Prospects for dilepton measurements with MPD at NICA

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ECT Workshop

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Outline

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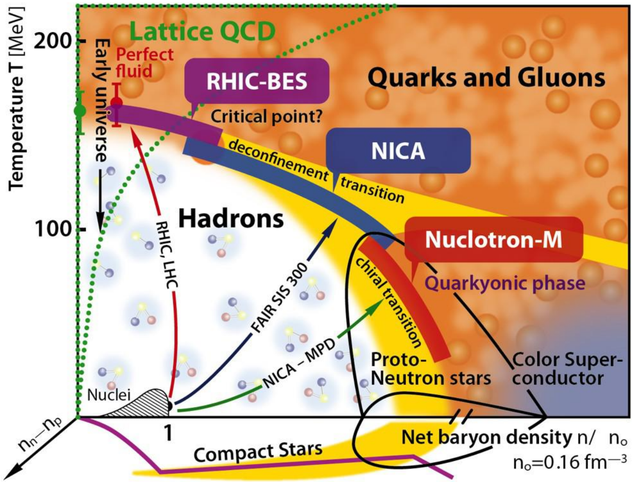
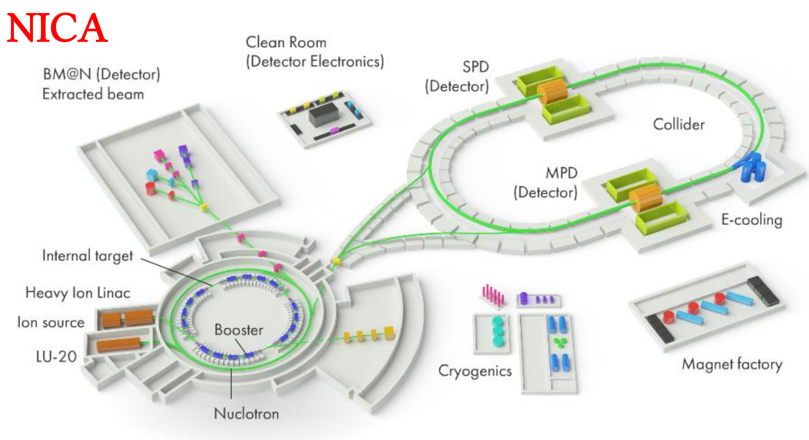
- Motivation
- MPD apparatus
- Di-electrons and challenges
  - Conversion rejection
  - Rejection of di-electrons from π^0 Dalitz decays
- Conclusions

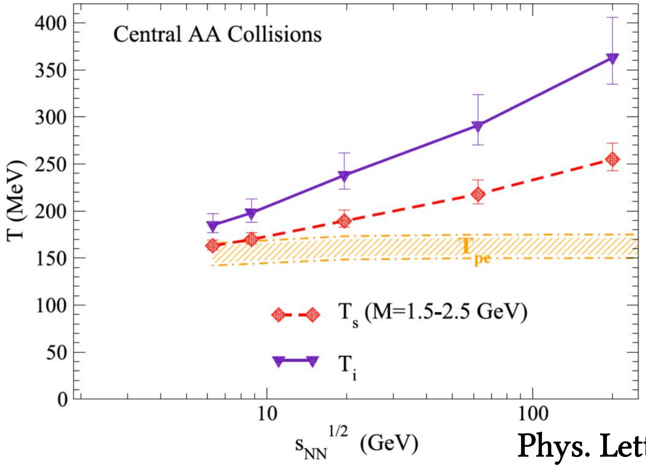
Motivation



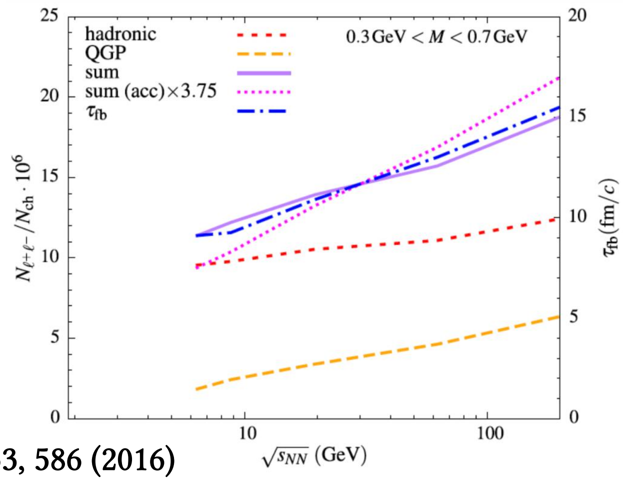


- Explore high μ_B matter.
- Center-of-Mass Energy: 4-11 GeV
- Designed luminosity: 10^{27} cm^{-1} s^{-1}
- Search for Critical end point and 1st order phase transition.
- Multi Purpose Detector (MPD) experiment: Rich and exciting di-electron program.

Motivation

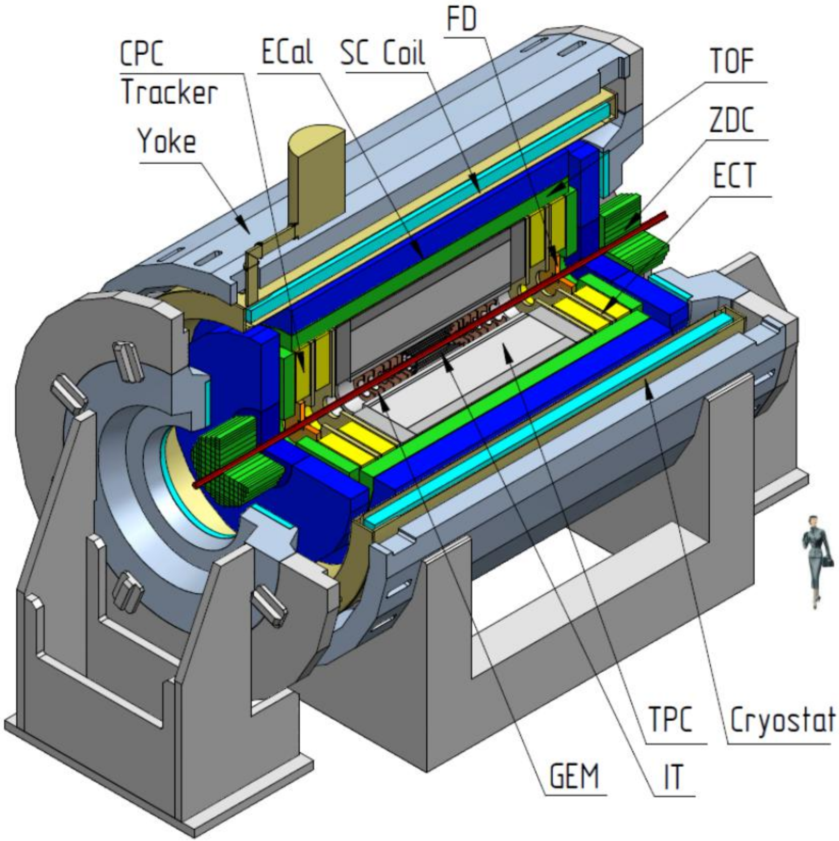


Phys. Lett. B 753, 586 (2016)



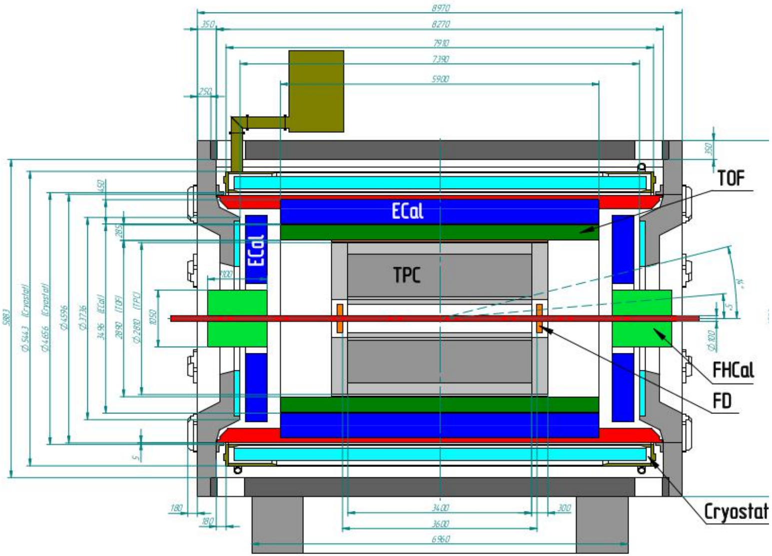
- Intermediate Mass Region: Excitation function of the inverse-slope parameter, T_s (M = 1.5 – 2.5 GeV).
- Closely related to the initial temperature T_i of the fire ball: “thermometer” for the heavy-ion collision
- Low Mass Region: At SPS and RHIC, the excess in dilepton yields: restoration of chiral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

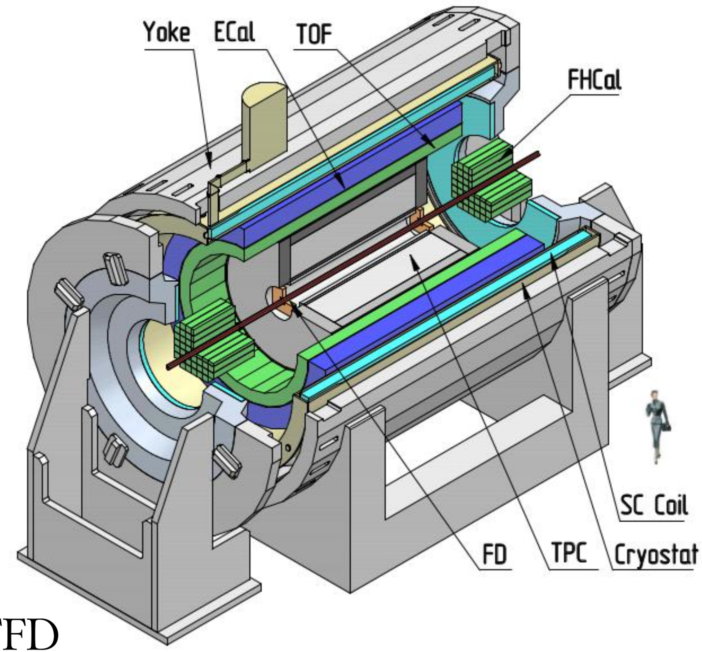
MPD setup: Full configuration



- 4π configuration.
- TPC, TOF, ECAL, FHCal, FFD, ZDC, IT and EndCap Tracker.
- To be constructed in two stages.

MPD setup: Stage I

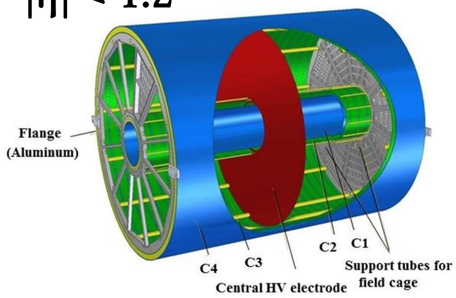


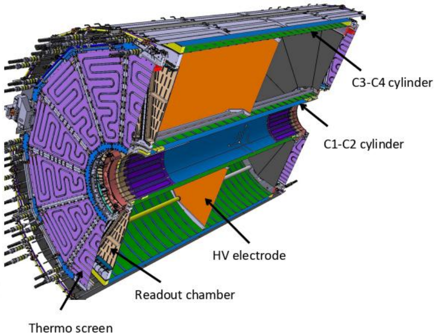


- Stage 1: TPC, TOF, ECAL, FHCal, FFD
- Stage 2: + ITS + EndCap trackers.
- Stage 1: To be ready for commissioning with beam at the end of 2022.

Time Projection Chamber (TPC)

$|\eta| < 1.2$



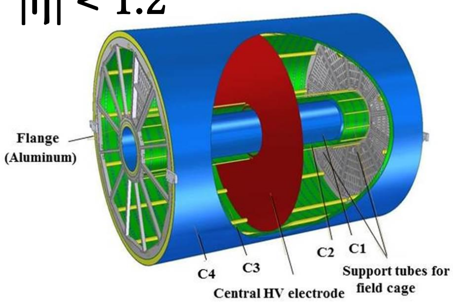


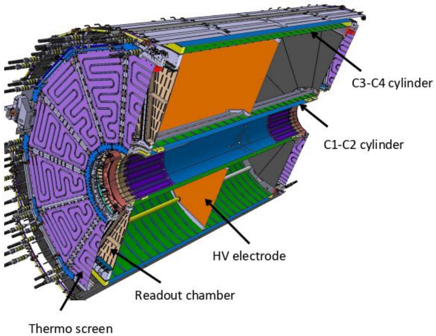
- Read-out chambers (ROC): MWPC.
- 12 ROCs per end-cap: 53 pad rows per ROC.
- Gas mixture of 90% Ar+10% CH_4
- Maximum design event rate for the TPC: 7 kHz.
- The TPC vessel construction and production of ROCs are in advanced stage.

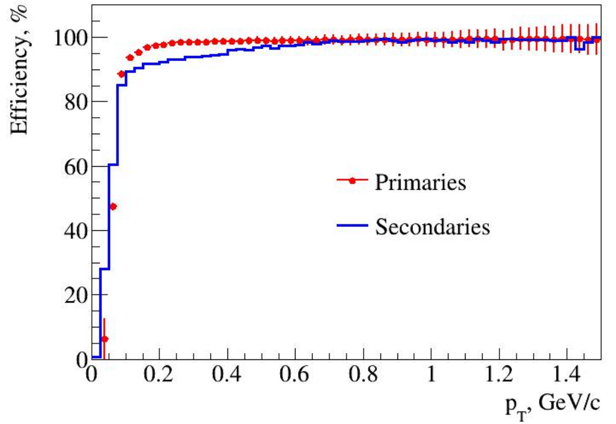
Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Drift vol. outer radius	133 cm
Drift vol. inner radius	34 cm
Drift vol. length	163 cm (of each half)
HV electrode type	Central membrane
Electric field strength	$\sim$ 140 V/cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% 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

Time Projection Chamber (TPC)

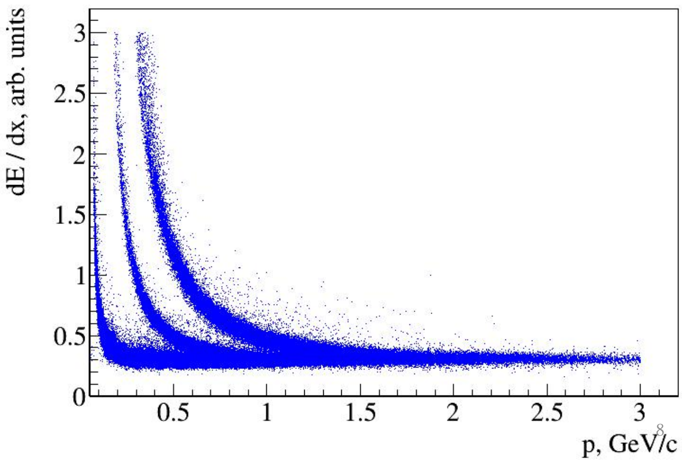
$|\eta| < 1.2$







- 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)

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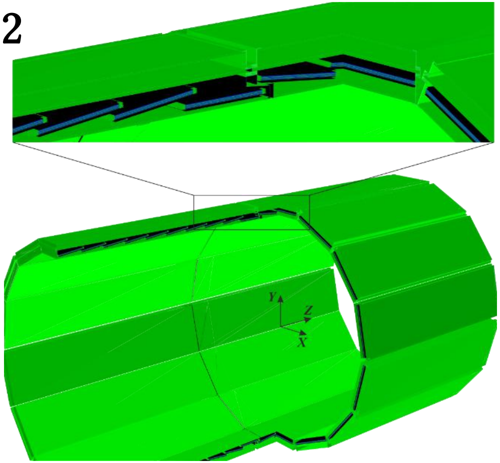
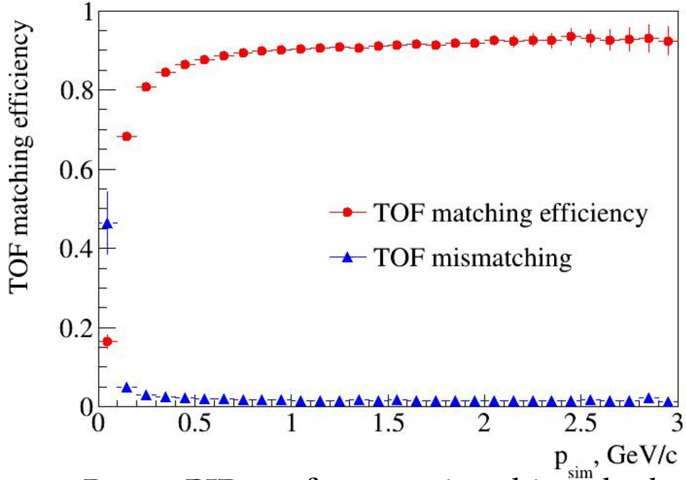
$|\eta| < 1.2$





- Based on the technology of (MRPC).
- Measures time-of-flight of the track.
- Prototype is developed for testing ToF modules with cosmic rays: commissioning of service systems is 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)

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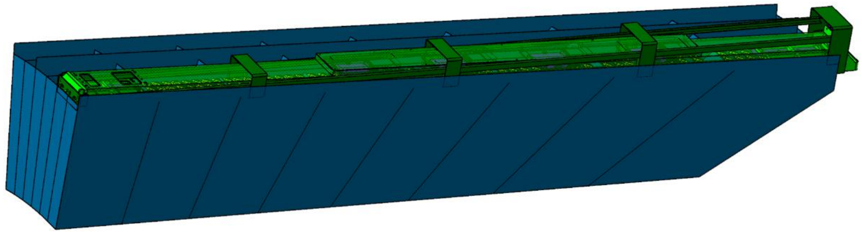

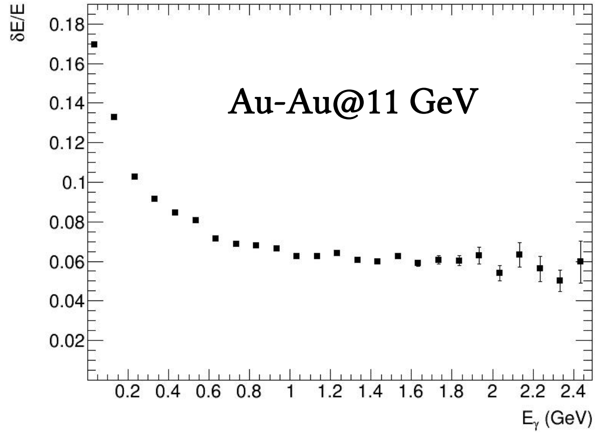

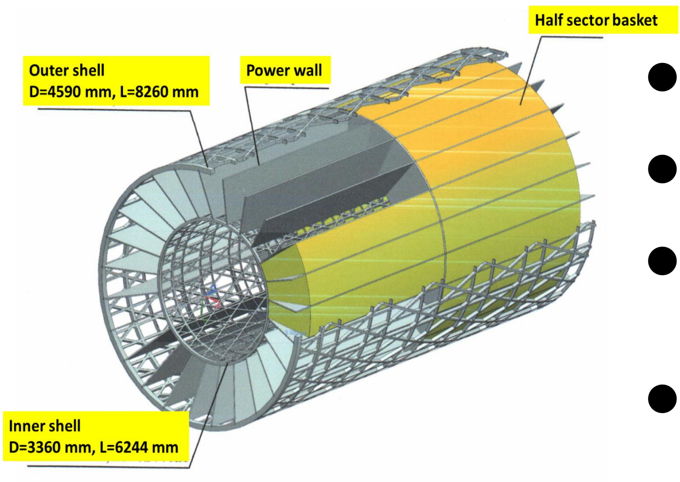

- A shashlik type calorimeter made of Pb-scintillator.
- Full configuration: 50 half-sectors in full azimuth (25 full sectors): Range, $360^{o}/25 = 14.4^{o}$
- Measures time-of-flight and E/p of the track and detect particles of energy from 10 MeV to a few GeV.
- Energy resolution of about 6% for high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

Forward Hadron Calorimeter (FHCal

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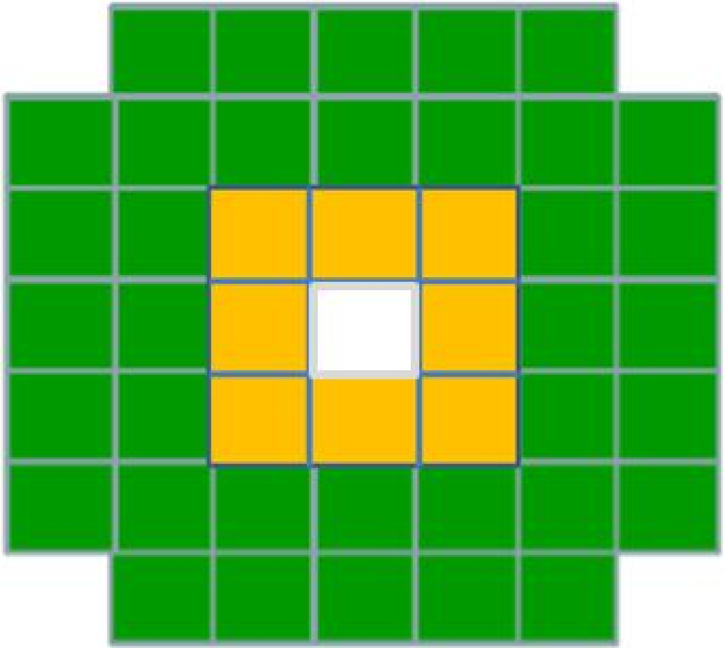
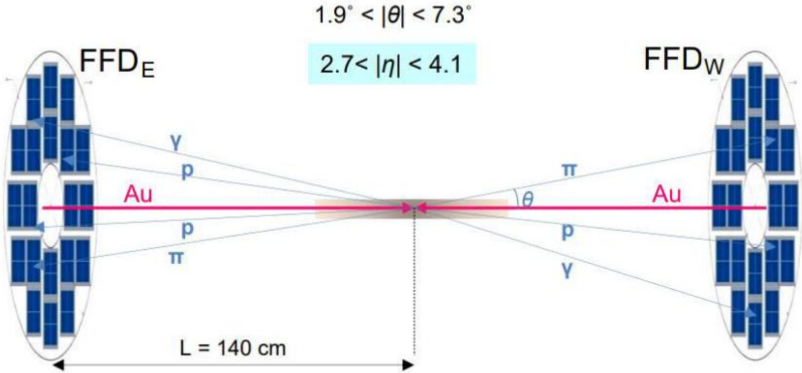
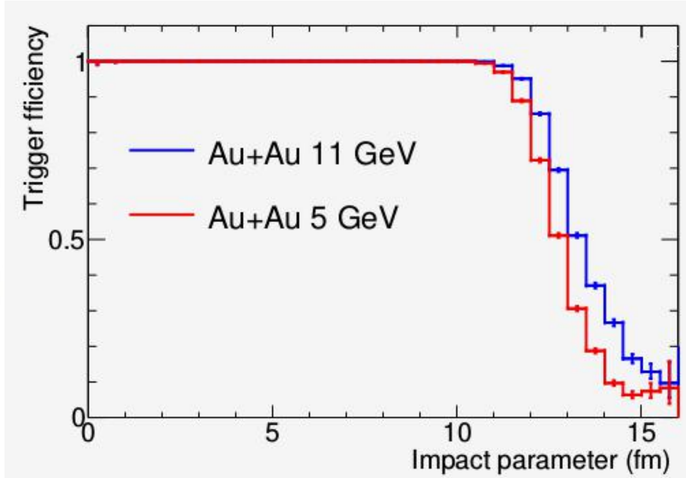


$2 < |\eta| < 5$

- 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.
- Relative calorimeter energy resolution, $\sigma E / E \approx 55\% / \sqrt{E}$ (GeV).

Fast Forward Detector (FFD)



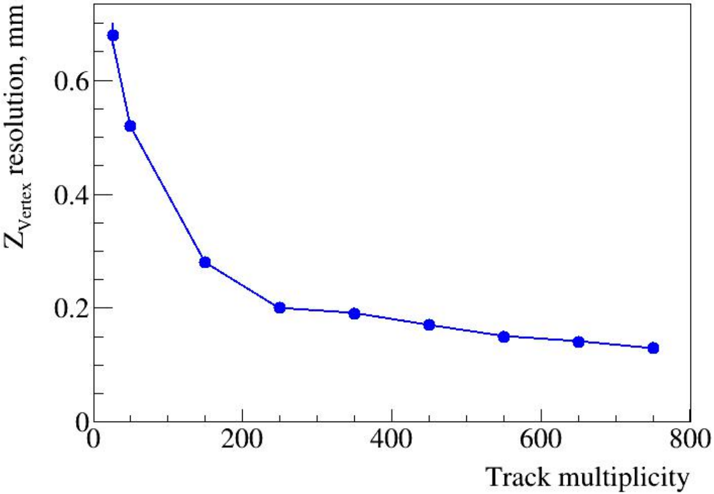


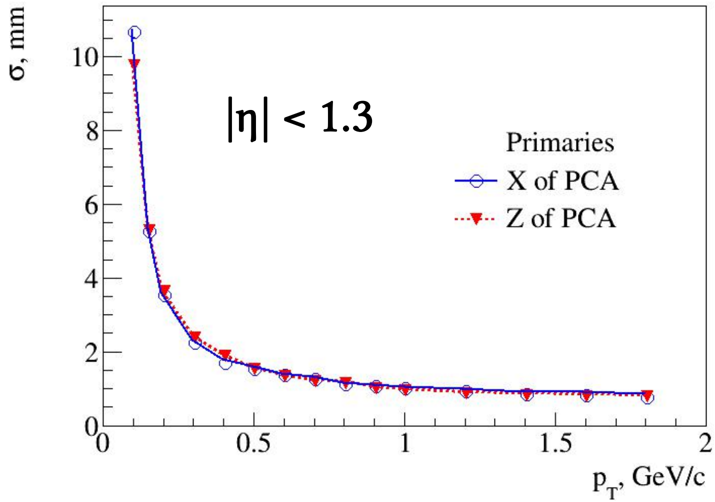
- FFD: Provides fast triggering of A+A collisions and generates the start-time (T0) pulse generation for the ToF and ECal detector with a time resolution better than 50 ps.

- 20 Cherenkov modules with each module consists of a 10 mm lead converter, a 15 mm quartz radiator etc.

- 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

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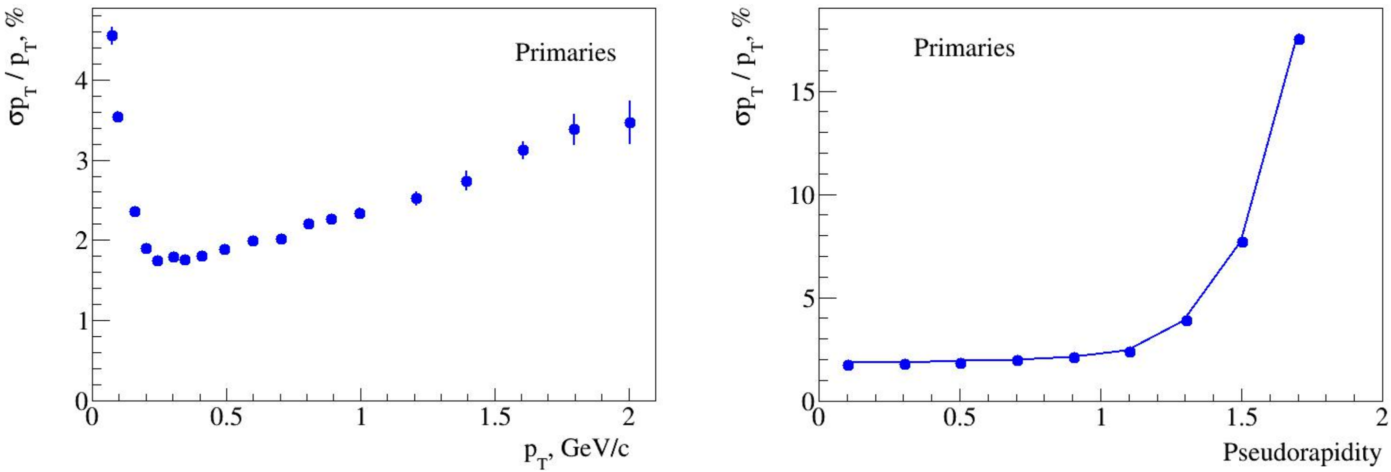
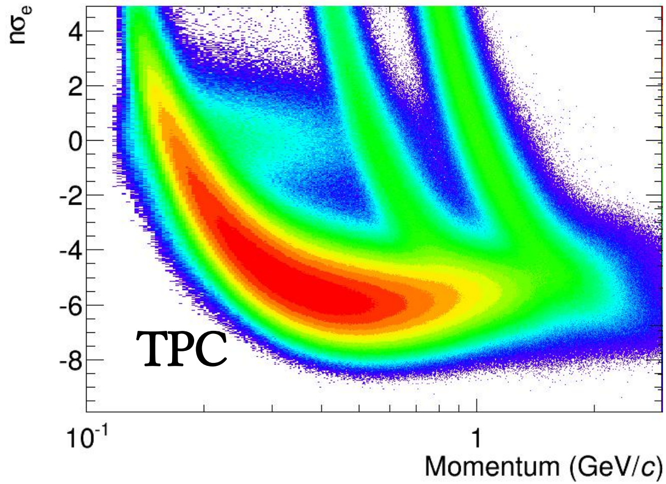
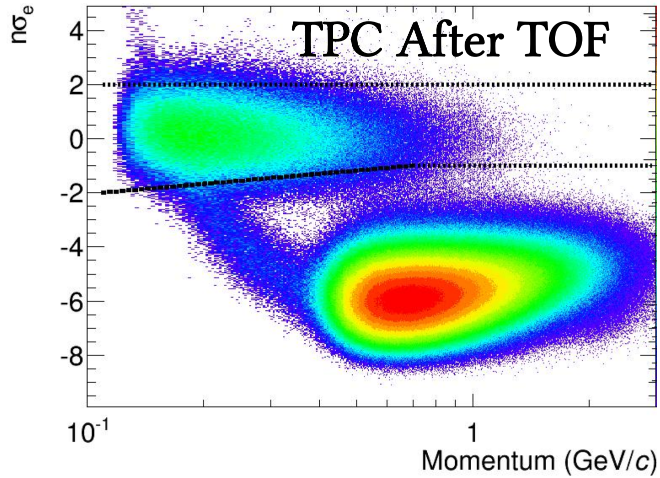


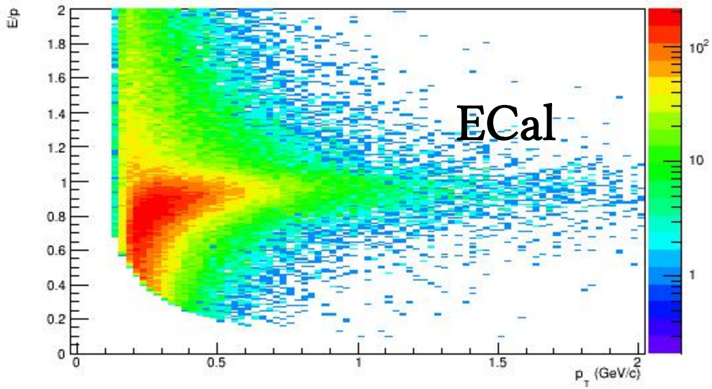
- Maximum achievable relative transverse momentum resolution for charged particles of 2% as function of p_T (0.2-0.8 GeV/c) and η (|η| < 1).

Particle Identification with MPD



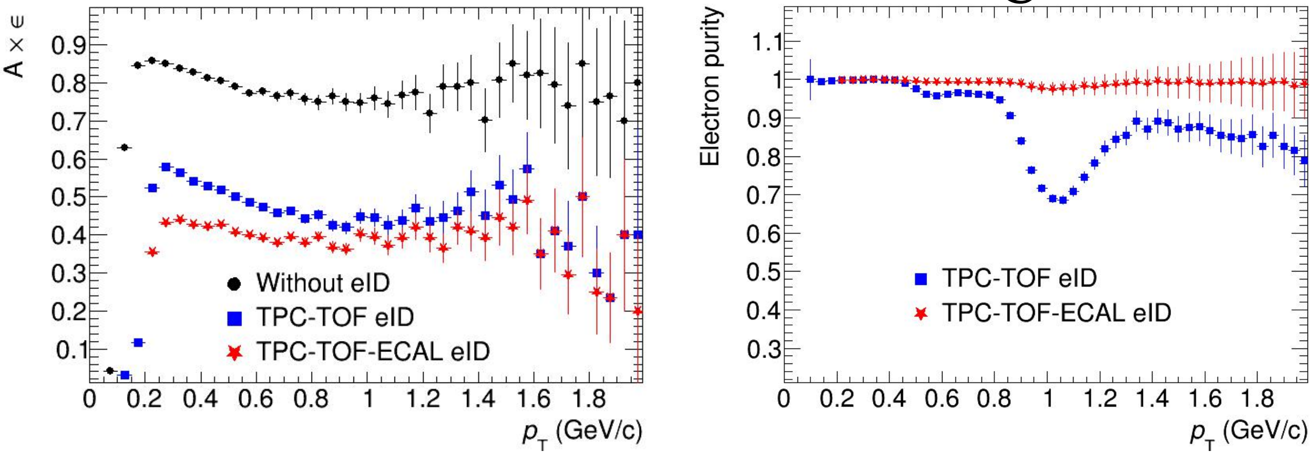


- For PID, TPC (dEdx information), TOF (Time-Of-Flight) and ECal (E/p) is used.
- TPC+TOF is good enough to identify electrons with decent purity.
- However, ECal helps to gain even higher purity.



Efficiency and Purity

Au-Au@11 GeV



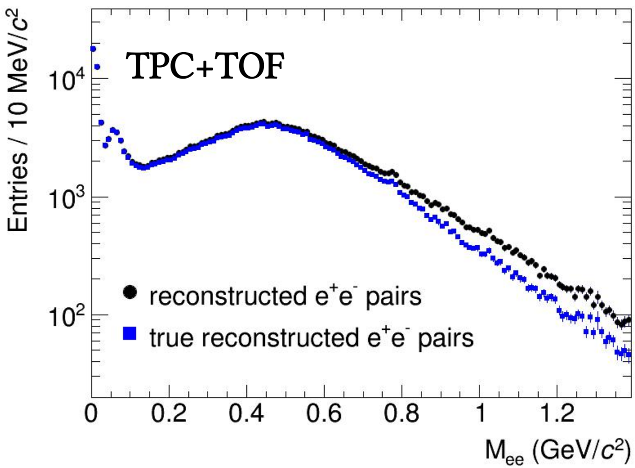
Typical cuts on electrons:

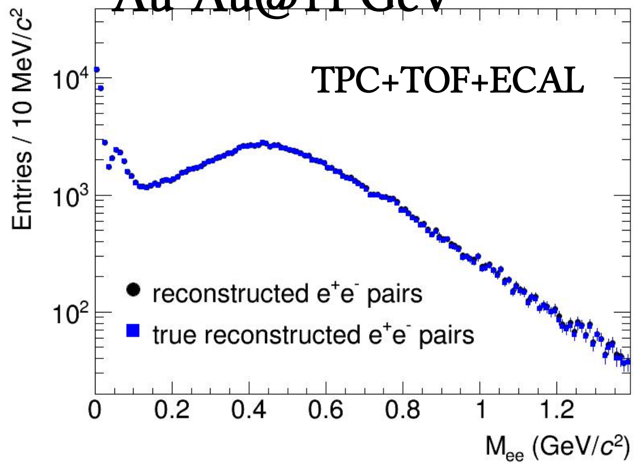
1. $|\eta| < 1$
2. DCA < 3σ
3. $p_T > 50$ MeV/c
4. at least 39 hits in TPC
5. 2σ electron PID in TPC/TOF

- Single electron efficiency: Constant PID efficiency of 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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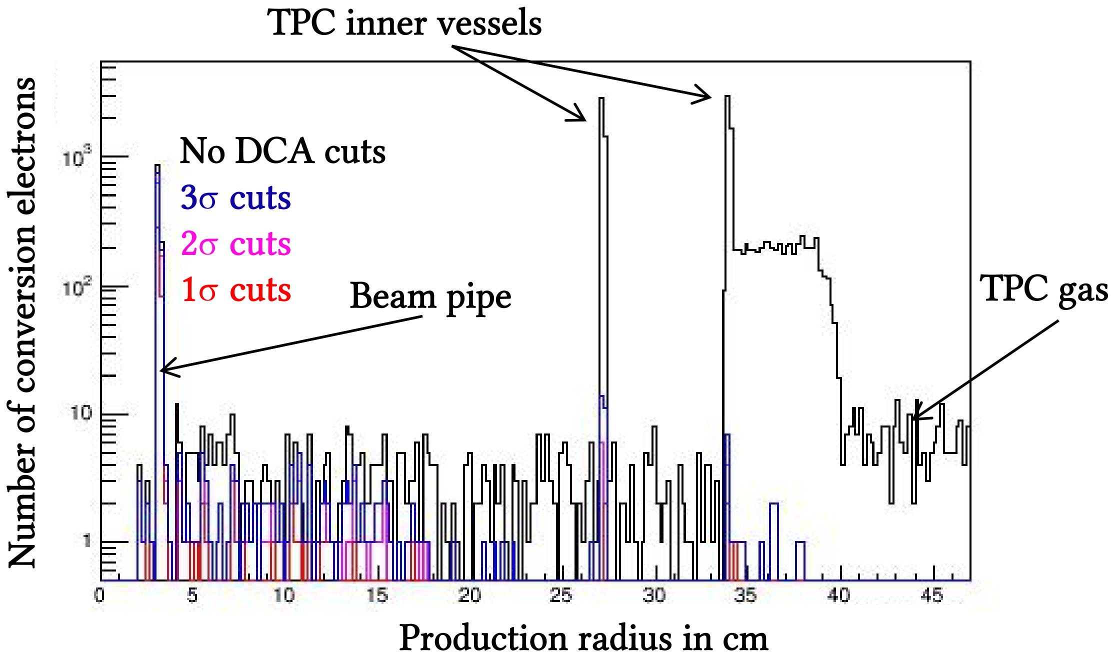
- Optimization of track and eID selection cuts:
  - more differential DCA parameterizations
  - better control over the track-to-TOF matching
  - better treatment of eID in the TPC, TOF and ECAL
- Special efforts are in progress to reduce the CB from gamma conversion and π^0-η Dalitz decays.
  - rejection 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

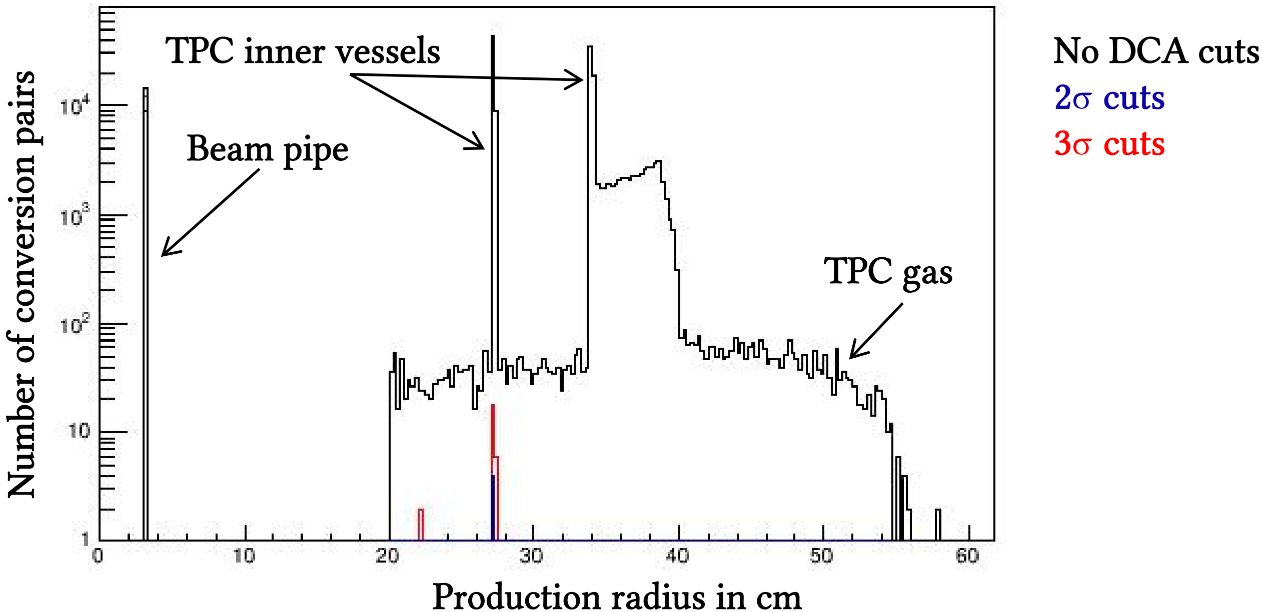
Rejection of single conversion electron



- 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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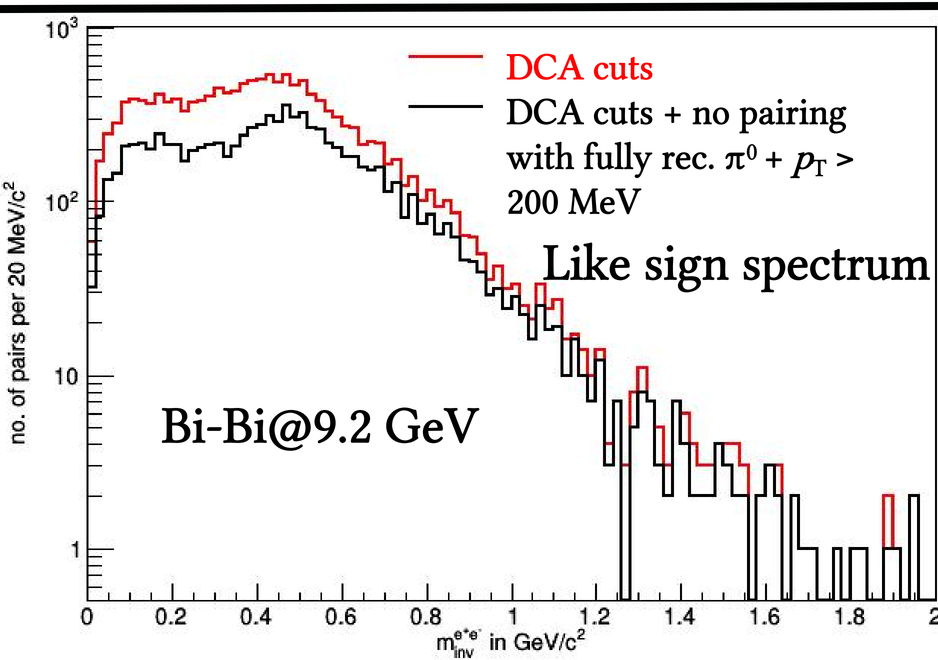

Selection cuts:

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 strategy further rejection of combinatorials can be achieved.

Dielectron M_{inv} spectra: p_T integrated

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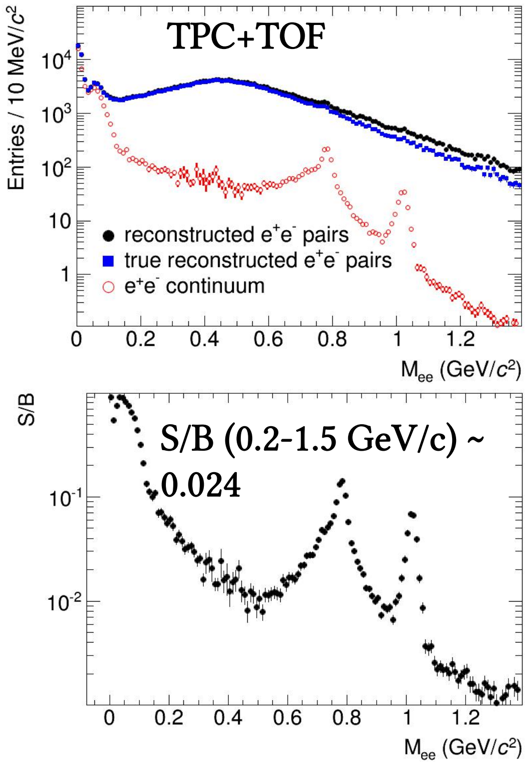
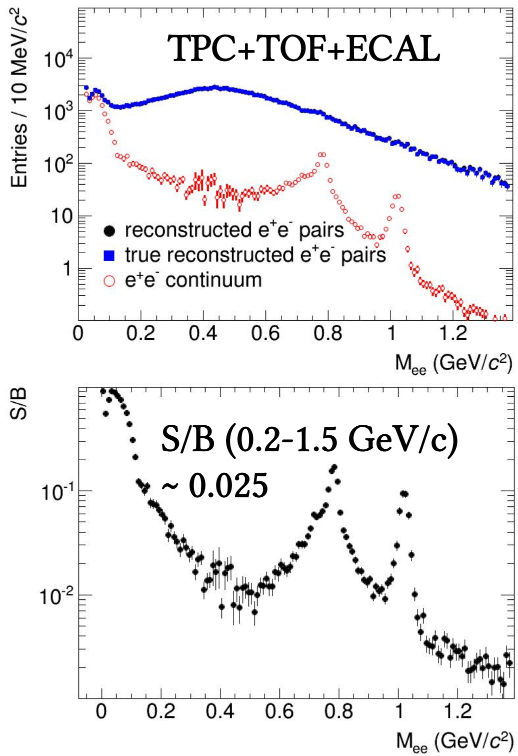
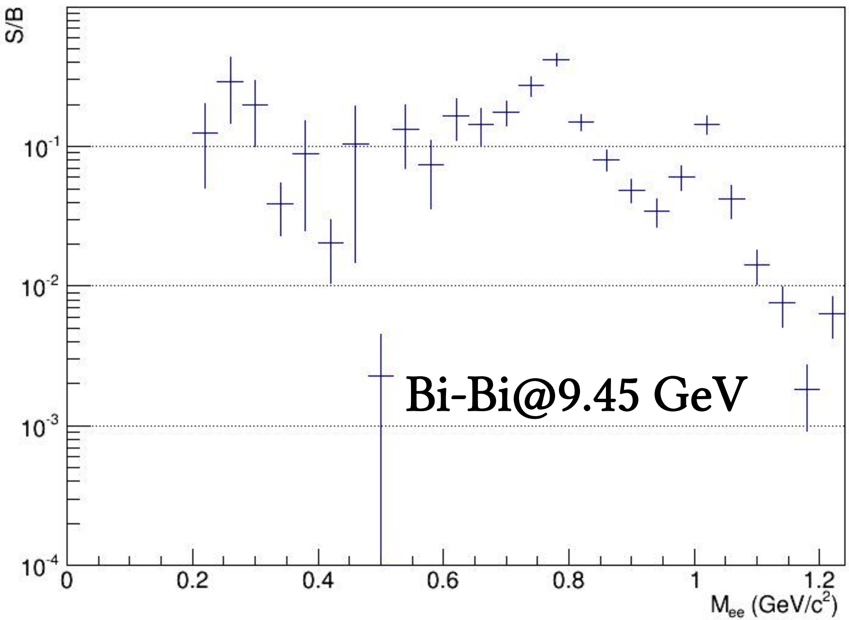


- Minbias AuAu@11 (UrQMD v3.4) events.
- Good control over contamination at higher M_{inv} masses using ECAL.
- Comparable S/B ratio irrespective of ECAL.



Best estimate of the Signal to background ratio



- Optimization of selection cuts could lead to some improvements.
- Signal to Background ratio of 0.12 between 0.2 to 1.5 GeV/c^2 invariant mass region.
- Continuous dedicated efforts are being put to improve S/B ratio with 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. Good control over CB from conversions using DCA selection except at beam pipe: ongoing efforts to reduce combinatorial background.

4. Various event generators are being utilized to simulate event with di-electrons sources: Large signal to background with good signal significance can be achieved.

Thank you

BACK-UP

TPC efficiencies

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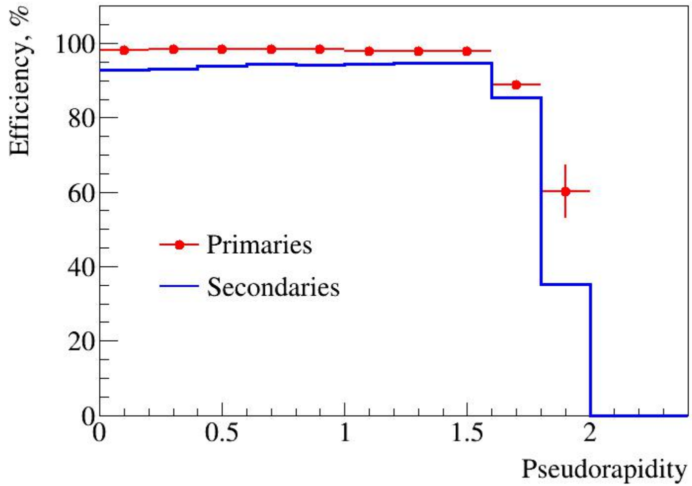

- Track reconstruction efficiency for particles with the number of measured points in the TPC (hits) greater than 14 as a function of p_T for $|\eta| < 1.3$ and as a function of $|\eta|$ for $p_T > 0.1$ GeV/c. Symbols and lines present primary and secondary particles, respectively. Secondary particles here were defined to be those produced within 50 cm from the interaction point.

MPD Front Cross-section

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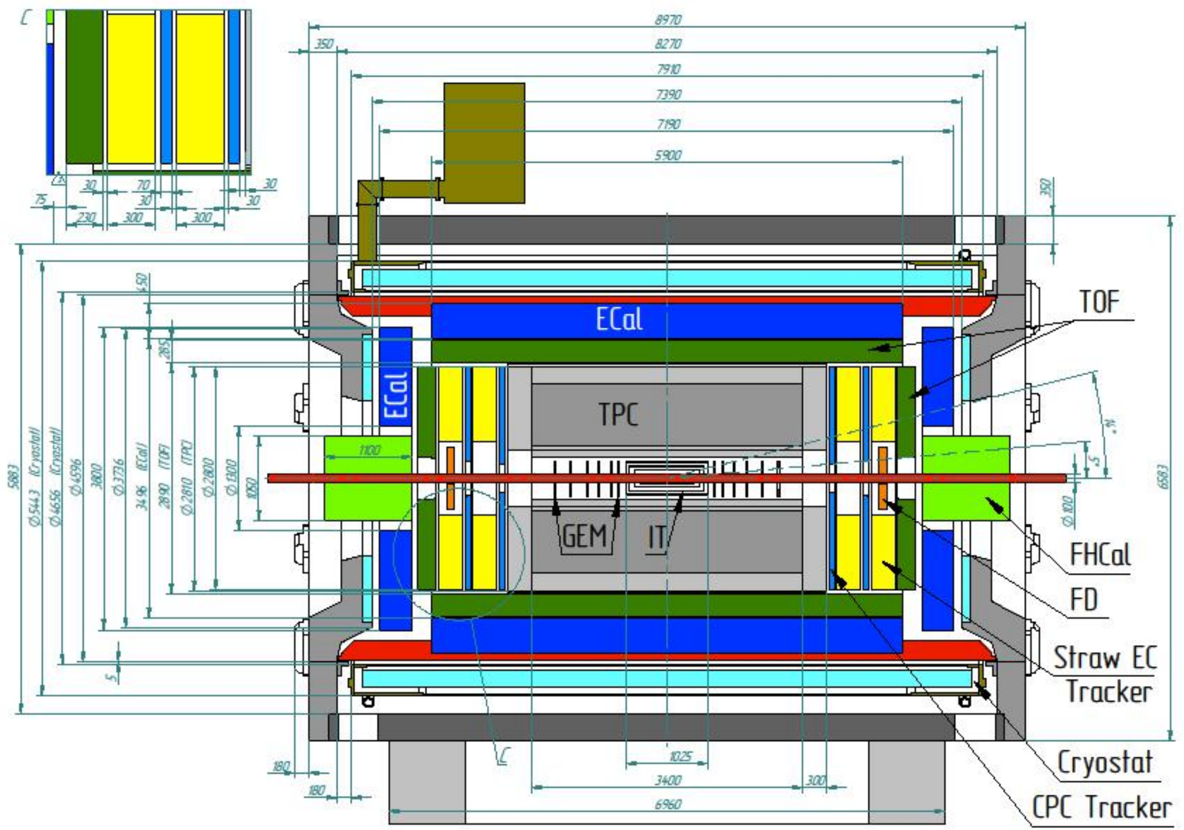

MPD Cross-section

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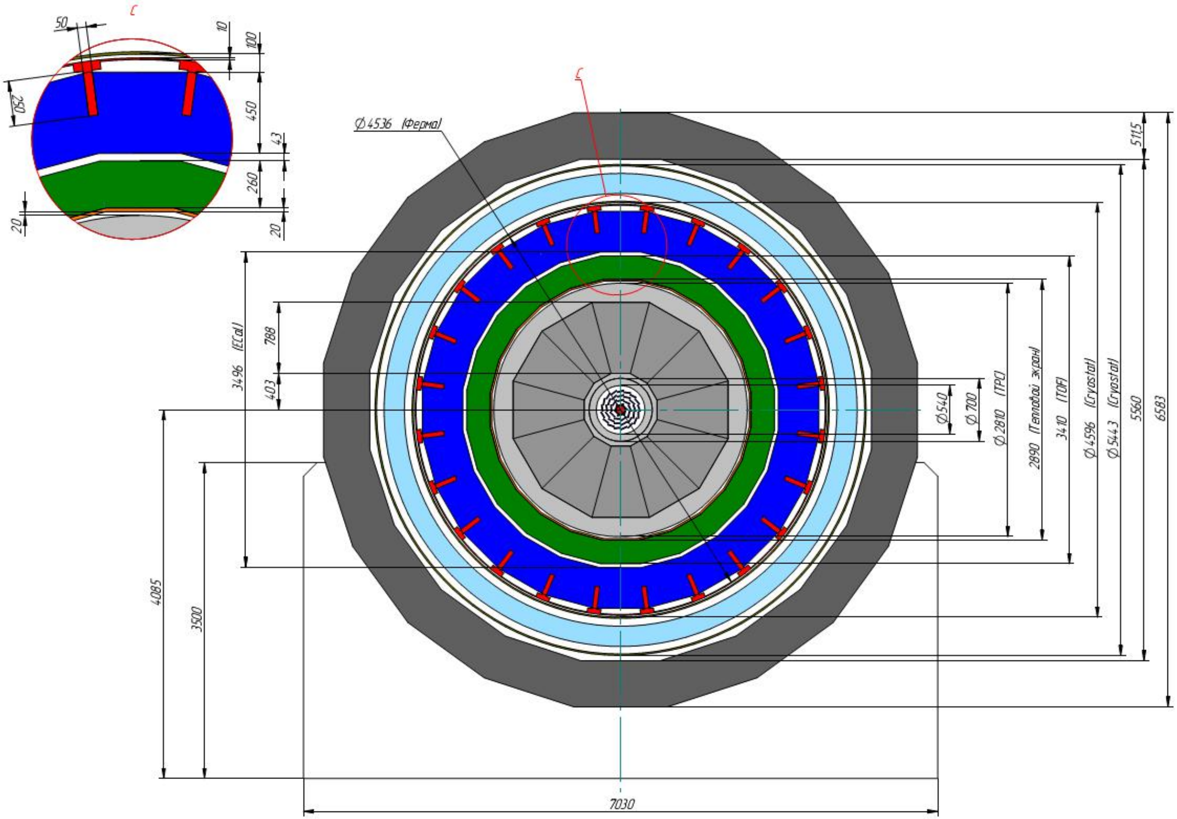

TPC Cross-section

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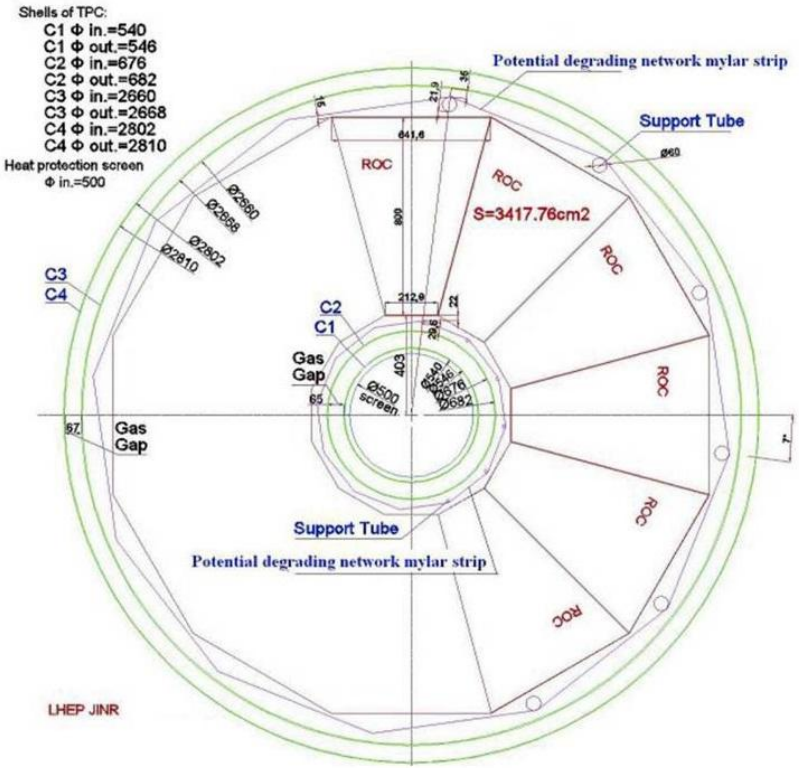
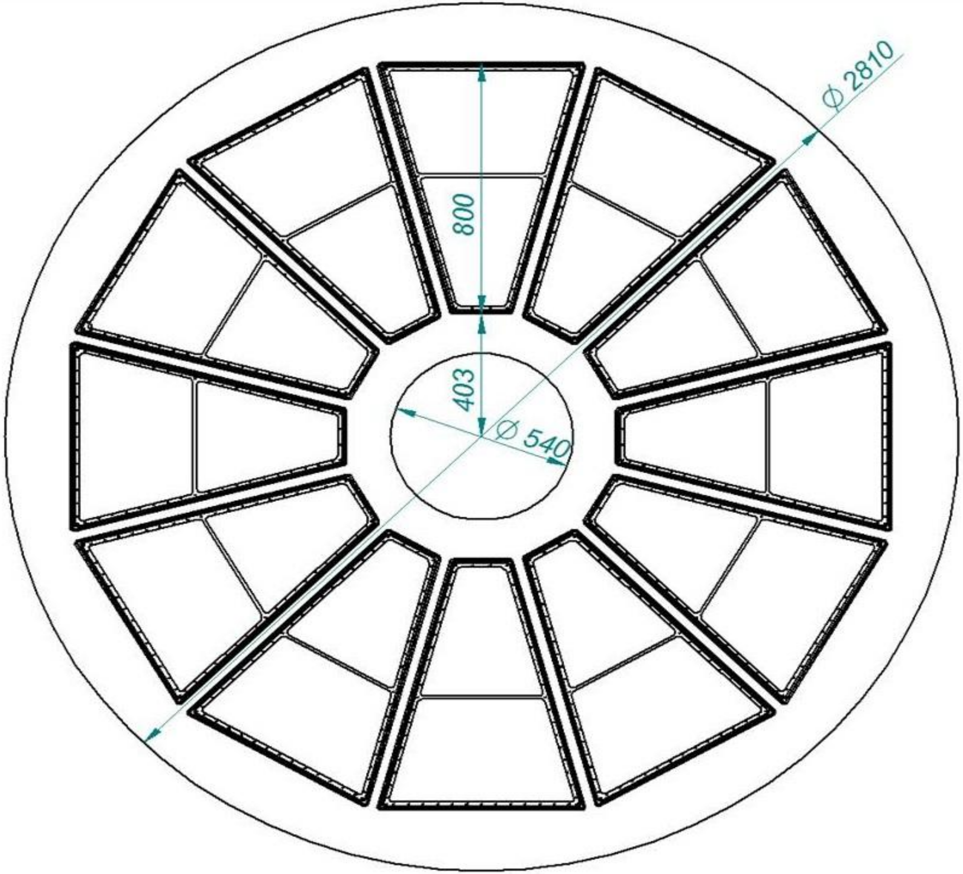


TPC Cross-section



Pseudorapidity coverage

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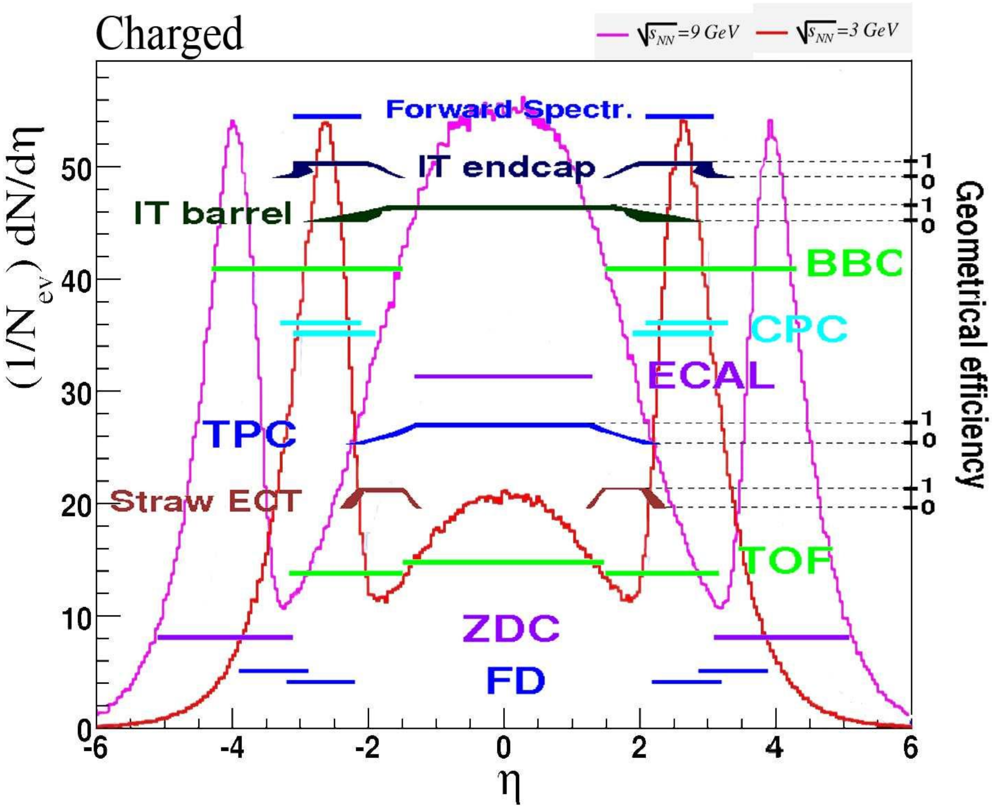
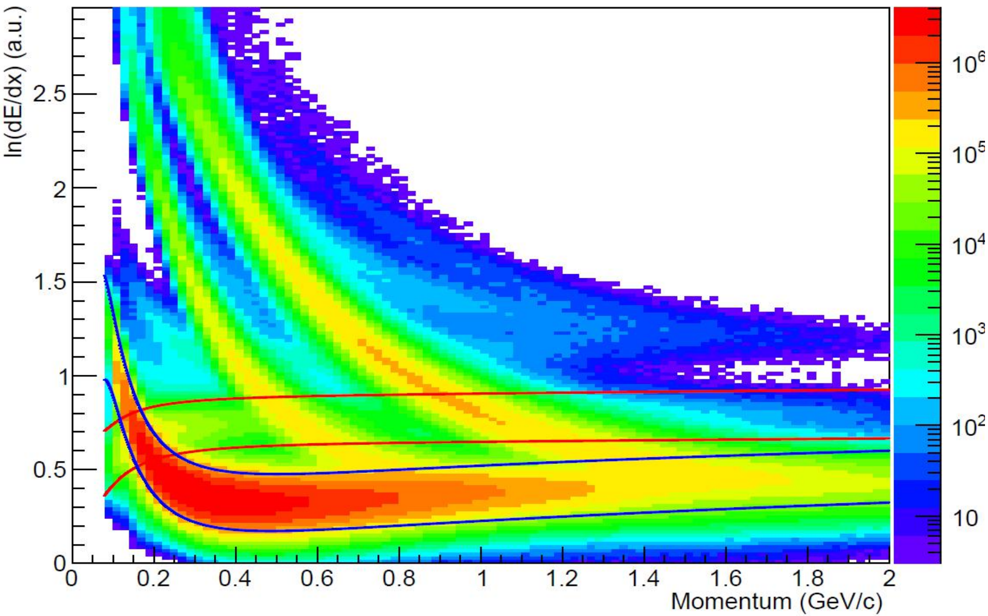


TPC dE/dX parametrization



I. Selected tracks:

1. hits > 39
2. |η| < 1
3. |DCA_x,y,z| < 3σ

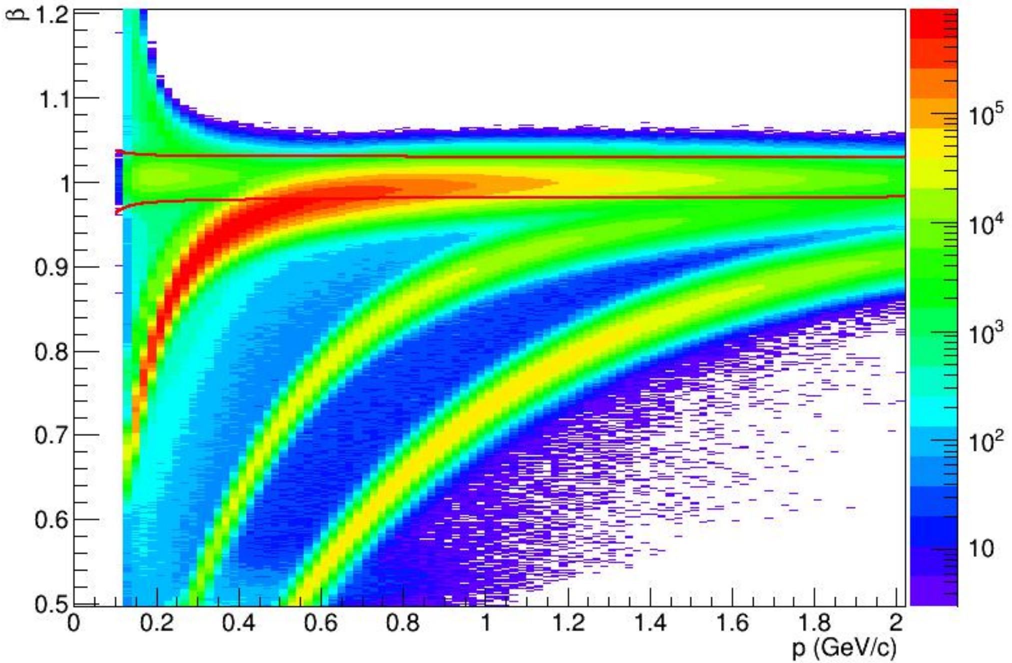
II. Parameterized log(dE/dx) vs. momentum for electrons and pions.

III. Red and blue bands show 2σ selections for electrons and pions.

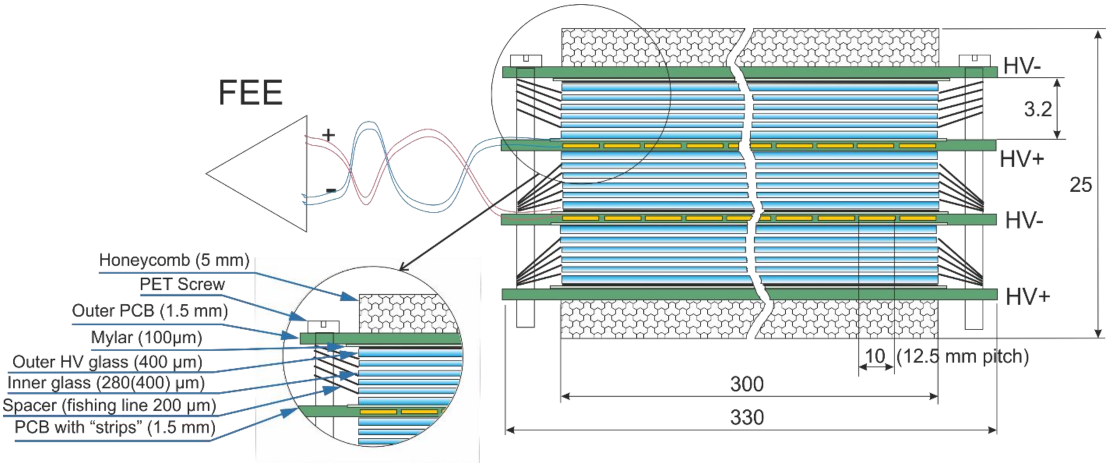
TOF β distribution

Selected tracks

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



TOF



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