NICA MPD

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Prospects for Dilepton Measurements in MPD Experiment at NICA

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Physics at NICA

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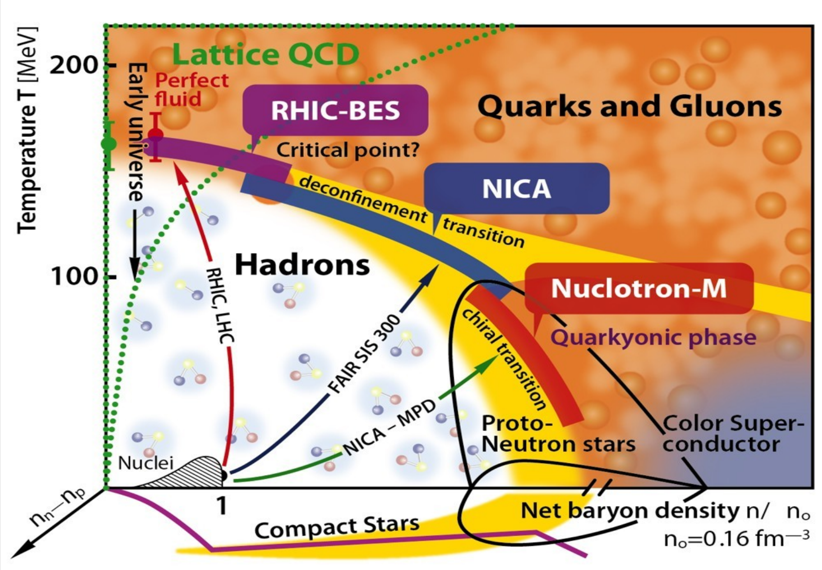
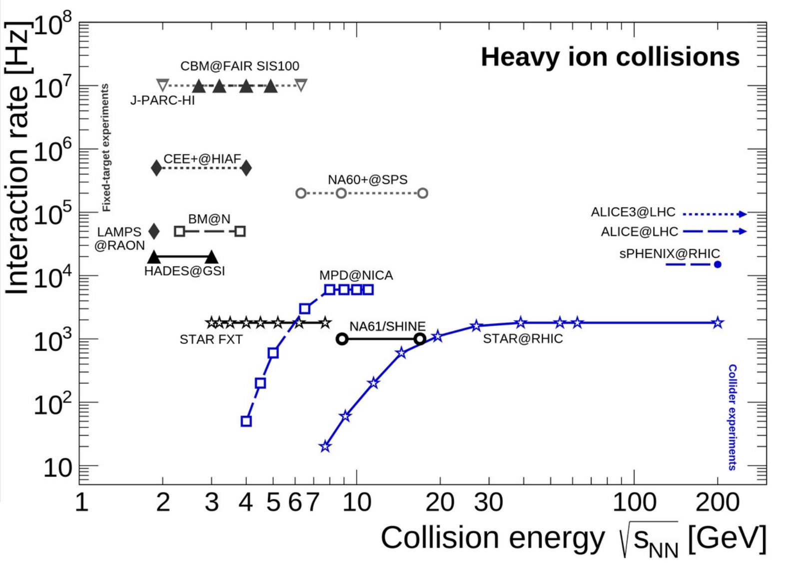


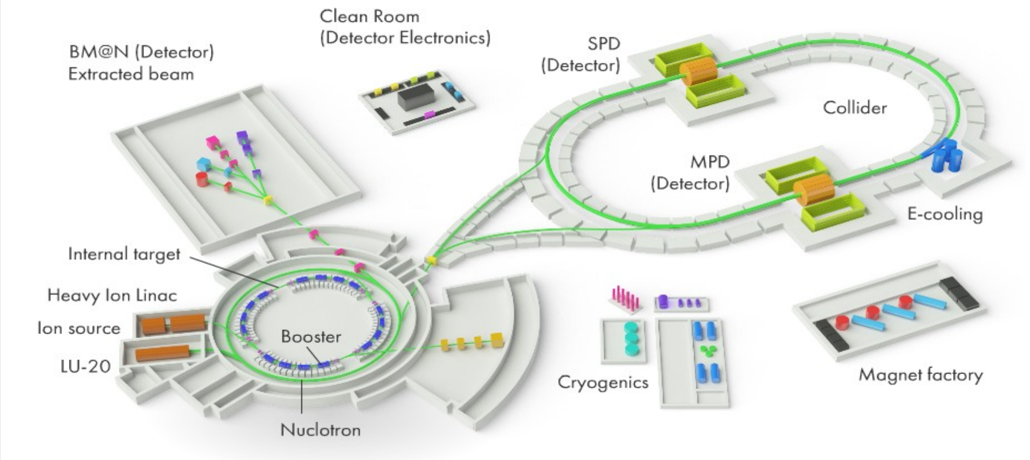


T. Galatyuk, Nucl. Phys. A982(2019);
https://github.com/tgalatyuk/interaction_rate_facilities

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

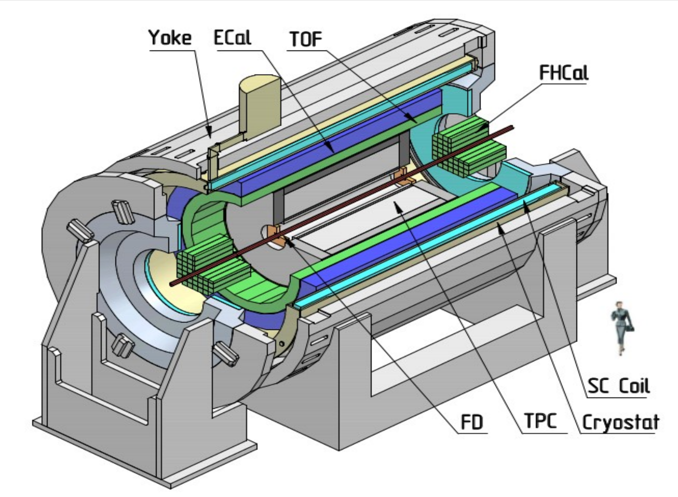
NICA project

- The first megascience project in Russia → approaching its full commissioning:
  - already running in the fixed-target mode – BM@N
  - start of operation in collider mode in 2024-2025 – MPD



Collider parameters for 45 T·m, 11 GeV/u for Au^{79+}			
Ring circumference (m)	503.4	Luminosity (cm^{-2} s^{-1})	10^{27}
Number of bunches	22	RMS bunch length (m)	0.6
β (m)	0.35	Energy in CM (GeV)	4 - 11
RMS Δρ/ρ (10^{-3})	1.6	IBS growth time (s)	1800

MPD@NICA

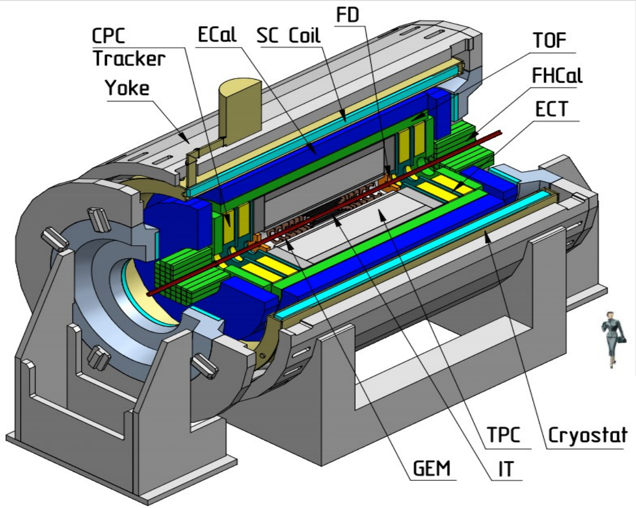


Stage I: TPC, TOF, ECAL, FHCal, FFD

Acceptance:

	$\|\Delta\phi\|$	$\|\eta\|$
TPC:	$< 2\pi$	≤ 1.6
TOF, EMC:	$< 2\pi$	≤ 1.4
FFD:	$< 2\pi$	$2.9 - 3.3$
FHCal:	$< 2\pi$	$2 - 5$

Upgrade

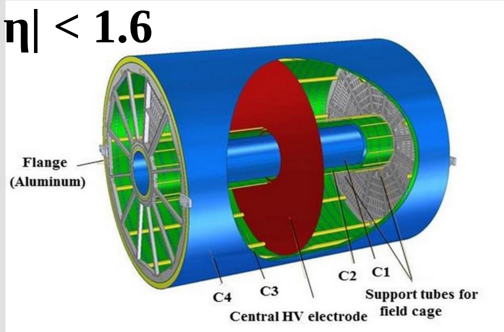


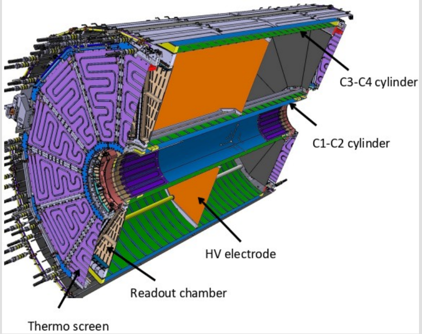
Stage II: ITS and Forward spectrometers

- Expected beam configuration in Stage-I:
  - not-optimal beam optics with wide z-vertex distribution, z ~ 50 cm
  - reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
  - collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209) → start with Bi+Bi @ 9.2 GeV in 2025

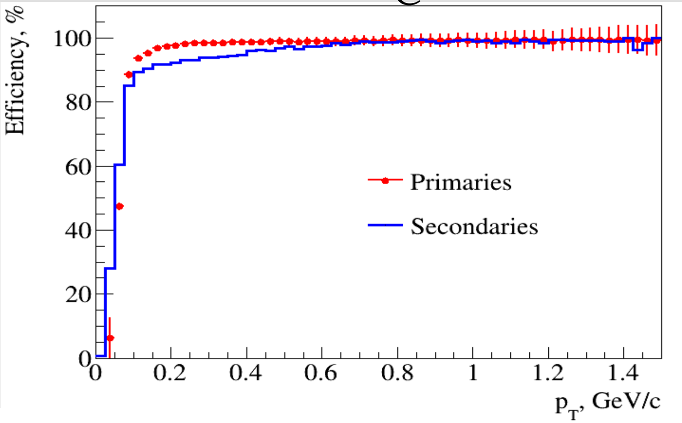
Time Projection Chamber (TPC)

|η| < 1.6

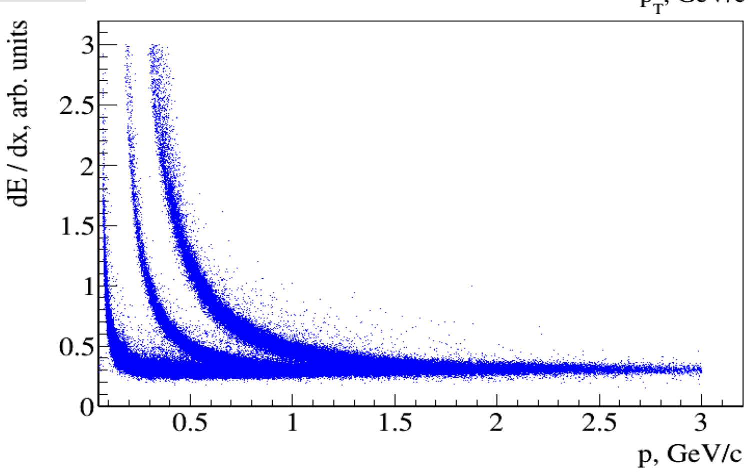




Au-Au@11 GeV

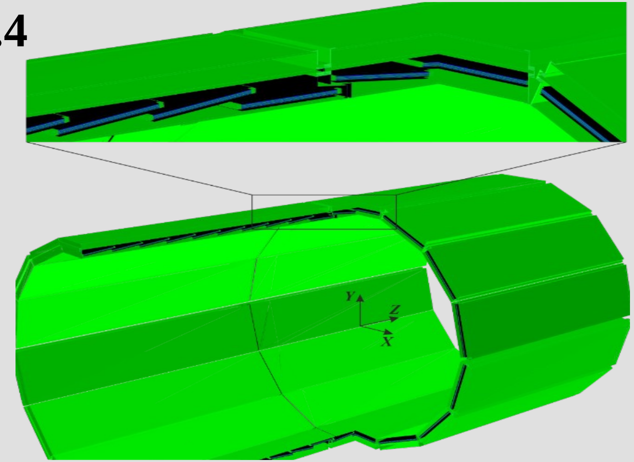


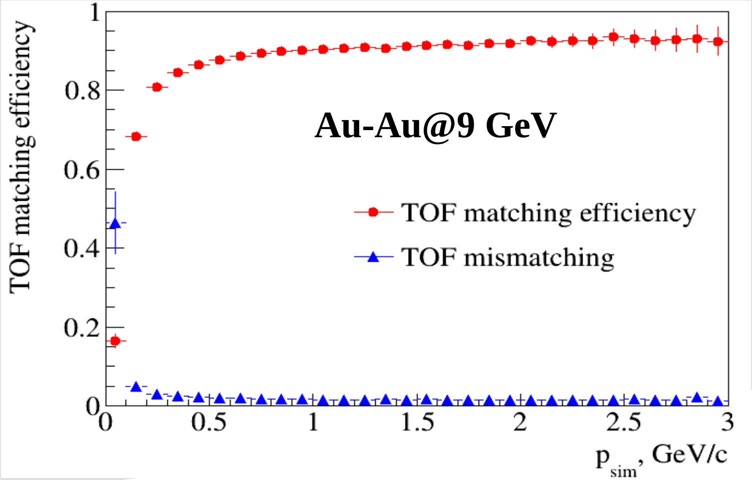
- 3D tracking + dE/dx measurement.
- TPC assembling is ongoing.
- The achieved accuracy of the energy loss <dE/dx> is 6-7%.
- Discrimination of charged pions from kaons up to momenta of ≈ 0.7 GeV/c and kaons from protons up to ≈ 1.1 GeV/c.



Time-Of-Flight (TOF)

|η| < 1.4

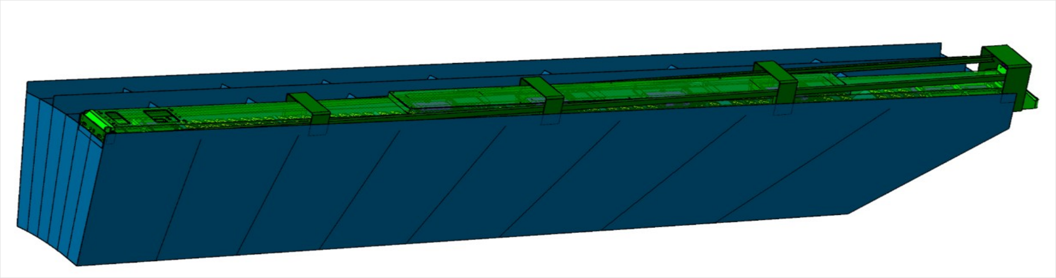




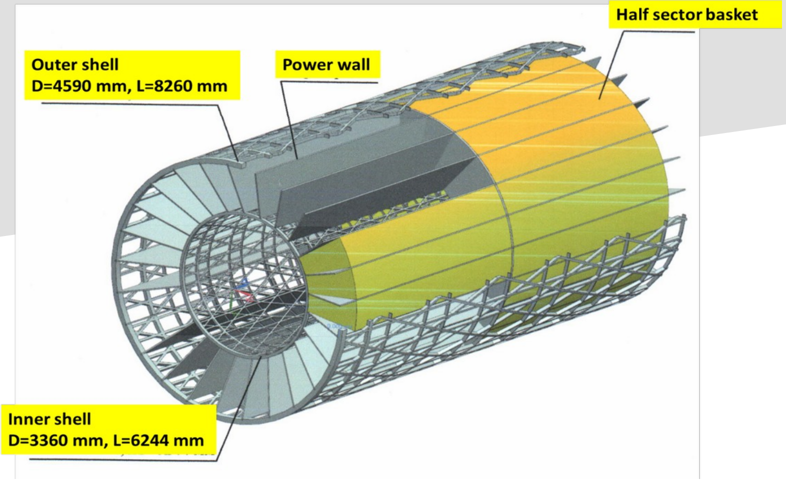
- Based on the technology of (MRPC).
- Measures time-of-flight of the track.
- Assembling of TOF modules and gas system is ongoing.
- Designed Time and coordinate resolution of ≈80 ps and ≈0.5 cm, respectively.

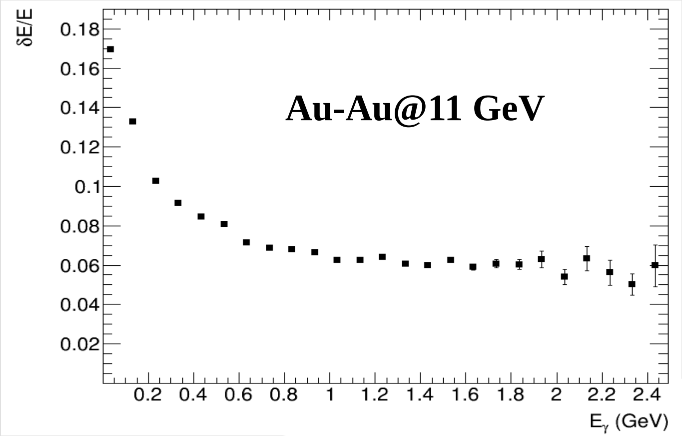
- Better PID perfomance is achieved when combined with TPC.
- TOF matching efficiency: about 90% and it drops below 80% for track momenta below 250 MeV/c.
- Correct identification of protons and $\pi^{+/-}$ (K) with 90% (80%) upto p ≈ 2.5 (1.7) GeV/c.

Electromagnetic Calorimeteter (ECal)



|η| < 1.4





- A shashlik type calorimeter made of Pb-scintillator sandwiches.
- Full configuration: 50 half-sectors in full azimuth (25 full sectors): Range, $360^{o}/25 = 14.4^{o}$
- Measures deposited energy of the track and detect particles of energy from 10 MeV to a few GeV.
- Energy resolution is about 6% at 1 GeV.

Dileptons: Motivation

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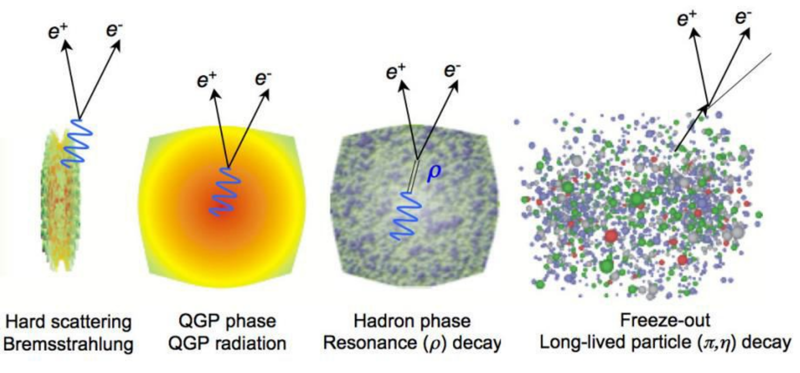
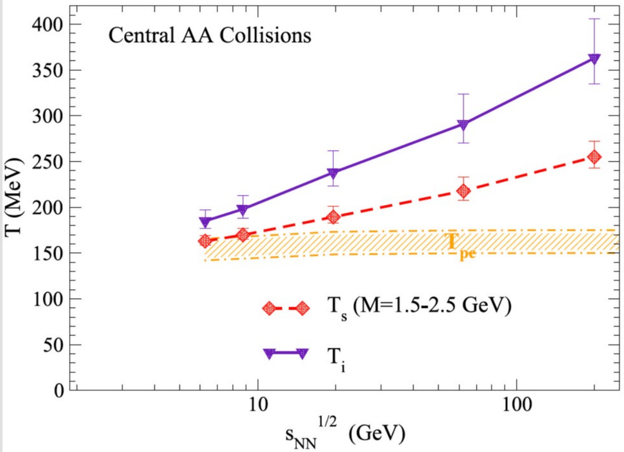
- Dileptons: Penetrative probe of hot and dense nuclear matter.
  - Deconfinement
  - Chiral symmetry restoration
- Advantages:
  - Interacts electromagnetically
  - Large mean free path in contrasts to system size
  - Provide undistorted information at the time of their production.
- Challenges:
  -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

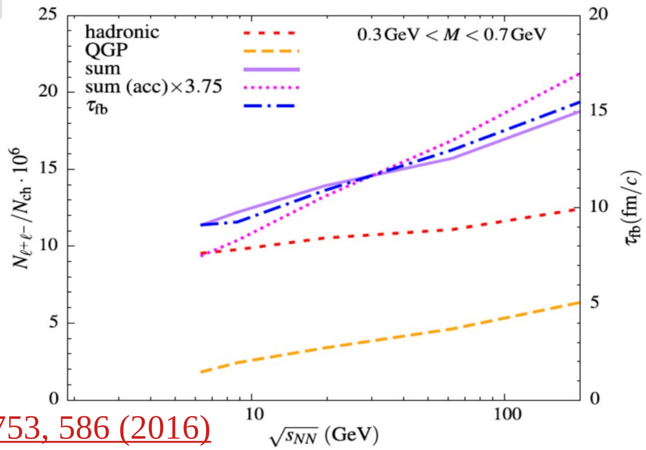


i	Dilepton channels	
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+ e^-$
2	Dalitz decay of η:	$\eta \to \gamma l^+ l^-$
3	Dalitz decay of ω:	$\omega \to \pi^0 l^+ l^-$
4	Dalitz decay of Δ:	$\Delta \to N l^+ l^-$
5	Direct decay of ω:	$\omega \to l^+ l^-$
6	Direct decay of ρ:	$\rho \to l^+ l^-$
7	Direct 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: Motivation

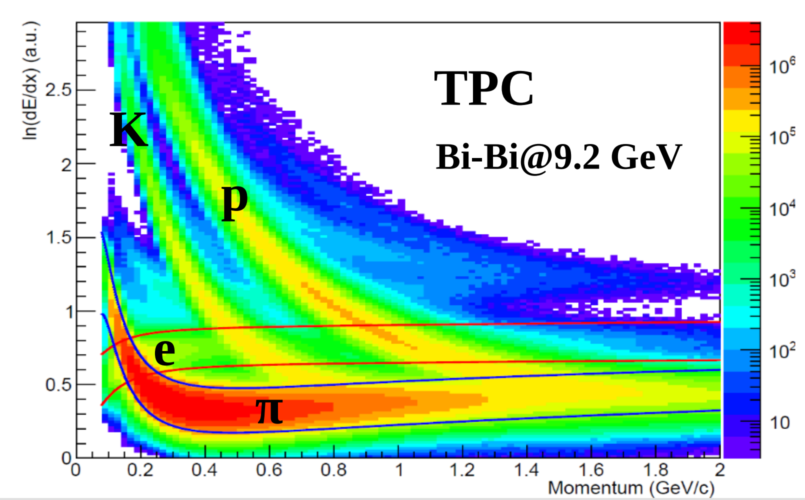
- ✓ Thermal dileptons provide direct fingerprint of the QGP and HG matter.
- ✓ Intermediate Mass Region: Excitation function of the inverse-slope parameter, T_s (M = 1.5 − 2.5 GeV).
- ✓ Closely related to the initial temperature T_i of the fire ball: “thermometer” for the heavy-ion collisions.
- ✓ Low Mass Region: Sum of QGP and hadronic contributions proportional to fireball lifetime: “chronometer” for heavy-ion collisions

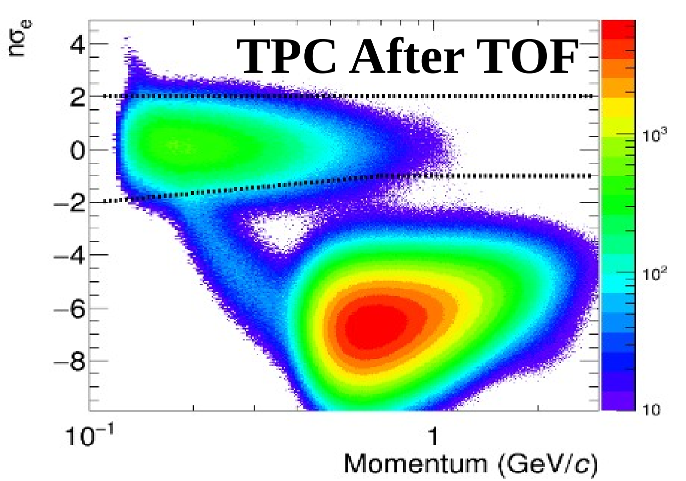


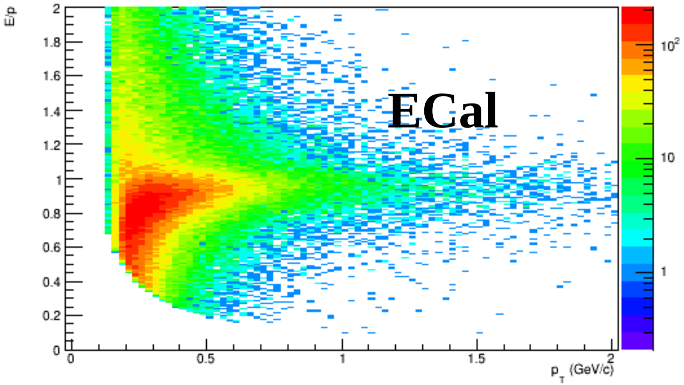


Phys. Lett. B 753, 586 (2016)

Detector performance: Particle Identification with MPD

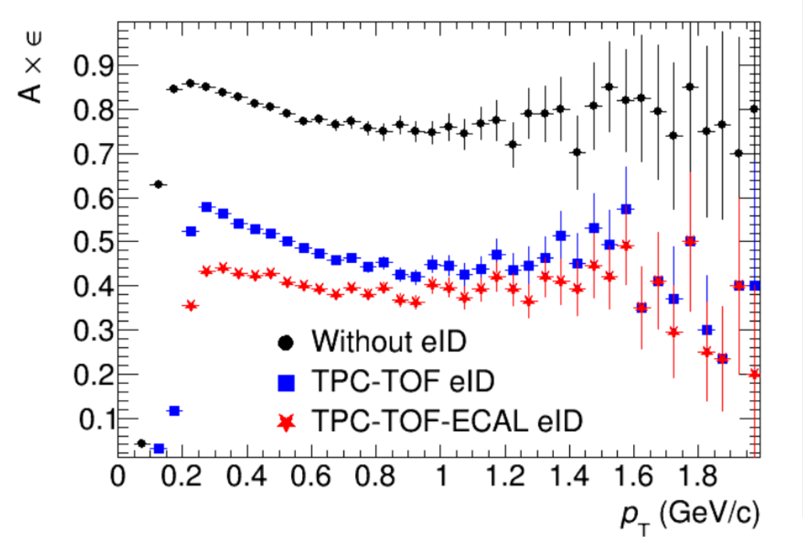


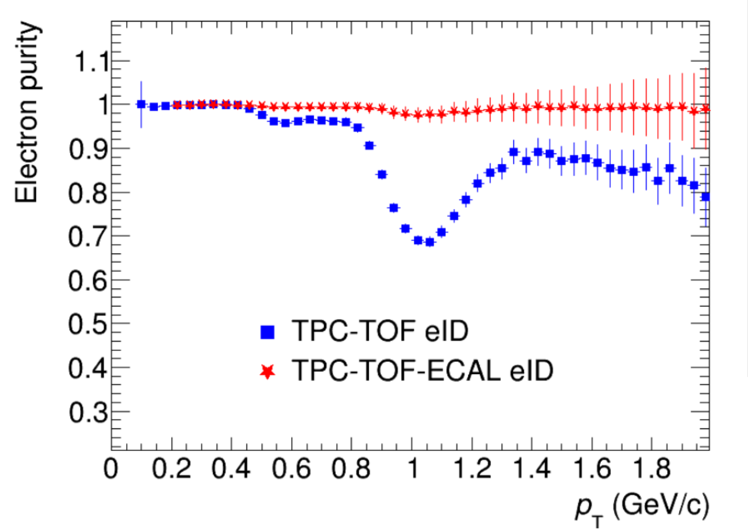




- For PID, TPC (dEdx information), TOF (Time-Of-Flight) and ECal (E/p) is used.
- TPC+TOF is good enough to identify electrons with decent purity.
- ECal helps to gain even higher purity.

Detector performance: Efficiency and Purity





- Typical cuts on electrons:
  - $|\eta| < 1$.
  - DCA < 3σ.
  - $p_T > 50$ MeV/c
  - at least 39 hits in TPC
  - 2σ electron PID in TPC/TOF

- Single electron reconstruction efficiency: about 40% using TPC-TOF-ECal eID above 250 MeV/c.

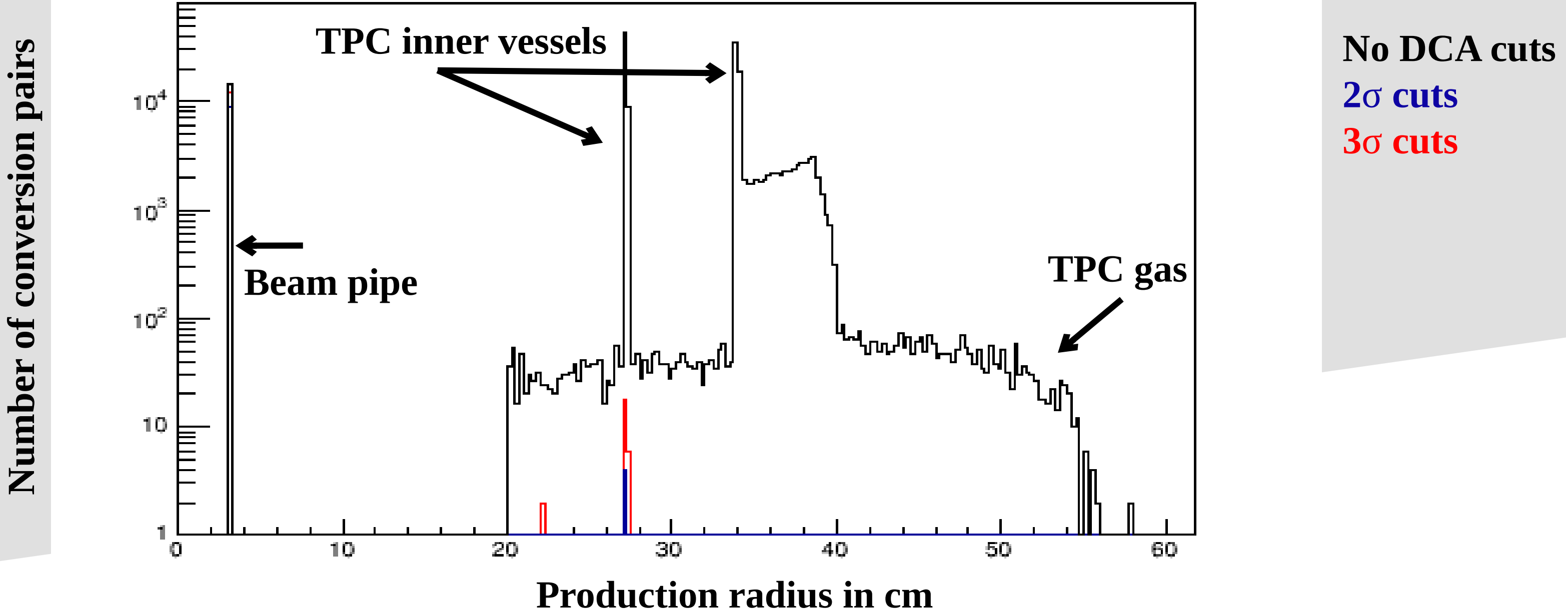
- Purity of 70-90% at high p_T using TPC-TOF for eID and almost 100% using additional information from ECal.

Ongoing studies

- Optimization of track and eID selection cuts
- Special efforts are in progress to reduce the CB from gamma conversion and π^0-η Dalitz decays.
  - Conversions: Distance of Closest Approach (DCA) selection
  - Dalitz decay pair candidates:
    - Divide acceptance into fiducial and veto area for better recognition of Dalitz pairs.
    - No further pairing of reconstructed π^0 Dalitz/conversion pairs
- Use of Machine Learning tools to improve the overall electron identification efficiency to enhance the signal and subsequently, reject combinatorial background.
- Criteria:
  - larger statistical significance of signals $\rightarrow$ smaller statistical uncertainties
  - higher S/B ratio $\rightarrow$ smaller systematic uncertainties from background normalization
- Signals:
  - Low Mass region $\rightarrow$ 0.2-0.6 GeV/c^2
  - LVM: φ, ρ, ω

Conversion pairs rejection

Bi-Bi@9.2 GeV



- Similarly, it is very effective in reducing contributions from conversion pairs in TPC vessels.
- Not so much at the beam pipe: source of combinatorials.

Combinatorial background Rejection

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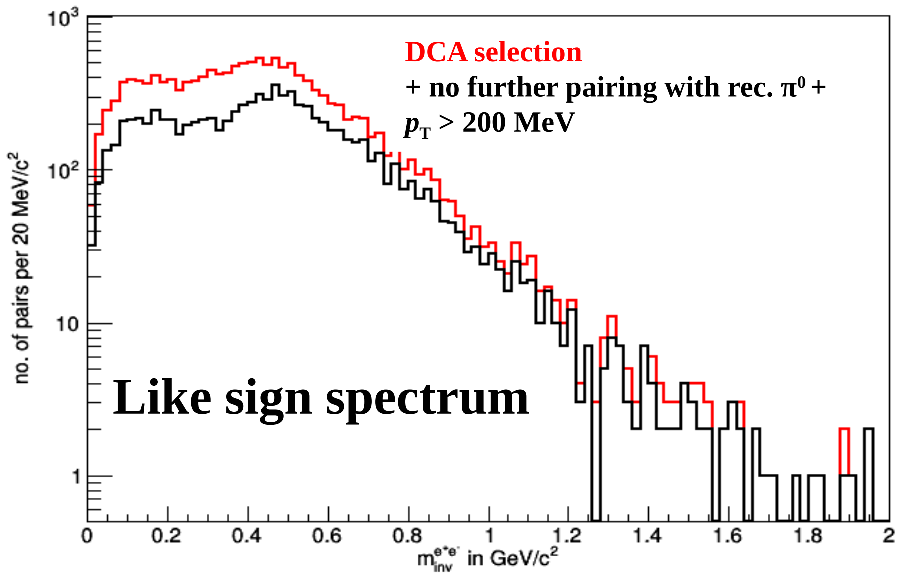
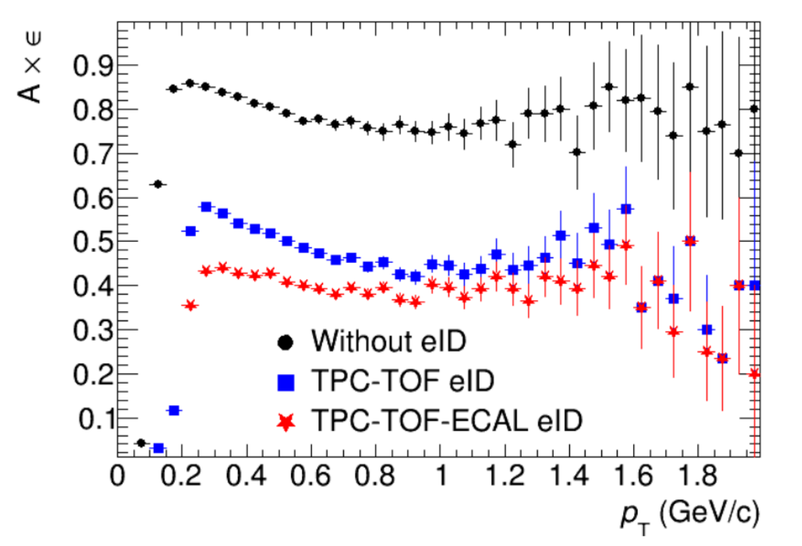


Bi-Bi@9.2 GeV

- Selection cuts:
  - Fid. acc. |η| < 0.3
  - DCA < 3σ
  - At least 39 hits in TPC.
  - 2σ electron PID in TPC/TOF

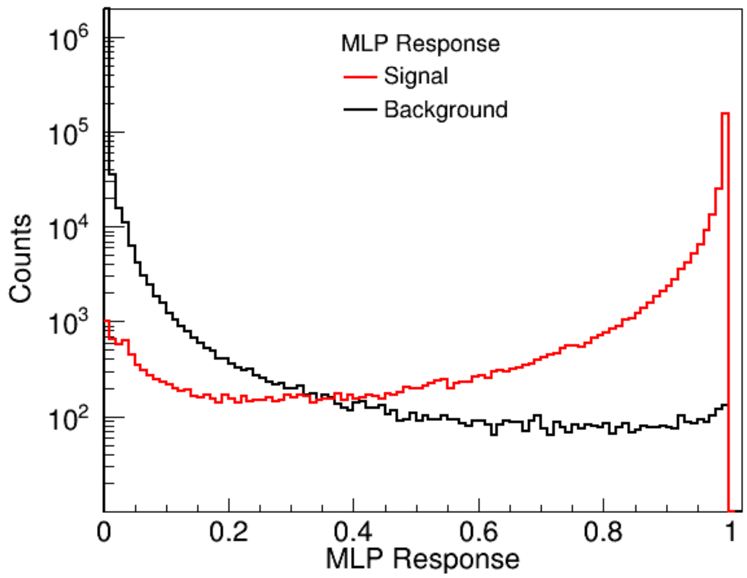
- Perform analysis in fiducial acceptance (say |η| < 0.3) and other is veto (0.3 < η < 1.0).
- With different analysis strategies, further rejection of combinatorials can be achieved.
- Better reconstruction of low p_T tracks allow significant reduction in CB → already reasonable improvement with tuned selection.
- Test reduced magnetic field (B = 0.2 T) sample.

Machine Learning

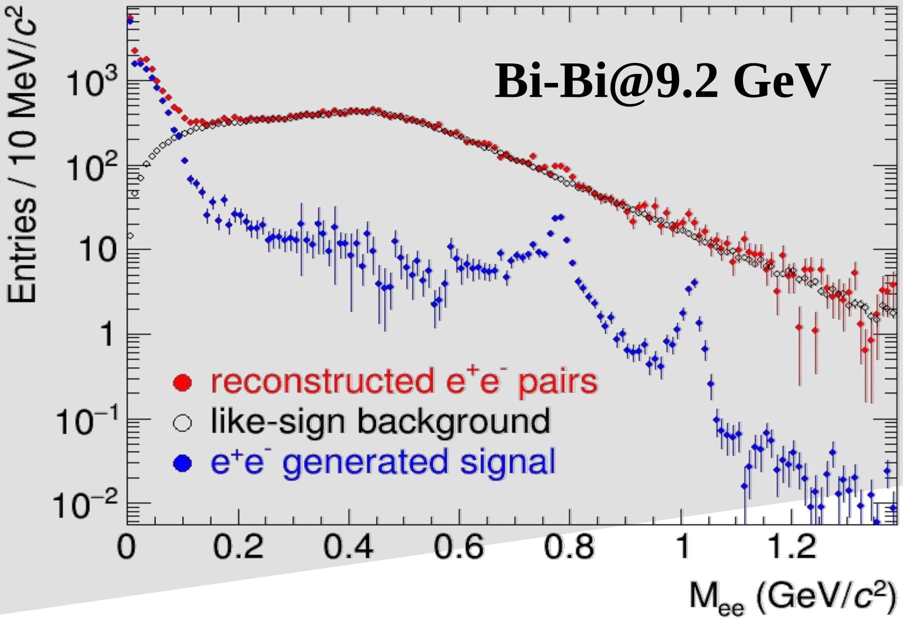


- Electron reconstruction efficiency: about 40% using TPC-TOF-ECal eID above 250 MeV/c.
- Efficiency drops significantly as various track selection cuts are applied.

- Various Neural network options: e.g. Multi-Layer Perceptrons (MLP)
- Provide information about the correlation among the variables.
- Expect significant improvement in the electron identification efficiency.



Current status: Combinatorial background Rejection



BiBi@9.2 GeV (UrQMD), 50 M events → full event/detector simulation and reconstruction

- Optimization of selection cuts could lead to some improvements.
- Signal to Background ratio of 5-10% between 0.2 to 1.5 GeV/c^2 invariant mass region.
- Meaningful measurements at ~100M events → First observations possible at ~ 50 M events.
- Dedicated mass productions for di-electron analyses.
- Continuous dedicated efforts are being put to improve S/B ratio while preserving signal significance.

Summary

- MPD is under construction at NICA → Commissioning and first data taking is expected in 2025 with BiBi@9.2 GeV.
- Dielectrons are valuable probes and capable of delivering strong physics messages: Exciting dielectron program is anticipated at MPD using dedicated sub-detectors.
- Excellent PID and high purity can be achieved using ECal in addition to TPC+TOF.
- Good control over CB from conversions using DCA selection except at beam pipe.
- Ongoing efforts to reduce combinatorial background from Dalitz decays.
- Improvement in overall electron identification efficiency using Machine Learning tools.

Thank you

BACK-UP

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Detector performance: Momentum resolution

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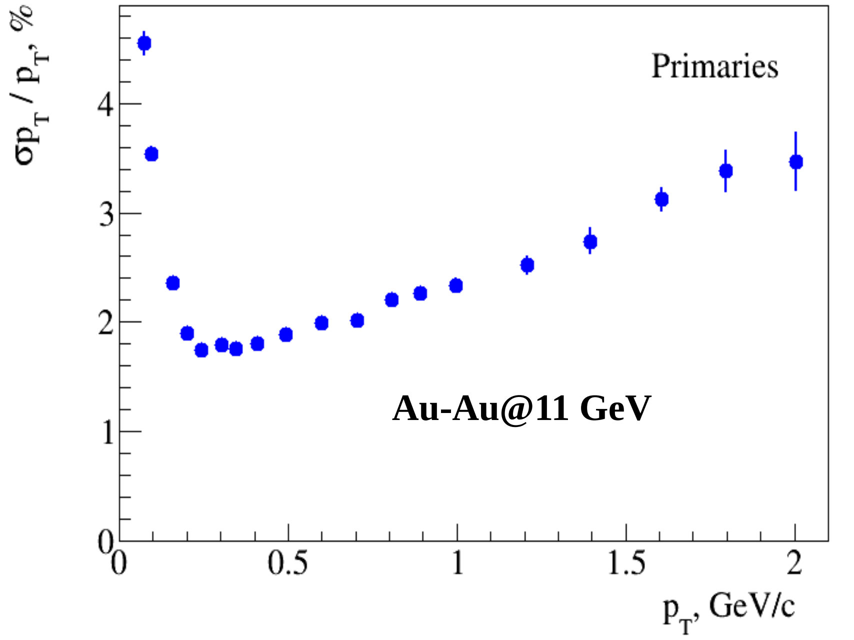
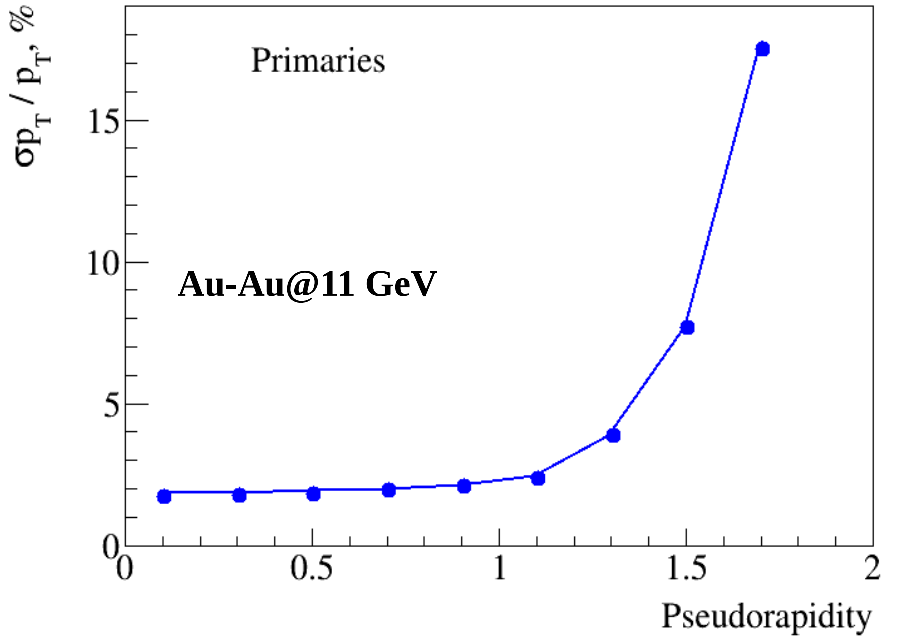
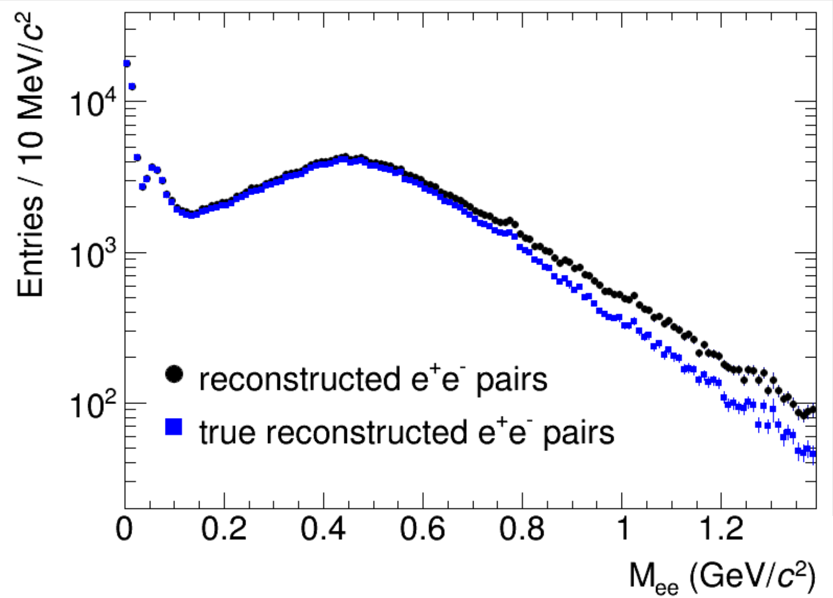
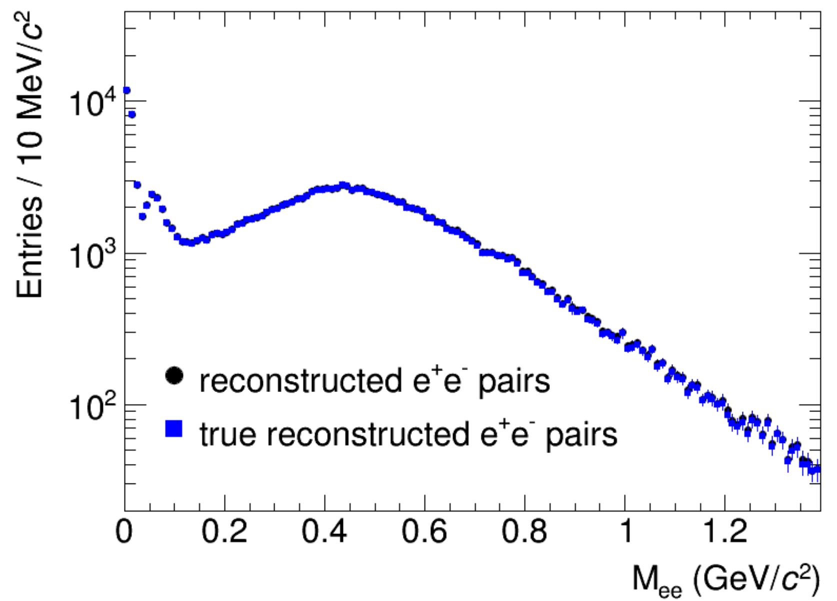




- Maximum achievable relative transverse momentum resolution for charged particles of 2% as function of p_T (0.2-0.8 GeV/c) and η (|η| < 1).

Detector performance: Purity



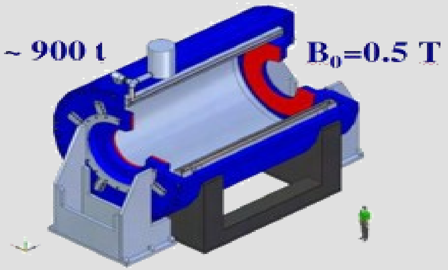


- TPC and TOF PID is sufficient to get decent purity however, high pt and high invariant mass region is still contaminated.

- Nevertheless, additional information from ECal helps removing the contamination.

MPD Subsystems

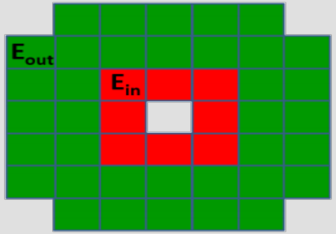
SC Solenoid + Iron Yoke



TOF

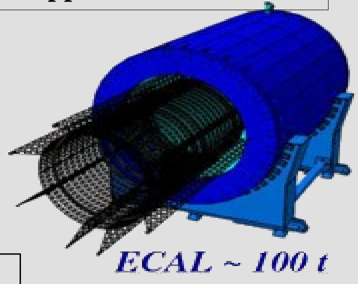
100% of MRPCs(modules) are ready, cosmic tests ongoing.

FHCal

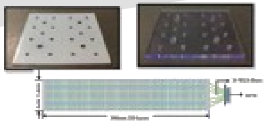


In advance stage of production

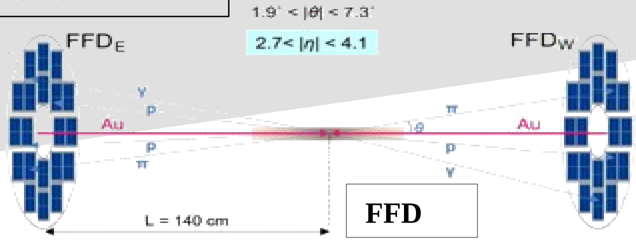
Support structure



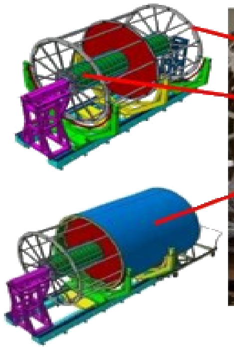
ECal (geometry)



66-83% of of the detector would be produced for stage - I



FFD



TPC

Forward Hadron Calorimeter (FHCal)

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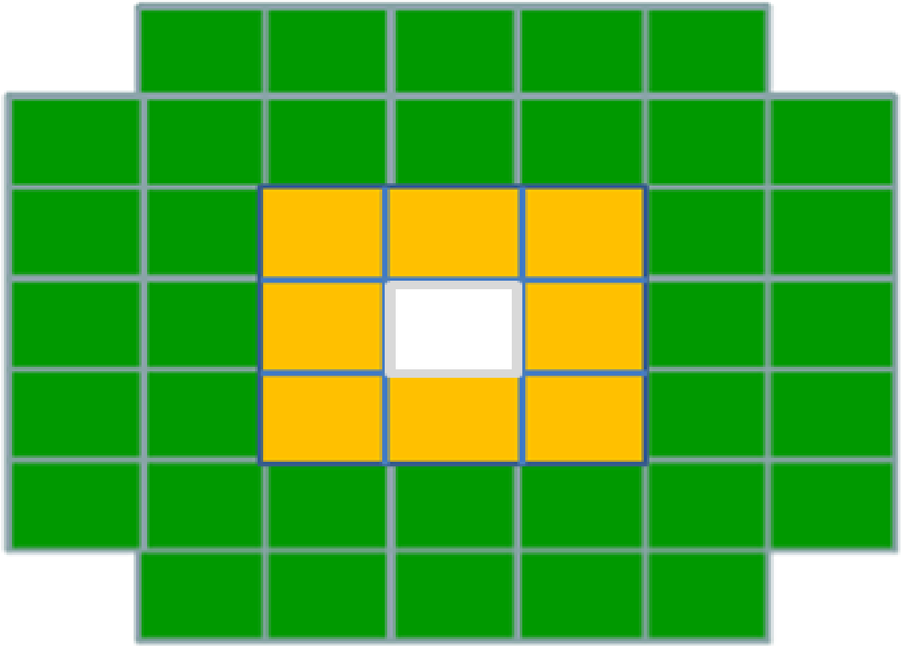
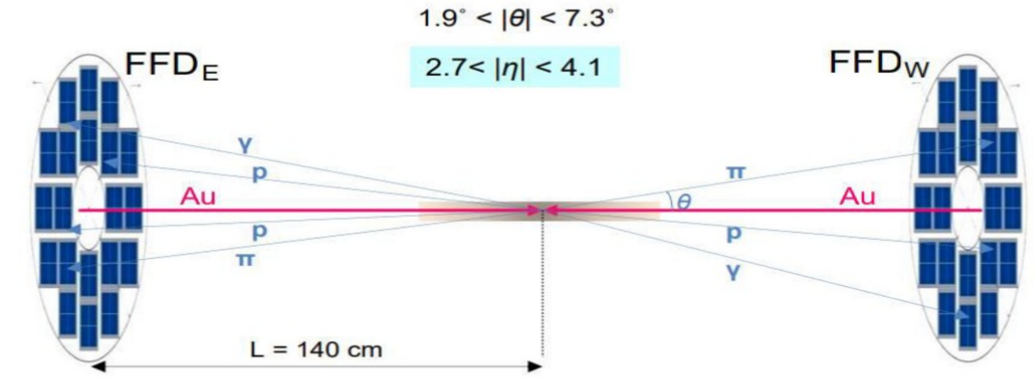
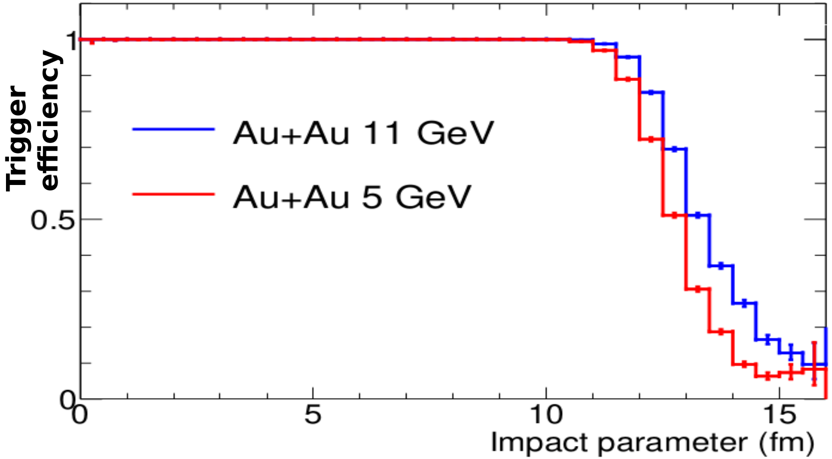


$2 < |\eta| < 5$

- FHCal: Event centrality and reaction plane measurements with potential for event triggering.
- Two identical detectors, each with 44 modules placed approx. 3.2 m upstream and downstream from the center of the detector.
- The module transverse size of 15 x 15 cm^2.
- Modules and FEE boards are produced and tested.
- Relative calorimeter energy resolution, $\sigma_E /E \approx 55\%/\sqrt{E}$ (GeV).

Fast Forward Detector (FFD)





- FFD: 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.
- Consists of 20 Cherenkov modules based on Planacon multianode MCP-PMTs with each module consists of a 10 mm lead converter, a 15 mm quartz radiator.
- Almost 100% L0 trigger efficiency for central to mid-central collisions.