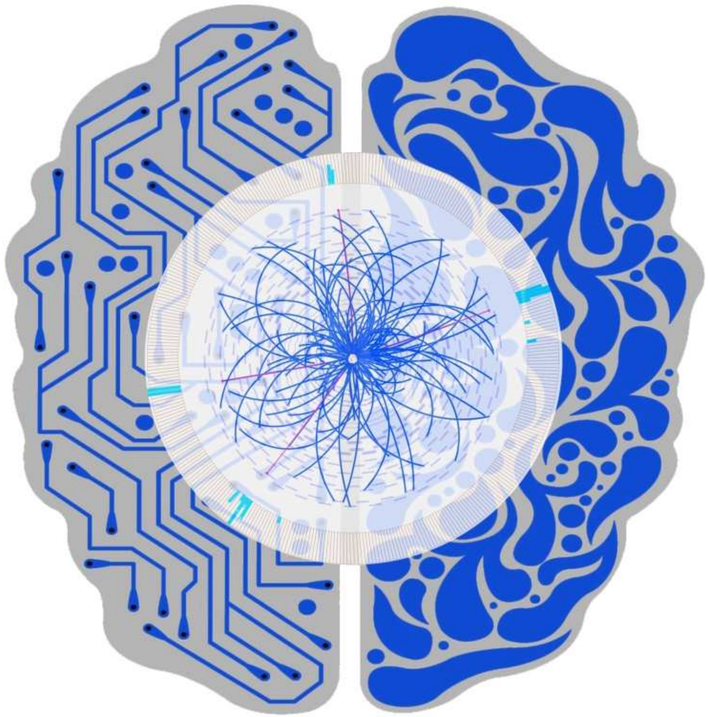
NSF
AI
Advance physics knowledge — from the smallest building blocks of nature
to the largest structures in the universe — and galvanize AI research innovation

AI²: Ab Initio Artificial Intelligence

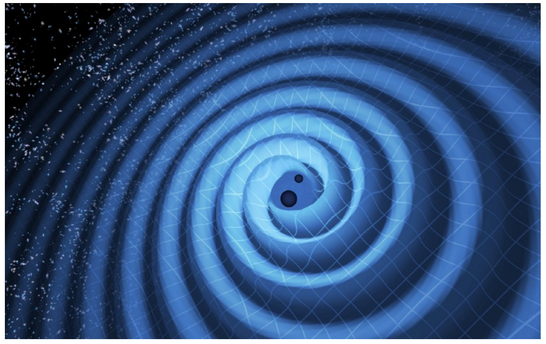


Machine learning that incorporates
first principles, best practices,
and domain knowledge
from fundamental physics

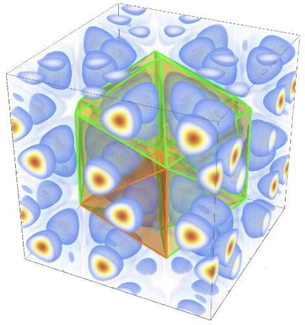
Symmetries, conservation laws, scaling relations, limiting behaviors, locality, causality, unitarity, gauge invariance, entropy, least action, factorization, unit tests, exactness, systematic uncertainties, reproducibility, verifiability, …

Artificial Intelligence ⇔ Fundamental Physics

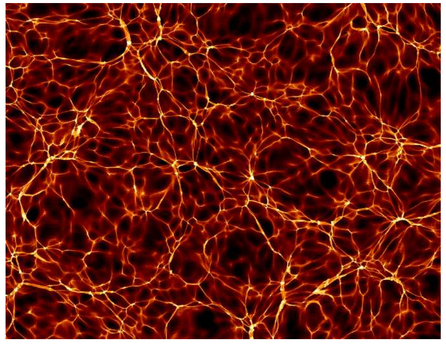
Gravitational Waves



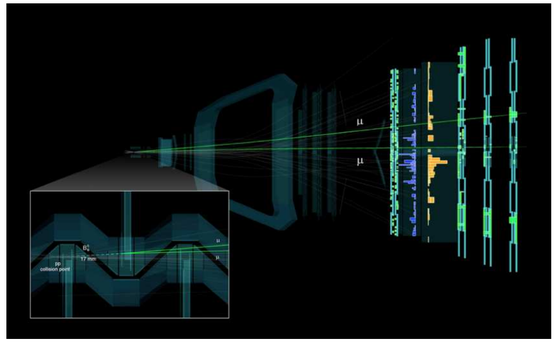
Nuclear Physics



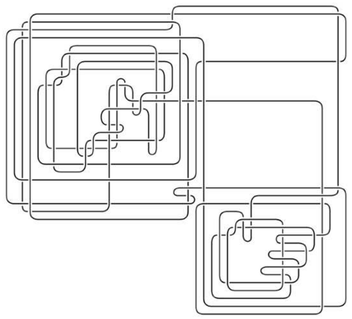
Dark Matter



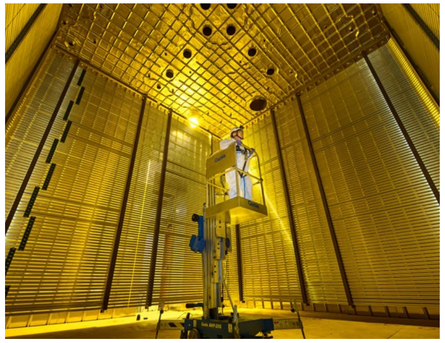
Particle Colliders



Mathematical Physics



Neutrino Detection



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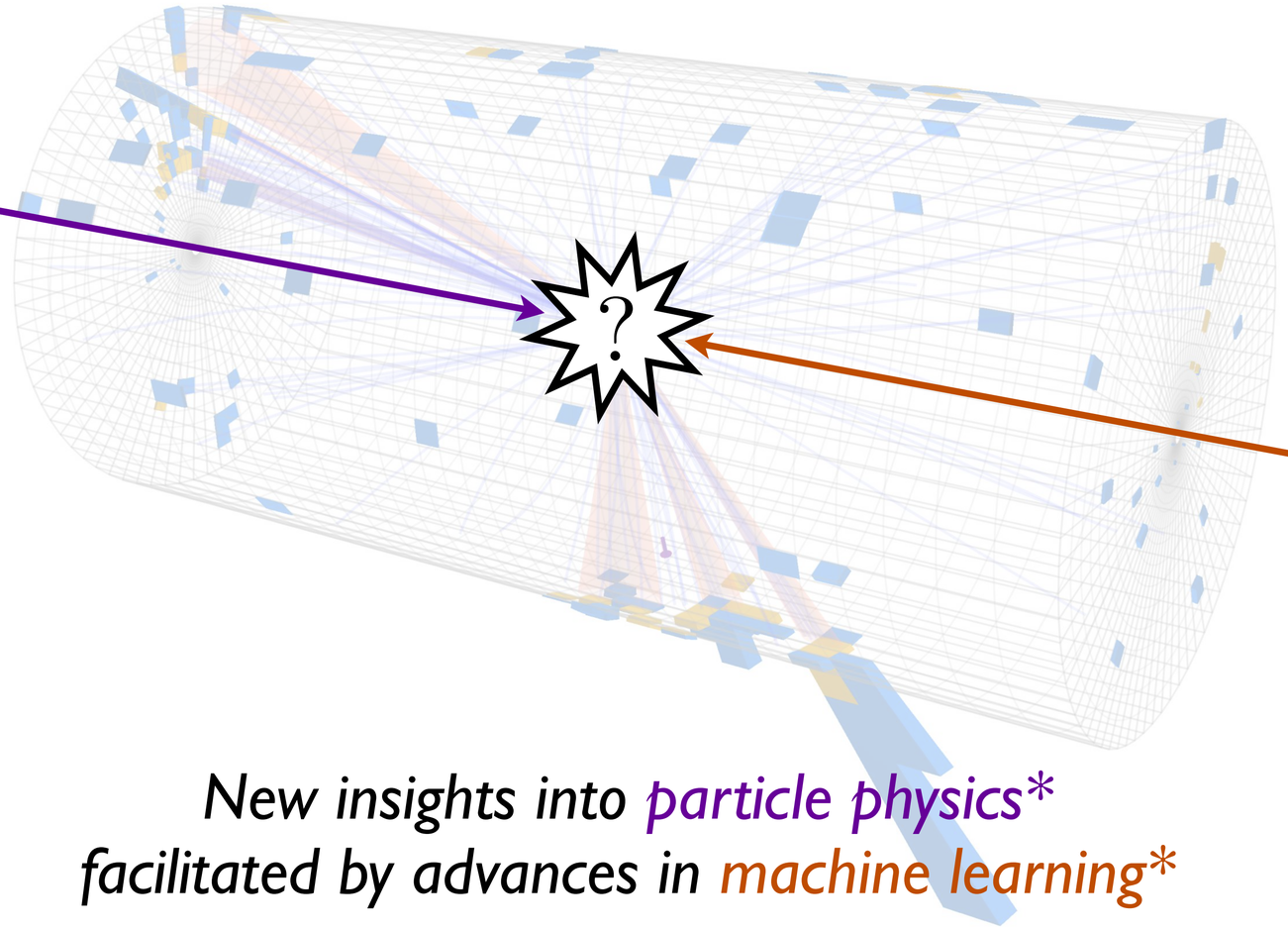
[iaifi.org]

“Collision Course”

Theoretical
High Energy
Physics



Mathematics,
Statistics,
Computer Science

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

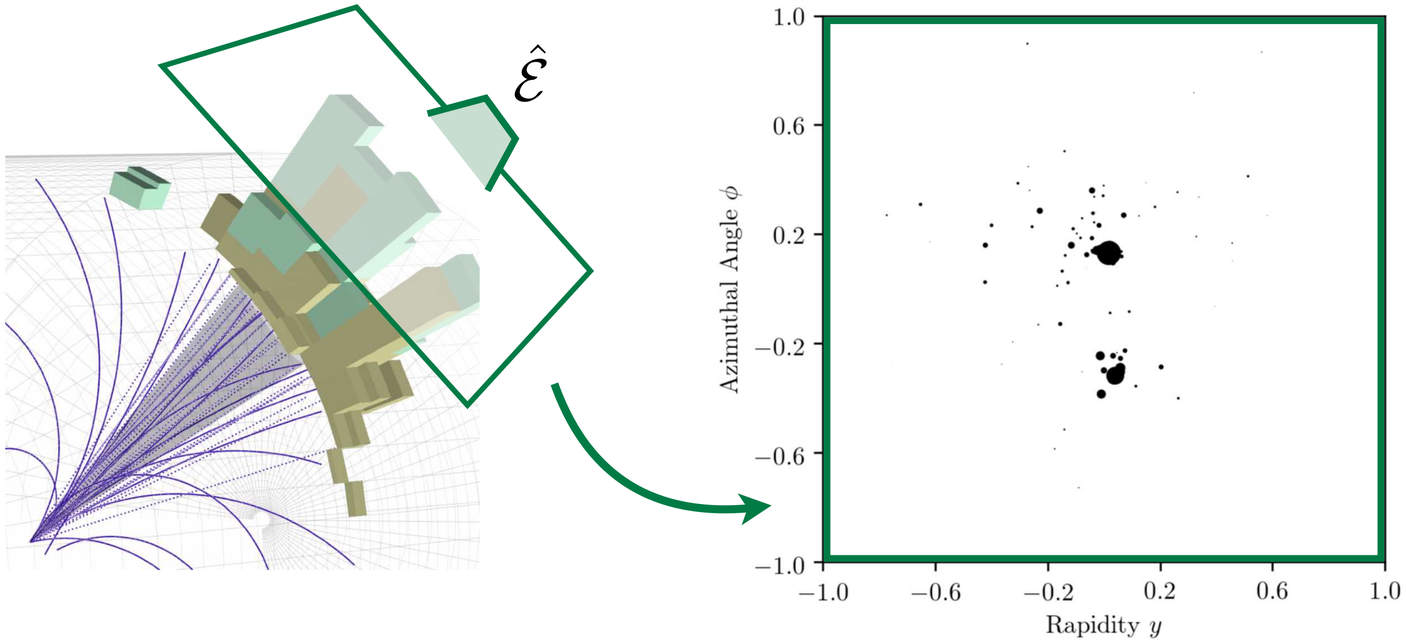
[e.g. Harvard Physics Colloquium, November 2020]

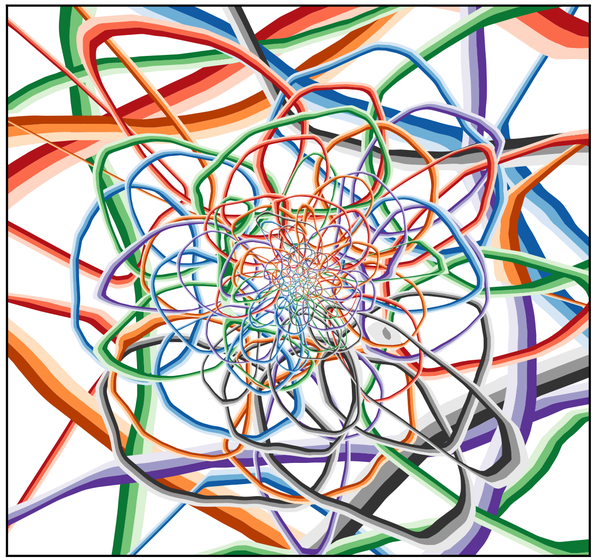
Energy Flow Networks

Collider events consist of "point clouds" of particles…

…but only "energy flow" is robust in perturbative QFT…

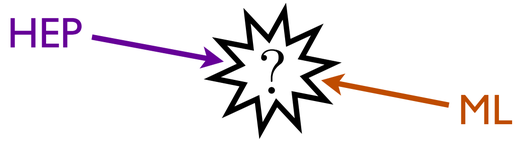
…inspiring network architectures for weighted point clouds



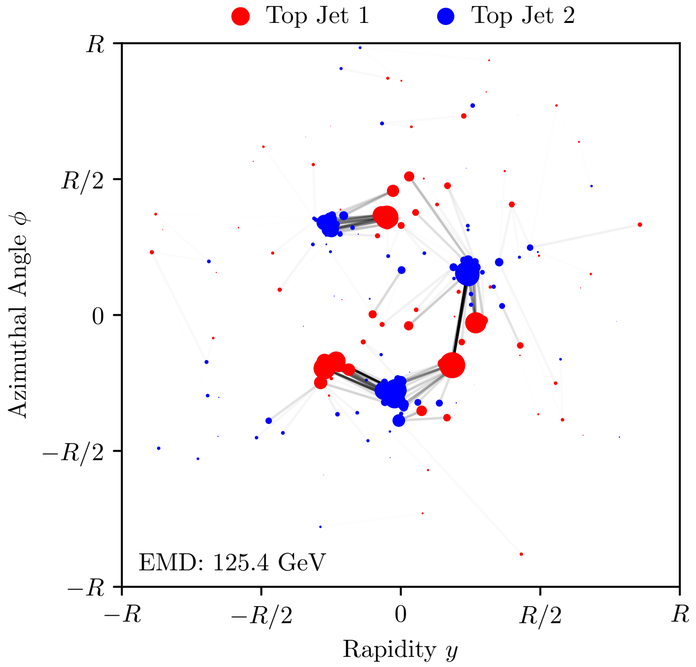


[Komiske, Metodiev, JDT, JHEP 2019; see also Komiske, Metodiev, JDT, JHEP 2018, PRD 2020; special case of Zaheer, Kottur, Ravanbakhsh, Poczos, Salakhutdinov, Smola, NIPS 2017]

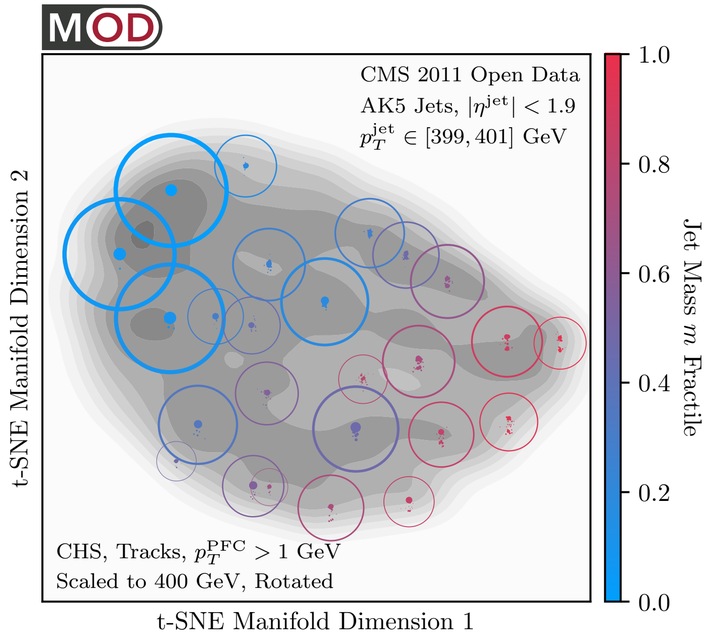
Energy Mover's Distance



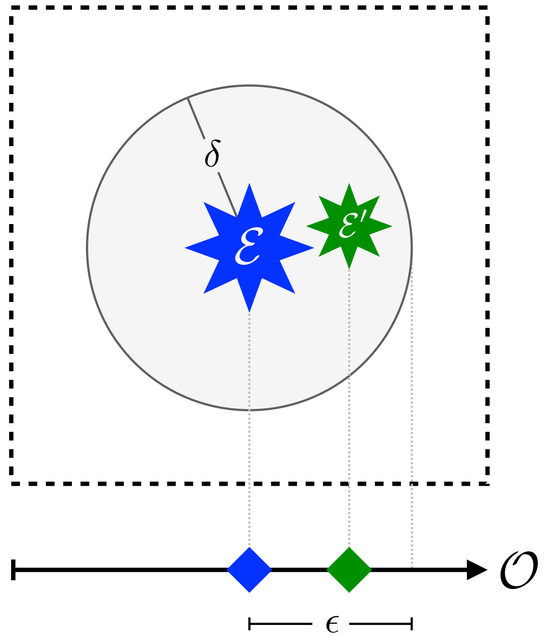
Optimal transport plan between energy flows…



…defines a metric space for collider events…

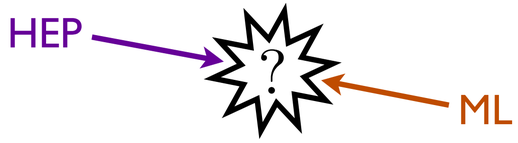


…yielding precise criteria for calculability in QFT

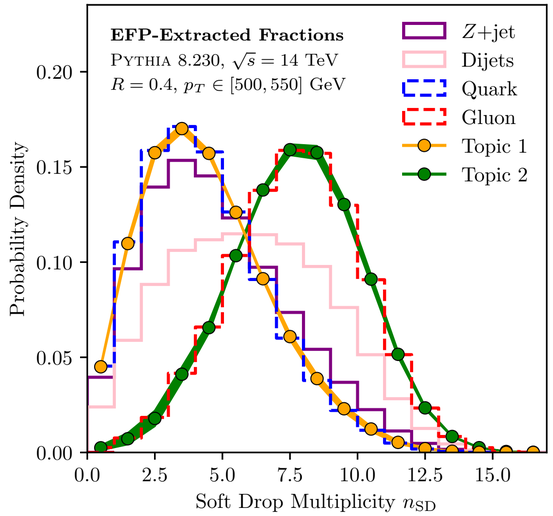


[Komiske, Metodiev, JDT, PRL 2019; Komiske, Mastandrea, Metodiev, Naik, JDT, PRD 2020; Komiske, Metodiev, JDT, JHEP 2020; see also Cesarotti, JDT, JHEP 2020; based on Peleg, Werman, Rom, IEEE 1989; Rubner, Tomasi, Guibas, ICCV 1998, ICJV 2000; Pele, Werman, ECCV 2008; Pele Taskar, GSI 2013]

More Collisions…

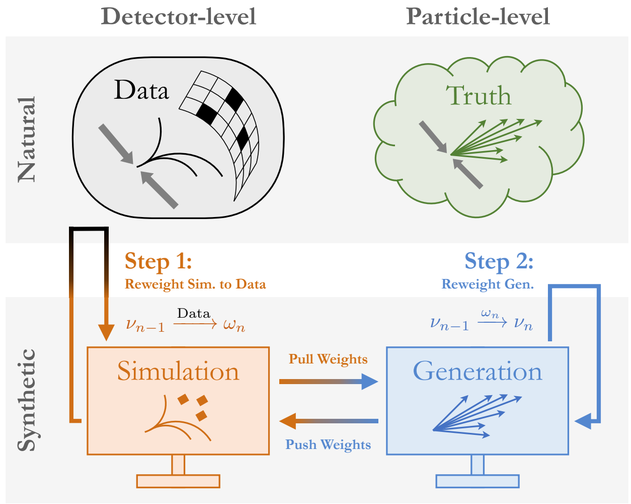


Quark/Gluon Jets via Blind Source Separation



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

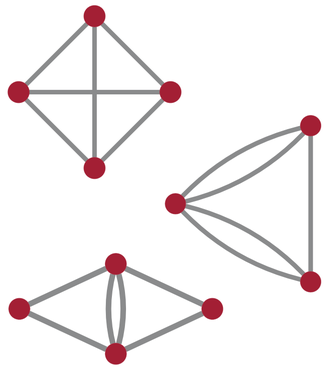
Detector Unfolding via Point Cloud Learning



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

Kinematic Decomposition via Graph Theory

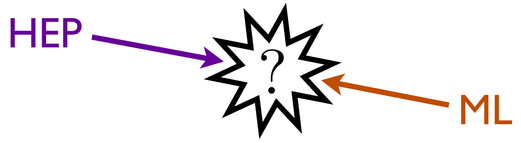
	Leafless Multigraphs	
	Connected	All
Edges d	A307317	A307316
1	0	0
2	1	1
3	2	2
4	4	5
5	9	11
6	26	34
7	68	87
8	217	279
9	**718**	**897**
10	**2 553**	**3 129**
11	**9 574**	**11 458**
12	**38 005**	**44 576**
13	**157 306**	**181 071**
14	**679 682**	**770 237**
15	**3 047 699**	**3 407 332**
16	**14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

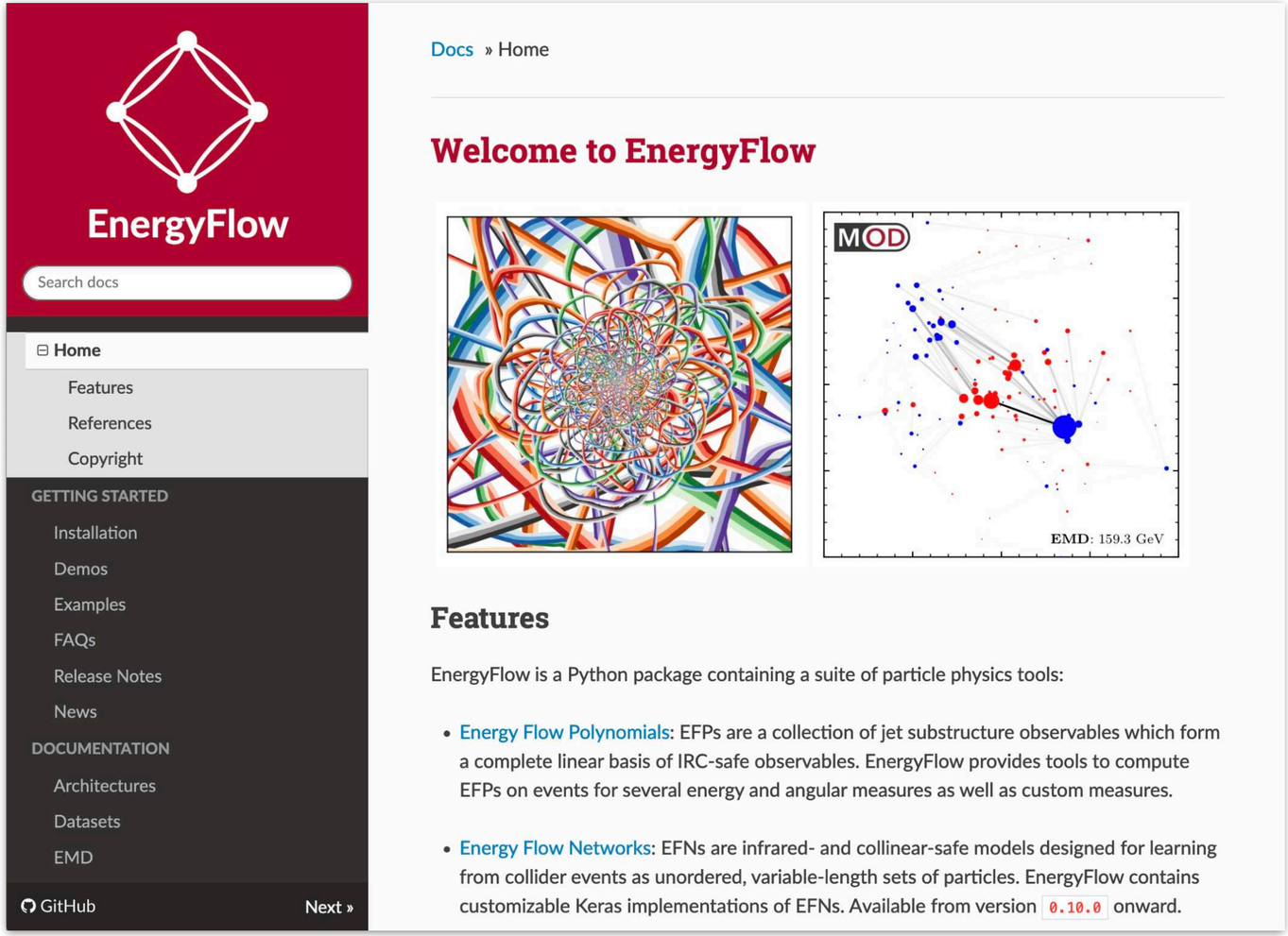


[Komiske, Metodiev, JDT, JHEP 2018, PRD 2020]

Lots of Code!

energyflow.network





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