Prospects for Dilepton Measurements in MPD at NICA

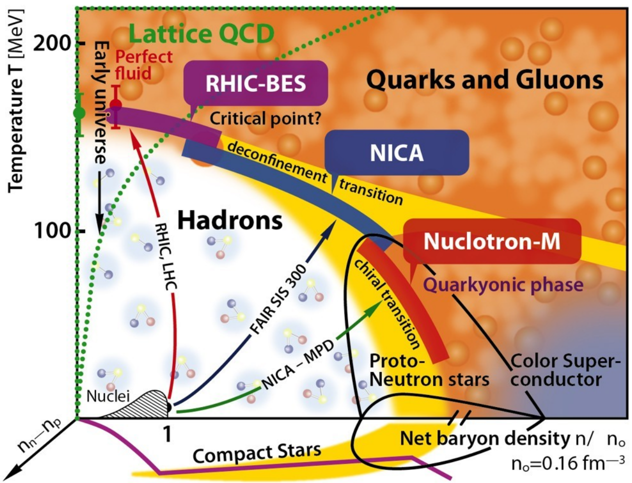
Sudhir Pandurang Rode for the MPD collaboration

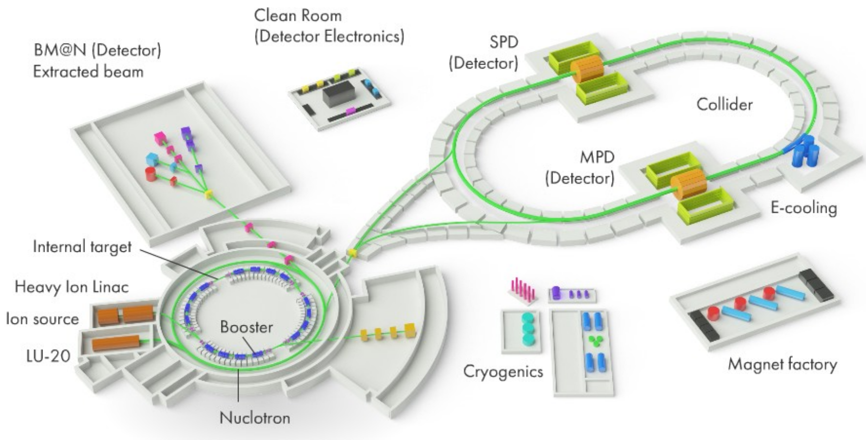
DAE-BRNS Symposium on CETHENP 2022

Outline

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

Motivation

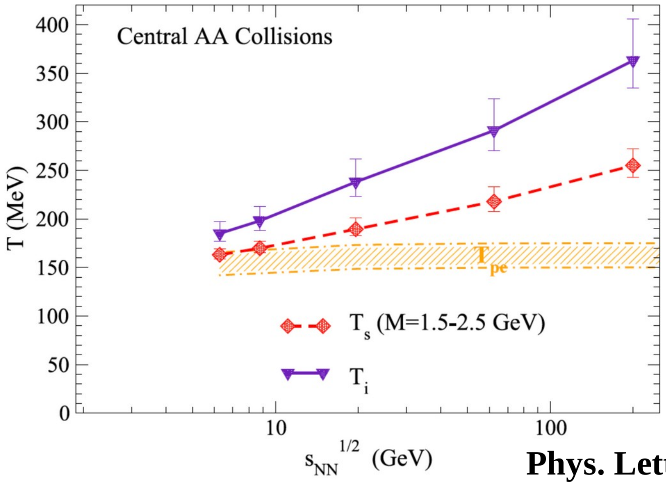


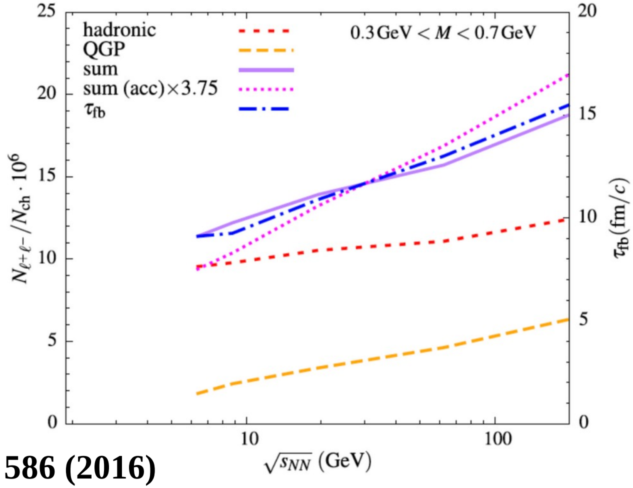


Nuclotron-based Ion Collider fAcility (NICA)

- Explore high μ_B matter.
- Search for Critical end point and 1st order phase transition.
- $\sqrt{s_{NN}}$: 4-11 GeV $\rightarrow$ Designed luminosity: 10^{27} cm^{-2} s^{-1}
- Experiments@NICA: MPD, SPD and BM@N.
- BM@N taking data since 2018.
- Multi Purpose Detector (MPD) experiment: Rich and exciting di-electron program.

Motivation

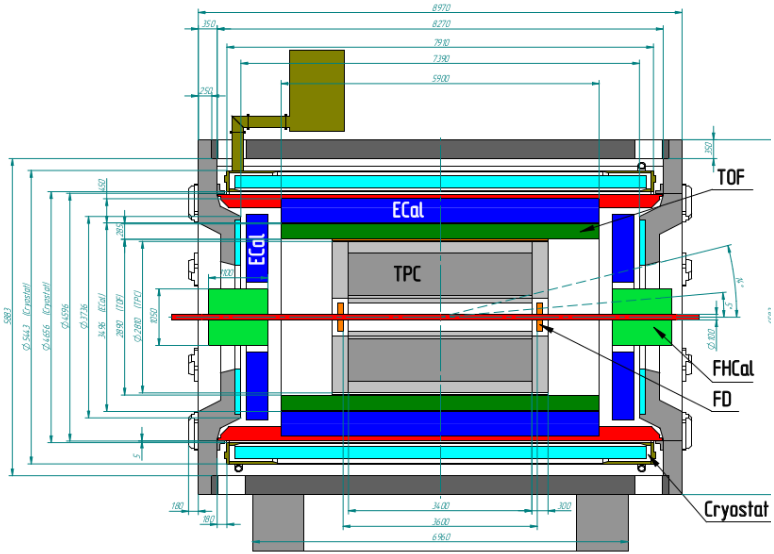


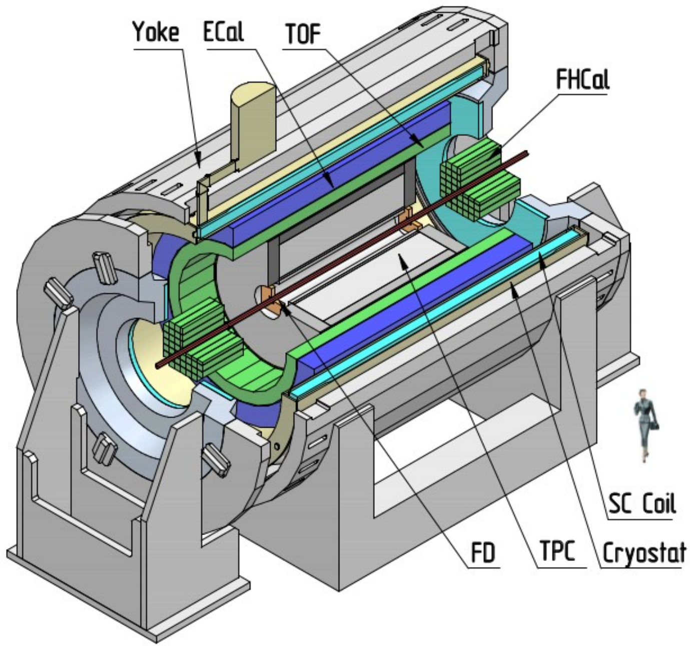


Phys. Lett. B 753, 586 (2016)

- 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: Stage I

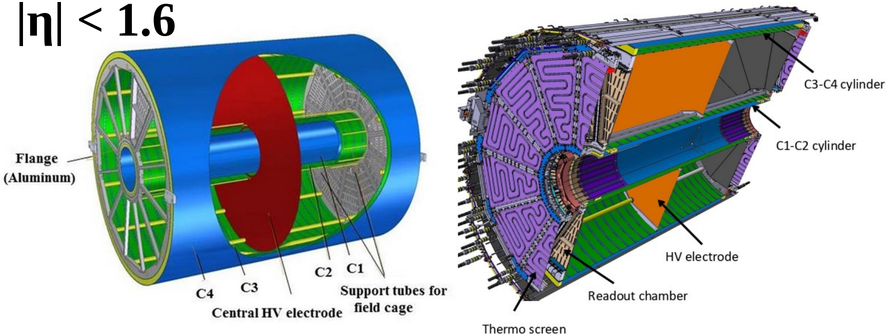




- Stage 1: TPC, TOF, ECAL, FHCal, FFD
- Stage 2: + ITS + EndCaps.
- Stage 1: Commissioning is expected at the end of 2023.
- Nominal magnetic field, B = 0.5 T.
- First data taking is expected in 2024 with Bi-Bi beam at $\sqrt{s_{NN}}$ = 9.2 GeV.

Time Projection Chamber (TPC)

$|\eta| < 1.6$

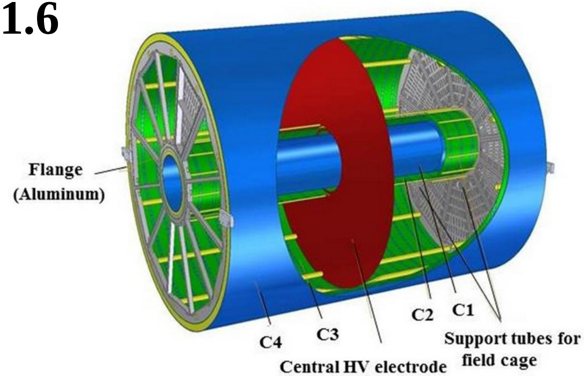


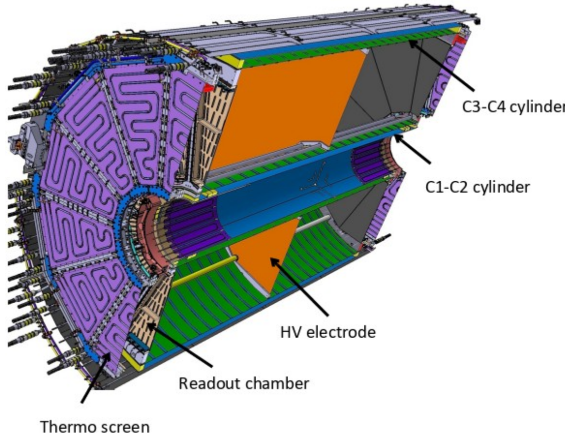
- Read-out chambers (ROC): MWPC.
- 12 ROCs per end-cap: 53 pad rows per ROC.
- Gas mixture of 90% Ar+10% CH_4
- Maximum design event rate for the TPC: 7 kHz.
- **The TPC vessel and ROCs are done: Electronics in mass production.**

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

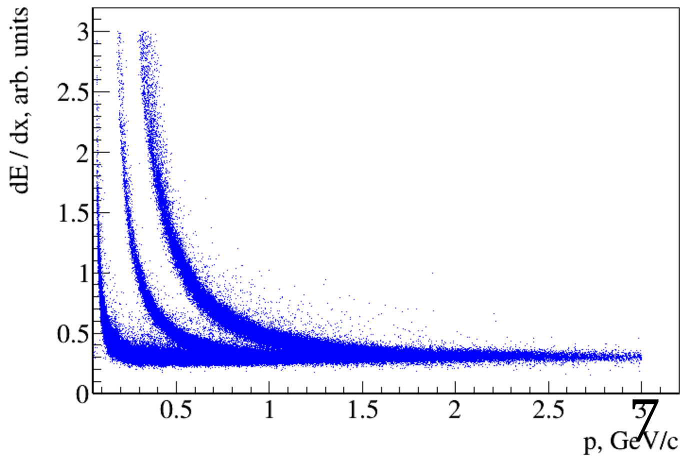
Time Projection Chamber (TPC)

$|\eta| < 1.6$

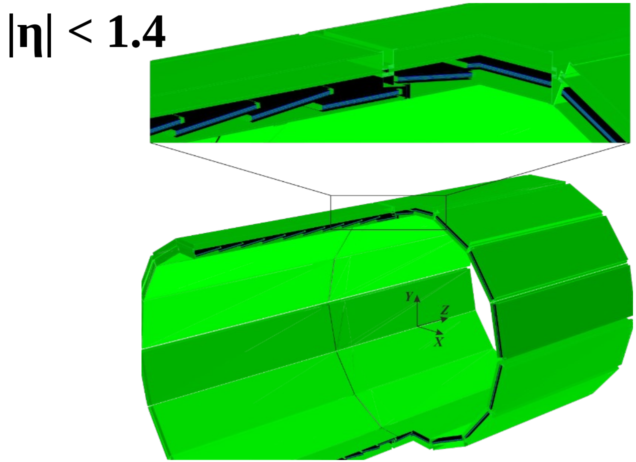


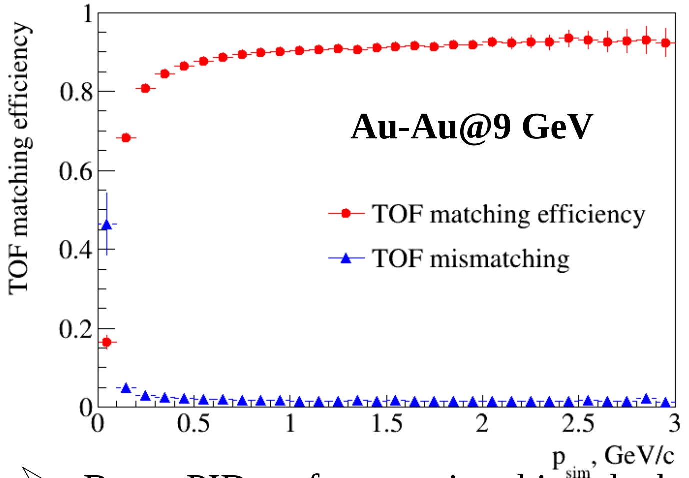


- 3D tracking + dE/dx measurement.
- The achieved accuracy of the energy loss <dE/dx> is 6-7%.
- Discrimination of charged pions from kaons up to momenta of ≈ 0.7 GeV/c and kaons from protons up to ≈ 1.1 GeV/c.



Time-Of-Flight (TOF)



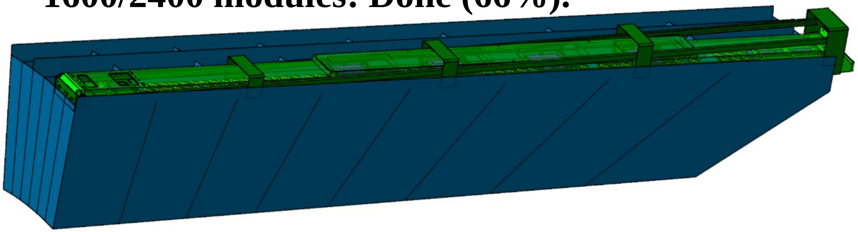


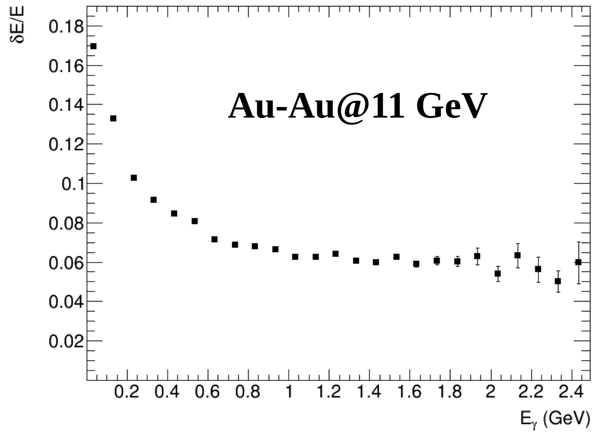
- Based on the technology of (MRPC).
- Measures time-of-flight of the track.
- **MRPCs ready: testing in spring 2023.**
- Designed Time and coordinate resolution of ≈50 ps and ≈0.5 cm, respectively.

- 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.

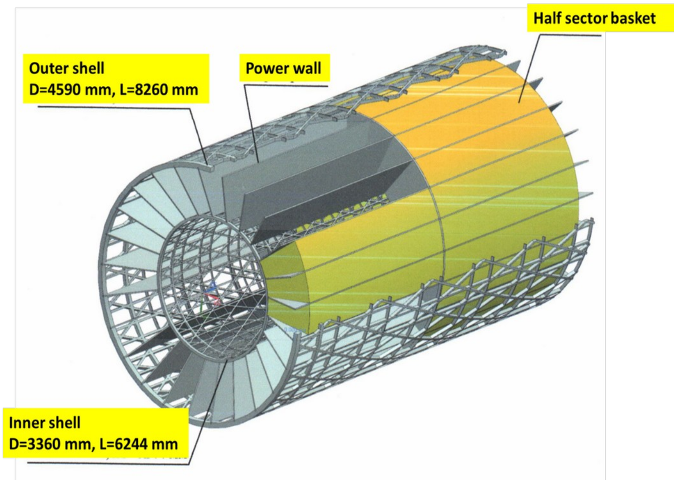
Electromagnetic Calorimeteter (ECal)

48 modules/half-sector → 50 half-sectors
1600/2400 modules: Done (66%).



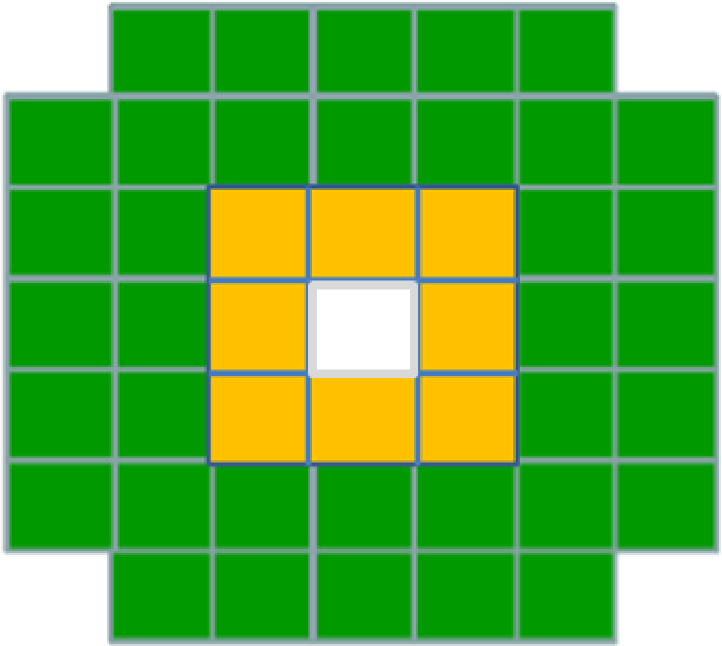


|η| < 1.4



- 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 ~ 5% at 1 GeV.

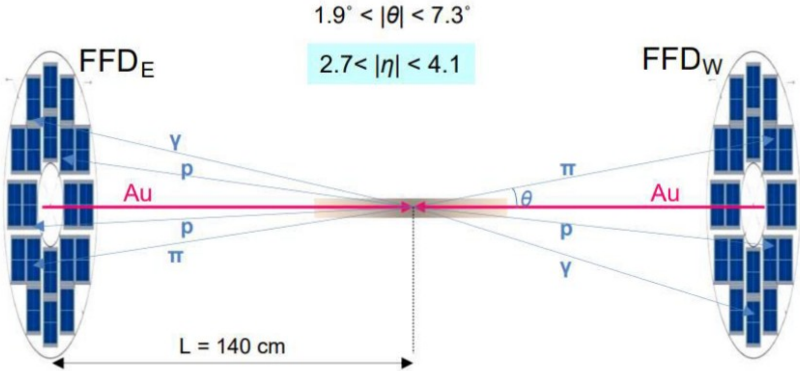
Forward Hadron Calorimeter (FHCal)

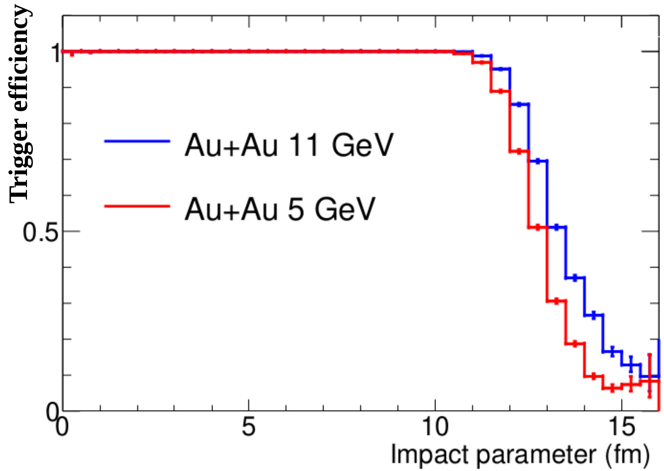


$2 < |\eta| < 5$

- FHCal: Event centrality, reaction plane measurements and 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).

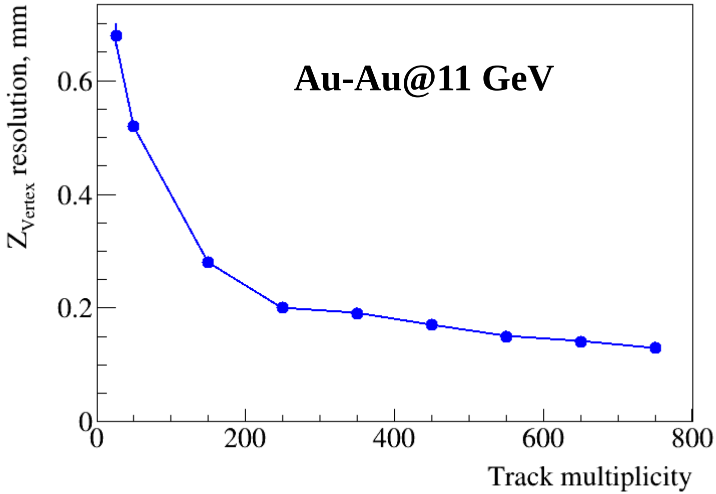
Fast Forward Detector (FFD)

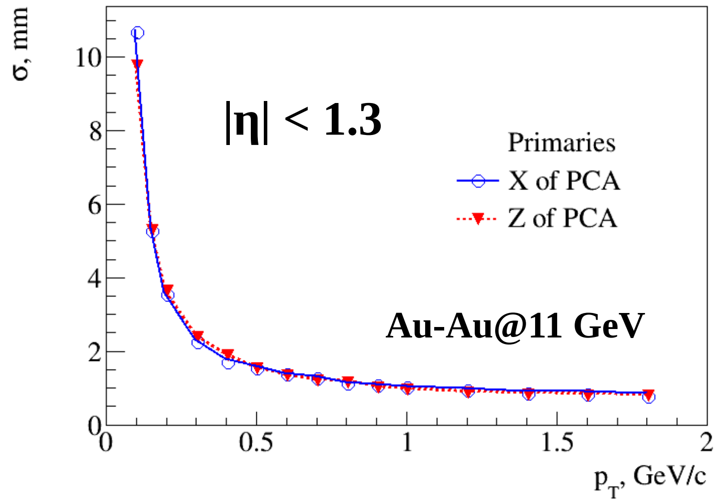




- FFD: Provides fast triggering of A+A collisions and generates the start-time (T0) pulse for the ToF detector with a time resolution better than 50 ps.
- Consists of 20 Cherenkov modules with each module consists of a 10 mm lead converter, a 15 mm quartz radiator.
- Almost 100% L0 trigger efficiency for central to mid-central collisions.

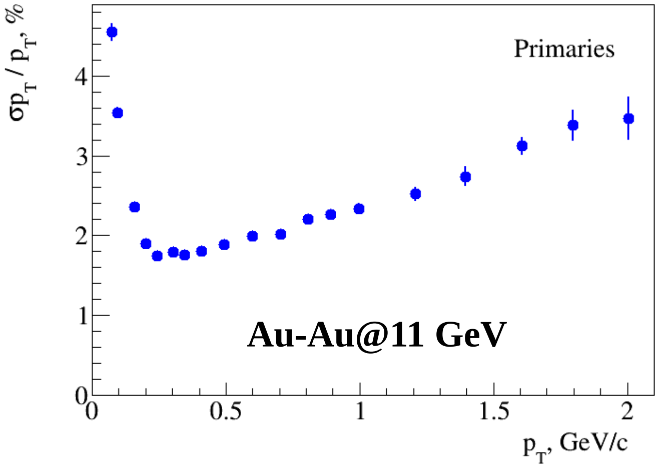
Vertex resolution

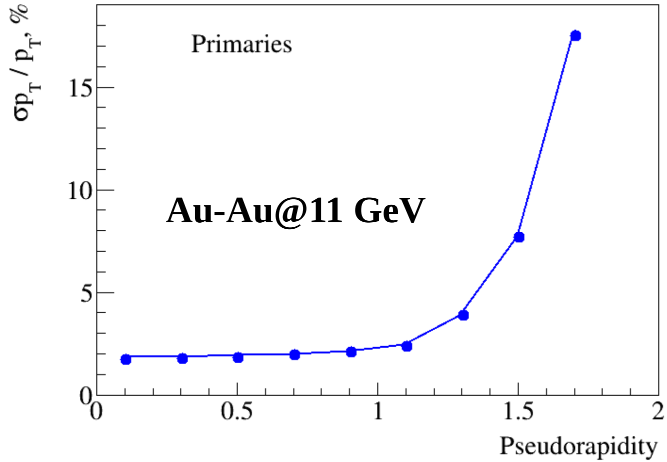




- Vertex is reconstructed using TPC reconstructed tracks.
- Uncertainty of the longitudinal position of the reconstructed primary vertex increased by factor 2-3 for low track multiplicity events.
- Transverse and longitudinal position uncertainties for TPC reconstructed primary tracks increases at low p_T.

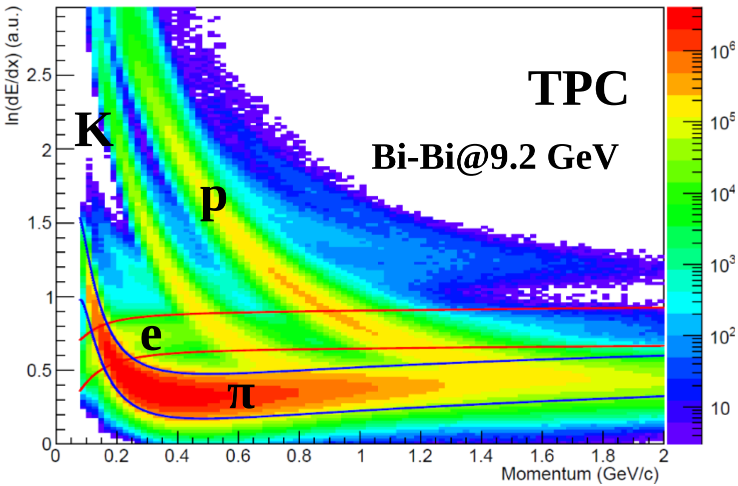
Transverse momentum resolution

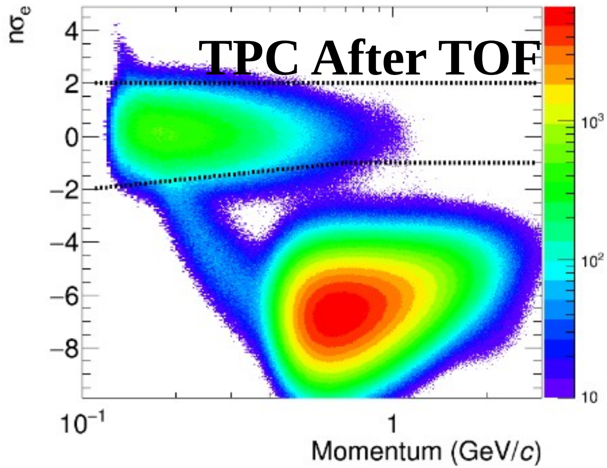


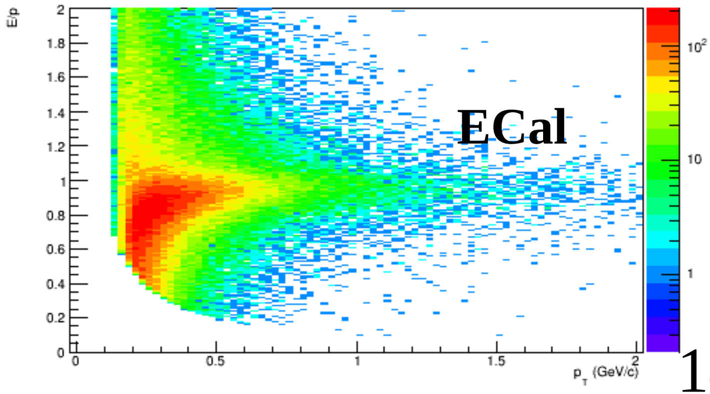


- Maximum achievable relative transverse momentum resolution for charged particles of ~ 2% as function of p_T (0.2-0.8 GeV/c) and η (|η| < 1).

Particle Identification with MPD

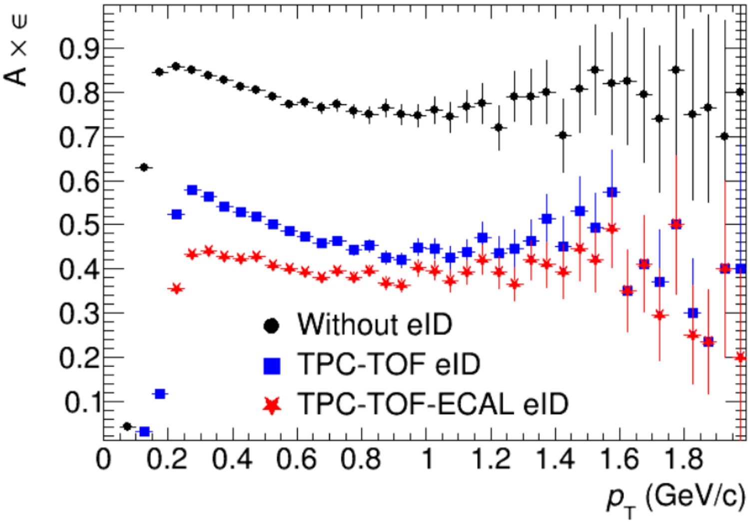


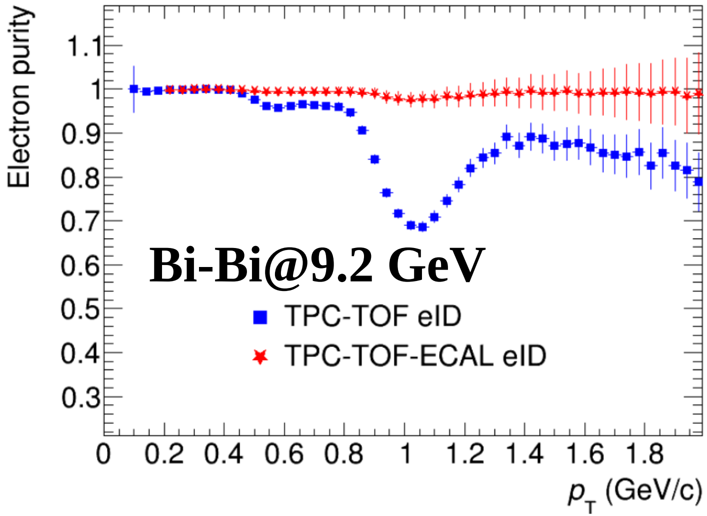




- For PID, TPC (dEdx information), TOF (Time-Of-Flight) and ECal (E/p) is used.
- TPC+TOF is good enough to identify electrons with decent purity.
- However, ECal helps to gain even higher purity.

Efficiency and Purity





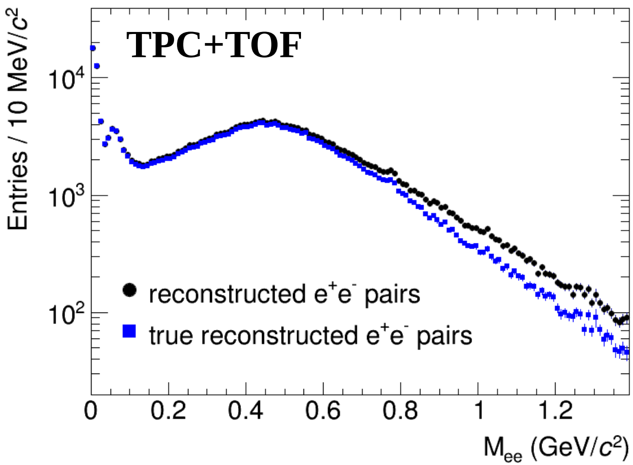
- Typical cuts on electrons:
  - $|\eta| < 1$.
  - DCA < 3σ.
  - p_T > 50 MeV/c
  - at least 39 hits in TPC
  - 2σ electron PID in TPC/TOF

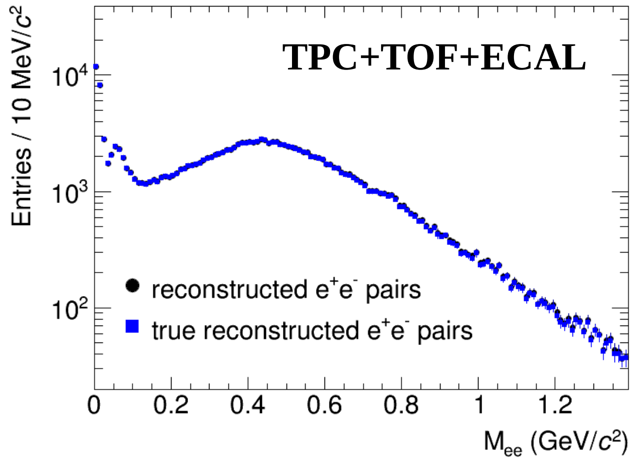
- Single electron reconstruction efficiency: about 40% using TPC-TOF-ECal eID above 250 MeV/c.

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

ECal helps on the hadron rejection

Bi-Bi@9.2 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

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

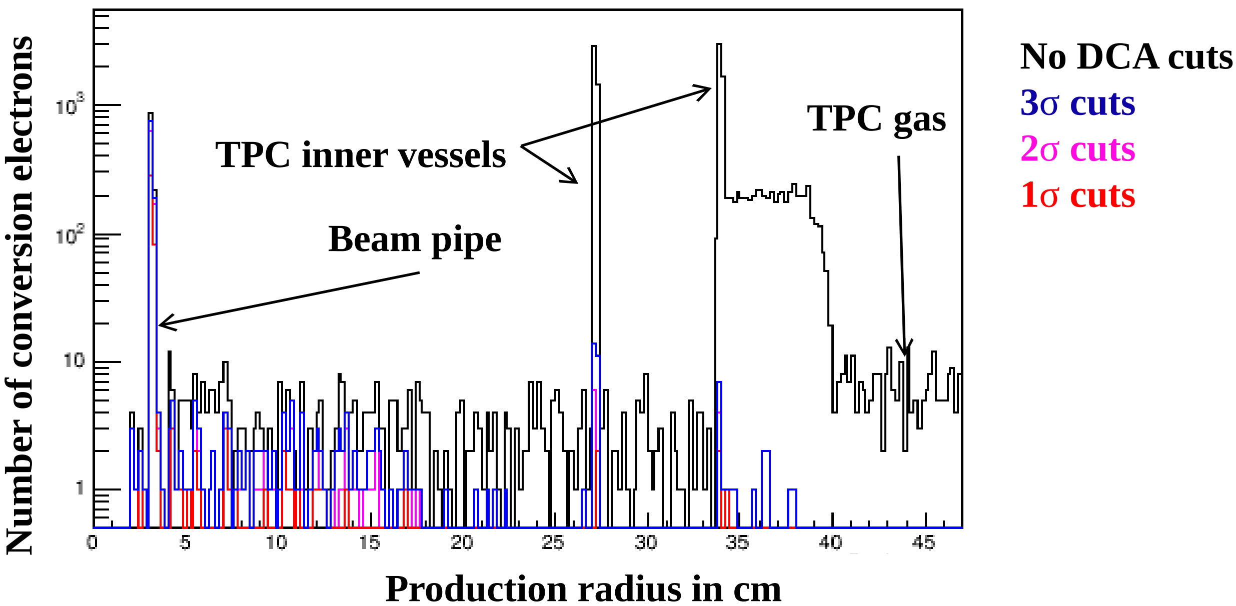
- Dalitz decays are major source of background.
- Major challenge is to reduce the combinatorials, and improve S/B.
- UrQMD and PHSD are employed for the simulations: Results with PLUTO are being studied.

Ongoing Investigations

- 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 γ conversions 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

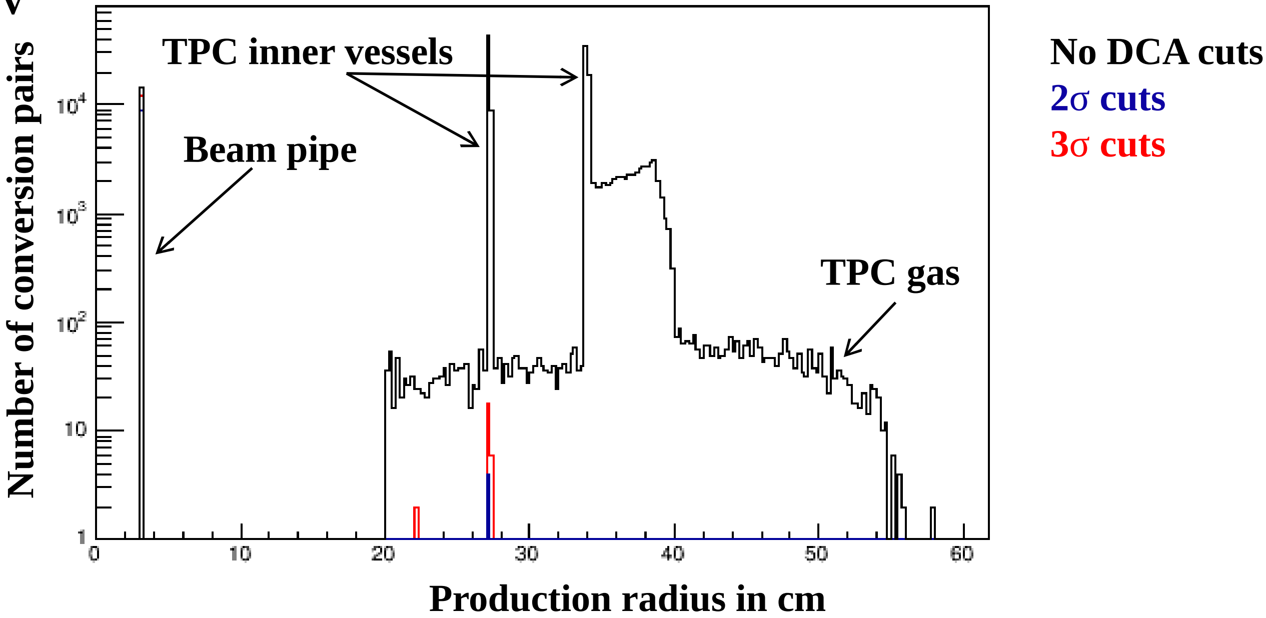
Bi-Bi@9.2 GeV



- 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

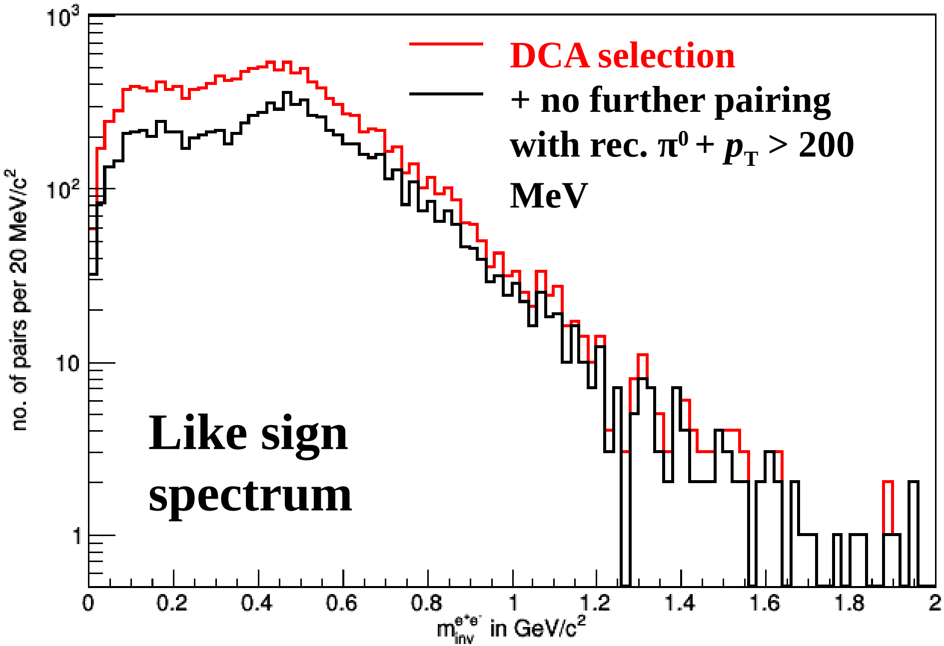
Bi-Bi@9.2 GeV



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

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

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

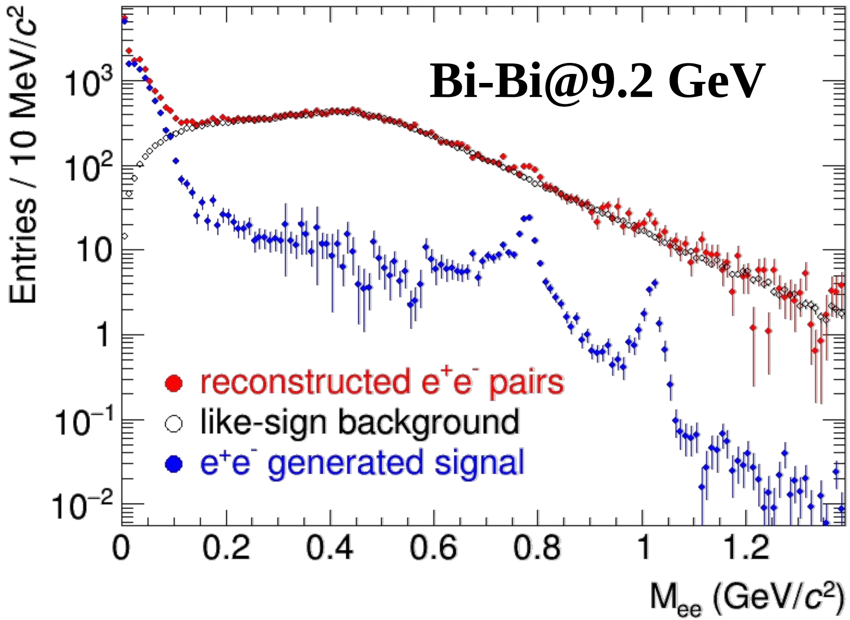


Bi-Bi@9.2 GeV

- Selection cuts:
  - Fid. acc. $|\eta| < 0.3$
  - DCA < 3σ
  - At least 39 hits in TPC.
  - 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 different analysis strategies, further rejection of combinatorials can be achieved.
- Better reconstruction of low p_T tracks → already 30% reduction in CB with tuned selection.
- Test reduced magnetic field (B = 0.2 T) sample.

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/c² 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.

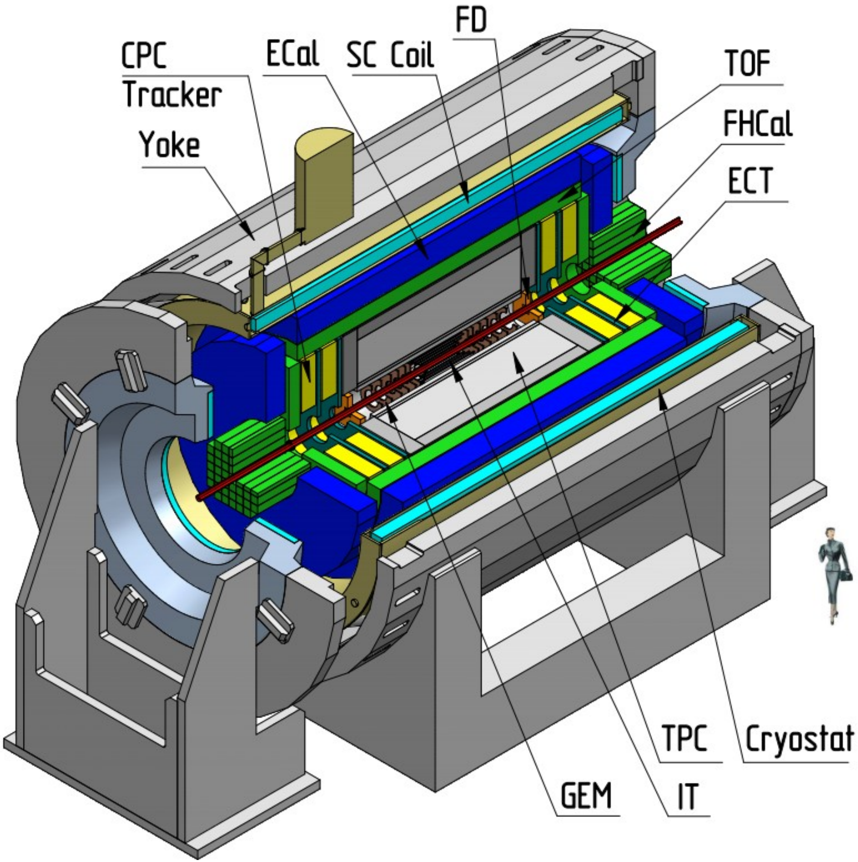
Conclusions

- MPD is under construction at NICA → Commissioning is expected at the end of 2023 → First data taking is expected in 2024 with BiBi@9.2 GeV.
- Dielectrons are valuable probes and capable of delivering strong physics messages: Exciting di-electron program is anticipated at MPD using dedicated sub-detectors.
- Excellent PID and high purity can be achieved using ECal in addition to TPC+TOF.
- Various event generators are being utilized to simulate event with di-electrons sources.
- Good control over CB from conversions using DCA selection except at beam pipe: ongoing efforts to reduce combinatorial background from Dalitz decays.

Thank you

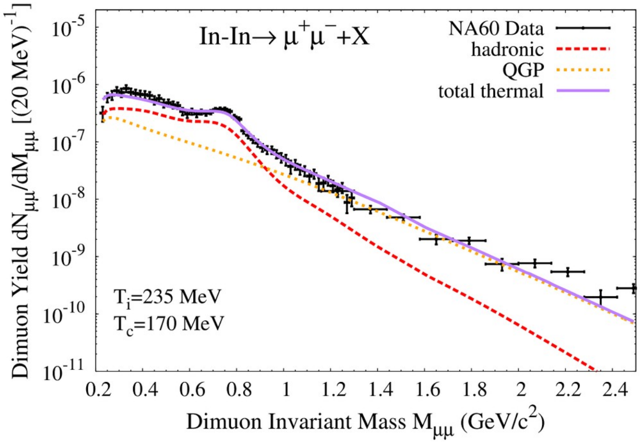
BACK-UP

MPD setup: Full configuration



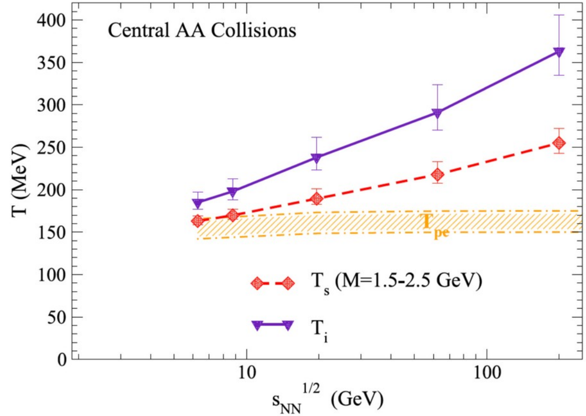
- 4π configuration.
- TPC, TOF, ECAL, FHCal, FFD, ITS and EndCaps.
- To be constructed in two stages.

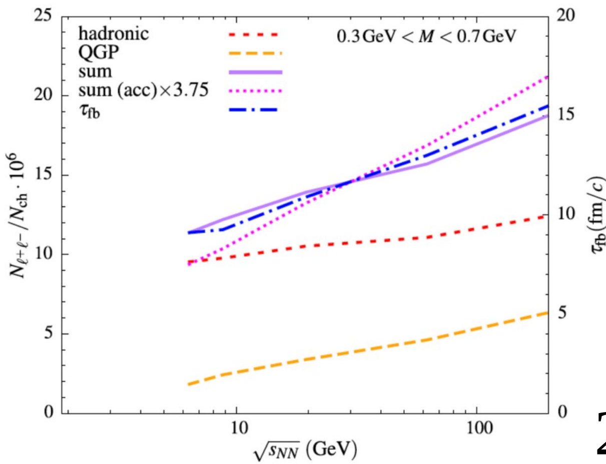
Motivation



Phys. Lett. B 753, 586 (2016)

- <u>Intermediate Mass Region:</u> 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: "<u>thermometer</u>" for the heavy-ion collisions.
- <u>Low Mass Region:</u> 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: "<u>chronometer</u>" for heavy-ion collisions

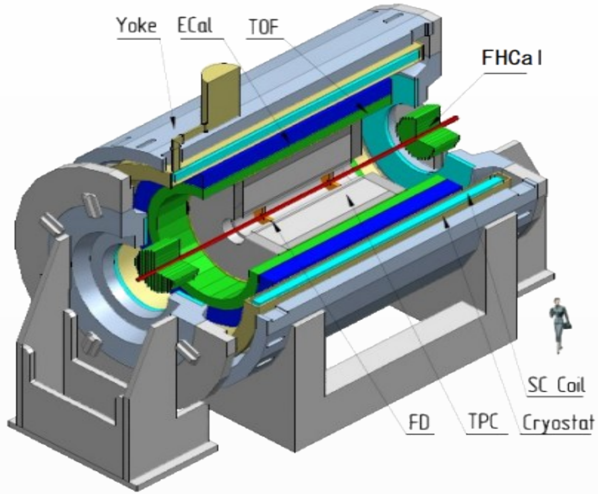




Multi-Purpose Detector (MPD) Collaboration

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

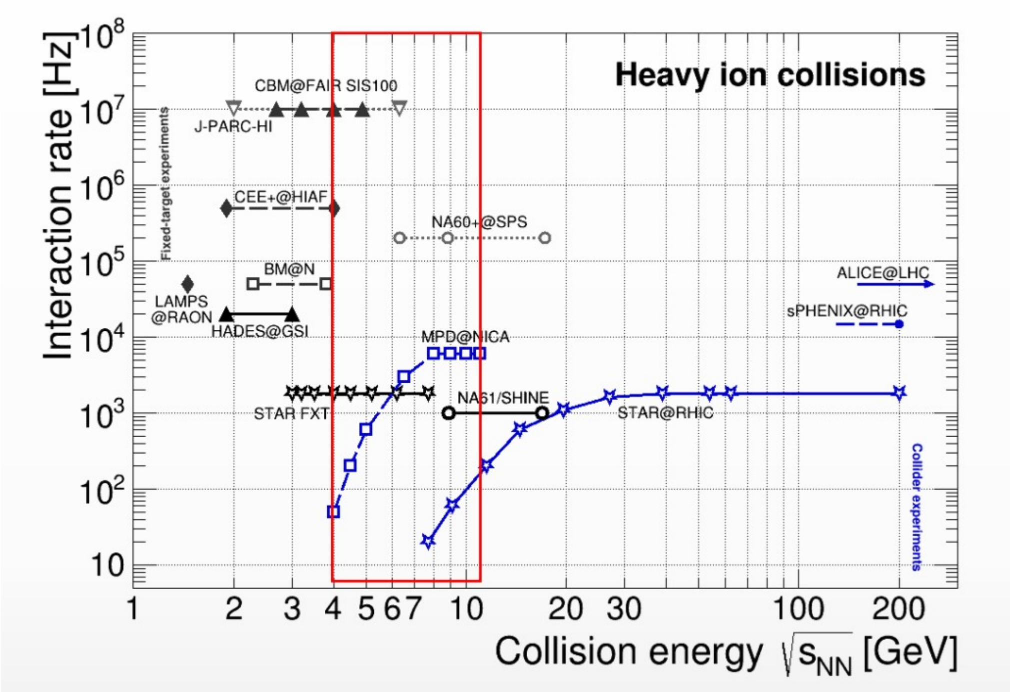
10** Countries, **>450** participants, **31** Institutes and **JINR



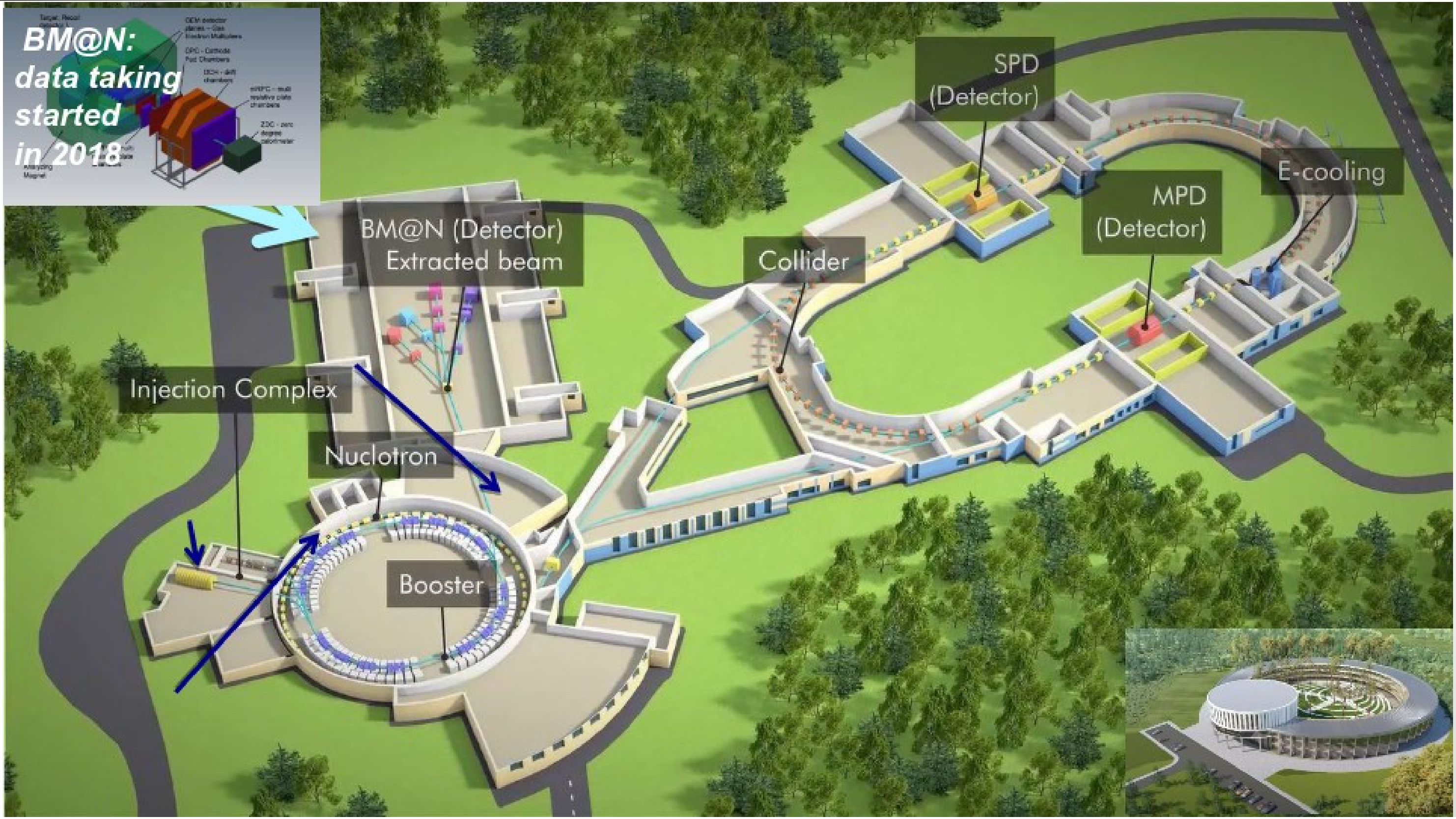
Organization

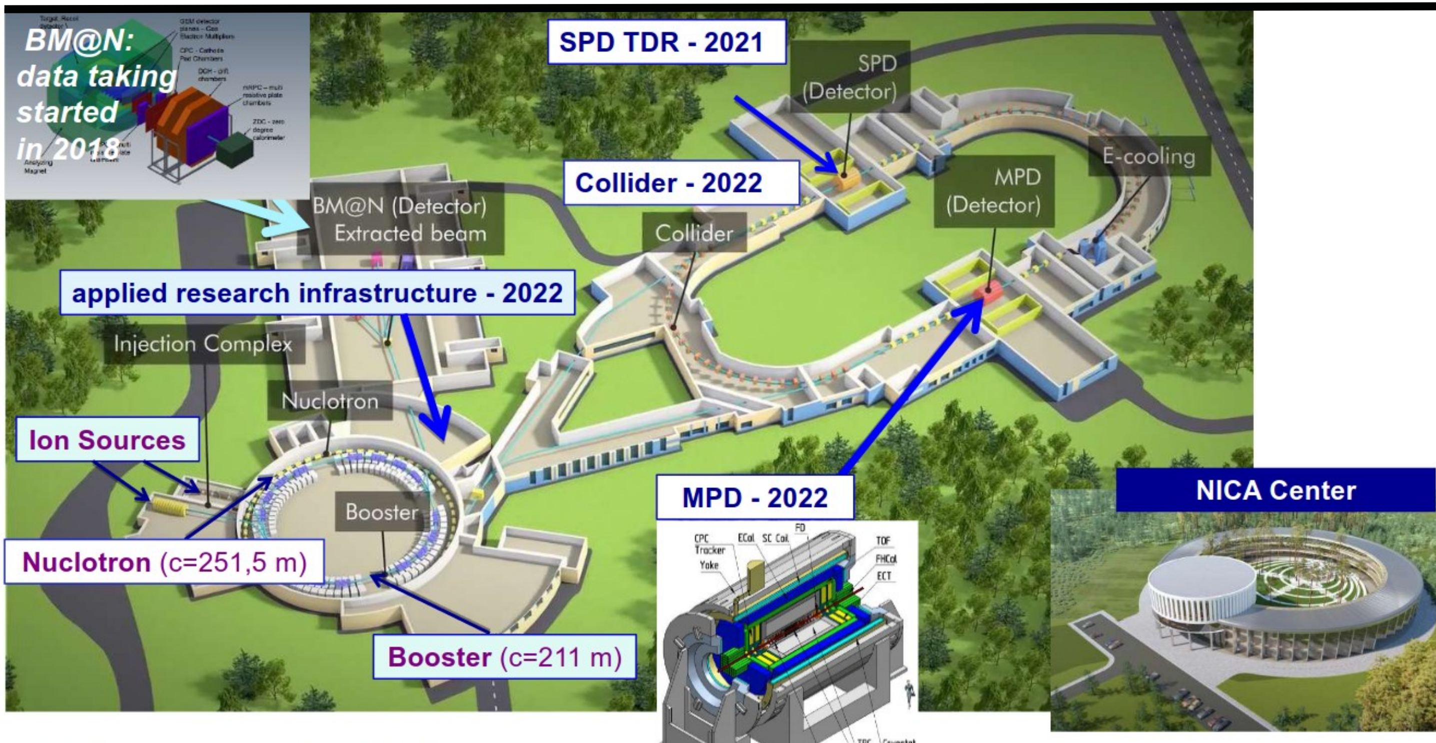
Acting Spokesperson:	***Victor Riabov***
Deputy Spokesperson:	***Zebo Tang***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***

***Joint Institute for Nuclear Research**;*
*AANL, Yerevan, **Armenia;***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*IHEP, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*FCFM-BUAP (Heber Zepeda) Puebla, **Mexico**;*
*FC-UCOL (Maria Elena Tejeda), Colima, **Mexico**;*
*FCFM-UAS (Isabel Dominguez), Culiacán, **Mexico**;*
*ICN-UNAM (Alejandro Ayala), Mexico City, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*
*Belgorod National Research University, **Russia**;*
*INR RAS, Moscow, **Russia**;*
*MEPhI, Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*NRC Kurchatov Institute, ITEP, **Russia**;*
*Kurchatov Institute, Moscow, **Russia**;*
*St. Petersburg State University, **Russia;***
*SINP, Moscow, **Russia**;*
*PNPI, Gatchina**, Russia**;*
*Vinča Institute of Nuclear Sciences**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***



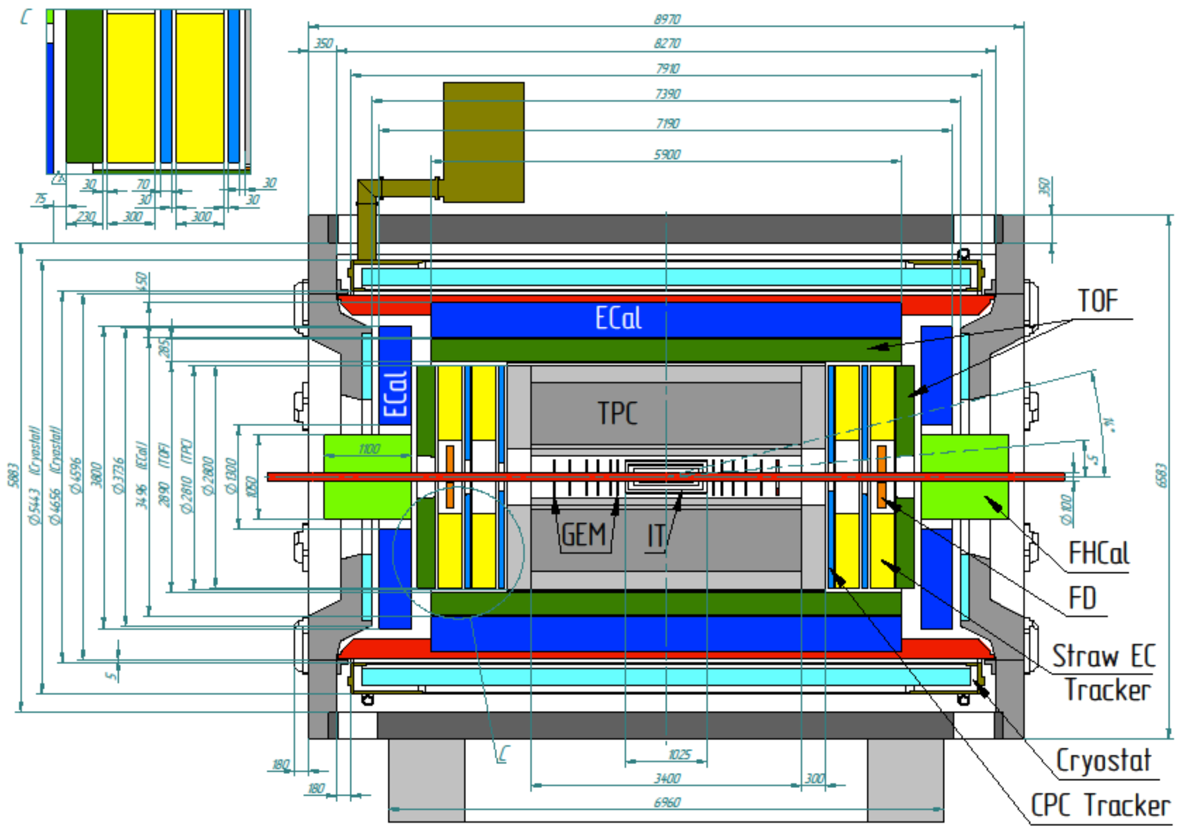
- Many ongoing programs and future experiments in comparable energy ranges.
- Physical program of the MPD should be considered in close cooperation with BM@N.
- Continuously developing MPD physical program based on recent advancements in the field.
- Close cooperation with theoreticians to look for new signals/observables unique for the MPD.


BM@N:
data taking
started
in 2018
BM@N (Detector)
Extracted beam
SPD
(Detector)
Collider
MPD
(Detector)
E-cooling
Injection Complex
Nuclotron
Booster

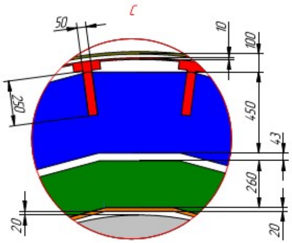


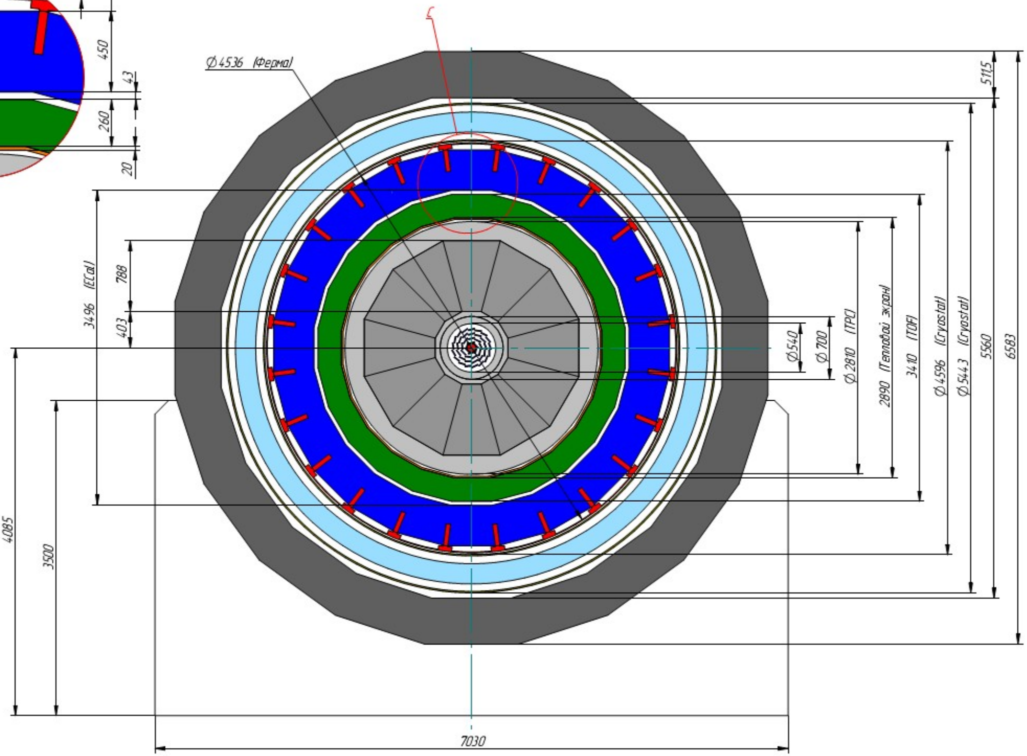
Budget: approx. 500 M$

MPD Front Cross-section

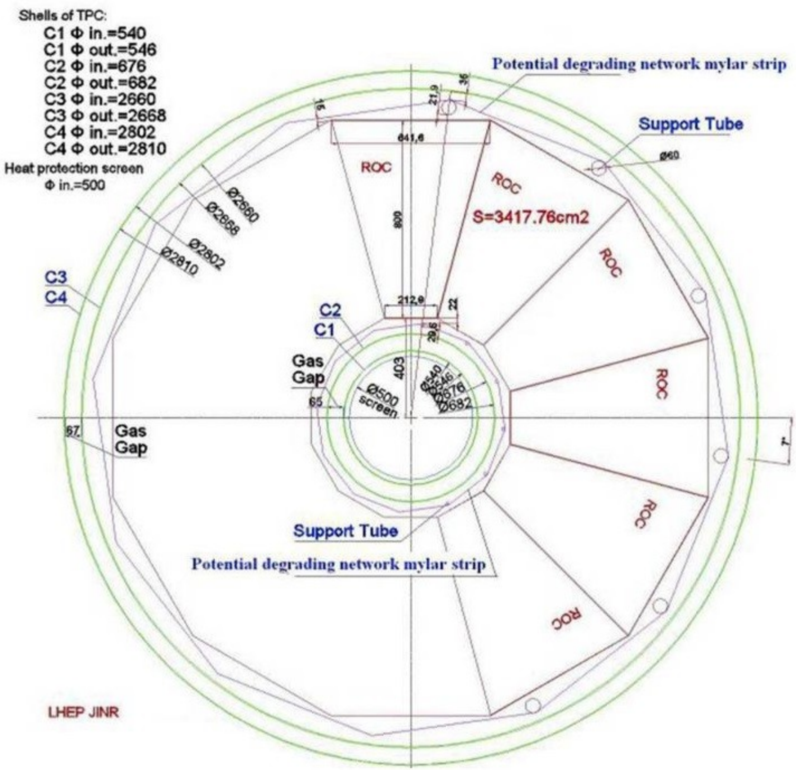


MPD Cross-section

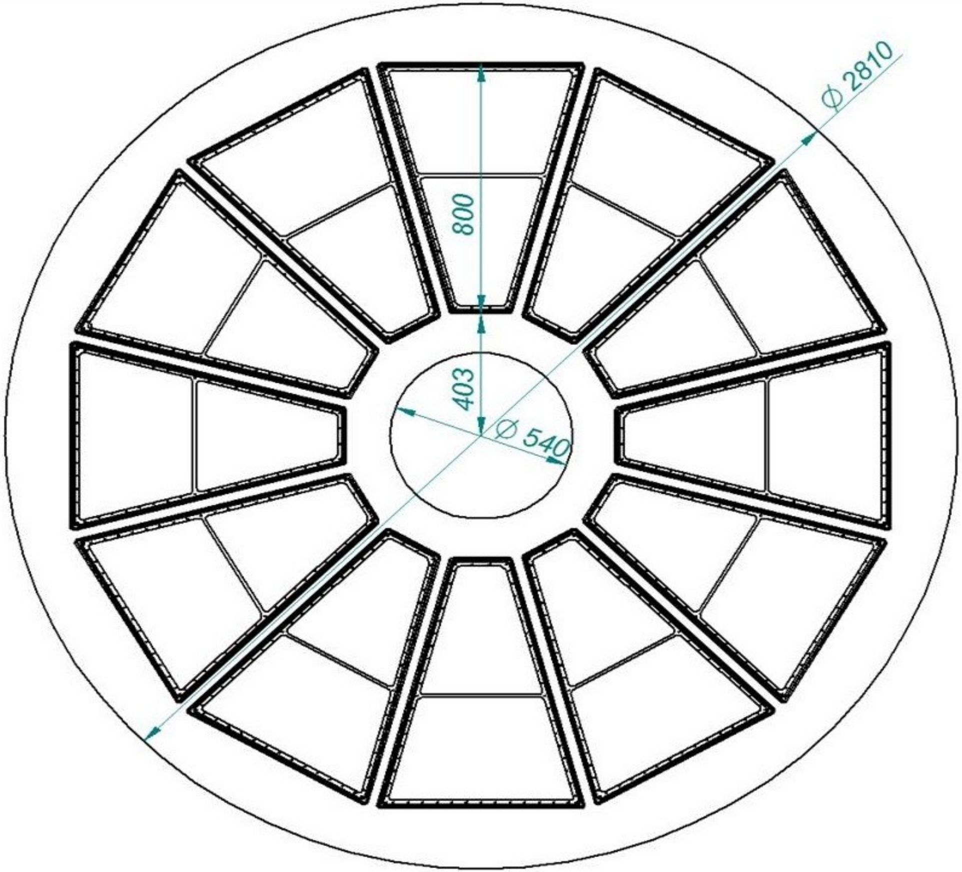




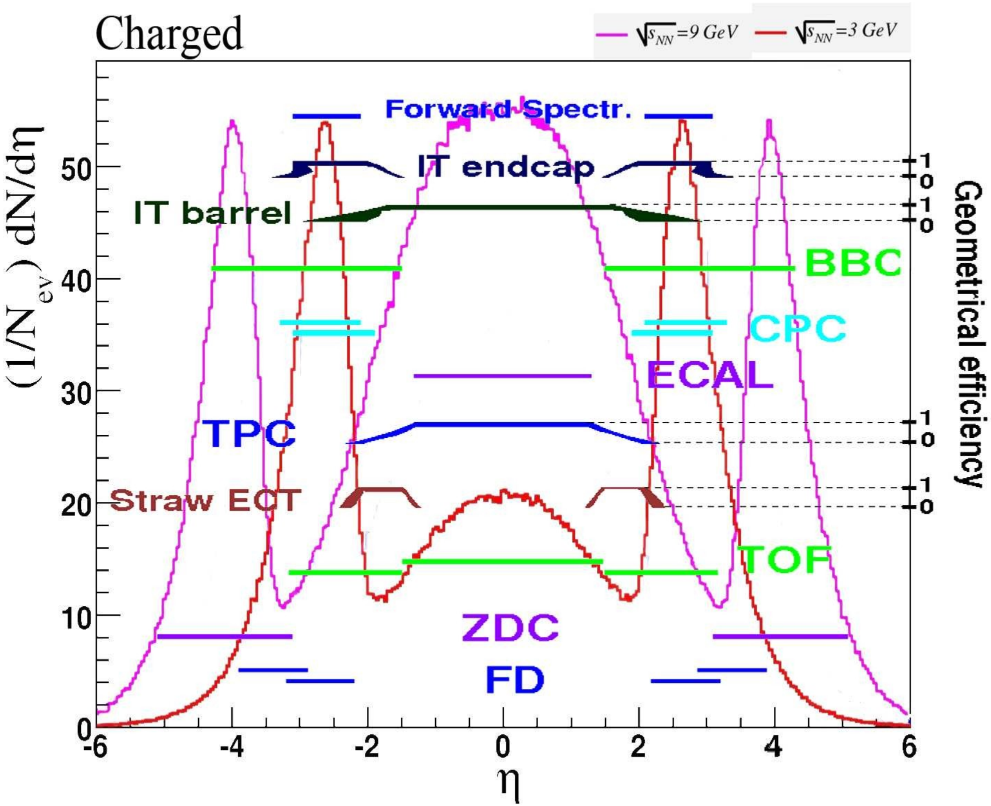
TPC Cross-section



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