Multi-modal and multi-facility application of the FM4NPP foundation model: silicon trackers and electron colliders

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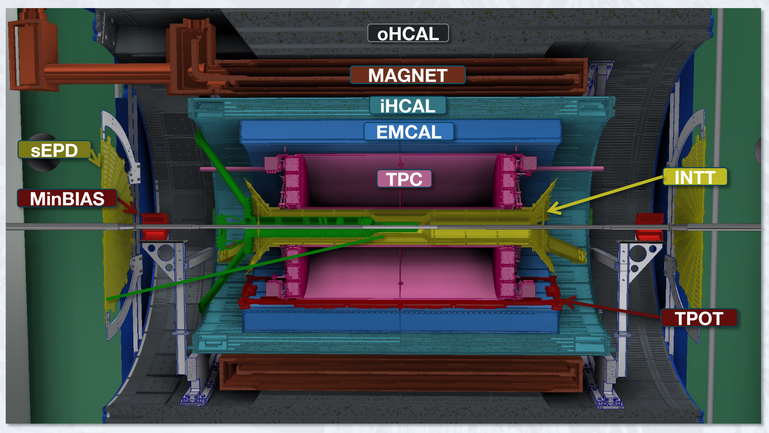
Abstract

Foundation models are large AI systems pretrained through self-supervision on diverse datasets, then adapted efficiently to many downstream tasks. Initial FM4NPP work demonstrated this approach for detector reconstruction and inference [1]. Training on simulated sPHENIX TPC proton–proton collisions at RHIC showed predictable scaling with model size, token count, and compute, while lightweight adapters supported track reconstruction and particle identification [2]. We now extend FM4NPP to test transfer, robustness, and scaling across detector modalities and collision domains [3], incorporating sPHENIX silicon-detector data and LEP/HERA electron–positron and electron–proton collision data.

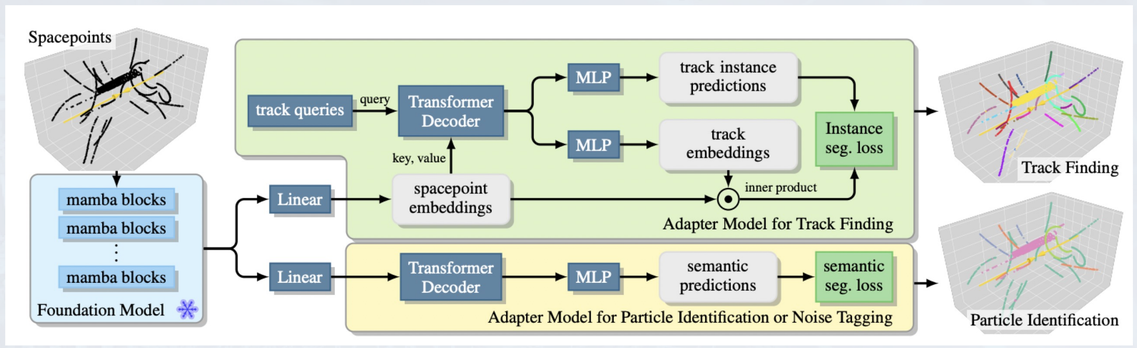
sPHENIX

- Situated at BNL's Relativistic Heavy Ion Collider
- Designed to study quark-gluon plasma
- Collected 300 PB of data between 2023 and 2026
- Took data from proton-proton, oxygen-oxygen and gold-gold collisions
- Gold-gold collisions can produce over 300 particle tracks per collision
- Proton-proton collisions occurred up to one million times per second

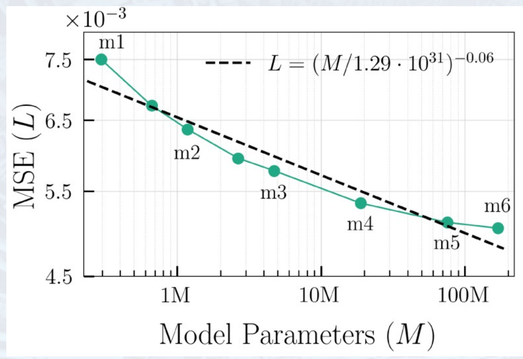


sPHENIX at RHIC

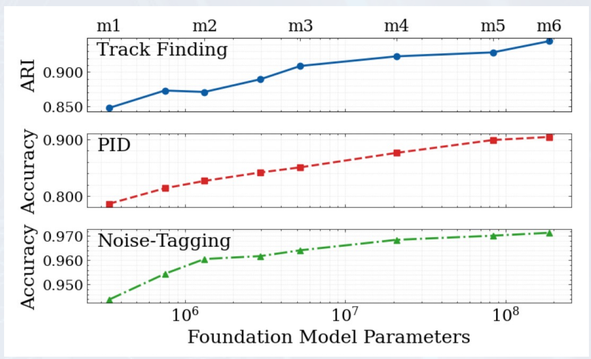
FM4NPP1: Prototype



- Easily expandable to large data sets
- Adapted to Mamba state machine allowing continuous-time modeling and efficient implementation
- Highly effective at critical TPC tasks such as particle identification, track finding and noise detection



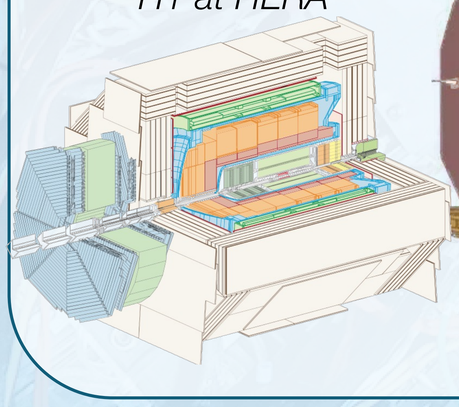
Left - Neural scaling behavior of FM4NPP demonstrated via increase model parameter size Right – Task performance improvement with model size

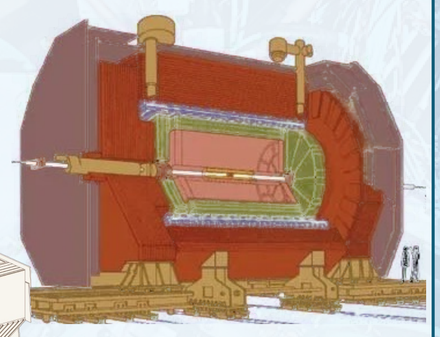


HERA & LEP

- HERA
  - Situated at Deutsches Elektronen-Synchrotron (DESY)
  - Designed to study structure of the proton
  - Collided electrons (or positrons) with protons
  - Collisions occurred up to 10 million times per second
- LEP
  - Situated at CERN
  - Collided electrons and positrons
  - Collisions occurred up to 90000 times per second

H1 at HERA

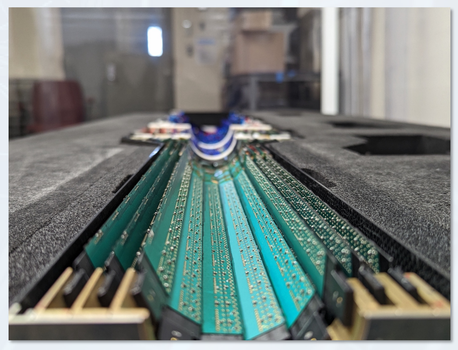




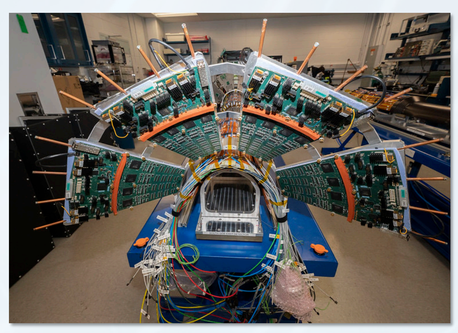
ALEPH at LEP

Genesis Project Scope

- Multi-modality
  - Input information from new sPHENIX systems, the MVTX and INTT, tests the model's ability to work over multiple data types
- New performance metrics
  - Reconstructing events using multiple subsystems enables new tasks such as
    - Noise studies
    - Clustering
    - Global alignment
    - Displaced particle tagging
- Cross-domain
  - LEP and HERA generated data from completely different collision types to RHIC, with very different collaborations and data formats
- Looking to the future of nuclear physics
  - Successful demonstration of HERA integration allows us to look at applications to future nuclear physics experiments at the upcoming EIC
  - Successful demonstration of LEP integration and full tracking with the TPC and silicon allows us to look at applications to the FCC-ee



Top – sPHENIX MVTX
Bottom - sPHENIX INTT



References

[1] D. Park et al. FM4NPP: A scaling foundation model for nuclear and particle physics, 2025. ***arXiv 2508.14087***
[2] A. Adare et al. An upgrade proposal from the PHENIX collaboration, 2015. ***arXiv 1501.06197***
[3] Y. Ren et al. A Roadmap towards Scaling, Reasoning and Self-evolving Foundation Model for Nuclear and Particle Physics. ***SSRN 5467666, dx.doi.org/10.2139/ssrn.5467666***

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