Prospects for Dilepton Measurements in the MPD Experiment at NICA

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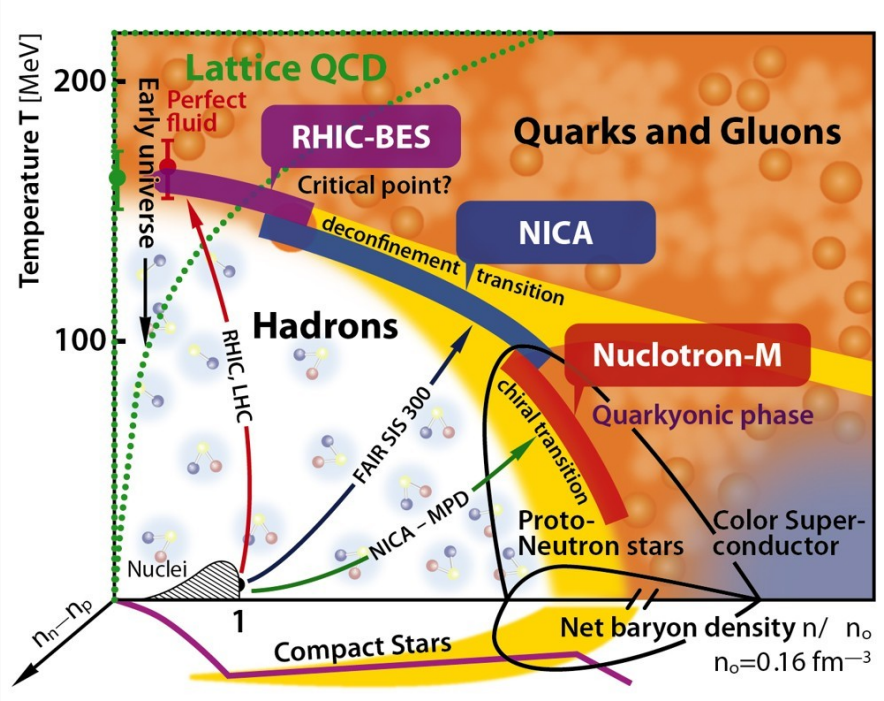
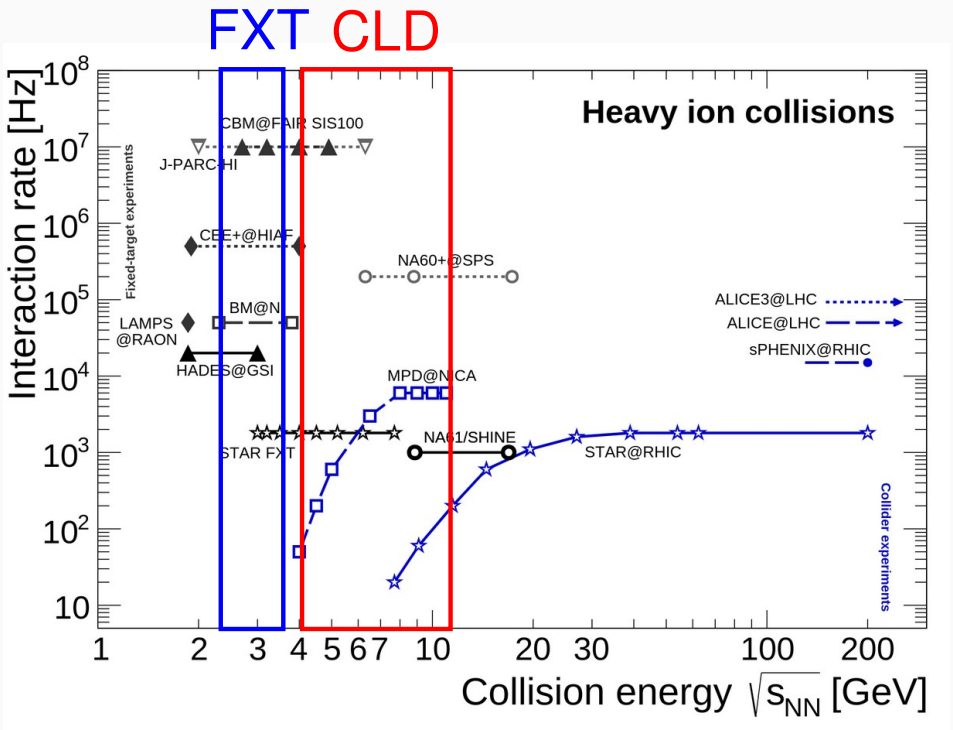
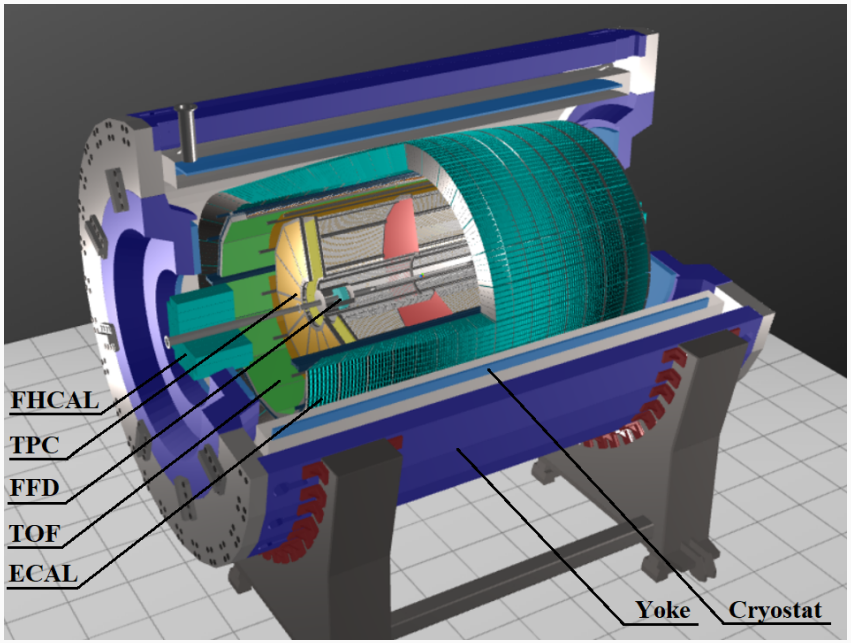
Heavy-ion collisions

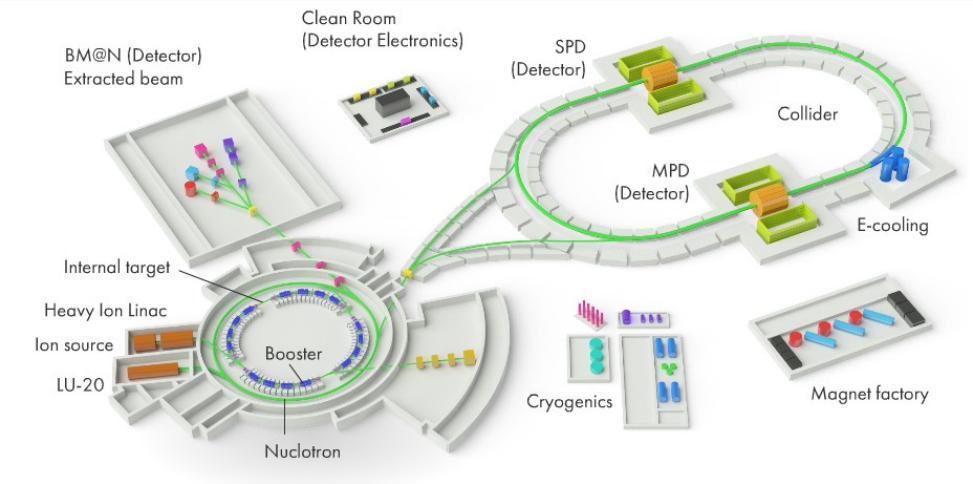




- Smooth crossover at $\mu_B \approx 0 \leftarrow$ Early universe like conditions.
- Explore high μ_B matter $\rightarrow$ Critical end point and 1st order phase transition.
- Similar net baryon density expected as in the core of neutron stars.
- MPD and BM@N $\rightarrow$ QCD matter study at these densities.
- Various experiments, such as NA61/Shine, STAR-BES and CBM in similar beam energy range.

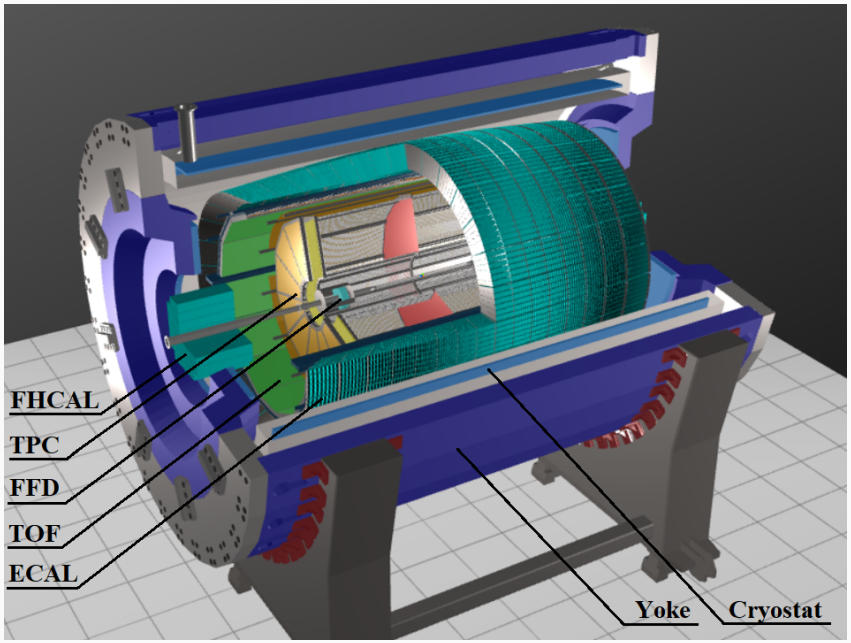
Multi-Purpose Detector (MPD) experiment at NICA

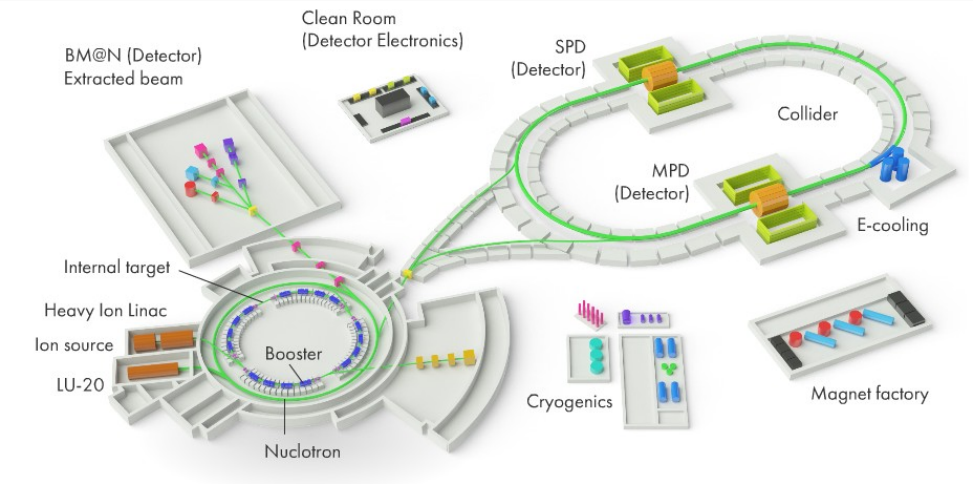




- Nuclotron-based Ion Collider fAcility (NICA) is the first megascience project in Russia $\rightarrow$ approaching its full commissioning.
- MPD is a flagship experiment at NICA: starting operations in 2026.
- Modes of operation:
  - Collider mode: two beams, $\sqrt{s_{\mathrm{NN}}}$ = 4-11 GeV $\rightarrow$ Xe+Xe/Bi+Bi at $\sqrt{s_{\mathrm{NN}}} \approx 7$ GeV, $\approx$ 50 Hz at start-up
  - Fixed-target mode: one beam + thin wire (50 μm), $\sqrt{s_{\mathrm{NN}}}$ = 2.4-3.5 GeV $\rightarrow$ Xe/Bi+W/Au at $\sqrt{s_{\mathrm{NN}}} \approx 3$ GeV, $\approx$ kHz at start-up

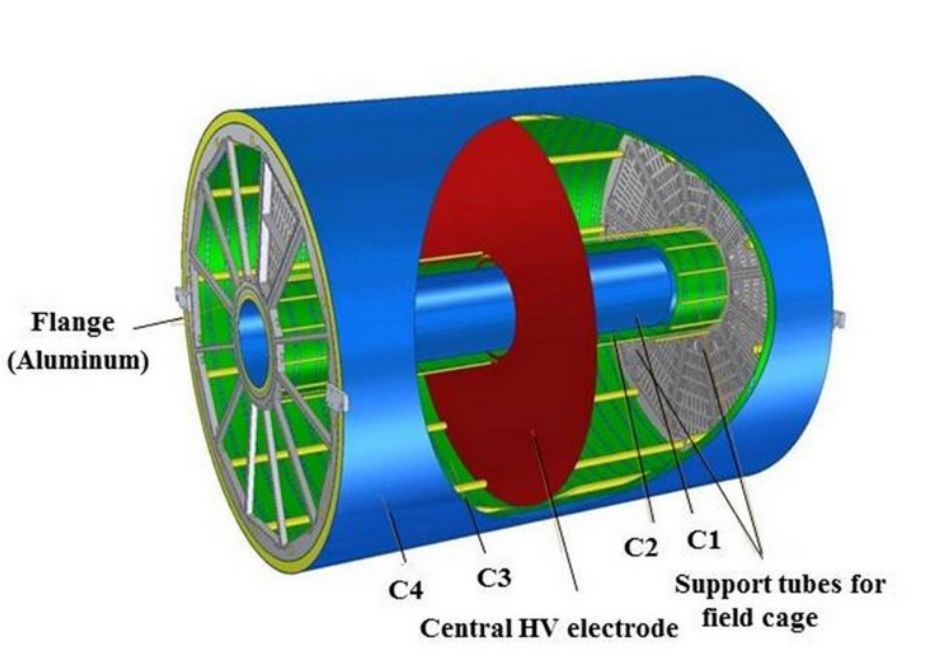
Multi-Purpose Detector (MPD) experiment at NICA

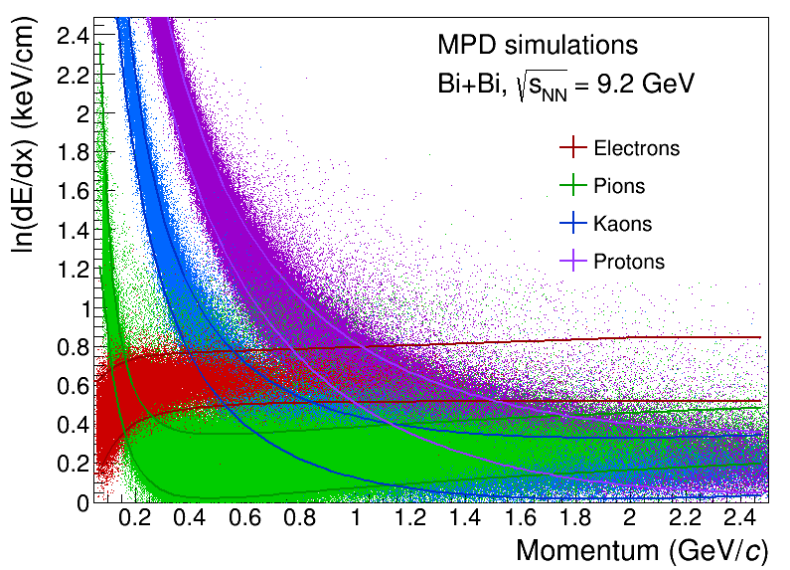




- Strategy: High luminosity scans in energy and system size to measure different signals.
- Advantages: Same apparatus for scans with benefits of collider geometry.
  - maximum phase space, correlated systematic effects for different systems and energies.
- Sub-systems with modern technologies: TPC, TOF, ECal, FFD, FHCal.
- Suitable for dilepton measurements: e+e- pairs.

Time Projection Chamber (TPC)

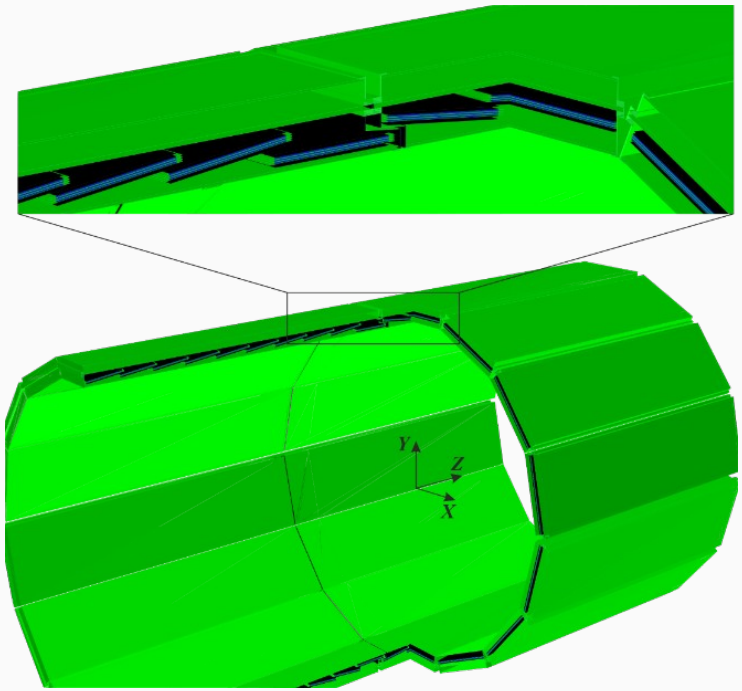


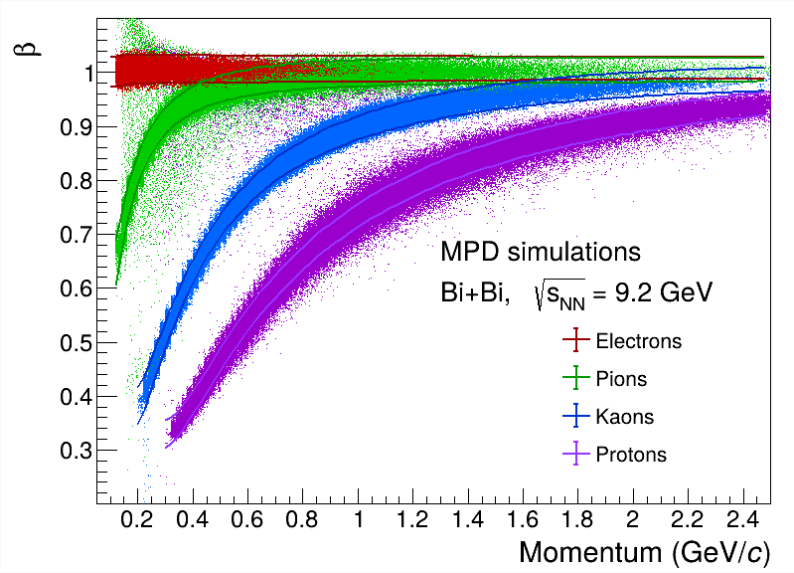


- 3D tracking + dE/dx measurement.
- The achieved accuracy of the energy loss is 6-7% and momentum resolution between 1-3%.
- Discrimination of charged pions from kaons up to momenta of ≈ 0.7 GeV/c and kaons from protons up to ≈ 1.1 GeV/c.
- 24+ ROC ready; 100+ % FE cards manufactured TPC gas volume assembly and HV/leakage tests – ongoing TPC + ECAL cooling systems under commissioning

Ready for installation by end of the year

Time Of Flight (TOF)

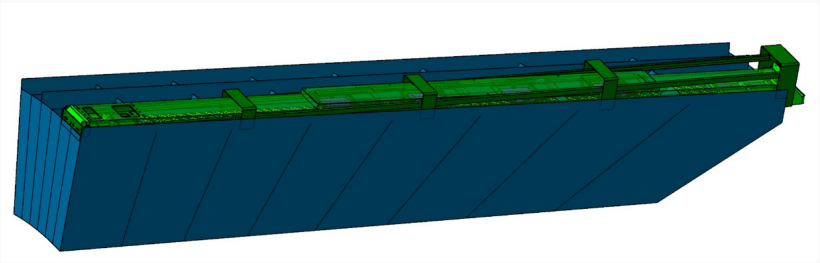


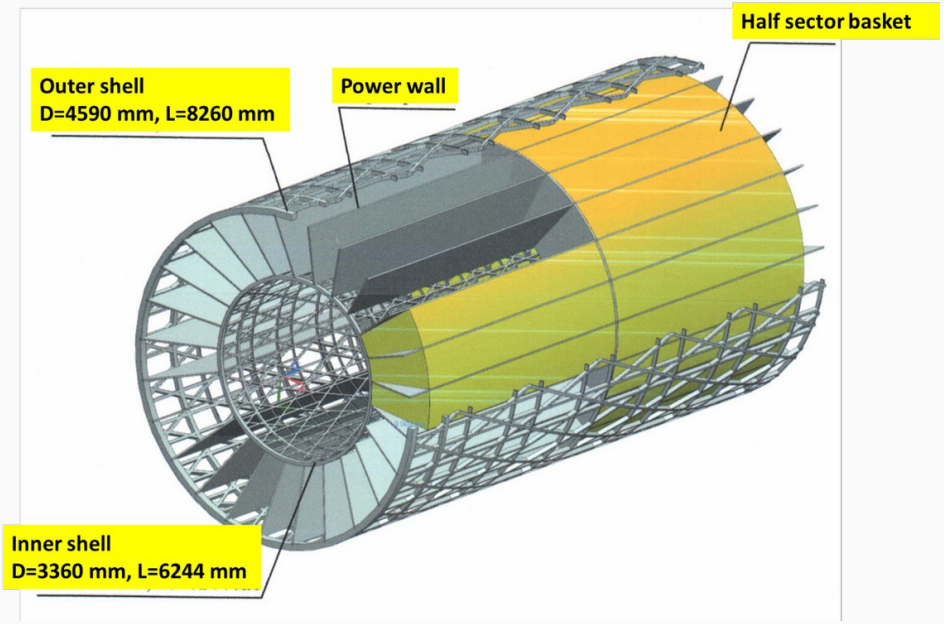


- Based on the technology of (MRPC).
- Measures time-of-flight of the track.
- All 28 (100%) TOF modules are assembled, tested, stored and ready for installation and Spare modules in production.
- Designed Time and coordinate resolution of $\approx$ 80 ps and $\approx$ 0.5 cm, respectively.
- Better PID perfomance is achieved when combined with TPC.

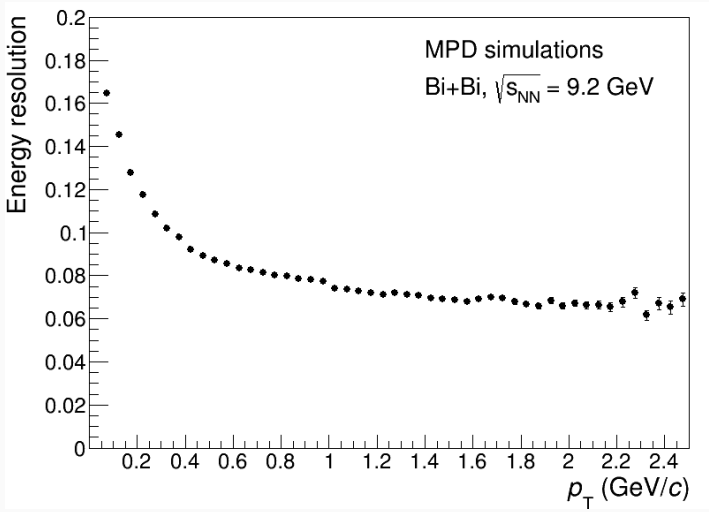
Ready for installation

Electromagnetic Calorimeter (ECal)





- A shashlik type calorimeter made of Pb-scintillator sandwiches.
- Full configuration: 50 half-sectors in full azimuth (25 full sectors).
- Measures deposited energy and detect particles from 10 MeV to a few GeV.
- Energy resolution is about 7% at 1 GeV.
- 40 (45) half-sectors to be ready by August (October), the rest depends on WLS fiber supply.



Expected installation by end of the year

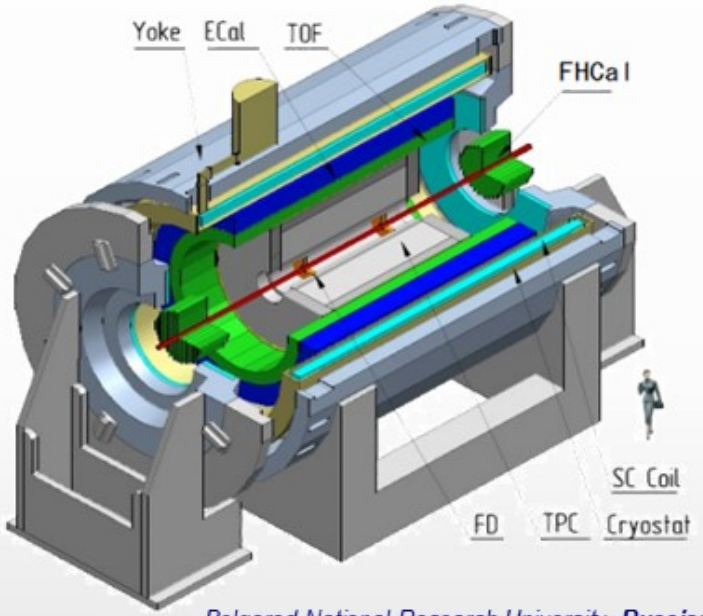
Multi-Purpose Detector (MPD) Collaboration

MPD *International Collaboration was established in* ***2018*** *to construct, commission and operate the detector*

12 *Countries,* ***>500*** *participants,* ***38*** *Institutions and* ***JINR***

Organization

Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***



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Institute of Power Engineering of the National Academy of Sciences of Belarus, ***Belarus***;
University of Plovdiv, ***Bulgaria;***
Tsinghua University, Beijing, ***China***;
University of Science and Technology of China, Hefei, ***China***;
Huzhou University, Huizhou, ***China***;
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China***;
Central China Normal University, ***China***;
Shandong University, Shandong, ***China***;
University of Chinese Academy of Sciences, Beijing, ***China***;
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Institute of Modern Physics of CAS, Lanzhou, ***China***;
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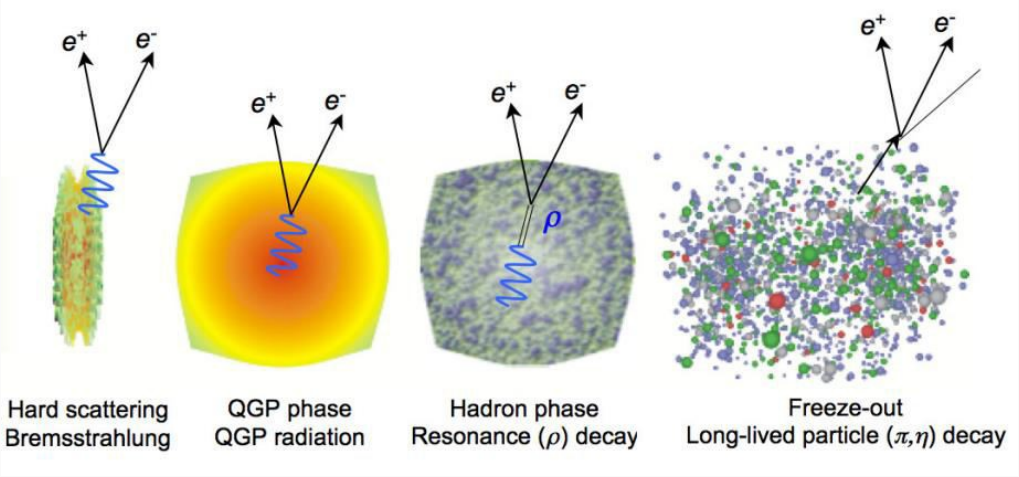
Petersburg Nuclear Physics Institute, Gatchina, ***Russia***;
Vinča Institute of Nuclear Sciences, ***Serbia***;
Pavol Jozef Šafárik University, Košice, ***Slovakia***

Dileptons

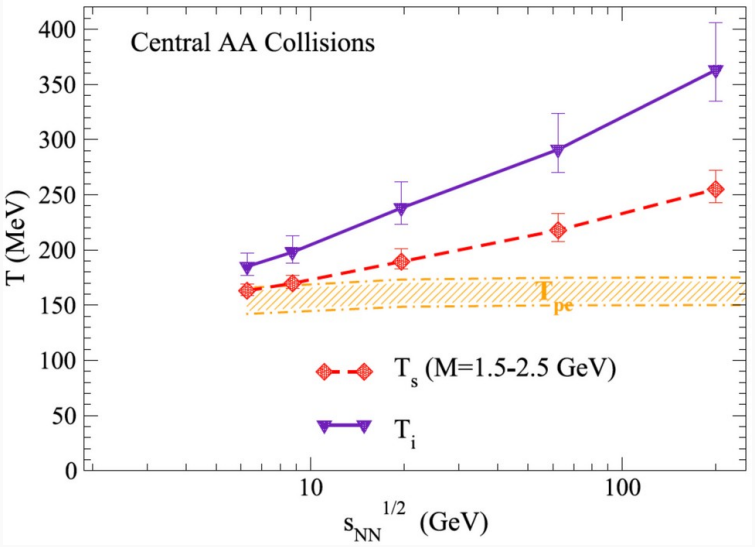
- Penetrative probe of hot and dense nuclear matter.
  - Deconfinement
  - Chiral symmetry restoration
- Advantages:
  - Interacts electromagnetically
  - Large mean free path in contrasts to system size
  - Provide undistorted information at the time of their production.
- Challenges:
  - Overlapping signal→produce at different stages of the collision.
  - Inherit large combinatorial background from Dalitz as well as conversions.

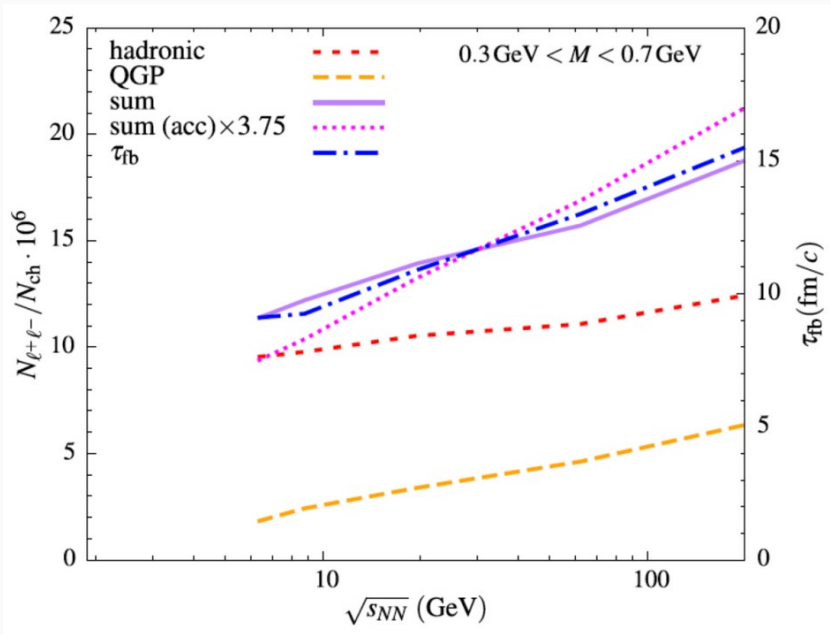


i	Dilepton channels	
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+ e^-$
2	Dalitz decay of η:	$\eta \to \gamma l^+ l^-$
3	Dalitz decay of ω:	$\omega \to \pi^0 l^+ l^-$
4	Dalitz decay of Δ:	$\Delta \to N l^+ l^-$
5	Direct decay of ω:	$\omega \to l^+ l^-$
6	Direct decay of ρ:	$\rho \to l^+ l^-$
7	Direct decay of ϕ:	$\phi \to l^+ l^-$
8	Direct decay of J/Ψ:	$J/\Psi \to l^+ l^-$
9	Direct decay of Ψ':	$\Psi' \to l^+ l^-$
10	Dalitz decay of η':	$\eta' \to \gamma l^+ l^-$
11	pn bremsstrahlung:	$pn \to pn l^+ l^-$
12	$\pi^\pm N$ bremsstrahlung:	$\pi^\pm N \to \pi N l^+ l^-$

Dileptons

- Thermal dileptons provide direct fingerprint of the QGP and HG matter.
- Provide insights into fireball properties when measured in different invariant mass region.
- Intermediate Mass Region: Closely related to the initial temperature of the fire ball: “thermometer” for the heavy-ion collisions.
- Low Mass Region: Sum of QGP and hadronic contributions proportional to fireball lifetime: “chronometer” for heavy-ion collisions



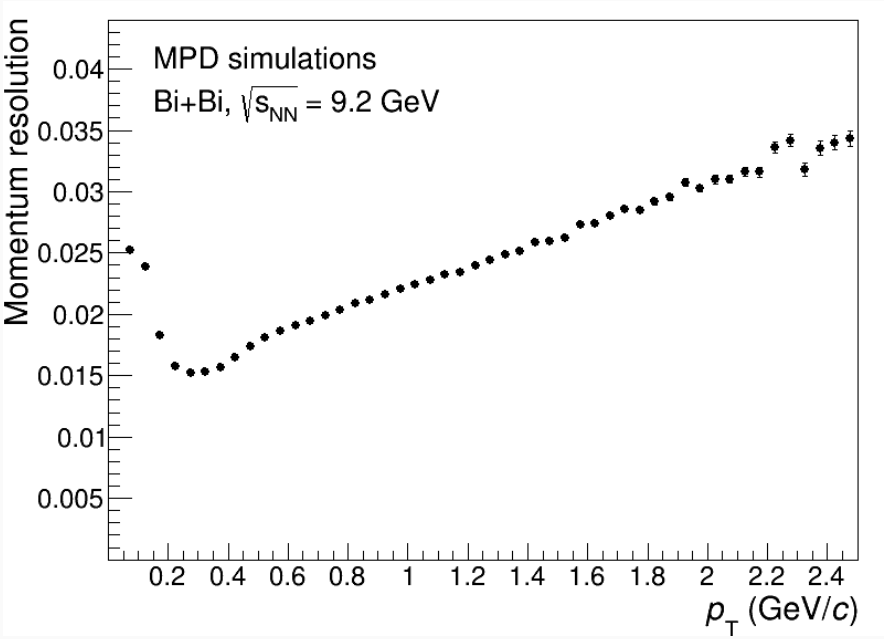


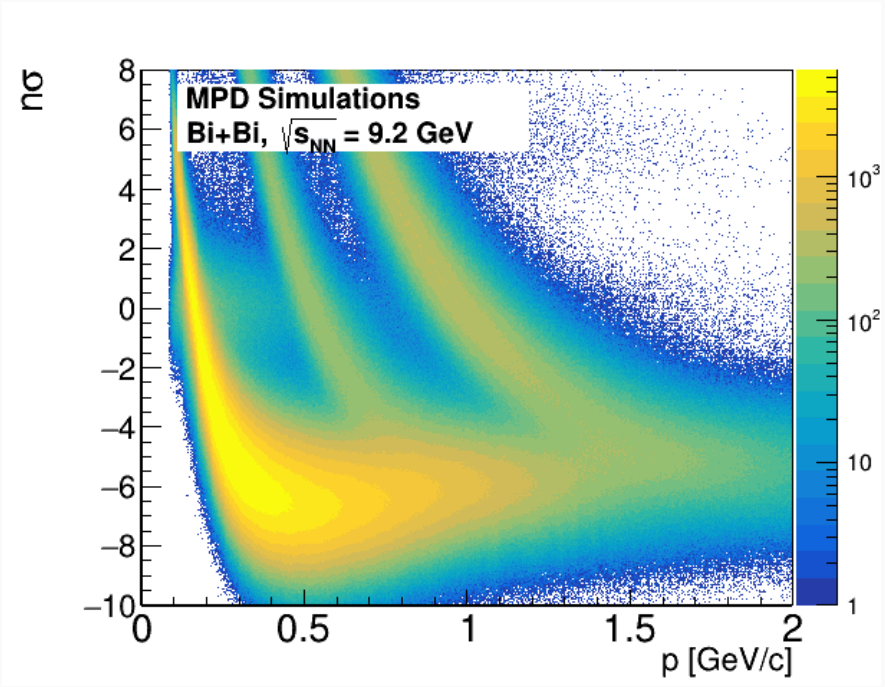
Dilepton analysis

- UrQMD event generator is used to simulate heavy-ion events: 15 million minimum bias Bi+Bi collisions at $\sqrt{s_{\mathrm{NN}}}$ = 9.2 GeV.
- Dielectron cocktail shapes and multiplicities in UrQMD were matched to those from PHSD event generator.
- To improve statistical significance, branching ratios of dielectron sources, except π^0 and η dalitz decays, were enhanced by factor 20.
- Challenges in dielectron measurements:
  - Small multiplicities as well as branching ratios of the signal dielectron sources compared to the background: analyses are statistics hungry.
  - Huge combinatorial background (CB) from photon conversions and Dalitz decays pairs: when one of the legs is not reconstructed.

For such complicated analysis, excellent detector performance is needed!

Track reconstruction and Particle Identification (PID)

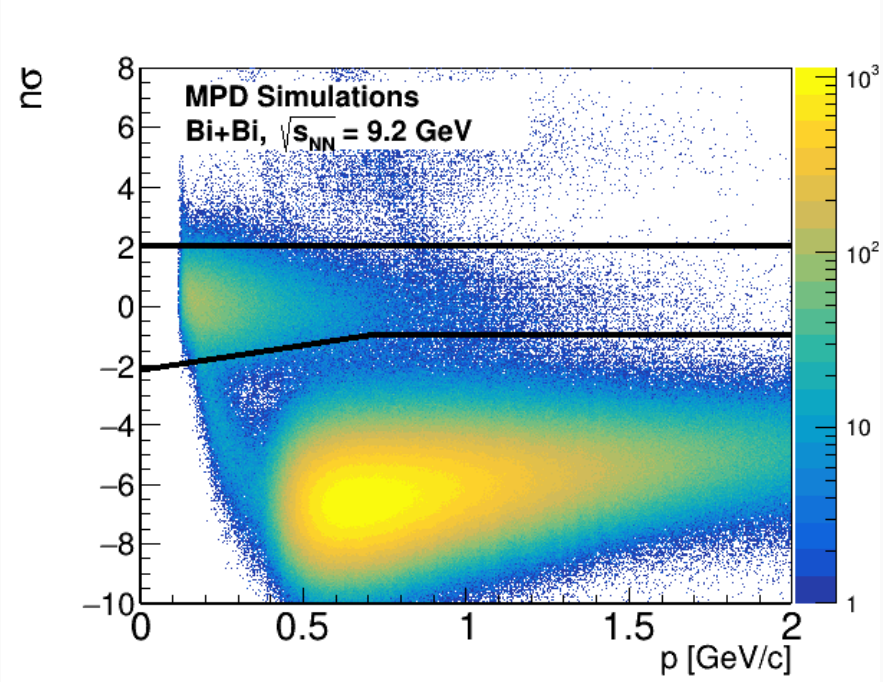


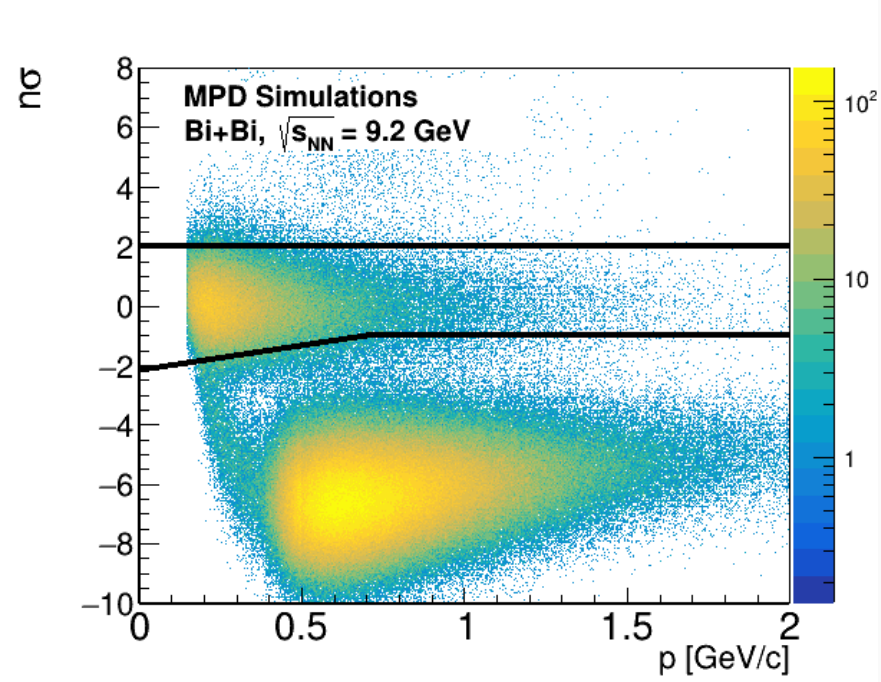


- MPD has excellent track reconstruction and particle identification capabilities with the help of TPC, TOF and ECal.
- TPC measures momentum and provides resolution of about 1-3%.

Measures $< \mathrm{dE/dX} >$ as well with good resolution!

Track reconstruction and Particle Identification (PID)

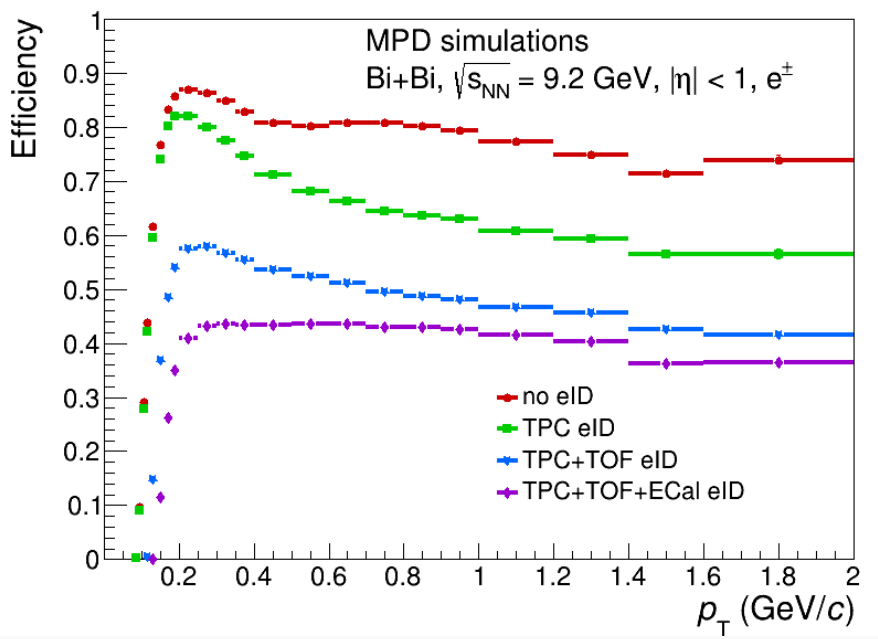


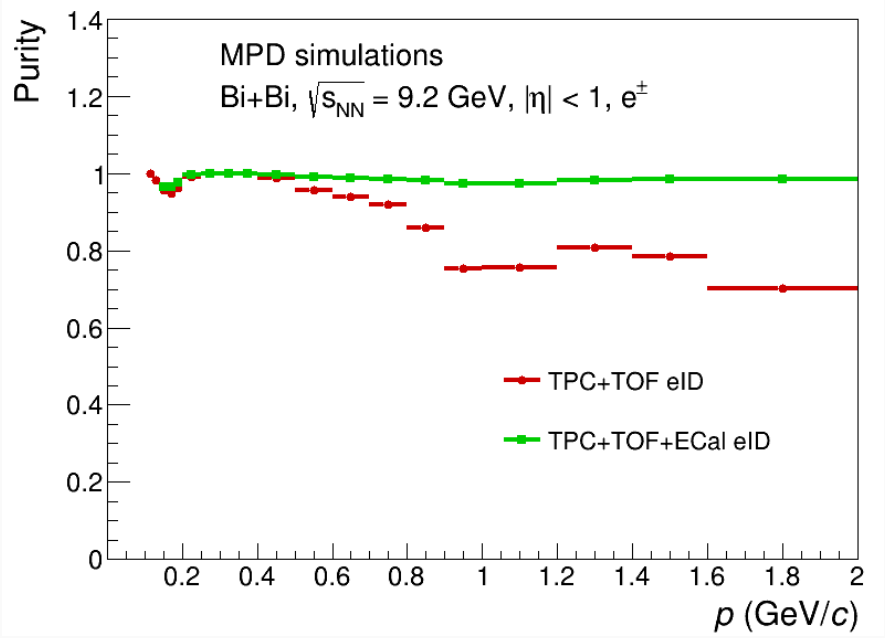


- MPD has excellent track reconstruction and particle identification capabilities with the help of TPC, TOF and ECal.
- TPC measures momentum and provides resolution of about 1-3%.
- TPC alone is not enough to achieve pure electron sample.

The purity improves with TOF and ECal!

Electron reconstruction efficiency and Purity

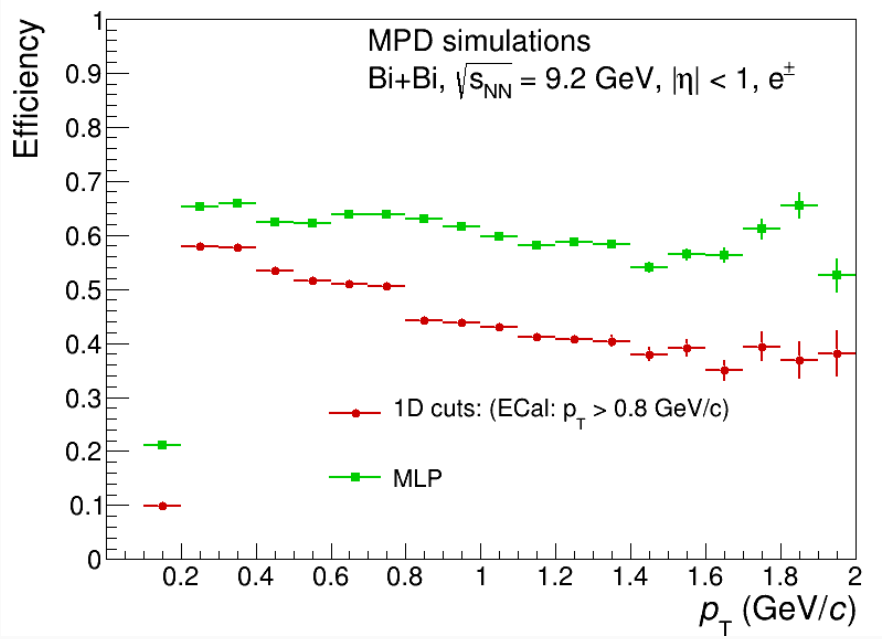


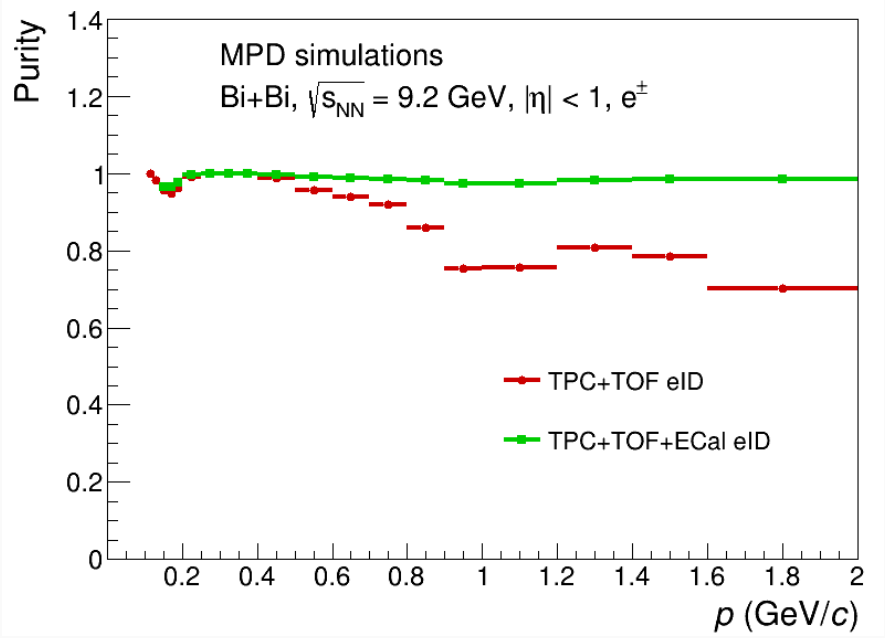


- With TOF, purity reaches about 80% and efficiency of about 50% is achieved.
- The purity can reach up to 100% with the help of ECal along with nearly 45% efficiency: exceptional electron-hadron separation above $p \gtrapprox 0.8$ GeV/c.

Such performance is crucial for dilepton analysis!

Benefit of Machine learning in PID

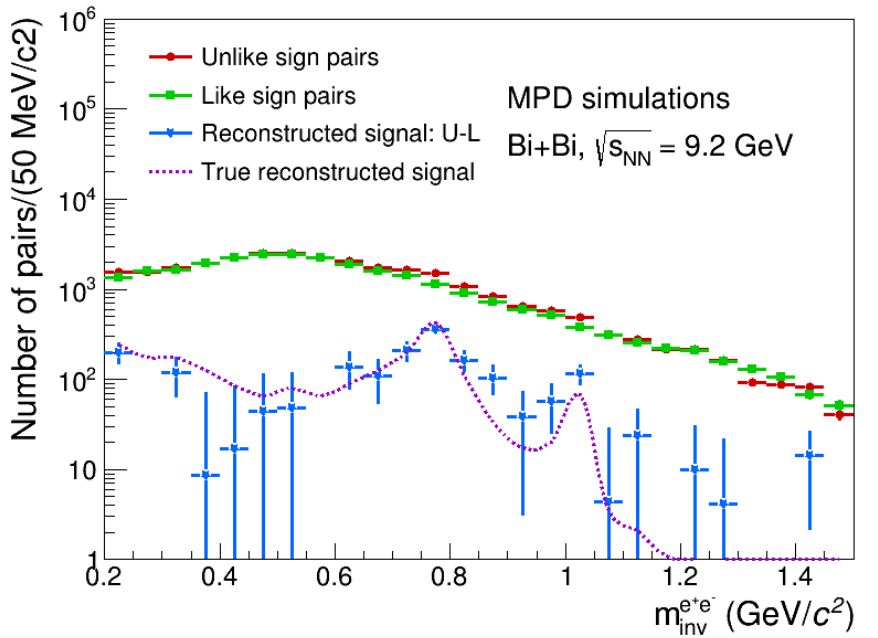


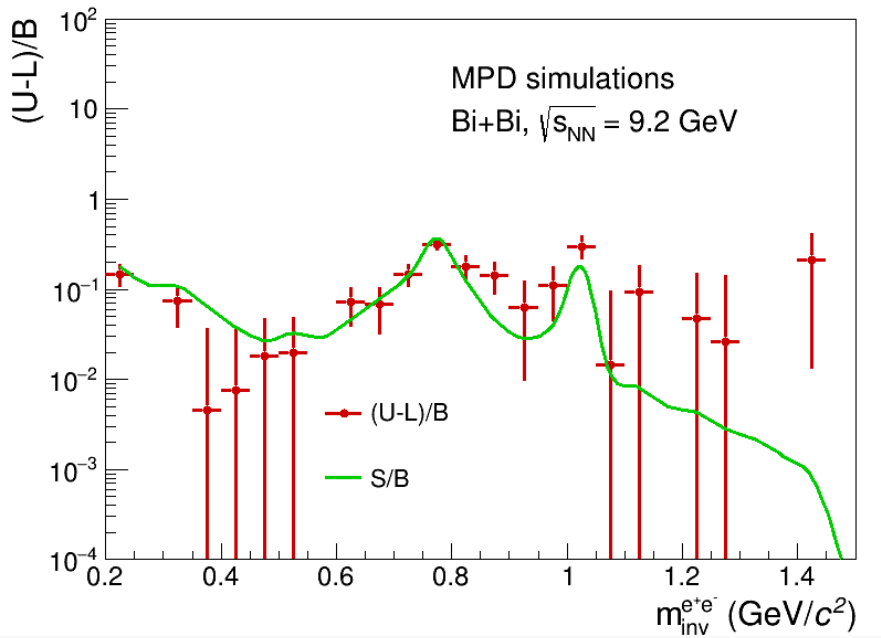


- 1-dimensional (1D) cuts on different discriminant variables suppress the efficiency significantly.
- Machine learning neural network methods such as Multi-layer Perceptrons (MLP) is helpful in enhancing the electron identification performance of the MPD.

Efficiency is improved by 50% above $p_T > 0.8$ GeV/c!

Dielectron invariant mass spectra





- Dedicated mass productions for dielectron analyses.
- Combinatorial background is removed using various analysis methods and techniques.
- S/B ratio up to 10% can be obtained in the invariant mass range 0.2 to 1.5 GeV/c2, however, a few hundred million events are required for meaningful signal measurements.

Precise and clear signal is expected with large statistics!

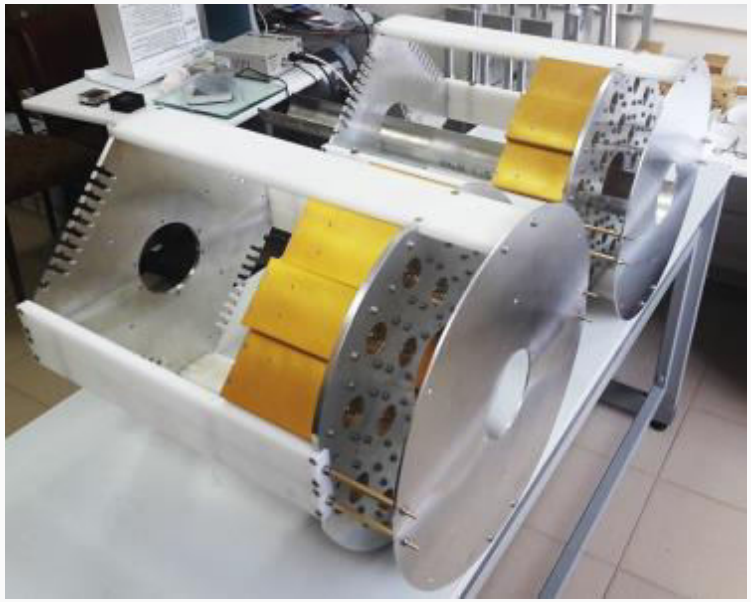
Conclusions

- MPD experiment is well equipped to measure dielectrons using dedicated sub-systems.
- All sub-systems are in advanced stage and ready for commissioning by end of the year $\rightarrow$ MPD is expected to begin operations in 2026.
- ECal provides excellent electron-hadron separation: leads to highly pure electron sample.
- Improvement in electron identification using Machine Learning tools $\rightarrow$ enhances the signal.
- S/B up to 10% is measurable: more statistics needed for meaningful signal.
- Results are work in progress: higher statistics sample is being produced.
- Ongoing efforts to further suppress combinatorial background.

THANK YOU

BACK-UP

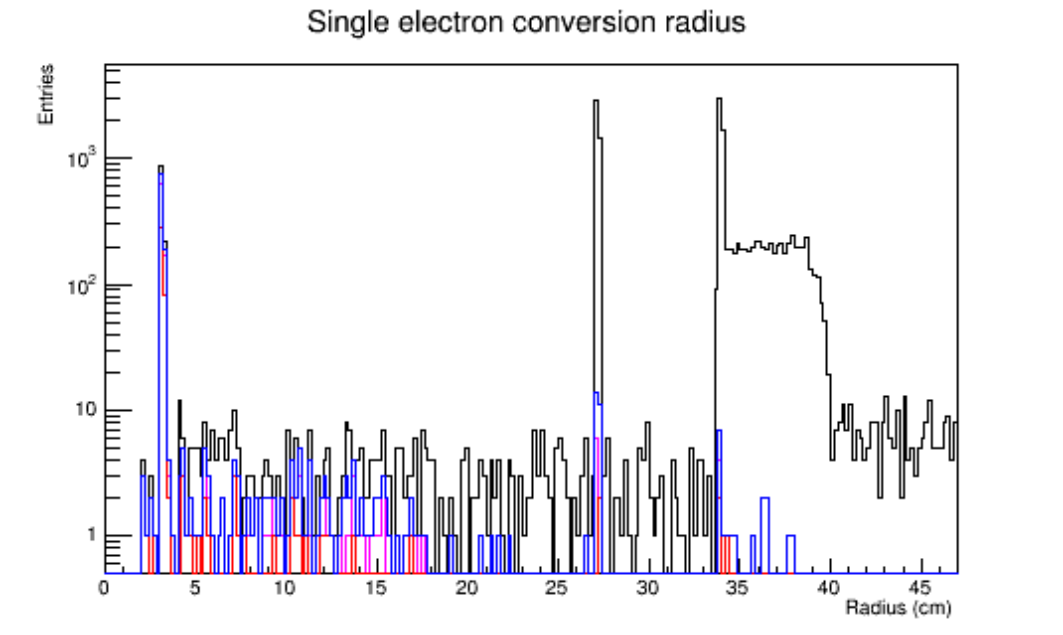
Forward detectors

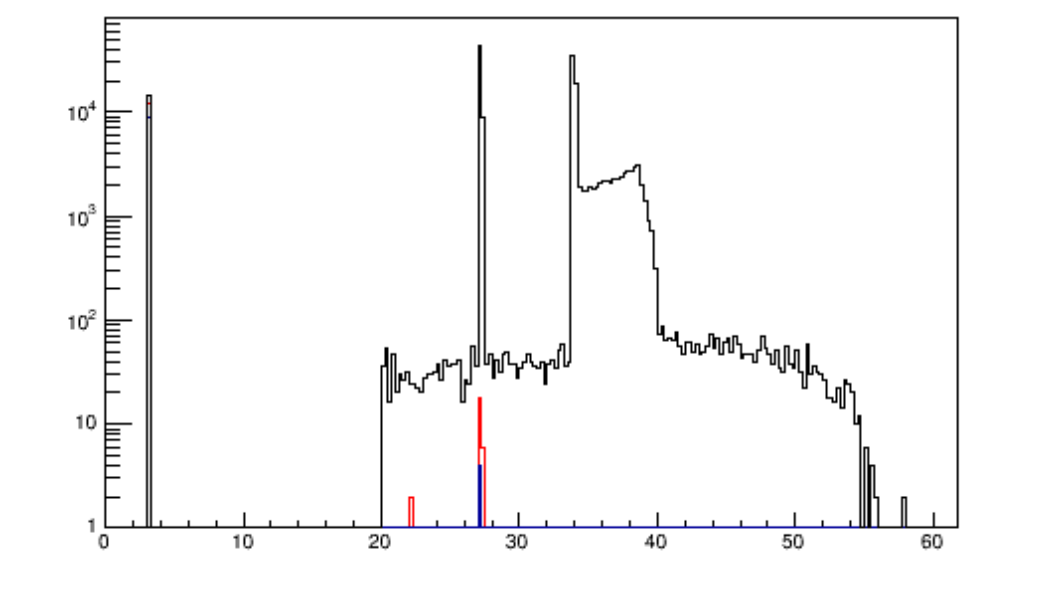


- FFD (Fast Forward Cherenkov Detector): Provides fast triggering of A+A collisions and generates the start-time (T0) pulse generation for the ToF detector with a time resolution better than 50 ps.
- Two FFD detectors at $2.7 < |\eta| < 4.1$
- FHCal (Forward Hadron Calorimeter): Event centrality and reaction plane measurements with potential for event triggering.
- Two FHCAL detectors at $2 < |\eta| < 5$, $\approx$ 1x1 m^2 each

Ready for installation

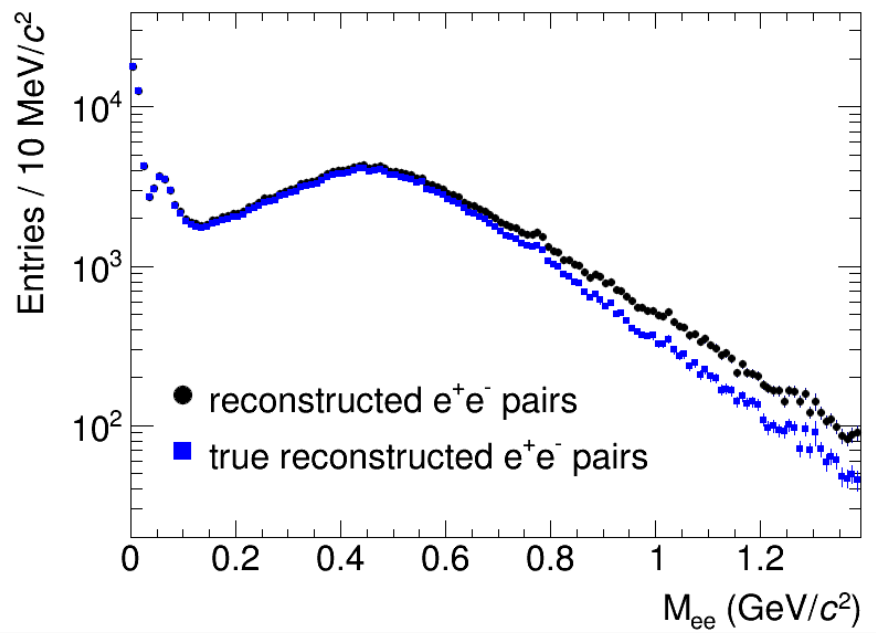
Rejection of conversions

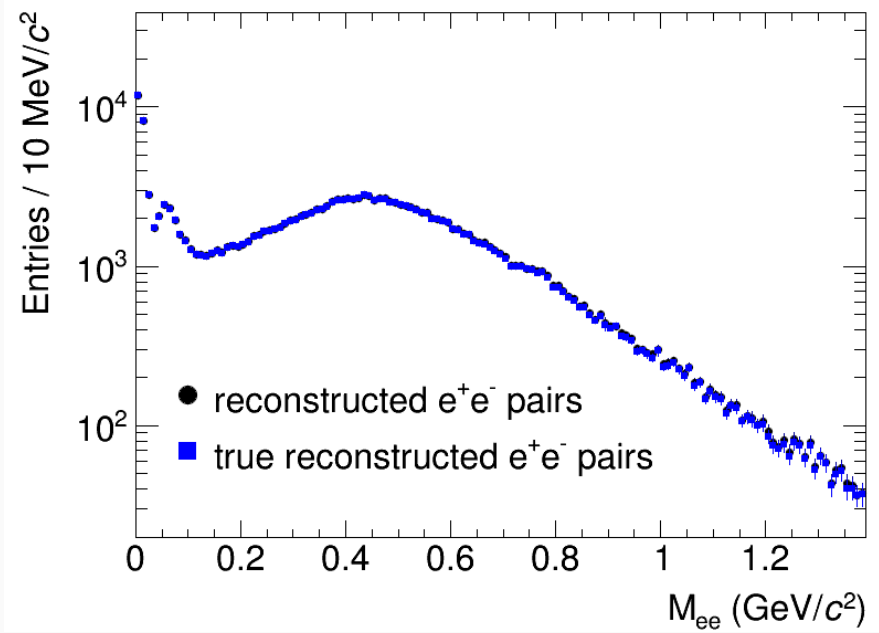




- DCA selection is very effective in reducing contributions from single conversion track as well as pairs in TPC vessels.
- Not so much at the beam pipe: source of combinatorials.

Benefit of ECal in dielectron analysis





- TPC and TOF PID is sufficient to get decent purity however, high p_{T} and invariant mass region is still contaminated.
- Additional information from ECal helps removing the contamination.