Deep Learning for LHC Physics

...and Beyond!

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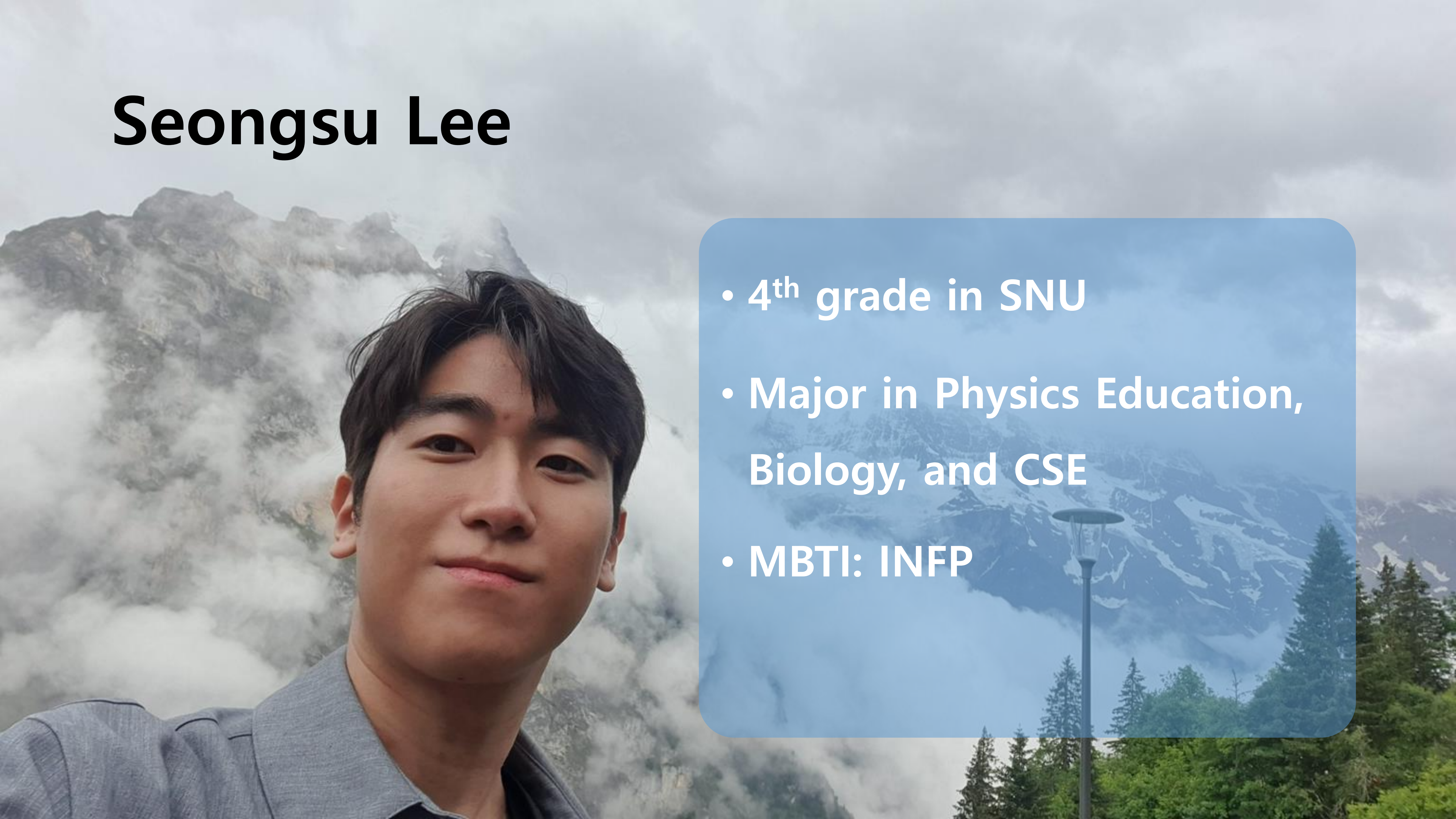
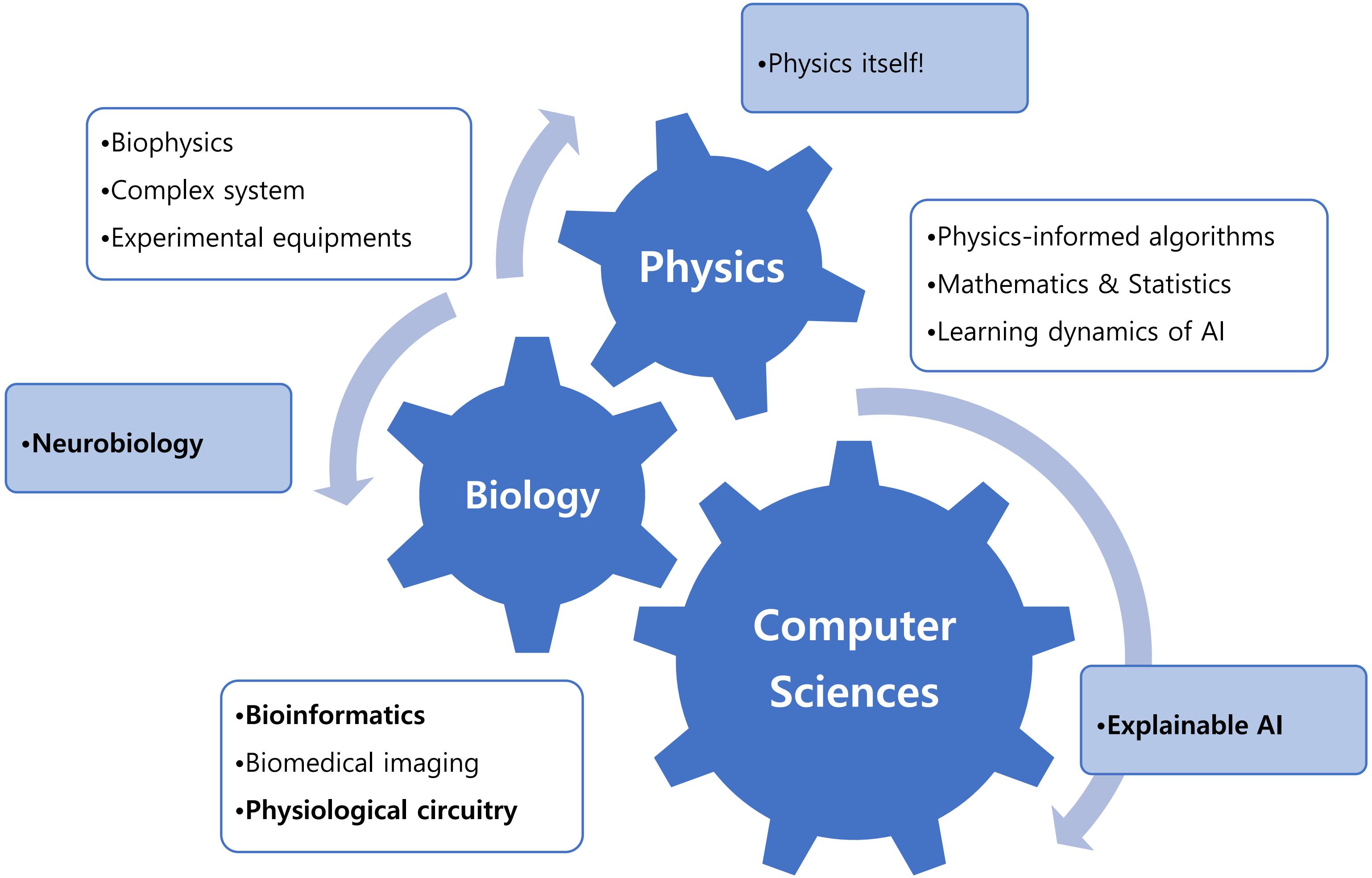

Seongsu Lee
• 4th grade in SNU
• Major in Physics Education, Biology, and CSE
• MBTI: INFP

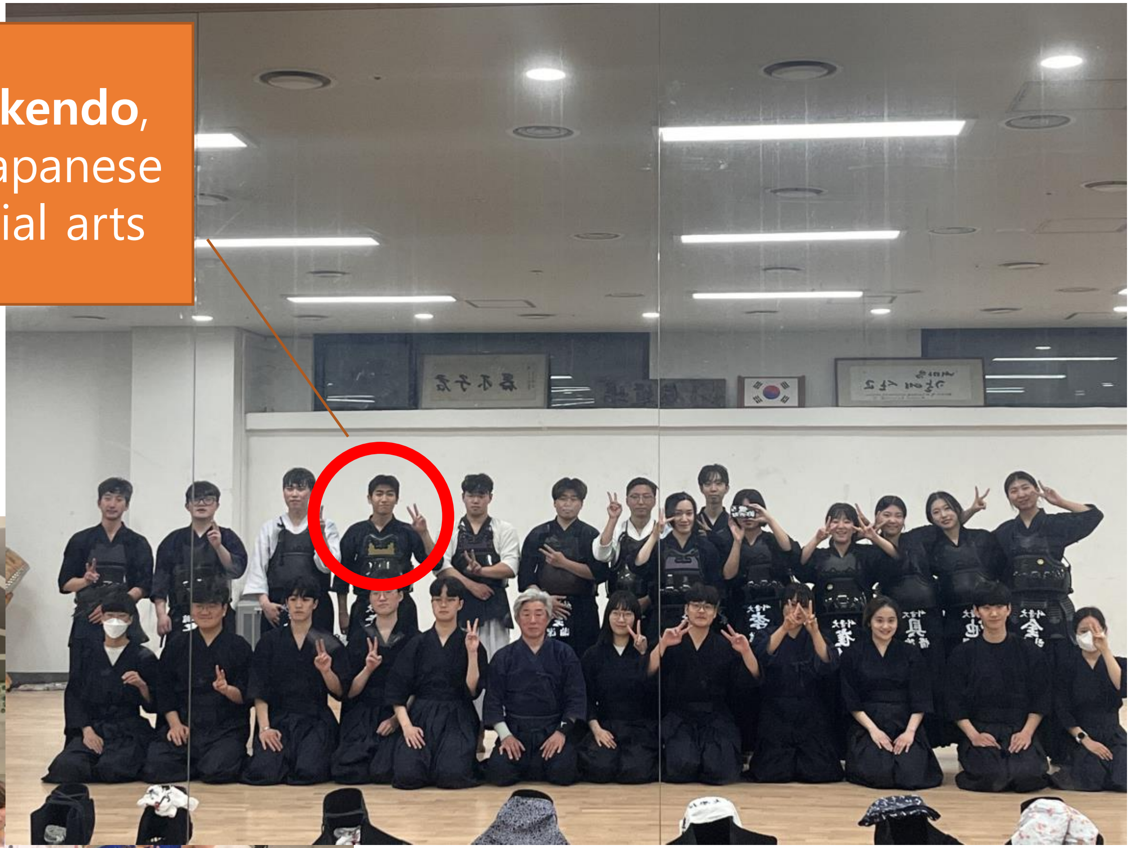
Interests

- Brain sciences
- Artificial intelligence
- High-order ideas in Sciences

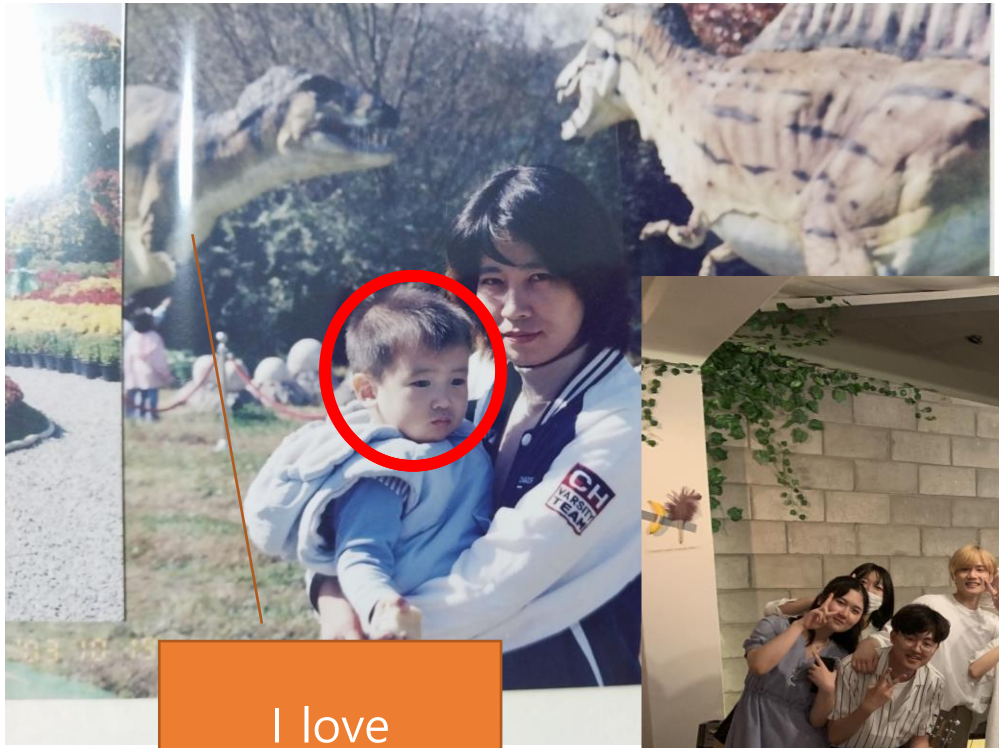
Interests


•Physics itself!
•Biophysics
•Complex system
•Experimental equipments
Physics
•Physics-informed algorithms
•Mathematics & Statistics
•Learning dynamics of AI
•Neurobiology
Biology
Computer Sciences
•Explainable AI
•Bioinformatics
•Biomedical imaging
•Physiological circuitry

Interests



I do **kendo**, the Japanese martial arts



I love **dinosaurs** so much!

I had played the **guitar**, and **sing** as well

Machine Learning & Deep Learning

Artificial Intelligence

Any technique that enables computers to mimic human intelligence. It includes *machine learning*

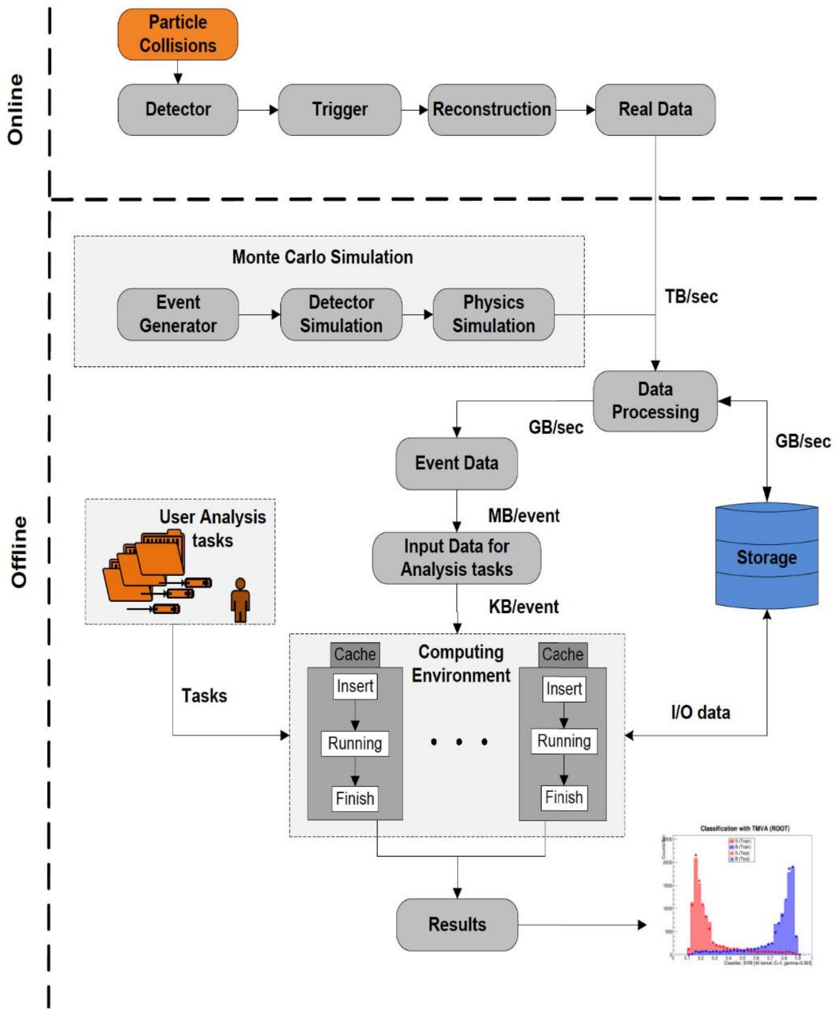
Machine Learning

A subset of AI that includes techniques that enable machines to improve at tasks with experience. It includes *deep learning*

Deep Learning

A subset of machine learning based on neural networks that permit a machine to train itself to perform a task.

Why Deep Learning Matters

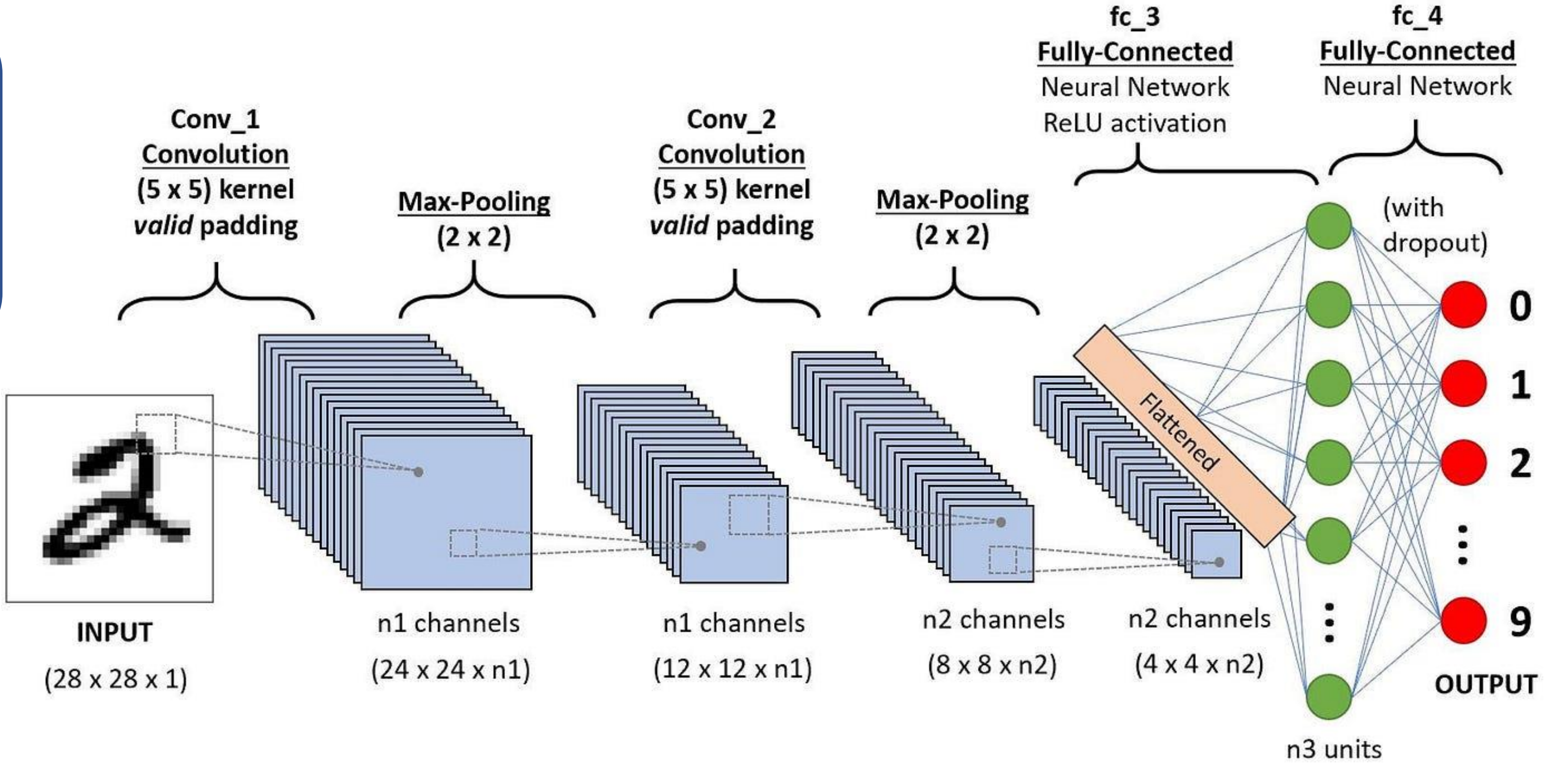


- Accelerator control
- Data acquisition
- Event triggering
- Anomaly detection
- New physics scouting
- Event reconstruction
- Event generalization
- Detector simulation
- LHC grid control
- Signal extraction
- Background rejection
- …etc.

Most of the processes are involved in ML/DL!

Why Deep Learning Matters (cont'd)

From large data bunch

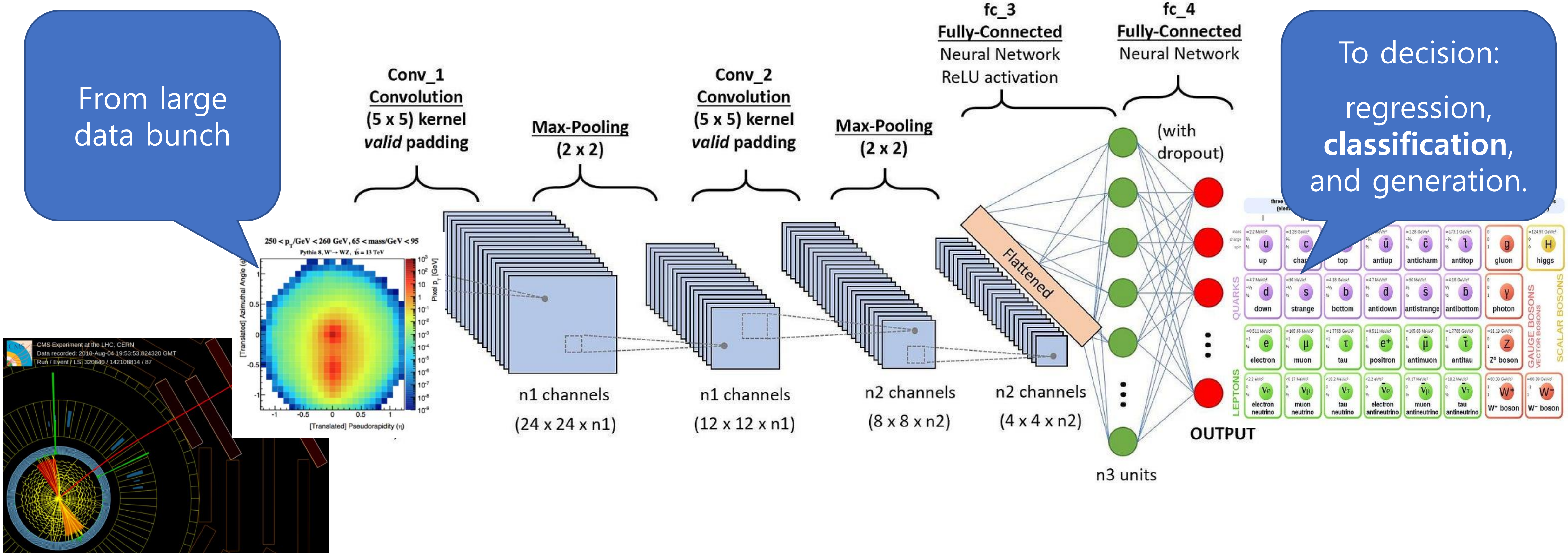


To decision:

regression, classification, and generation.

Why Deep Learning Matters (cont'd)

(Jet classification)



Use Proper DL Algorithms for Each Task!

- E.g.
  - CNN (Convolutional Neural Network) for jet classification
    - ∵ Calorimetry in detectors ≈ Image data
    - https://iopscience.iop.org/article/10.1088/1742-6596/2438/1/012103/meta
  - GNN (Graph Neural Network) for tracking
    - ∵ GNN for geometrical structure
    - https://arxiv.org/abs/2106.01832

The Advantages of DL in Particle Physics

- Needles in a haystack!
- <u>Faster</u>; do not suffer from the *curse of dimensionality*
  - Rule-based algorithms always go with time complexity problems
  - Simply propagating into the MLP is way more fast
- <u>Enormous size of data</u>

  → free from data augmentation problem

The Advantages of DL in Particle Physics

Rule-based algorithms	Statistical analysis	Deep Learning
Hard to make primarily, no training required	Short training time	Long training time
Innate dimension-dependent time consumption	Long running time	Short running time

The Advantages of DL in Particle Physics

Rule-based algorithms

- Hard to make primarily, no training required
- Innate dimension-dependent time consumption

Statistical analysis

- Short training time
- Long running time

Deep Learning

- Long training time
- Short running time

How To Use DL in Particle Physics?

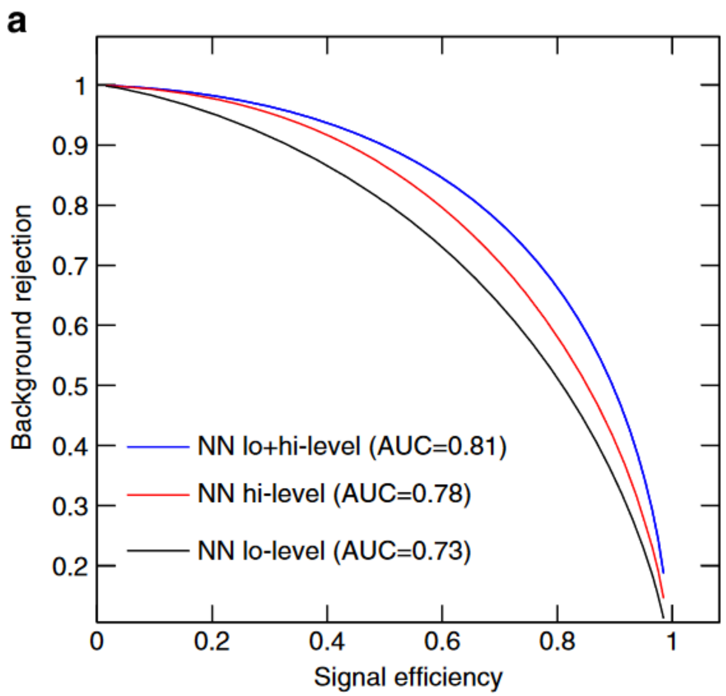
Are there any specialized approaches in this field?

Just Make It Deeper!

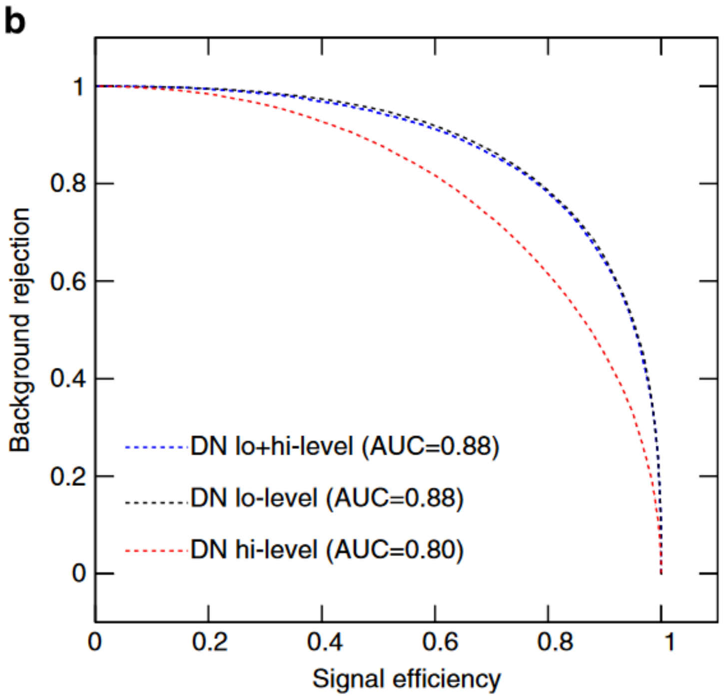
- Dr. Junghwan Goh

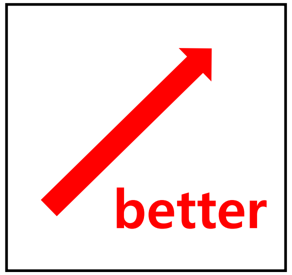
Why Deeper?

Shallow

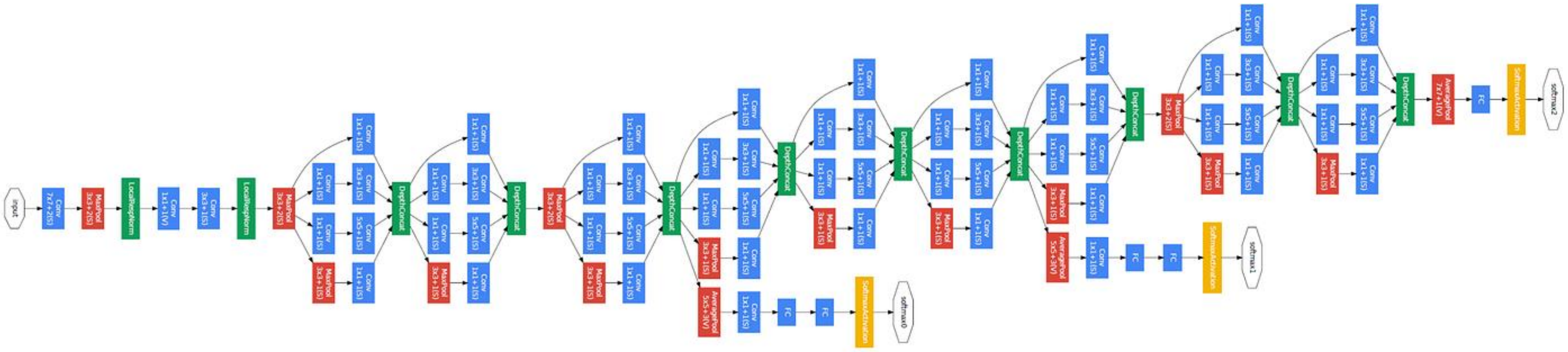


Deep

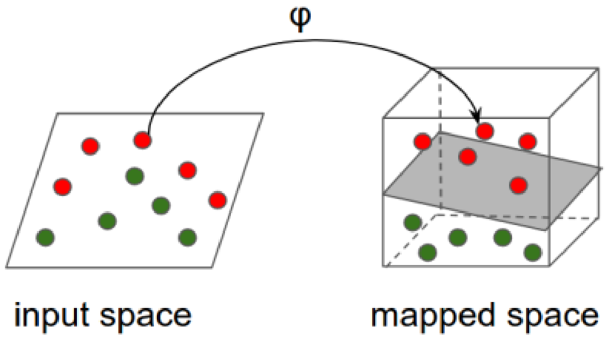




Why Deeper?: High-Dimensional Feature Space

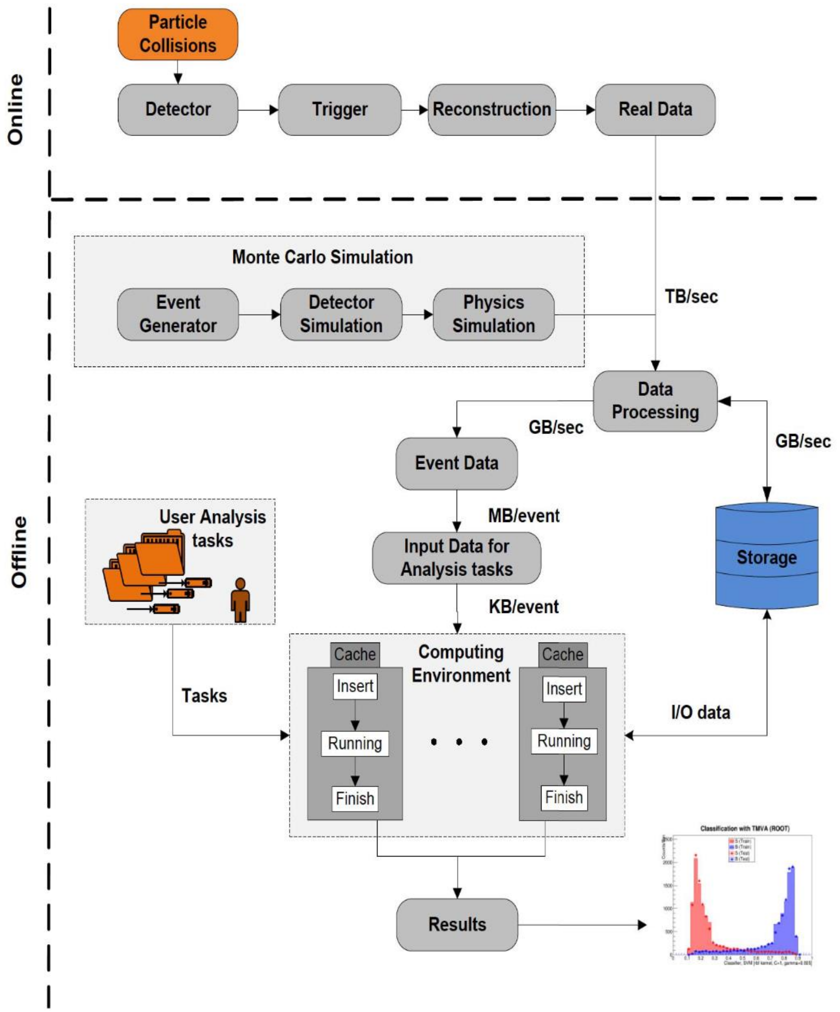


Low-level feature



High-level (abstracted) feature

Deep Learning Example: **Higgs Signal**



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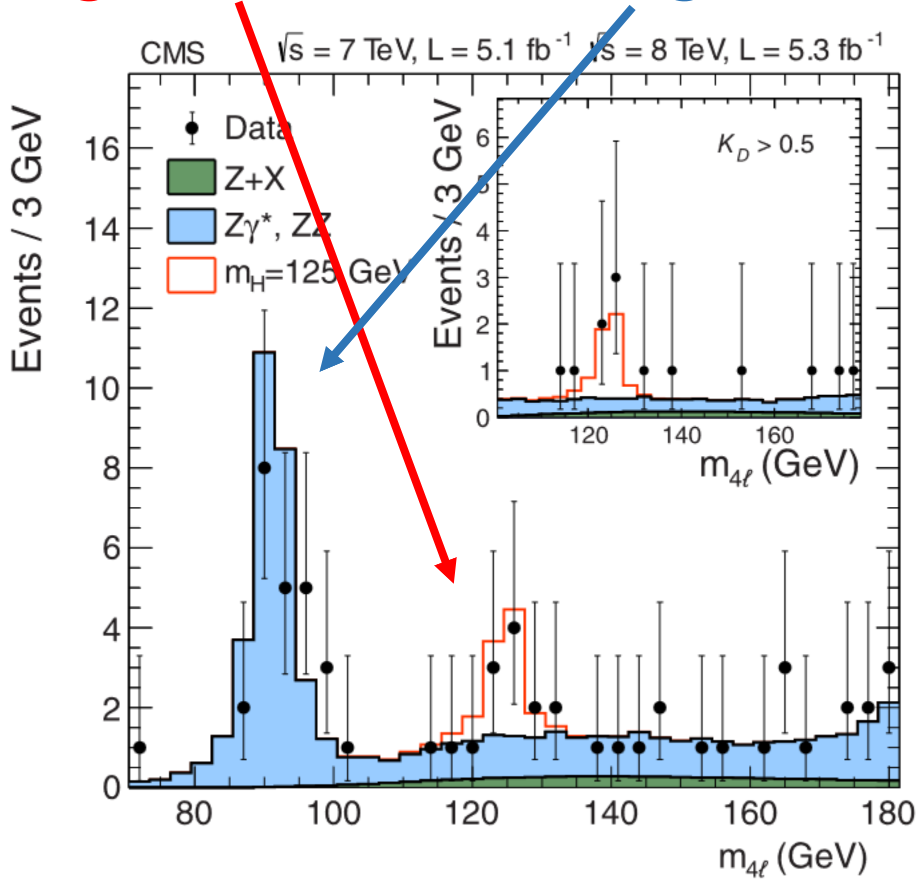
Deep Learning Example: **Higgs Signal**

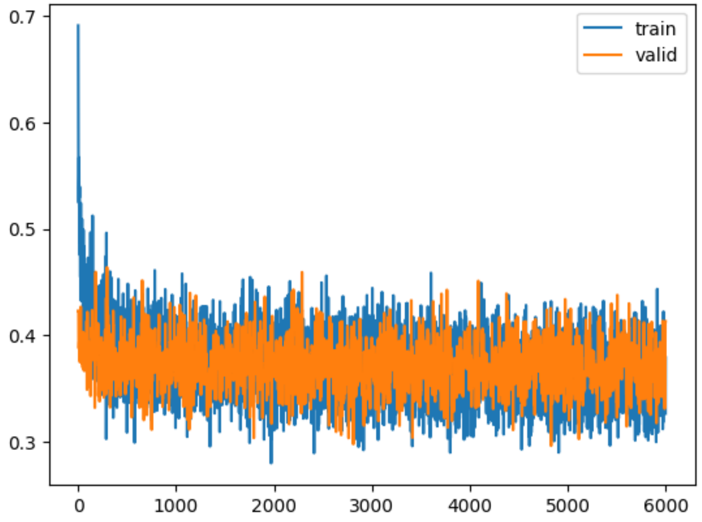
- Signal data vs background data classification (<u>event selection</u>)

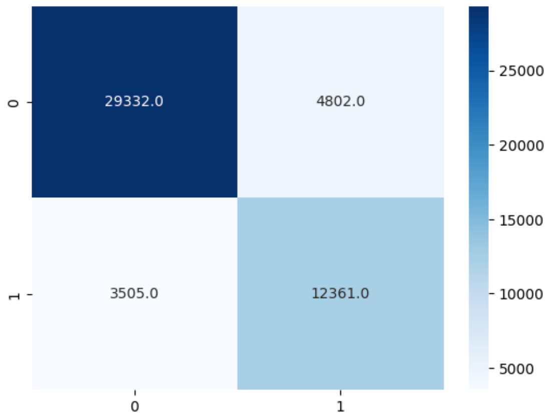


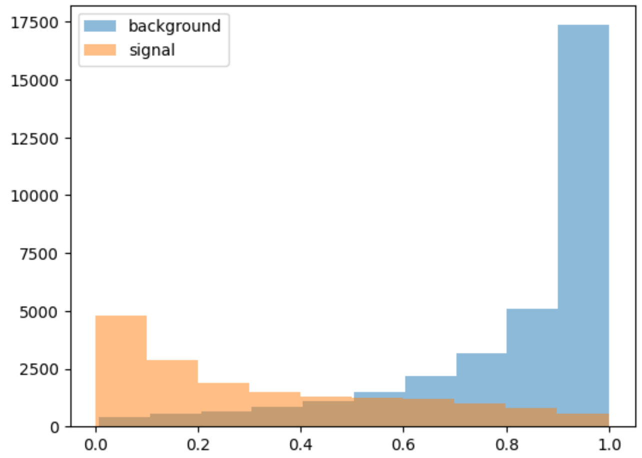
Deep Learning Example: **Higgs Signal**

- My own hands-on deep learning work!

- https://colab.research.google.com/drive/1uQWFq_y4g9vZTml-MMkNpBt75ymff2lk?usp=sharing







What Deep Learning Cannot Do

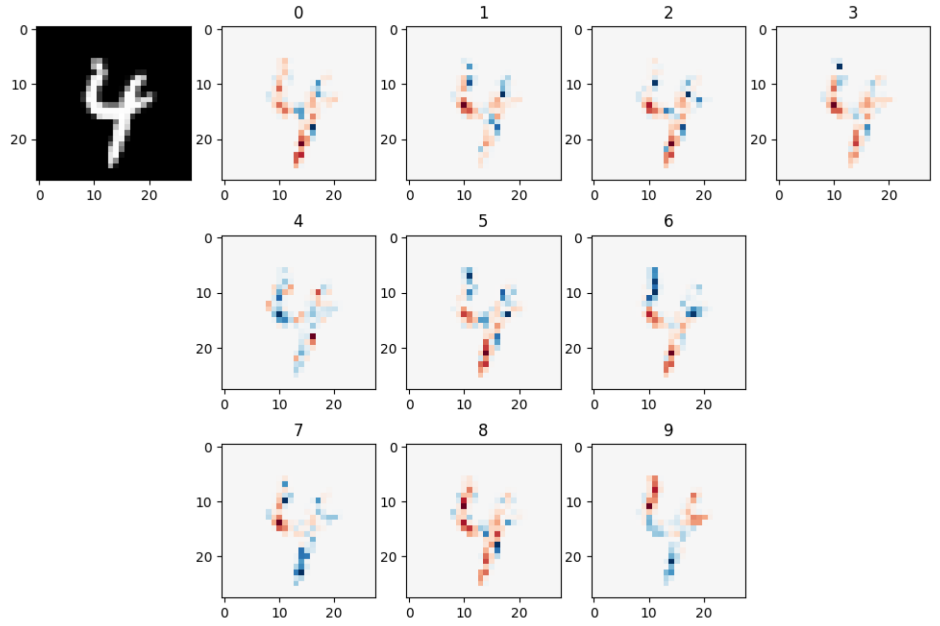
- Some generalization tasks
  - OOD (Out Of Distribution) problems; similar to extrapolation
- Reasoning
  - Transparency is important in social applications, but also in scientific analysis
  - Deep learning models have been known as **black-boxes**
  - They <u>cannot</u> construct any <u>general principles</u>, they only exploit them

Maybe They can Do?

(personal opinion)

eXplainable AI

- My main research field
- “WHY did the ML model say this?”
  - Providing reliability in serious tasks
  - Key object for fine-tuning
  - Can learn how the machines think

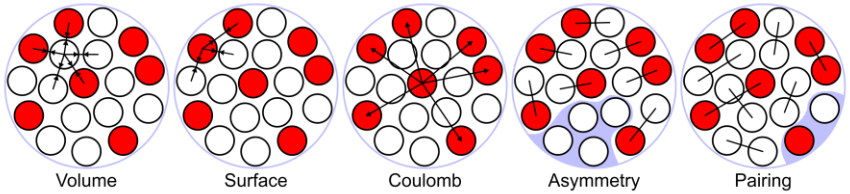


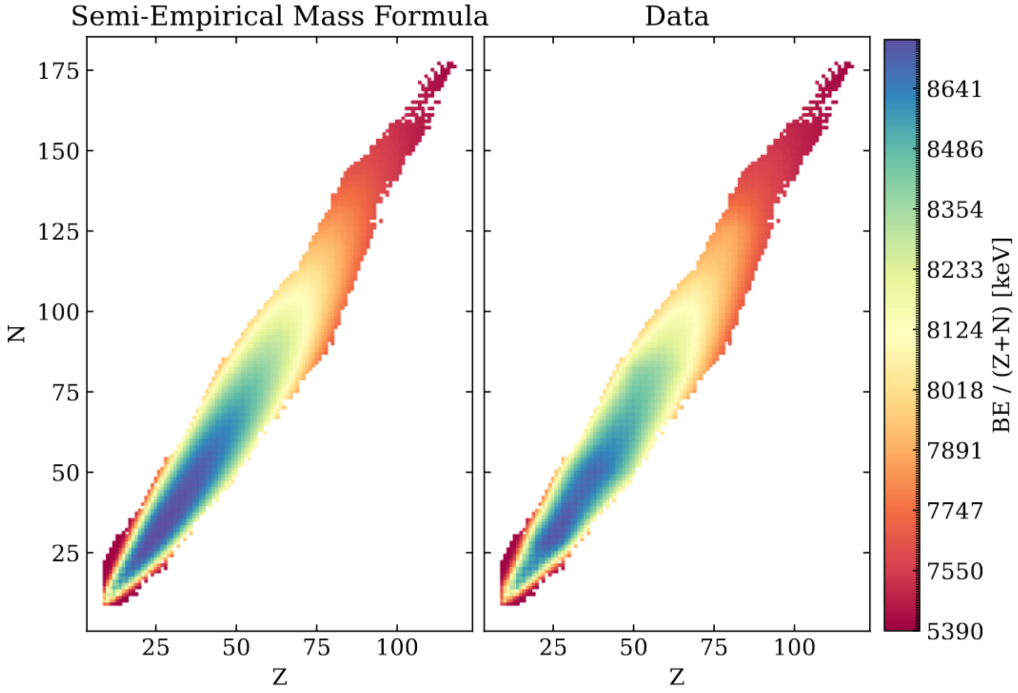
eXplainable AI for Principle Discovery

- Known model of **nuclear physics** (in CERN, ISOLDE is at its forefront)
  : Semi-Empirical Mass Formula (SEMF, **Weizsäcker formula**)

$$A = N + Z$$

$$E_B = \underbrace{a_V A}_{\text{Volume}} - \underbrace{a_S A^{2/3}}_{\text{Surface}} - \underbrace{a_C \frac{(Z^2 - Z)}{A^{1/3}}}_{\text{Coulomb}} - \underbrace{a_A \frac{(N - Z)^2}{A}}_{\text{Asymmetry}} + \underbrace{\delta(N, Z)}_{\text{Pairing}},$$



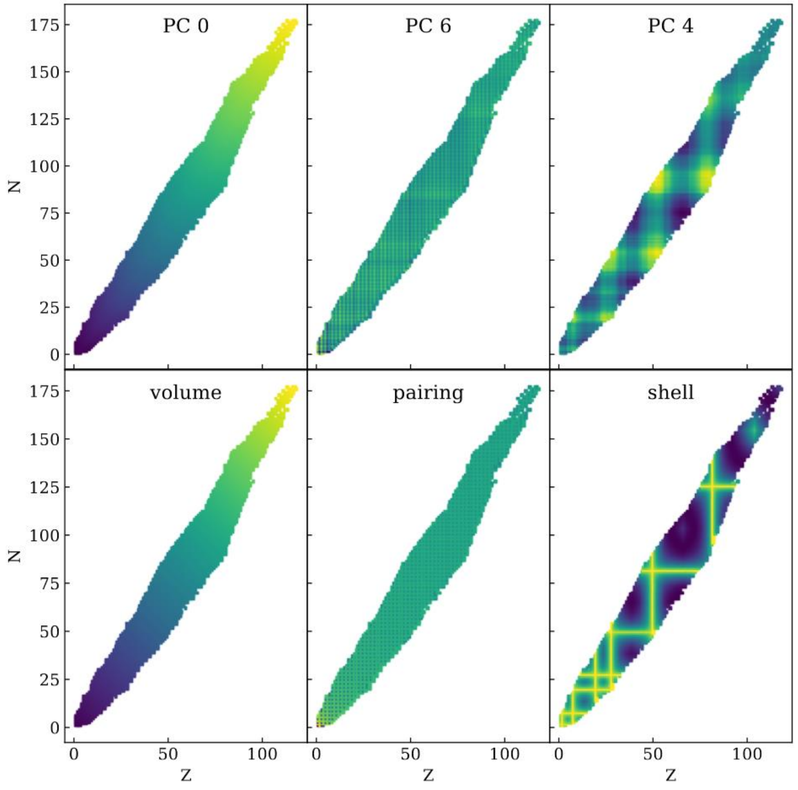


eXplainable AI for Principle Discovery

- PCA on the model's internal values
  → Each component resembles the SEMF formula

$$A = N + Z$$

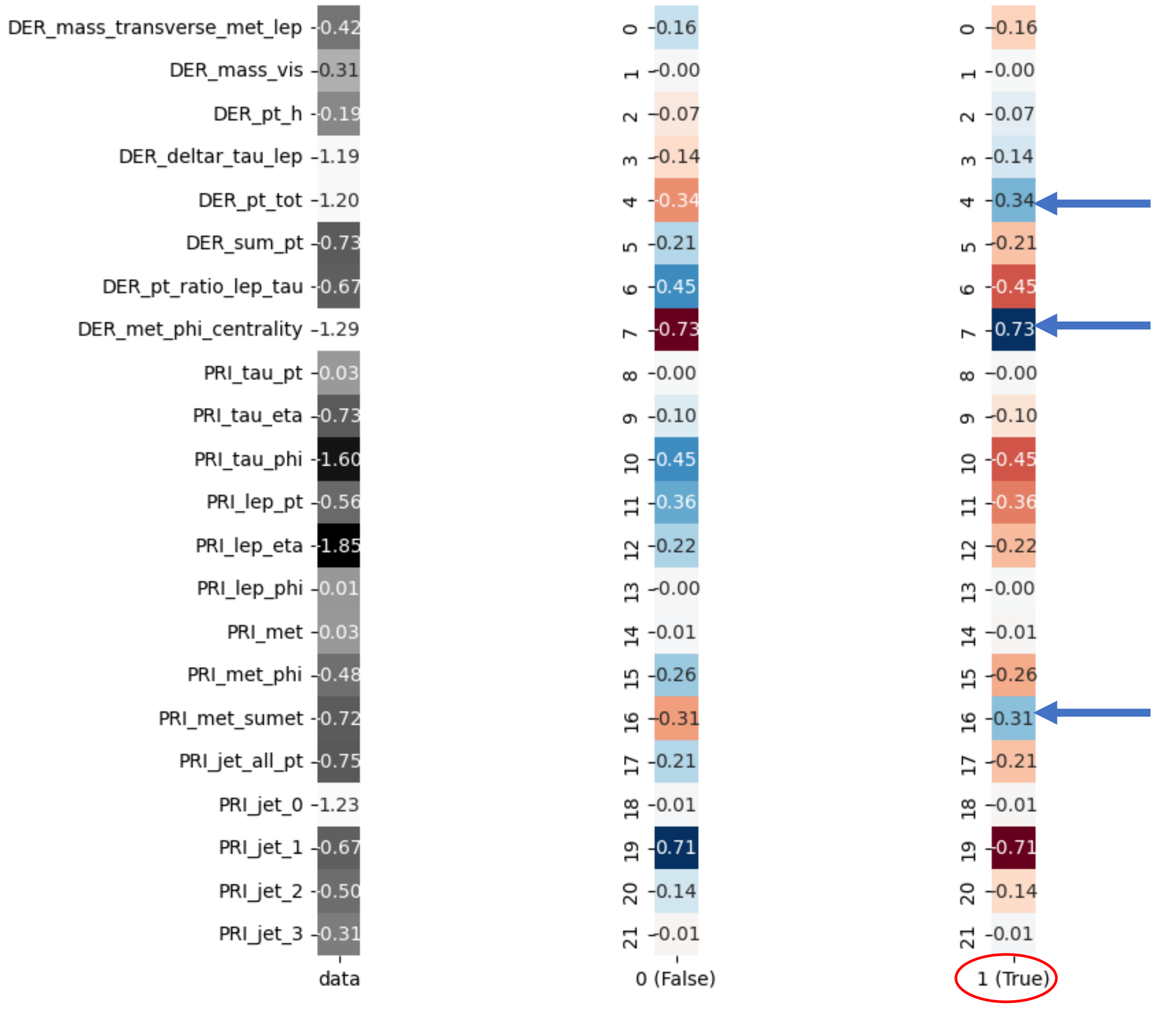
$$E_B = \underbrace{a_V A}_{\text{Volume}} - \underbrace{a_S A^{2/3}}_{\text{Surface}} - \underbrace{a_C \frac{(Z^2 - Z)}{A^{1/3}}}_{\text{Coulomb}} - \underbrace{a_A \frac{(N - Z)^2}{A}}_{\text{Asymmetry}} + \underbrace{\delta(N, Z)}_{\text{Pairing}},$$



Hands-on example

- This data is <u>signal</u> because…
  - DER_pt_tot = 1.20σ (total momentum)
  - DER_met_phi_centrality = 1.29σ
    - met stands for 'missing transverse energy'
    - Phi: angle φ
    - Centrality ∝ 1/event distance from center
  - PRI_met_sumet = -0.72σ (scalar sum of met)

- Someone may compare to other data and extract the intuition about Higgs detection



References

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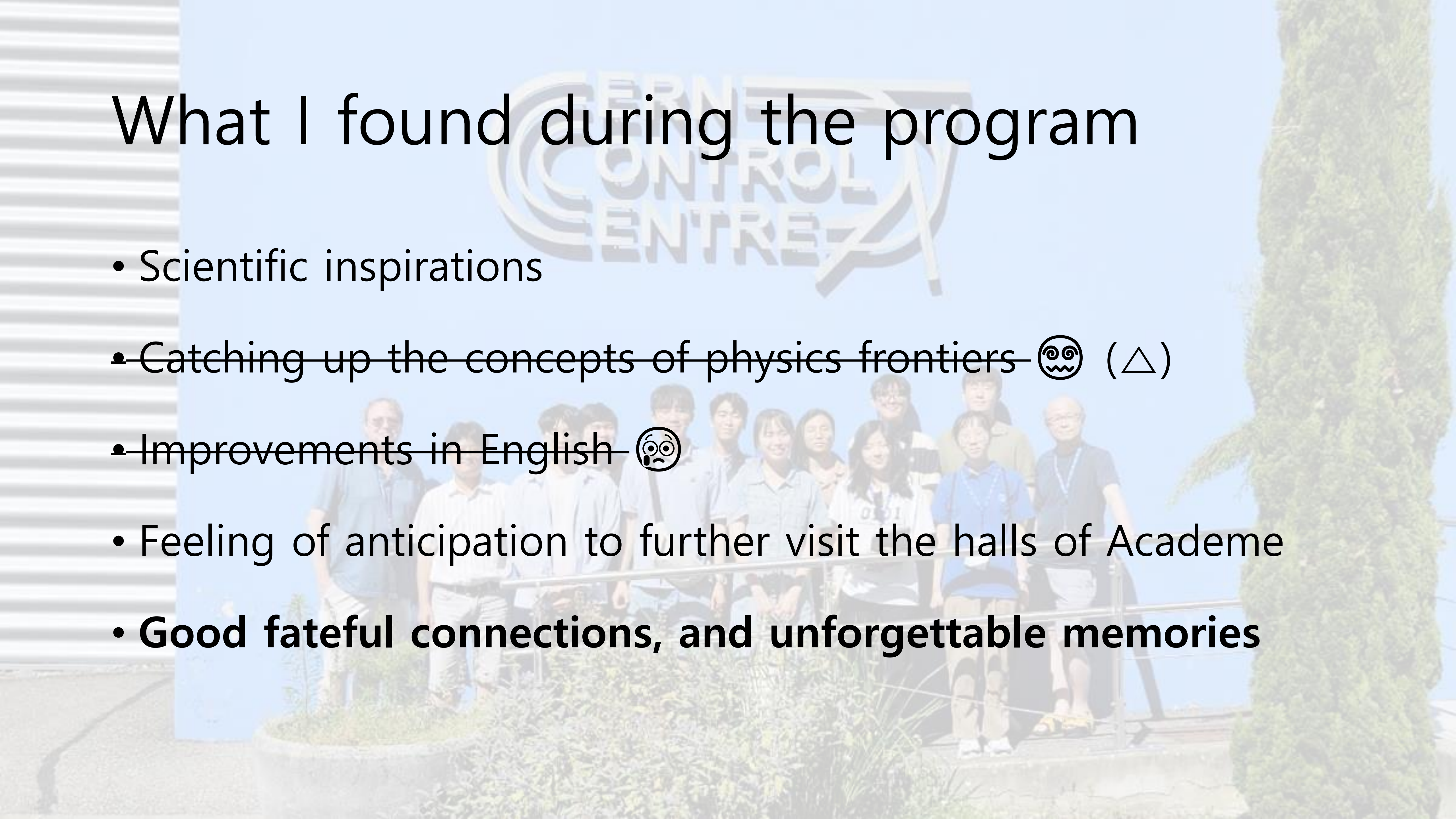
- https://en.wikipedia.org/wiki/Semi-empirical_mass_formula

What I expected to find here at CERN

- Scientific inspirations
- Catching up the concepts of physics frontiers
- Improvements in English
- Feeling of anticipation to further visit the halls of Academe

What I found during the program



- Scientific inspirations
- ~~Catching up the concepts of physics frontiers~~ 😵‍💫 (△)
- ~~Improvements in English~~ 😨
- Feeling of anticipation to further visit the halls of Academe
- **Good fateful connections, and unforgettable memories**

Thank you!