实验粒子物理计算研讨会（2023）

Saturday, 15 July 2023 - Tuesday, 18 July 2023

Book of Abstracts

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HERD 实验离线软件系统

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高能辐射探测（HERD) 探测器将于 2027 年在中国空间站长期运行，HERD 探测器五面灵敏，三维测量，以极高的灵敏度寻找暗物质，并将首次直接在空间探测宇宙线到膝区，是未来空间宇宙线实验的旗舰级实验。本报告将介绍 HERD 实验离线软件系统（HERDOS），HERDOS 采用 Sniper 框架，基于 Geant4, 利用 DD4HEP 几何描述、PODIO 输入输出等主流软件，并针对 HERD 实验特点，整合了 CRMC、Genfit 等第三方软件，用于 HERD 实验的模拟、重建、刻度和物理分析。

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PandaX-4T 实验数据处理流程升级

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PandaX-4T 实验是一个多物理目标的大型深地液氙实验。目前已经采集了约 750PB 的高质量数据用于物理分析。面对接下来采样率翻倍，采数周期更长的挑战，我们对现有的数据处理流程进行了升级。通过有针对性地保留原始数据中的物理部分以及降低物理部分中时间精度要求不高部分的采样率，我们可以节省最多 65% 的存储，同时将数据处理速度提升一倍以上。此次升级也将从事例重构算法上提升几个 keV 以下物理事例的探测效率。

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JUNO Offline Software and Computing

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The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose experiment under construction in southeast China, designed to determine the neutrino mass ordering, precisely measure neutrino oscillation parameters, and probe the fundamental properties of the neutrinos by detection of solar. supernova, atmospheric and geo-neutrinos.

JUNO is equipped with a 20 kton liquid scintillator central detector, with designed energy resolution 3%@1MeV. JUNO is expected to start data taking in 2024, with about 2PB data of raw data per year.

The rich physics program and the scale of the JUNO detector with the world's largest scintillator volume present data processing challenges across all areas. This talk will present JUNO offline software for data processing and analysis, including framework, simulation, reconstruction, event display, data quality monitoring and computing model.

Invited Talks / 4

AMS 实验的数据处理与分析

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国际空间站 AMS 实验是运行在外太空的高精度大型磁谱仪，主要通过测量宇宙线研究暗物质、反物质、宇宙线起源和空间辐射。本报告将简要介绍 AMS 实验的数据处理与分析过程，包括 DAQ、触发、刻度、重建和能谱测量等。

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HERD 硅电荷探测器原理样机的电荷重建

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高能宇宙辐射探测设施（HERD）是中国空间站未来的重要实验载荷。HERD 主要科学目标为暗物质的搜寻、原初宇宙射线各成分能谱的精细测量以及伽玛射线巡天观测。硅电荷探测器 (SCD) 作为 HERD 的主要载荷之一，能够实现带电粒子电荷量的精确测量。针对 SCD 原理样机的束流实验数据，开发了新的电荷重建算法，完成 Z=1~28 的电荷重建，并与传统电荷重建算法进行交叉验证。

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Computation in PandaX-4T

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PandaX-4T is a 4-tonne scale liquid xenon experiment located in CJPL. It aims to search for elusive dark matter particles, Majorana neutrinos and astrophysical neutrinos. PandaX-4T has completed the detector construction and the subsequent commissioning run in 2021, and more physics data are being collected and analyzed now. To fulfill the requirements for multiple physics topics, a series of computation technologies have been explored and realized throughout the entire process of the PandaX-4T experiment. In this talk, I will present the details of data acquisition, processing, slow control, data analysis, simulation, and related support tools in PandaX-4T.

Supporting Tools / 7

HEP ML Lab —An end-to-end framework for signal vs background analysis in high energy physics

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We have developed an end-to-end data analysis framework, HEP ML Lab (HML), based on Python for signal-background analysis in high-energy physics research. It offers essential interfaces and shortcuts for event generation, dataset creation, and method application.

With the HML API, a large volume of collision events can be generated in sequence under different settings. The representations module enables easy conversion of event data into input formats required by various methodologies. The API also includes three categories of analysis methods: cut-based analysis, multivariate analysis, and neural networks, to cater to diverse needs. Coupled with built-in metric parameters, users can preliminarily assess the performance of different analytical methods while using them.

While the high-energy physics research community has already explored several frameworks that integrate data and analysis methods, we advocate for integrating the entire end-to-end process into a single framework. By offering a unified style of programming interface, it reduces the need for researchers to switch between different software and frameworks. This not only simplifies and clarifies the research process, but also facilitates the reproduction of previous research results, leading to more persuasive conclusions.

To demonstrate the convenience and effectiveness of HML, we provide a case study that differentiates between Z jets and QCD jets. We provide benchmark testing for the three built-in methods and ultimately export shareable datasets and model checkpoints.

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神经网络在伽马射线径迹重建中的应用

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随着近几年深度学习的发展，神经网络等深度学习方法不断被应用在高能物理研究领域，本报告提出了将探测器数据完整的送入经过训练的卷积神经网络模型，经卷积神经网络模型计算后直接输出重建后的方向，此方法避免了人为选择的偏见，以最直接的数据输出最直接的结果。为了验证此算法的准确性，我们使用暗物质粒子探测卫星（DAMPE）的伽马数据（100GeV 到 10TeV 能级的数据）对模型进行了训练、测试以及验证，数据验证得到的结果为方向重建的单侧投影的残差正态分布 sigma 值为 0.166。此外，此算法重建精度会随着沉积能量变高而变高，且此算法亦适用于其他带电粒子的方向重建。

Machine Learning / 9

Reconstruction of Neutrino Event in TRIDENT Based on Trident-Net

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The tRoplcal DEep-sea Neutrino Telescope (TRIDENT) is a next-generation neutrino detector located in the South China Sea. High computational efficiency is required for event reconstruction methods in order to calculate the incident particle's direction and energy. In a typical neutrino event, less than 1% of photosensors are hit, making Graph Neural Networks particularly well-suited for their reconstruction. In this study, a Graph Neural Network named TridentNet has been constructed to achieve high resolution in direction and energy reconstruction. We present results from TridentNet and make comparisons with traditional reconstruction method.

Invited Talks / **10**

CEPCSW: the Key4hep-based software for CEPC

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The CEPC (Circular Electron Positron Collider) is a future experiment to explore the properties of the Higgs bosons, as well as the W and Z bosons. Initially, the experiment utilized the iLCSoft software, which served as the foundation for the completion of the CEPC conceptual design report. To facilitate further research and development activities, the experiment has decided to develop a new software called CEPCSW within the Gaudi software framework. One of the benefits brought by this transition is to make it straightforward to subsequently integrate with the Key4hep, a common software stack developed for future HEP experiments such as CEPC, CLIC, FCC, and ILC, etc. By employing the common event data model, EDM4hep, the CEPC experiment can transparently share tools, algorithms, and other software components with the experiment owning a similar detector configuration. This abstract highlights the successful adoption of CEPCSW and its compatibility with the Key4hep, emphasizing the potential for enhanced cooperation and advancement in the field of High Energy Physics.

Invited Talks / **11**

CMS Software and Computing

Author: Qiang Li[1]

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A brief introduction of software and computing in the LHC CMS experiment will be given, including the history, current status and future prospects towards HL-LHC.

Supporting Tools / **12**

Event viewer software in the PandaX-4T experiment

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The PandaX-4T event viewer is a dedicated integrated GUI program for visualizing data information, especially the waveform and charge distribution of detected signals, which has already become a powerful and indispensable supporting tool in the PandaX-4T experiment. In this talk, I will present two versions of viewer software used during PandaX-4T data analysis based on different motivations and techniques. A series of tools are provided, covering the entire run level to a single PMT channel level and helping users better understand their data samples. Besides, some advanced features will also be discussed in my talk.

Invited Talks / **13**

Computational Methods in the ATLAS experiment

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This talk will give an overview of the computational metholds used in the ATLAS experiment, a general-purpose detector experiment at Large Hardon Collider. Upon the collision of proton-proton bunches, microscopic interations take place. Physicists have to rely on sophiscated software program applied to computational hardware to take raw data from detector, trigger on and store interesting events, reconstruct physics objects, and analyse the data in comparison to simulation predictions to reach at physics conclusions. Those key ingredients will be discussed in the talk.

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Offline Computing for the Muon g-2 Experiment at Fermilab

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The Muon g-2 experiment at Fermilab aims to measure the muon anomalous magnetic moment with an unprecedented precision of 140 ppb. In 2021, the first result of the experiment confirmed the previous measurement and increased the deviation with the Standard Model predicition to 4.2 sigma. The size of the first dataset is at multi-petabyte-size level and the final dataset is expected to be 20 times bigger, bringing up a critical challenge to the experiment. In this talk, the offline framework and infrastructure, data production workflow and computing tools for the Muon g-2 experiment are presented.

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PandaX 实验内的信息服务

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PandaX-4T 是一个多物理目标的液氙探测器实验。随着合作组规模的增大，需要一套工具来提供合作组内部的资源共享，提高合作组成员间的交流效率。在这个报告中，我们介绍 PandaX 内部使用的 IT 工具，如 Mattermost、Docs、Gitlab 以及 Digital-Logbook 等。它们以 IPA 为核心，以 PandaX Account 作为认证接口。Mattermost 作为沟通、组织协作的工具，它大大提高了我们内部沟通的效率；Docs 替代了之前的 Fermilab DocDB，解决了用户密码共用、中文乱码、搜索功能差以及浪费磁盘空间等问题，极大地改善了用户体验; GitLab 是一个集中式的代码仓库，它提供了强大的版本控制功能，使开发团队能够有效地管理代码的变更和版本历史，团队成员可以将代码存储在仓库中，并进行共享和协作。此外，目前正在积极开发中的 Digital-Logbook 将用于替代目前的 Electric Logbook。这些工具在保障 PandaX-4T 实验顺利进行的过程中起了很大作用。

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塑料闪烁光纤探测器的精细光学响应模型

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基于硅光电倍增器 (SiPM) 阵列读出的闪烁光纤探测器能够提供与传统硅微条探测器相当的高位置分辨率，在粒子物理实验 (LHCb、Mu3e、HERD 等) 和缪子成像领域具有广泛的应用前景。利用 Geant4 软件构建了塑料闪烁光纤探测器的精细光学响应模型，充分考虑光纤发光过程、光子束缚效率、光衰减、光纤串扰以及 SiPM 的探测效率、增益、噪声、饱和等效应，普遍适用于基于 SiPM 读出的塑料闪烁光纤探测器，可为该类探测器的整体设计和研制提供理论指导。

Machine Learning / **17**

Machine Learning Based Tracking Reconstruction in the Muon g-2 Experiment at Fermilab

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The first result of the Fermilab muon g-2 experiment shows that the anomalous magnetic moment of the muon has 4.2 standard deviation between the experimental and theoretical result, which provides a strong evidence for the new physics beyond the Standard Model. The tracking reconstruction plays an important role in many aspects of the experiment. In the Run1 analyses, both the speed and efficiency of the tracking reconstruction are below expectations. Recently, machine learning based tracking reconstruction methods have been well developed, they have the potential to significantly improve the tracking reconstruction speed and efficiency. I preresent a preliminary machine learning based study in the muon g-2 experiment to explore its potential usage in future data analyses.

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LHC 上寻找粲重子电磁偶极矩实验的可行性研究

Authors: Han Miao[1]; Elisabetta Spadaro Norella[2]; Jascha Peter Grabowski[3]; Jinlin Fu[4]; Sara Cesare[5]; Fernando Martinez Vidal[6]; Nicola Neri[2]; Tianyu Xing[1]

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测量基本粒子的电磁偶极矩对于寻找超越标准模型之外的新物理具有重要的意义。大型强子对撞机 (LHC) 上的高能束流使得测量粲重子（Λ_c^+, Ξ_c^+）的电磁偶极矩成为可能。我们计划使用弯曲的晶体中的通道来约束7 TeV 的质子束流与钨靶碰撞产生的粲重子，使其自旋取向在晶体中发生进动。其自旋的偏转与其电磁偶极矩息息相关，所以我们最终能够通过测量其飞出晶体后衰变末态粒子的角分布来获得其电磁偶极矩。本报告将简要介绍该实验可行性研究的最新进展以及基于 DD4hep, podio, Geant4 等高能物理常用软件的模拟与数据分析框架的设计与开发。

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基于拓展细胞自动机重建 AMS 伽马宇宙线的算法研究

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AMS 运行在国际空间站上，有 1.4kG 的磁场和位置分辨高、物质量少的硅微条探测器，具有精确测量伽马射线的能力和探测伽马射线极化的潜力。本报告通过采用拓展细胞自动机的方法，针对高能光子在 AMS 探测器的响应进行优化，构建了通过正负电子对测量高能伽马射线的通用算法。新算法实现了在 TOF 上转换的伽马重建效率在 200MeV 从 46% 提高到了 82%，1GeV 从 78% 提高到了 92%。在 L2 转换的伽马射线重建效率在 200MeV 从 39% 提高到了 81%，1GeV 从 74% 提高到了 94%。

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PandaX-III 实验中粒子径迹特征分析方法与灵敏度估算

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对马约拉纳中微子的研究是当前粒子物理领域探索超出标准模型新物理的热点研究方向，无中微子双贝塔衰变（NLDBD）是实验上可以确认中微子马约拉纳属性的稀有核衰变。PandaX-III 合作组致力于打造具有国际竞争力的百公斤靶质量实验，采用基于气体微结构探测器技术的高压气氙时间投影室来寻找 Xe-136 的 NLDBD 过程，其最显著优势在于能够通过带电粒子径迹特征进行信号本底鉴别，进而大幅提高实验对 NLDBD 的探测灵敏度。本报告将从 PandaX-III 实验中带电粒子径迹特征分析入手，介绍粒子径迹重建、信号本底鉴别、事例顶点重建等方法，推动 PandaX-III 朝着零本底实验条件发展。

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BESIII 实验的软件与计算

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BESIII 实验是目前国际上唯一运行在 tau-粲能区的大科学实验装置。BESIII 探测器由漂移室，飞行时间探测器，电磁量能器和缪子探测器组成。报告主要介绍 BESIII 实验的数据触发、获取和处理流程，包括各个子探测器的模拟，刻度与重建，以及部分物理分析工具软件的内容。

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量子机器学习在高能物理实验中的应用

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量子计算机是利用量子态的叠加性和纠缠性信息进行运算和处理的机器，其利用强并行性，打开了提升计算效率的完全不同的技术路径。在高能物理领域，量子计算的应用研究已经进行了多年，特别是 CERN 量子技术计划 (CERN QTI) 在 2021 年 10 月公布长期量子研究计划的路线图，促进了量子技术在高能物理学领域的应用。本报告主要集中于介绍量子机器学习的基本原理，以及目前在高能物理实验数据处理中的应用状态，包括粒子鉴别、图像处理、数据分析、径迹重建和快速模拟等领域。通过讨论量子计算机可能对机器学习带来的“量子优越性”，探索高能物理实验数据处理中使用量子计算机的可行性。

Data Process & Analysis / 23

A real-time monitor for TeV transients with LHAASO-WCDA

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With high duty cycle and wide aperture, the Large High Altitude Air Shower Observatory - Water Cherenkov Detector Array(LHAASO-WCDA) can conduct an unbiased gamma-ray sky survey in the energy range from a few hundred GeV to 100 TeV. The sensitivity of WCDA is as high as a few percent of Crab units, which allows us to monitor the VHE variability of blazars. The LHAASO Collaboration has developed an online monitoring program to monitor the extragalactic VHE flare in the WCDA’s field of view. Once a flare exceeding the threshold is detected, an alert will be generated automatically, and a follow-up multiwavelength observation could be carried out. In this talk, I will introduce the candidate sources, the methods, and current status of the monitor, as well as some prospects of alert issues in the future.

Invited Talks / 24

Emergence of Large Language Model and Application in Scientific Discoveries

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ChatGPT demonstrates extraordinary emergent abilities in complex reasoning and language generation. In this talk we introduce Big Bang Transformer[乾元], a pretrained LLM trained on blend of general text, scientific papers and code datasets. We discuss how LLMs acquire emergent abilities by instruct finetuning and RLHF. We propose to use statistical mechanics principles to study the fundamental mechanism of the emergence of intelligence in large parameter language models. Also, we discuss the potential application of large language model in scientific data analysis and discoveries, particularly in the field of experimental particle physics.

Data Process & Analysis / **25**

Track finding algorithm for the TPC detector at CEE experiment

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The Cooler-Storage-Ring External-target Experiment (CEE) is a spectrometer to study the properties of nuclear matter at high baryon density region. The CEE time projection chamber (TPC), which uses the state-of-the-art SAMPA electronics read-out chips is the key sub-detector of CEE. This talk presents the track-finding algorithm that is used for event reconstruction for the TPC detector at the CEE experiment. The algorithm is based on Cellular Automaton and Combinatorial Kalman filter techniques, which provides a good balance between speed and efficiency to find charged tracks and therefore meets the requirements of CEE experiment.

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eXTP 端对端观测数据模拟系统

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增强型 X 射线时变与偏振探测（enhanced X-ray Timing and Polarimetry，简称 eXTP）空间天文台是我国在成功发射硬 X 射线调制望远镜卫星后发展的下一代旗舰级 X 射线天文卫星。观测模拟是研制 X 射线天文卫星不可或缺的手段，对仪器性能参数的理解、科学性能的评估和观测数据的科学分析等方面有重要的意义。eXTP 端对端观测数据模拟系统能够提供具有天体物理意义的、反应有效载荷真实响应的、与在轨运行接近的观测数据，以满足标定和数据处理流程的需要。

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STCF offline event processing software

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With an electron-positron collider operating at center-of-mass-energy 2~7 GeV and a peak luminosity above 0.5 × 1035 cm−2 s−1, the STCF physics program will provide an unique platform for in-depth studies of hadron structure and non-perturbative strong interaction, as well as probing physics beyond the Standard Model at the τ-Charm sector suceeding the present Being Electron-Positron Collider II (BEPCII). A performant, extendable and maintenable offline event processing software to reconstruct and identfiy particles and events is very crucial to the design and construction of the detectors, and to eventually fulfill the physics targets and to further maximize the physics potential at the STCF.

In this talk, I will give an overview of the STCF offline event processing software, focusing on the event reconstruction algorithms and physics analysis tools implemented for STCF and their performance.

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LHAASO 的数据处理

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LHAASO 的数据处理

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Machine Learning in Track reconstruction at DarkSHINE Experiment

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The DarkSHINE Experiment is a proposed fixed-target operation using an electron beam to search for dark photons by measuring the missing momentum. The measurement relies on the efficient use of tagging and recoil trackers to measure the electron energy pre- and post-target. We present a comparative analysis of conventional methodologies and contemporary machine-learning techniques for tracking reconstruction. Initial findings suggest that the application of machine learning offers an expedited reconstruction process and a streamlined procedure, thereby significantly enhancing the efficiency of the DarkSHINE experiment. Particularly in scenarios with multiple tracks or high pile-up cases, machine learning techniques have shown great potential to become superior in speed and efficiency and maintain high performances with increasing complexity.

DAQ & Slow Control / 30

基于分页内存的新一代探测器数据采集系统

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介绍通过分页内存实现的新一代的探测器数据采集程序的特性，包括程序架构，排序时间以及性能损耗。

Invited Talks / 31

高能物理科学数据与计算系统

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高能物理实验将产生海量的科学数据，当前我国高能物理实验每年产生数十 PB 的科学数据，当新一代自由电子激光和同步辐射光源投入运行后，每年将产生数百 PB 的科学数据，这些科学数据是领域科研活动的重要要素。
海量科学数据为数据管理、长期保存和共享利用技术带来了巨大挑战，需要合理、高效的数据能力、软件能力和算力能力的组织与协作，以满足科研活动需求。本报告将介绍我国高能物理领域当前科学数据和科学计算现状和未来发展趋势。

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ParticleNet and its application at CEPC Jet Flavor Tagging

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ParticleNet, a customized neural network architecture based on Dynamic Graph Convolutional Neural Network, has achieved significant improvements over all existing methods in two jet tagging tasks in proton-proton collisions: top tagging and quark-gluon tagging. Currently, it is widely used in physics analyses conducted by CMS. In this study, we employ ParticleNet in the CEPC and analyze its performance in jet flavor tagging for different configurations of the CEPC vertex detector, which has a significant impact on flavor tagging. The obtained results provide solid evidence for the efficacy of ParticleNet in the CEPC.

Quantum Computing / 33

The prospect of quantum machine learning algorithms in High Energy Physics

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Quantum computing has emerged as a promising paradigm that offers potential solutions to complex computational problems intractable for classical computers. Over the last few years, there has been a surge of interest in exploring the application of quantum algorithms in various fields, including

High Energy Physics (HEP). This talk aims to provide an overview of quantum machine learning algorithms and their applicability to HEP research. We will discuss the fundamental principles of quantum computing, including quantum superposition, entanglement, and quantum gates. We will then delve into specific quantum algorithms, such as support vector machines, highlighting their potential impact on solving computationally challenging problems in HEP.

Additionally, we will introduce the concept of a quantum particle transformer technology for jet classification, building upon the classical particle transformer framework. We will present an innovative idea for implementing a quantum version of the particle transformer, potentially revolutionising jet classification in HEP. This technology holds promise for improving the accuracy and efficiency of jet identification, a critical component of particle physics experiments.

Workshop announcement / 34

鲲鹏🄵腾产业进展及在科研领域的成果案例

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本次报告主要介绍计算产业动态，华为鲲鹏🄵腾系列产品，鲲鹏🄵腾产业和生态进展，及部分行业实践。

Invited Talks / 35

上海交大校级计算平台应对数据密集和人工智能应用的初步经验

上海交大校级计算平台应对数据密集和人工智能应用的初步经验