A Proposal for the

miniBeBe Detector

for the Multi-Purpose Detector at NICA

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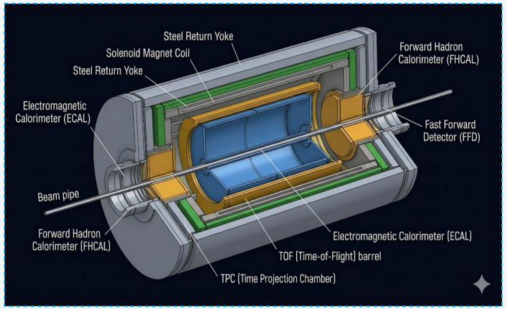
CONTEXT

The TOF Wake-Up Trigger Problem

CONTEXT

The MPD Experiment at NICA



- Multi-Purpose Detector at JINR, Dubna
- Designed for √sNN = 4–11 GeV heavy-ion collisions
- Collider mode + Fixed-Target mode
- Central barrel: TPC · TOF · ECAL
- Forward: FFD · FHCAL
- Goals: QCD phase diagram, CEP, flow, correlations

miniBeBe operates in the first phase of MPD, sharing the TPC volume with the ITS

The TOF needs a fast t_0 signal to identify π, K, and p over the full momentum range. For low-multiplicity events, the FFD provides insufficient acceptance at mid-rapidity. The miniBeBe fills this gap: 160 scintillator cells at $|\eta| < 1.44$, each read out by two SiPMs, deliver a coincidence trigger with σ < 50 ps per cell.

< 100 ps
TOF budget

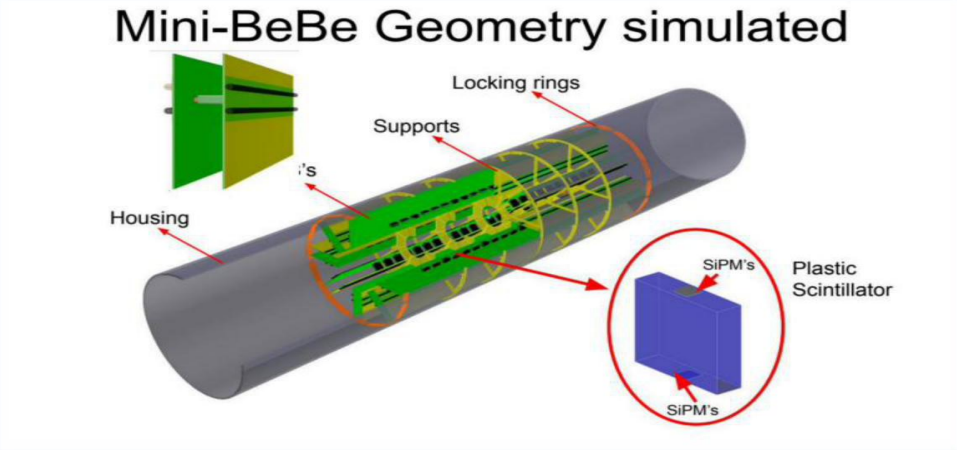
~ 50 ps
miniBeBe target

160 cells
8 strips × 20

Detector Concept & Key Parameters

DETECTOR OVERVIEW

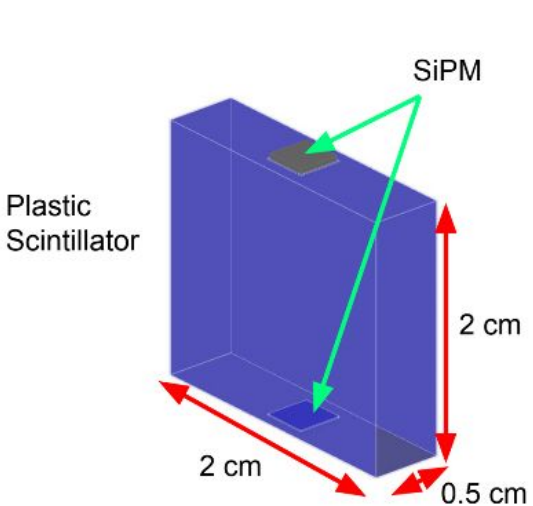
Detector Concept & Key Parameters

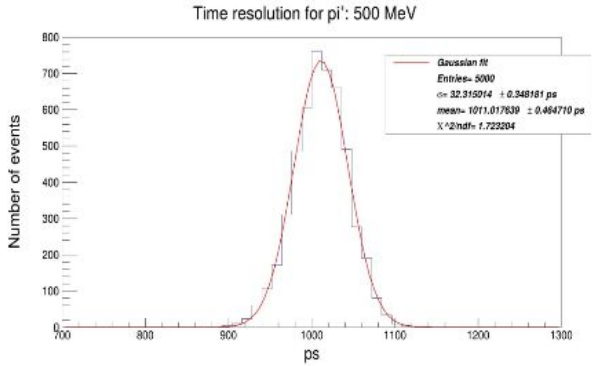


Parameter	Value
Geometry	Hollow cylinder
Radius	260 mm
Length	714 mm
Strips	8 × 600 mm
Cells / strip	20 (20×20×3 mm³)
Total cells	160
SiPMs / cell	2 (one per face)
Total SiPMs	360
Sensitive area	64,000 mm²
Target σt	< 50 ps / cell

Detection Cell: Dual-SiPM Readout

Cell Intrinsic time resolution





Bi+Bi at 9.2 GeV produce π with <E> ~ 0.5 GeV, If this π impact perpendicular to the scintillator, the optical photons produce average time resolution of ~ **32.3 ps.** The SiPM's are considered 100% efficiency

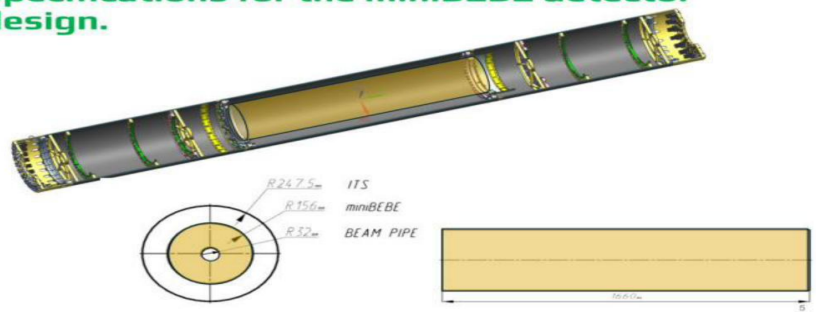
EJ-232 fast plastic scintillator (τ ≈ 1.4 ns) · Two SiPMs on opposite narrow faces · Averaging timestamps cancels position-dependent time walk

Mechanical Design v2.0 — Integration within MPD

MECHANICAL DESIGN

Mechanical Design & Integration within MPD

Specifications for the miniBEBE detector design.





Radial constraints: beam pipe (R=32 mm), miniBeBe (R=156 mm), ITS (R=247.5 mm)

2026 design: miniBeBe assembled inside ITS housing

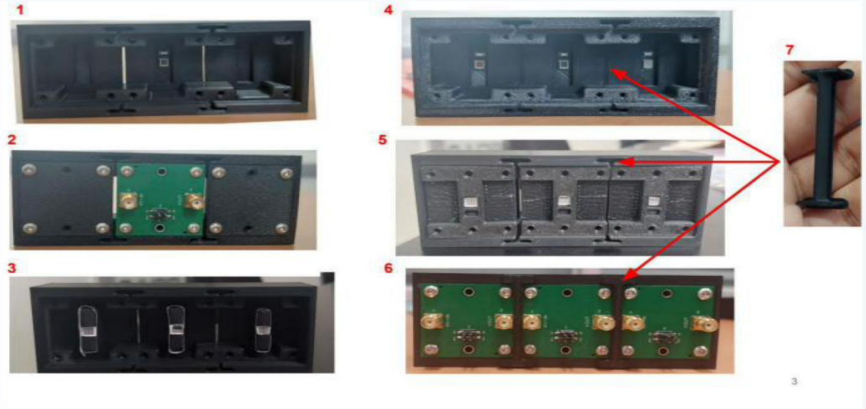
Non-magnetic construction · Carbon fiber + polypropylene + Al-5052 flanges · Installation via ITS container (4 mm clearance) · Water + ITS gas cooling

Non-magnetic construction · M55-J carbon fibre housing · Al-5052 flanges · ITS container insertion with 4 mm clearance · Water + ITS gas cooling

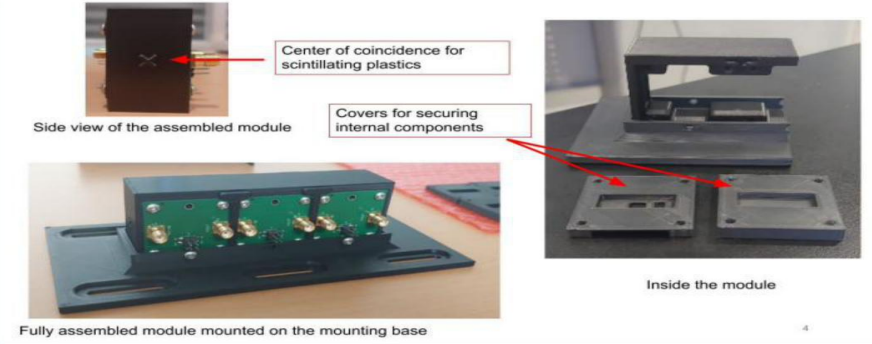
Prototype Module: Construction & Assembly

PROTOTYPE & VALIDATION

Prototype Module: Construction & Cosmic-Ray Tests



Assembly sequence of hermetically sealed prototype module (3 scintillator cells)

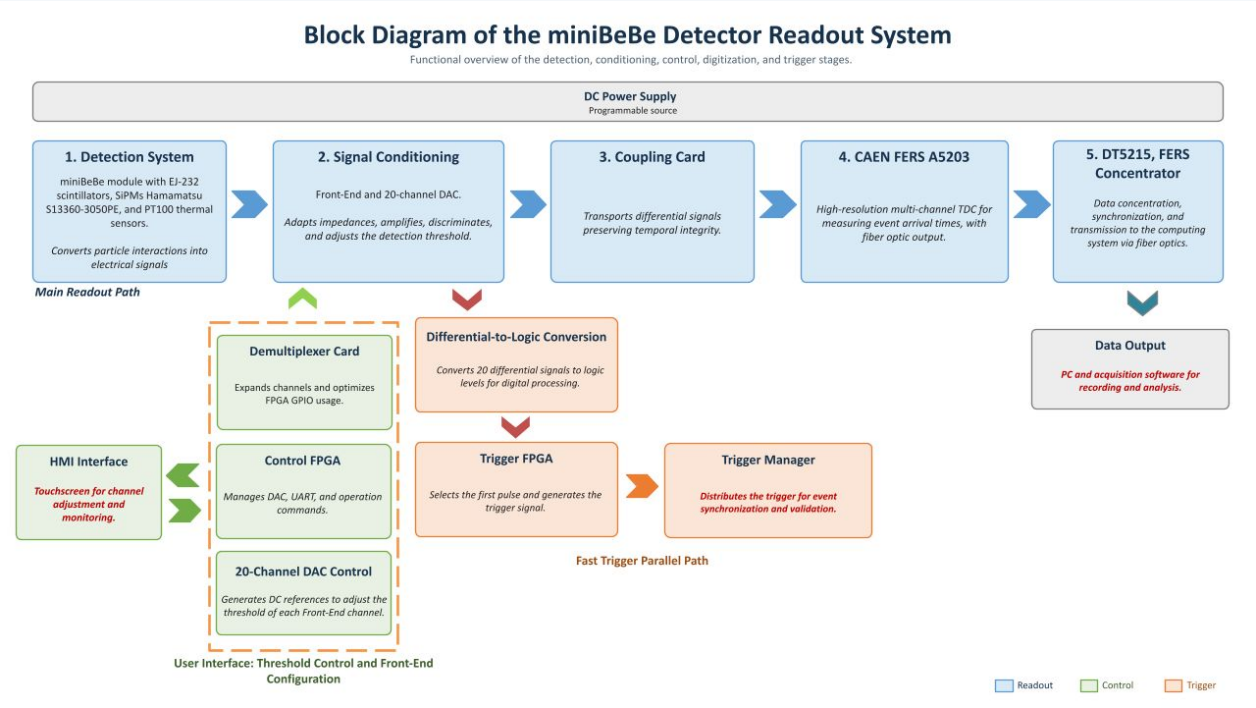


Fully assembled module mounted on test bench. SiPM bias PCBs visible (green boards)

Light-tight housing · No adhesives — all components mechanically constrained · Coincidence readout validated with cosmic muons

Light-tight hermetic housing · No adhesives — all components mechanically constrained · Coincidence readout validated with cosmic muons

Signal Readout Chain



SiPM → fast preamplifier → leading-edge discriminator → FPGA trigger logic → CAEN TDC/digitizer → DAQ

ELECTRONICS

Signal Readout Chain

Main Readout Path

Conversion of the physical event into high-precision temporal data.

MiniBeBe

Main detection and acquisition chain

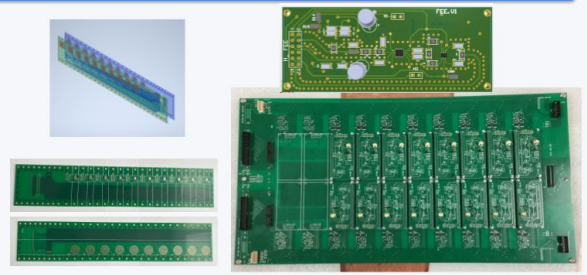
Functional Objective

Record signals generated by incident particles in the MiniBeBe.

Condition SiPM pulses to preserve amplitude and temporal integrity.

Obtain arrival times using CAEN TDC-based instrumentation.

Transfer data to the computing system for analysis, coincidences, and track reconstruction.



Simplified signal flow diagram



The main readout path prioritizes temporal fidelity, noise immunity, and multi-channel scalability.

Main Readout Path

Technical breakdown of each stage in the readout chain.

MiniBeBe

Main path stages and parameters of interest

1. Detection System

10 EJ-232 plastic scintillators of 5 × 20 × 20 mm.

Two boards with 10 Hamamatsu S13360-3075PE SiPMs.

PT100 sensors for thermal monitoring per channel/module.

2. Conditioning

Current-to-voltage conversion of the SiPM signal..

High-speed, low-noise amplification.

Event selection via a discriminator with adjustable thresholdthreshold

3. Digitization and Output

Differential coupling for robust pulse transport.

A5203 FERS: precise measurement of arrival times.

DT5215: concentration, synchronization, and transmission via fiber optics.

Final purpose: reliable temporal reconstruction of the event.

Critical quantities monitored in the main path



SiPM ⟶ fast preamplifier ⟶ leading-edge discriminator ⟶ FPGA trigger logic ⟶ CAEN TDC/digitizer ⟶ DAQ

Fast Trigger Parallel Path

Fast Trigger Parallel Path

Early selection of the first logic pulse to trigger the system.

MiniBeBe

Fast Trigger Architecture

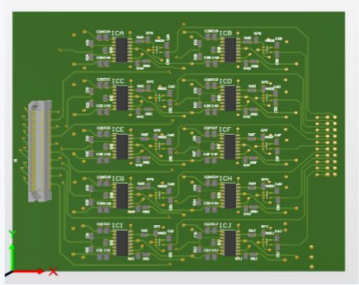
Trigger System Functiontrigger

Receive the discriminated signals from the readout.

Convert 20 differential channels to FPGA-compatible logic levels.

Identify the first channel registering an interaction and generate a single trigger signal.

Synchronize acquisition and support temporal validation of the event.



Temporal concept of the trigger

Channel 1 | Channel 7 | Channel 12 | **The first valid pulse is selected**

Each channel may exhibit different arrival times.

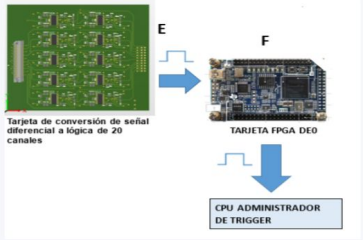
A unique trigger is generated for synchronization.

Fast Trigger Parallel Path

Operation sequence and design criteria.

MiniBeBe

Logical Trigger Processing



Technical requirements of the trigger path

Input	20 differential channels from Front-End boards
Conversion	Adaptation to logic via high-speed electronics
Processing	Implementation on DE0-Nano FPGA with VHDL bitstream
Output	Single trigger pulse for validation and synchronization
Advantage	Reduces latency and decouples the trigger from the main data path

The fast trigger does not replace TDC measurement; it complements it to enable early acquisition decisions.

SiPM → fast preamplifier → diferential to logic conversion →trigger FPGA → trigger manager

ELECTRONICS

User Interface and Threshold Control

User Interface and Threshold Control

Front-End configuration via HMI, FPGA, and demultiplexing.End

MiniBeBe

Threshold Control and Front-End Configuration

Purpose of the control interface

Allow the user to adjust discrimination thresholds per channel.thresholds

Manage HMI communication, UART, and control lines from a central FPGA.

More channels are controlled using the same FPGA pins, thanks to intelligent channel selection via multiplexers

Facilitate the operation, verification, and scalability of the readout system.readout.



Logical configuration chain

User selects channel → HMI sends command → FPGA interprets SCPI → Demux routes the channel → DAC updates threshold

User Interface and Threshold Control

Operational parameters and benefits of the control architecture.

MiniBeBe

Key configuration and scalability elements



Representative parameters for Front-End control

DAC Command	SOUR:DAC<x> <valor>
Digital range	0 to 65535
DAC reference	0 to 3.3 V
Adjustment resolution	on the order of mV in threshold
Logic level	3.3 V for FPGA/DAC; 5 V for HV modules

The user interface reduces adjustment errors and speeds up system commissioning.

Demultiplexer card ⟶ FPGA Control⟶ DAC Control⟶ HMI interface

DC Power Supply

DC Power Supply
Functional Architecture for SiPM Biasing and MonitoringSiPM
MiniBeBe

Functional Architecture for SiPM Biasing and Monitoring

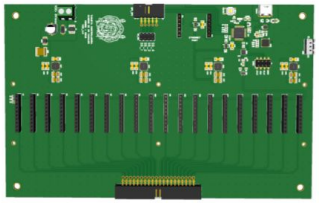
Functional Objective

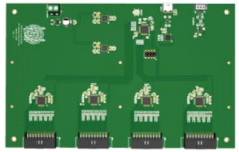
Supply stable DC bias voltage to the SiPMs of the MiniBeBe detector.

Adjust the operating point of each channel with 5 mV resolution and current protection.

Monitor voltage, current, and temperature to keep gain and dark noise within a reproducible operating regime.

Support multi-channel readout operation without degrading the temporal integrity of the detector





Design parameters

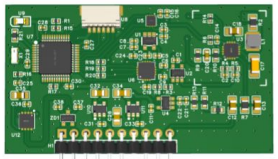
10–58 V per channel	I limit ≈ 100 µA
noise < 1 mV RMS	thermal compensation

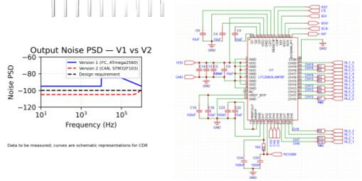
DC Power Supply
Functional Architecture for SiPM Biasing and MonitoringSiPM
MiniBeBe

Functional Architecture for SiPM Biasing and Monitoring

Relevant technical performance

Architecture	20 independent channels
Output range	2.5 to 58 V
Bias resolution	≈ 0.86 mV/bit
Current protection	up to 100 µA per channel
Monitoring	voltage, current, and PT100
Measured noise	< 0.3 mV RMS a 53.5 V
Stability at 53.3 V	σ ≈ 0.6 mV over 1.5 h



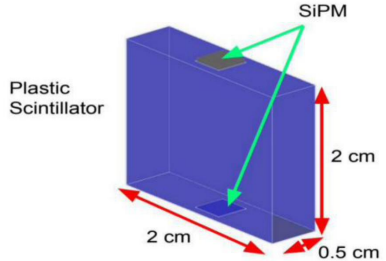


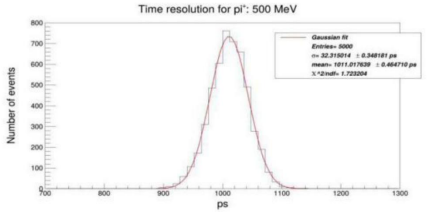
Intrinsic Time Resolution — Geant4 Simulation

DETECTION CELL

Detection Cell: Plastic Scintillator + SiPM

Cell Intrinsic time resolution





Bi+Bi at 9.2 GeV produce π with <E> ~ 0.5 GeV, If this π impact perpendicular to the scintillator, the optical photons produce average time resolution of ~ **32.3 ps.** The SiPM's are considered 100% efficiency

EJ-232 fast plastic scintillator (τ ≈ 1.4 ns) · Two SiPMs on narrow ±z faces · Coincidence suppresses dark noise · σt ≈ 32 ps from simulation (π⁻ at 500 MeV)

Geant4 — EJ-232 cell
(20 × 20 × 3 mm³)

σ□ = 33.2 ps

μ at 4 GeV

σ□ = 32.3 ps

π at 500 MeV

Result is independent of particle species and incident energy — photon transport inside the cell is not the limiting factor.

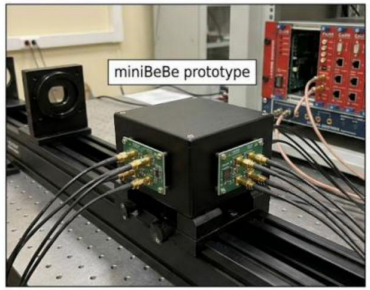
Time Resolution — Experimental Validation

PROTOTYPE & VALIDATION

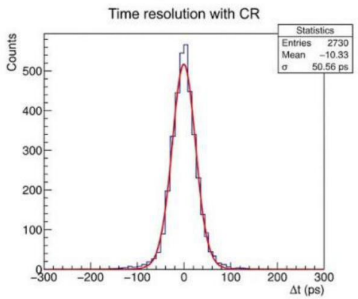
Prototype Validation — CR@VBLHEP-JINR

Cosmic ray test of miniBeBe detector prototype at VBLHEP-JINR

LEFT PANEL



RIGHT PANEL



LEFT PANEL RIGHT PANEL

[Beam-test results figure — See prompt P4]

- Tested at VBLHEP-JINR
- Hamamatsu PMT R6249 + SensL SiPM (C-60035-4P1521)
- Result: time resolution consistent with simulation
- 49.5±0.5ps

Cosmic rays
@UMSNH

49 ± 5 ps

CR @VBLHEP-JINR

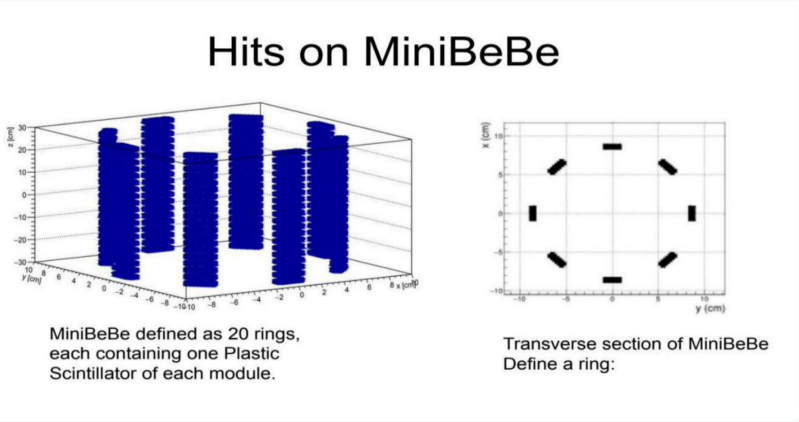
49.5 ± 0.5 ps

Target: < 50 ps ✓

Detector Geometry in MPDRoot & Trigger Efficiency

SIMULATIONS

Detector Geometry in MPDRoot & Hit Distributions



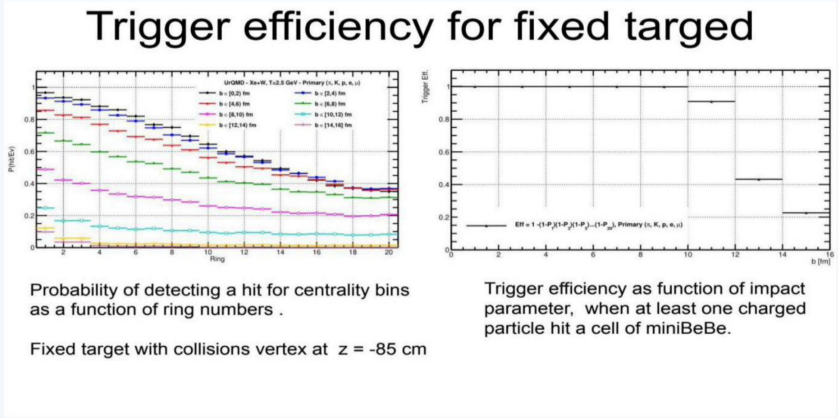
MiniBeBe defined as 20 rings, each containing one Plastic Scintillator of each module.

Transverse section of MiniBeBe Define a ring:

Geometry included in MPDRoot v12.20.25 · 8 strips × 20 cells reproduce observed hit pattern · Transverse view defines the ring structure used for trigger efficiency calculation

SIMULATIONS

Trigger Efficiency — Fixed-Target Mode



Probability of detecting a hit for centrality bins as a function of ring numbers .

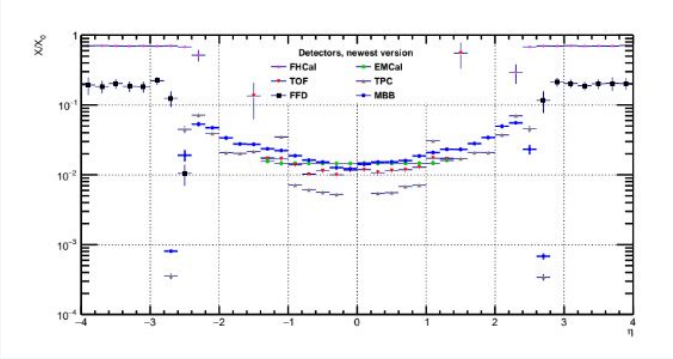
Fixed target with collisions vertex at z = -85 cm

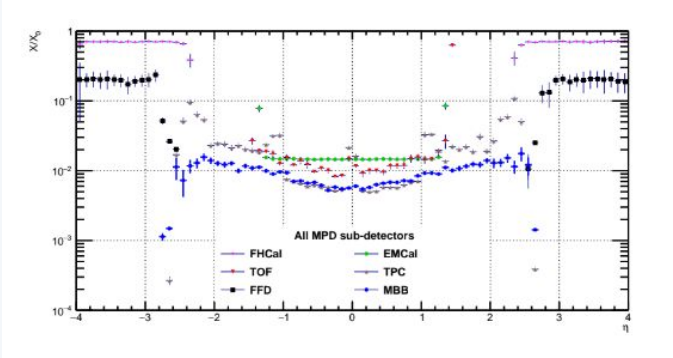
Trigger efficiency as function of impact parameter, when at least one charged particle hit a cell of miniBeBe.

Xe+W at T=2.5 GeV, vertex z = −85 cm · Efficiency → 1 for central collisions (b < 4 fm) · Sensitivity preserved up to b ≈ 12 fm · Displacement studies guide optimal positioning along z

|η| < 1.1 (MPDRoot) · Trigger: at least one hit in any cell · Eff. > 90% for all centralities (centred config., Xe+W, T = 2.5 GeV)

Material Budget within the MPD Acceptance





Current design
(4-layer PCB)

10.45 %

X/X_0 at mid-rapidity

Optimised design
(Rohacell + CF support)

~ 5 %

X/X_0 (under study)

[IMAGE P1 — material budget diagram]

COST ESTIMATE

Estimated Production Cost

150,000 – 200,000 EUR

Full detector — components, PCB fabrication, assembly, and commissioning

Scintillator cells	SiPMs	Custom HV boards	Mechanics & cooling	DAQ & integration
160 EJ-232 tiles + optical coupling	320 devices (2 per cell)	20-channel V2 PCB fabrication	M55-J CF housing Al-5052 flanges	CAEN digitizers FPGA + cabling

Summary

Time resolution	σ□ ≈ 32–33 ps (Geant4) | 49 ± 5 ps (cosmic) | 49.5 ± 0.5 ps (CR@JINR) — target < 50 ps ✓
Material budget	10.45% X/X_0 (current PCB) — optimisation to ~5% in progress
Mechanical design	v2.0 integrates inside ITS housing with 4 mm clearance, fully non-magnetic
Electronics	Custom 20-channel HV board V2: CAN bus, 24-bit ADC, LTC2983 temperature board
Trigger efficiency	> 90% across all centralities in both collider and fixed-target modes
Cost estimate	150,000 – 200,000 EUR for full detector production and commissioning

OUTLOOK

Next Steps

1. **TRD v0** — May
2. **Power Supply** — July
3. **Front Electronics** — August
4. **Integration with MPD** — Sept



Oct 26

OUTLOOK

Next Steps Toward Final Approval

1	**Radiation tolerance tests**	Qualify STM32F103 and LT3905 in the NICA underground hall environment
2	**Flange & housing stress update**	Complete FEA with the revised v2.0 geometry to validate 4 mm clearance under gravity
3	**Thermal characterisation**	Full closed-loop voltage control across the expected JINR hall temperature range
4	**Integration with MPD DAQ**	Validate trigger output timing and latency against the MPD central trigger unit
5	**TDR submission to NIM-A**	Final manuscript submitted upon completion of validation steps above