A proposed beam-beam monitoring detector for the MPD-NICA experiment

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Cinvestav

BUAP

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Outline

1. Introduction: Colliders, NICA, Multi-Purpose Detector (MPD) and the Beam-Beam monitoring detector (BeBe)
2. BeBe cell prototypes
3. Physics performance of BeBe
4. Conclusions and prospects

1. Introduction

Colliders

7 in operation now:

SuperKEKB, VEPP-2000, VEPP-4M, BEPC, DAFNE, LHC, and RHIC

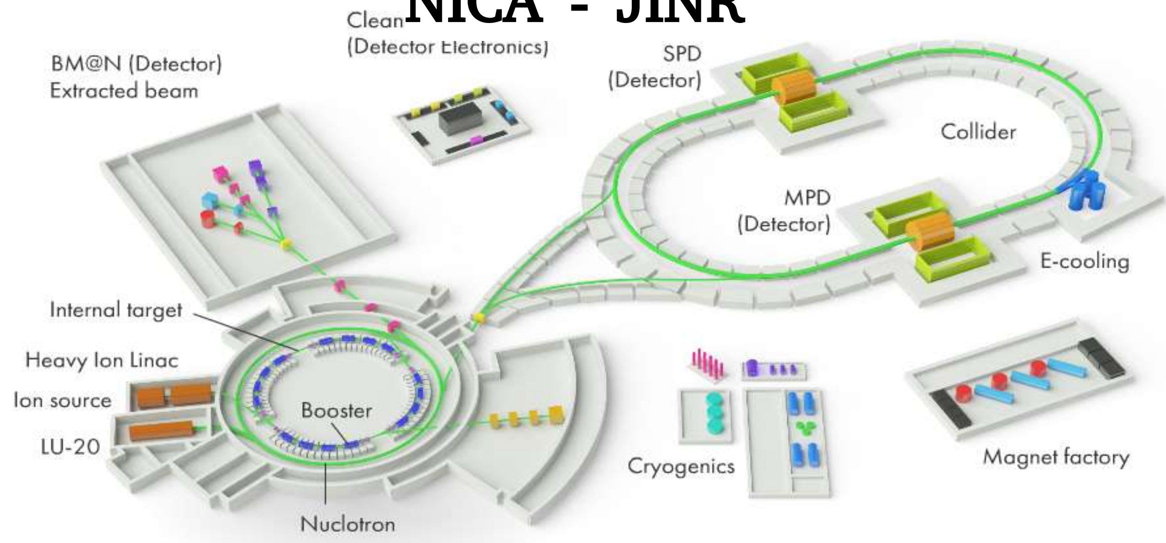
2 under construction:

FAIR and NICA

1 in project phase:

Electron-Ion Collider (EIC)

Nuclotron-based Ion Collider fAcility NICA - JINR

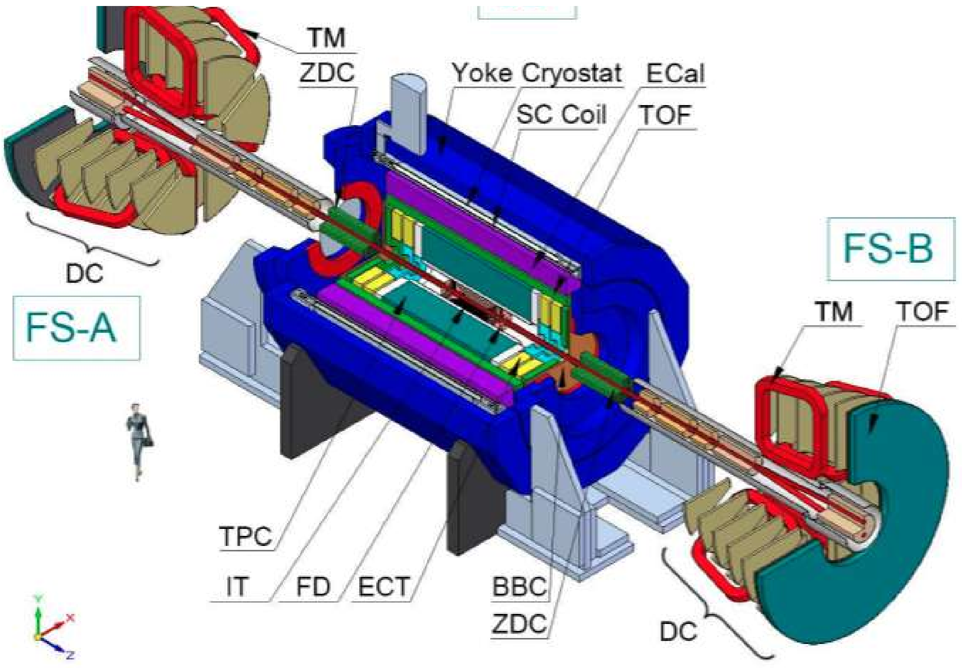


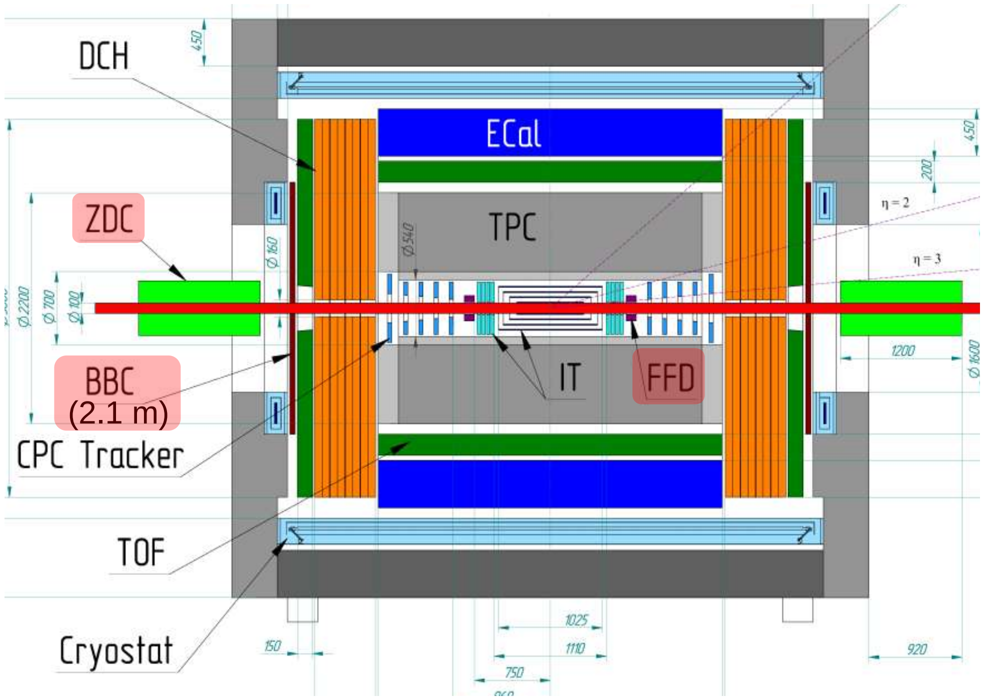
- **BM@N 1-6 GeV/n**
  - (2016) Deuteron
  - (2017-2018) C/Ar/Kr
  - (2019-2020) Au, p
  - (2021) Fe/Kr/Xe
- **MPD (4-11GeV/n)**
  - Bi+Bi 9.2 GeV/n
  - Au+Au: 11 GeV/n
- **Protons**
  - LINAC: LU-20 5MeV
  - Booster: 600 MeV/n
  - Nuclotron: 13 GeV
  - Collider up to 27 GeV
- **SPD Upgrade [<2028]** with polarized beams: Protons, deuteron, He.

The investigation of the properties of dense QCD matter represents an important field of research at FAIR and NICA. The experimental setups used for these measurements are **CBM at FAIR,** and **BM@N and MPD at NICA. CBM and MPD will be ready in ~~2021~~ → 2024**

Nuclotron-based Ion Collider fAcility (NICA)

Multi-Purpose Detector (MPD)



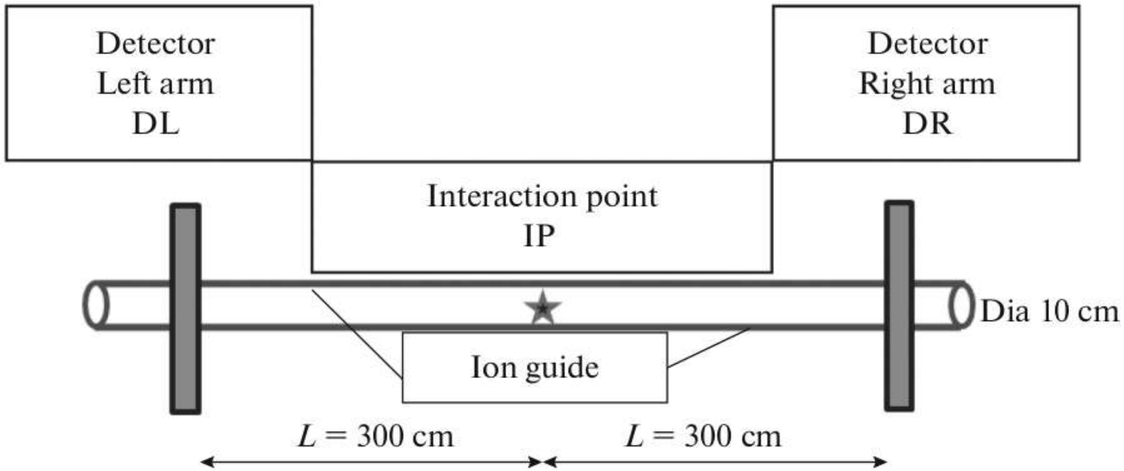


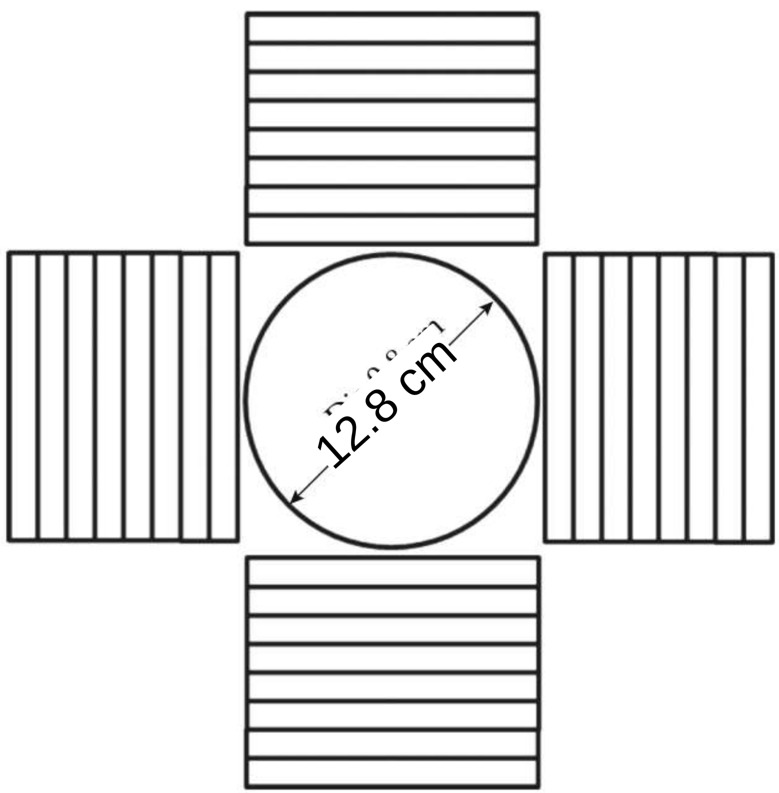
- **Stage 1:** TPC, TOF, Ecal, FHCal(ZDC) and FFD
- **Stage 2:** ITS + forward spectrometers

The conceptual proposal contemplated that the FFD, ZDC and BBC systems would provide the **L0-trigger** for MPD.

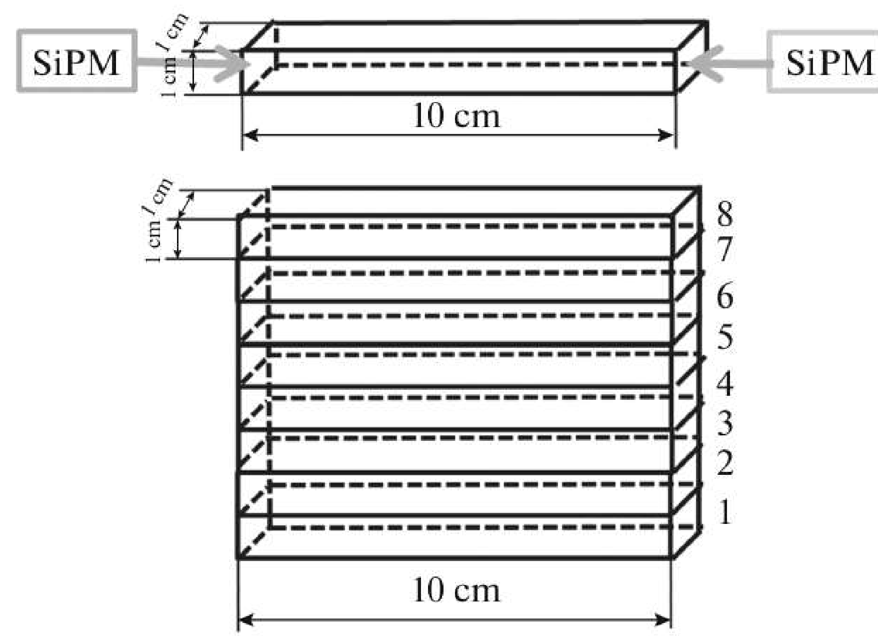
MPD CDR (2016):http://mpd.jinr.ru/wp-content/uploads/2016/04/MPD_CDR_en.pdf

Proposed luminosity detector for stage 1





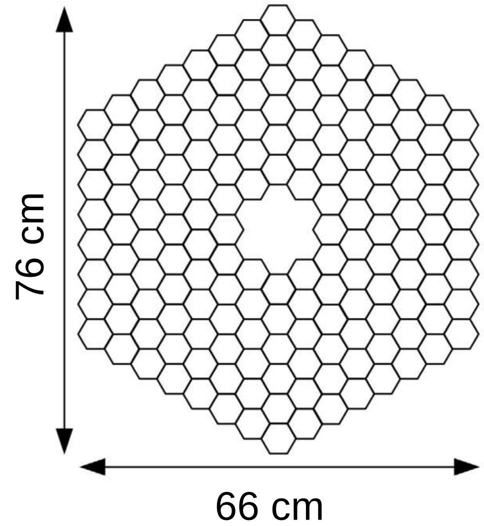
SiPM HAMAMATSU
S13360-6025CS



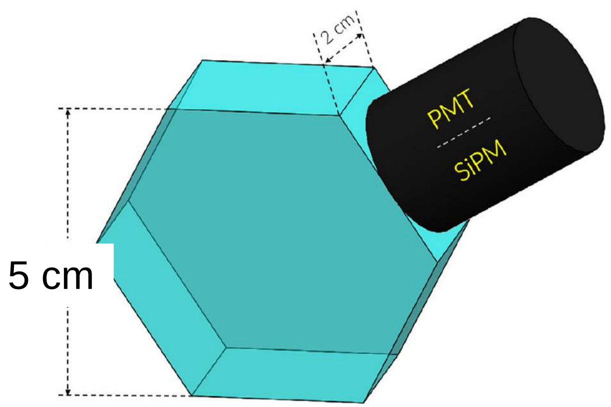
Determining the position of the interaction vertex along the collision axis (Z) in the luminosity detector is calculated from the difference in the time of flight for the left and right halves of the detector. Time resoltuion arround 100ps

From A.Litvinenko, X-MPD colllaboration meeting, Nov 2022

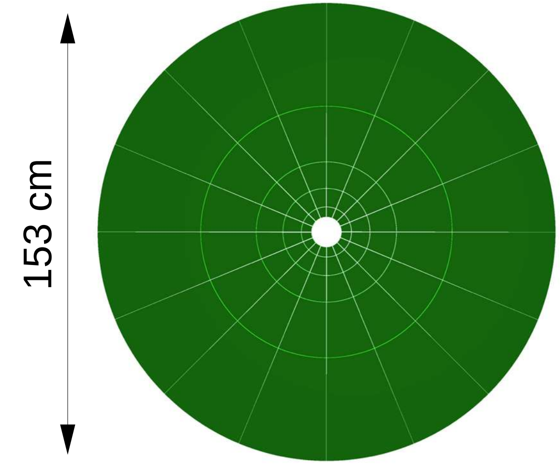
Proposed luminosity detectors for stage 2: Beam-Beam monitoring detector (Be-Be). 2 hodoscope detectors, 2m away from the I.P.



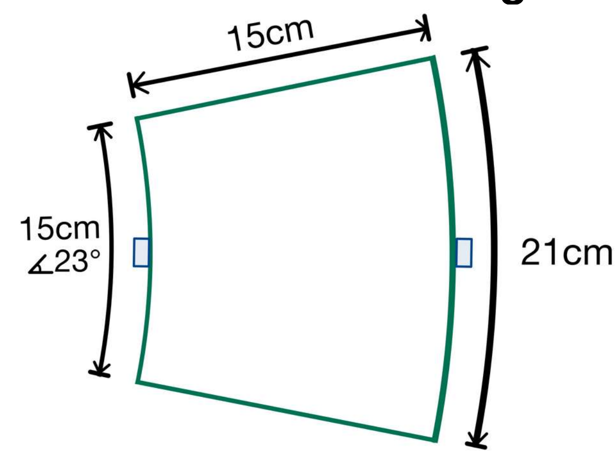
162 cells (BC404) distributed in 6 rings



M. Alvarado, et al. "**A beam-beam monitoring detector for the MPD experiment at NICA**" NIMA A 953, 163150, (2020)

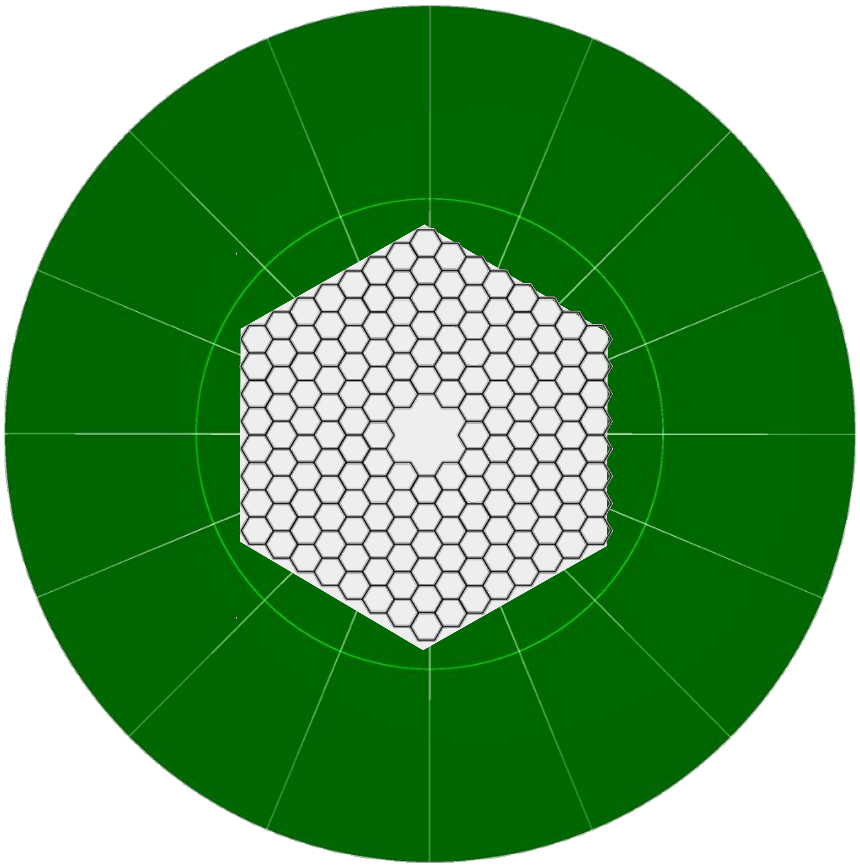


80 cells (BC404, 22.5°) distributed in 5 rings



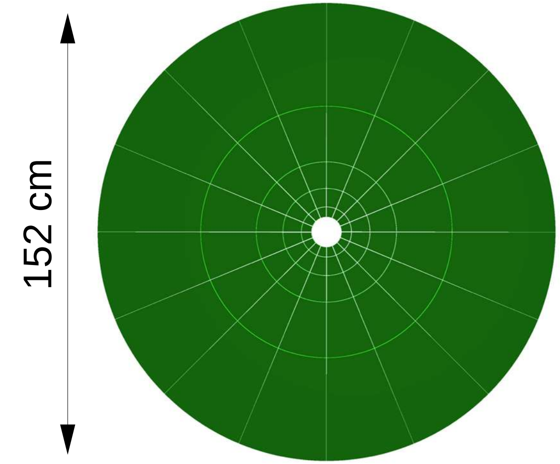
MAAT, L. Espinoza et al, "**Performance of BeBe, a proposed dedicated beam-beam monitoring detector for the MPD-NICA experiment at JINR**" JINST 17 P09031, (2022)

Beam-Beam monitoring detector (Be-Be)
2 hodoscope detectors, 2m away from the I.P.



Increase in η coverage!

Proposed to increase the trigger capabilities for stage 2 of MPD



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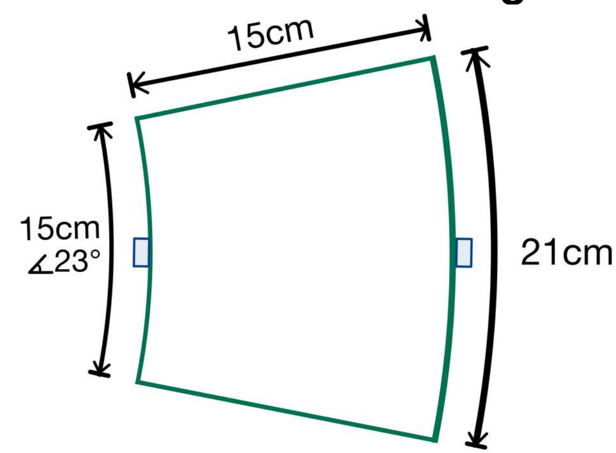
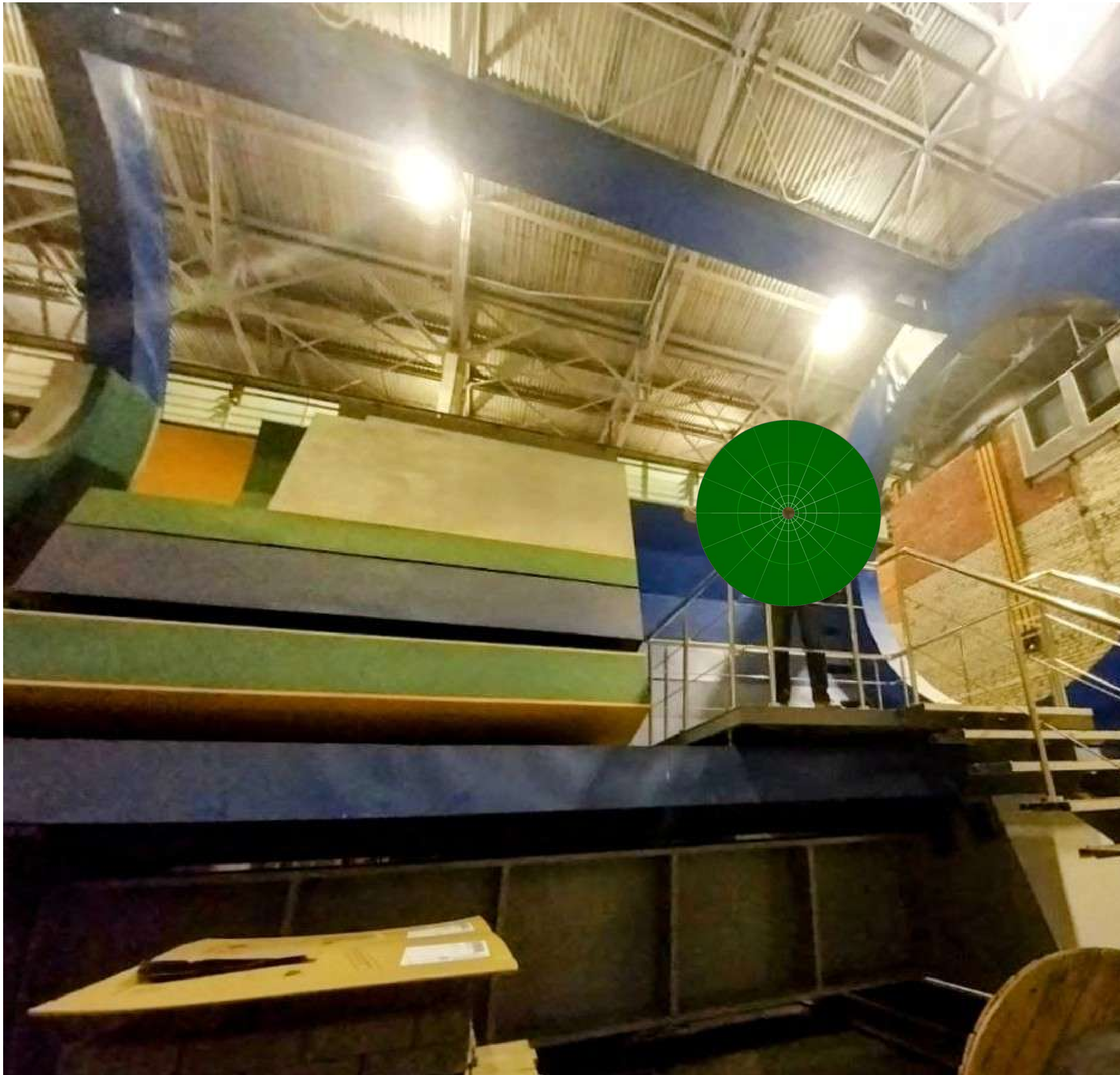
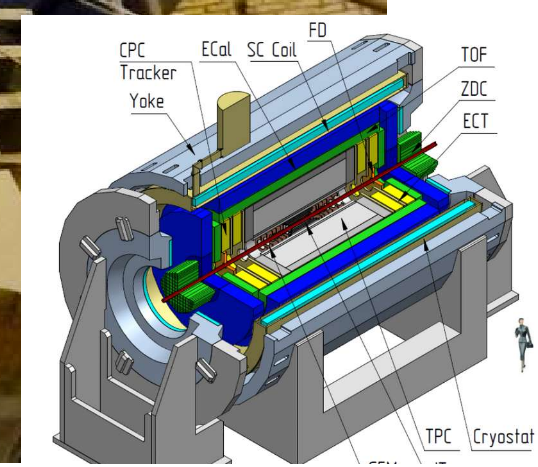


MAAT, L. Espinoza et al, "**Performance of BeBe, a proposed dedicated beam-beam monitoring detector for the MPD-NICA experiment at JINR**" JINST 17 P09031, (2022)

MPD 1:1 scale model (W~8.1 m, Ø~5.3 m)

MPD 1:1 scale model (BeBe Ø=1.5 m)





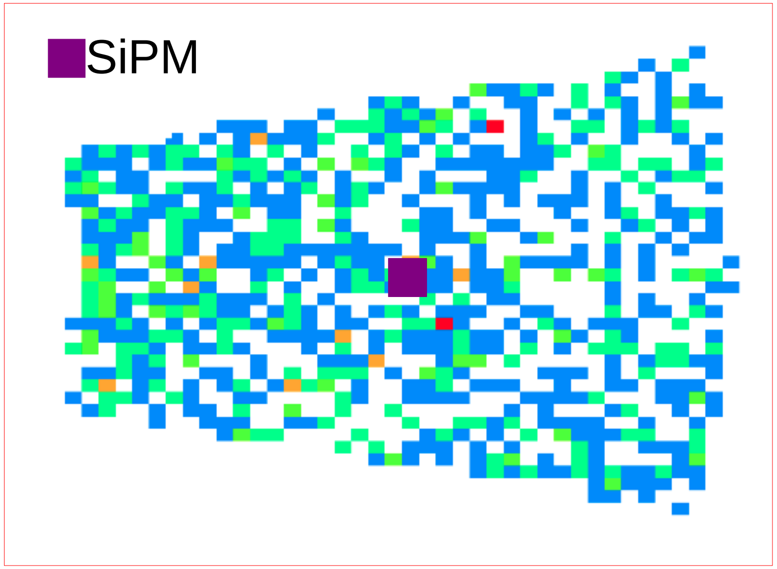
2. BeBe cell prototypes

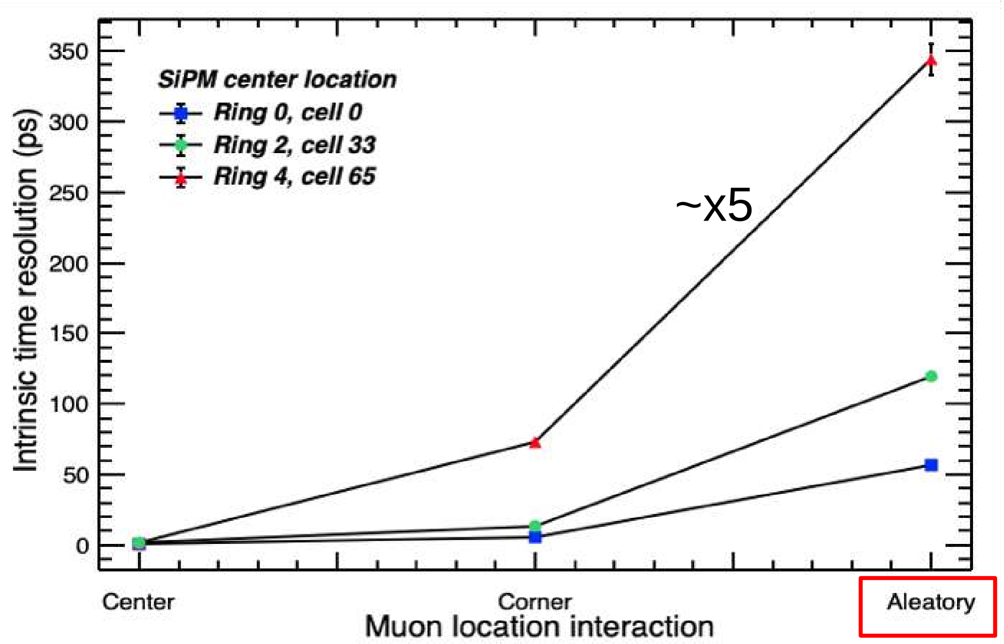
Intrinsic time resolution (ITR) – Geant4

We considered three different cell sizes with **1 GeV muons** striking the BeBe cell.

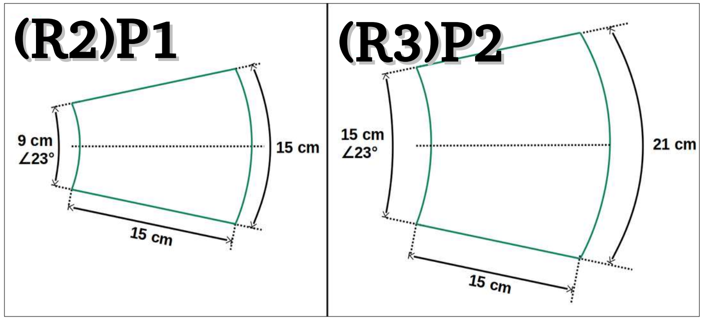
- Scintillator-environment surface was simulated 95% reflective.
- Scintillator-**photosensor** surface: It was simulated with **100% absorption,** in order to avoid double counting of optical photons arriving at the photosensor.

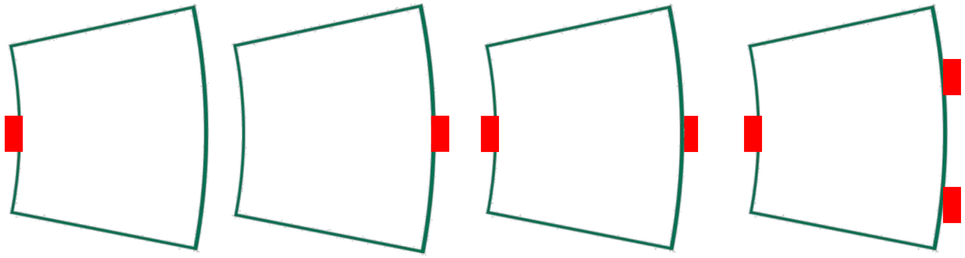
Event by event we plotted the **optical photon arrival time (OPAT)** to the PhS. Fitting the OPAT distributions with a Landau function, we estimated numerically the mean value.

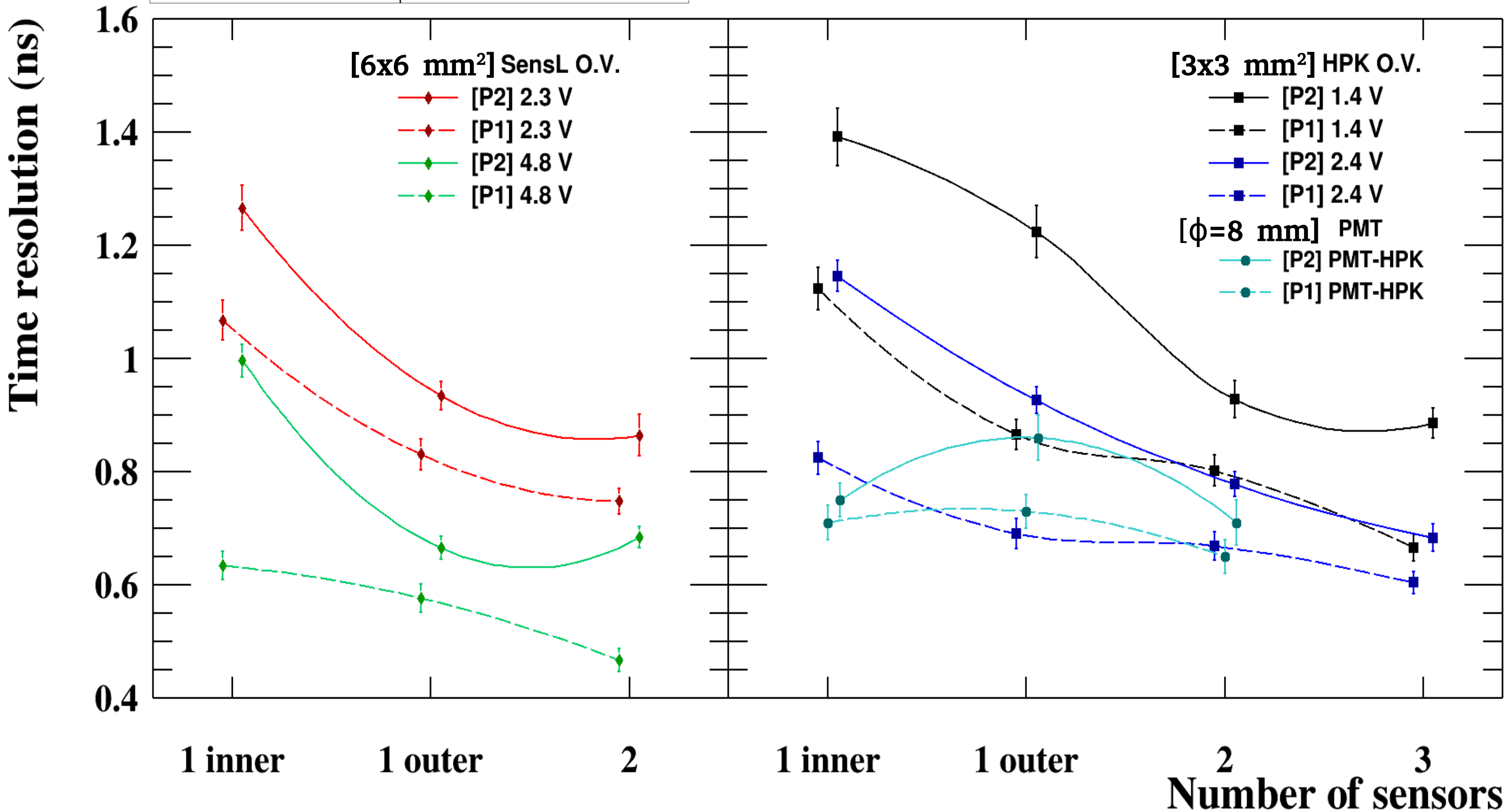




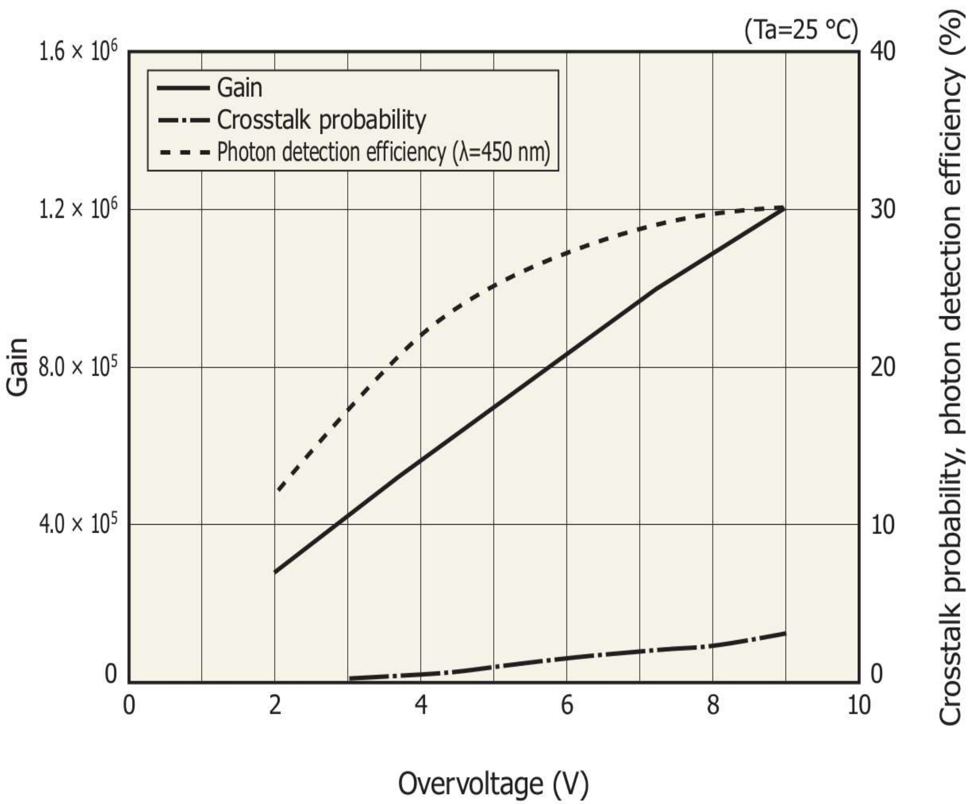
Time resolution laboratory measurements

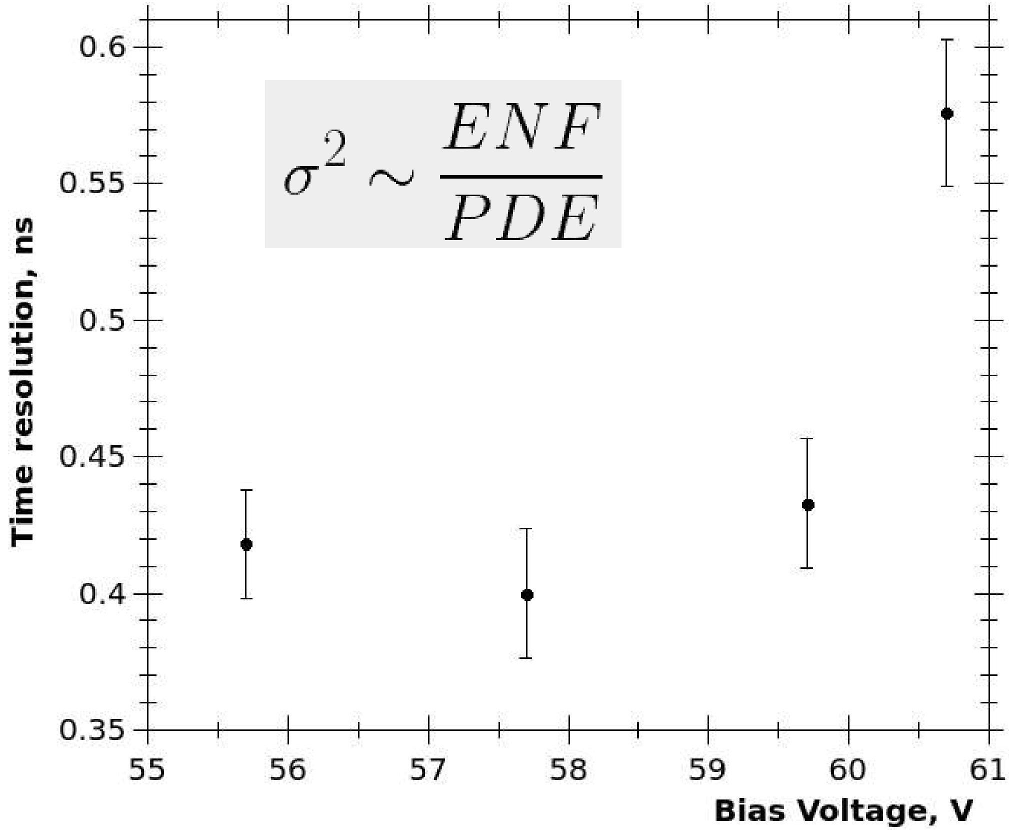




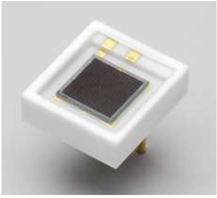


Time resolution and main SiPM properties





SiPM HPK S13360-3050CS



The **photodetection efficiency** (PDE) **AND** the **excess noise factor** (ENF) of the SiPM **increases** as a function of the **overvoltage.**

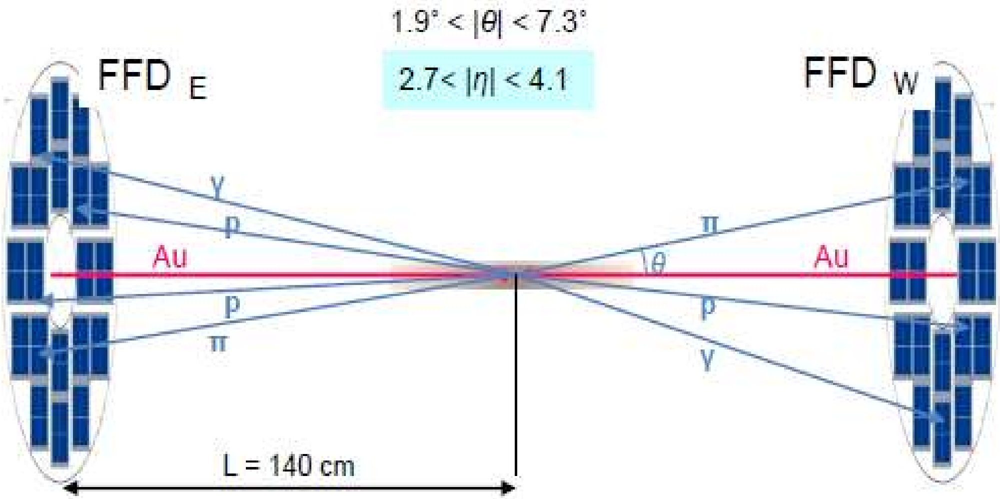
3. Physics performance of BeBe

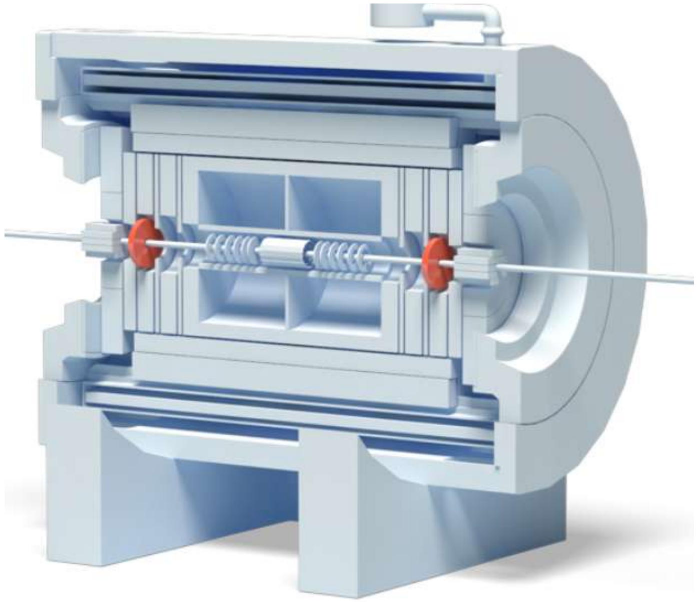
-Trigger efficiency

-Centrality of the collision

-Event plane reaction

Fast Forward Detector (FFD)



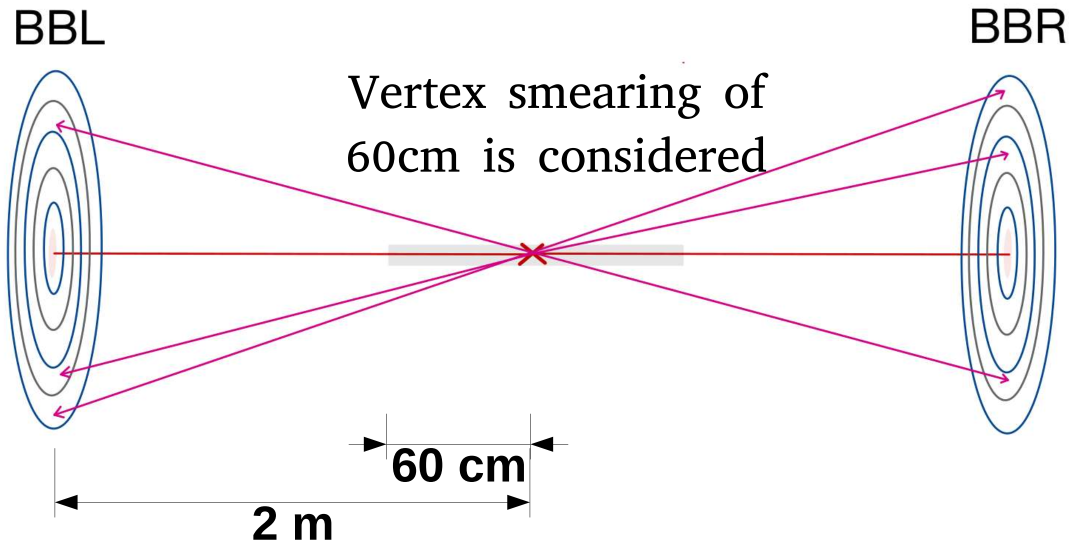


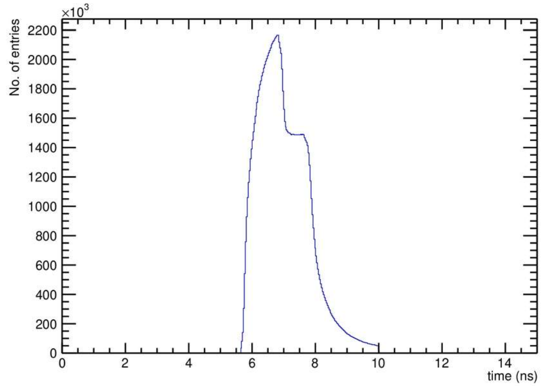
The main requirements for the FFD are:

- **Fast and effective triggering events of Au + Au** collisions in the center of the MPD setup.
- The detector must be able to see each beam crossing (the dead time must be less of 75 ns).
- Generation of the **start pulse t0 for the TOF** detector with **time resolution σ_{t0} < 50ps** (it corresponds to time-of-flight resolution of <100 ps).
- The **uncertainty of determination** of **z-position for Au+Au collision** is **<2 cm.**

TDR FFD (2019):http://mpd.jinr.ru/wp-content/uploads/2019/09/FFD-TDR-Aug-2019.pdf

Trigger efficiencies of BeBe





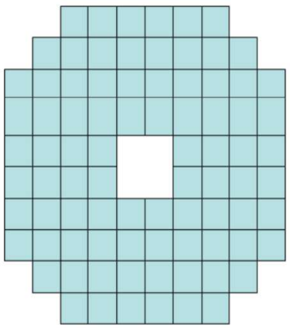
We defined a time window of
$\Delta\tau = 7 \pm 3$ ns
to the time of flight distribution

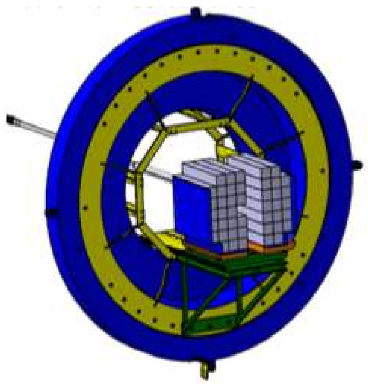
Process (UrQMD)	BBR	BBL	BBRandBBL	BBRorBBL	V. Smearing
p+p, 9 GeV	58.06%	57.86%	20.26%	95.66%	Yes
p+p, 9 GeV	72.85%	72.79%	50.12%	95.52%	No
p+p, 11 GeV	59.84%	59.87%	23.41%	95.52%	Yes
p+p, 11 GeV	74.31%	74.42%	52.7%	96.03%	No
Au+Au, 11 GeV	100%	100%	100%	100%	Yes
Au+Au, 11 GeV	100%	100%	100%	100%	No

Process	BBRorBBL	FFD*	FHCal*	FFDorFHCal*
Bi+Bi with v. smearing	94% (UrQMD @ 9GeV)	89%	93%	94%
		(DCM-QGSM-SMM@ 9.2GeV)		

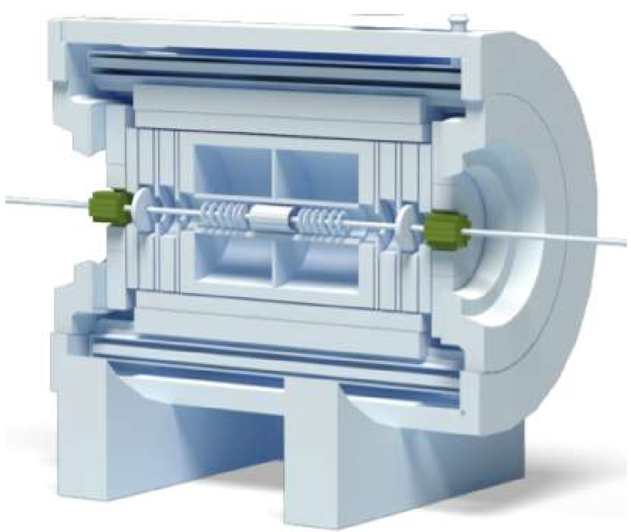
*Values from V. Raibov, IX-MPD collaboration metting, 2022

Zero degree calorimeter (ZDC) or FHCal





~1x1 m^2
3.1 m (from I.P.)



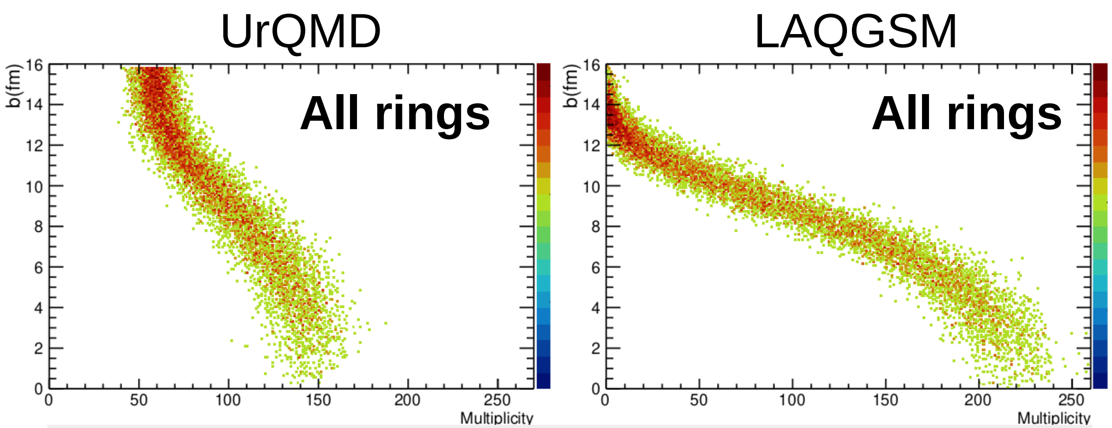
Detector for **<u>event centrality and reaction plane</u>** measurements with **<u>potential for event triggering</u>** $2<|\eta|<5$.

The FHCal must have both appropriate **energy resolution** and modular structure with high enough **transverse granularity** to measure the **event-by-event centroid of the spectator distribution**. The main requirements to the FHCal performance are:

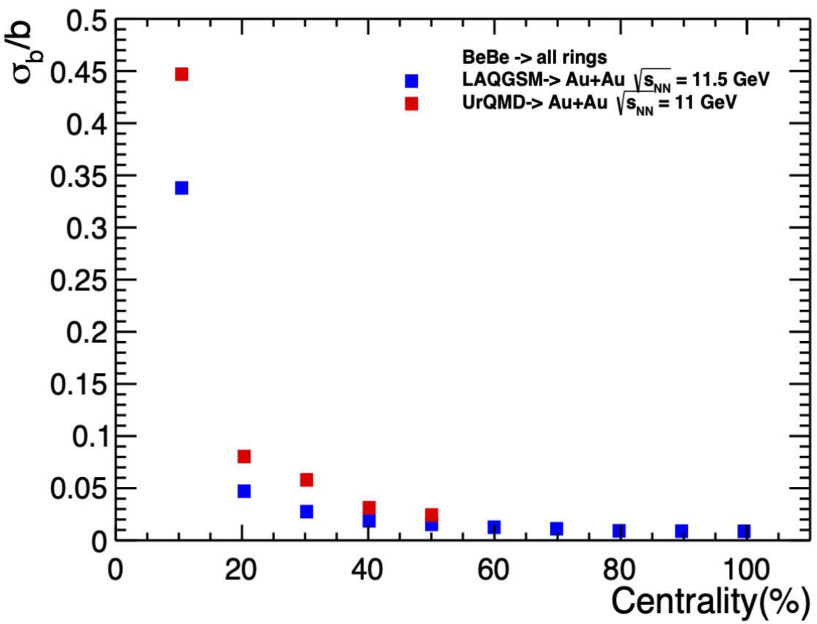
- Spectators detection in the **energy range 1−6 GeV.**
- Operation at the trigger rates up to 6 kHz.
- **Reaction plane determination** using particles produced at forward rapidity with accuracy close.
- **Collision centrality determination** using particles produced at forward rapidity with impact parameter **resolution between 5-10% for (mid-)central collisions.**

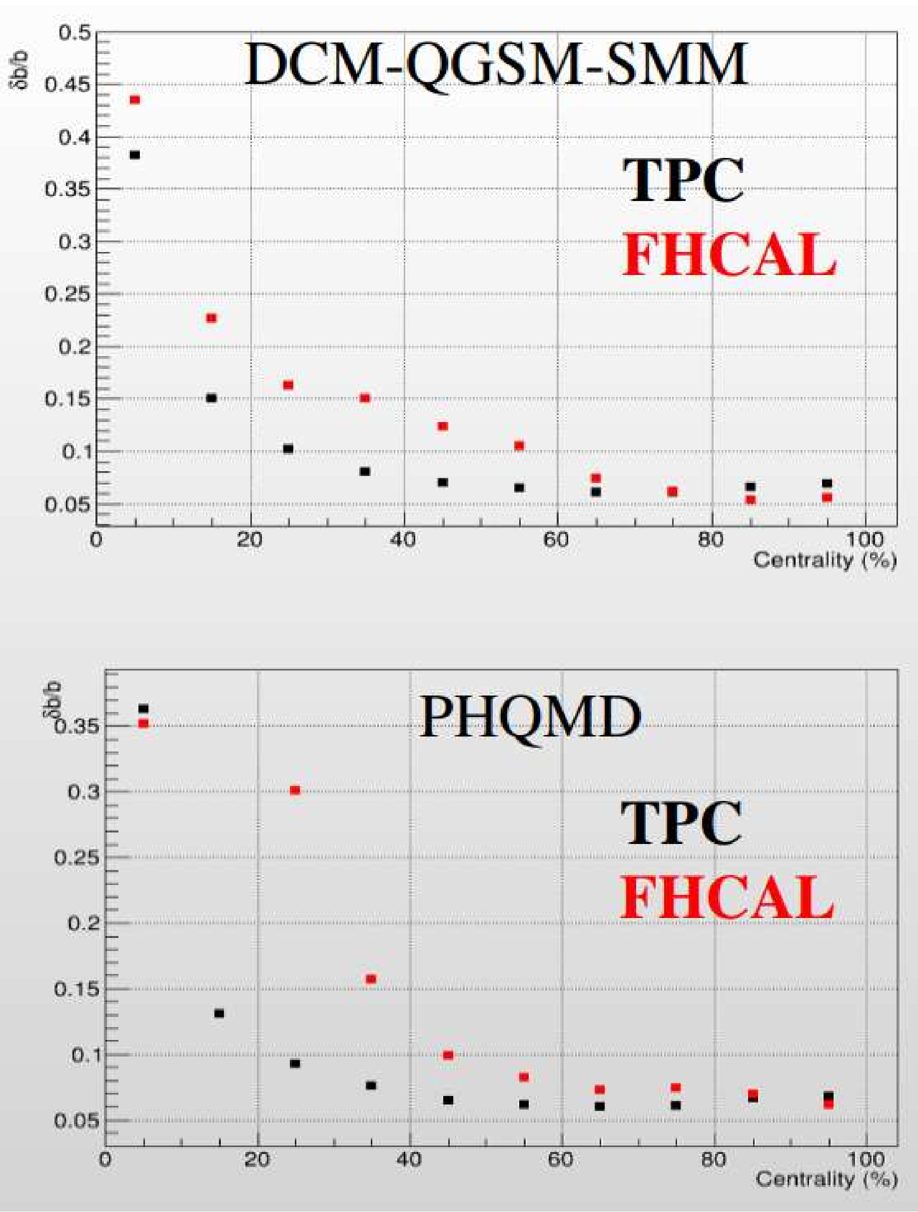
TDR FHCal (2018): http://mpd.jinr.ru/wp-content/uploads/

Centrality resolution of BeBe (left) FHCAL and TPC (right)



Using the hit multiplicity of **all the BeBe** detector rings, **UrQMD (LAQGSM)** predicts a **centrality resolution** of **45% (34%) for central collision.**





V. Riabov, MPD Status, April 2022

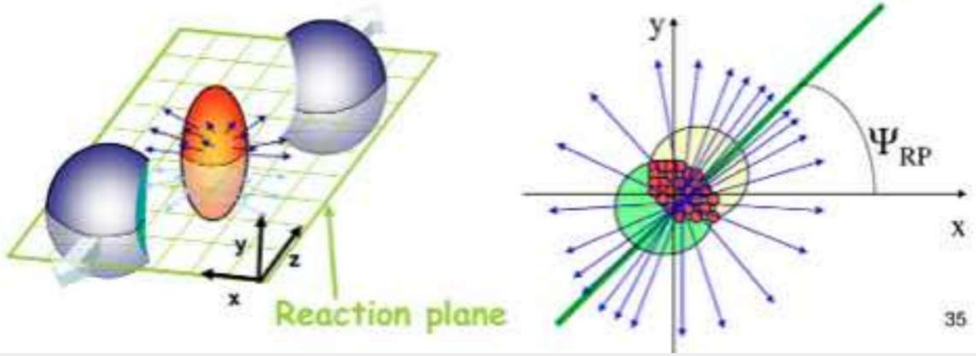
Event plane resolution of BeBe

Determination of the **reaction plane** for flow studies provides physics insight into the **early stages of the reaction.**
The information provided by **BeBe** can be used to **study the anisotropic flow of particles produced in heavy-ion collisions** which is typically quantified by the coefficients in the Fourier decomposition of **the azimuthal angular particle distribution.**
Ψn is the reaction plane angle corresponding to the *n*th-order harmonic.
Profiting from **the high granularity of the BeBe, we can resolve the event plane angle.**

$$\Psi_n^{BB} = \frac{1}{n}\tan^{-1}\left[\sum_{i=1}^{m} w_i \sin(n\varphi_i) \Big/ \sum_{i=1}^{m} w_i \cos(n\varphi_i)\right]$$

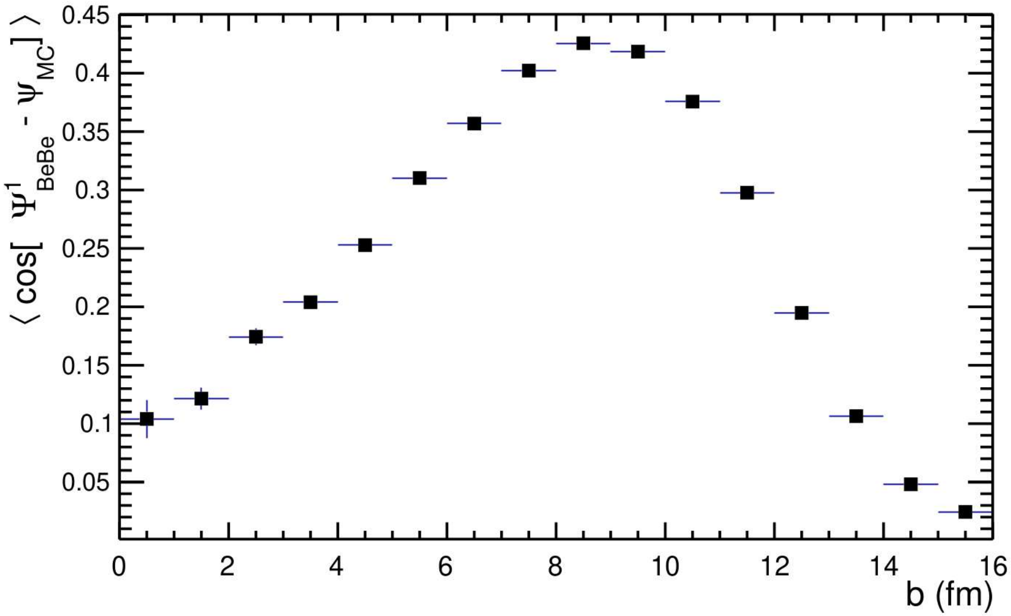
wi* is the multiplicity measured in the *i*-th cell, *m* is the total number of BeBe cells and** ***φi is the *i*th-cell's azimuthal angle measured from the center of the **hodoscope to the cell centroid.**

arXiv:1511.04380



10^6 Bi+Bi collision events at $\sqrt{s_{NN}}$=9 GeV
The **multiplicity per cell,** *wi* , was estimated at hit-level and the **event plane resolution with the BeBe** detector for n = 1 as:

$$\left\langle \cos\left(n \times (\Psi_n^{BB} - \Psi_n^{MC})\right)\right\rangle,$$



Conclusions

- **The time resolution of an individual BeBe cell ranges from 0.4 and 1.4 ns** depending on **the number of photosensors attached** to the cell.

- Our results suggest that **at NICA energies** the BeBe detector can be used for NICA **beam monitoring in p+p and heavy-ion collisions** with:
  - **Excellent trigger efficiencies and centrality resolution for both systems**
  - The **maximum event plane resolution** of BeBe **is 43%** for an impact parameter range between 6 and 11 fm

- For **centrality determination, BeBe is a complementary detector to the FHCAL for central collisions.**

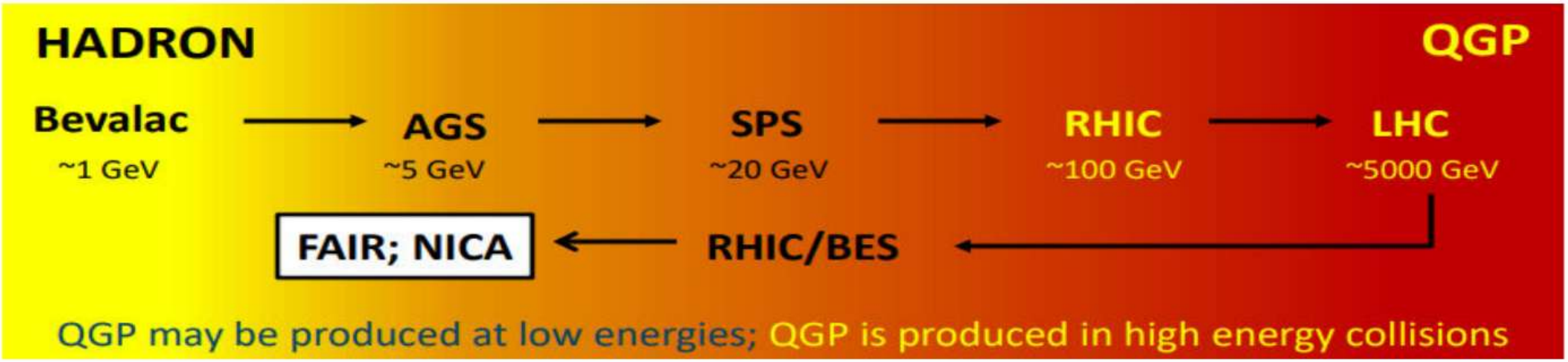
Thank you!

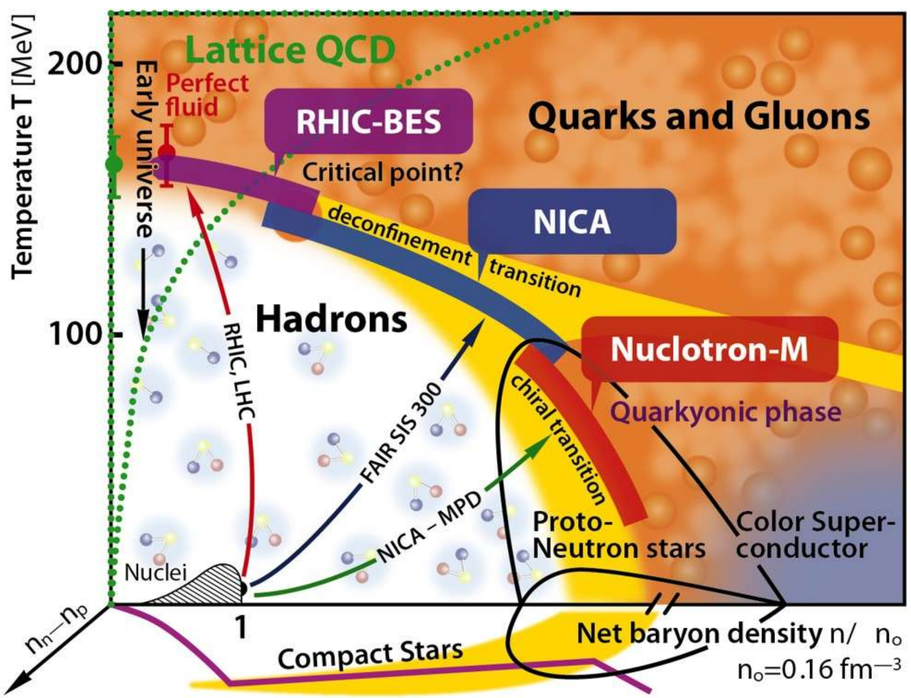
Support from CONACyT grants

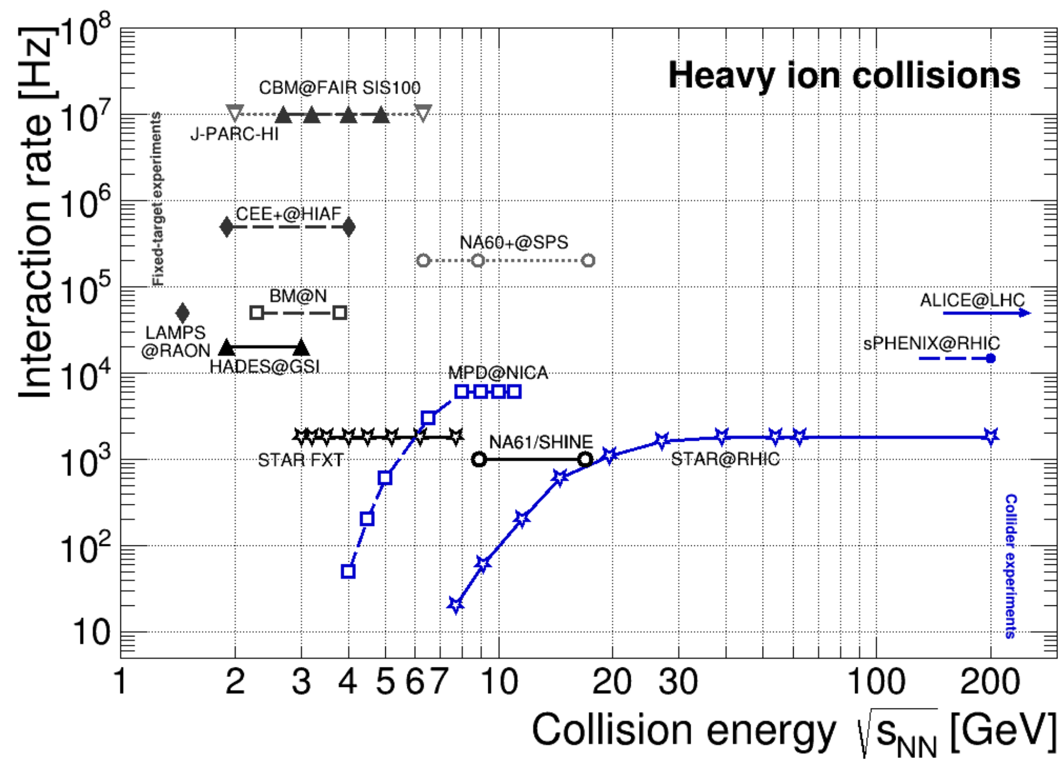
A1-S-13525 and A1-S-23238

is acknowledged

NICA: Study of the QCD medium at extreme baryon densities

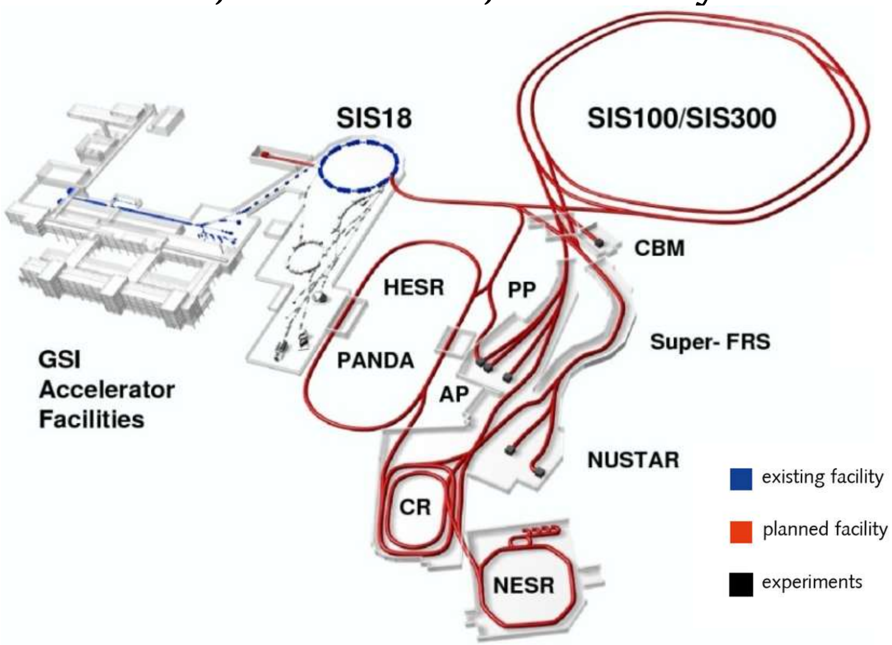






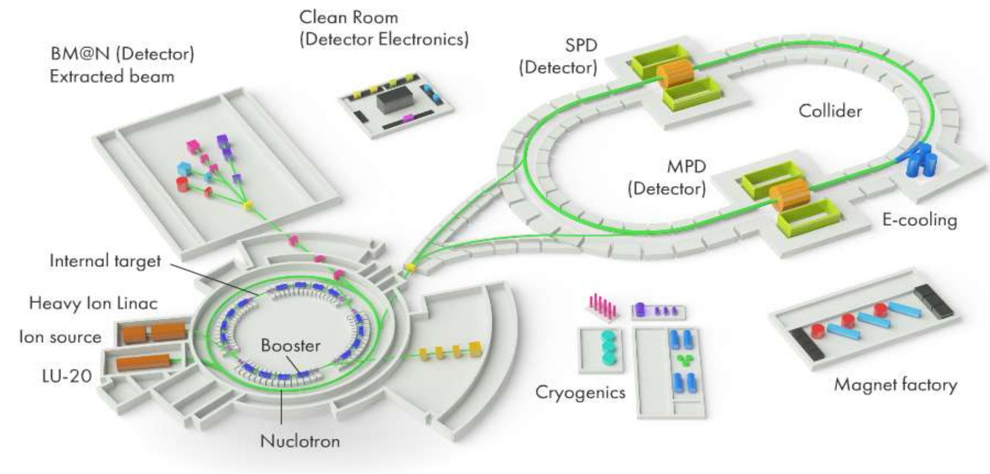
Colliders: 2 under construction

Facility for Antiproton and Ion Research (FAIR), Darmstadt, Germany. GSI



The investigation of the properties of dense QCD matter represents an important field of research at FAIR and NICA. The experimental setups used for these measurements are CBM at FAIR, and BM@N and MPD at NICA

Nuclotron-based Ion Collider fAcility (NICA), Dubna, Russia. JINR

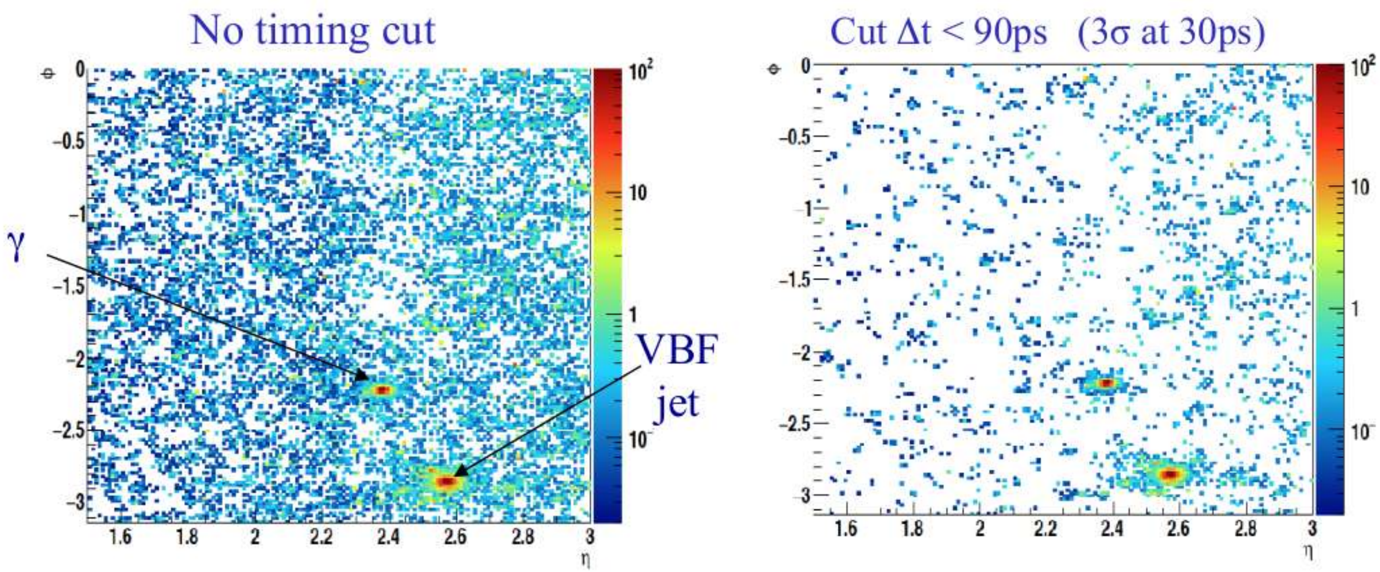


- BM@N 1-6 GeV/n
  - (2016) Deuteron
  - (2017-2018) C/Ar/Kr
  - (2019-2020) Au, p
  - (2021) Fe/Kr/Xe
- MPD (4-11GeV/n)
  - (2023) Bi+Bi 9.2 GeV/n
  - (2024) Au+Au: 11 GeV/n
- Protons
  - LINAC: LU-20 5MeV
  - Booster: 600 MeV/n
  - Nuclotron: 13 GeV
  - Collider: 27 GeV
- SPD Upgrade [2028>] with polarized beams: Protons, deuteron, He.

Time resolution for background rejection

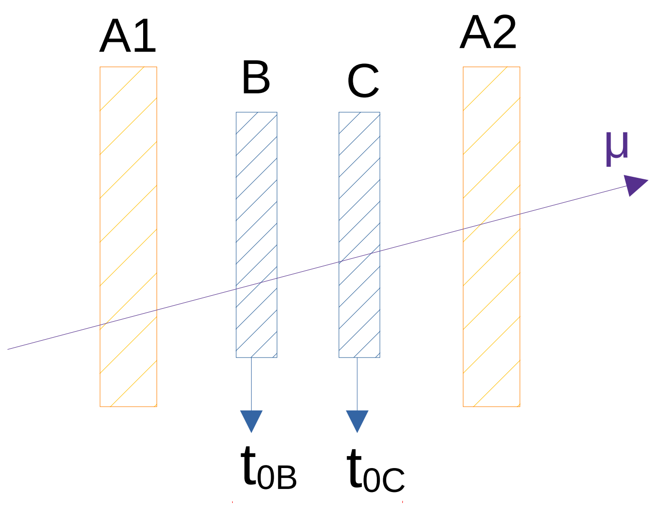
Granularity and Timing for Background (Pileup) Rejection

- CMS: expect up to 200 pileup events at HL-LHC
  - VBF (H→gg) event with one photon and one VBF jet in the same quadrant



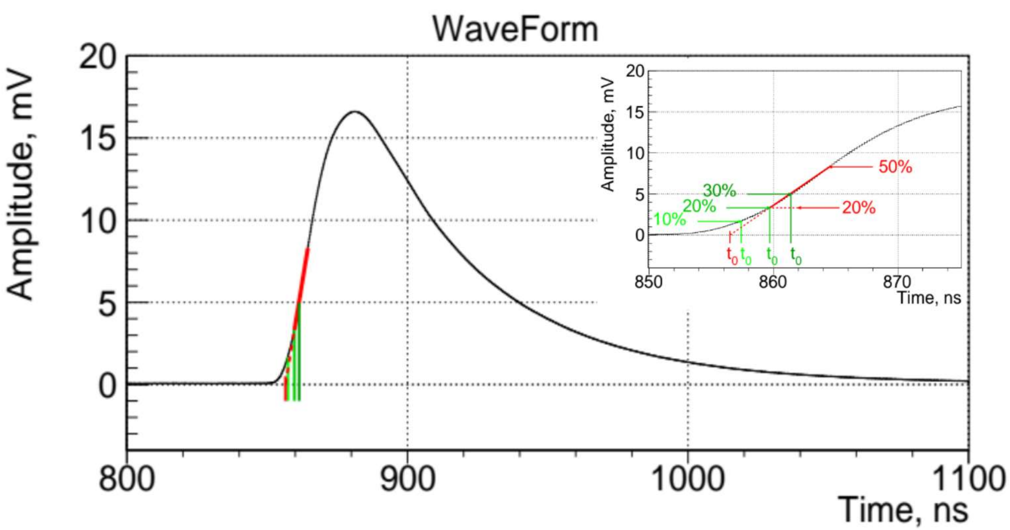
Plots show cells with Q > 12fC (~3.5 MIPs @300mm - threshold for timing measurement) projected to the front face of the endcap calorimeter.
Concept: identify high-energy clusters, then make timing cut to retain hits of interest

From Katja Krüger (EDIT2020) DESY, 26. February 2020, Calorimetry III: Particle Flow Calorimeters



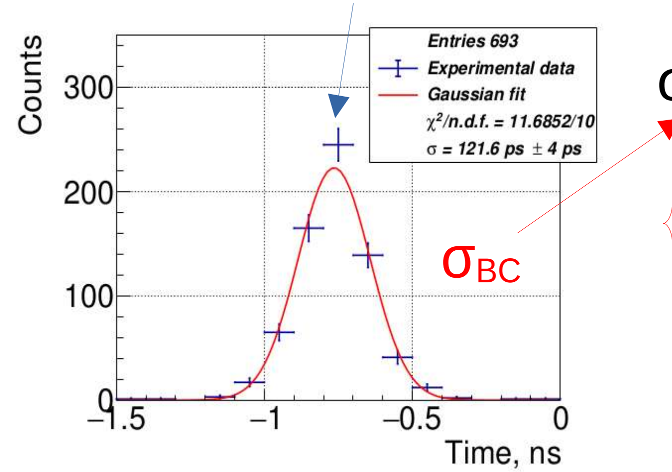
The time resolution can be affected by different factors:

- **Plastic Scintillator**: Atenuation length, decay constant and rise time
- **Photosensors**: Geometry and photodetection efficiency
- **Electronics**: Noise level and signal processing



Arrival time of the signal (t_0)

$\Delta t = t_{0B} - t_{0C} \pm \sigma_{BC}$

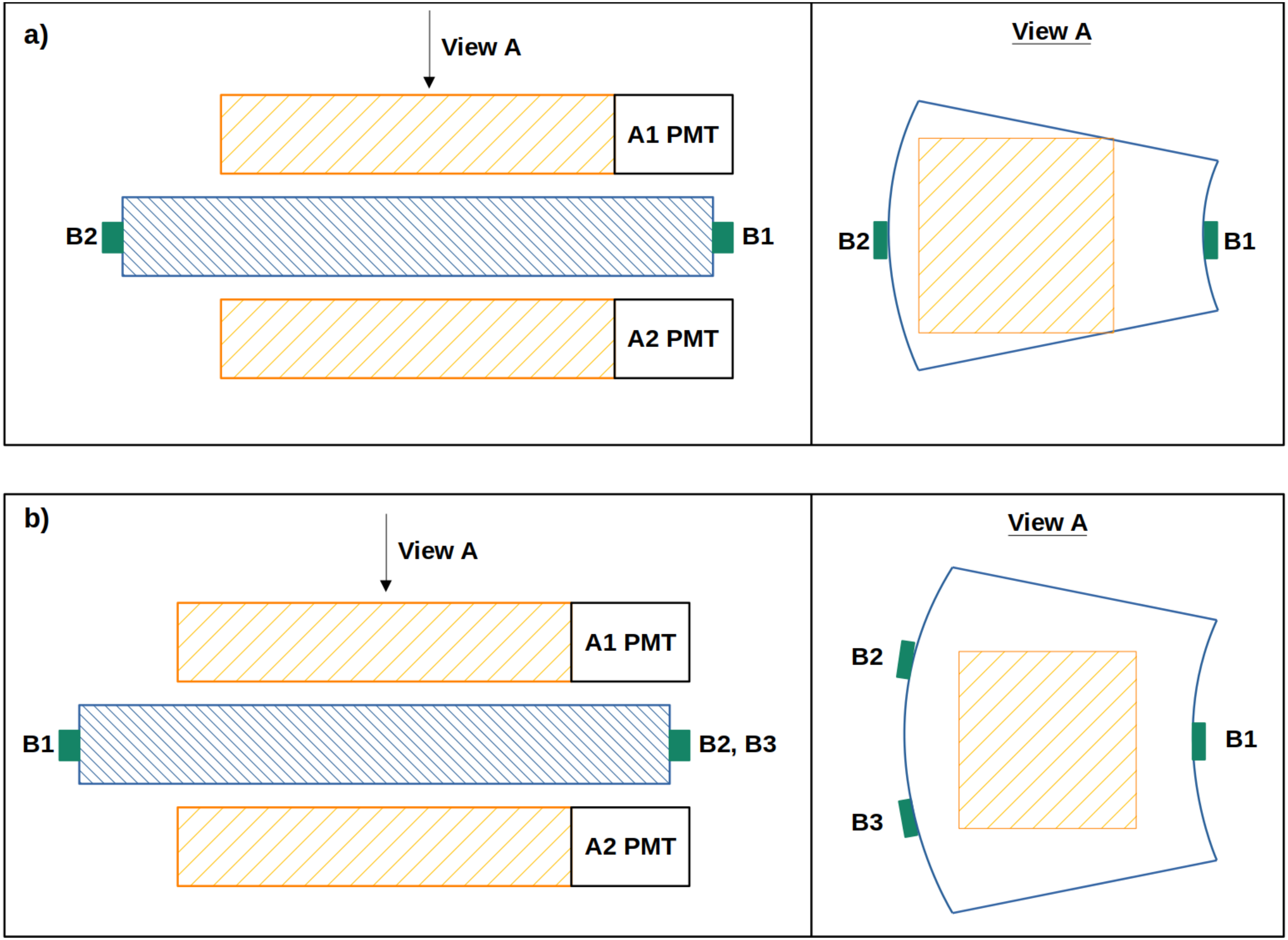


$\sigma^2_{BC} = \sigma^2_B + \sigma^2_C$

if($\sigma_B == \sigma_C$)

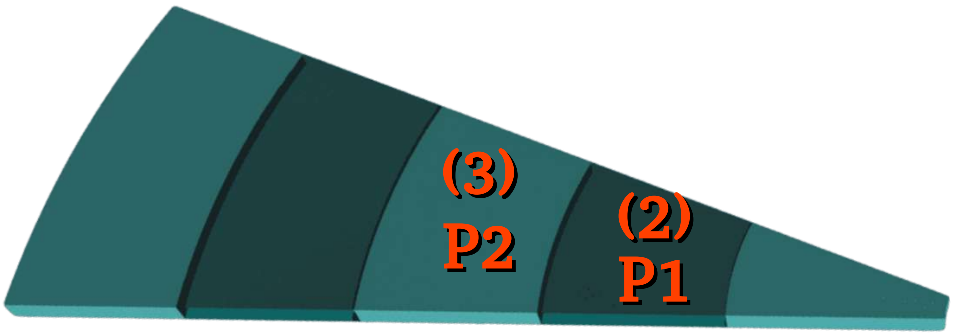
$\sigma_B = \sigma_{BC}/\sqrt{2}$

Setup

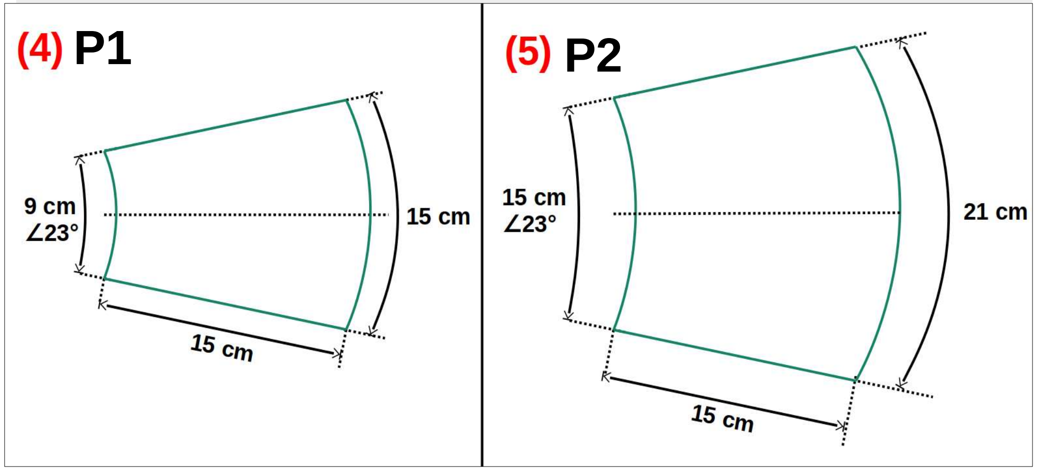


a)
View A
A1 PMT
B2
B1
A2 PMT
View A
B2
B1
b)
View A
A1 PMT
B1
B2, B3
A2 PMT
View A
B2
B1
B3

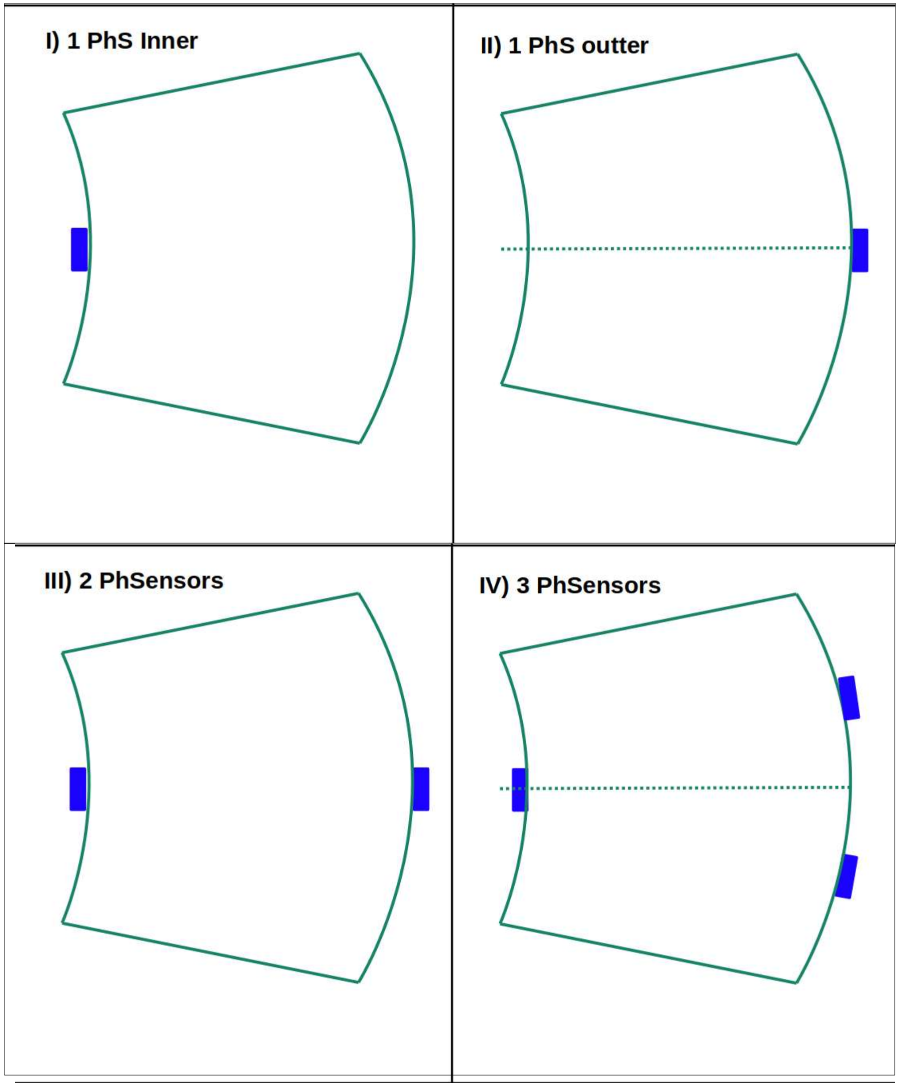
BeBe cell prototypes



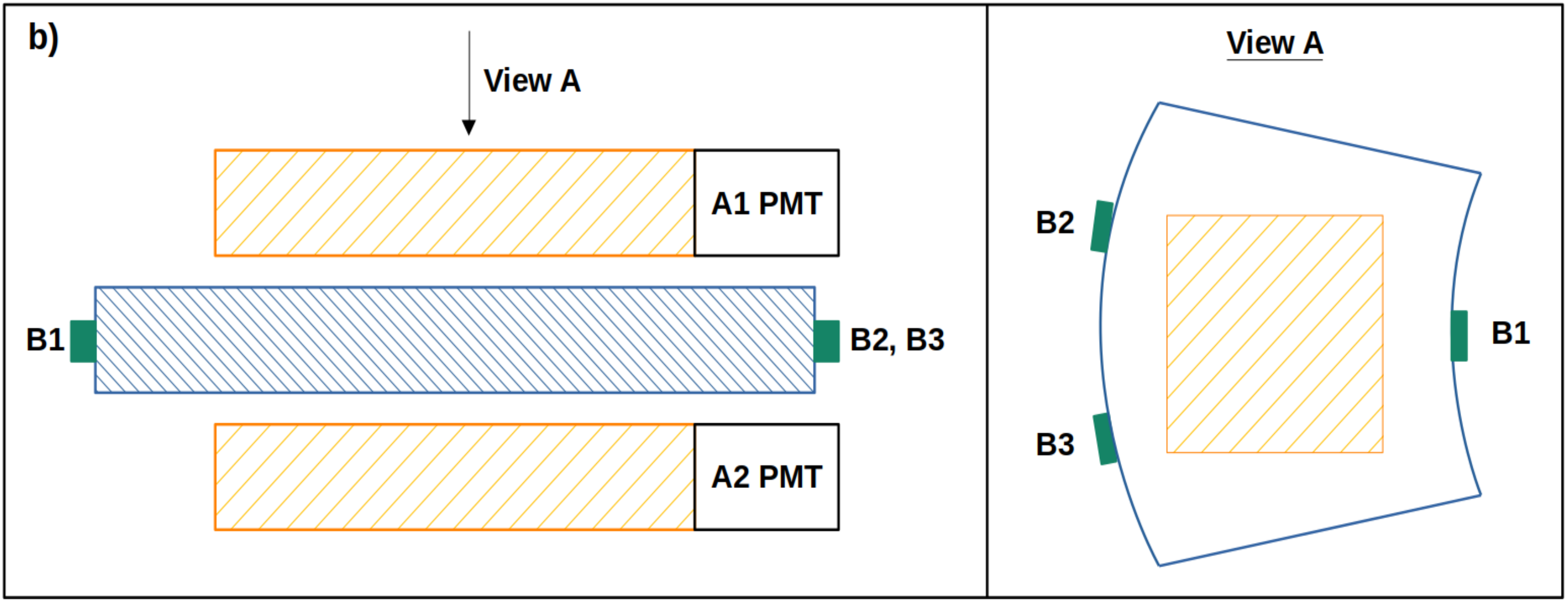
Two prototypes of the were studied using **secondary particles of cosmic rays as a radiation source.** The time resolution of each prototype depends on the volume (P2 is bigger than P1) due to internal light losses due to multiple reflections and the reduced amount of light arriving in every photodetector.



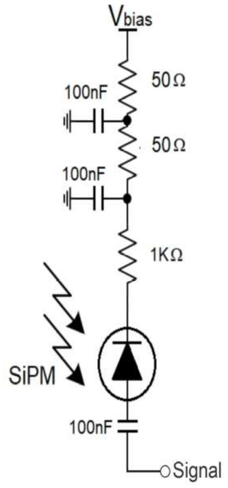
The photosensors were coupled to the cells in 4 different ways:



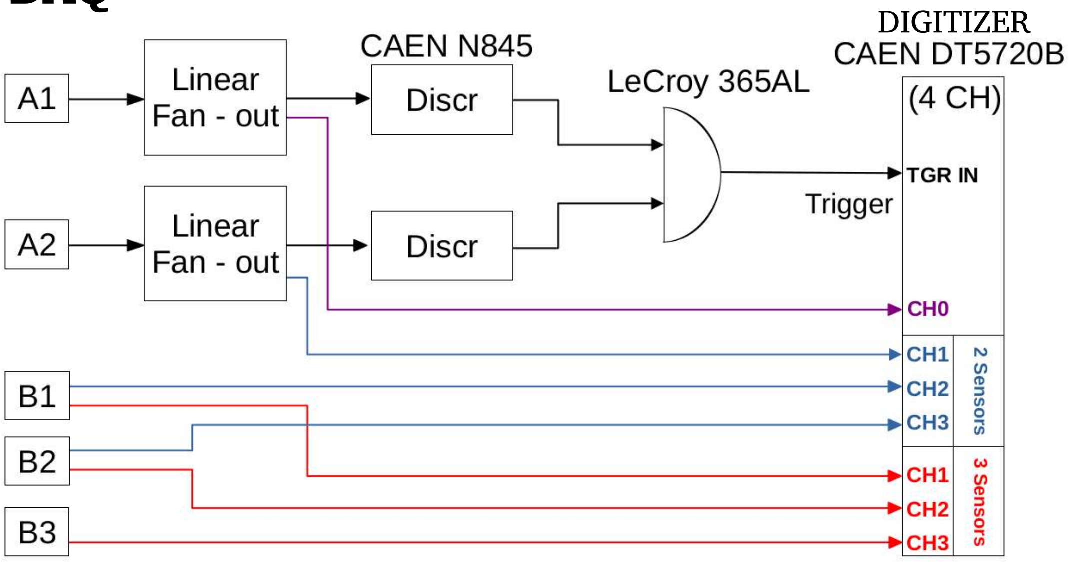
Setup - Laboratory measurements



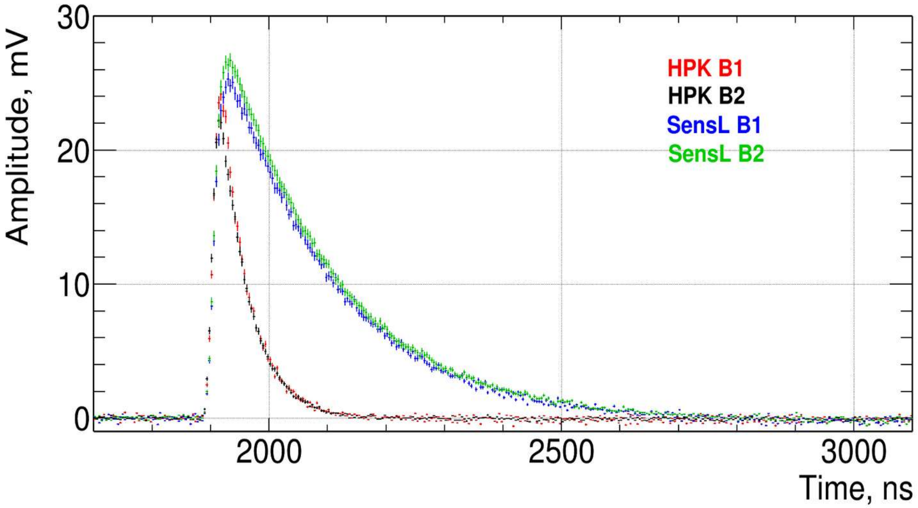
Polarization Circuit



DAQ

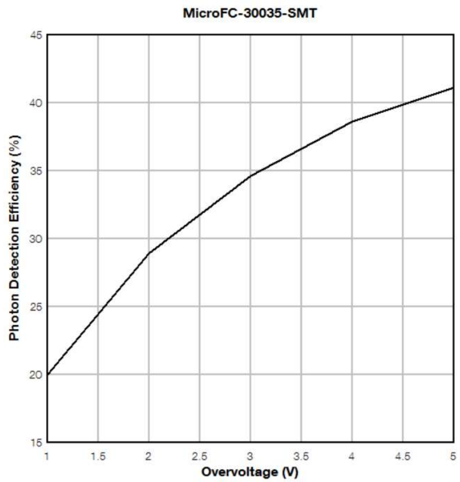


SiPM signals

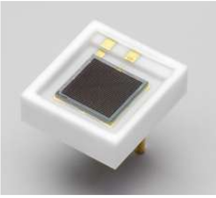


SiPM SensL MICROFC-60035-SMT-TR1

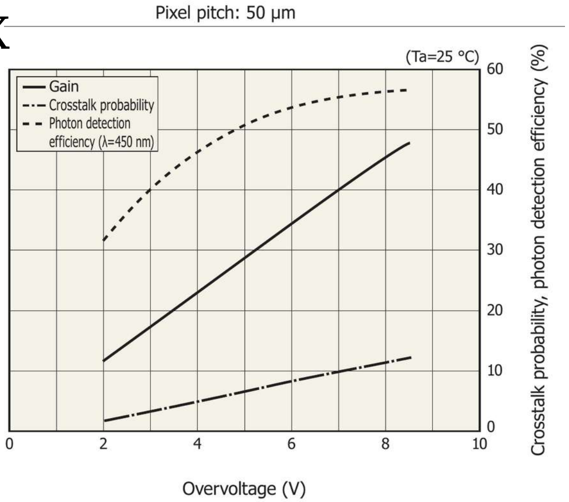
6x6 mm²

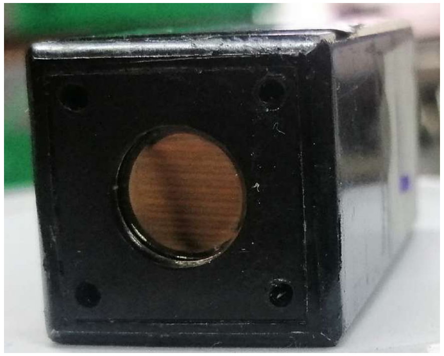


SiPM HPK S13360-3050CS



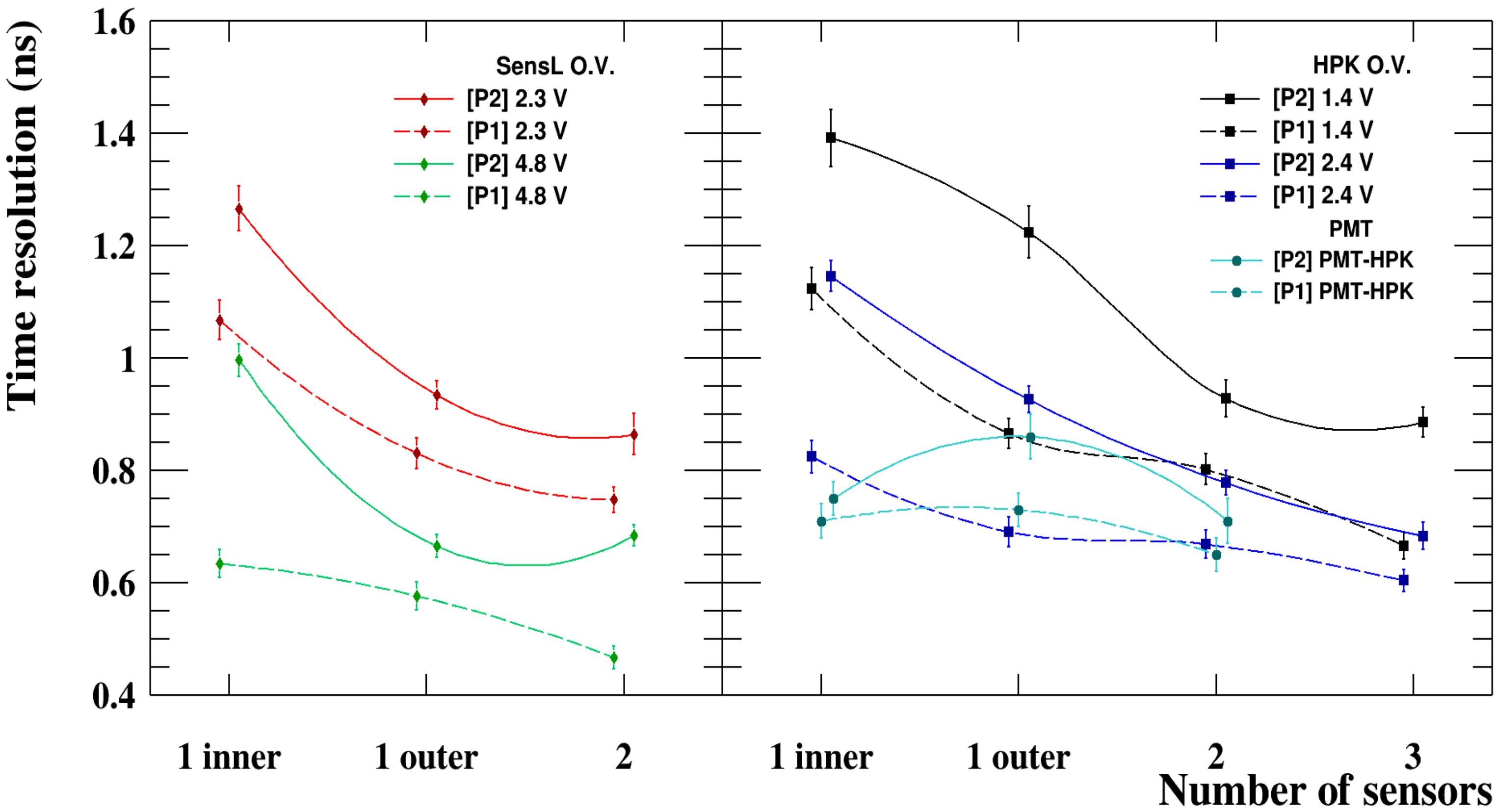
3x3 mm²





PMT HPK H5783

ϕ=8 mm

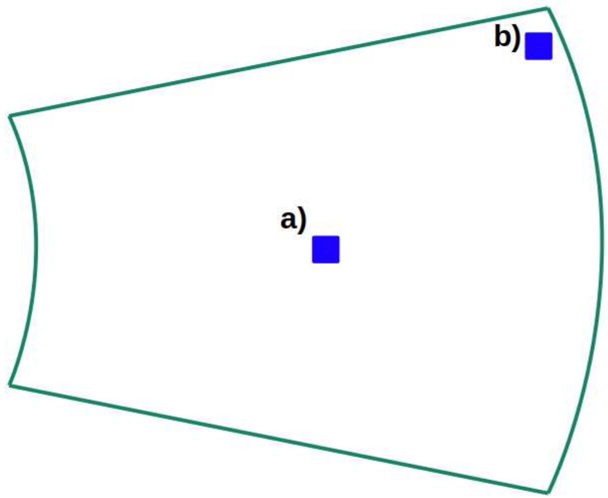


The **photodetection efficiency** (PDE) of the SiPM **increases** as a function of the **overvoltage.** We considered two O.V. values for each SiPM and we observed that by increasing the overvoltage the **time resolution reaches lower values.**

Intrinsic time resolution (ITR)

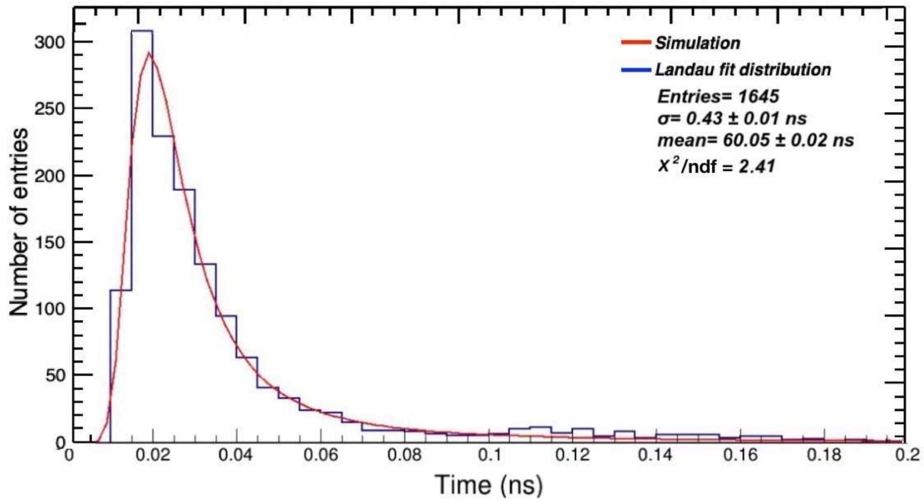
Geant4 simulation: We considered three different cell sizes with **1 GeV muons** striking the BeBe cell.

- Scintillator-environment surface was simulated 95% reflective.
- Scintillator-**photosensor** surface: It was simulated with **100% absorption,** in order to avoid double counting of optical photons arriving at the photosensor



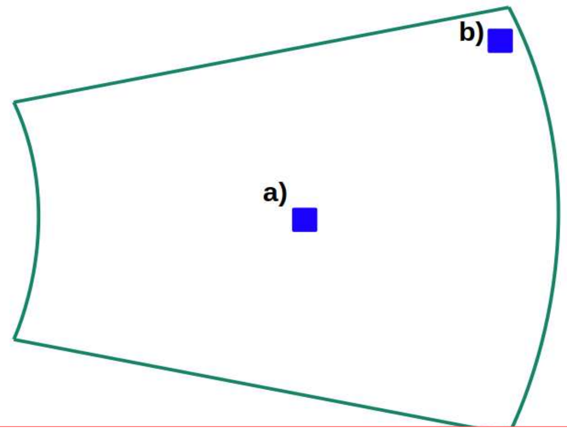
Event by event we plotted the **optical photon arrival time (OPAT)** to the PhS. Fitting the OPAT distributions with a Landau function, we estimated numerically the mean value.

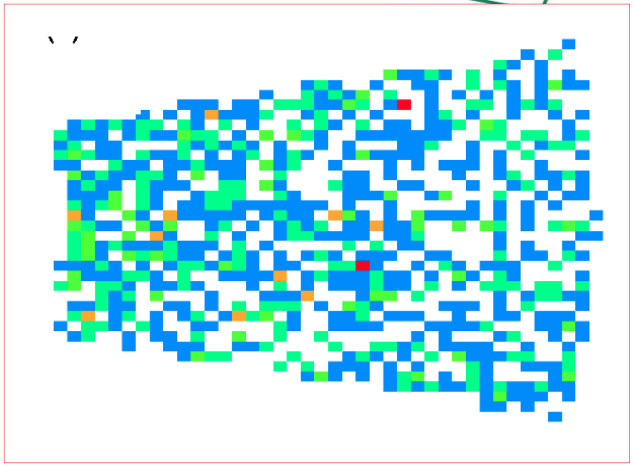
The **gaussian distribution constructed with all the MPV** extracted from the Landau fits to the OPAT distributions, **we estimated the intrinsic time resolution (ITR).**

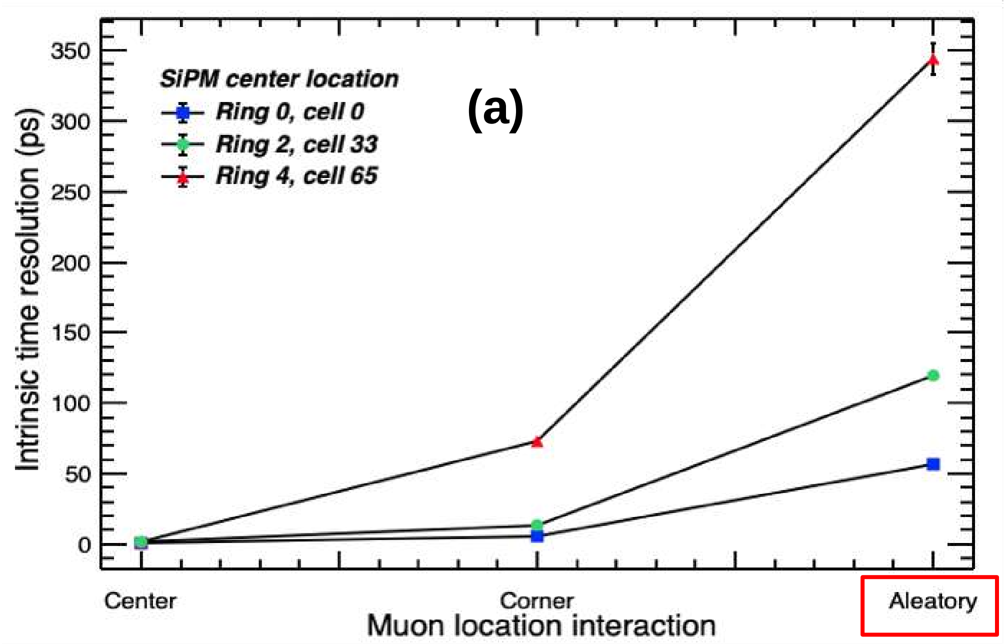


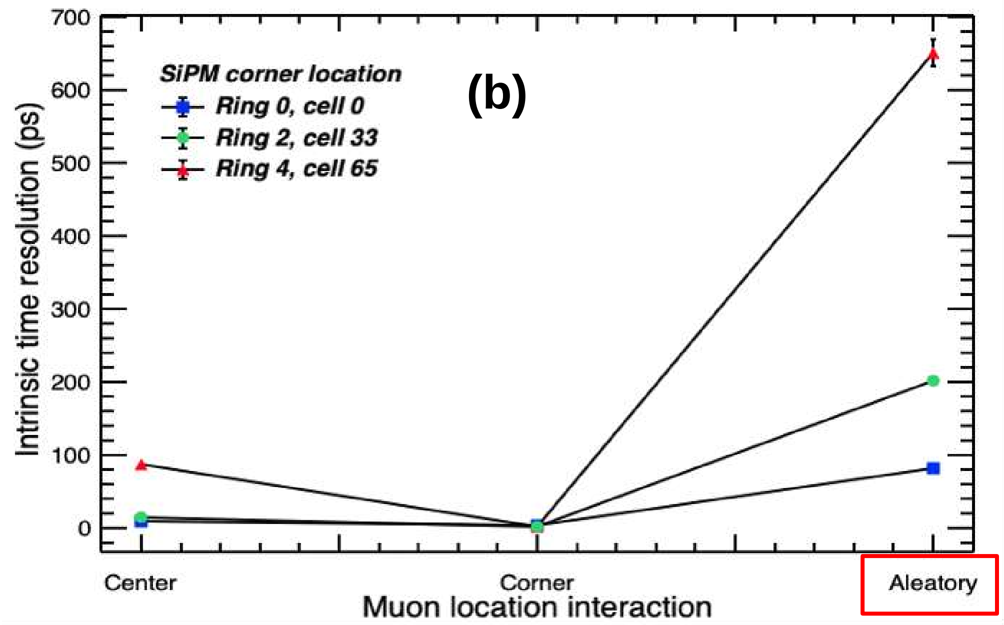
Intrinsic time resolution (ITR)

The **ITR is not constant** and it **depends** on the **hit location** of the generated particle into the BeBe cell and **the location of the SiPM.** The ITR helps us determine the **minimum value** that we can achieve and gives us a **guide** to build our **prototypes.**







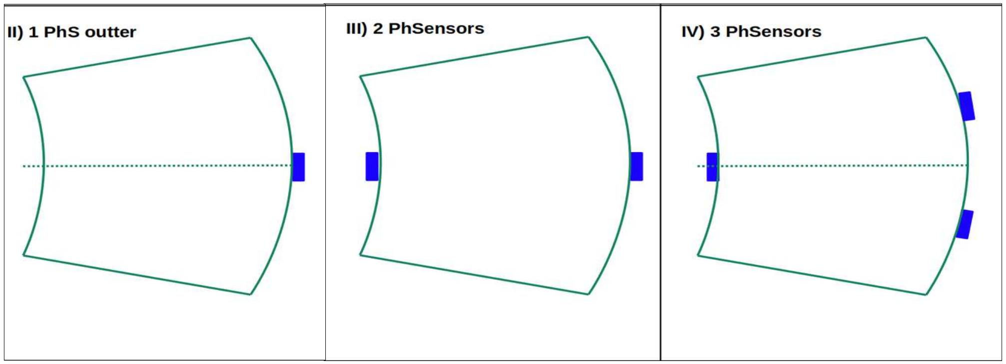


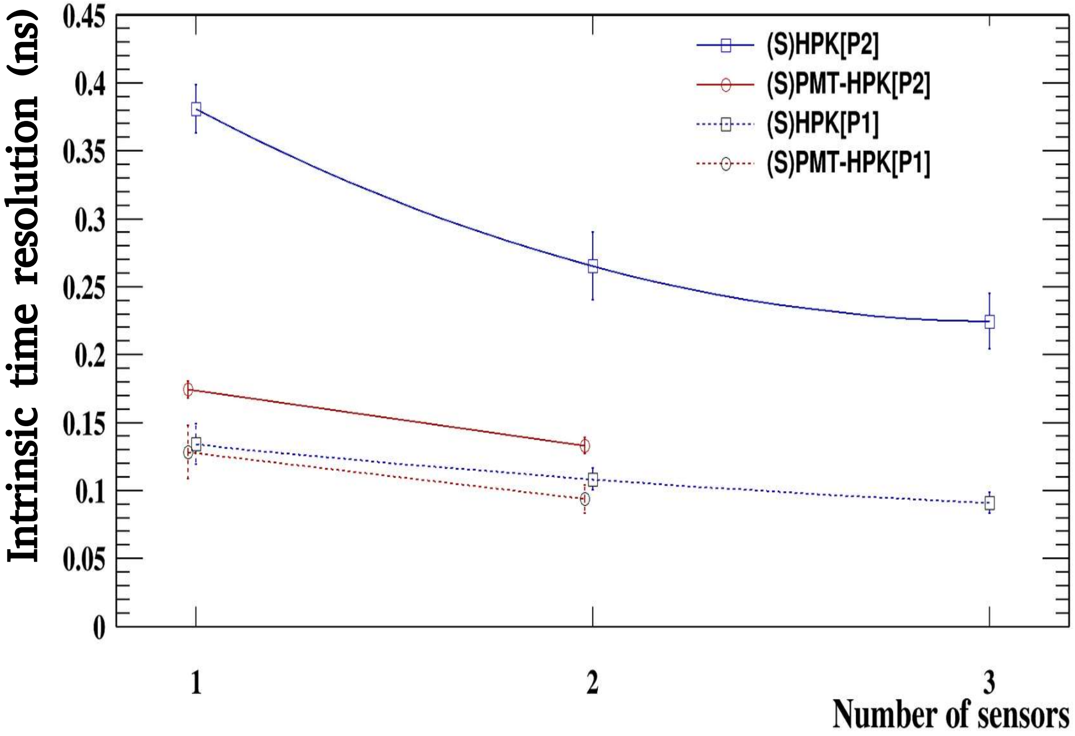
Intrinsic time resolution (ITR)

Muons were considered as **incident particles to the scintillators' frontal surface** area and following the energy spectrum distribution of the cosmic rays on Earth's surface[1]

Comparing the laboratory results against the simulation we can observe an evident difference due to particular features not taken into account in the simulation.

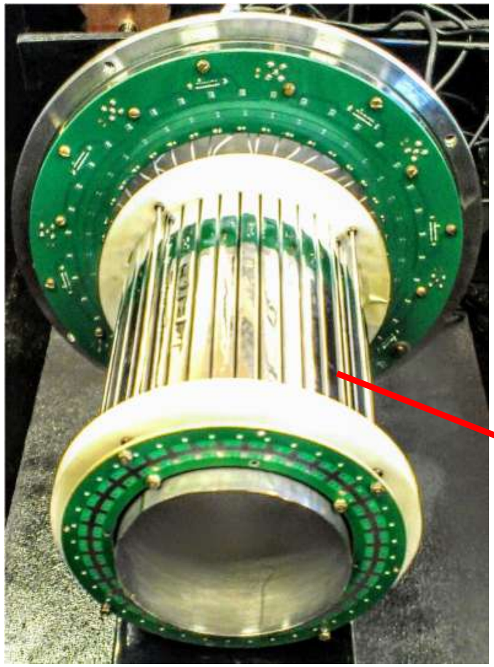
The ITR is **independent of the electronics and data acquisition system** and **it only depends on the geometry of the scintillator, number of photosensors, specie and energy of incident particles.**





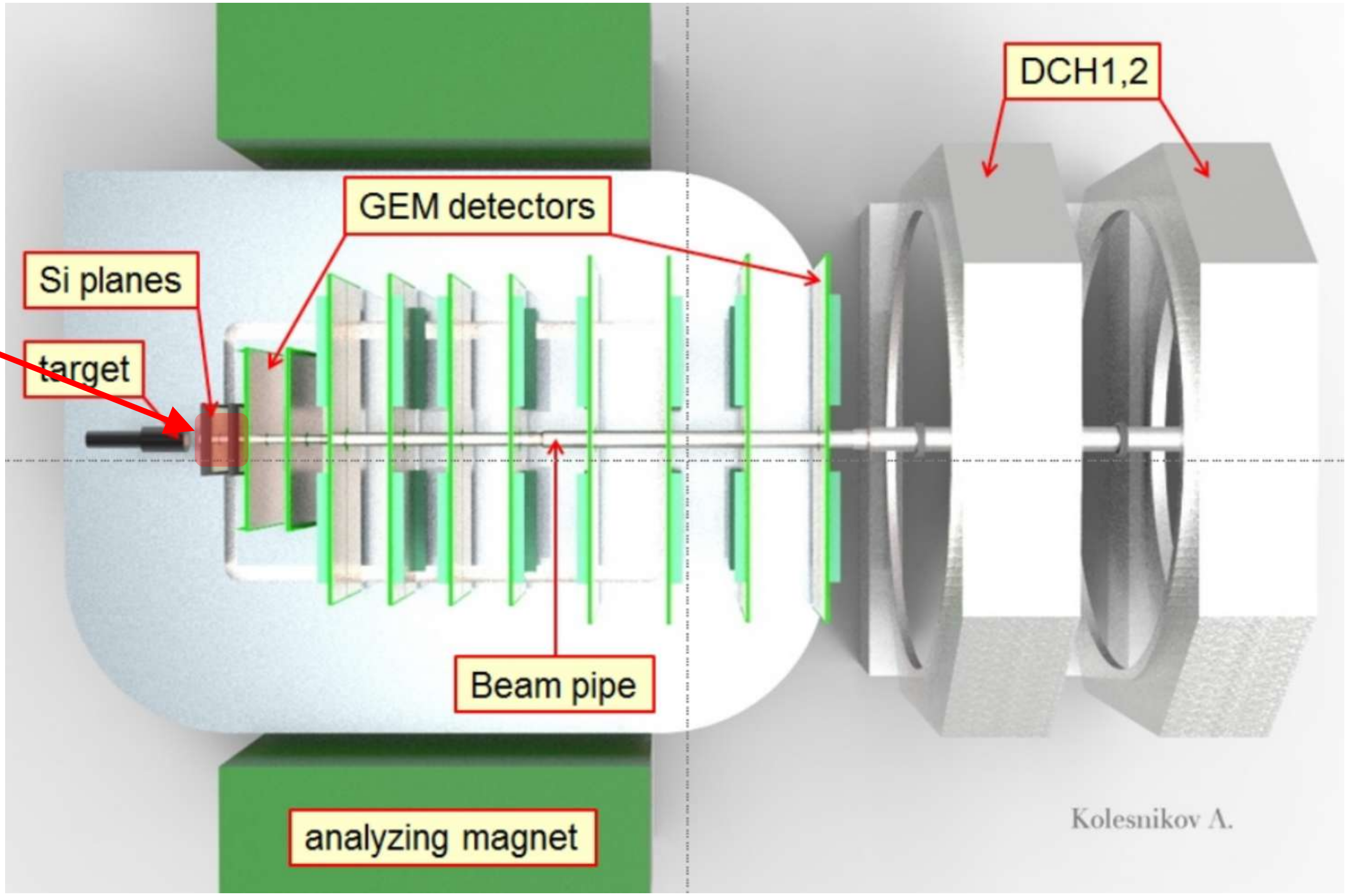
[1]W. Adam et al., "Performance studies of the CMS Strip Tracker before installation," JINST, vol. 4, p. P06009, 2009.

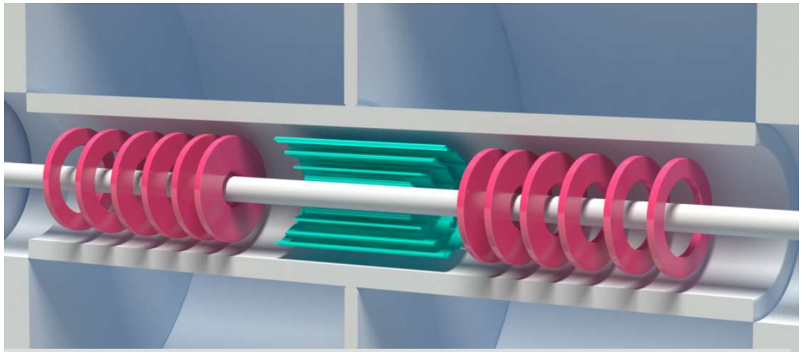
Baryonic Matter at Nuclotron (BM@N)



Barrel Detector (BD)

* 40 plastic scintillator strips (BD418)
150 × 7 × 7 mm³
* SiPM: SensL Micro FC-60035-SMT (active area 6 × 6 mm2)





ø<54cm

IT Tracker

-2 < η < 2

-55 < z < 55 cm

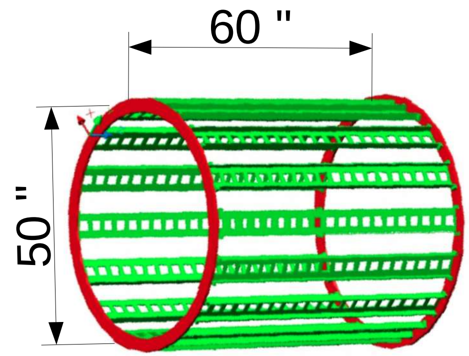
Gem Tracker

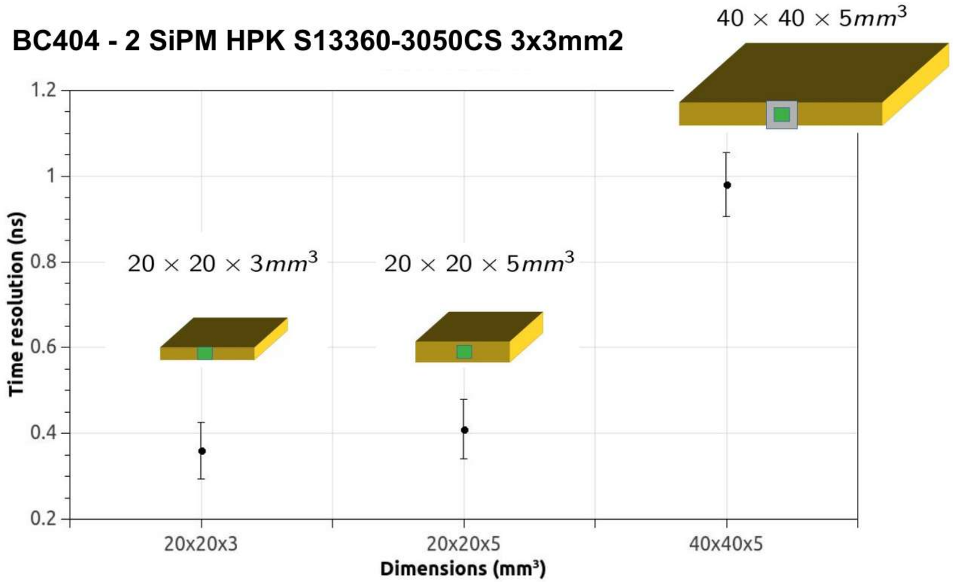
-125 < z < 125 cm

Barrel detector for MPD

16 strips with 20 plastic scintillators (BC400)

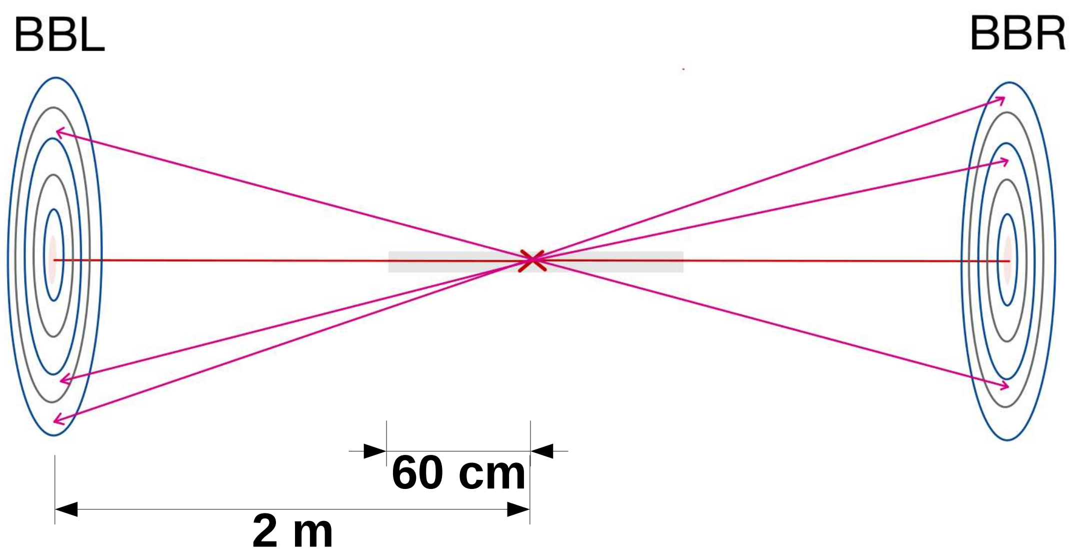
Requirement $\sigma_t < 30$ ps ($\sigma_z \sim 1$cm)



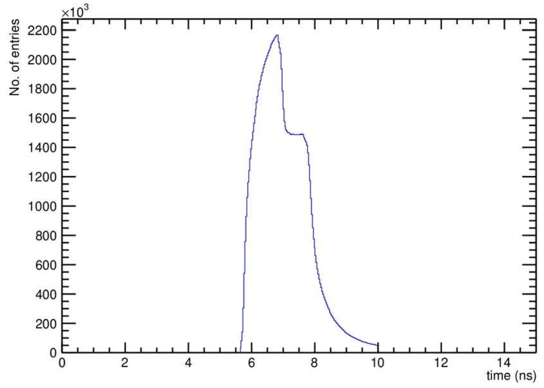


Measured σ_t is one order of magnitud higher

BeBe: Trigger capabilities



Smearing of 60cm is considered



We defined a time window of
$\Delta\tau = 7 \pm 3$ ns
to the time of flight distribution

Trigger flags

- **BBL/R:** if the Z coordinate of the BeBe hit is positive/negative and the time of flight of the first BeBe hit is within the time window defined by $\Delta\tau$.
- **BBL AND BBR:** logical AND of the coincidence of BBL and BBR.
- **BBL OR BBR:** logical OR of BBL and BBR.

Trigger efficiencies of BeBe

For **p+p collisions the trigger efficiency** given either by **BBR or BBL** is of the order of **58% if a vertex smearing is assumed** (with) in the simulation. Our results suggest that both trigger efficiencies **increase** up to **73% when no smearing** on the vertex simulation is considered.

The **BBR OR BBL** trigger efficiency is **95.6% for p+p collisions at $\sqrt{s}$=9GeV.**

The estimation of the trigger efficiencies of BeBe detector seems to be independent of the Monte Carlo generator used.

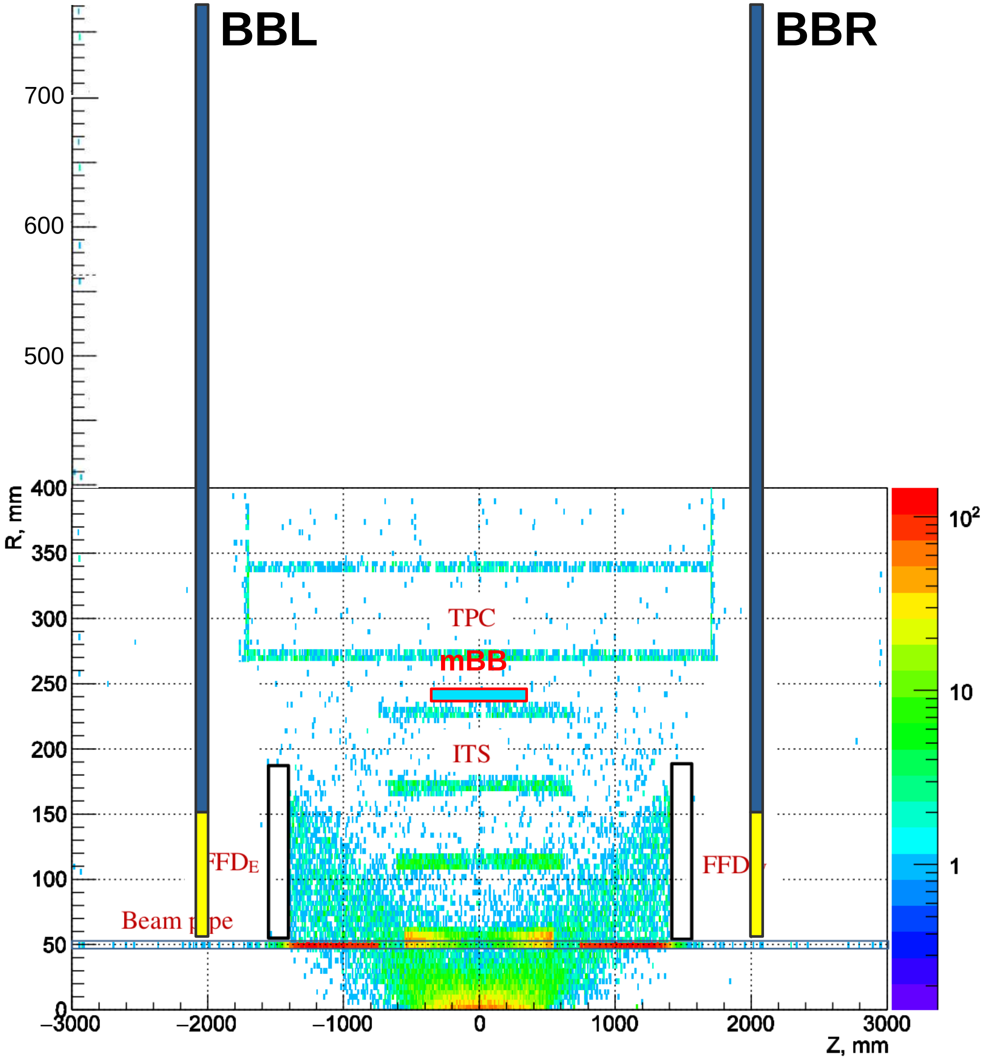
UrQMD: p+p @ $\sqrt{s}$ 9GeV y 11GeV
Impact parameter b∈[0-15.9] fm.
Au+Au @ $\sqrt{s_{NN}}$=11GeV

Process	BBR	BBL	BBRandBBL	BBRorBBL	Vertex smearing
p+p, 9 GeV	58.063%	57.86%	20.26%	95.66%	Yes
p+p, 9 GeV	72.85%	72.79%	50.12%	95.52%	No
p+p, 11 GeV	59.84%	59.87%	23.41%	95.52%	Yes
p+p, 11 GeV	74.31%	74.42%	52.7%	96.03%	No
Bi+Bi, 9 GeV	94.07%	94.07%	89.88%	98.26%	Yes
Bi+Bi, 9 GeV	100%	100%	100%	100%	No
Au+Au, 11 GeV	100%	100%	100%	100%	Yes
Au+Au, 11 GeV	100%	100%	100%	100%	No

LAQGSM, Au+Au @ √sNN=11.5GeV

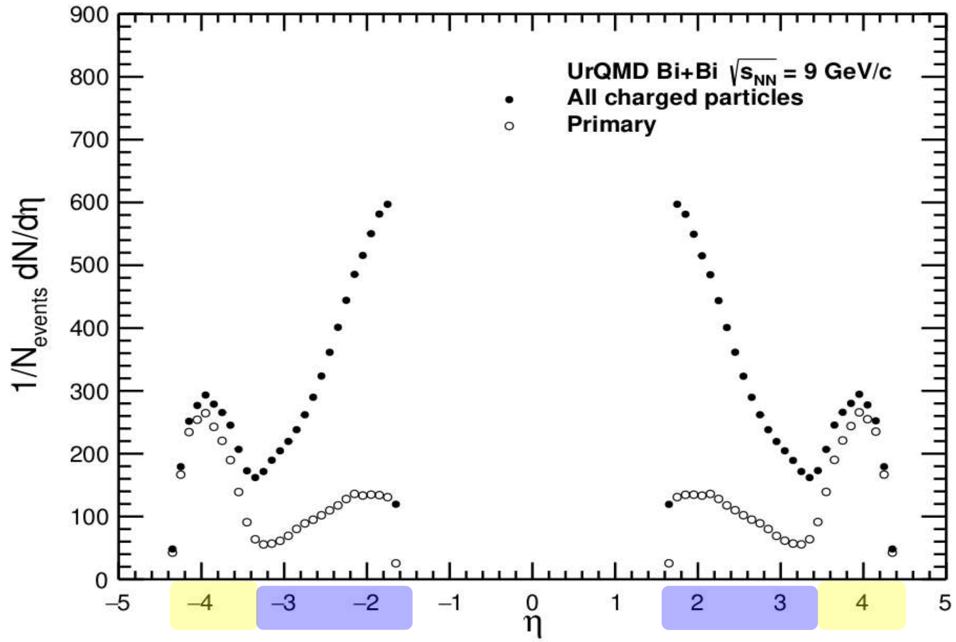
Process	BBR	BBL	BBRandBBL	BBRorBBL
AuAu@11.5GeV	97.7%	97.6%	95.4%	99.9%

BeBe rings configurations for centrality measurements



Au + Au @ √sNN = 11 GeV.

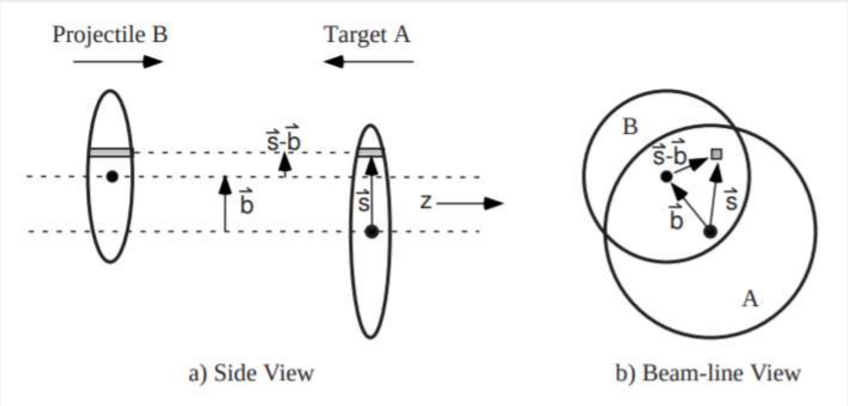
Adapted from TDR FFD (2019):
http://mpd.jinr.ru/wp-content/uploads/2019/09/FFD-TDR-Aug-2019.pdf



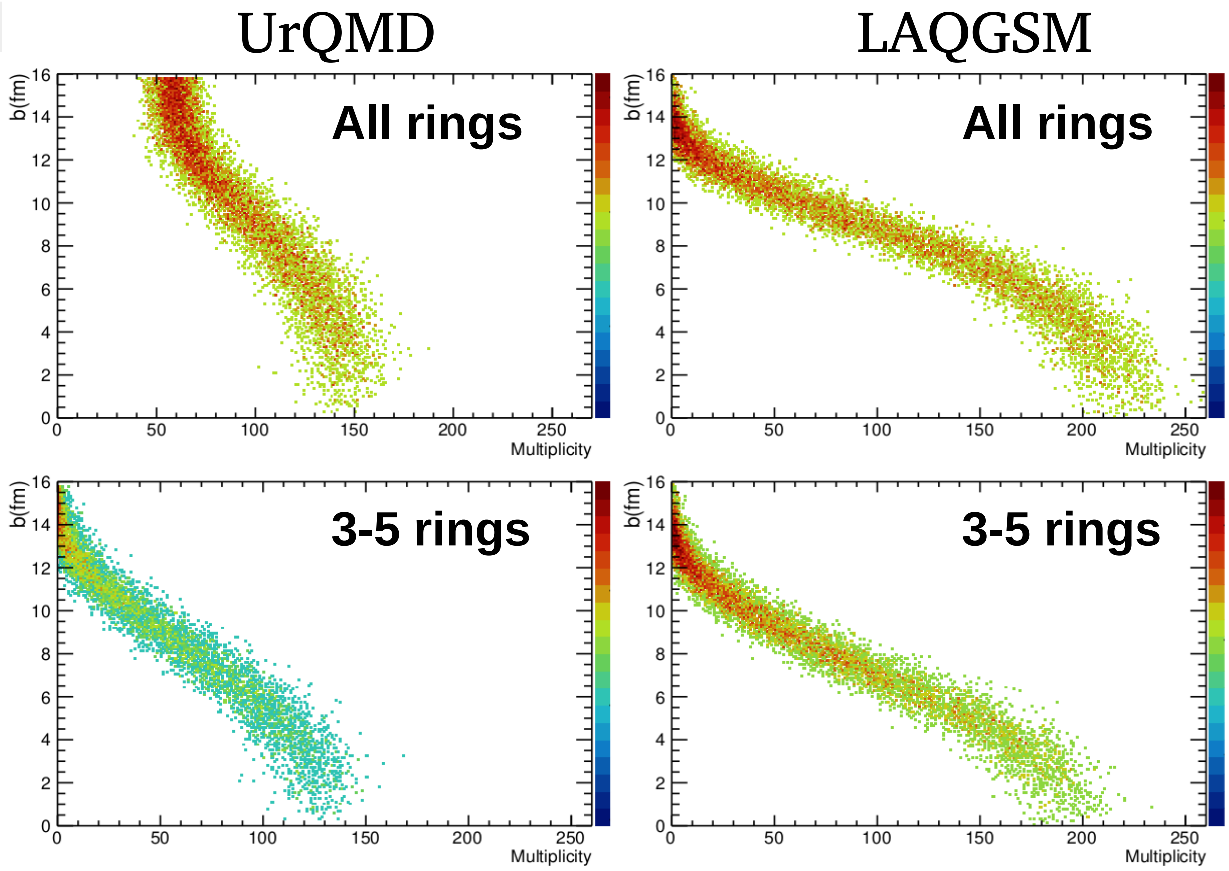
Ring	η	R_{min}	R_{max}
1	3.87 - 4.36	5.1	8.3
2	3.31 - 3.87	8.5	14.5
3	2.84 - 3.31	14.7	23.4
4	2.26 - 2.84	23.6	42
5	1.68 - 2.26	42.2	76.63

We studied several BeBe rings configurations

Centrality resolution of BeBe



Centrality is a key variable for characterizing the geometric properties of the heavy-ion collisions. We correlated **the impact parameter with the hit multiplicity in BeBe** and looked for the best curve behavior, a linear correlation.



The largest hit multiplicity is found in the two most inner BeBe rings. With the proposed geometry for BeBe detector, we observe that it is **not a good option** to employ all the five rings of BeBe detector, **UrQMD prediction.** This behavior is in **contrast** with the prediction given by **LAQGSM model where the BeBe hits distribution exhibits a nice curve that can be adjusted by a Glauber-like function**. For **UrQMD**, this situation **improves if we only take into account the hit multiplicity of the three outer rings of BeBe.**

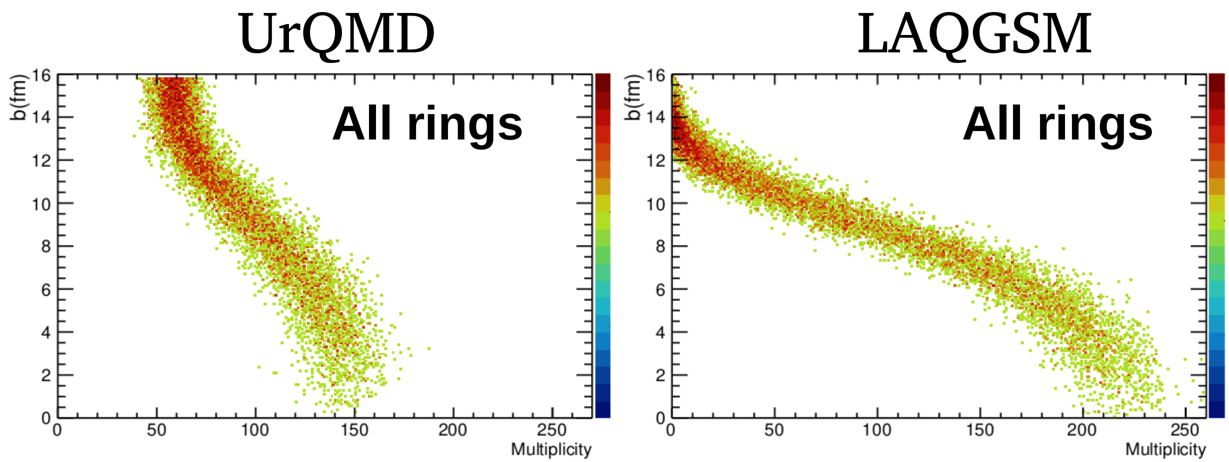
Centrality resolution of BeBe

To **compute the centrality resolution** we computed the difference between the centrality given by the number of hits in the BeBe detector (*cent BeBe*) with respect to the generated centrality (*centMC*):

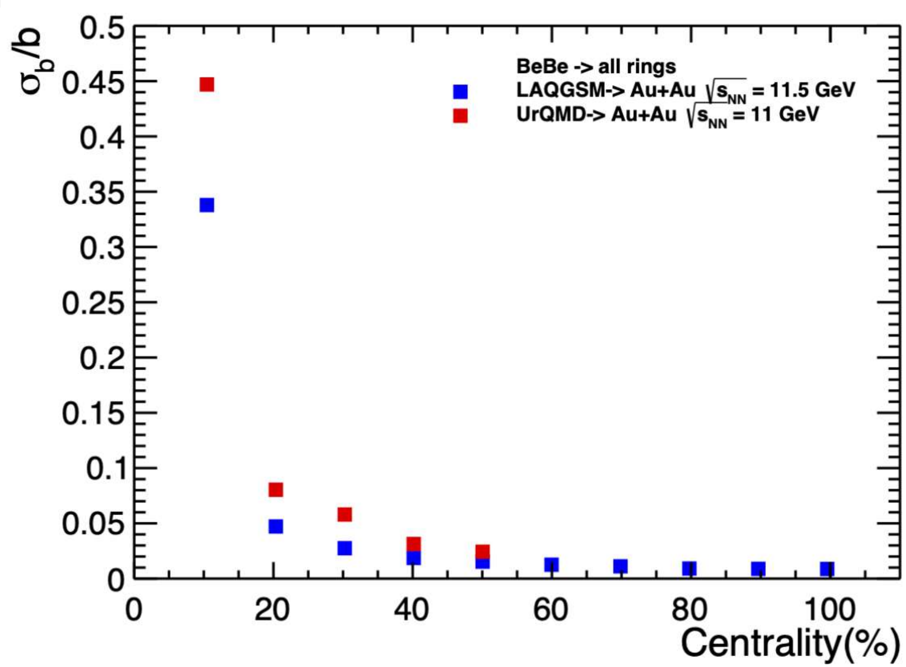
$$cent = cent_{MC} - cent_{BeBe}$$

The width of a Gaussian fit of *cent* distribution will give us the centrality resolution with respect to the centrality of the collision.

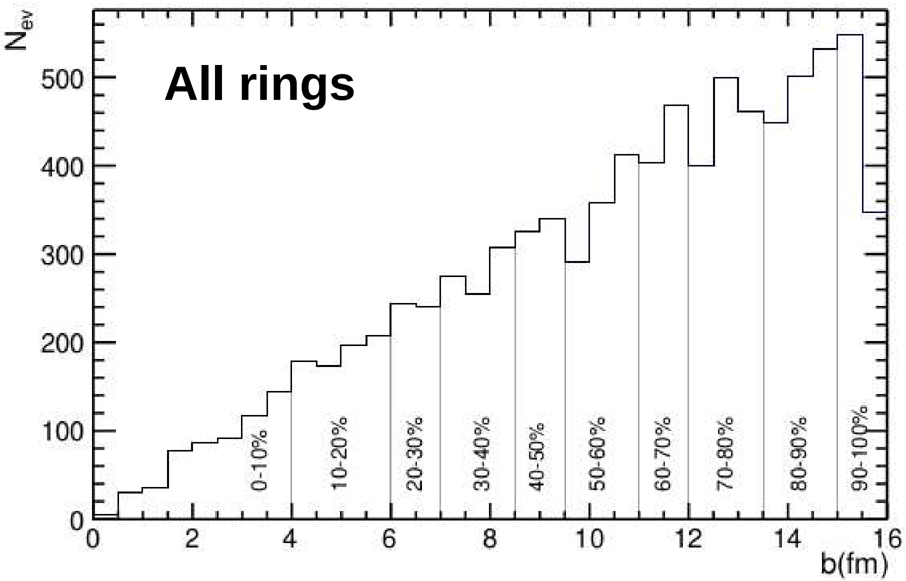
The centrality determination given by BeBe detector **is fully complementary** to the one that can be reached with the **FHCAL especially for central collisions** where the FHCAL detector may lose resolution.

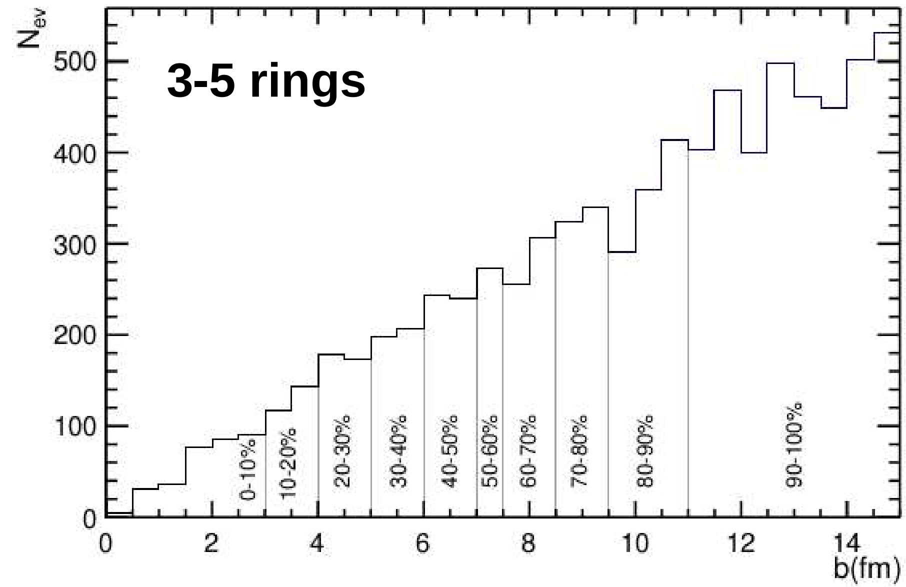


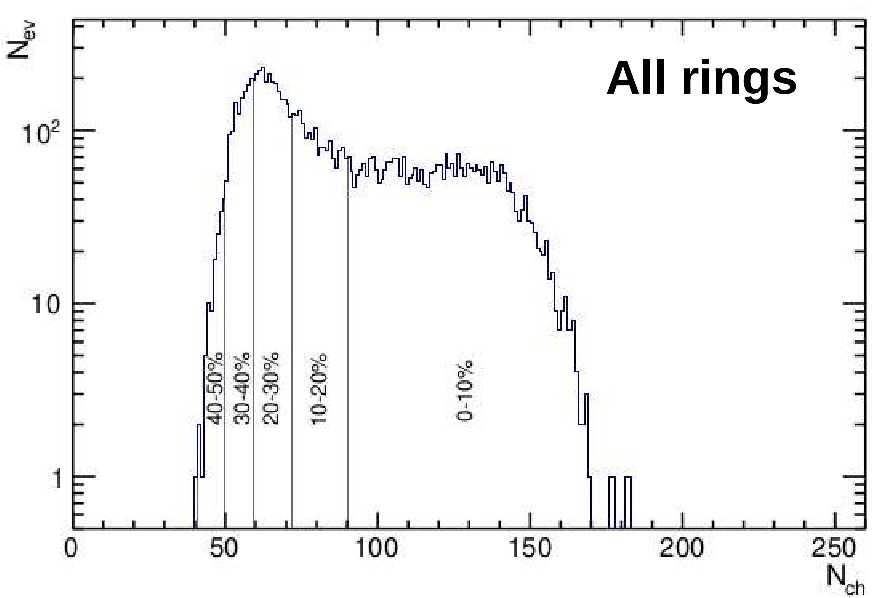
Using the hit multiplicity of **all the BeBe** detector rings, **UrQMD (LAQGSM)** predicts a **centrality resolution** of **45% (34%) for central collision.**

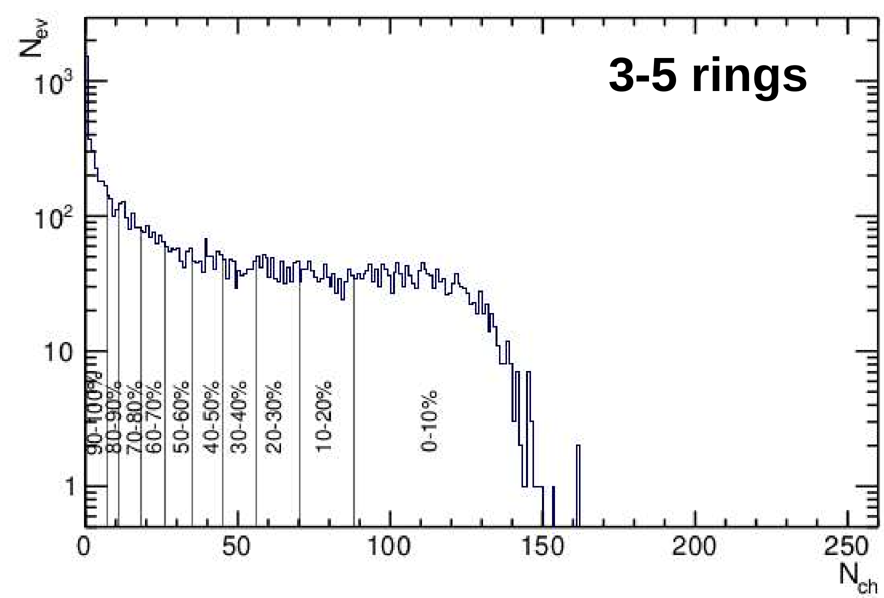


Centrality classes, impact parameter ranges (top), and the number of hits (bottom) Au+Au at 11 GeV with UrQMD

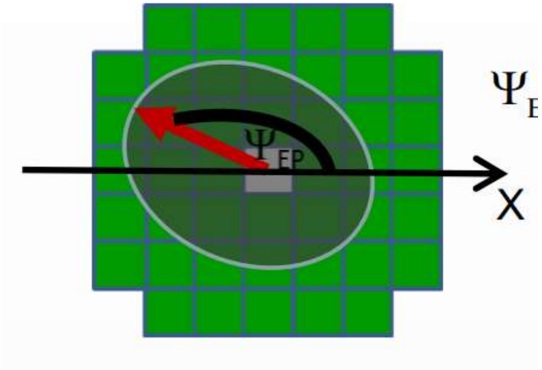


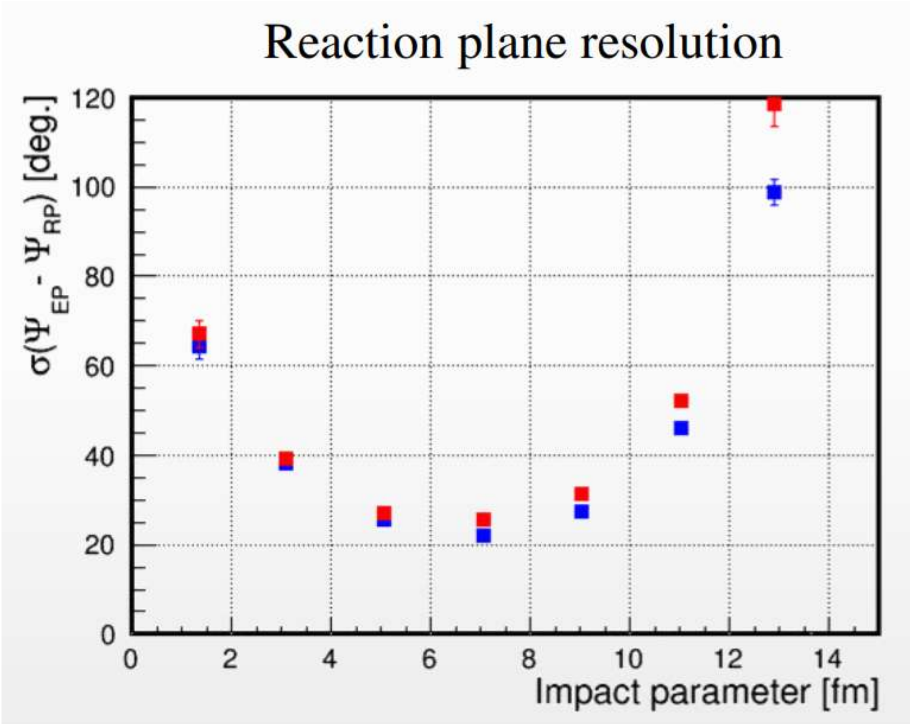






Reaction plane measurements by FHCAL(L) and BeBe(R)



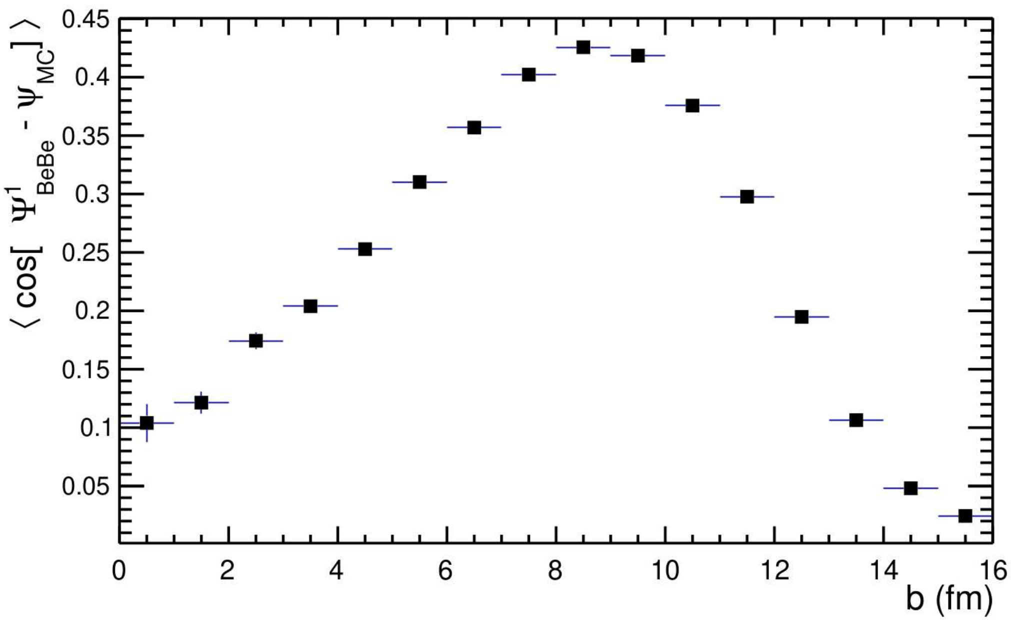


V. Riabov, MPD Status, April 2022

10^6 Bi+Bi collision events at $\sqrt{s_{NN}}$=9 GeV
The **multiplicity per cell,** wi , was estimated at hit-level and the **event plane resolution with the BeBe** detector for n = 1 as:

$$\Psi_n^{BB} = \frac{1}{n} \tan^{-1}\left[\sum_{i=1}^{m} w_i \sin(n\varphi_i) \Big/ \sum_{i=1}^{m} w_i \cos(n\varphi_i)\right]$$

$$\left\langle \cos\left(n \times (\Psi_n^{BB} - \Psi_n^{MC})\right)\right\rangle,$$



Multiplicity in the inner region for VO-like detectors

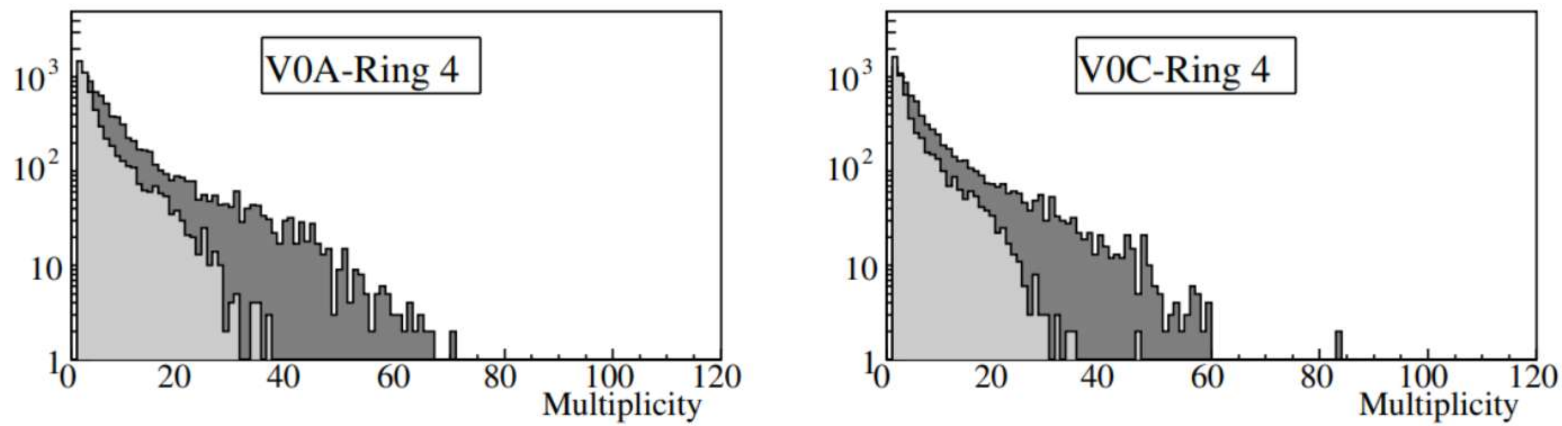
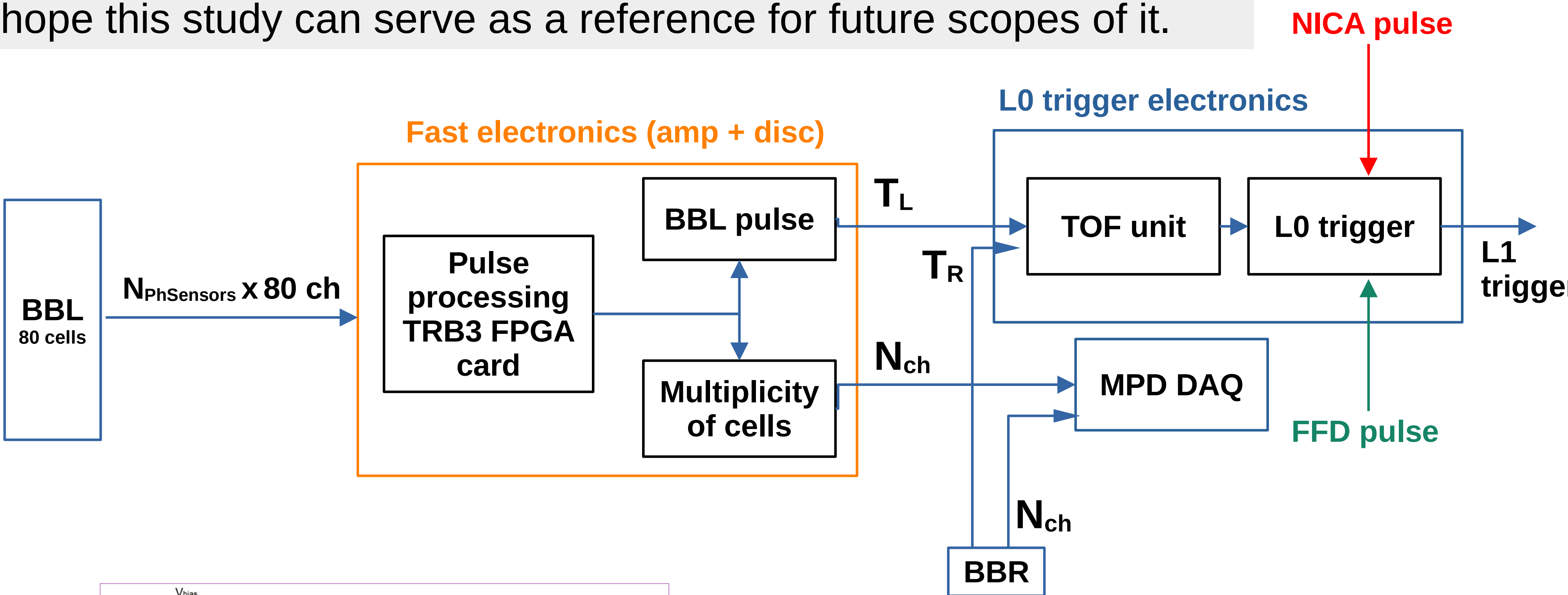


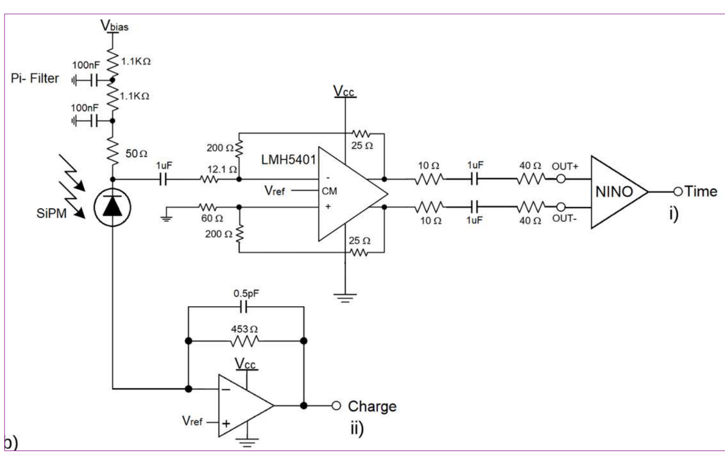
Figure 3.4: Charged-particle multiplicity distributions in pp reaction through each ring of the V0A and V0C arrays as given by 7820 PYTHIA inelastic events after transport of particles in vacuum (light grey) and in the ALICE environment (dark grey).

https://cds.cern.ch/record/781854/files/lhcc-2004-025.pdf

Conception of the BeBe readout electronics

The development of the proposed data acquisition system for BeBe detector is a work in progress to be reported elsewhere. We hope this study can serve as a reference for future scopes of it.





- Improve of the read out electronics is planed
- The dedicated calibration system with a pulsed laser (ps) is an important part of the structure.