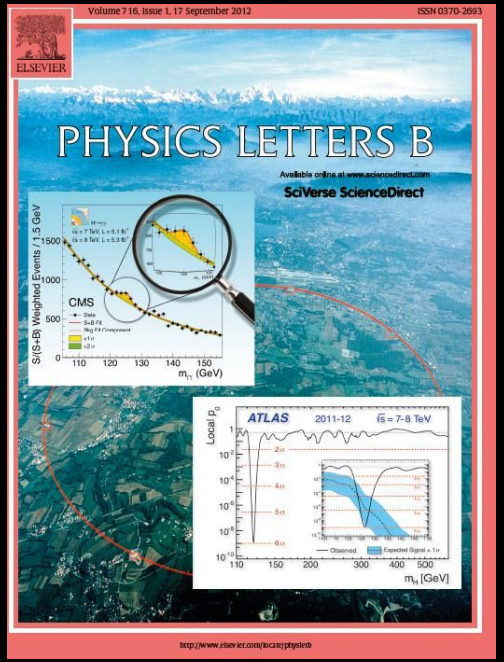
Discovering the Dark Universe with Artificial Intelligence

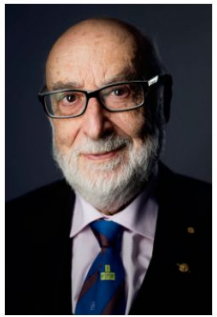
Shih-Chieh Hsu
University of Washington / A3D3

Sep 5 2023
Joint Colloquia, National Taiwan University

https://spec.ntu.edu.tw/20220704-page-act-phys/



2012



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François Englert

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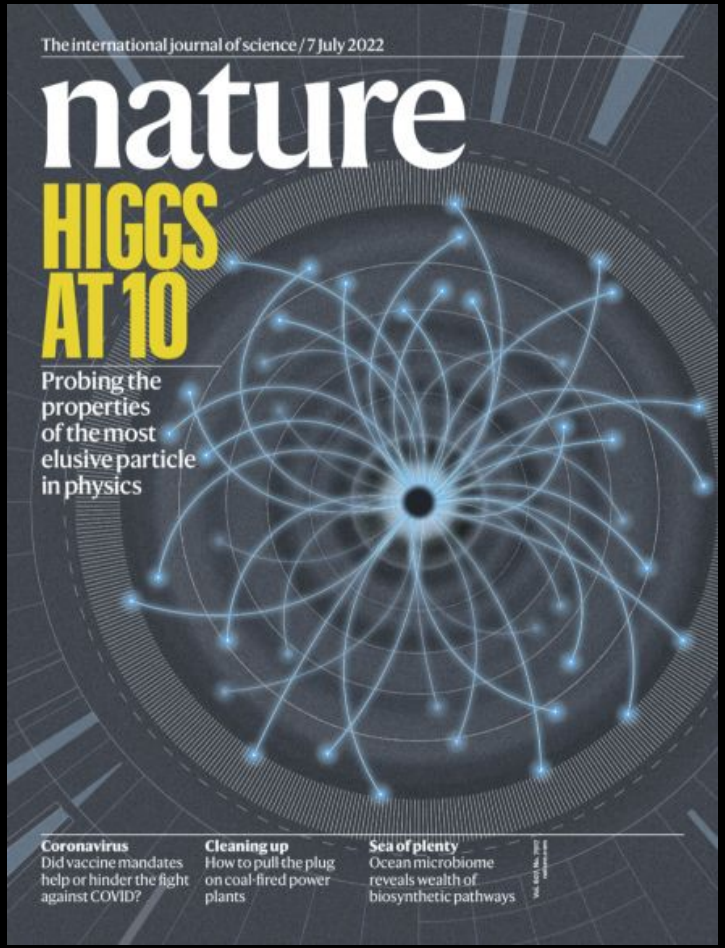
Peter W. Higgs

2013



https://www.nature.com/collections/gbfhieacie

σ(pp→H) uncertainty from **25%** to **6%**

Nature volume 607, p41–47 (2022)

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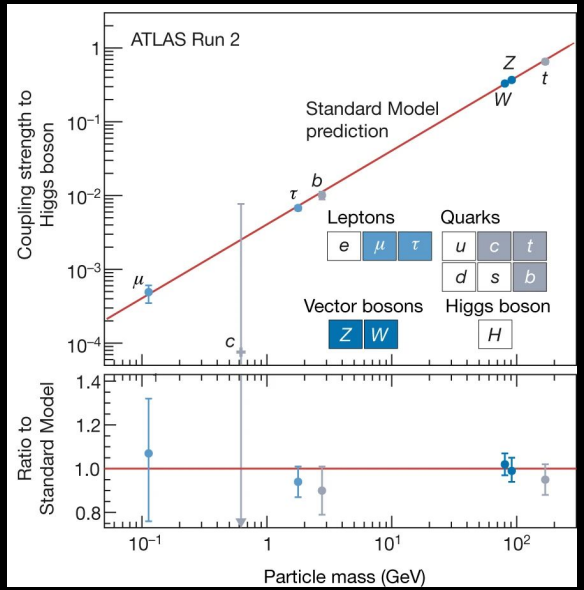

https://www.nature.com/collections/gbfhieacie

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$\sigma(pp \rightarrow H)$ uncertainty from **25%** to **6%**

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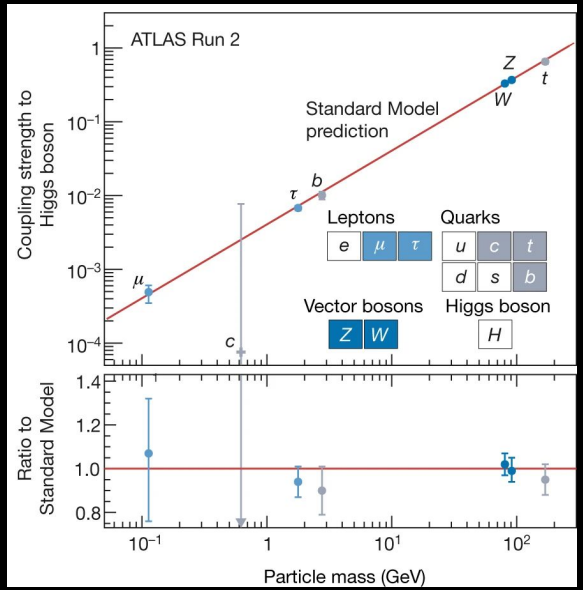
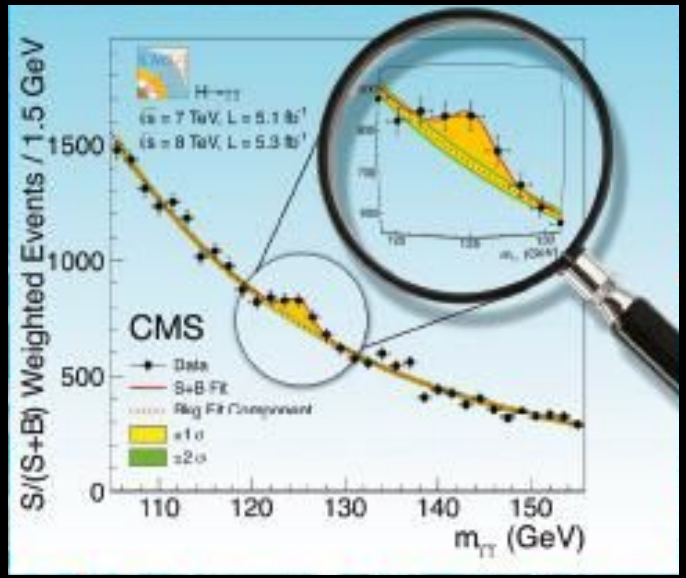


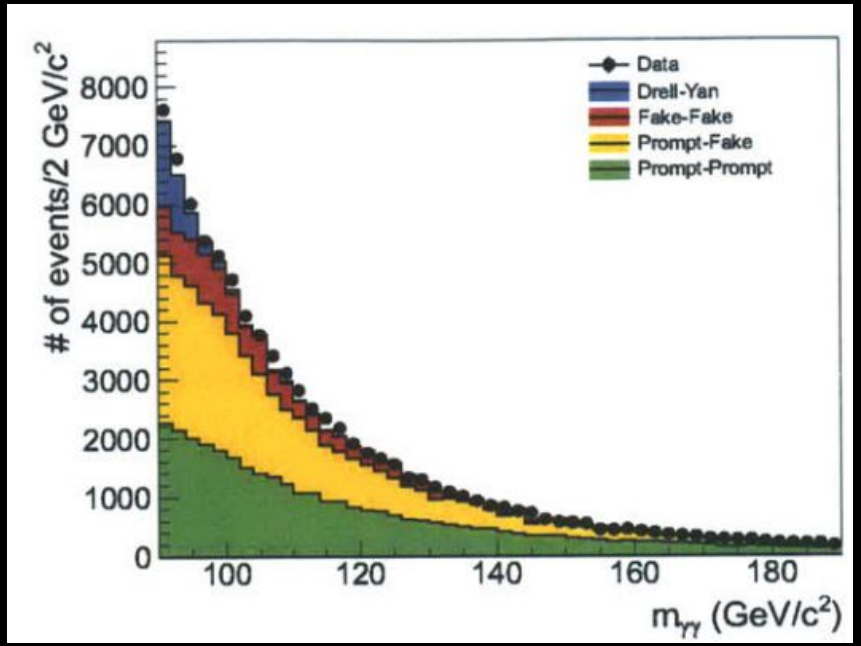
Fabio Cerutti: All analyses use **AI/ML** techniques to perform several tasks, e.g. object identification, calibration, and event discrimination.

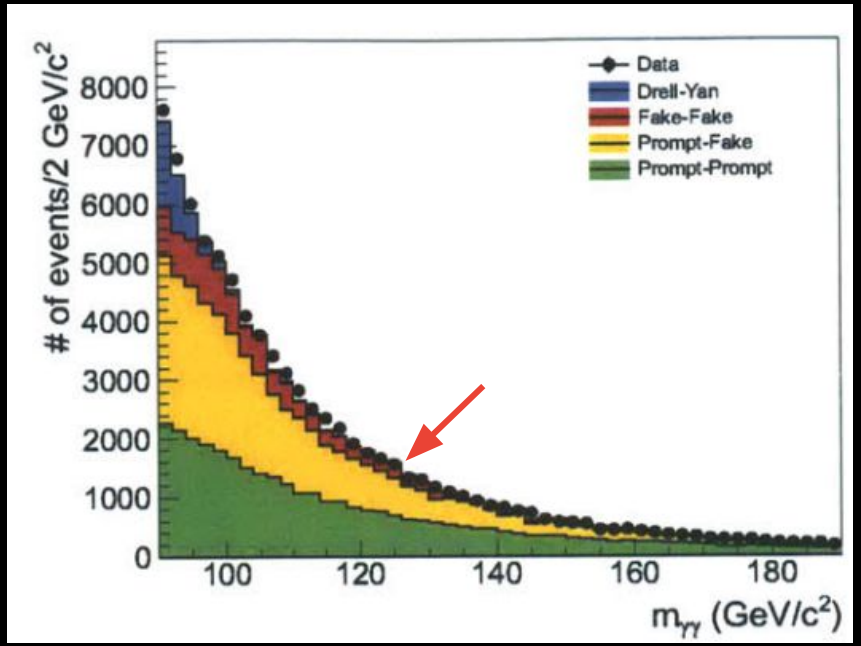
Higgs 2022 | PISA 11-7 Nov 2022

AI has made critical contributions to the Higgs Discovery!



PHYSICS LETTERS B Volume 716, Issue 1, 17 September 2012


Data
Drell-Yan
Fake-Fake
Prompt-Fake
Prompt-Prompt
# of events/2 GeV/c^2
8000
7000
6000
5000
4000
3000
2000
1000
0
100
120
140
160
180
$m_{\gamma\gamma}$ (GeV/c^2)


Data
Drell-Yan
Fake-Fake
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# of events/2 GeV/c²
8000
7000
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5000
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2000
1000
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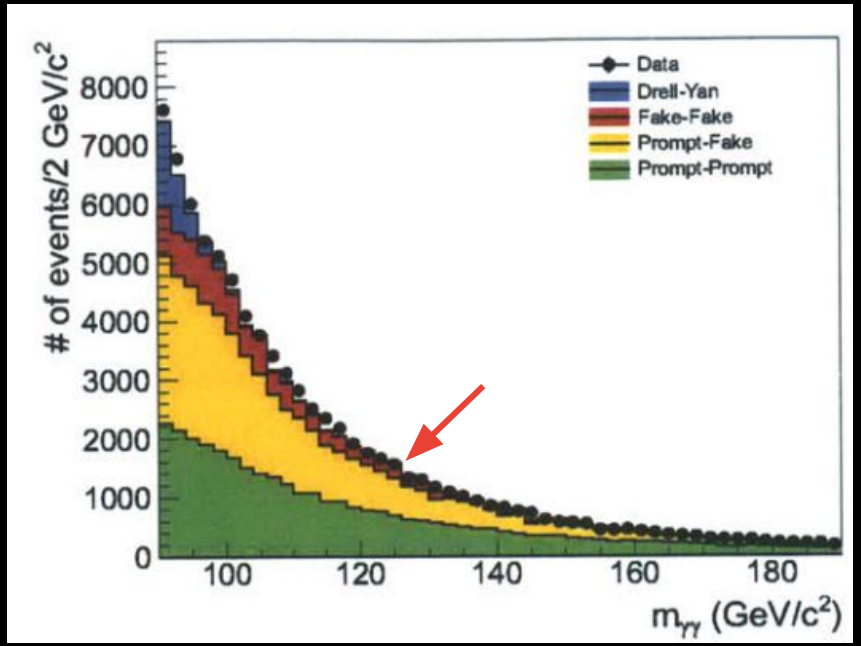
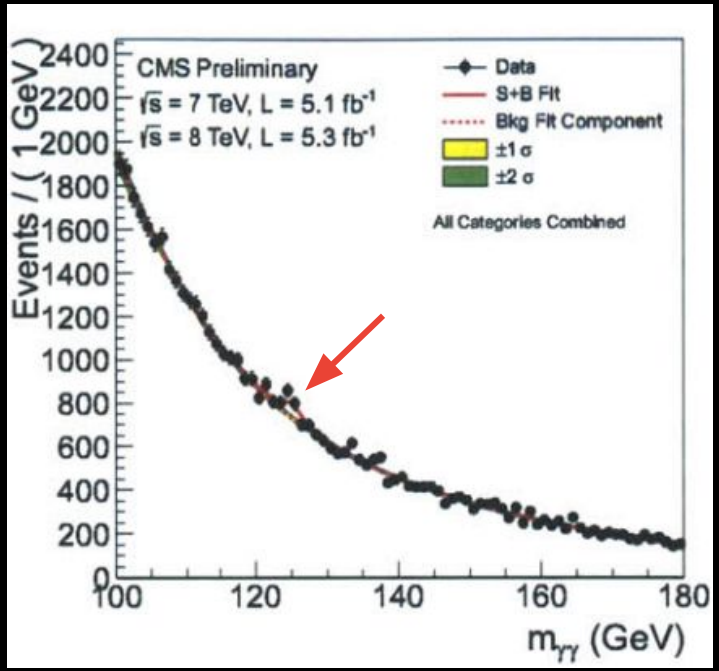
100
120
140
160
180
m_γγ (GeV/c²)

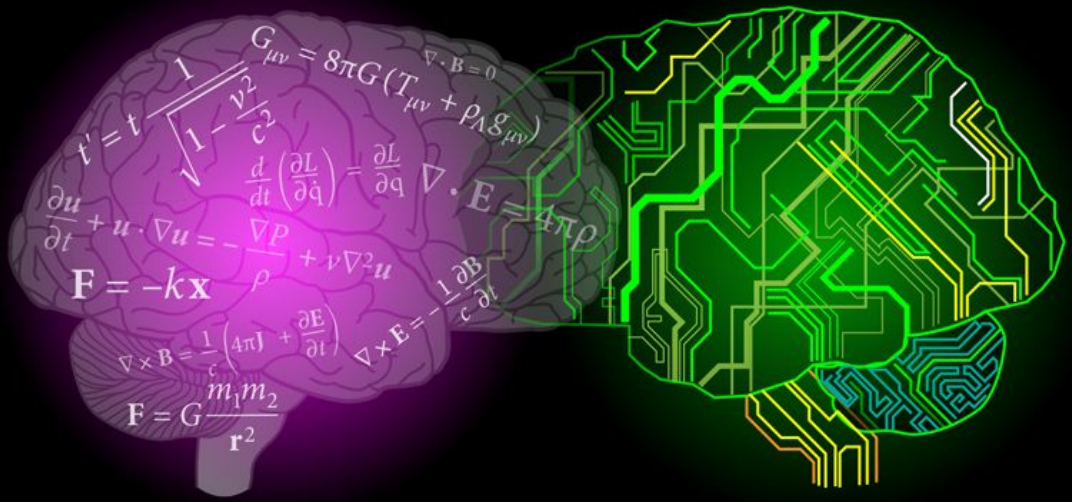
CERN-THESIS-2013-079



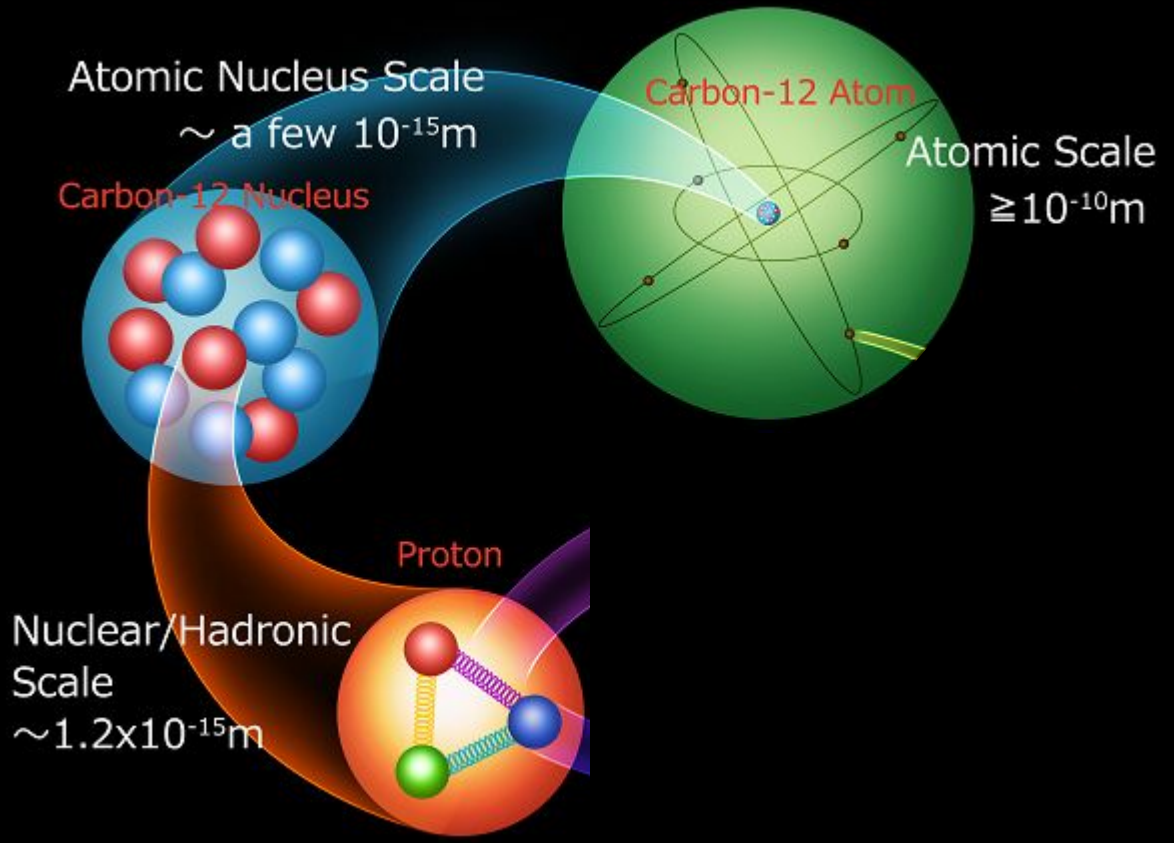
AI

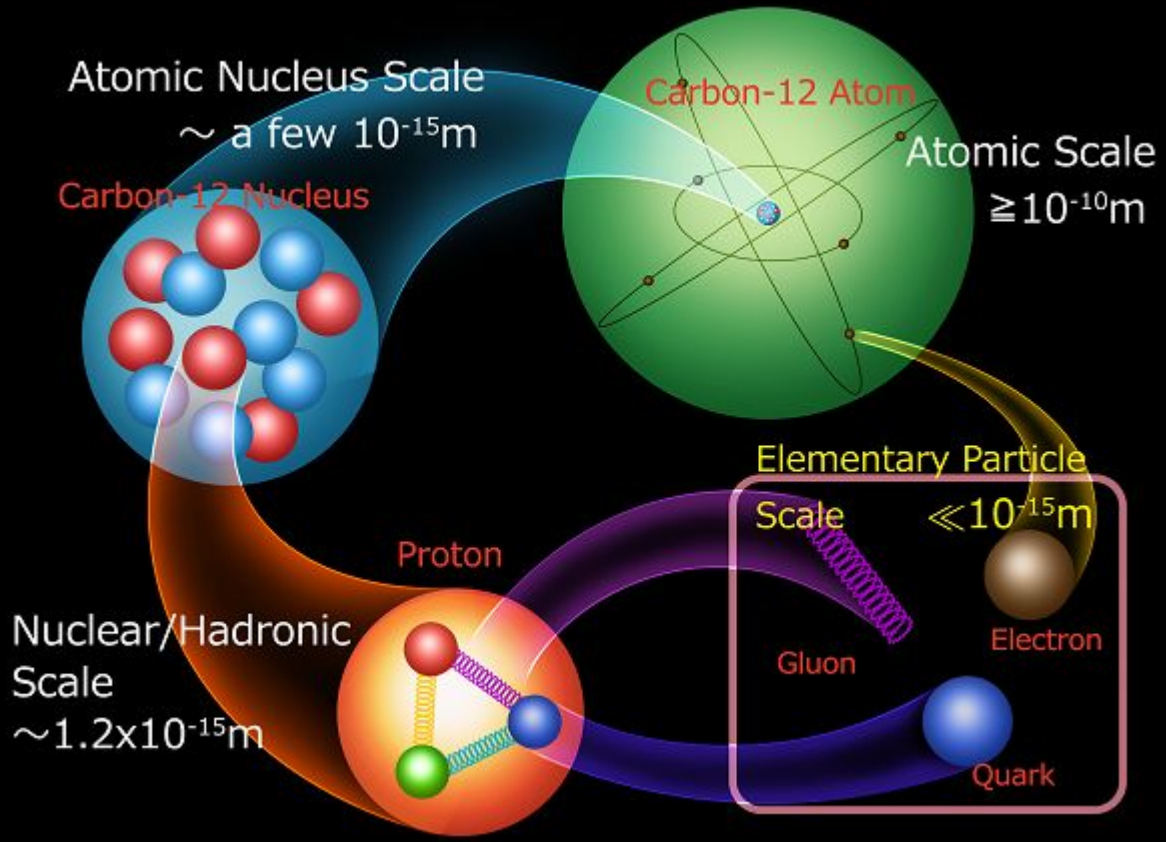


AI has been revolutionizing particle physics. How?

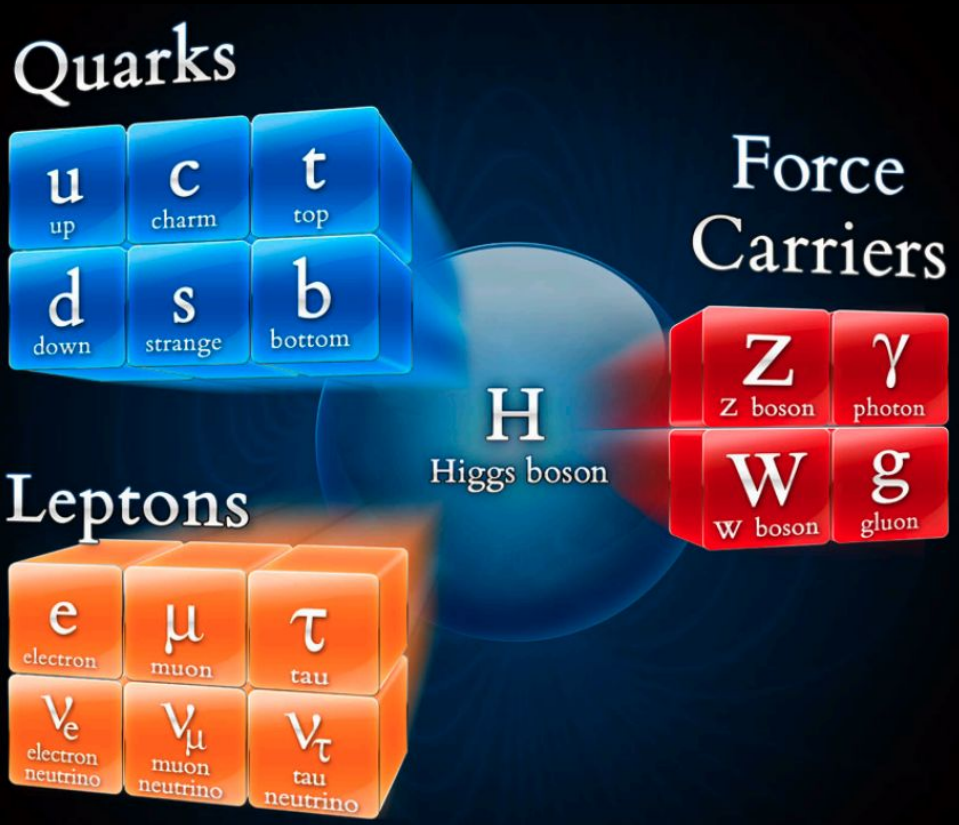


APS/Alan Stonebraker

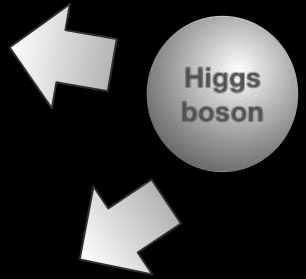

Atomic Nucleus Scale
~ a few 10-15m
Carbon-12 Nucleus
Carbon-12 Atom
Atomic Scale
≧10-10m
Proton
Nuclear/Hadronic
Scale
~1.2x10-15m


Atomic Nucleus Scale
~ a few 10-15m
Carbon-12 Nucleus
Carbon-12 Atom
Atomic Scale
≧10-10m
Elementary Particle
Scale
≪10-15m
Proton
Nuclear/Hadronic
Scale
~1.2x10-15m
Gluon
Electron
Quark

The Standard Model explains **ALMOST** everything in the **VISIBLE** Universe.

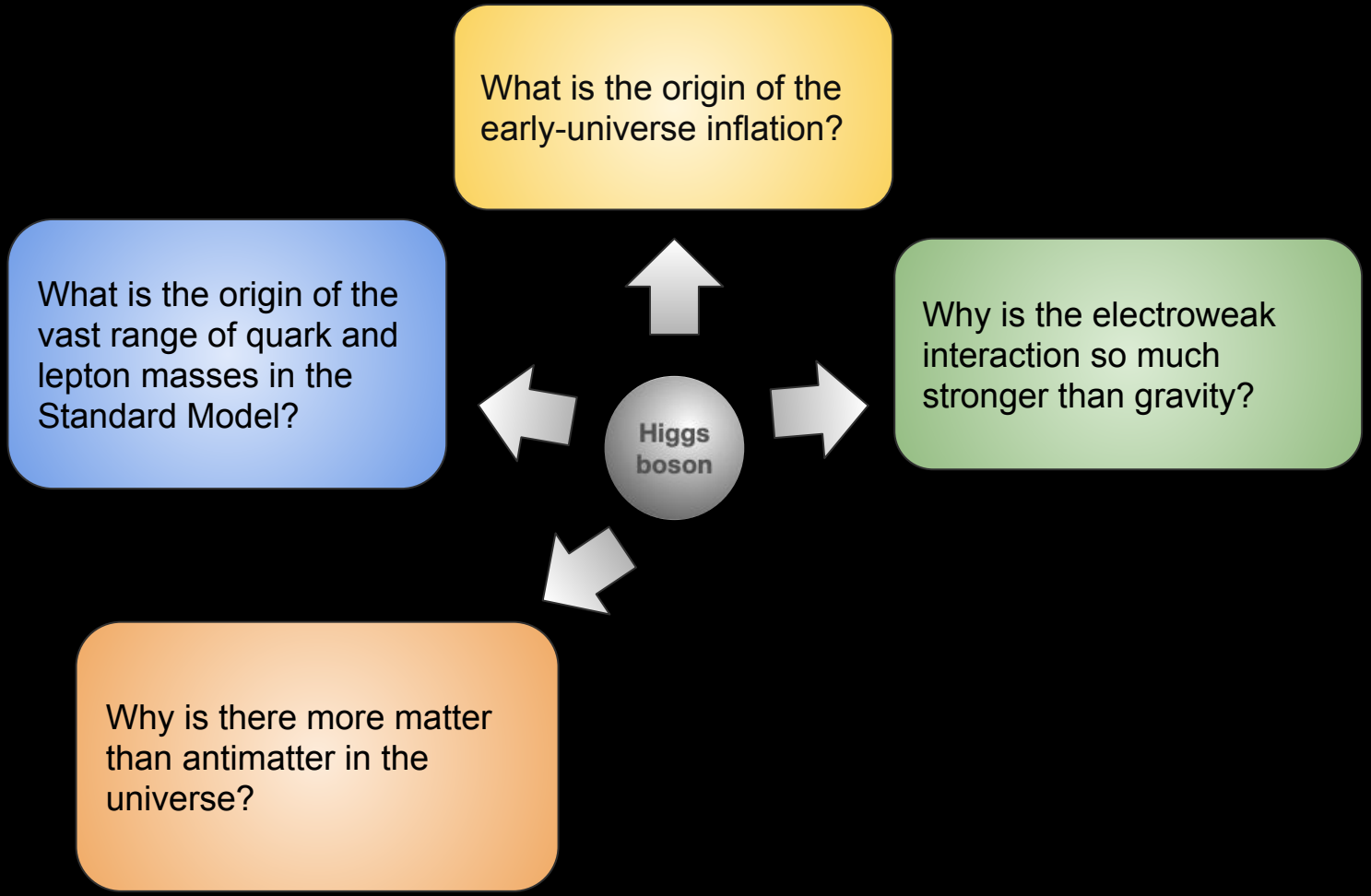


What is the origin of the vast range of quark and lepton masses in the Standard Model?



Why is there more matter than antimatter in the universe?

arXiv:2207.00478



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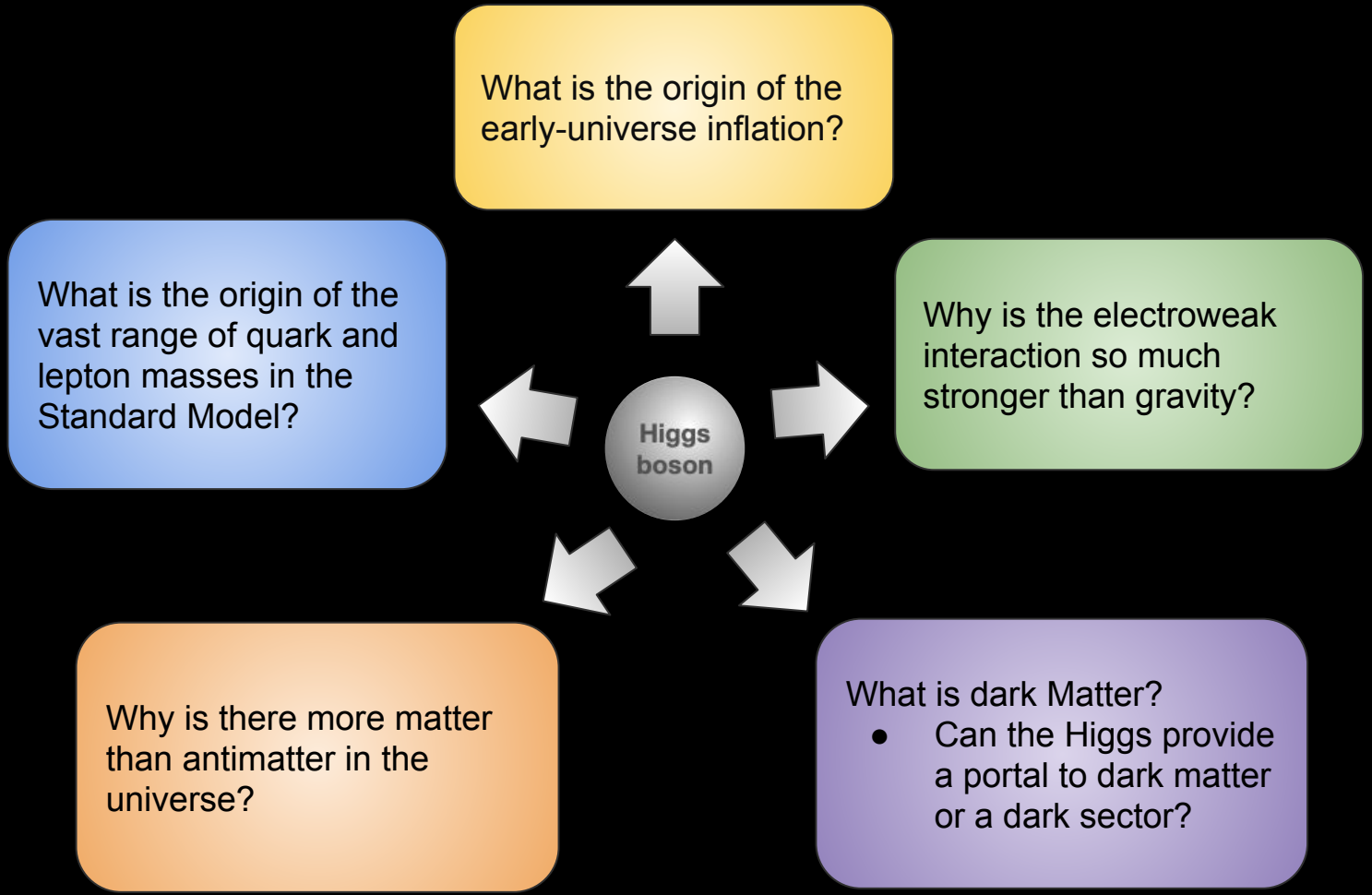


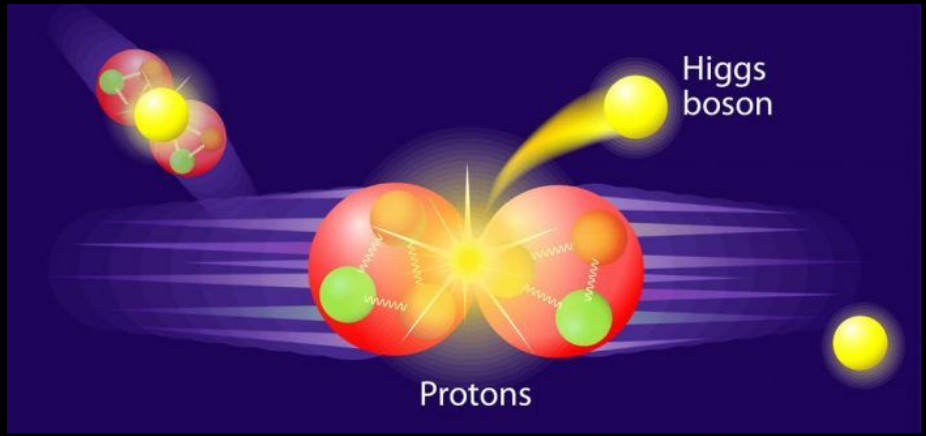
arXiv:2207.00478

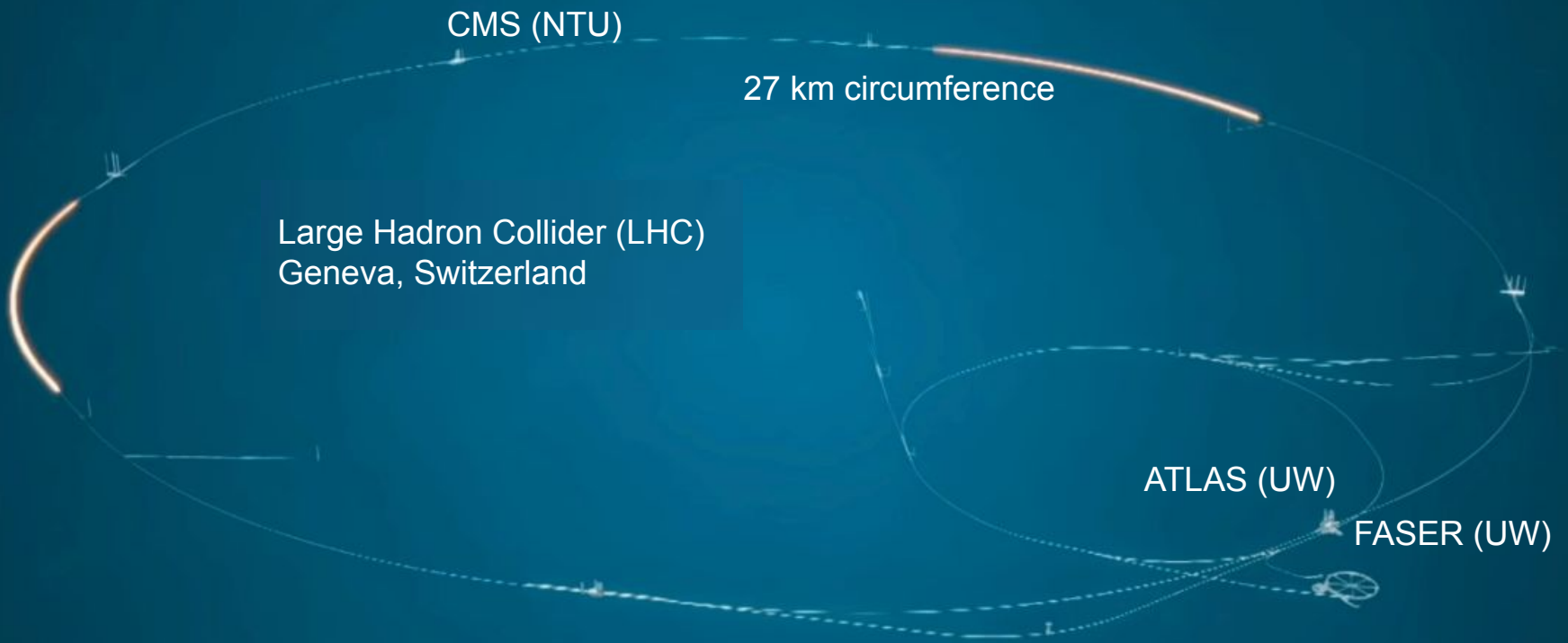
How can we study zeptometer scale (10^{-21} m) physics?

Quantum Mechanics relation
Heisenberg's Uncertainty Principle

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Probing zeptometer scale
by smashing 7 TeV protons.

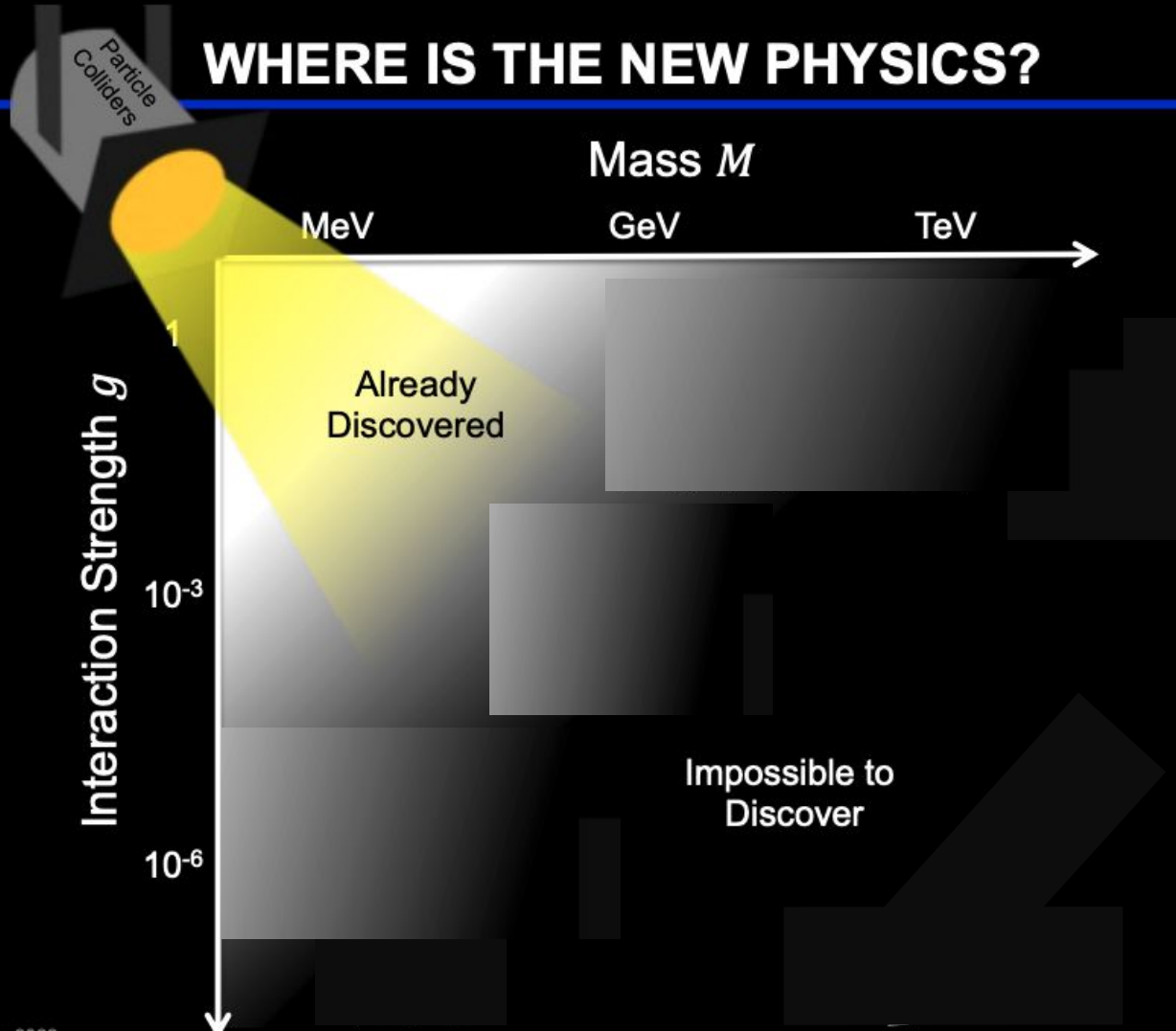




Proton-Proton Center-of-mass energy 13.5 TeV

Can the Higgs provide a portal to dark matter or a dark sector?

WHERE IS THE NEW PHYSICS?



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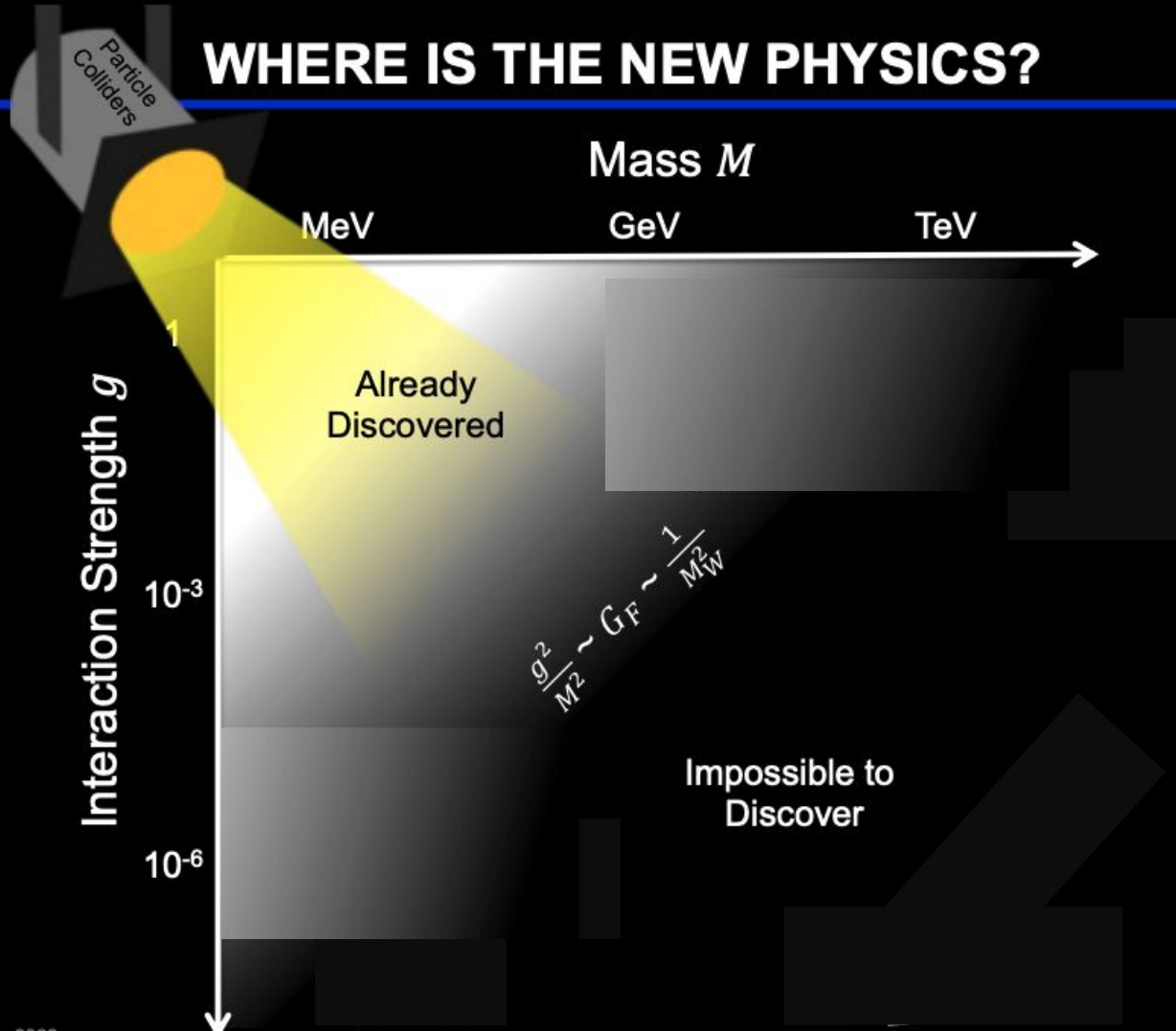

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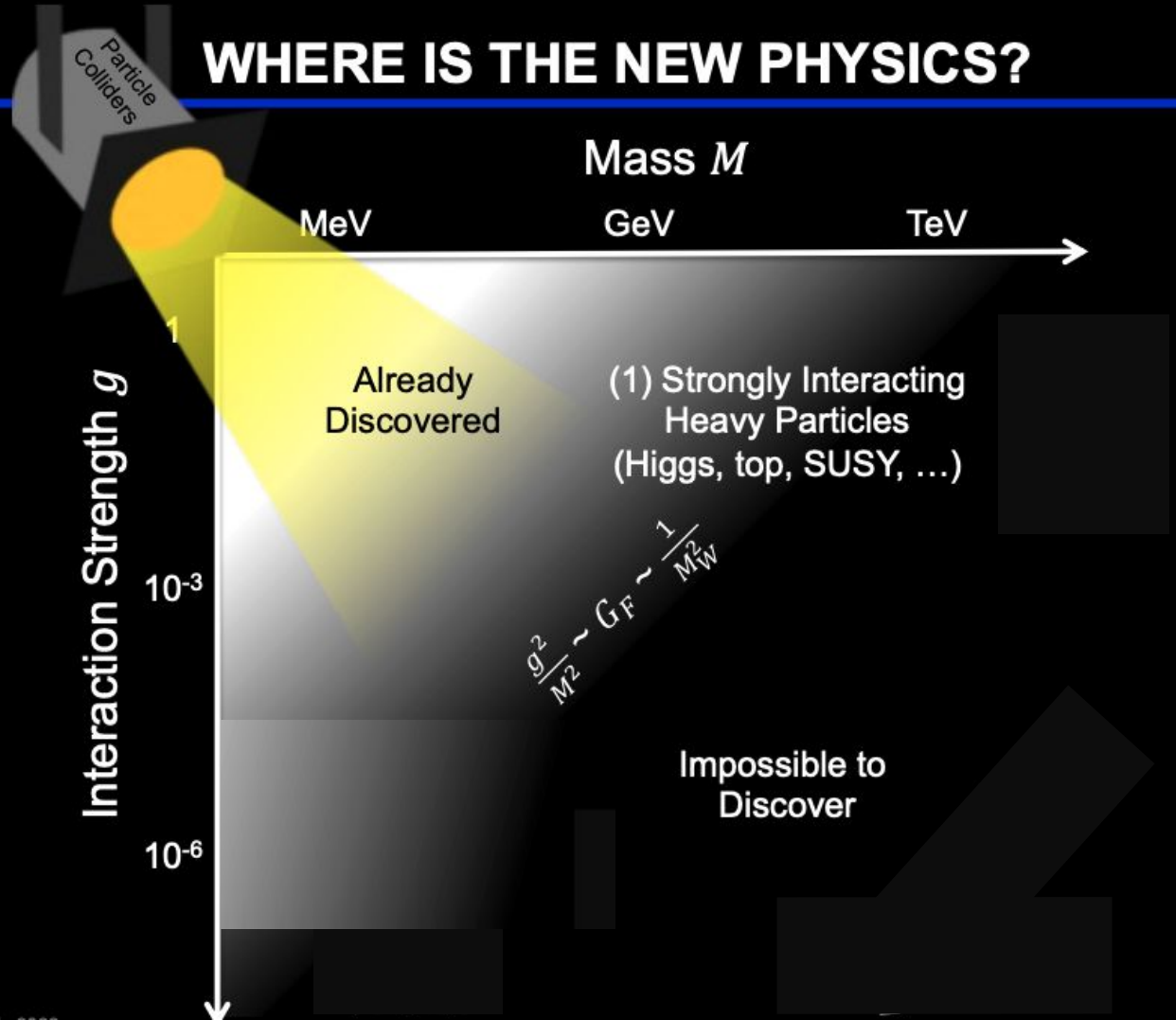

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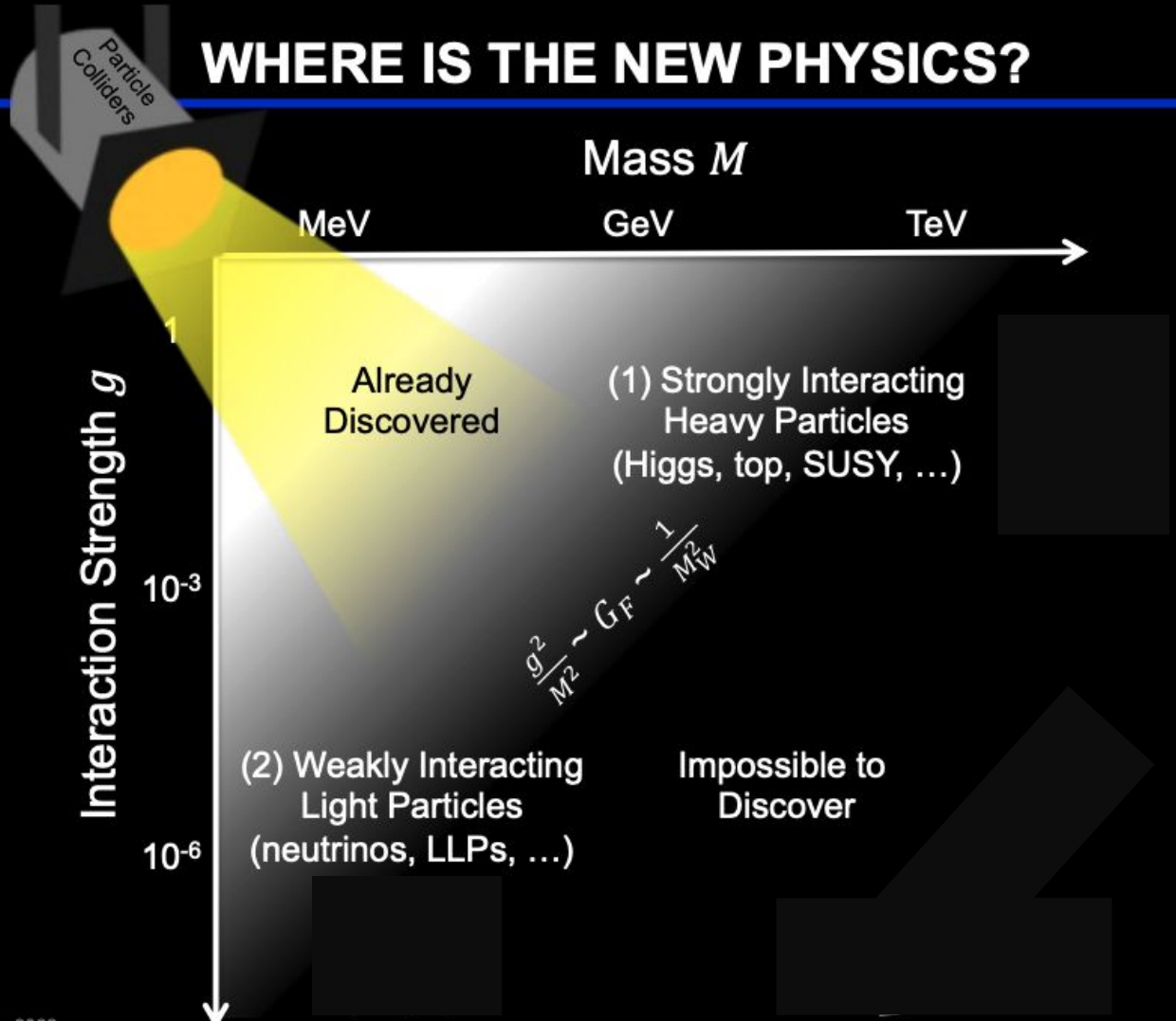

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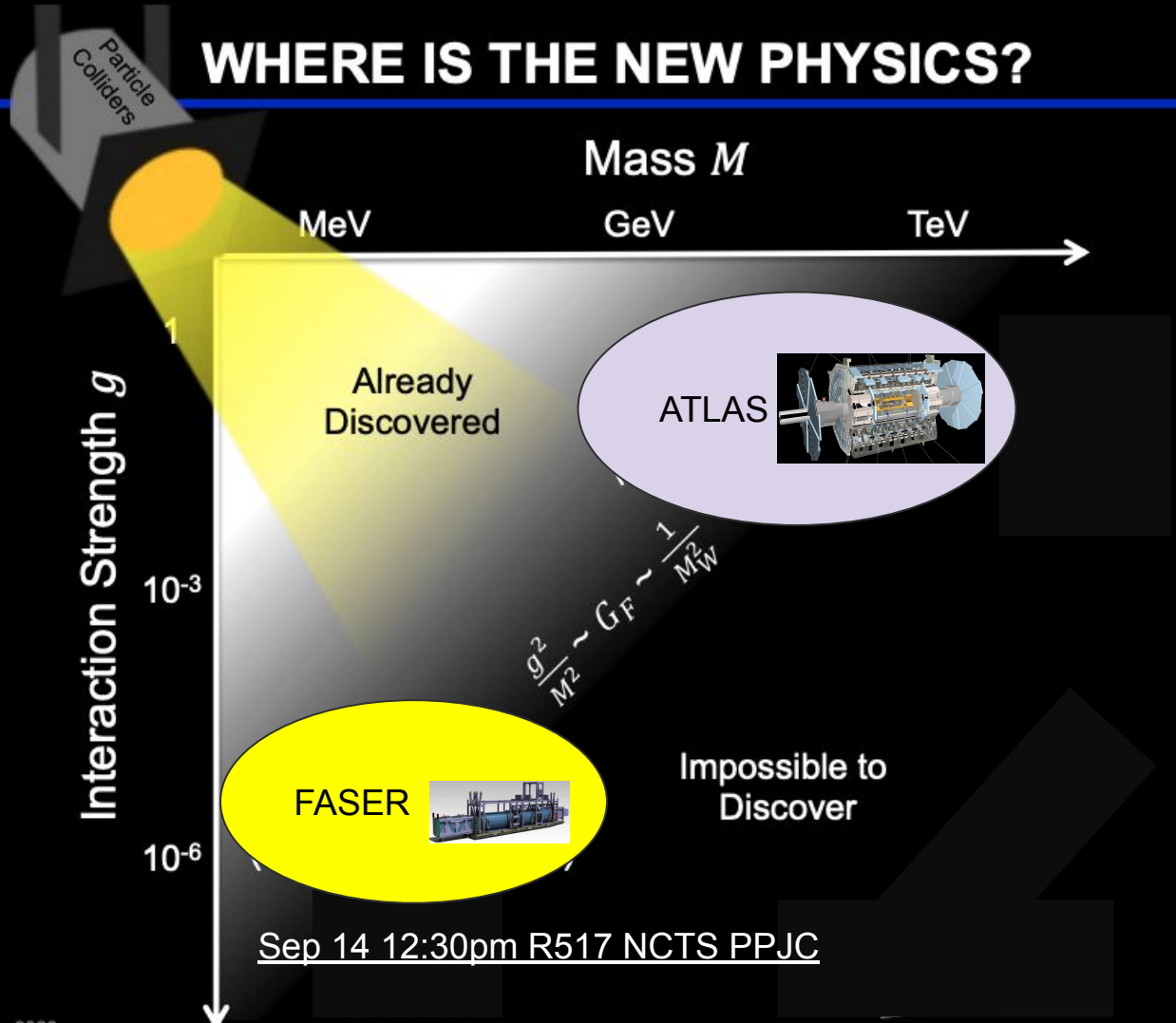
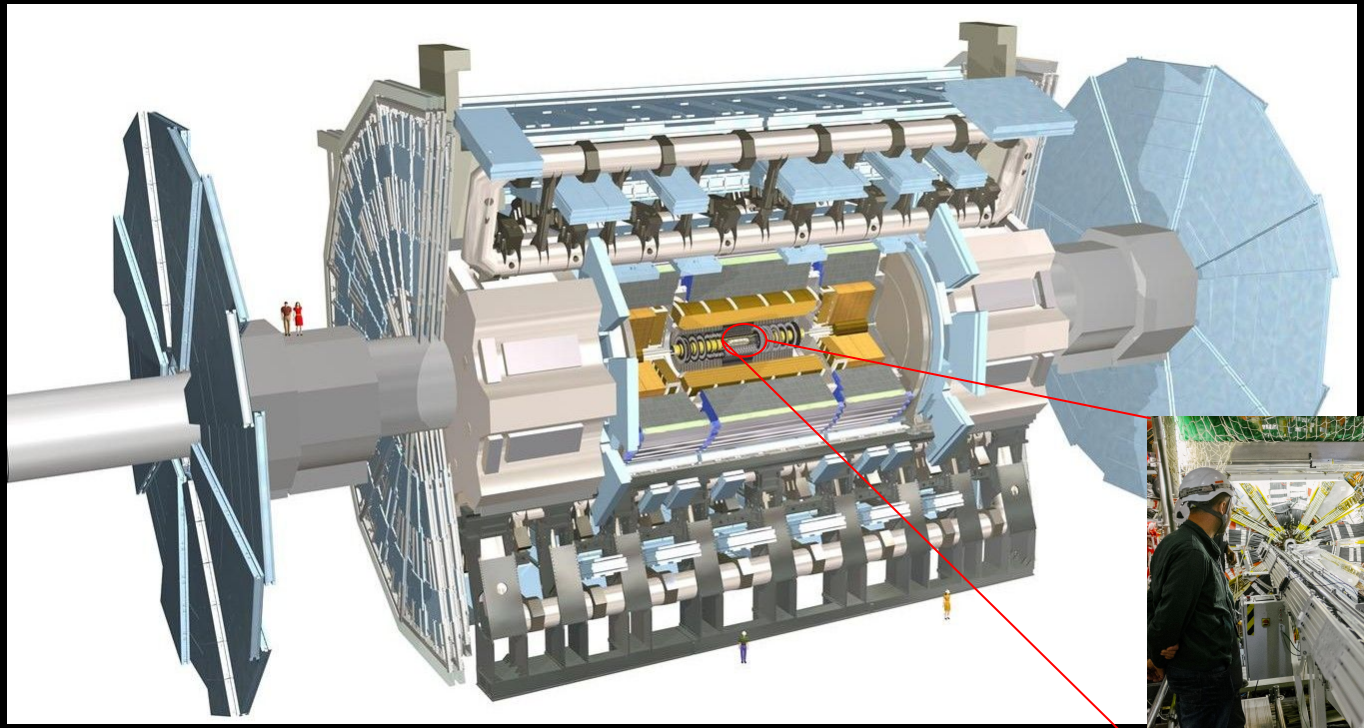


Sep 14 12:30pm R517 NCTS PPJC

UW ATLAS Pixel

i) DAQ firmware maintenance
ii) Emulator and readout upgrade



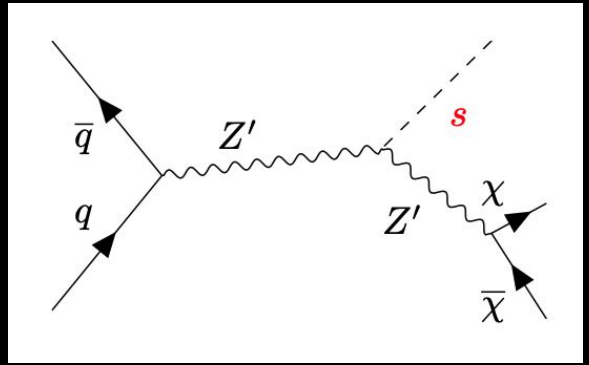
Insertable B-layer

How do we search Beyond Standard Model at the LHC?

Model dependent search: Dark Higgs Model

$$\mathcal{L}_\chi = -\frac{1}{2} g_\chi Z'^\mu \bar{\chi} \gamma^5 \gamma_\mu \chi - g_\chi \frac{m_\chi}{m_{Z'}} s \bar{\chi} \chi + 2\, g_\chi\, Z'^\mu Z'_\mu \left(g_\chi\, s^2 + m_{Z'} s \right)$$

M. Duerr et al., JHEP 04 (2017) 143

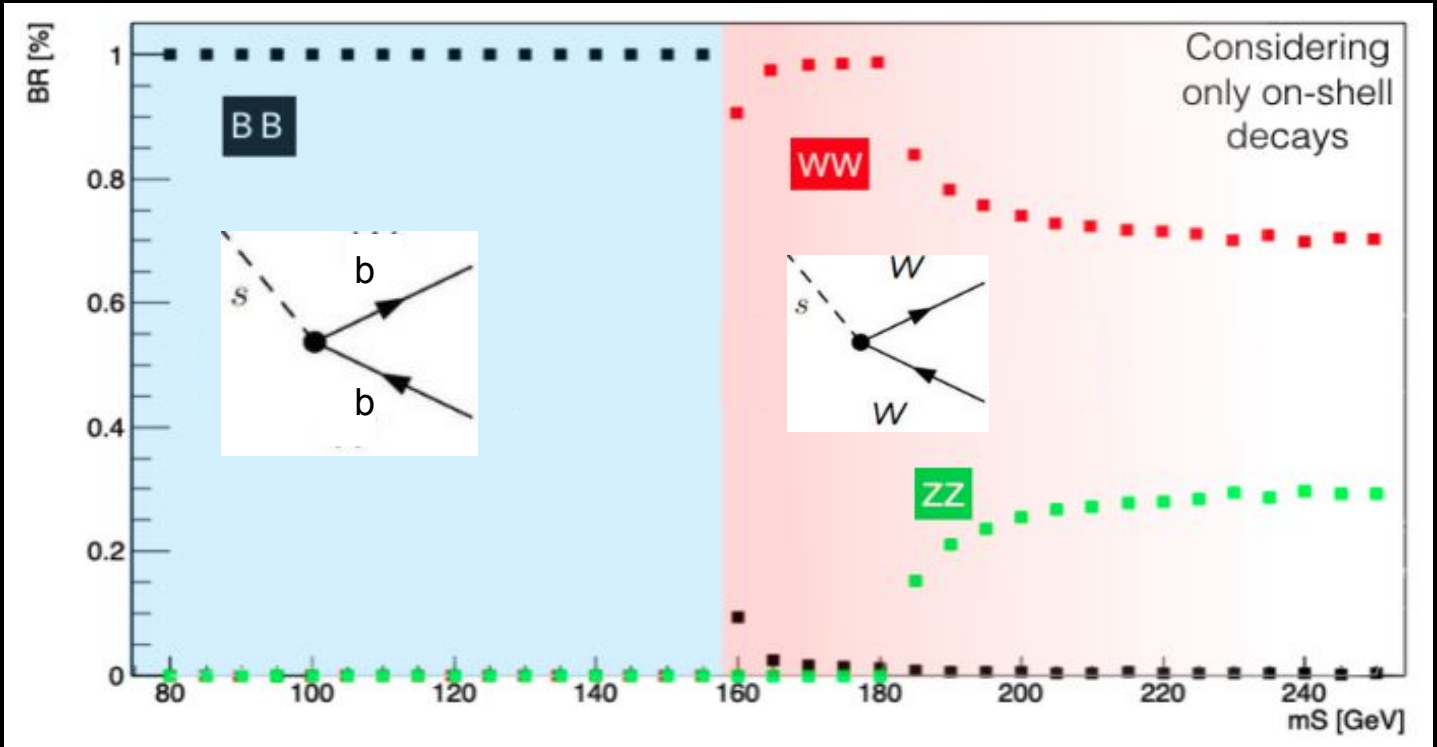


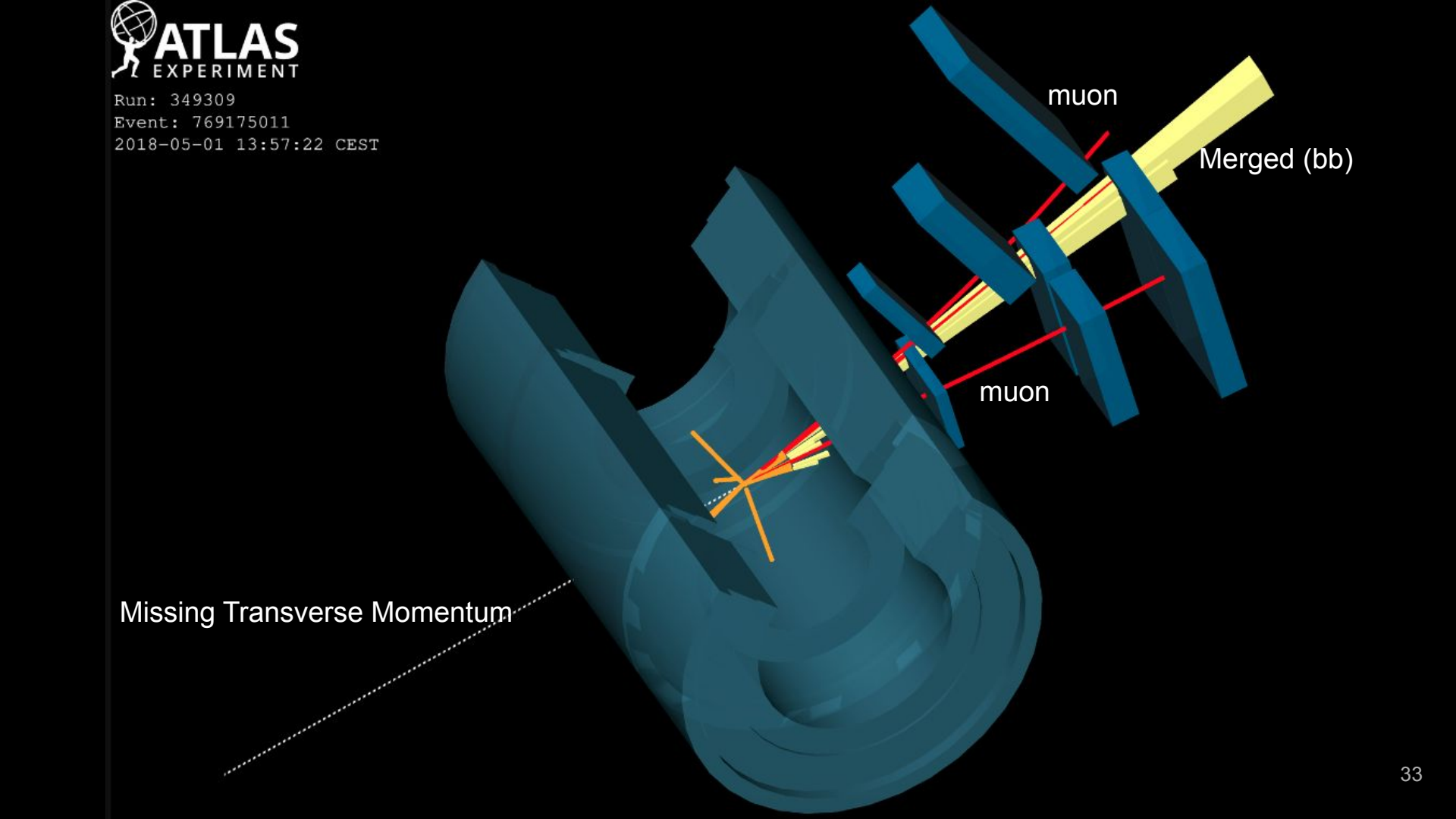
Dark Higgs s decays to bb, WW

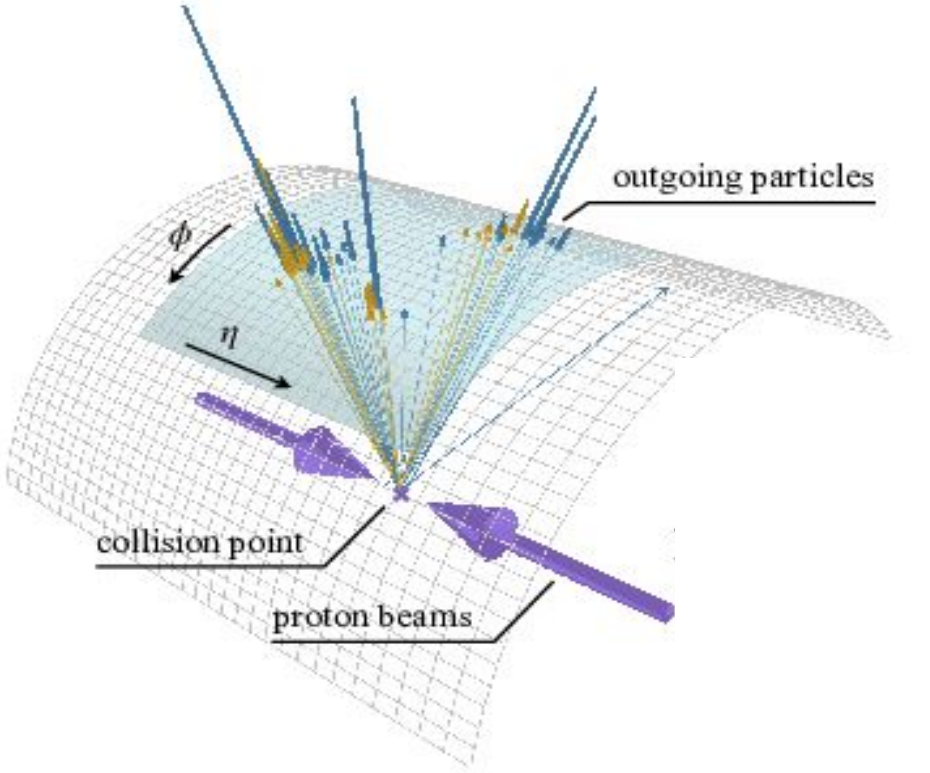
Dark Matter χ escapes from detector without detection.

ATL-PHYS-PUB-2019-032/

Phys. Rev. Lett. 126 (2021) 121802

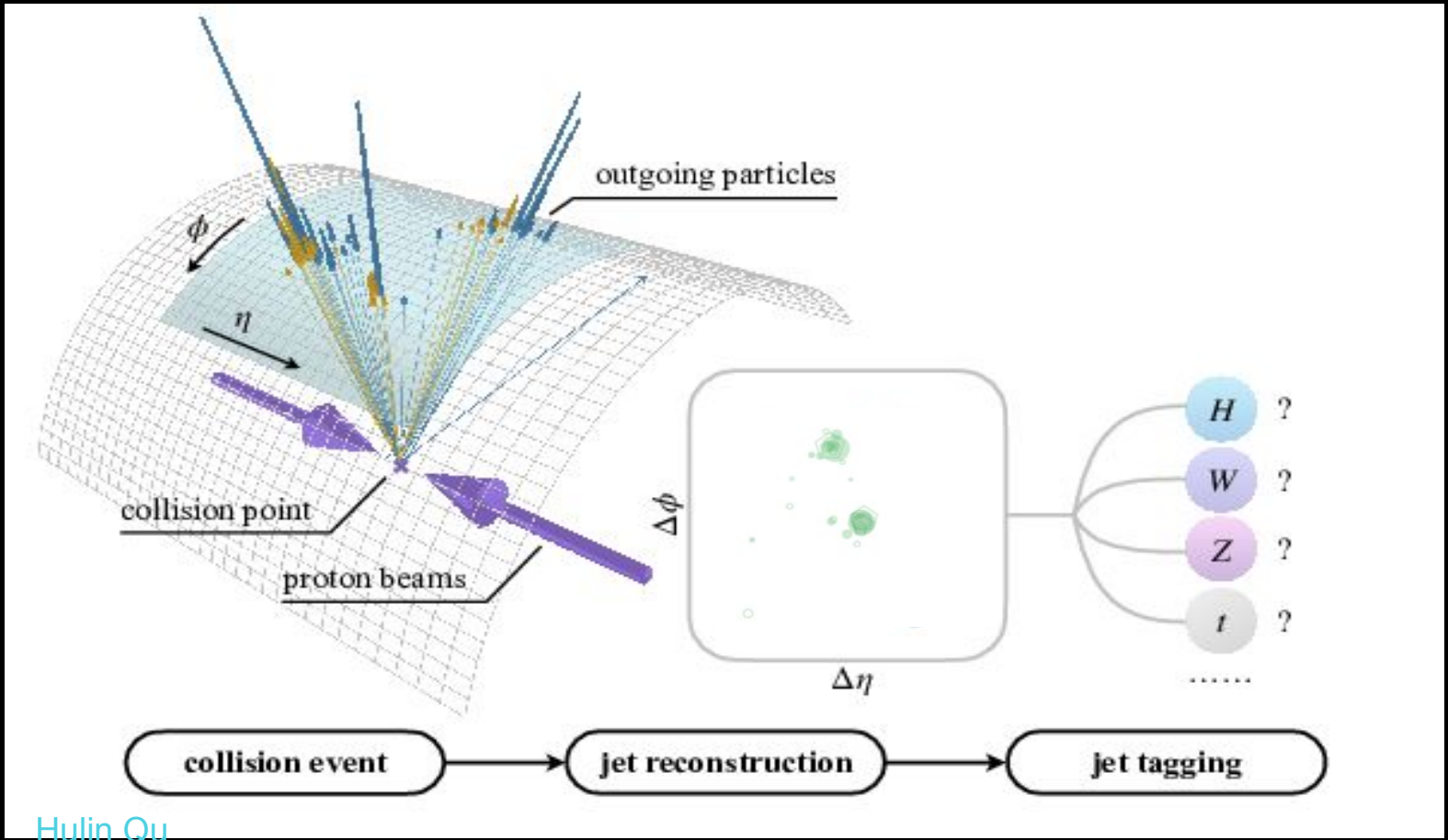



ATLAS
EXPERIMENT
Run: 349309
Event: 769175011
2018-05-01 13:57:22 CEST
muon
Merged (bb)
muon
Missing Transverse Momentum



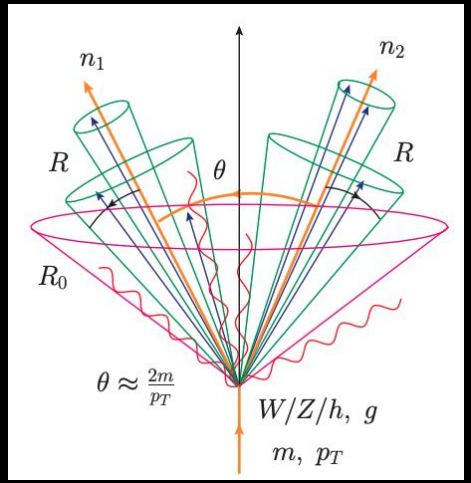
collision event → jet reconstruction

Hulin Qu

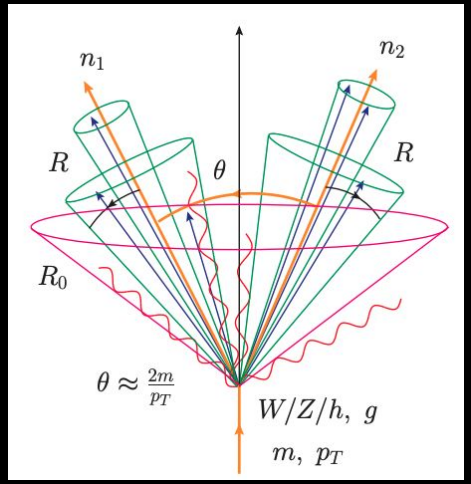

outgoing particles
ϕ
η
collision point
proton beams
$\Delta\phi$
$\Delta\eta$
H ?
W ?
Z ?
t ?
.....
collision event
jet reconstruction
jet tagging

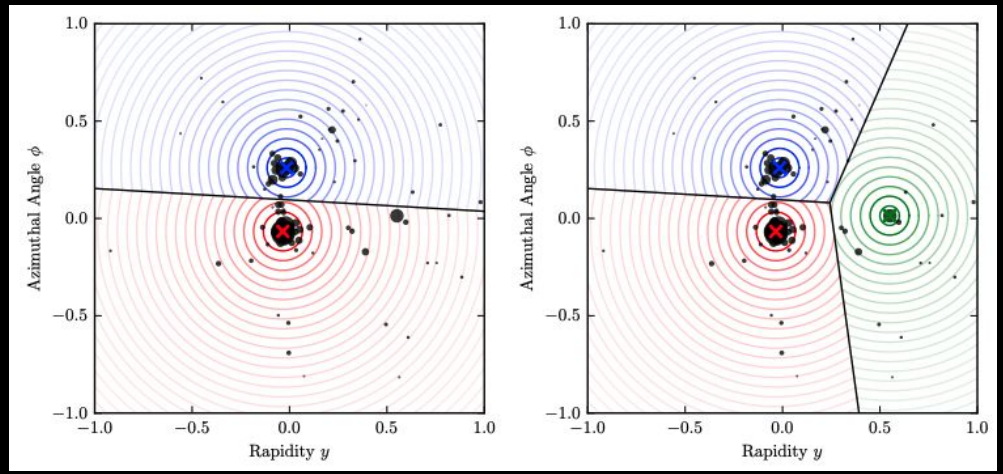
Hulin Qu

Y.-T. Chen, A. Emerman, S.-C. Hsu, et. al.
PRD D 101, 114006 (2020)

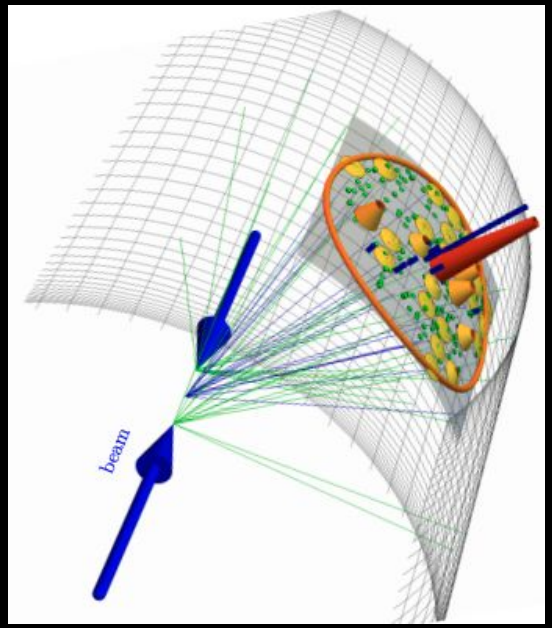


Y.-T. Chen, A. Emerman, S.-C. Hsu, et. al.
PRD D 101, 114006 (2020)

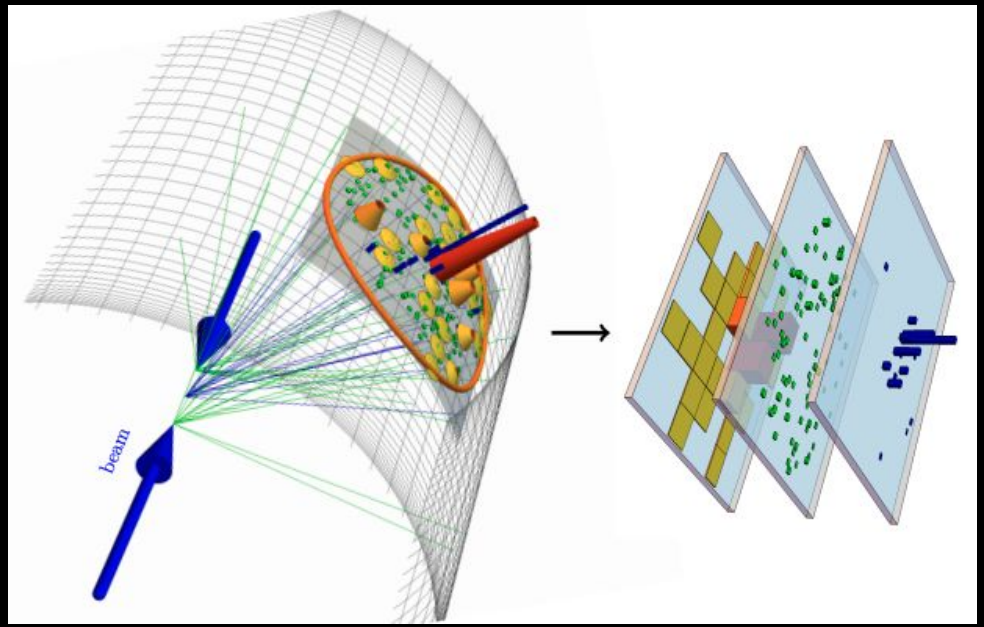




Translate Particle Physics problems into Machine Learning problems.



Translate Particle Physics problems into Machine Learning problems.



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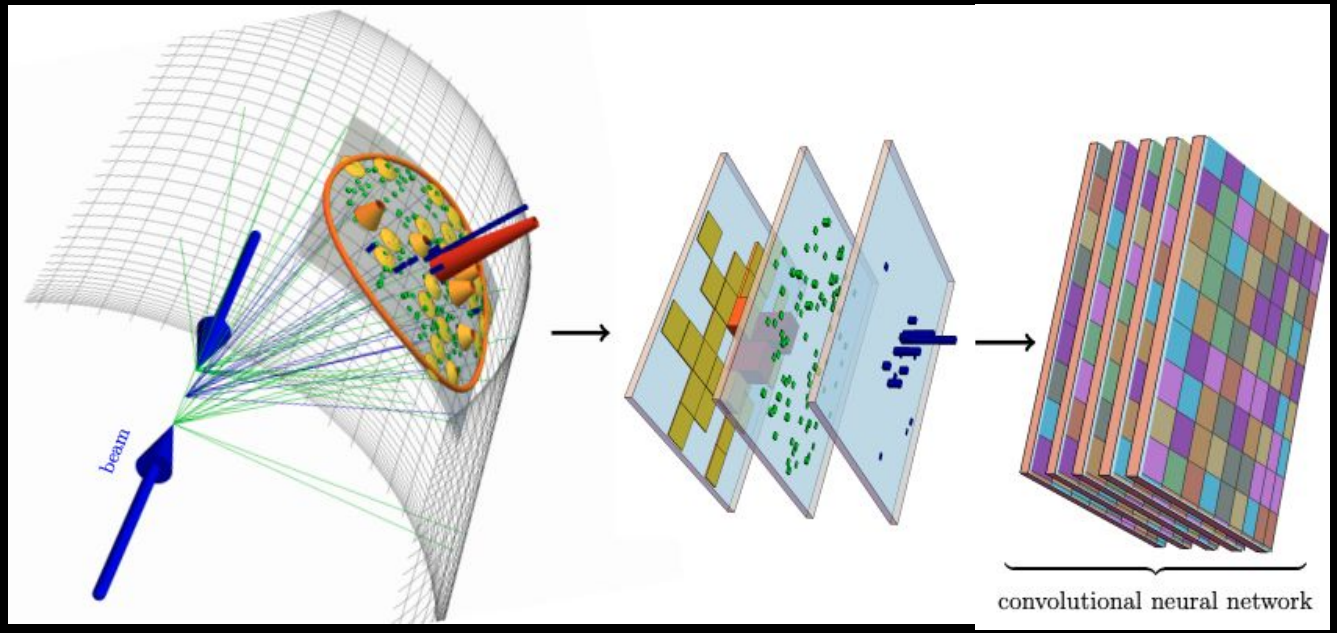

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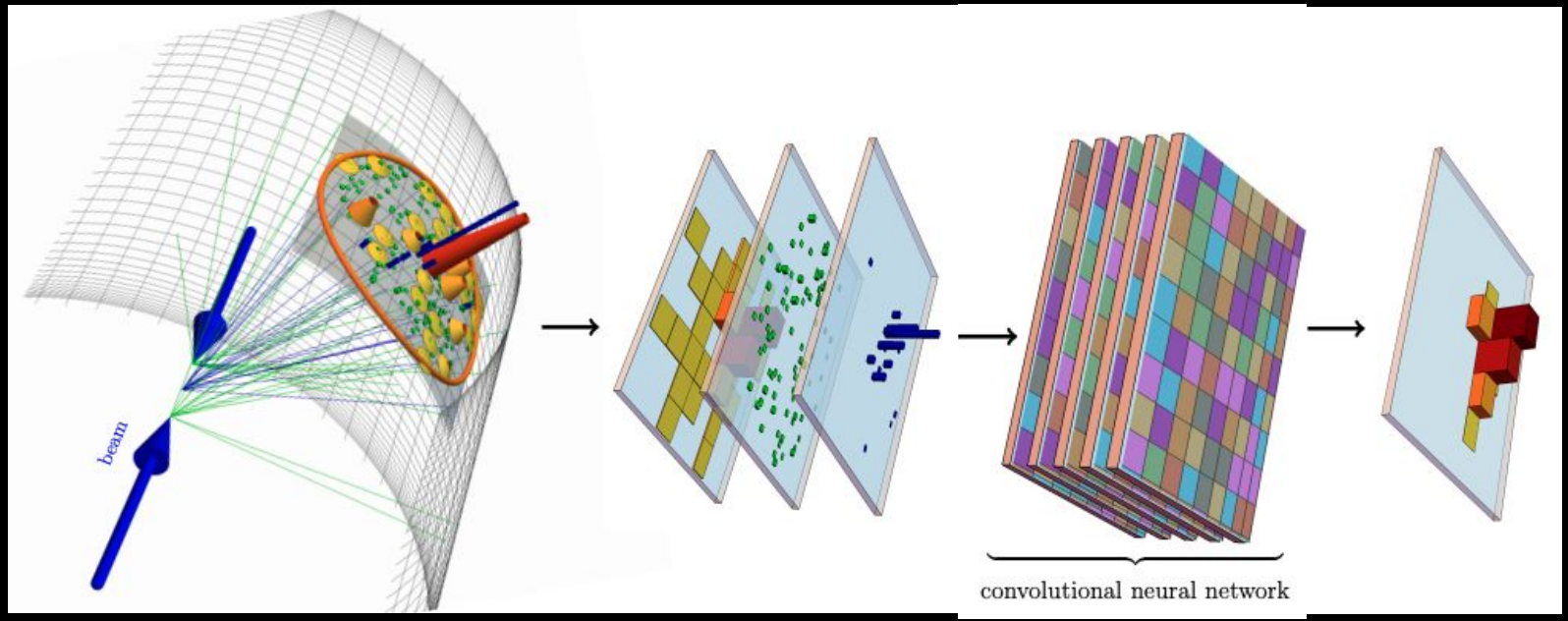
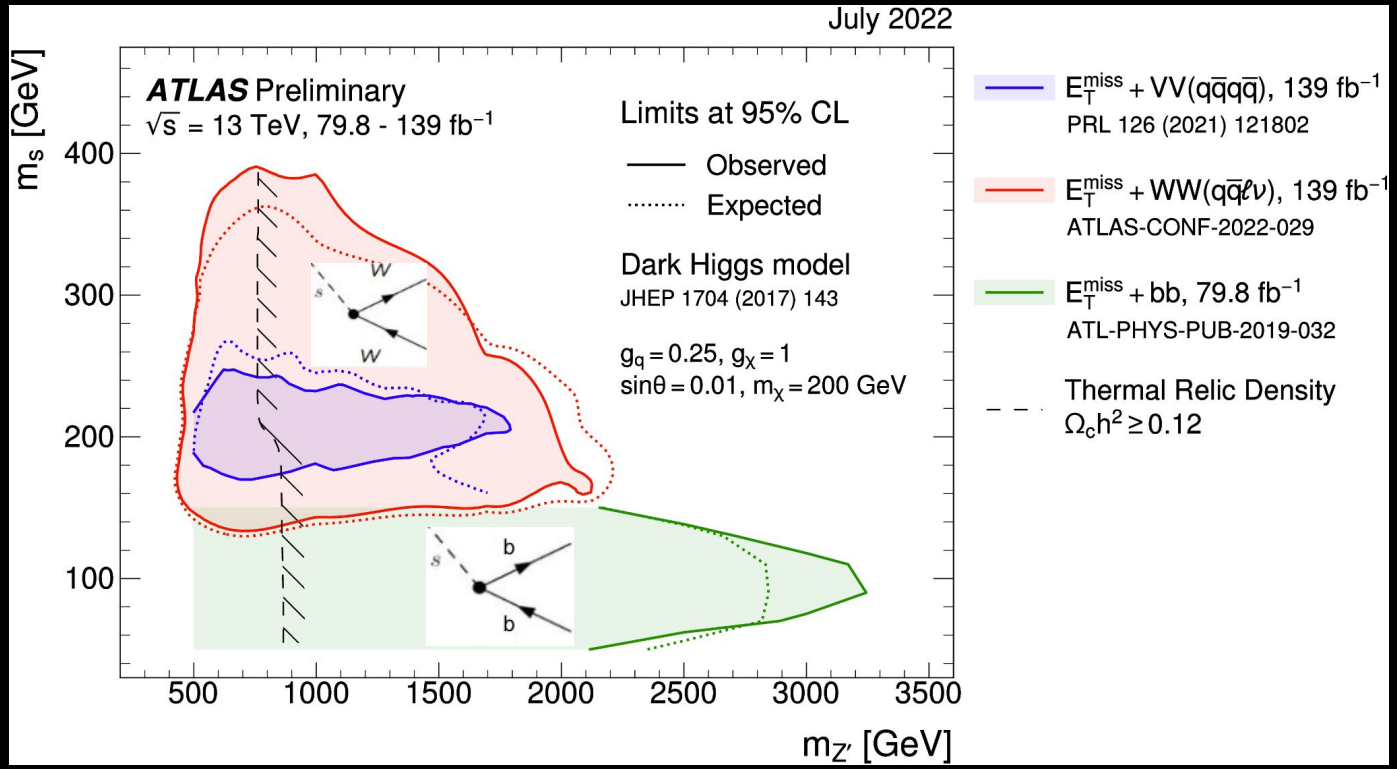


JHEP12 (2017) 051

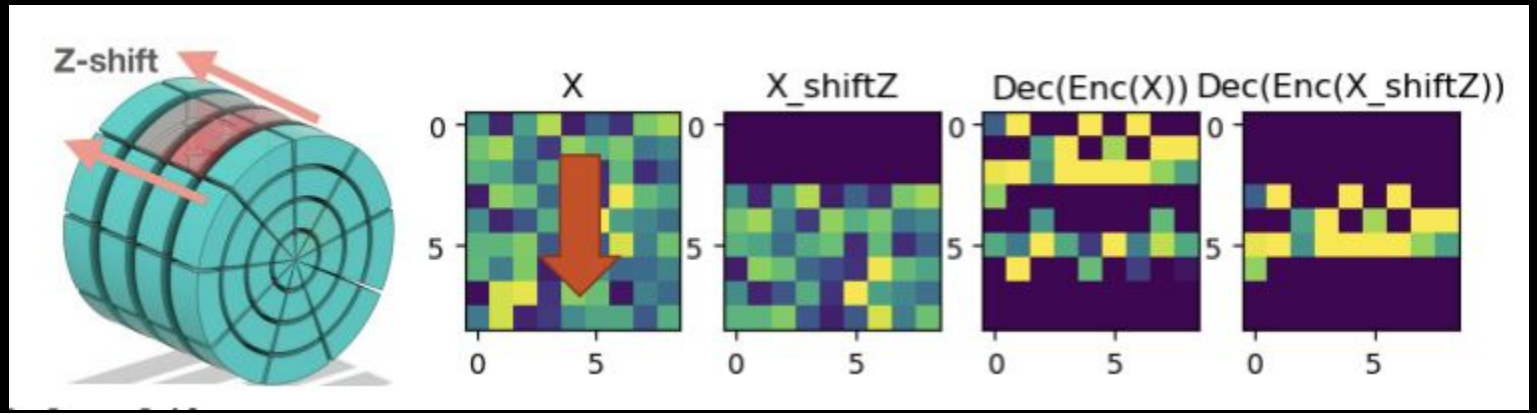
ATL-PHYS-PUB-2022-036/

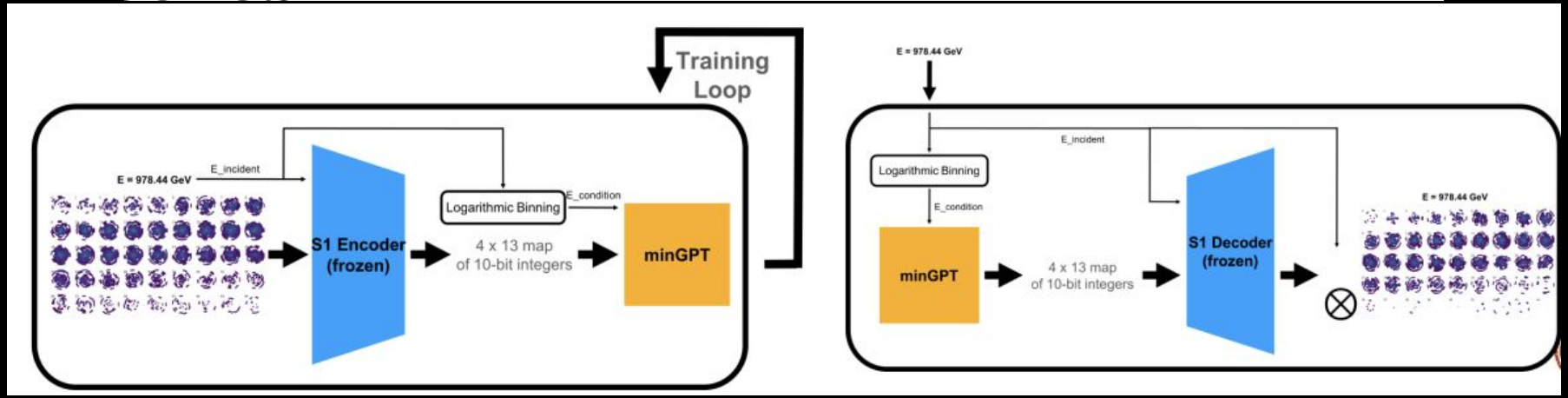


More advanced AI Algorithms!

Calorimeter Generative Model

Qibin Liu, S-C- Hsu CaloChallenge 2023

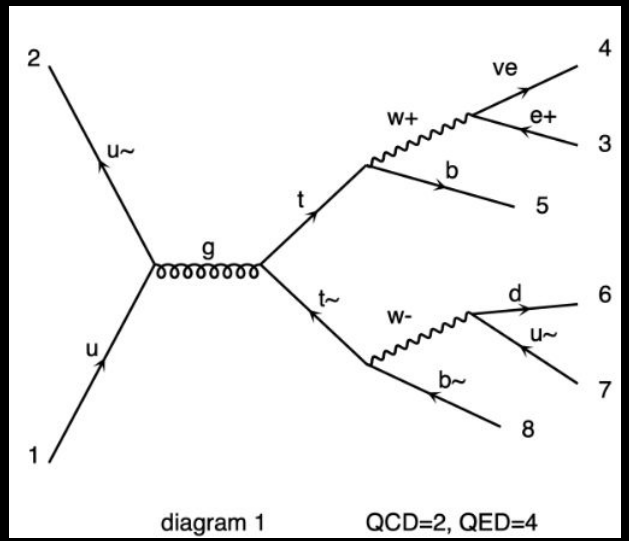


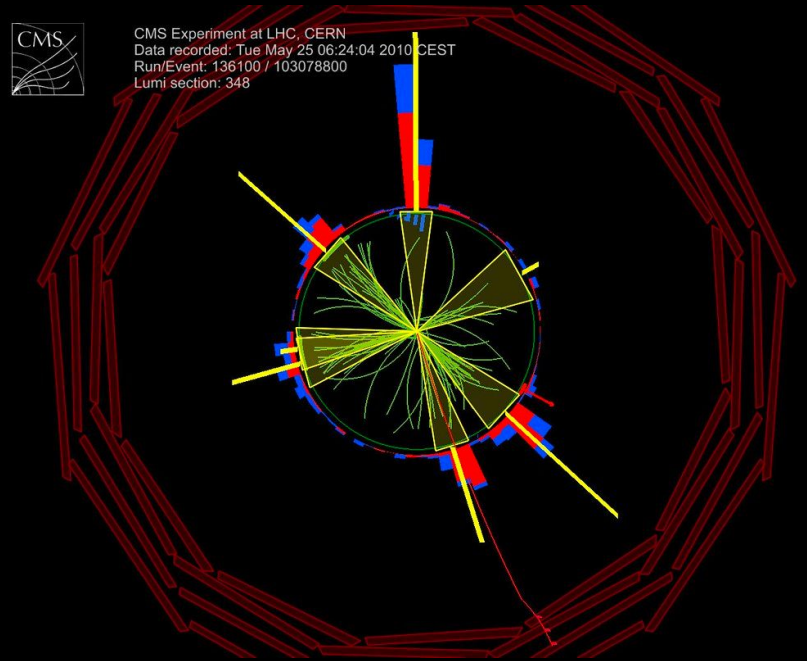


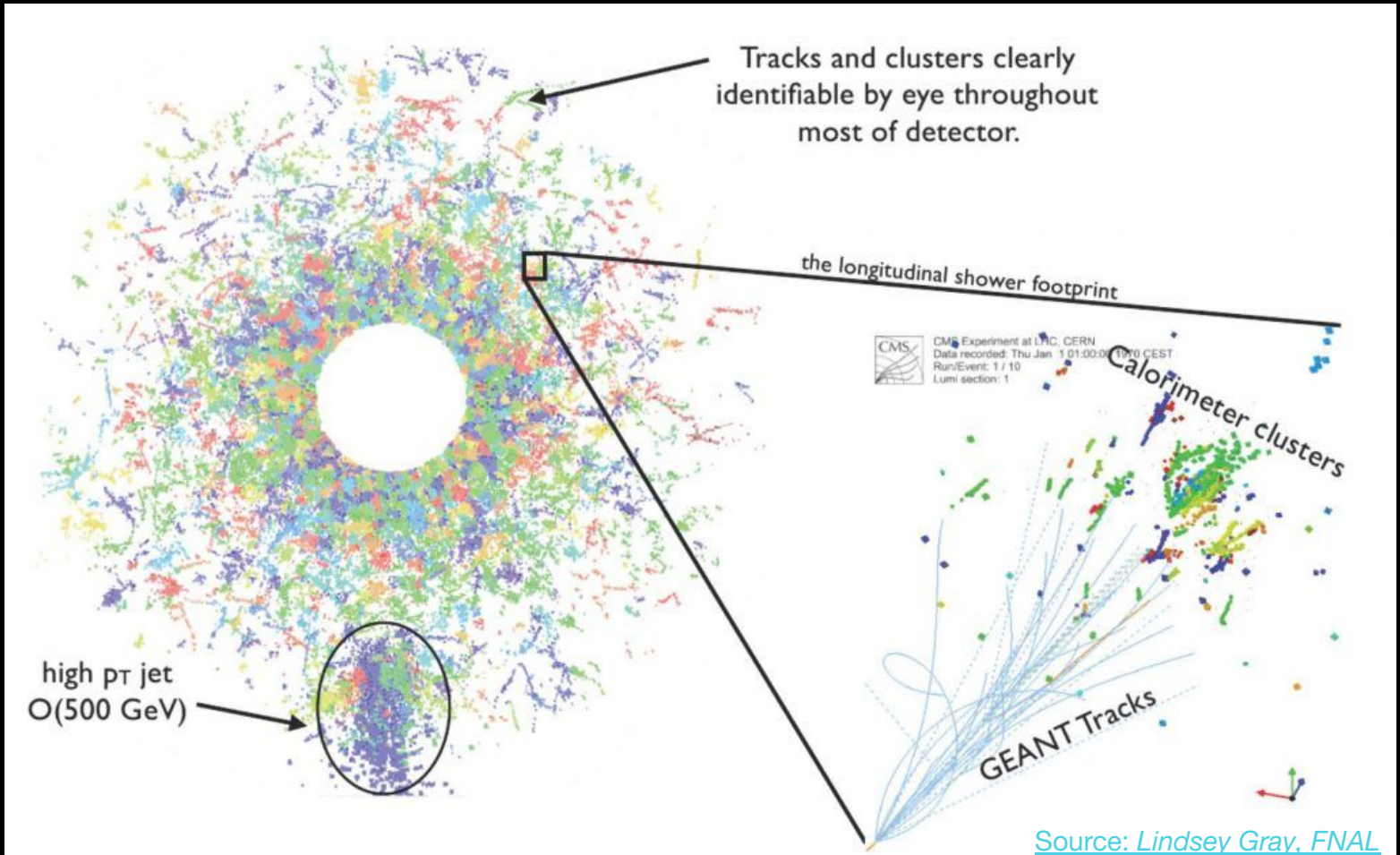
Cheng-Wei Chiang, Feng-Yang Hsieh (NTU)

Deep learning jet parton match

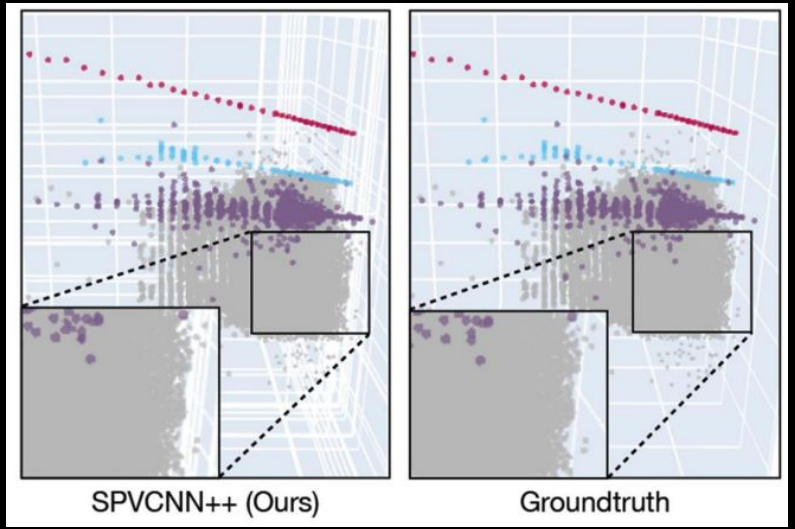
SPANet uses the invariance property in jet assignment, improving the accuracy



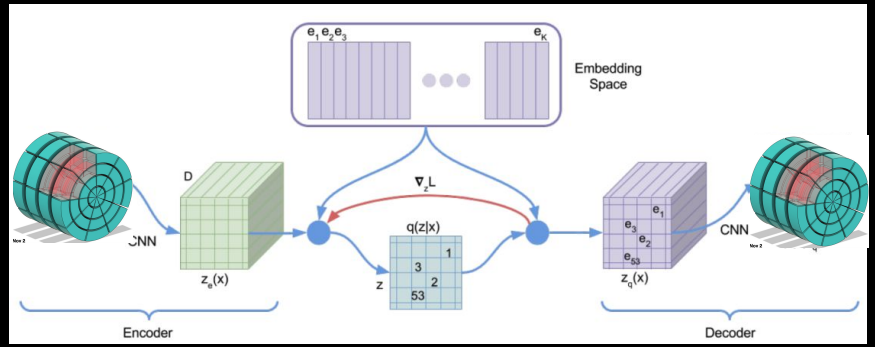




Source: *Lindsey Gray, FNAL*

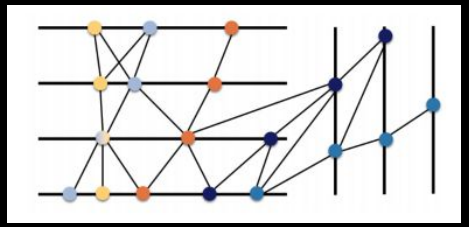

SPVCNN++ (Ours)
Groundtruth

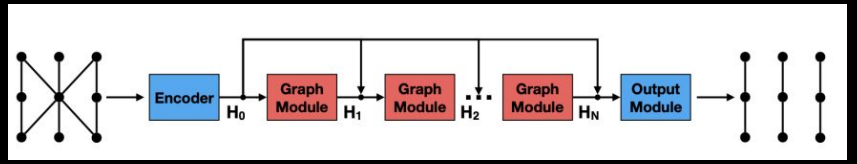
Calorimeter Generation



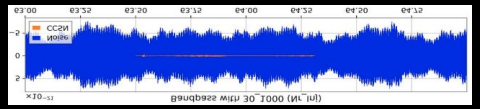
Graph NN Tracking

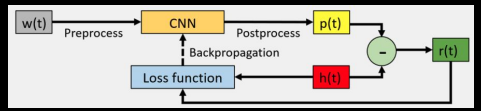
arxiv:2103.06995



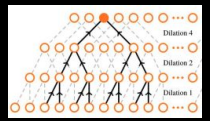


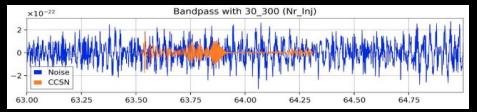
Denoising for KAGRA



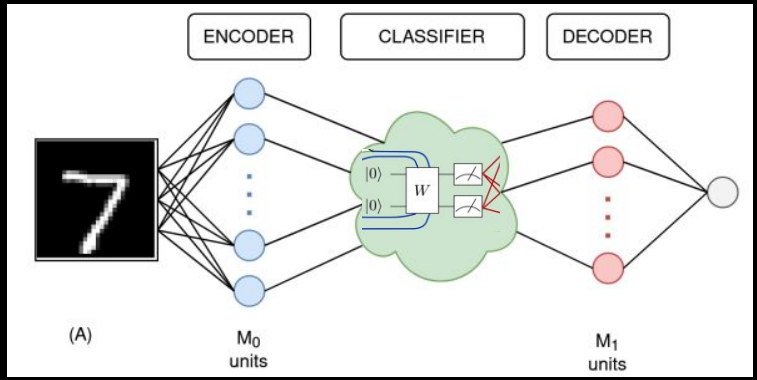


CCSN detection

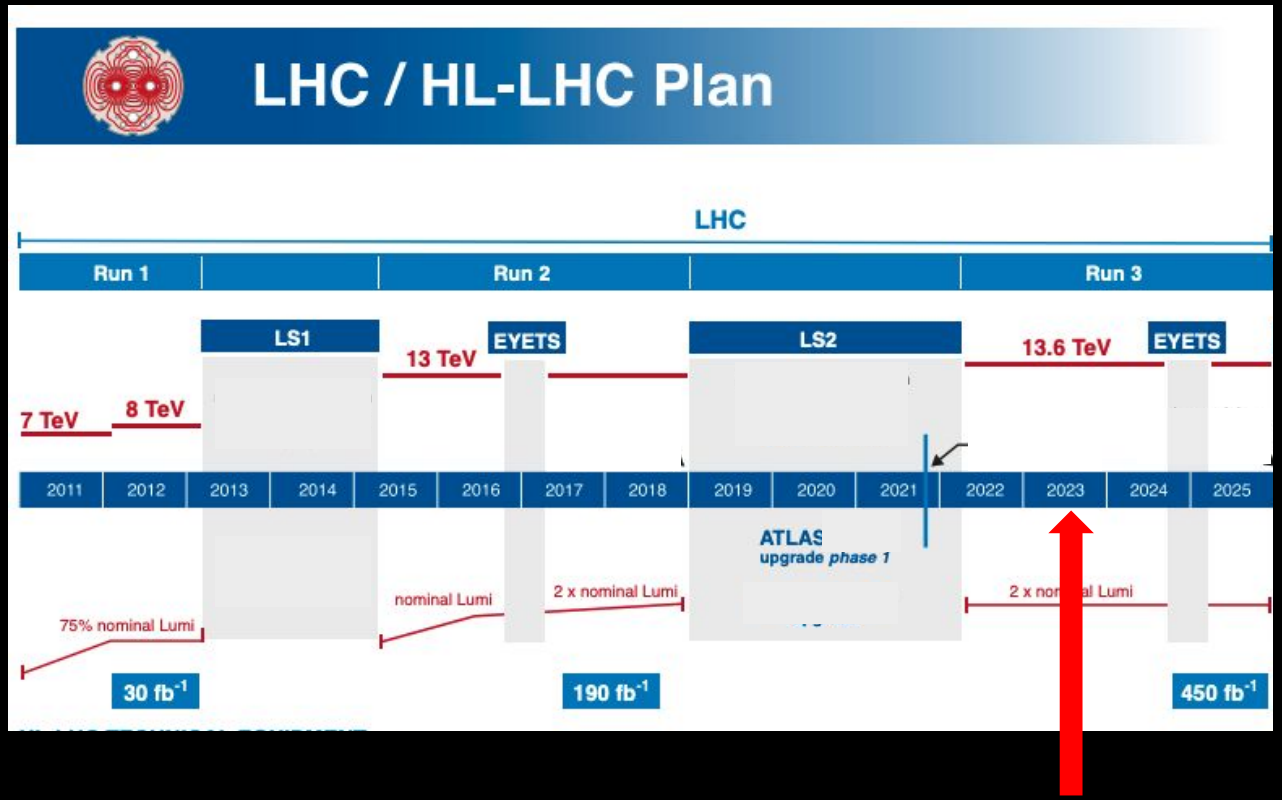




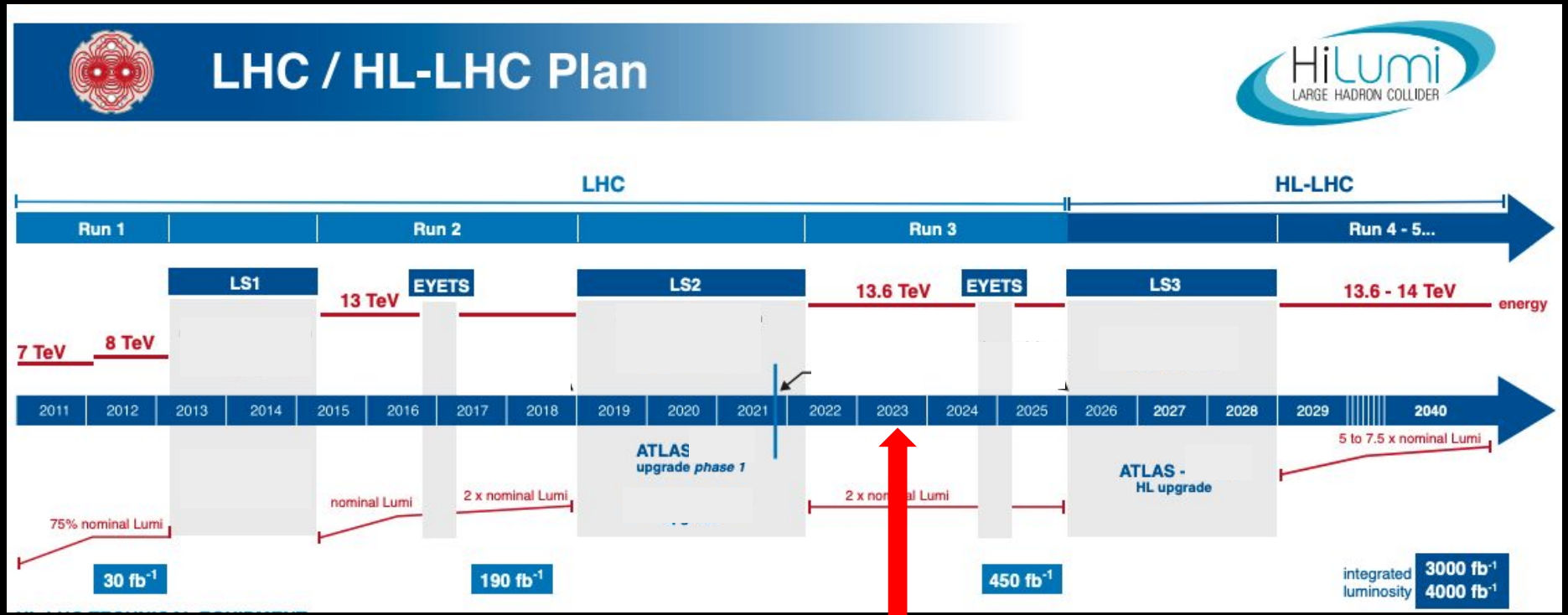
Quantum 6, 727 (2022)



What is the next step of the LHC?

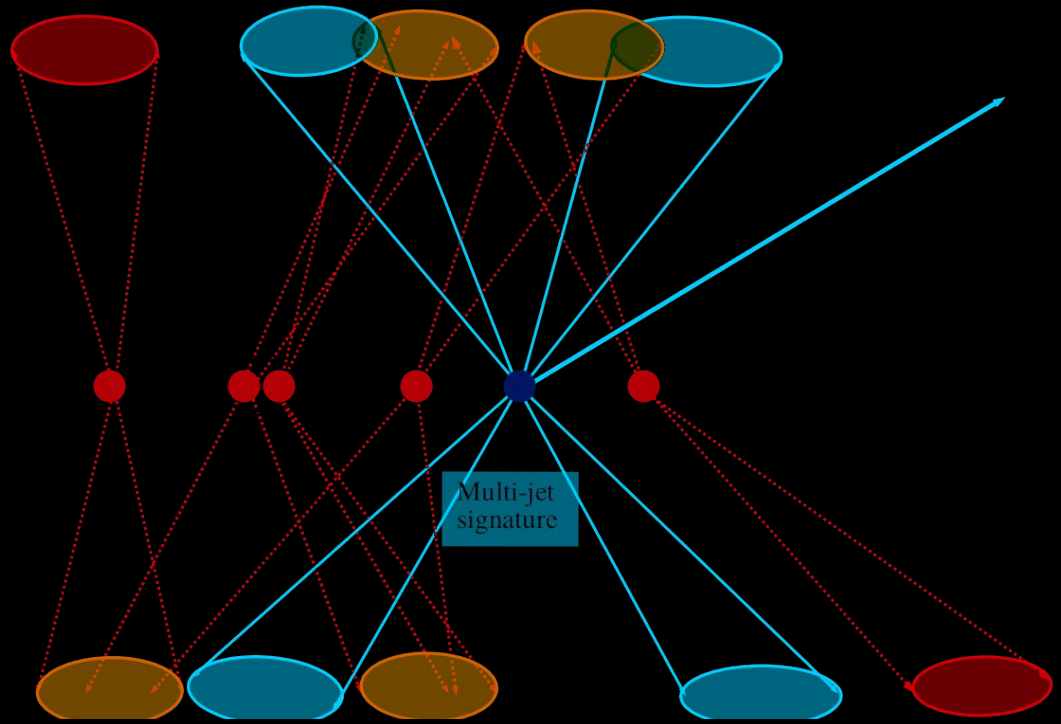

LHC / HL-LHC Plan
LHC
Run 1
Run 2
Run 3
LS1
EYETS
LS2
EYETS
7 TeV
8 TeV
13 TeV
13.6 TeV
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
ATLAS
upgrade phase 1
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1

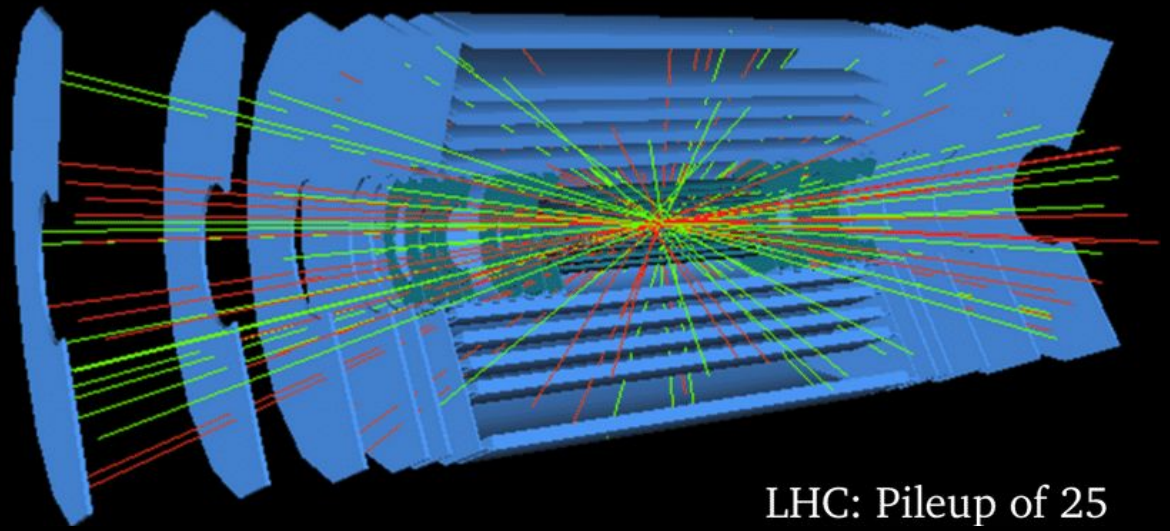
Today x 2.5~3



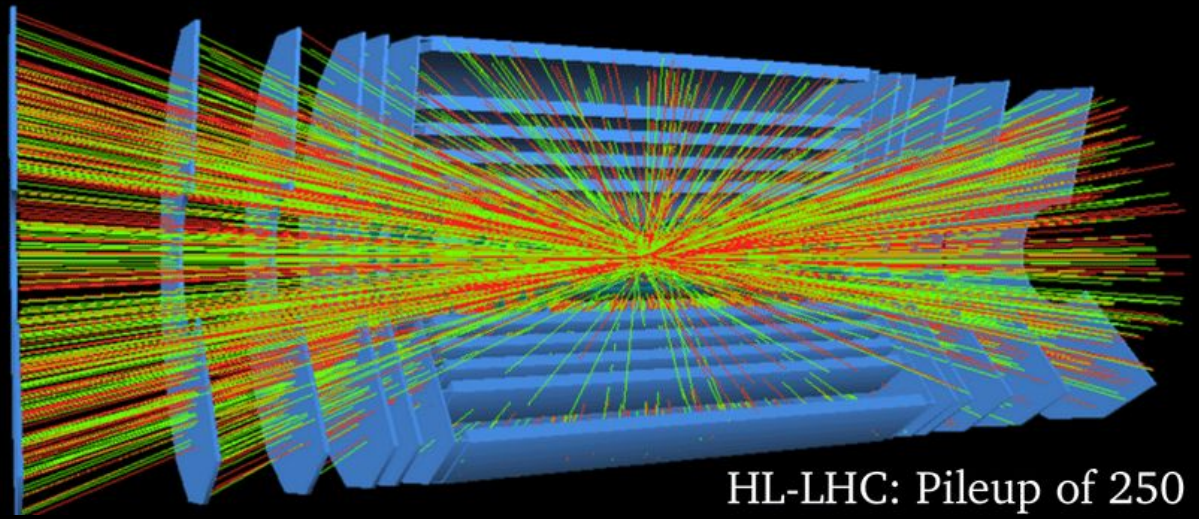
Today x 2.5~3 x15~20

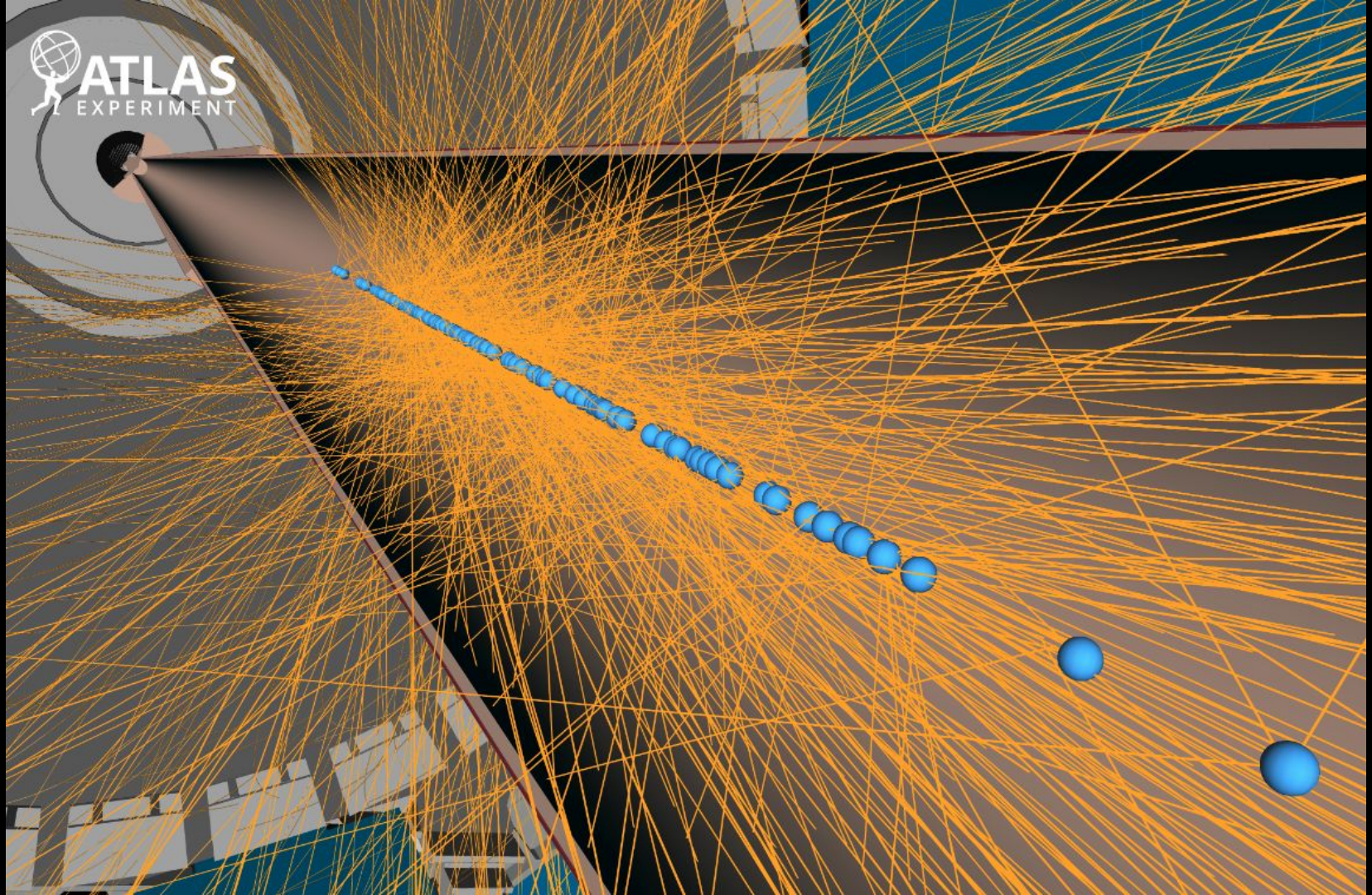
Colliding more than 1 proton pairs within 25 ns



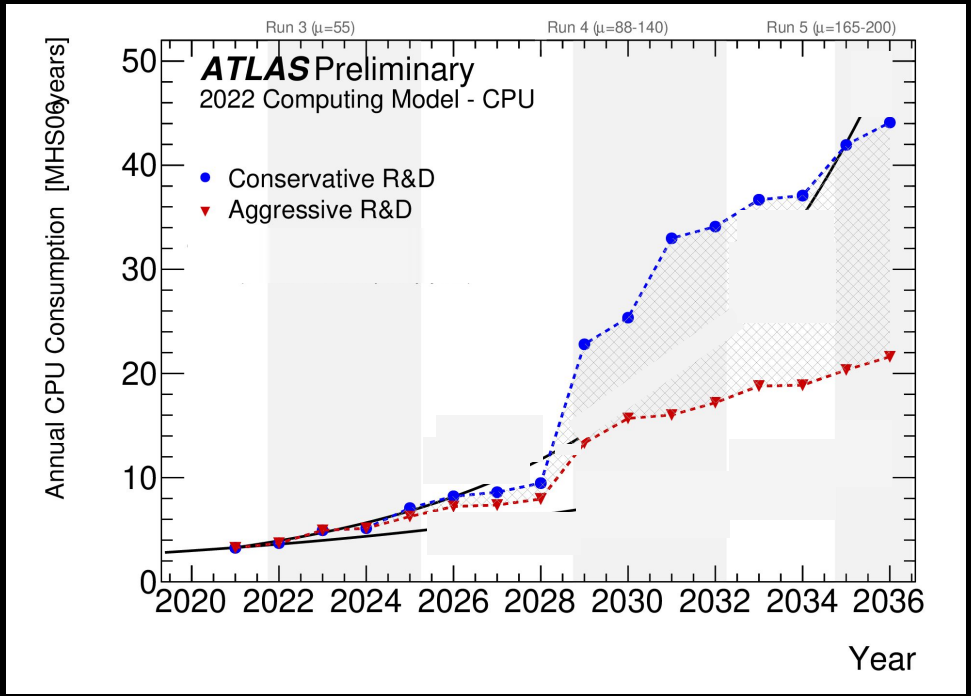


LHC: Pileup of 25


HL-LHC: Pileup of 250

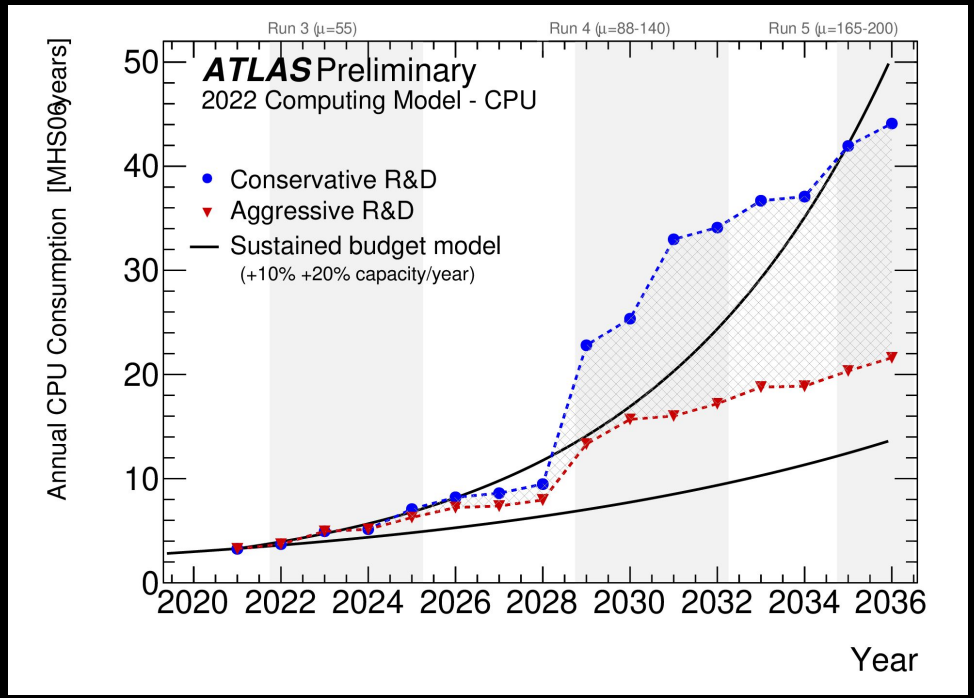

ATLAS
EXPERIMENT

Even Aggressive R&D can’t be fulfilled by sustained budget.



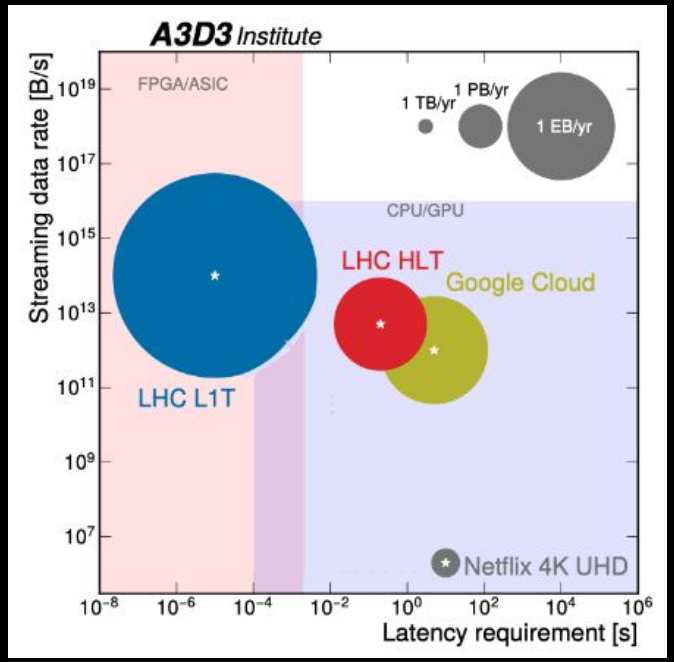
We need alternative solutions!

Even Aggressive R&D can’t be fulfilled by sustained budget.



We need alternative solutions!

The broader use of ML in industry and academia is fueling rapid innovation in hardware.



[Snowmass 2021 Computational Frontier Report]

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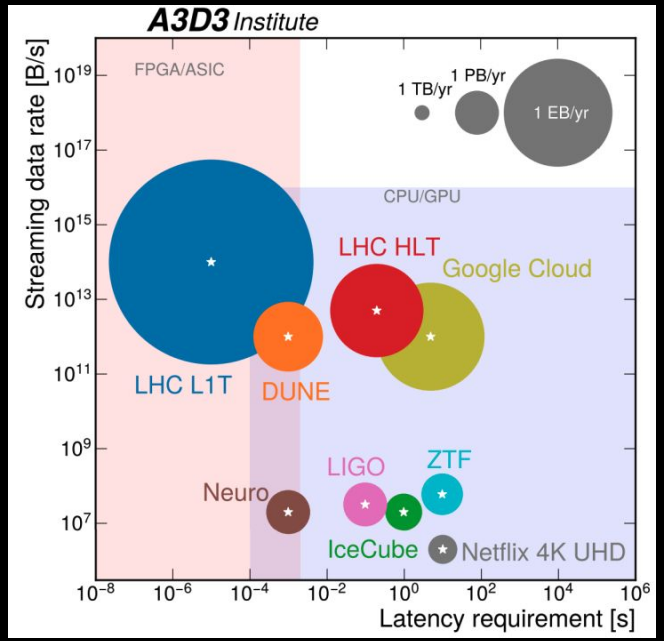
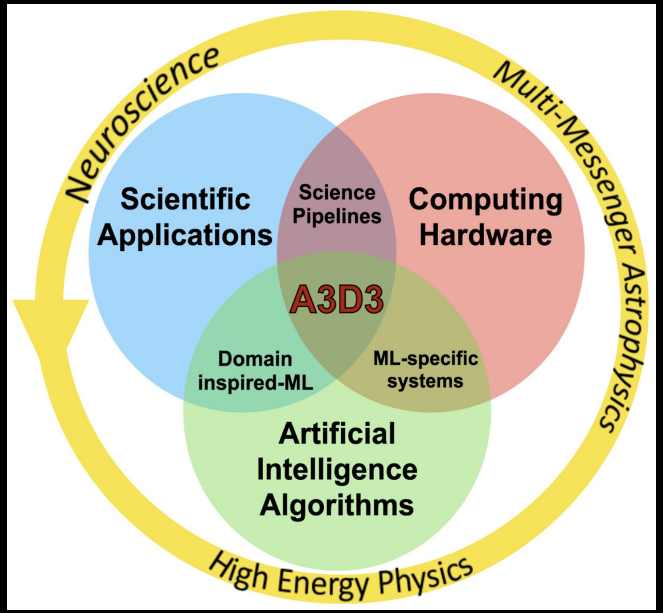


[Snowmass 2021 Computational Frontier Report]

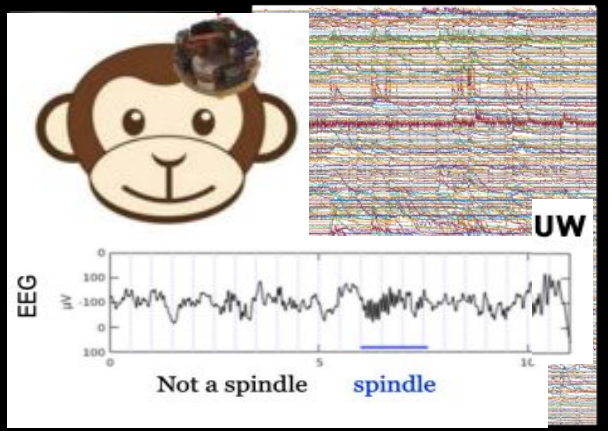
https://a3d3.ai/

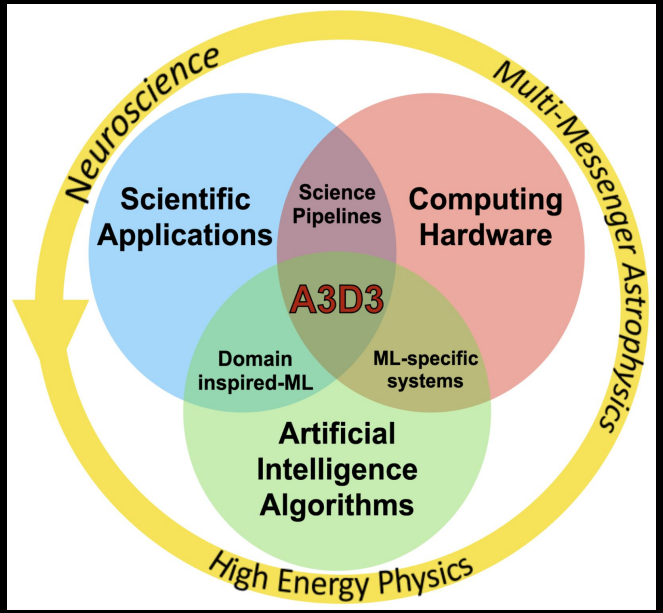
Our vision is to make **real-time AI** user friendly in order to transform science and engineering discoveries.



Our vision is to make **real-time AI** user friendly in order to transform science and engineering discoveries.

Neuroscience



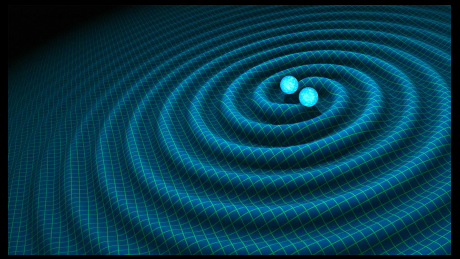


Our vision is to make **real-time AI** user friendly in order to transform science and engineering discoveries.

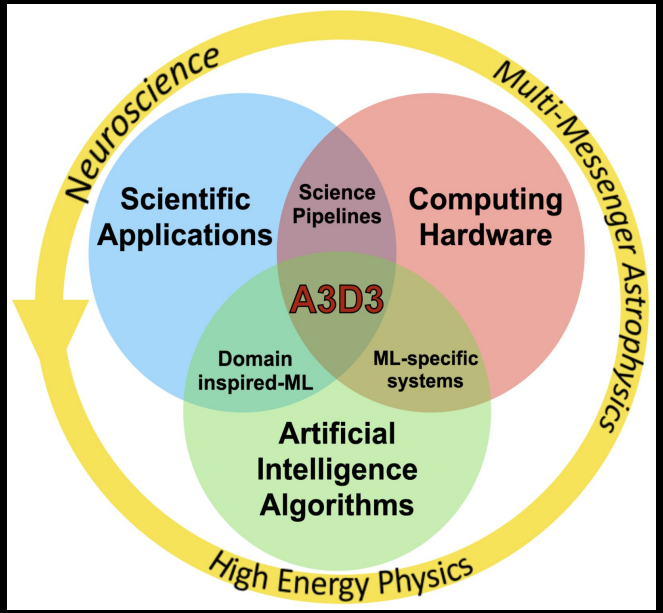

Y, Yang
NYCU


A. Kong
NTHU

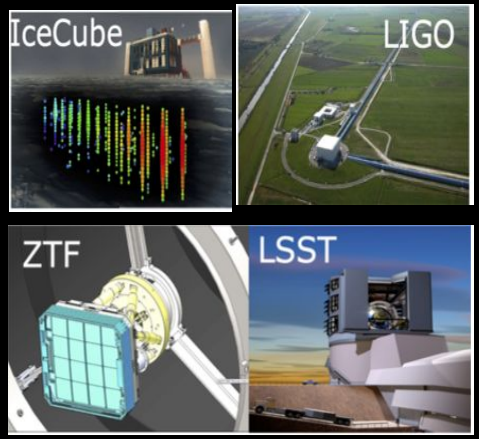

K-C. Pan
NTHU



KAGRA

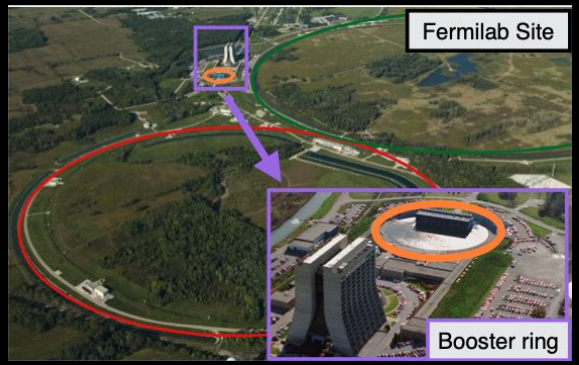


Multi-messenger Astrophysics



Broader Impact beyond A3D3 domain sciences

Accelerator Control



Material Science

Nation to International

trainees.html

10 Institutes, 80 Members

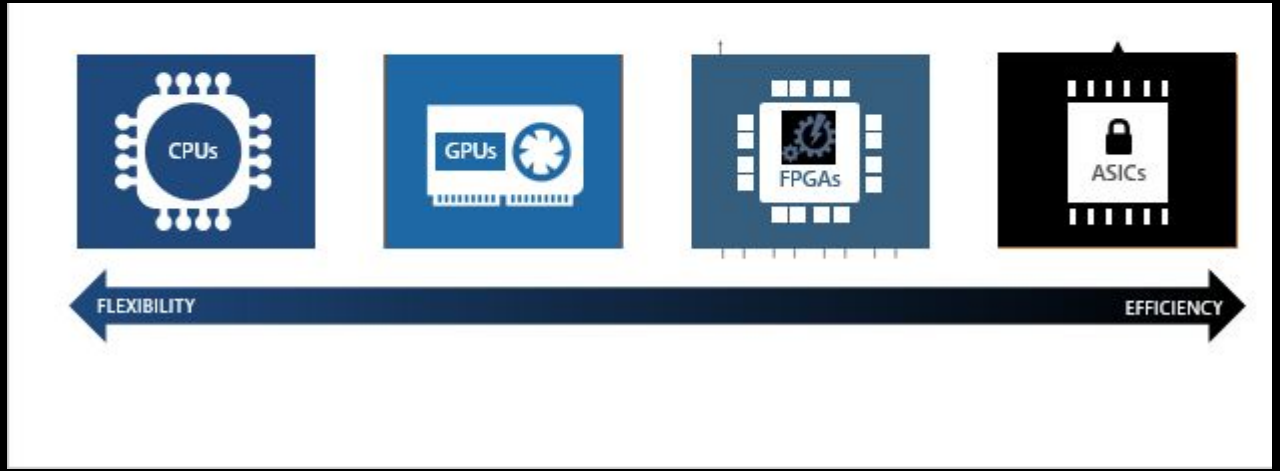
Members:

- 17 faculty
- 5 scientists/staffs
- 5 affiliated faculty
- 11 Postdocs
- 27 PhD
- 3 MS
- 12 Undergrad
- 4 Postbacs
- 1 High School

B.-C. Lai
Affiliated Professor
NYCU, TW

How can we accelerate AI Inference?

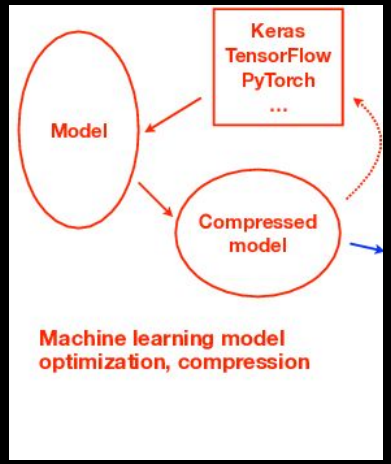
Advancement of Hardware



Altcoin

Hardware level: Targeted system for low latency/power

- hls4ml: an open-source package enabling FPGAs & ASICs deployment of ML/AI algorithms (github ★798)



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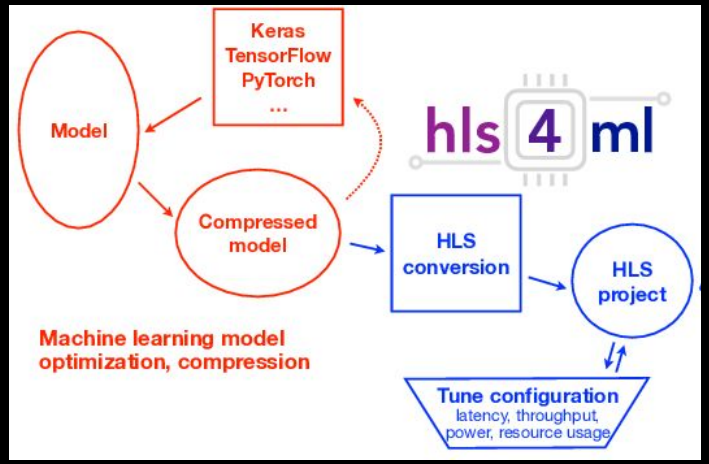

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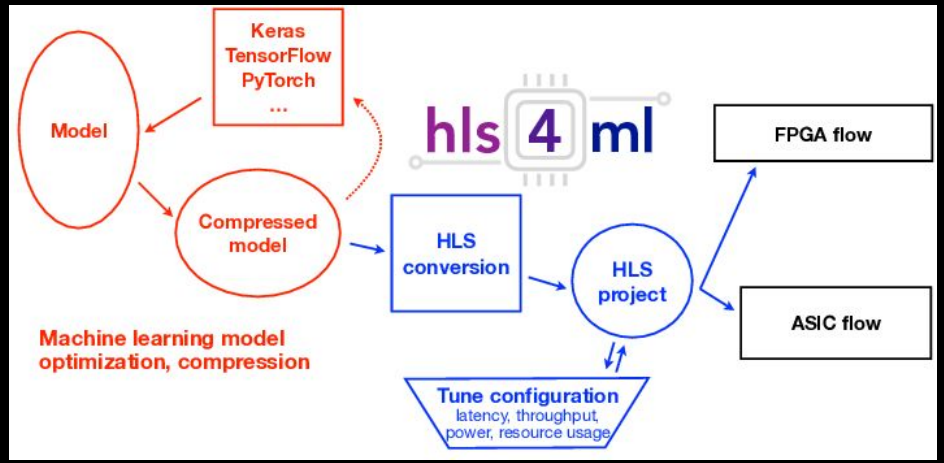

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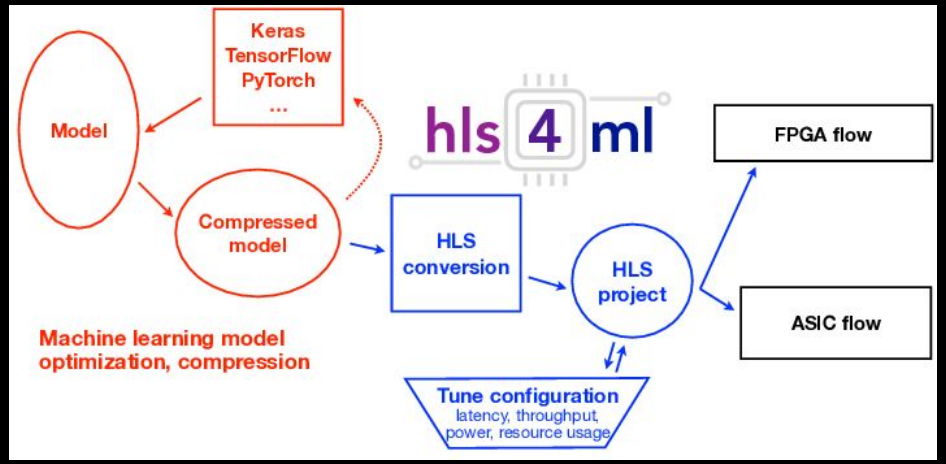


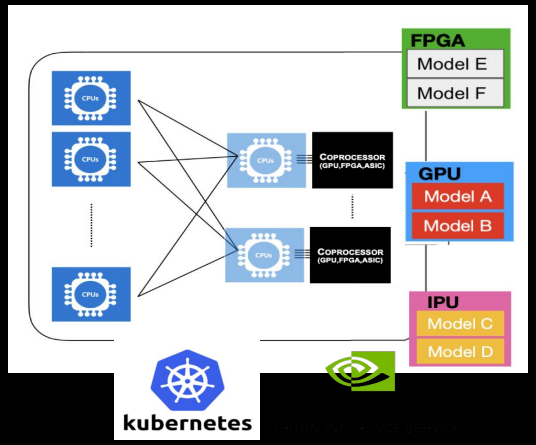
Bo-Cheng Lai
NYCU, TW

AMD XILINX

intel

Computing level: Heterogeneous system for high throughput

- **ML as-a-Service** (SONIC, hermes) enabling users in sync with the most up-to-date AI model, and the inference server handling job execution in heterogeneous computing system.



IT Cloud Providers

High Performance Computing

NSF HDR Institute for Accelerated Artificial Intelligence Algorithms for Data-Driven Discovery

Postbaccalaureate Research Fellowship 2023— 2024

Get Involved!

Application deadline:

March 3, 2023

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https://a3d3.ai/jobs.html

Summary

- Particle Physics heavily utilizing AI/ML
  - From physics objects to classification and signal extraction discriminant, AI/ML is everywhere.
  - Model dependent search being the most sensitivity search, while model independent search is the least un-biased way to search for BSM
- A3D3 revolutionizing data-driven discovery via real-time AI
  - HL-LHC is the science driver of the NSF HDR.
  - Our work is benefit to global science and engineering community.

UW A3D3 on accelerating AI techniques

hls 4 ml

E. Khoda, C. Paikara, R. Rao, A. Wang, S.-C. Hsu, etc. https://arxiv.org/abs/2207.00559 (submitted to MLST)

A.Elabd, M. Trahms Front. Big Data 5 (2022) 828666

Machine Learning-as-a-Service

M. Trahms, S.-C. Hsu, etc. Comput Softw Big Sci (2019) 3: 13

M. Trahms, K. Lin, Y. Lou, S.-C. Hsu, etc. H2RC, 2020, pp. 38-47

M. Trahms, S.-C. Hsu, etc. MLST 2 (2021) 035005

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