Prospects for dilepton measurements with MPD at NICA

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ECT* Workshop
Exploring High μ_B Matter With Rare Probes

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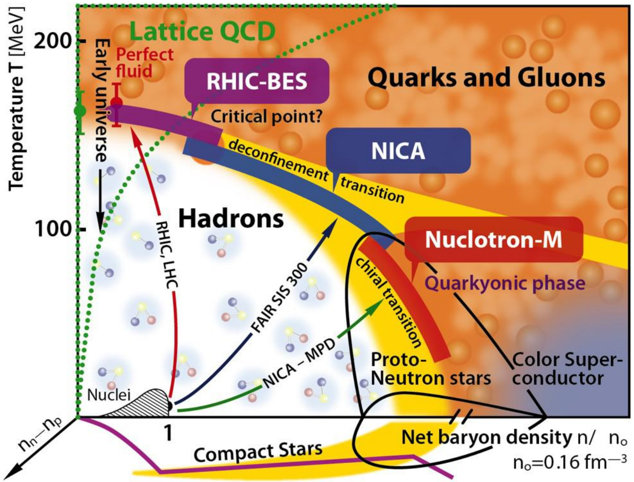
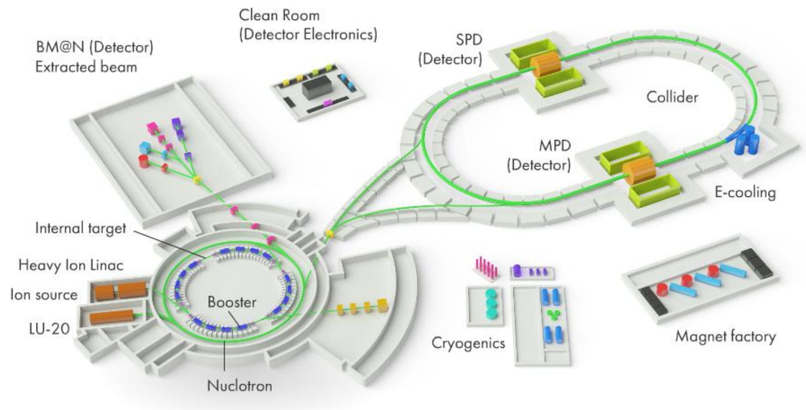
Outline

- Motivation
- MPD apparatus
- Di-electrons and challenges
  - Conversion rejection
  - Rejection of di-electrons from π^0 Dalitz decays
- Conclusions

Motivation

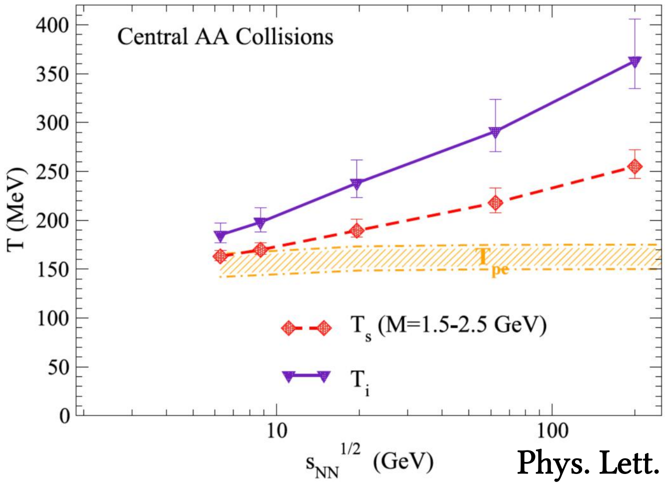


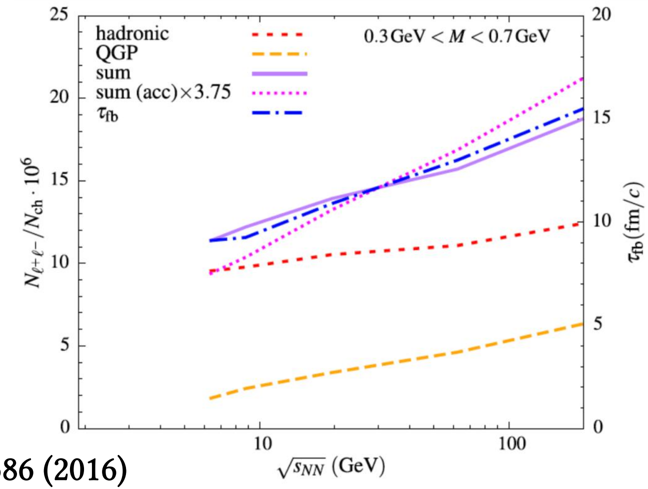
NICA accelerator complex



- $\sqrt{s_{NN}}$: 4-11 GeV
- Designed luminosity: 10^{27} cm^{-2} s^{-1}
- Explore high μ_B matter.
- Search for Critical end point and 1st order phase transition.
- Multi Purpose Detector (MPD) experiment: Rich and exciting di-electron program.

Motivation

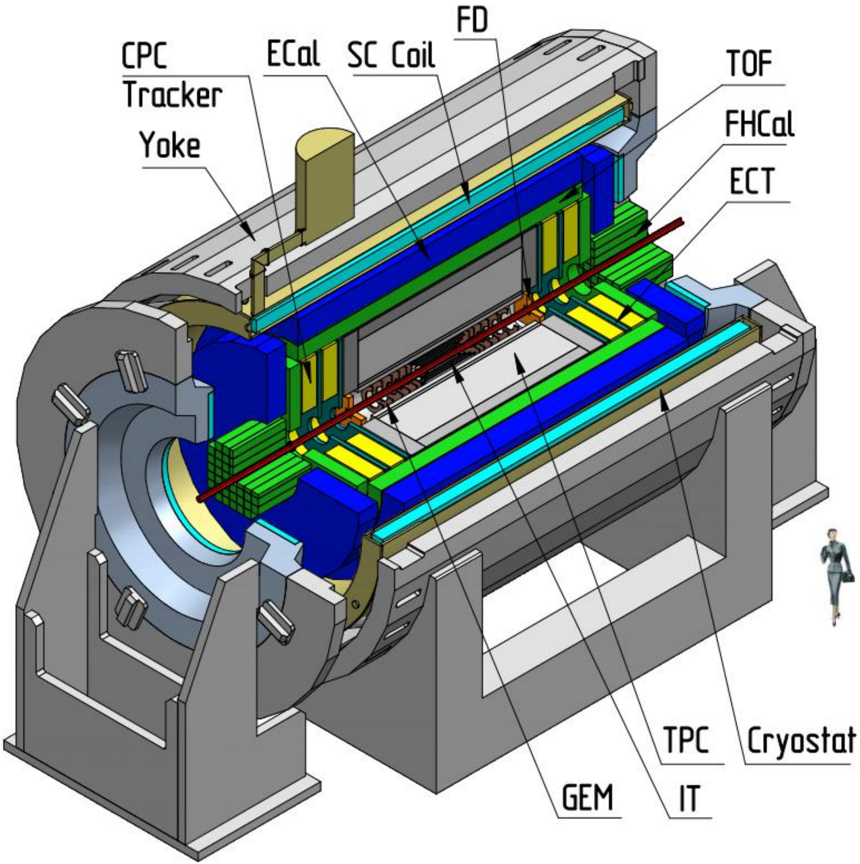




Phys. Lett. B 753, 586 (2016)

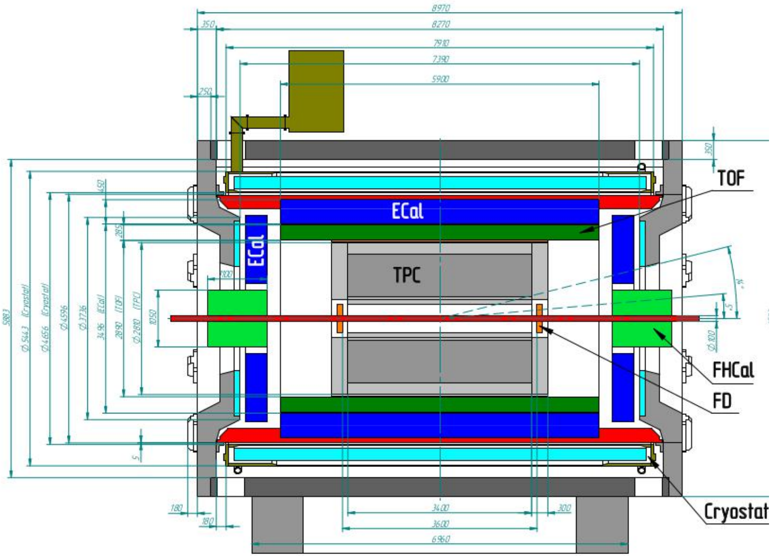
- Intermediate Mass Region: Excitation function of the inverse-slope parameter, T_s ($M = 1.5 - 2.5$ GeV).
- Closely related to the initial temperature T_i of the fire ball: "thermometer" for the heavy-ion collisions.
- Low Mass Region: At SPS and RHIC, the excess in dilepton yields: broadening of the ρ meson spectral function -> restoration of chiral symmetry.
- Sum of QGP and hadronic contributions proportional to fireball lifetime: "chronometer" for heavy-ion collisions

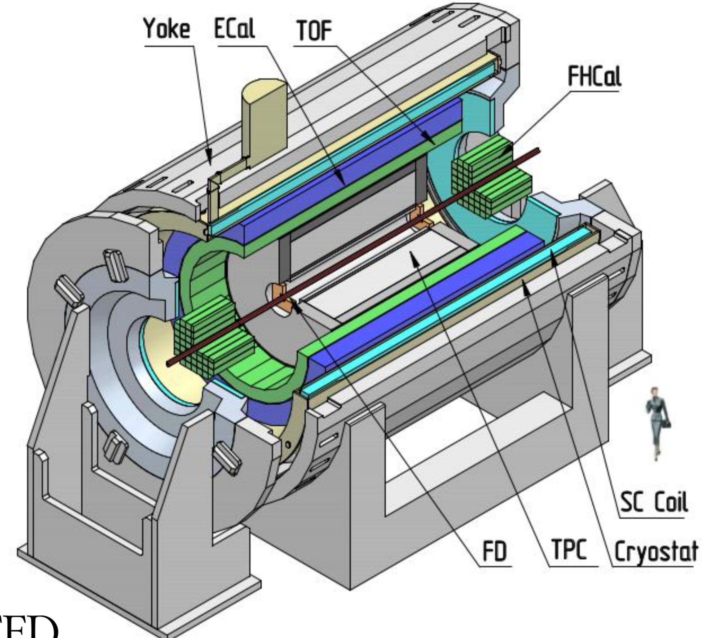
MPD setup: Full configuration



- 4π configuration.
- TPC, TOF, ECAL, FHCal, FFD, ITS and EndCaps.
- To be constructed in two stages.

MPD setup: Stage I

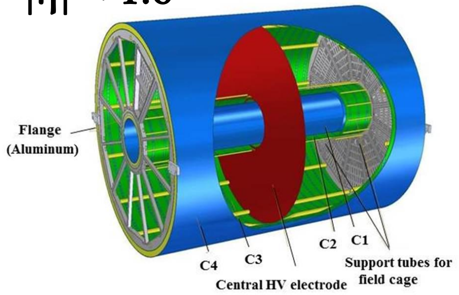


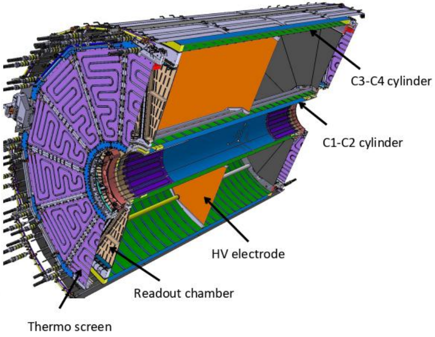


- Stage 1: TPC, TOF, ECAL, FHCal, FFD
- Stage 2: + ITS + EndCaps.
- Stage 1: To be ready for commissioning with beam in 2023.
- Beam: Bi-Bi at $\sqrt{s_{NN}}$ = 9.2 GeV expected for first day of operation.

Time Projection Chamber (TPC)

$|\eta| < 1.6$



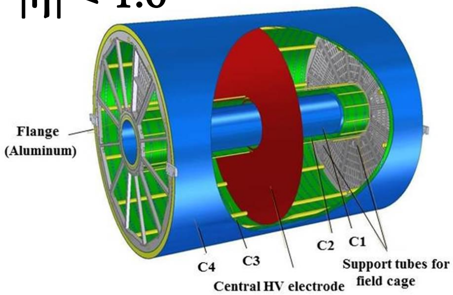


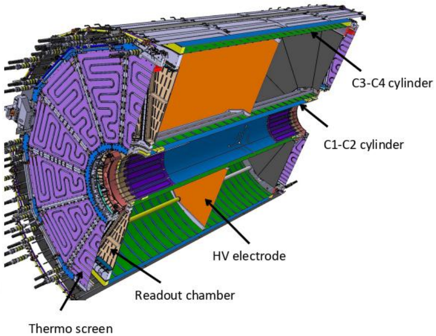
Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Drift vol. outer radius	133 cm
Drift vol. inner radius	34 cm
Drift vol. length	163 cm (of each half)
HV electrode type	Central membrane
Electric field strength	$\sim$ 140 V/cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% CH_4
Pressure	Atm. pressure +2mbar
Gas amplification factor	$\sim 10^4$
Drift velocity	5.45 cm/μs
Drift time	< 30 μs
Temperature stability	< 0.5 °C
Readout chambers	24 (12 per end-plate)
Segmentation in ϕ	30°
Inner pad size	5x12 mm^2
Outer pad size	5x18 mm^2
Total number of pads	95232
Pad row count	53
Maximum event rate	7 kHz ($L = 10^{27}$ $cm^{-2}s^{-1}$)
Electronics shaping time	$\sim$ 180-190 ns
Signal-to-noise ratio	30:1
Signal dynamical range	10 bits
Sampling rate	10 MHz
Sampling depth	310 time buckets
Two-track resolution	$\sim$ 1 cm

- Read-out chambers (ROC): MWPC.
- 12 ROCs per end-cap: 53 pad rows per ROC.
- Gas mixture of 90% Ar+10% CH_4
- Maximum design event rate for the TPC: 7 kHz.
- **The TPC vessel and ROCs are done: Electronics in mass production.**

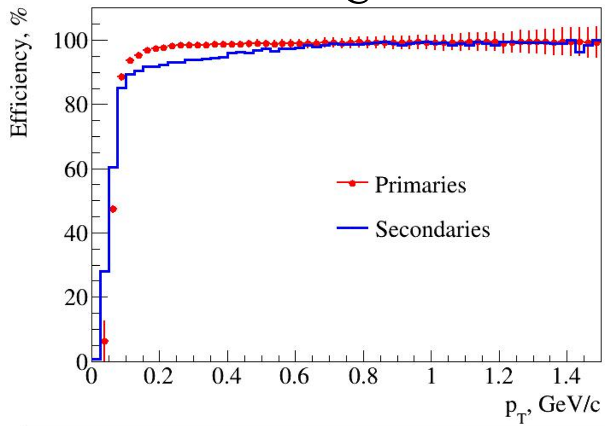
Time Projection Chamber (TPC)

$|\eta| < 1.6$

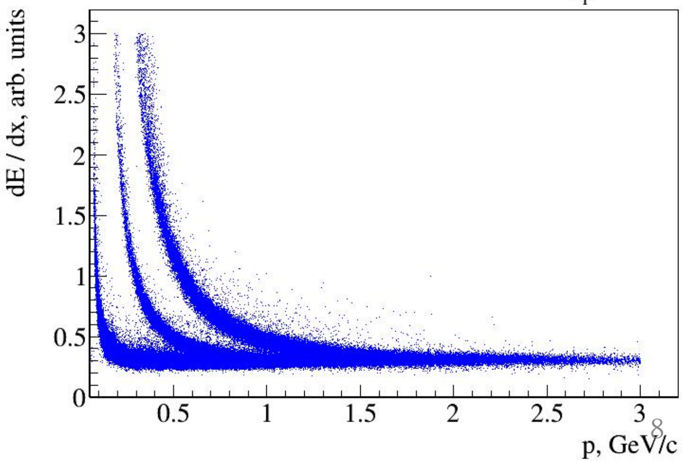




Au-Au@11 GeV

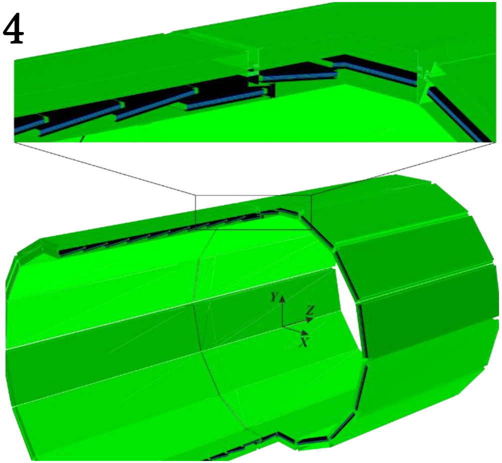


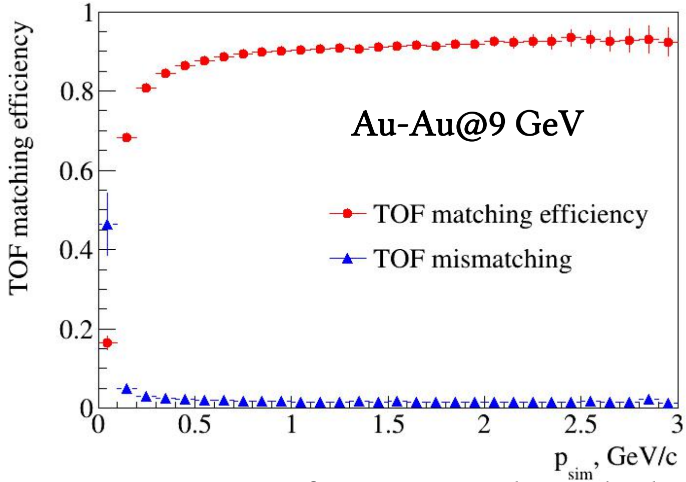
- 3D tracking + dE/dx measurement.
- Track reconstruction efficiency for primary tracks is almost 100% above 200 MeV/c.
- The achieved accuracy of the energy loss <dE/dx> is 6-7%.
- Discrimination of charged pions from kaons up to momenta of ≈ 0.7 GeV/c and kaons from protons up to ≈ 1.1 GeV/c.



Time-Of-Flight (TOF)

$|\eta| < 1.4$



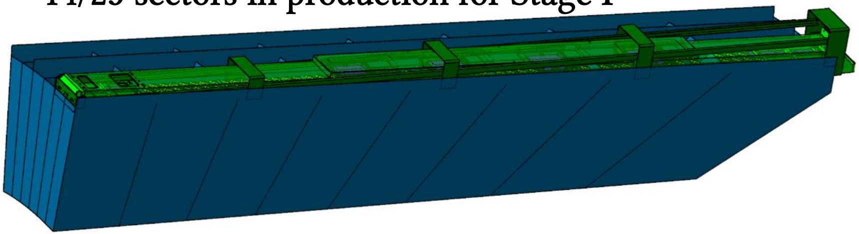


- Based on the technology of (MRPC).
- Measures time-of-flight of the track.
- **40% of MRPCs ready: Mass production ongoing.**
- Designed Time and coordinate resolution of $\approx$80 ps and $\approx$0.5 cm, respectively.

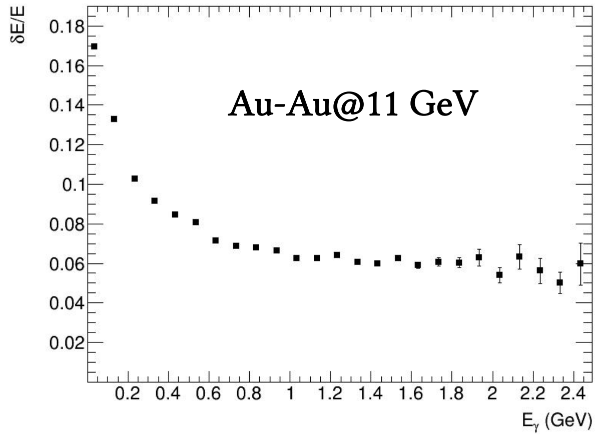
- Better PID perfomance is achieved when combined with TPC.
- TOF matching efficiency: about 90% and it drops below 80% for track momenta below 250 MeV/c.
- Correct identification of protons and $\pi^{+/-}$ (K) with 90% (80%) upto p $\approx$ 2.5 (1.7) GeV/c.

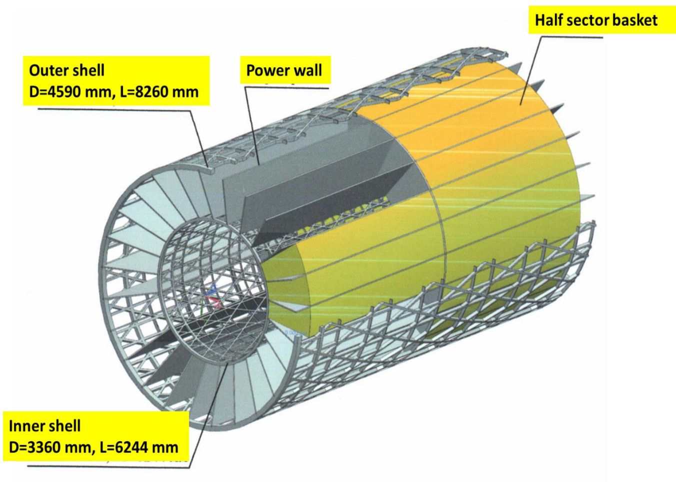
Electromagnetic Calorimeteter (ECal)

3/25 sectors: Done.
14/25 sectors in production for Stage I



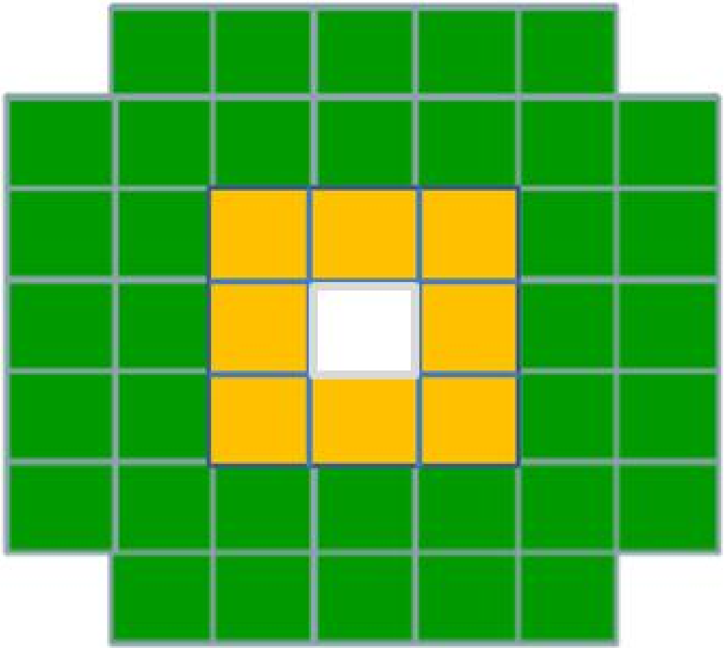
$|\eta| < 1.4$





- A shashlik type calorimeter made of Pb-scintillator sandwiches.
- Full configuration: 50 half-sectors in full azimuth (25 full sectors): Range, 360°/25 = 14.4°
- 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.

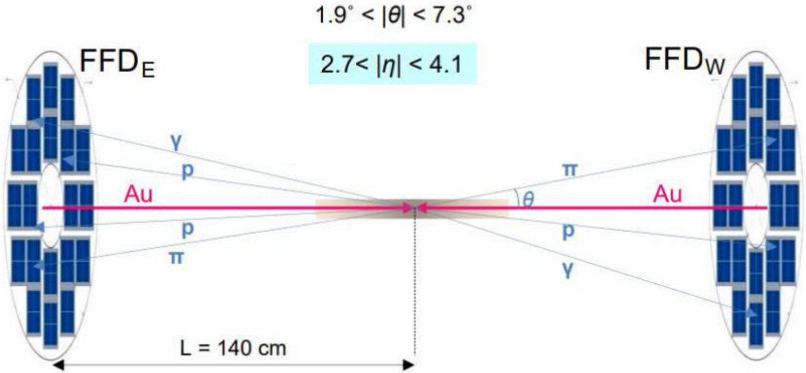
Forward Hadron Calorimeter (FHCal)

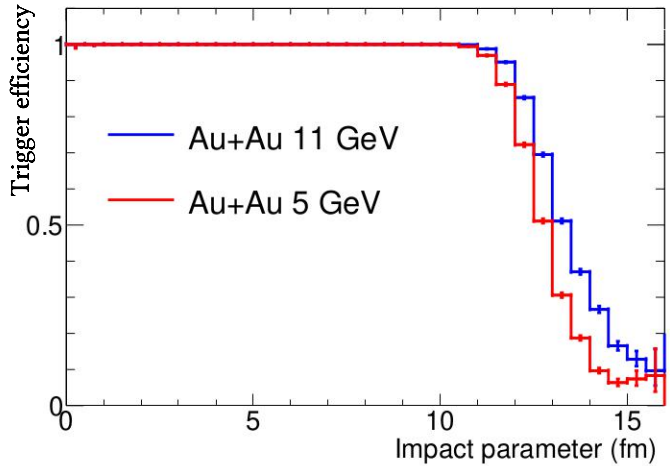


$2 < |\eta| < 5$

- 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)



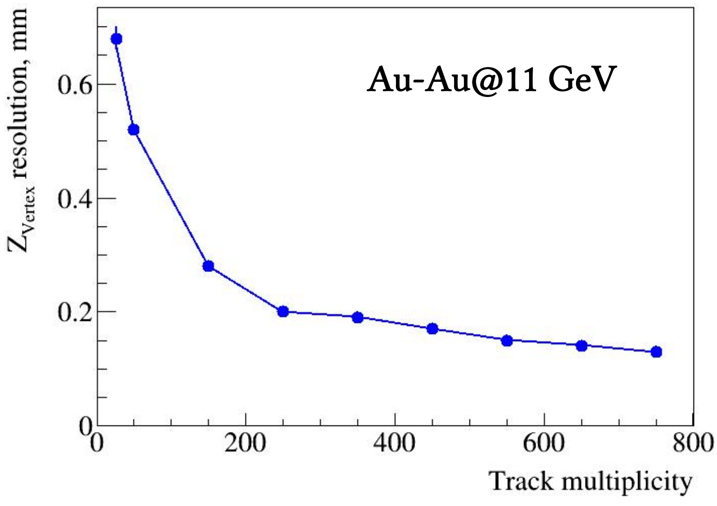


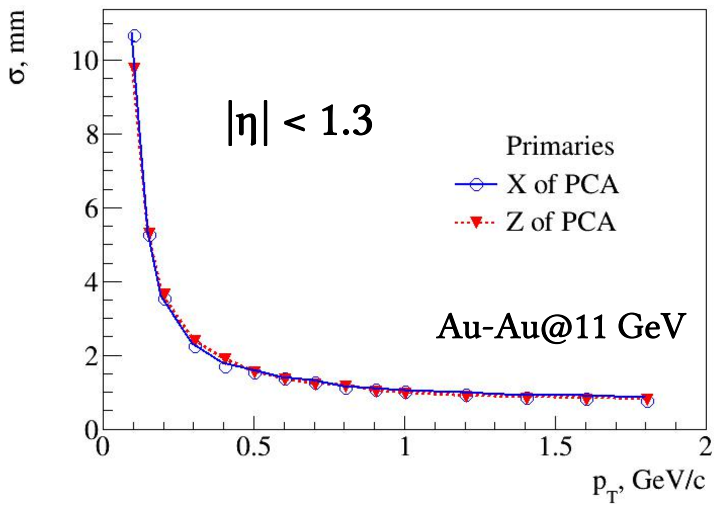
- FFD: Provides fast triggering of A+A collisions and generates the start-time (T0) pulse generation for the ToF detector with a time resolution better than 50 ps.

- 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.

Z_{vertex} resolution

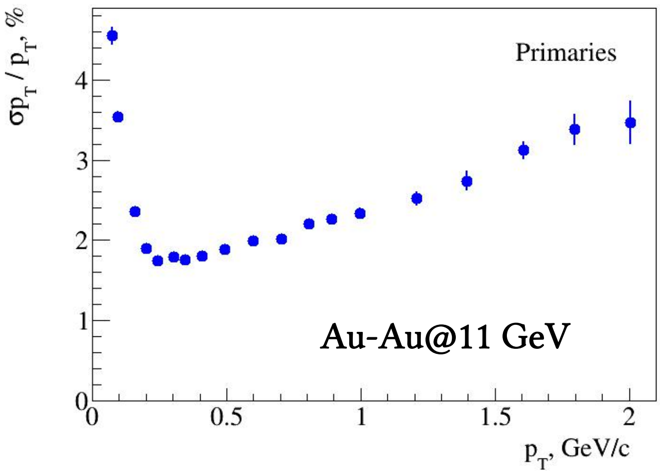


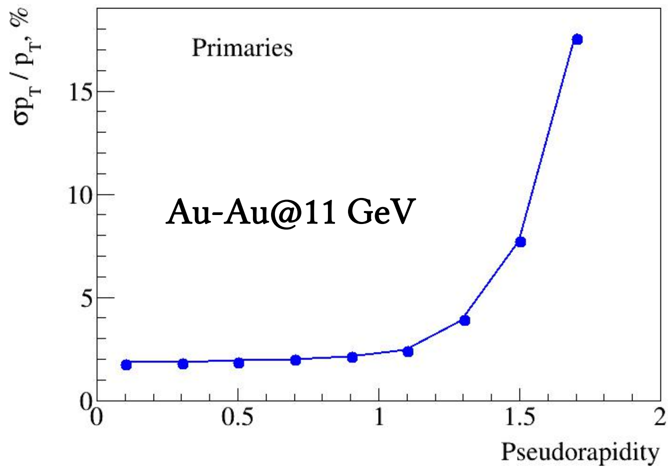


- Uncertainty of the longitudinal position of the reconstructed primary vertex increased by factor 2-3 for low track multiplicity events.

- Transverse and longitudinal position uncertainties for TPC reconstructed primary tracks increases at low p_T.

p_T resolution for charged particles





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

Particle Identification with MPD

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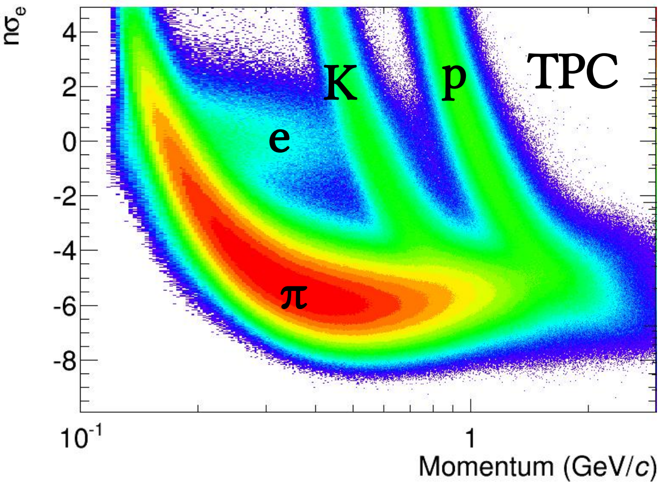
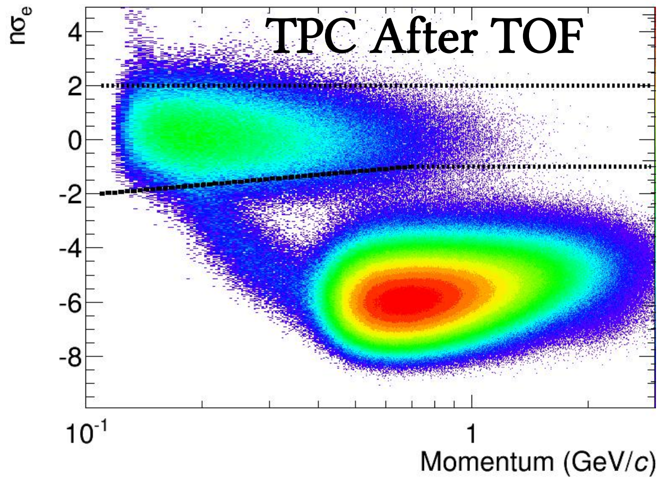
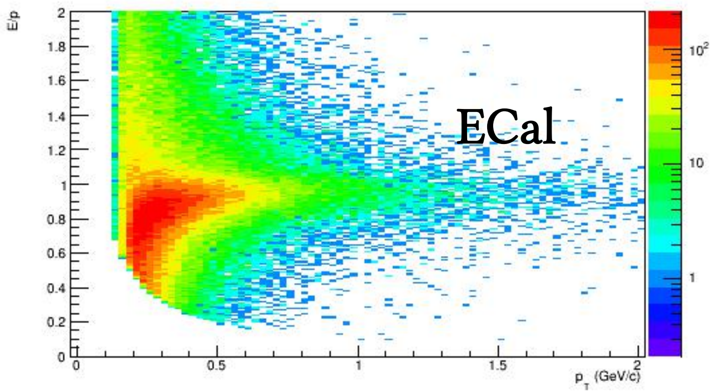
Au-Au@11 GeV

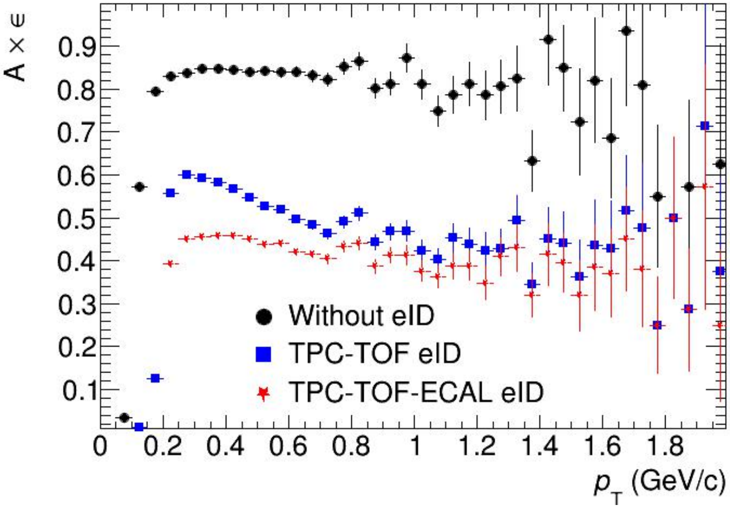


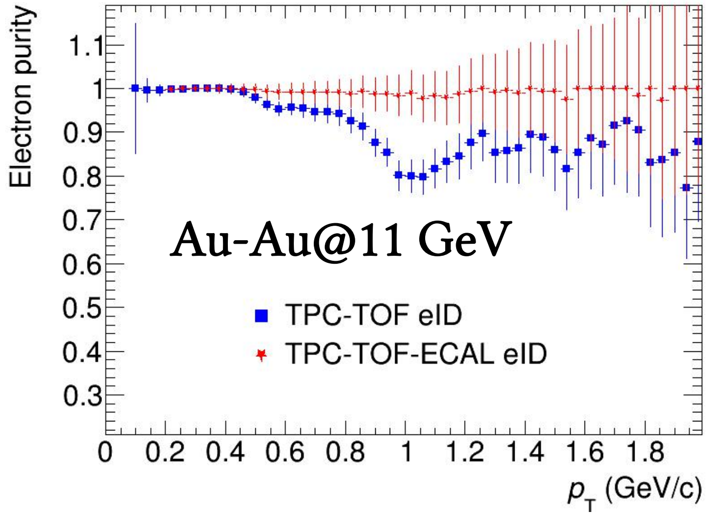




- For PID, TPC (dEdx information), TOF (Time-Of-Flight) and ECal (E/p) is used.
- TPC+TOF is good enough to identify electrons with decent purity.
- However, ECal helps to gain even higher purity.

Efficiency and Purity





Typical cuts on electrons:

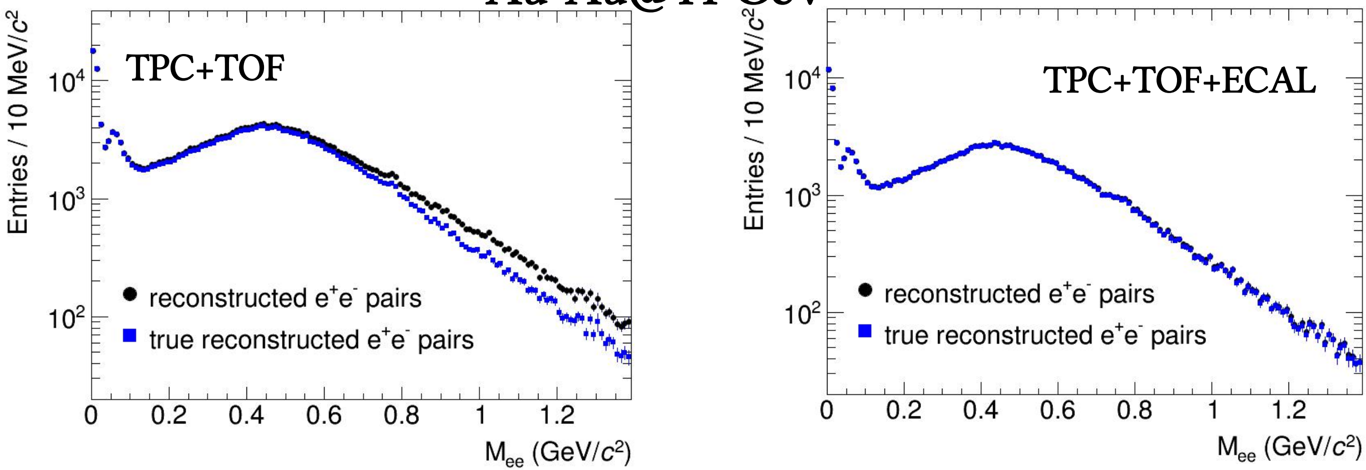
1. $|\eta| < 1$
2. DCA < 3σ
3. p_T > 50 MeV/c
4. at least 39 hits in TPC
5. 2σ electron PID in TPC/TOF

- 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.

ECal helps on the hadron rejection

Au-Au@11 GeV



- 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.

Dielectrons: signal and background

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- Possible main sources of dielectrons

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:	$\pi^\pm N \to \pi N l^+ l^-$

- Dalitz decays are major source of background.
- Major challenge is to reduce the combinatorials, and improve S/B.
- UrQMD and PHSD are employed for the simulations: Results with PLUTO is being studied.

Ongoing studies

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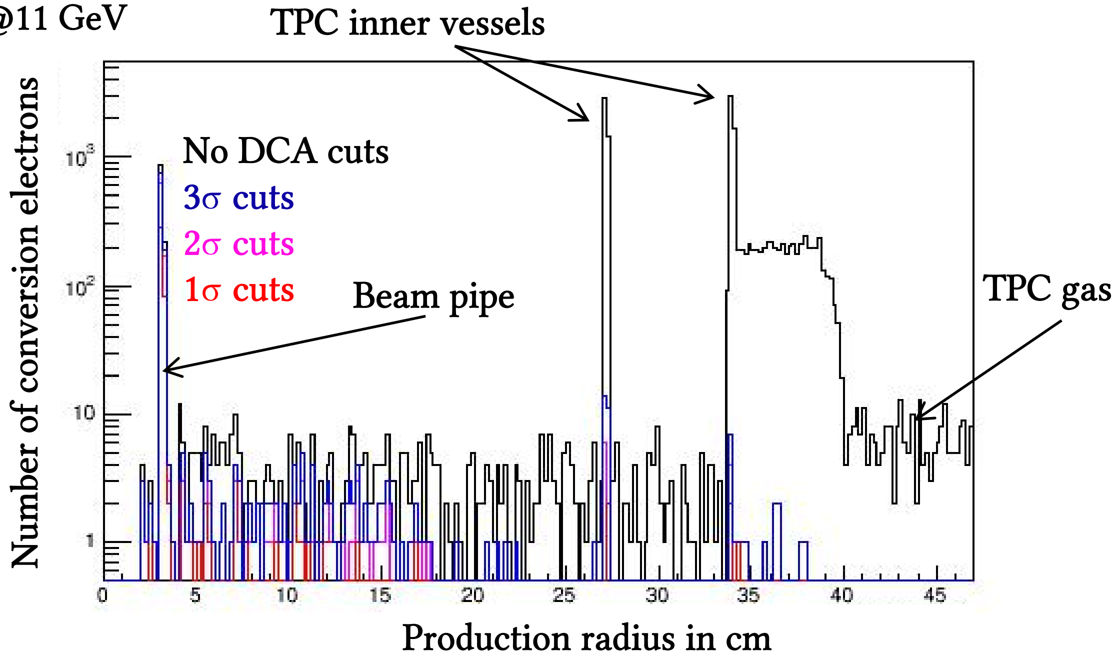
- Optimization of track and eID selection cuts:
  - more differential DCA parameterizations
  - better control over the track-to-TOF matching
  - better treatment of eID in the TPC, TOF and ECAL
- Special efforts are in progress to reduce the CB from gamma conversion and π^0-η Dalitz decays.
  - rejection of conversions: DCA cut
  - rejection of Dalitz decay track candidates:
    - Tracks belonging to fully reconstructed π^0 Dalitz are tagged and not used for further pairing.
    - Divide the acceptance into the fiducial and veto area for better recognition of Dalitz pairs.
- Criteria:
  - larger statistical significance of signals => smaller statistical uncertainties
  - higher S/B ratio => smaller systematic uncertainties from background normalization
- Signals:
  - Low Mass region -> 0.2-0.6 GeV/c^2
  - LVM: φ, ρ, ω

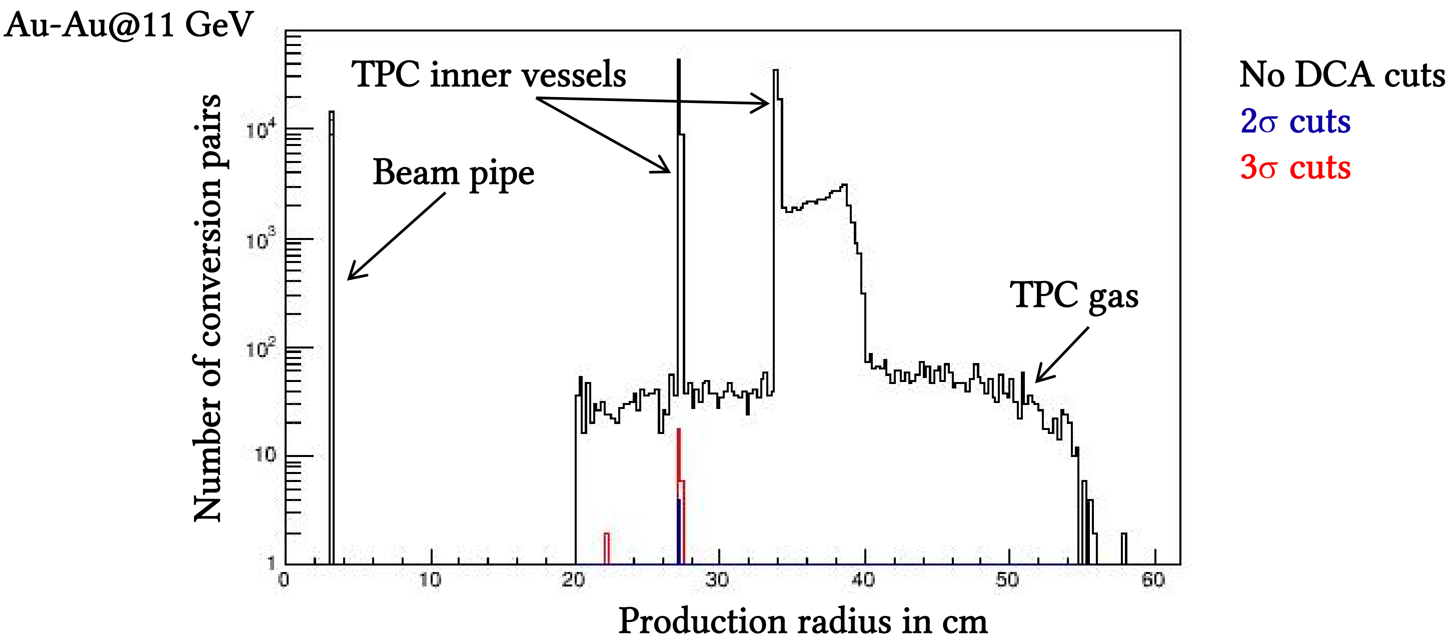
Rejection of single conversion electron

Au-Au@11 GeV



- DCA selection of 2 or 3σ is very effective in reducing contributions from single conversion track in TPC vessels.
- Not so much at the beam pipe: source of combinatorials.

Rejection of e⁺e⁻ pairs from conversions



- Smilarly, it is very effective in reducing contributions from conversion pairs in TPC vessels.

- Not so much at the beam pipe: source of combinatorials.

Rejection of e^+e^- pairs from π^0 Dalitz decays

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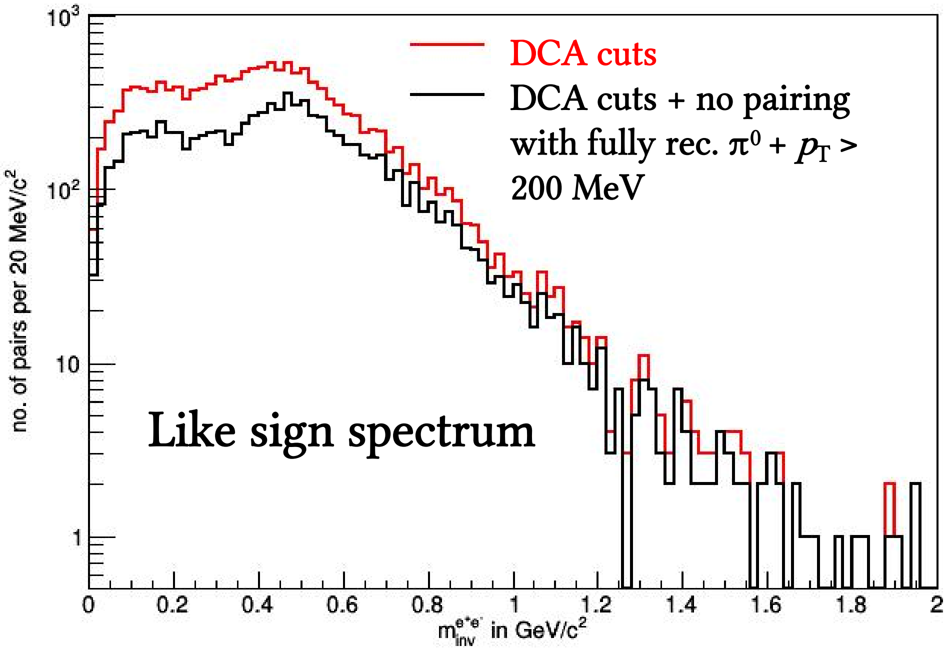


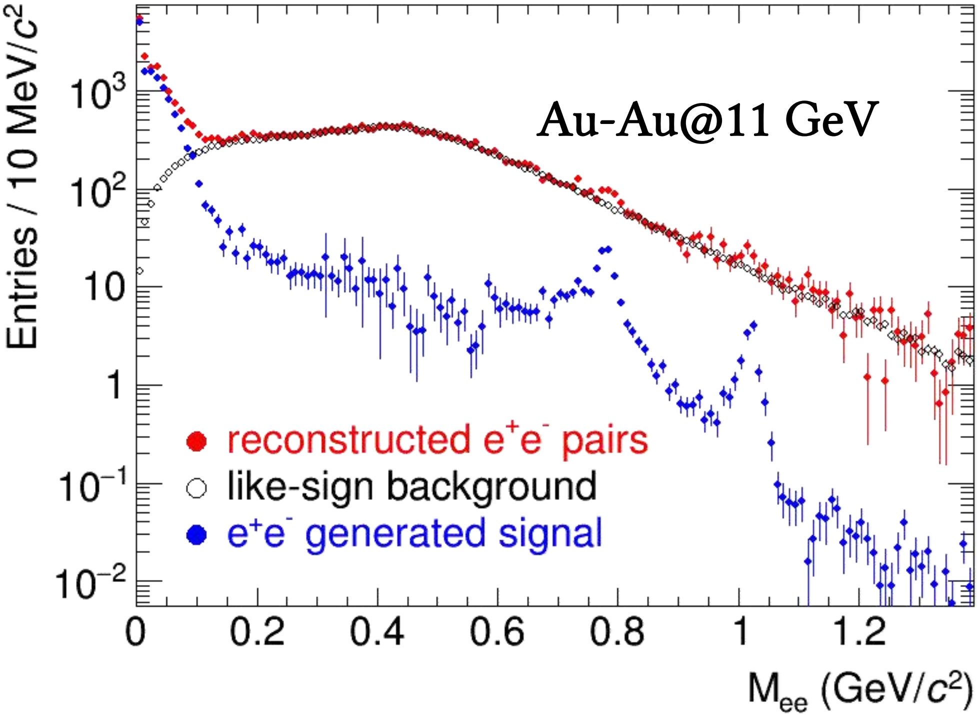
Au-Au@11 GeV

Selection cuts:

1. Fid. acc. $|\eta| < 0.3$
2. DCA < 3σ
3. At least 39 hits in TPC
5. 2σ electron PID in TPC/TOF

- Perform analysis in fiducial acceptance (say $|\eta| < 0.3$) and other is veto ($0.3 < \eta < 1.0$).
- With some analysis strategies, further rejection of combinatorials can be achieved.

Current status



- 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.

- Continuous dedicated efforts are being put to improve S/B ratio while preserving signal significance.

Conclusions

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1. Dielectrons are valuable probes and capable of delivering strong physics messages: Exciting di-electron program is anticipated at MPD using dedicated sub-detectors.

2. Excellent PID and high purity can be achieved using ECal in addition to TPC+TOF.

3. Various event generators are being utilized to simulate event with di-electrons sources.

4. Good control over CB from conversions using DCA selection except at beam pipe: ongoing efforts to reduce combinatorial background.

Thank you

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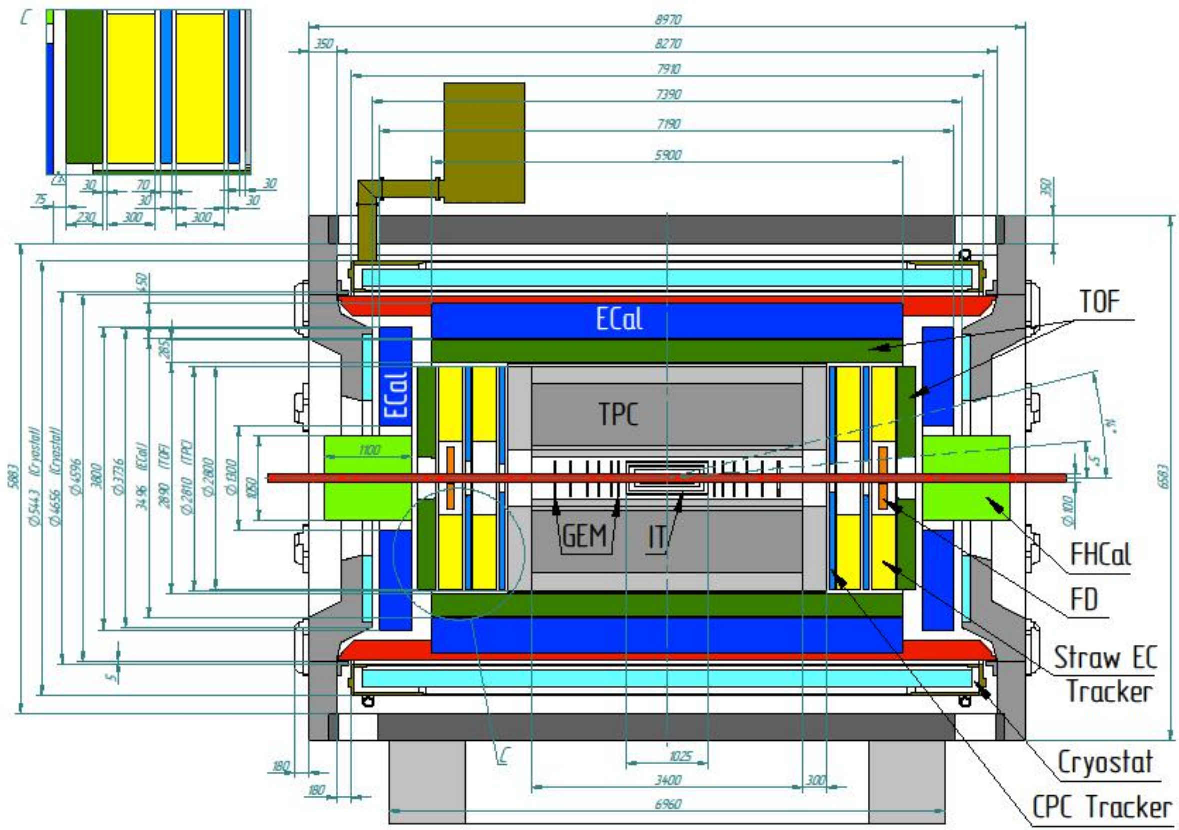
BACK-UP

MPD Front Cross-section



MPD Cross-section

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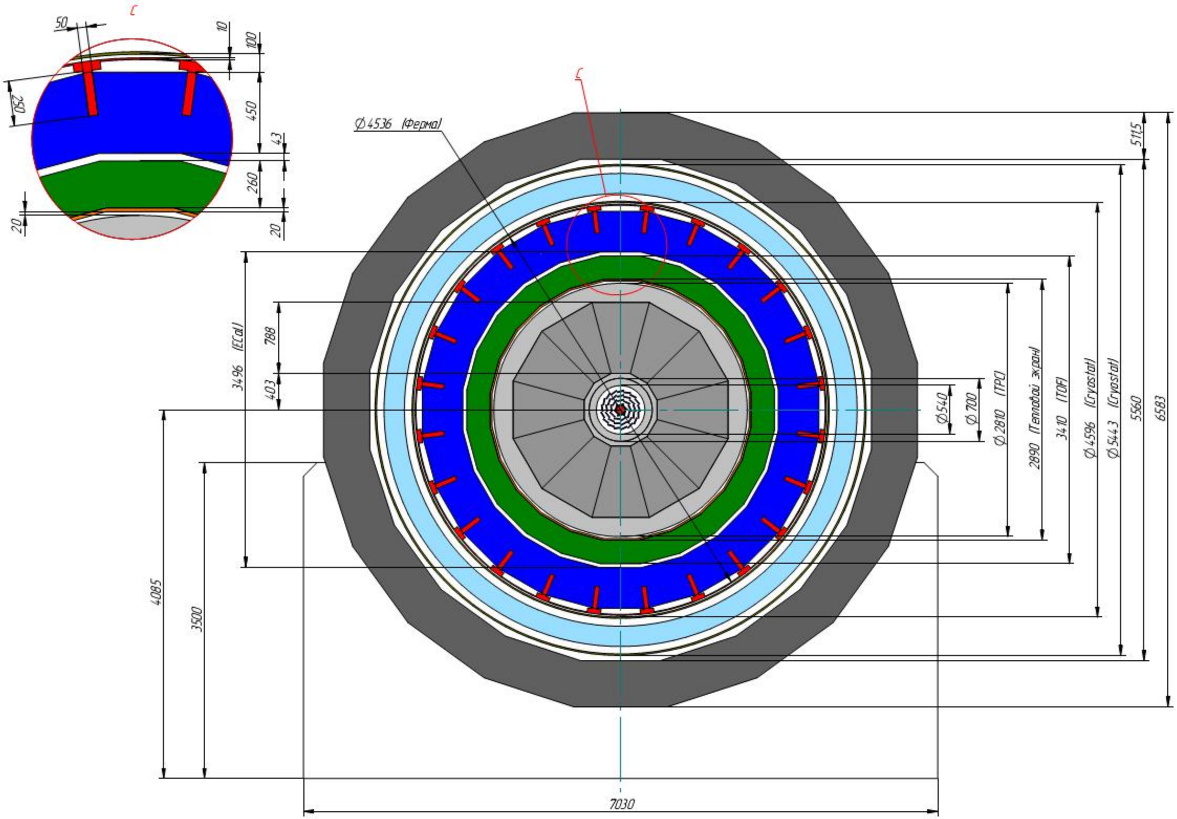
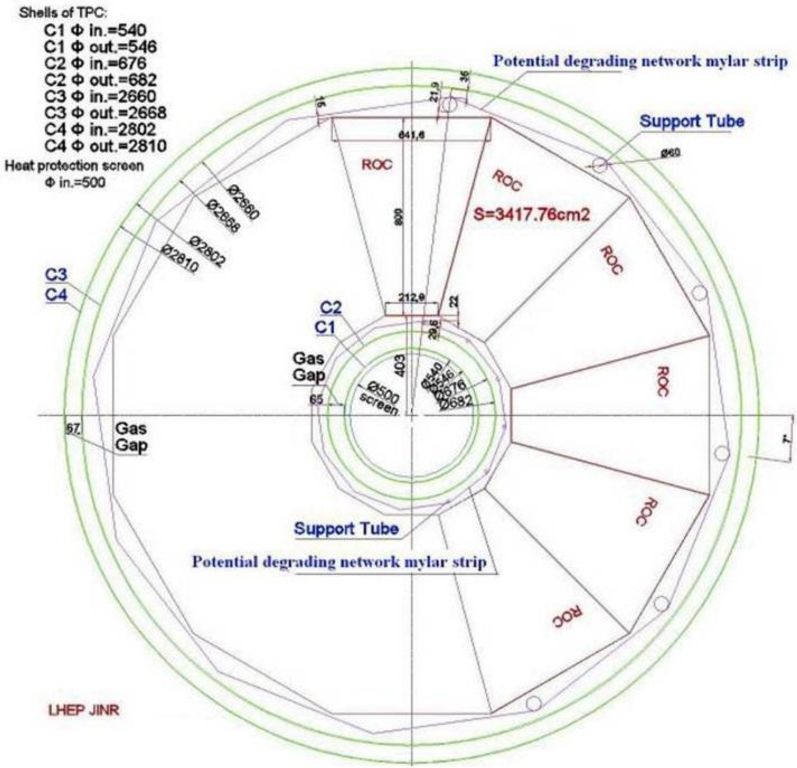
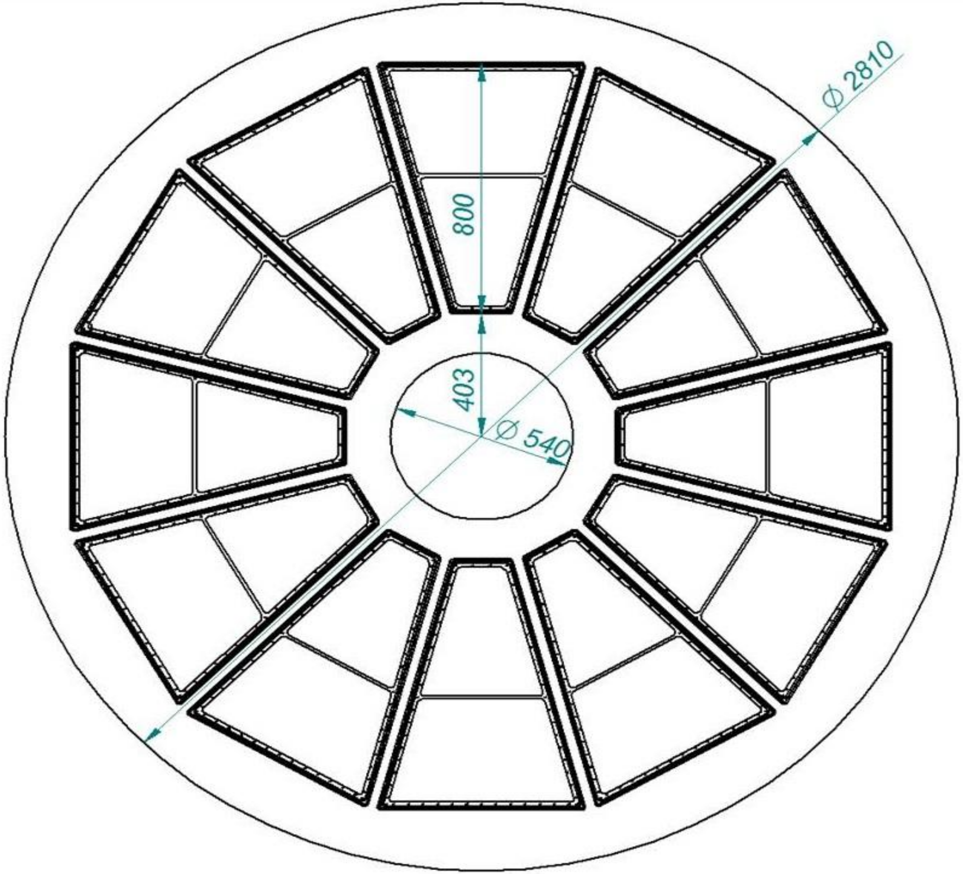


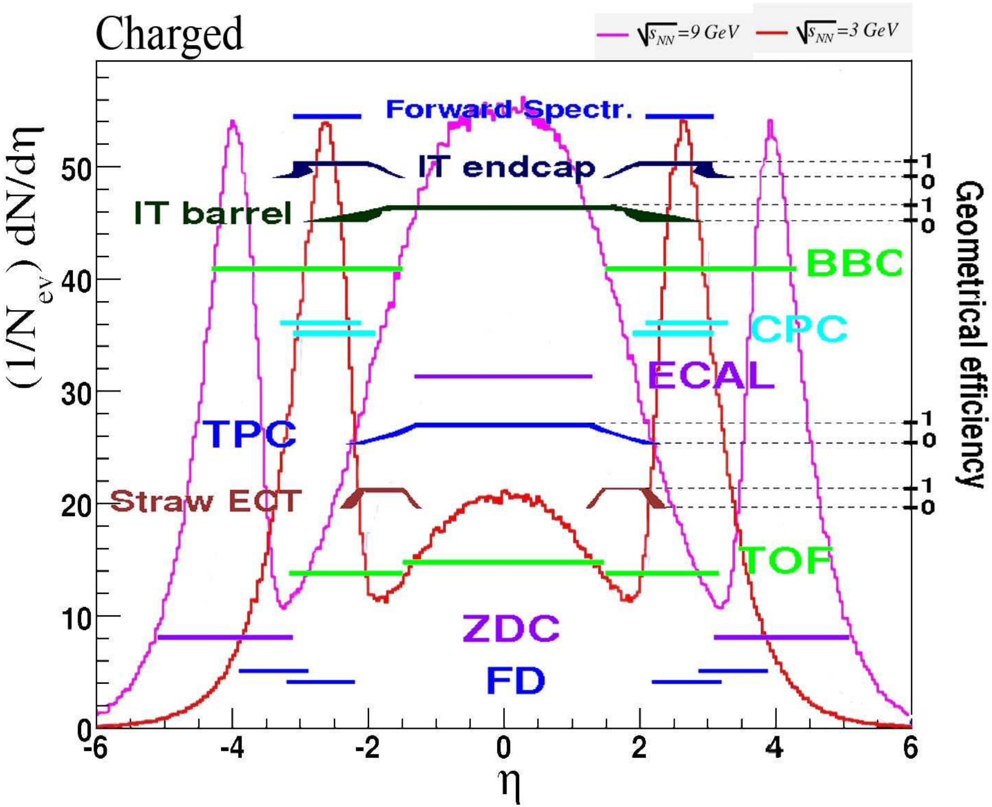
TPC Cross-section



TPC Cross-section



Pseudorapidity coverage



TOF β distribution

Selected tracks

1. hits > 39
2. $|\eta| < 1$
3. |DCA_x,y,z| < 3
4. 2σ matching to TOF