The Study of the Quark-Gluon Plasma with the ALICE-LHC Experiment

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Scientific Context

- The Quark-Gluon Plasma (QGP) remains a key focus in high-energy physics, with active research at RHIC (USA) and LHC (Europe).
- The ALICE collaboration, focusing on relativistic heavy ion collisions, completed its detector upgrade (ALICE 2) in the past four years, following the LASF4RI strategy plan.
- ALICE aims to characterize the QGP using rare probes, focusing on high-rate data collection (50 kHz for Pb–Pb collisions) and upgraded tracking and particle identification systems.

Scientific Context

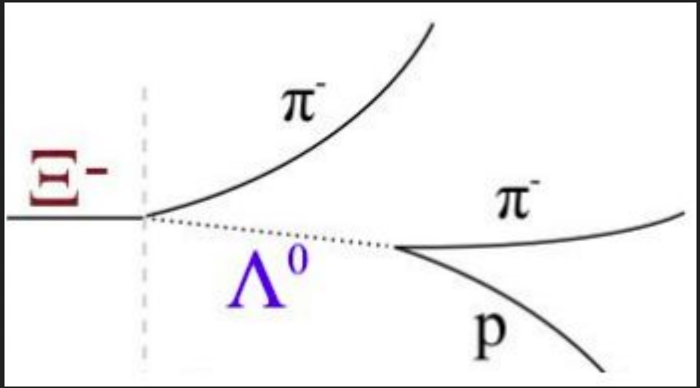
- The upgrade targets an interaction rate of 50 kHz and aims to inspect 10 nb^{-1} of Pb–Pb collisions, with enhanced data acquisition and trigger systems.
- Accurate measurements with proton-proton and proton-Pb collisions are necessary for reliable comparison with Pb–Pb data, requiring 6 pb^{-1} of integrated luminosity.
- ALICE's upgrade enhances particle identification, vertexing, and tracking, with significant contributions from Brazilian groups, including the development of the SAMPA chip for the new TPC readout system.

Objectives

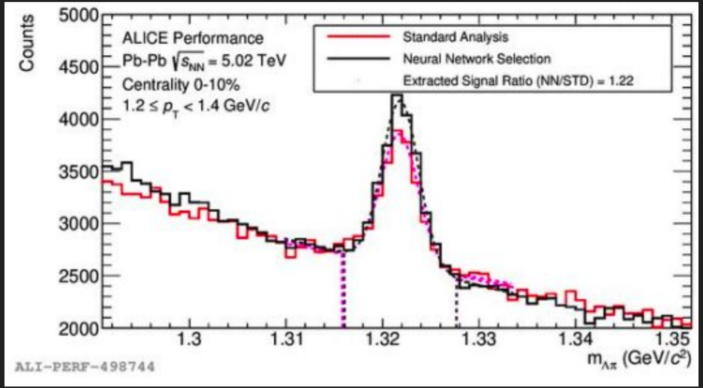
- This White Paper updates the proposal for studying Quark-Gluon Plasma within Brazilian institutions participating in the ALICE-LHC Experiment.
- The goal is to make significant contributions to Quark-Gluon Plasma research through active involvement in ALICE at the LHC.
- Objectives include developing physics analysis, advanced instrumentation, particle detectors, electronics, and software infrastructure for the experiment.
- Another key objective is training future scientists by creating graduate-level scientific projects within the ALICE collaboration.

Methodology: Strangeness Production in RHI Collisions

- Strange baryons are crucial for QGP studies, with observed enhancement in heavy-ion collisions indicating QGP formation.
- ML algorithms improve strange baryon reconstruction, especially in low p_T regions.



Cascade Decay



Cascade S/B ratio improved by ML

Methodology: Strangeness Production in RHI Collisions

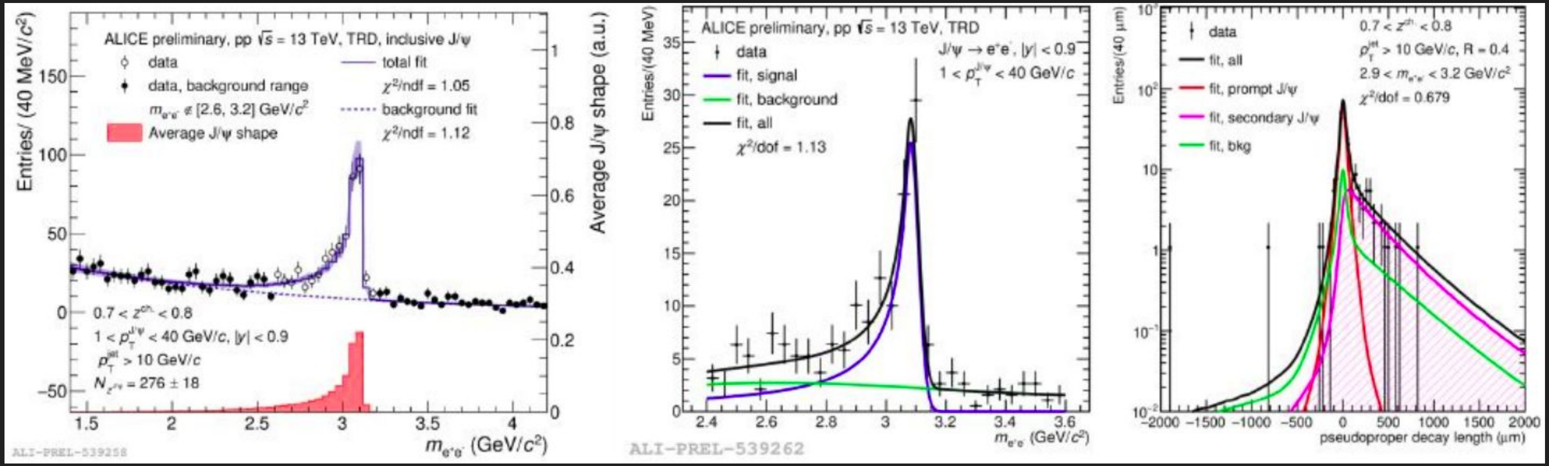
- Brazilian groups aim to enhance strange baryon measurement precision using Run 3 data and ML techniques.
- Lambda polarization studies at LHC focus on QGP vorticity and jet thermalization as hydrodynamical evolution signatures.

QGP Tomography with Hard Probes

- The study of hard probes, focusing on heavy quarkonia states and jets from heavy quark fragmentation, continues using electrons as probes.
- Heavy quarkonia like J/ψ and $\psi(2S)$ are key to understanding QGP dynamics through the interplay of suppression and recombination.
- Exotic hadrons, which don't fit traditional meson or baryon classifications, provide insights into QGP properties and medium dynamics.
- X(3872), an exotic hadron discovered by the Belle Collaboration, will be studied in the $J/\Psi\pi^+\pi^-$ channel using ALICE data.

QGP Tomography with Hard Probes

- The study of heavy quark jets will include heavy flavor jet tagging and analyzing jet fragmentation functions (FFJ), which for J/ψ, show discrepancies with current models.



J/ψ in jets

Ultra-peripheral collisions

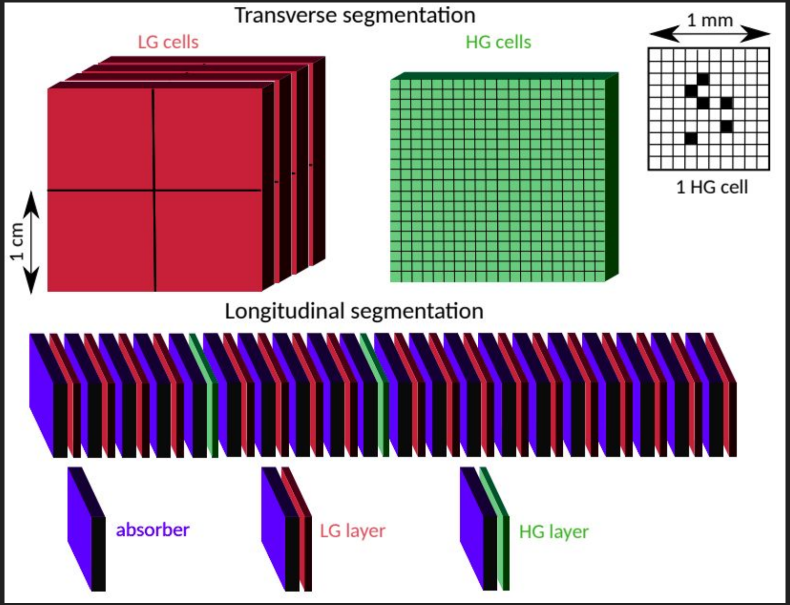
- The study of heavy quarkonia will extend to ultra-peripheral Pb-Pb collisions using the new ALICE detector, FoCal, with significant Brazilian involvement.
- J/Ψ photoproduction in ultra-peripheral Pb-Pb collisions provides insights into nuclear effects, gluon saturation, and non-perturbative QCD at very low Bjorken-x values.
- FoCal's performance was evaluated in measuring J/Ψ and Ψ' in various collision types, showing its capability to differentiate both particles through simulated data.
- Future work will expand simulations to include incoherent production and explore peripheral collision regimes beyond UPC.

Current status and expected challenges: LHC Run-3 analysis status

- Several physics analyses on Run-3 data are being conducted using ALICE's new O2 framework.
- The light flavored physics group is focusing on $\Sigma^0 \rightarrow \Lambda + \gamma$ measurement, improving photon and Lambda reconstruction by optimizing the V0 finder using Machine Learning techniques.
- Lambda reconstruction is being refined for polarization measurements, with Monte Carlo simulations evaluating polarization signals from QGP vorticity.
- Heavy flavor jets analyses involve D^0, J/ψ, and Λ_C^+ as heavy flavor taggers, aiming to study charm fragmentation in jets and the non-universal charm-to-hadron fragmentation discovered by ALICE.

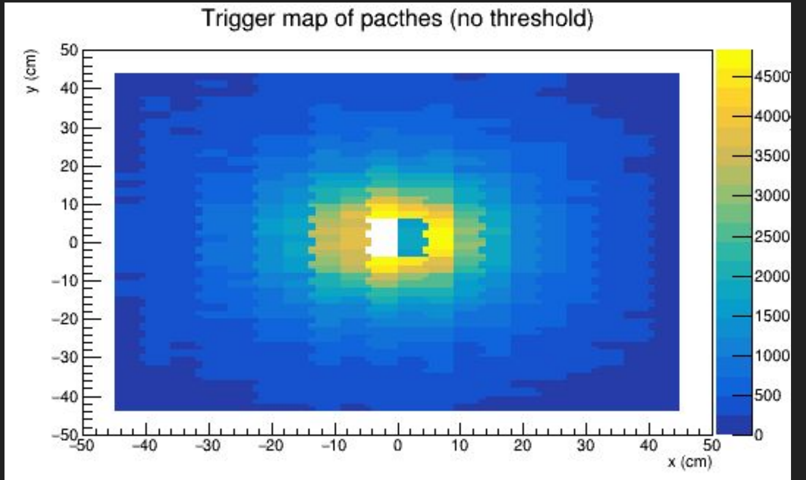
Current status and expected challenges: ALICE Upgrade for LHC Run-4

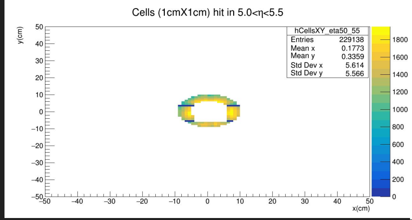
- The Brazilian ALICE group is involved in the FoCal project, a new sampling calorimeter with high spatial resolution, designed for the next LHC Run.
- FoCal's rapidity coverage enables measurements at very low Bjorken-x values, aiding in the study of gluon saturated states in nuclei.

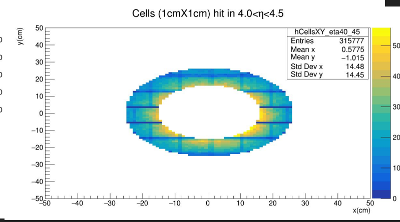


Current status and expected challenges: ALICE Upgrade for LHC Run-4

- The team is conducting simulations on the detector's sensitivity to isolated direct photons coinciding with jets to investigate gluon saturation.
- They are also simulating the need for regional triggering in PAD layers to prevent Busy-time violations when reading pixel layer data.





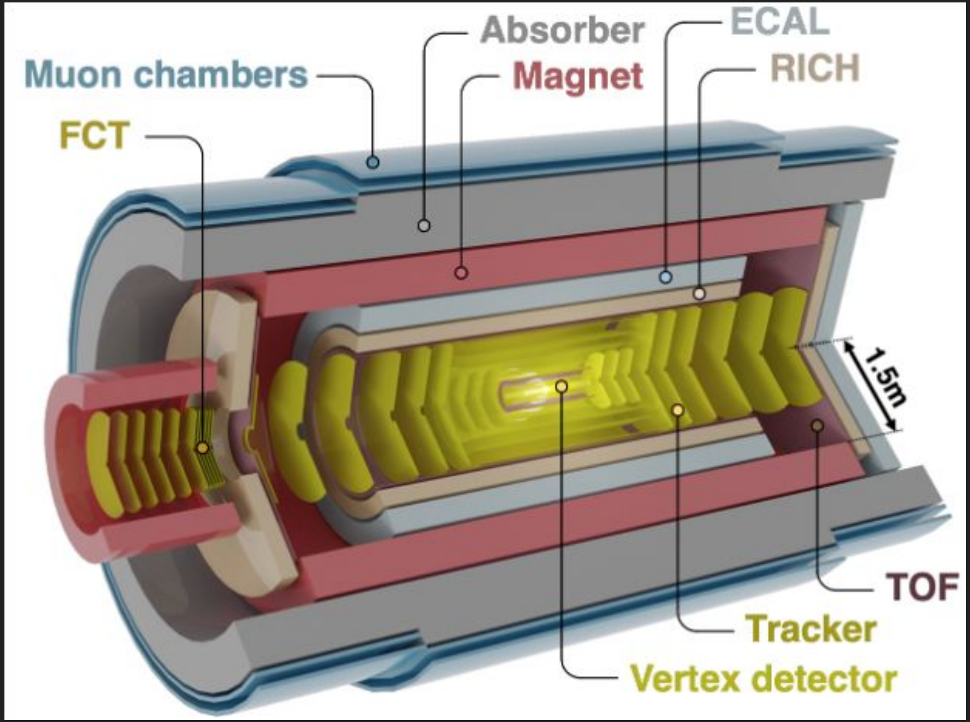


Current status and expected challenges: ALICE Upgrade for LHC Run-5

- For LHC RUN5, ALICE proposes a new detector focused on heavy ion collisions to study heavy flavor hadrons and soft electromagnetic/hadronic radiation, aiming to extract QGP properties.
- The experiment will emphasize soft phenomena in hadronic collisions, requiring high-rate capability to fully utilize LHC luminosity, and allowing studies like dark photon searches and exotic hadron measurements.

Current status and expected challenges: ALICE Upgrade for LHC Run-5

- The proposed detector will feature an all-silicon tracker with ultra-thin sensors for low transverse momentum measurements, covering rapidity $|\eta| < 4$, and a high timing resolution (≃ 20 ps) time-of-flight system for particle identification.
- Brazilian ALICE groups are actively involved in simulations and hardware development, particularly in the time-of-flight system.



Timeline

The goals discussed in this White Paper concerns the Brazilian participation in the ALICE experiment for the next 5 years, including:

- the contribution for the remaining of the LHC Run 3, until the end of 2025,
- the preparation for the LHC Run 4 during the Long Shutdown 3, from 2026 to 2028, and
- the participation in the definition of the time-of-flight system design for ALICE3 (Run 5).

Construction and operational costs: (M&O)

- Participation in large international collaborations requires shared contributions for maintenance and operation (M&O) of the experiment.
- M&O-A covers basic and general costs, divided among all PhD authors, with Brazilian groups expected to contribute 109,017 CHF in 2024 (9 scientists).
- M&O-B covers specific detector expenses, with Brazilian groups contributing to the TPC and MFT detectors, totaling around 30,000 CHF per year until Run 4 ends.
- An additional M&O-B fee of 10,000 CHF per year is expected for the FoCal upgrade during LHC Run 4.

Construction and operational costs: FoCal Readout System

- Studies on the HGCROC chip, used in FoCal's pad layers, will continue, focusing on its wide dynamic range and advanced electronics.
- The HGCROC chip features pulse height measurement, time-over-threshold techniques, and 72 readout channels, with over 7900 configuration parameters.
- Brazilian groups will develop the firmware for the Common Readout Unity (CRU) for FoCal, which interfaces data acquisition and control systems.
- The CRU, based on high-performance FPGA processors, processes, formats, and multiplexes detector data, ensuring proper communication and timing.

Construction and operational costs: ALICE3 Time Of Flight

- The ALICE3 proposal includes a high timing resolution detector (~20 ps) for particle identification, with Brazilian groups contributing to its development.
- The time-of-flight system will feature two layers in the barrel region and one in each forward region, using high granularity timing silicon detectors.
- Brazilian groups participated in testing possible detector candidates (MadPix, LGADs, SiPM) at CERN's T10 PS line with 10 GeV/c protons.
- MadPix (Monolithic CMOS Avalanche Detector PIXelated Prototype), a monolithic LGAD with integrated high-speed electronics, is the main candidate, with a final technology decision expected by 2025.

Computing requirements

- The ALICE groups in Brazil have contributed to the experiment through the SAMPA (*Sistema de Análise e Multi-Processamento Avançado*) cluster, financed by FAPESP and hosted at IFUSP.
- SAMPA has 2408 CPU cores, offering 18.7 kHS06 of processing power and 1.5 PB of storage, supported by IFUSP's infrastructure.
- A 15% annual increase in computing power and storage demand is expected over the next 5 years.
- Brazilian ALICE groups are committed to securing funds to meet the growing computing needs.
- The SAMPA cluster has been essential since the start of LHC operations, continuously supporting the ALICE experiment

List of the interested scientists in the community

- Alexandre A. P. Suaide (USP) - Computing Infrastructure and Data Analysis
- Cristiane Jahnke (UNICAMP) - Data Analysis
- Cristiano Krugg (UFRGS) - Instrumentation
- Marco Bregant (USP) - Instrumentation
- Tiago Fiorini da Silva (USP) - Instrumentation