NICA

The MexNICA program at the Multi-Purpose Detector

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on behalf of the MexNICA Collaboration

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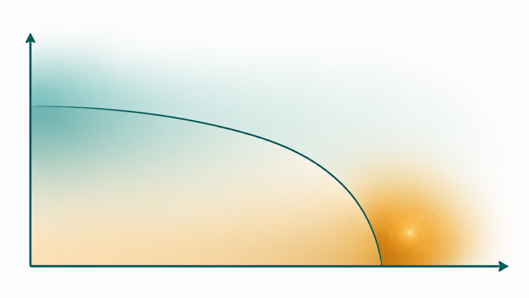
Where we are going

Three threads, one program.

This talk follows three connected ideas. First, the physics that makes the baryon-rich corner of the QCD phase diagram worth exploring. Then the detector that Mexican groups built to read those collisions, the miniBeBe. And finally the predictions that the theory and phenomenology groups put on the table for what the data should reveal.

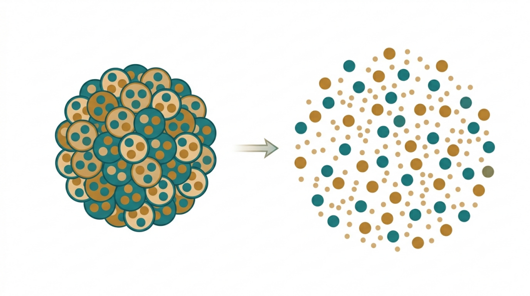


Why NICA: the physics

The question behind the program

What happens to matter squeezed far beyond the density of a nucleus?

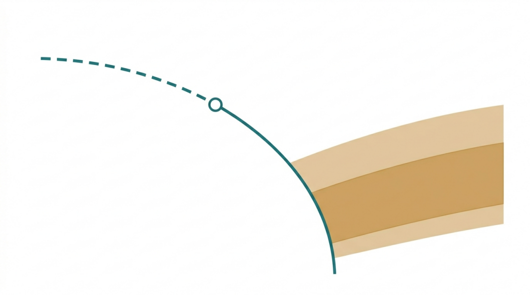
Protons and neutrons are not the final word. Push nuclear matter to a high enough temperature or density and the quarks and gluons inside stop behaving as separate, confined objects. NICA was designed to recreate that regime and to watch ordinary nuclear matter give way to a deconfined state.



The QCD phase diagram

A map with two axes: temperature and baryon density.

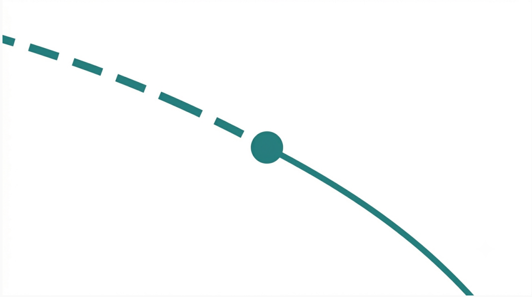
The hot, dilute corner is the one explored at the LHC and at the top energies of RHIC, where the change from hadrons to a quark-gluon plasma is a smooth crossover. The opposite corner, dense and comparatively cool, is far less understood. NICA sits squarely in that baryon-rich region, and that is exactly where theory predicts the most interesting structure.



The critical end point

The crossover does not stay a crossover forever.

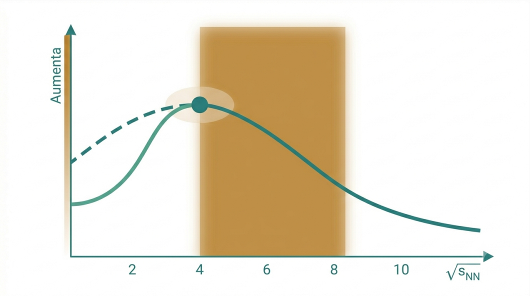
As baryon density grows, calculations suggest the smooth transition sharpens into a genuine first-order line. The point where that line begins, the critical end point, would be a landmark on the diagram, the analogue of a critical point in an everyday substance. Locating it, or bounding where it cannot be, is one of the central goals of the field.



Why these collision energies

Lower energy can mean denser matter.

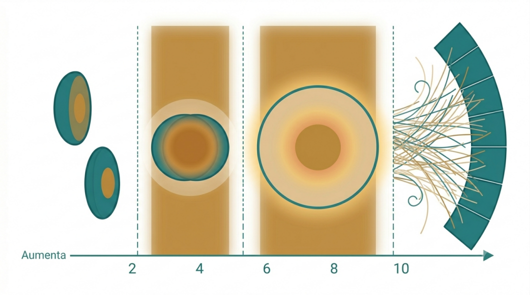
It sounds backwards at first. The highest energies make the hottest fireballs, but they also let the colliding nuclei pass through each other, leaving little net baryon density behind. At the energies NICA reaches, a few GeV per nucleon pair, the nuclei stop in one another and the density in the overlap region climbs to its maximum. That is what makes these energies the right tool for the dense corner of the diagram.



Heavy-ion collisions as the tool

A controlled, very small explosion.

Two heavy nuclei meet, deposit their energy in a tiny volume, and form a hot fireball that expands and cools in a few times 10^{-23} seconds. The particles that reach the detectors are the frozen-out remnants of that evolution. Reading them backwards, from the final spectra to the conditions that produced them, is how a single collision becomes a measurement of the phase diagram.

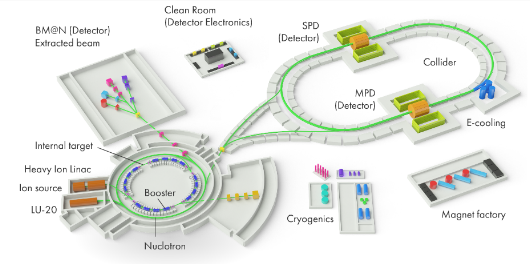


The facility and the MPD

NICA at JINR, Dubna

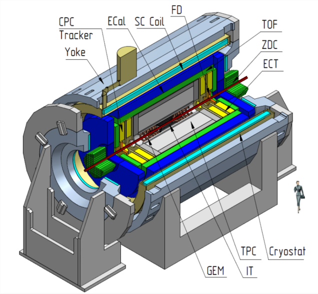
A new collider, built on an existing accelerator.

NICA, the Nuclotron-based Ion Collider Facility, is in final construction at the Joint Institute for Nuclear Research in Dubna. The existing Nuclotron feeds heavy ions into two new collider rings, and the beams meet at two interaction points. The machine can scan a range of energies, which is precisely what a search across the phase diagram needs.



Where the collisions are recorded.

The MPD wraps a set of subsystems around one interaction point inside a superconducting solenoid. A large time projection chamber reconstructs the tracks of charged particles, while a time-of-flight wall identifies them by how long each one takes to arrive. To separate pions, kaons, and protons cleanly, that timing has to be sharp, and sharp timing needs a precise start signal.



The MexNICA Collaboration

Mexico inside the experiment, since 2016.

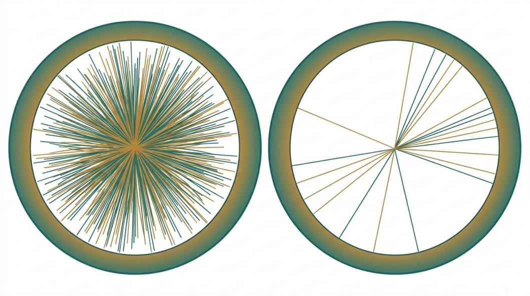
MexNICA brings together five Mexican institutions and a mix of researchers, postdocs, engineers, and students working on the MPD. The effort runs along two lines that this talk takes in turn: an experimental contribution centered on detector hardware, and a phenomenology and theory program aimed at the dense matter that NICA produces. The shared aim is to make Mexico a working partner in this physics, not only a spectator.

Experimental pillar: miniBeBe

The trigger problem

Not every interesting collision is a busy one.

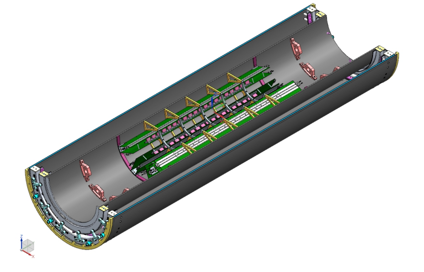
Central collisions throw hundreds of particles into the detector and are easy to flag. Peripheral collisions, and lighter colliding systems, produce far fewer, and a trigger tuned for crowded events can simply miss them. A detector that fires reliably even on low-multiplicity events widens the reach of the MPD toward exactly those cases.

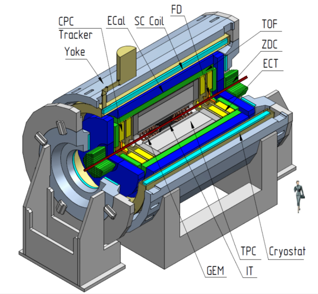


What miniBeBe is

A fast wake-up call for the time-of-flight system.

The miniBeBe is a compact, fast-timing detector that sits close to the beam pipe and announces that a collision has happened. It hands the time-of-flight wall a clean start signal with a resolution at or below 100 picoseconds, the figure required to tell pions, kaons, and protons apart across the full momentum range the MPD sees. Its small size and modest cost make it a practical choice for the first phase of operation.

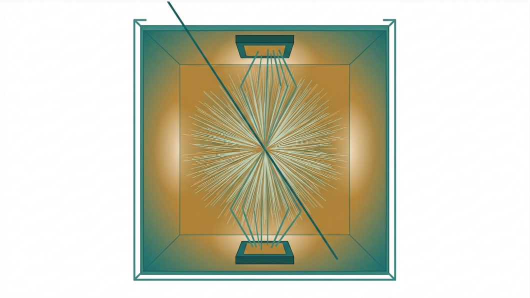




Detection principle

Plastic that glows, read from both sides.

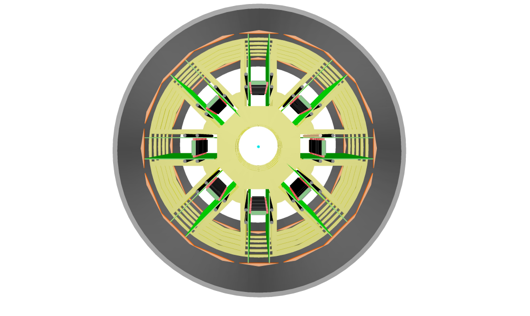
Each cell is a tile of plastic scintillator that flashes when a charged particle crosses it. Two silicon photomultipliers, one on each opposite face, collect that light. Reading both faces does two jobs at once: it gathers more light, and it cancels the dependence on where along the tile the particle passed, so the measured time no longer drifts with hit position.



Layout: one hundred sixty cells, eight modules

A geometry chosen with intent.

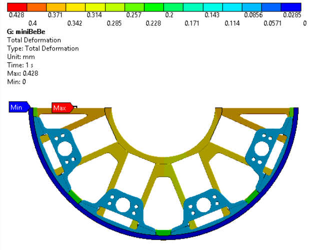
The cells are grouped into eight longitudinal modules around the beam line. The arrangement keeps the coverage uniform and the per-cell timing consistent no matter where a particle lands. What looks like a plain ring of scintillators is the outcome of balancing acceptance, light yield, and the tight space available near the interaction point.



Mechanical design

Engineering that has to respect a hostile neighborhood.

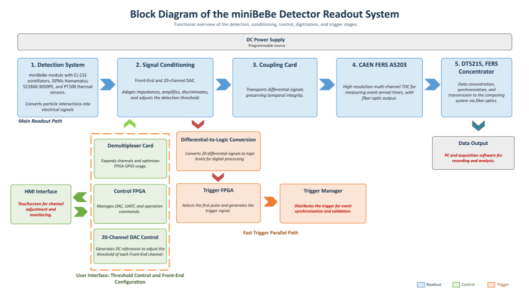
The support structure was validated with finite-element analysis and built from non-ferromagnetic materials, since it lives inside a strong magnetic field. It keeps the material budget low so it disturbs particle trajectories as little as possible, manages heat to hold the silicon photomultipliers at a stable temperature, and stays rigid under handling and operation. It was also designed to come out cleanly after Phase I, leaving room for the future inner tracking system.



Front-end and bias voltage

Every channel needs its own care.

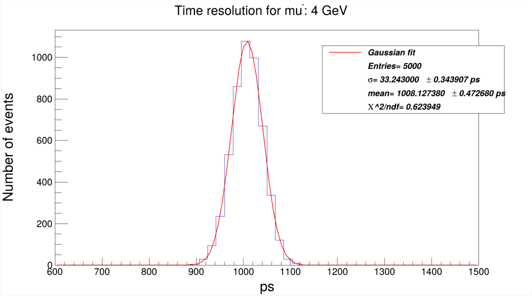
Behind the cells sits the front-end electronics that shape and time the photomultiplier pulses, together with a bias system that sets and trims the operating voltage channel by channel. Silicon photomultipliers respond strongly to their bias point and to temperature, so individual control over each channel keeps the whole array behaving uniformly.



Performance

Two independent checks, one answer.

Geant4 simulations and laboratory tests with cosmic muons were both used to measure how well a single cell keeps time. The two routes land on the same result: a per-cell resolution near 50 picoseconds, comfortably inside the requirement, with a trigger efficiency that holds up under realistic collision conditions. The material that the detector adds within the MPD acceptance was estimated as well and stays within budget.

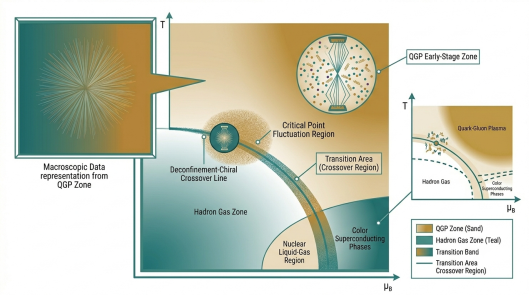


Phenomenological pillar

Predictions for the baryon-rich region

Theory pointing the experiment toward specific signals.

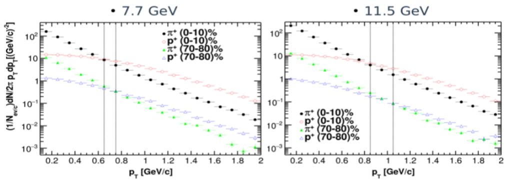
The phenomenology effort does not stop at general statements about dense matter. It produces concrete observables, each tied to a feature of the phase diagram, that the MPD can actually measure. The slides that follow walk through the main ones, several of them developed together with partners across Latin America.



Baryon-to-meson transition

Where the spectra cross.

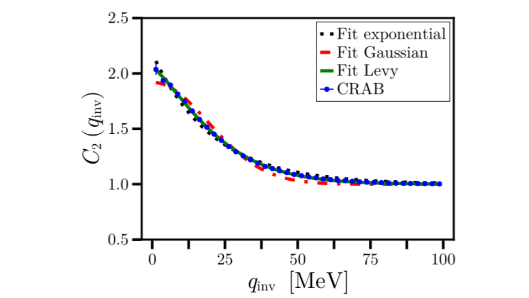
When the transverse-momentum spectra of baryons and mesons are compared, they meet at a crossing point whose position carries information about the freeze-out conditions. Following how that point moves with collision energy helps pin down where the transition region lies, turning a feature of the data into a coordinate on the phase diagram.



Pion femtoscopy with Lévy sources

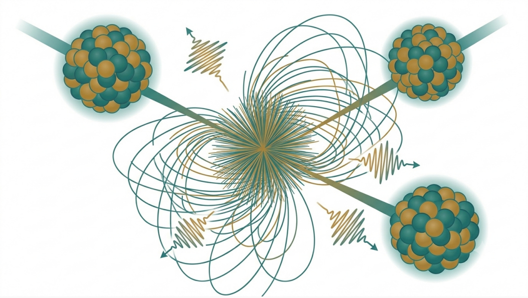
Measuring the size and shape of the source.

Correlations between pairs of pions encode the geometry of the region that emitted them. Describing that region with Lévy-stable distributions, rather than a simple Gaussian, captures its true structure more faithfully and opens a way to look for the large fluctuations that would appear near a critical point.



A glimpse of the first instants.

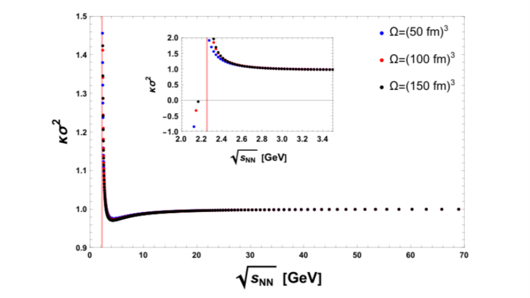
The colliding ions generate enormous, fleeting magnetic fields. Photons produced under those fields carry news from the pre-equilibrium stage, before the system settles, and probe processes dominated by gluons. Predicting their rates gives access to a moment in the collision that ordinary hadronic observables cannot reach.



Searching for the critical point

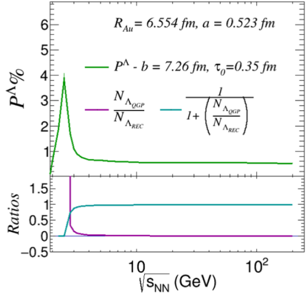
Several independent fingerprints, not just one.

A claim about the critical point is only convincing if more than one observable agrees. The program combines ratios of event-by-event cumulants, sensitive to fluctuations, with signatures in the speed of sound of the matter. Read together, these measurements can box in the location of the critical point rather than rest on a single number.



A flagship measurement that NICA is built for.

The matter created in an off-center collision swirls, and that vorticity can align the spins of produced hyperons. Predictions place a peak in this polarization right at the NICA energy range, which makes it a measurement uniquely suited to this facility. The core-corona picture connects the size of the effect to the vorticity and to the freeze-out dynamics, giving the data a clear physical reading.



Outlook

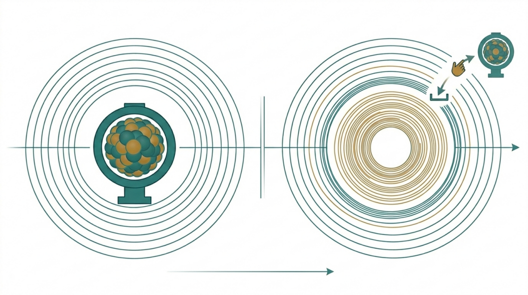
Building people and capabilities

The detector is not the only thing being built.

Carrying this work forward trains students and postdocs in detector technology, large-scale computing, and the theory of strongly interacting matter. Those skills travel well beyond NICA, into other parts of particle and nuclear physics, and they stay in Mexico as lasting capacity. The collaboration treats that human investment as part of the deliverable, not a side effect.

Phase I now, upgrades ahead.

The miniBeBe is ready to serve as the trigger for the first phase of MPD operation. Its removable design lets it step aside later to make room for the inner tracking system, so the contribution fits into the longer evolution of the experiment rather than fixing it in place. The data from these first runs is what the phenomenology predictions are waiting for.



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Thank you.