Contribution ID: **146** Type: **Oral Presentation**

Building a Virtual Research Environment for the Einstein Telescope Project

Friday, 20 March 2026 11:15 (25 minutes)

In this contribution, we present the development of a Virtual Research Environment (VRE) for the Einstein Telescope (ET) project, specifically in the Bologna research unit, designed to support collaborative, high-performance, and reproducible research within the ET community. The Einstein Telescope is a next-generation underground gravitational-wave observatory that will explore the Universe throughout its cosmic history. Achieving its ambitious scientific objectives - ranging from probing black-hole physics and neutron-star matter to studying dark energy and the early Universe - requires advanced computational and data-analysis infrastructures.

The ET Bologna VRE is built upon the so-called BETIF/DIFAET computing infrastructure, funded by the Italian NRRP (National Recovery and Resilience Plan): it adopts a modular, cloud-native architecture based on open-source technologies such as Docker, Kubernetes, Jupyter, and Rucio/Reana developed at CERN. This design enables both interactive analyses and large-scale computations within an orchestrated and containerized environment. The platform is fully customizable, supporting multiple software stacks via the CERN Virtual Machine File System (CVMFS) and providing seamless integration with external Rucio Storage Elements for distributed data management. Authentication and authorization are handled through Indigo-IAM, ensuring compliance with the ET federation's identity and access management policies.

Furthermore, the system supports heterogeneous computing resources, including CPU- and GPU-accelerated environments, and allows dynamic scaling according to workload and user requirements. Through its Python-friendly interface and integration with common scientific frameworks, the VRE lowers the entry barrier for analysis development while guaranteeing portability and reproducibility of workflows across the collaboration.

Beyond its immediate application to data analysis and algorithm prototyping, the ET Bologna VRE serves as a testbed for future computational strategies within the broader ETproject. It demonstrates how local resources can be orchestrated into a flexible, cloud-native environment, paving the way for a distributed, sustainable, and collaborative data-analysis model essential for the next era of gravitational-wave astronomy.

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Session Classification: Virtual Research Environment (VRE) - II

Track Classification: Track 5: Virtual Research Environment (including tools, services, workflows, portals, ... etc.)