Discussion Sessions

Dates: 8.21 & 8.22, 2025

Moderators: Tianji Cai, Teng Li, Ke Li

Qingdao, Shandong, China

Strategic Goals

- To further AI+HEP research, we propose to establish a community in China and formalize a roadmap through a whitepaper.
  - To summarize the currrent status of research in our field, both domestically and globally.
  - To chart out a map for future research directions in our field & set priorities for certain large-scale projects.
  - To summarize the needs of the community in the near to mid-term future, as an input to next-level planning.
- To advocate for our AI+HEP community and request the opening of dedicated funding channels.
  - For example, working toward recognition within the national AI4Science action.
- To decide if we would like to establish some kind of organization for targeted research in AI+HEP in China.
  - If so, what form(s) of collaboration would be most welcomed and most productive.

USA

Snowmass 2021 Computational Frontier CompF03 Topical Group Report: Machine Learning

Phiala Shanahan, Kazuhiro Terao, Daniel Whiteson

The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI)

Deep Learning (AI) + Deep Thinking (Physics) = Deeper Understanding

Japan

Machine Learning Physics

Discovering new laws, pioneering new materials

Solving fundamental problems in physics by integrating theoretical methods in machine learning and in physics

MLPhYs

Foundation of "Machine Learning Physics"

Revolutionary Transformation of Fundamental Physics by A New Field Integrating Machine Learning and Physics

文部科学省 MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

科研費 KAKENHI

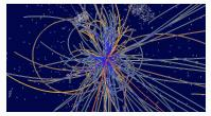
JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE 日本学術振興会

Advancing AI and fundamental physics: A European cross-disciplinary research and training network

Europe

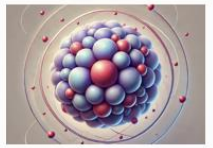
Theoretical physics

Crafting mathematical frameworks to predict and explain the fundamental laws of nature.



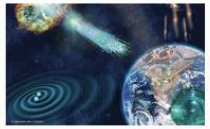
Particle physics

Unlocking the secrets of the tiniest building blocks of the universe.



Nuclear physics

Studying atomic nuclei to understand the forces that power stars and shape the elements around us.

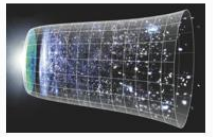


Astroparticle physics

Exploring cosmic rays, neutrinos, and dark matter to reveal the universe's mysteries.

Gravitational waves

Listening to the ripples in spacetime to witness the most violent cosmic events.



Cosmology

Investigating the origins, evolution, and ultimate fate of the universe on the grandest scales.

Accelerator physics

Pushing the frontiers of technology to accelerate particles and probe the structur of matter.

Strategic White Paper on AI Infrastructure for Particle, Nuclear, and Astroparticle Physics: Insights from JENA and EuCAIF

Sascha Caron, Andreas Ipp, Gert Aarts, Gábor Bíró, Daniele Bonacorsi, Elena Cuoco, Caterina Doglioni, Tommaso Dorigo, Julián García Pardiñas, Stefano Giagu, Tobias Golling, Lukas Heinrich, Ik Siong Heng, Paula Gina Isar, Karolos Potamianos, Liliana Teodorescu, John Veitch, Pietro Vischia, Christoph Weniger

Workshop Discussion Goals

- To discuss main physics contents of the paper with the whole community.
  - Current Sections: AI for High Energy Experiment; AI for High Energy Phenomenology; AI and High Energy Theory; Open Questions and Future Directions.
  - Existing research topics? Potential research questions of impact?
  - The "Why" question (Why using AI for XX question?). Then "How" (How to improve AI to solve XX question?). Future directions (What should we pursue in the next decade, in a general sense?).
- To conduct community surverys on common concerns and needs.
  - Current Sections: Infrastructure Need for AI+HEP Research; Community Needs, Research Organizations, and Scientific Collaborations.
- To assemble the team of main contributors for the white paper and organize the drafting process. --> May need additional small focused meetings.

White Paper Timeline

- **Summer 2025: Preparation.**
  - Hold the workshop.
  - Preparation work for the white paper drafting.
  - Determine the scope, contents, and organization of the white paper.
  - Decide on how to organize the writing process.
- **Fall 2025: Finish the 1st Draft.**
  - Finish writing individual physics section. --> Parallel work within each team.
  - Collaborate on writing the community sections.
  - Inter-group commenting and revising.
- **Winter-Spring 2026: Submit to arXiv.**
  - Revise the 1st draft to a finished version.
  - Present the version to the whole community for comments & feedbacks.
  - Submit the white paper to arXiv and incorporate further comments from the international community.
- **Summer 2026: Present at the 2026中国粒子物理大会.**

Current Paper Organizatior

CONTENTS

Mainly just placeholders. Contents to be modified.

May delete & distributed in each section

Another Option

- A short paper roadmap style (first).
  - ~1 Physics Section: Overview + Vision. --> Short. Only summary / intro level.
  - Community needs & recommendations: main
- Then a comprehensive physics paper (not too time-limited).
  - In-depth physics discussions as laid out in the physics sections above.
  - No need of community discussions.
  - Can be several overview papers focused on different physics topics, e.g., HEP-ex, HEP-ph, HEP-th, etc.

Discussion Notes

Paper

- Scope, contents, and organization of the white paper.
  - HEP-ex Section: Every exp group can summarize their specific physics domain knowledge, their AI needs in a short paragraph.
  - Need to leave room for open explorations. Research with less timelines, more freedom for our community.
  - Perhaps include the development of reasoning large models. --> HEP-th or maybe as an individual section (if reaching a critical mass).
  - Include our contributions in large international experimental collaborations, eg. LHC.
  - May want to mention quantum AI.
  - Open data --> generalize to AI-ready data ecosystem.
- How to differentiate our paper from other white papers written in the broader international community?
- Opinions & votes for the two options for paper writing.

Discussion Notes

Paper

- [KEY] **What's the purpose of the paper?** How to balance our Chinese speciaties and general physics (with international collaboration)?
  - Option 1 (1 big paper): Preferred by funding agency?
  - Option 2 (1 short + big papers later):
  - To advance the high energy (& AI) ecosystem in China, but open to the international community.
- Include an individual section for detector/accelerator/hardware design. Highlight its importance, given the large number of interested domestic researchers.
- May want to generalize the scope from just collider physics to include non-collider high energy physics.
- Time constraints. Perhaps need to shorten the paper and highlight the China

Discussion Notes

Paper

- Why particle physics is special to AI and is the key. Emphasize this aspect.
  - How different is particle physcis from other subjects? AI limitations (transformer based models) in particle physics. Its big impact on particle physics. And this would be how particle physics contribute to the AI research.

- Future direction: Next generation AI models. Can include quantum AI in this section.

Discussion Notes

Paper

- **[KEY] Goal (target) of the paper!**
- What might be some milestones in AI+HEP? Key topics in each subfield, e.g., uncertainty in ex, interpretability in ph, symbolic reasoning in th. Things like that to give the paper a unifiying theme (soul).
- Foudation model for the entire particle physics: a standalone topic to unify exp, ph, th.
- Need to engage all sub-communities, even though they may not be included in the paper.
- **Get inputs from 科学院. What are their requirements? Needs?**

Discussion Notes

Paper

- Top-down approach pros: Focus on a few key exps & questions, and then expand on more individual questions. cons: may miss something.
- Bottom-up approach: Might be more open and comprehensive, especially for new field like ours.

Discussion Notes

Community based

- [KEY] Better frameworks for cooperation. Some has good huge data, some has better AI expertise. How to coordinate the efforts?
  - Recommend designated roles to carry out certain duties in AI+HEP research, e.g., maintain the data repo, upgrade models, etc.
  - Coorperation of AI experts and scientists. Especially need AI expertise. Tool and service provider.
  - Establish AI-focused institutes within physics department in universities?
  - Emphasize the educational element.
- What are some specialties that our Chinese community can offer?

Discussion Contents

- Introduction: Above slides (30 mins)
- Session 1: AI for HEP-ex (45 mins)
- Session 2.1: Community Needs (30 mins)
- Session 3: AI for HEP-ph (45 mins)
- Session 4: AI & HEP-th (45 mins)
- Session 2.2: Community Needs (30 mins)
- Conclusion: Major Topics, Future Directions & Community Survey Feedbacks (15 mins)

Questions for the Audience

Our physics problem is … The traditional approach faces [challenges] ... We are trying [some AI method] to address [the specific issue] ... We have observed [successes], but have also encountered [obstacles] ... Our future direction is [your wishlist for AI on that problem] ... Our general vision on AI+HEP is … We would also like to see [non-physics research aspects] addressed by our community.

~5 mins Presentation

Session 1: AI for HEP-ex

Section Organization

Take Discussion Notes!

- Current Organization:
  - **Section Intro:**
  - **Targeted models for specific challenges**
    - e.g. trigger, jet tagging, event classification, detector design, uncertainties
  - **General purpose models as foundation tools**
    - e.g. LLM for assistant and automation, experimental foundation models (ref to HEP-ph)
  - **Combining targeted models and general-purposed models**
    - build a "Pragmatic AI experimentalist" (name suggestions?) (ref to HEP-ph)
  - **We need to define key challenges, potentially useful techniques, and proposals in each section.**
- New Suggestions?

~10 pages

Goals: Science Driven

- Big question in HEP, e.g. new physics, higgs properties, neutrino mass, replies on experimental sensitivity and discovery potential
- Targeted models for HEP
  - Fast machine learning and data compression for trigger
  - Detector/software design
  - Generative models for simulation
  - Object reconstruction/identification
  - Event classification
  - Uncertainty quantification
  - etc.

Pragmatic Foundation AI for Particle Physics

- Foundation models for analyses
- LLM-based
  - Knowledge system
  - Analysis automation
- Do we need a domain-LLM (that can take in domain data)?
  - What it should do? how it can help us?
  - How to combine text-based knowledge with specially formatted domain data?
- Common challenges
  - benchmarks, sustainability, etc.
- Any other?

Need to decide on a good terminology to distinguish this foundation model from the other foundation model that "knows" physics (focus on AI interpretability). (see HEP-ph)

Discussion Notes

Open Questions & Future Directions

- What innovations for deep learning algorithms might be needed? Why & How?
  - Open data: simulation & pre-processed exp data.
  - Common problems: triggering, tagging, fast simulation, detector design.
  - Establish hackathons ? Cooperation with AI community & industry? How?
- Future directions for large models ?
  - Do we need domain-specific large models? Why? What should it do & why other smaller models cannot do it?
  - Beyond pragmatic usages, more foundamental impact on particle physics? Ref to HEP-ph & AI Interpretability study there.
- We need deep thinking too. How to better collaborate with phenomenologists & theorists? Connect pragmatic AI with scientific AI?
- Need a roadmap now!

Discussion Notes

Others

- Writing angles: Milestones; Major topics; Open questions.
  - Currently too diverse. Perhaps extract several major "open questions"? Some visions needed.
- How to improve foundation models? Benchmarks (specifically for particle physics) are key! Lacking now. Need to establish a particle physics-specific benchmark ecosystem and open to the broader community.
  - Good quality open data is also critical.
- How to improve the interface of LLM and particle physics? Develop MCP (API protocol by Anthropic)?
- A potential major contribution of physics to AI is to develop the methodology for creating a world model, one that actually have physical laws in it.
- Perhaps include accelerator physics?
- Also need inputs from domestic researchers doing all types of HEP-ex, cosmic rays, neutrinos etc.

Session 2.1: Community Needs

Drafting Logistics

- How to organize the writing process.
  - Establish the writing group
  - Hold regular meetings & mailing list
  - Define major milestones
    1. .
    2. .
    3. .
    4. .

Infrastructure Needs

- Computing resource:
  - How best to share?
- Open data ecosystem:
  - Best platforms to host the data (Zenodo)? Accessible by all, demostic & international?
  - Organize hackathons and develop educational materials using such open data.
- Open softwares & workflow platforms

Community Building

- What community activities are needed? Workshops, discussion forums, summer/winter schools (see next point)?
- What educational programs may be most appropriate? Hackathons critical.
- What's the best way for us to communicate and organize collaborations?
  - More free-styled individual collaboration groups?
  - Some (relatively loose) organization like MLPhys and others in Japan & Europe?
  - Or more structured organization like IAIFI in US? (perhaps in the future?)
  - Or some new structure: A consortium of many small collaboration groups?
  - Best platform for communication? International collaborations?
  - Industry collaborations?

Survey Question Collection

- What are some important questions that need to be addressed by the community? We need your inputs!

Thanks for your participation in Day 1

Session 3: AI for HEP-ph

Section Organization

- Current Organization:
  - **Section Intro:** Brief survey of the state-of-the-art AI applications; Commonalities of the scientific problems (generation, classification, etc).
  - **Commonly-used General AI Methods:** Generation (diffusion models etc); Classification (GNN, Transformers, etc); SBI; anything else? --> Common challenges of AI methods & ways to address them.
  - **Physics-informed AI methods:** Special architectures with physics priors (e.g. Lorentz invariant NN); New methods rooted in math & physics (e.g. collider metrics); anything else?
  - **Towards Scientific Foundation AI Models for Particle Physics:** Current works on buidling collider foundation models (another name: Physics Model); Physics Goals & Future Directions.
- Roughly 5 pages each, totaling 20 pages in single-column format.
- New Suggestions?

Discussion Notes

HEP-ph Section Org

- X

Discussion Notes

General AI Methods

- Generative problems:
  - Models:
  - Phys Apps:
- Classification problems:
  - Models:
  - Phys Apps:
- Simulation-based Inference problems:
  - Models:
  - Phys Apps:

Discussion Notes

Common Challenges

- X:
  - X:
  - X:
- X:
  - X:
  - X:
- X

Discussion Notes

Physics-informed AI

- Other names for physics-informed AI?
- Physics priors into model architecture design
  - Lorenz-invariant networks
  - Others?
  - Connections with & Improvements over general AI methods.
- New methods rooted in math & physics
  - Collider metrics: Optimal transport, phase space
  - Others?
  - Theoretical implications.
  - Connections with other AI methods.

Discussion Notes

- Other name suggestions?
  - X:
- Goals:
  - To learn meaningful representations of particle physics directly from domain-specific data, serving a large variety of downstream tasks in collider analyses.
  - To extract physics knowledge from the representations of such foundation models.
- Exisiting Works?
  - Foundation models:
  - Studies about Foundation Models: Connections with physics-informed AI methods.
- Future Directions?

Discussion Notes

Open Questions & Future Directions

- X

Discussion Notes

Others

- X

Session 4: AI for HEP-th

Section Organization

- Current Organization:
  - **Intro:** Brief summary on a vareity of HEP-th topics that have already attemped AI approaches, then explore the underlying logic for why AI works/fails at those problems, and brainstorm about new problems to try, finally focus on areas of most interest to domestic experts.
  - **AI for Individual HEP-th Problems:**
    - **Option 1 (By topic):** Scattering amplitudes; Lattice Field Theory; PDF; others?
    - **Option 2 (By logic):** 1) Find more/better solutions in a large search space; 2) Find better path from one point to another in a large search space; 3) Find the exact answer(s) in a large search space, where solutions are easy to check, yet hard to generate.
    - Discuss the **pros and cons** of AI methods for each type of problems.
  - **HEP Theory for AI:** NNFT (Anindita's talk), others?
  - **AI for (Physics) Discovery:** AI Newton, AI Feynman, etc.
- New Suggestions?

Discussion Notes

HEP-th Section Org

- X

Discussion Notes

AI for HEP-th

- X

Discussion Notes

HEP-th for AI

- X

Discussion Notes

AI for Discovery

- X

Discussion Notes

Open Questions & Future Directions

- X

Discussion Notes

Others

- X

Conclusion:

Main Topics, Future Directions & Community Survey Feedbacks

Survey Question Feedback

- X

Workshop Summary

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