BeBe detector for luminosity measurements

Mario Rodríguez Cahuantzi
Benemérita Universidad Autónoma de Puebla, México
6th. Collaboration meeting of the MPD Experiment at NICA Facility

28.10.2020

Previous presentations

- ☑ **First contact between MexNICA and MPD** (December 2016)
- ☑ **Forward detector** (1st MPD Collaboration meeting, April 12th 2018): https://indico.jinr.ru/event/385/contributions/3179/
- ☑ **Status of the proposal for a Beam-Beam counter detector for MPD** (2nd MPD Collaboration meeting, Oct. 30th 2018): https://indico.jinr.ru/event/610/contributions/5218/
- ☑ **Status of the proposal for a beam-beam monitoring system for the MPD** (4th MPD Collaboration meeting, Oct. 23rd 2019): https://indico.cern.ch/event/802303/contributions/3590175/

Also there has been another proposal, based on MCP, for a **fast beam monitoring detector** made by the group of **Grigori Feofilov** (https://doi.org/10.1016/j.nima.2019.04.108 , https://indico.cern.ch/event/802303/contributions/3590210/) Oct. 24th 2019

Motivation for a beam-beam counter detector for MPD

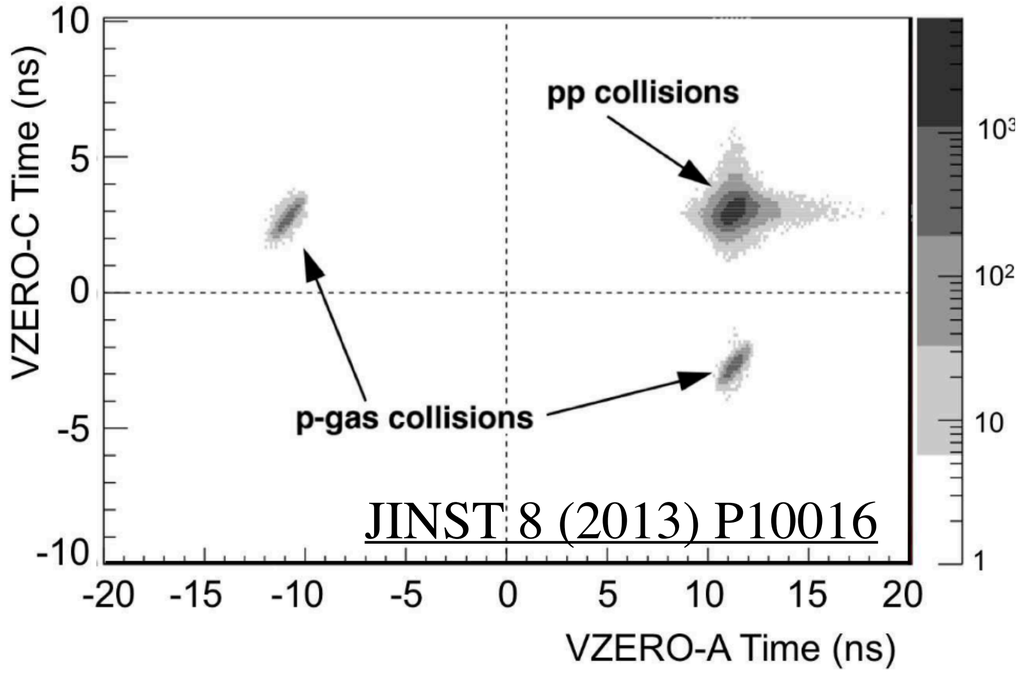
In collider experiments, a beam–beam counter detector is highly desirable.

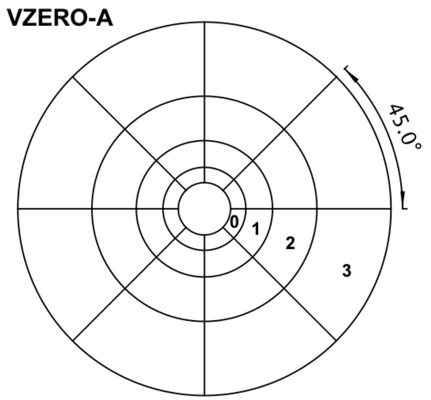
- **trigger system**: to identify and to discriminate beam–beam minimum bias or centrality events from background and beam–beam interactions.

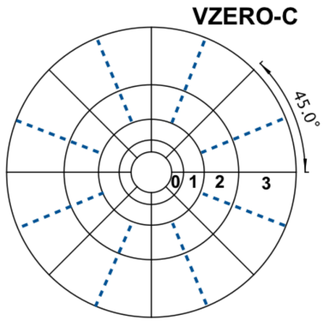
- **bonus, physics studies**:

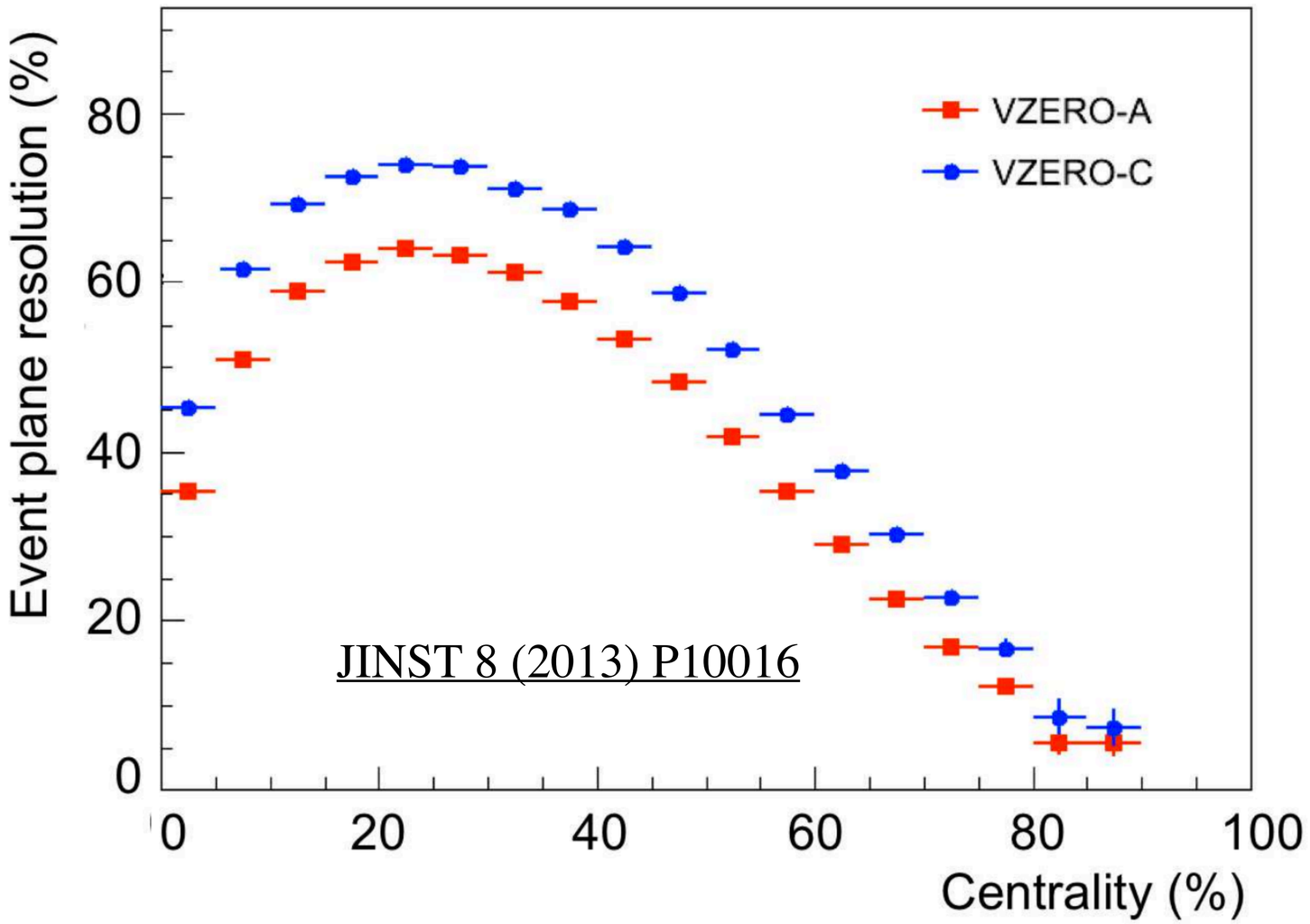
  - luminosity measurements, for the determination of absolute cross sections of reaction processes
  - multiplicity of charged particles, key observable for the determination of the centrality of the collisions events and event plane resolution

Motivation for a beam-beam counter detector for MPD



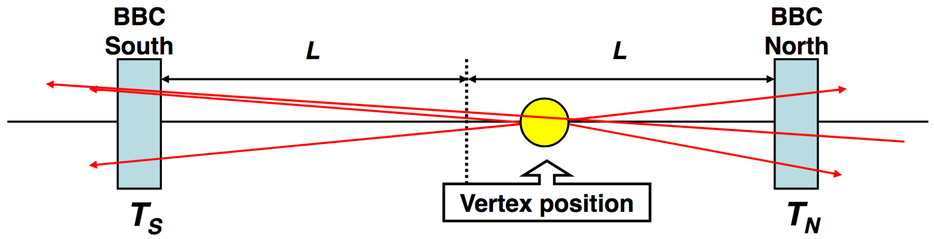






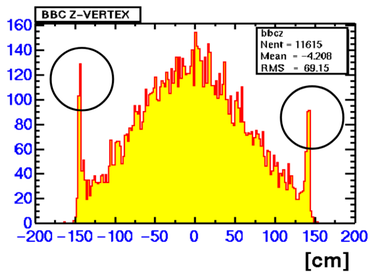
Motivation for a beam-beam counter detector for MPD

https://www.phenix.bnl.gov/WWW/intro/detectors/focus/focus_bbc.pdf

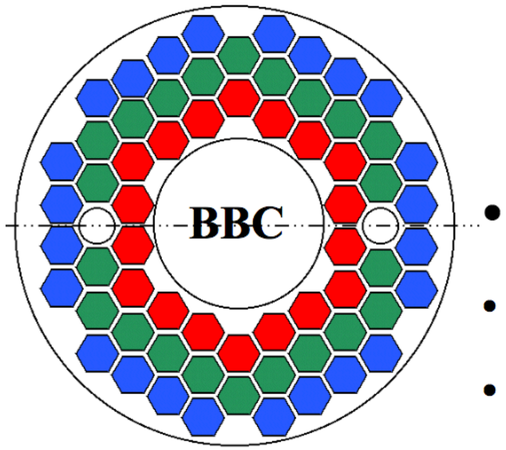


- ***Z-Vertex*** $= \dfrac{T_S - T_N}{2} \times c$

- **Time zero** $= \dfrac{T_S + T_N - 2L/c}{2}$

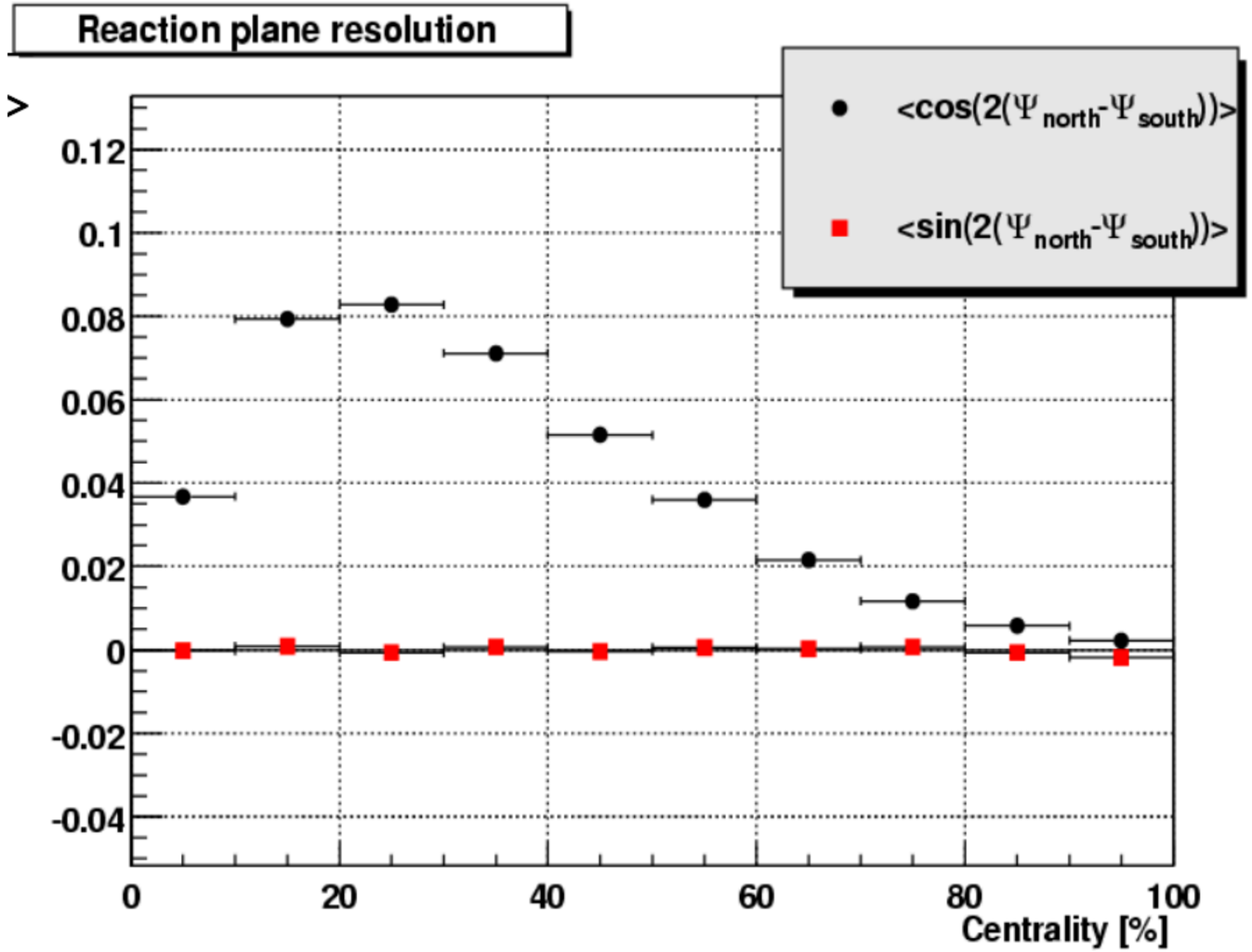


$T_{N/S}$: average hit time, c : light velocity, L : 144.35 cm

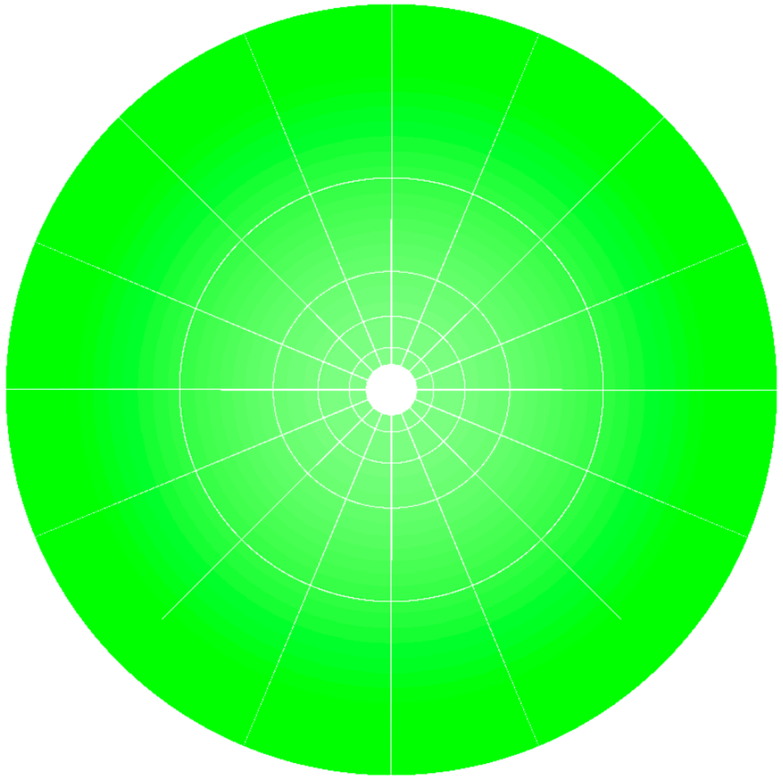


RING ID

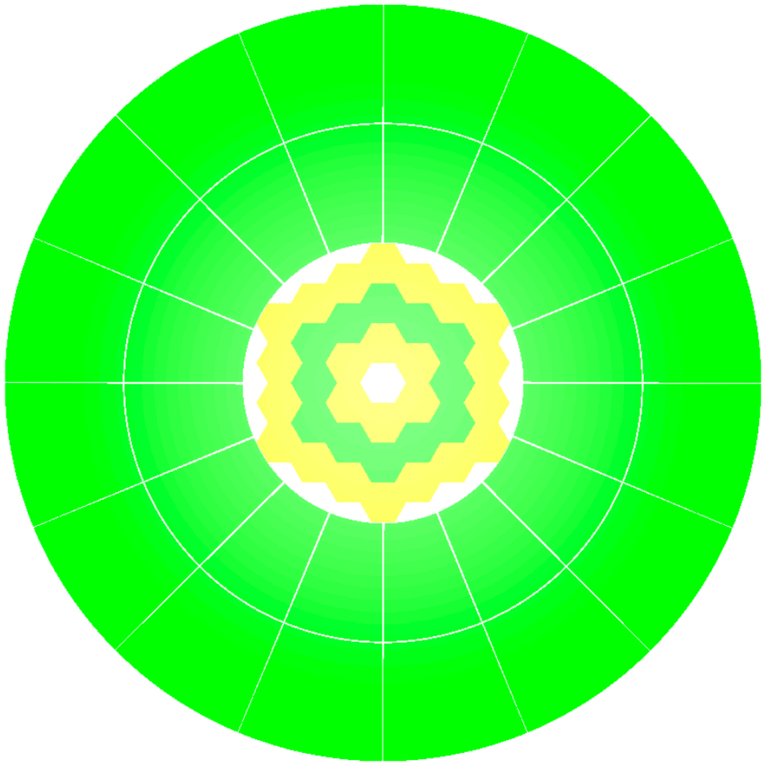
- **inner ring**
- **middle ring**
- **outer ring**



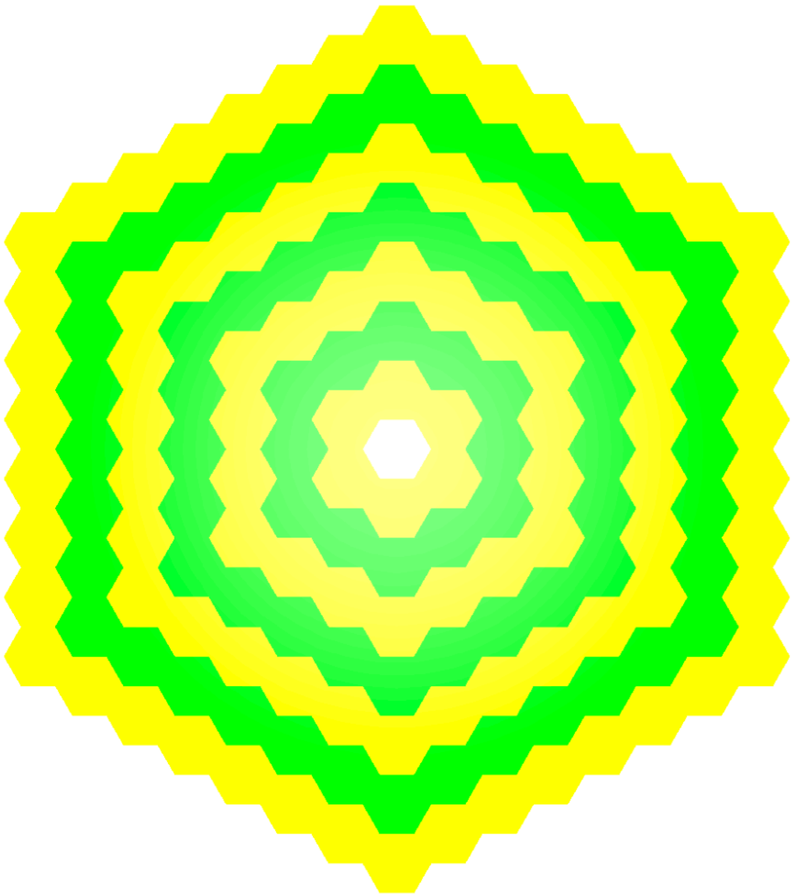
Evolution of BeBe geometry through the years (2016-Today)



2016,2020 (ALICE-LHC)



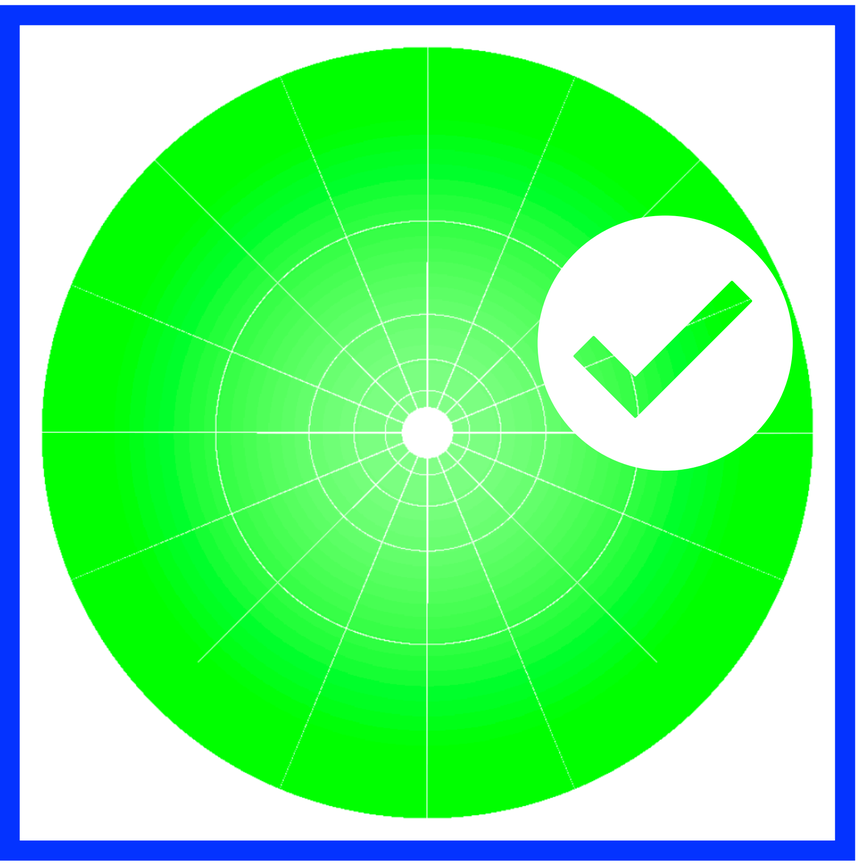
2017 (hybrid)

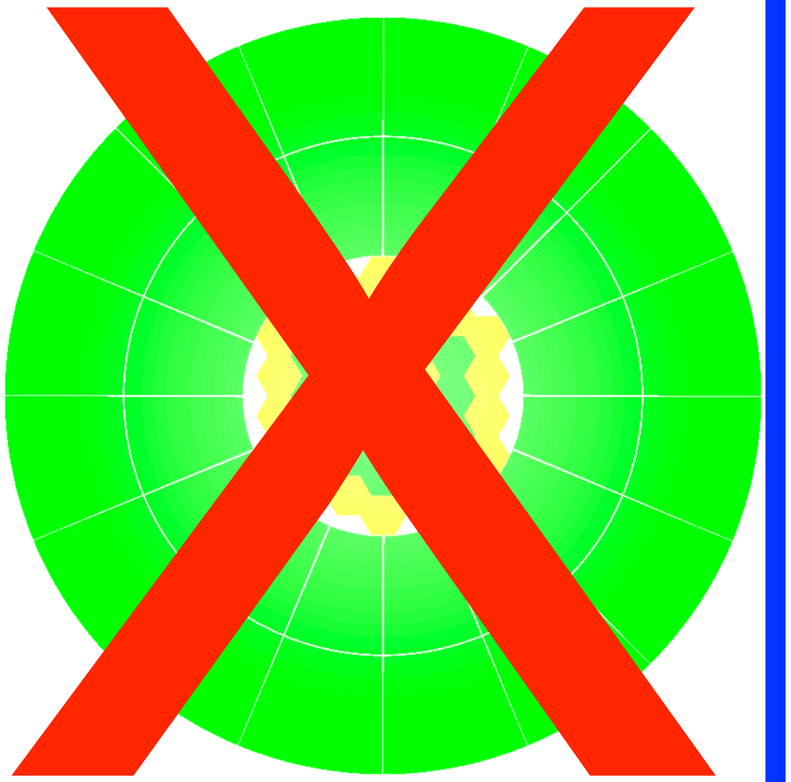


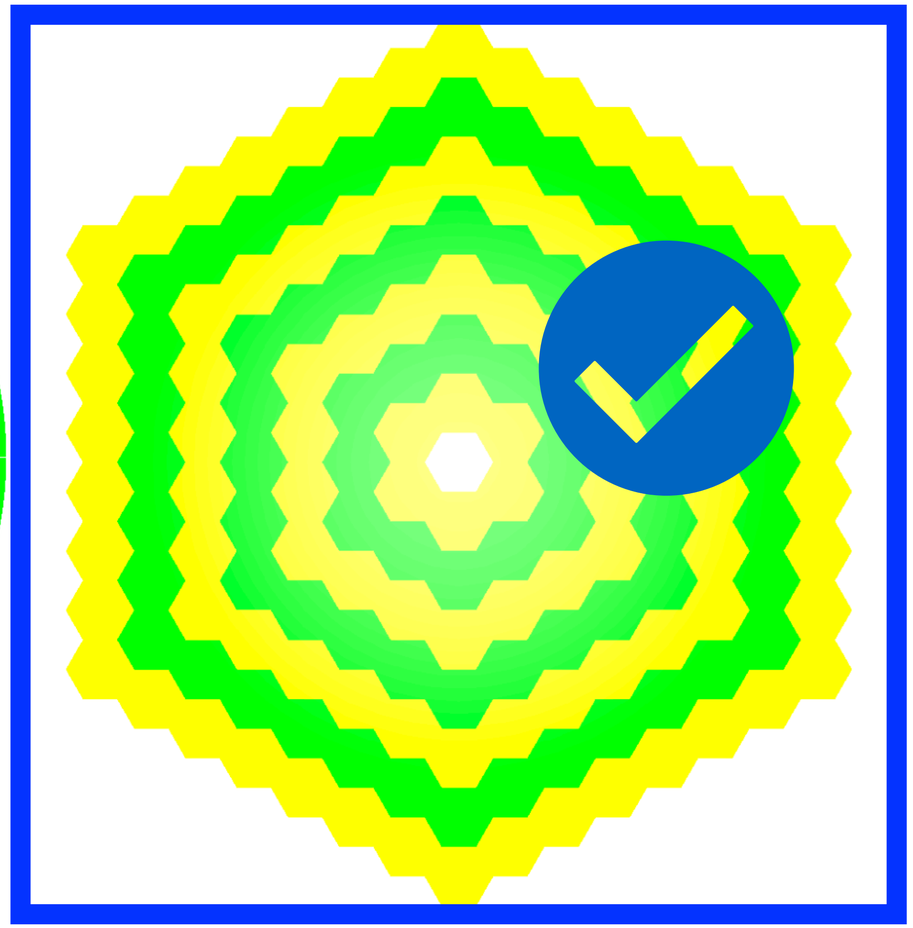
2018-2020 (RHIC)

Evolution of BeBe geometry through the years (2016-Today)

OBSOLETE







2016,2020 (ALICE-LHC)

2017 (hybrid)

2018-2020 (RHIC)

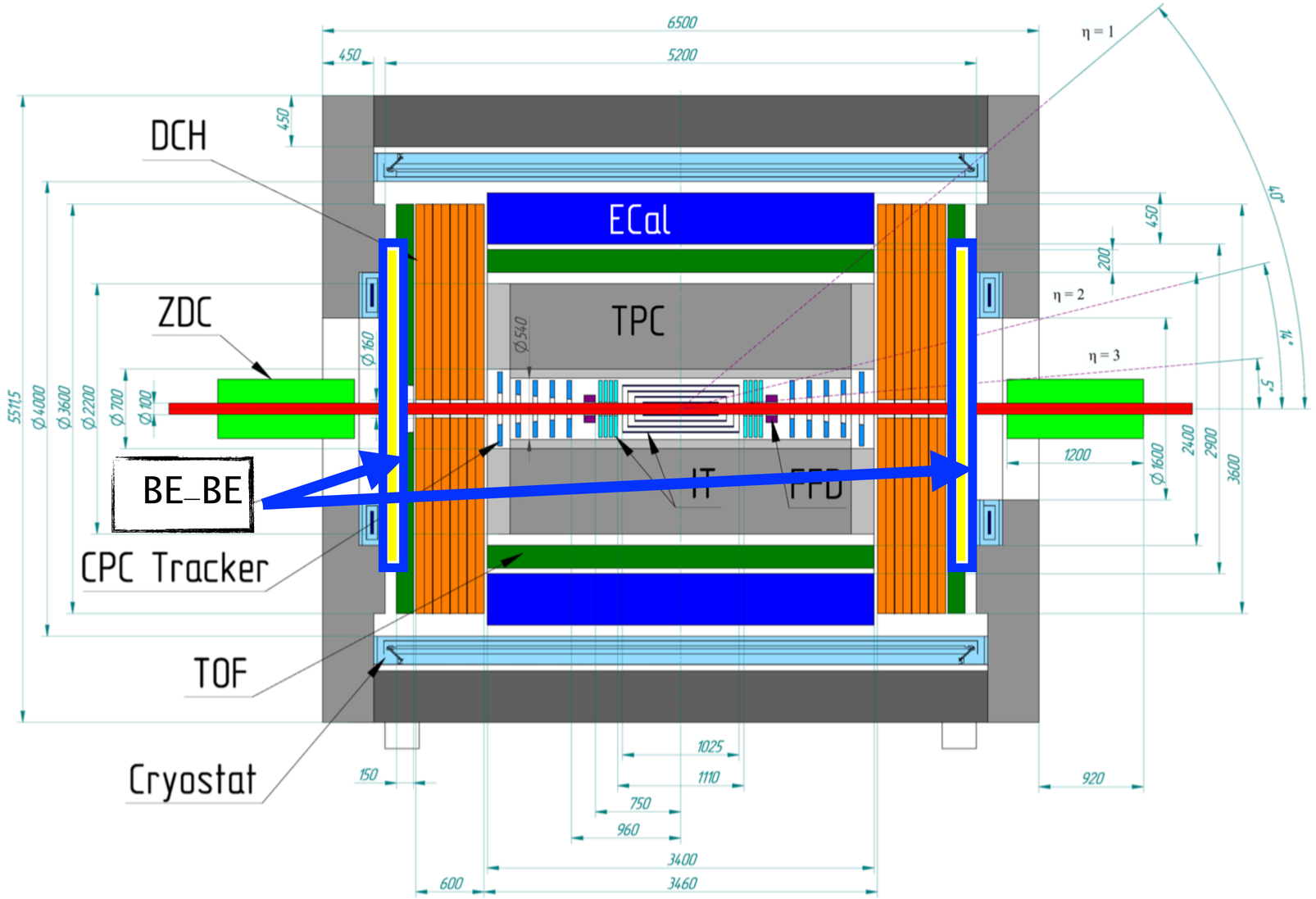
Detector concept

Geometry of BeBe detector

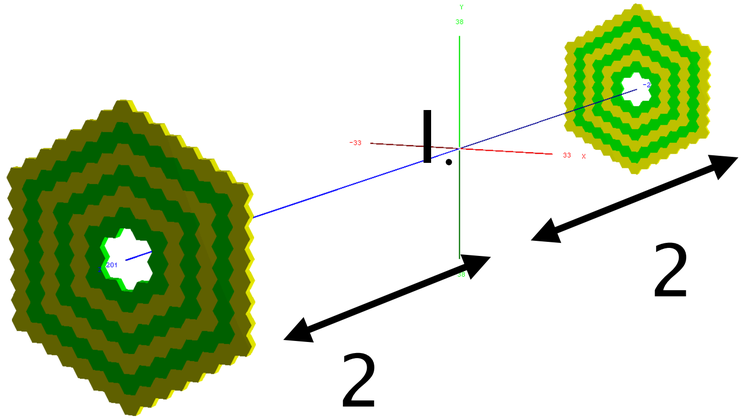
- two hodoscope detectors located, each located 2 m away from interaction point at opposite sides.

- two approaches: hexagonal cells (RHIC) OR disk cells (ALICE)

Detector concept

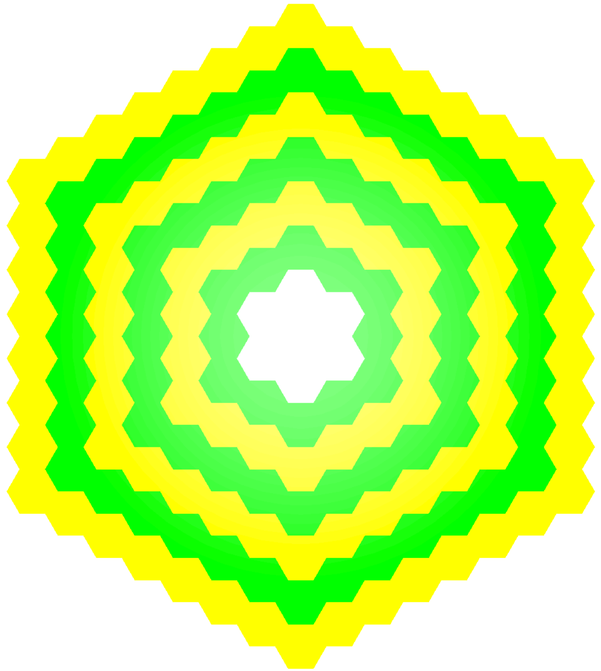


Detector concept: hexagonal cells

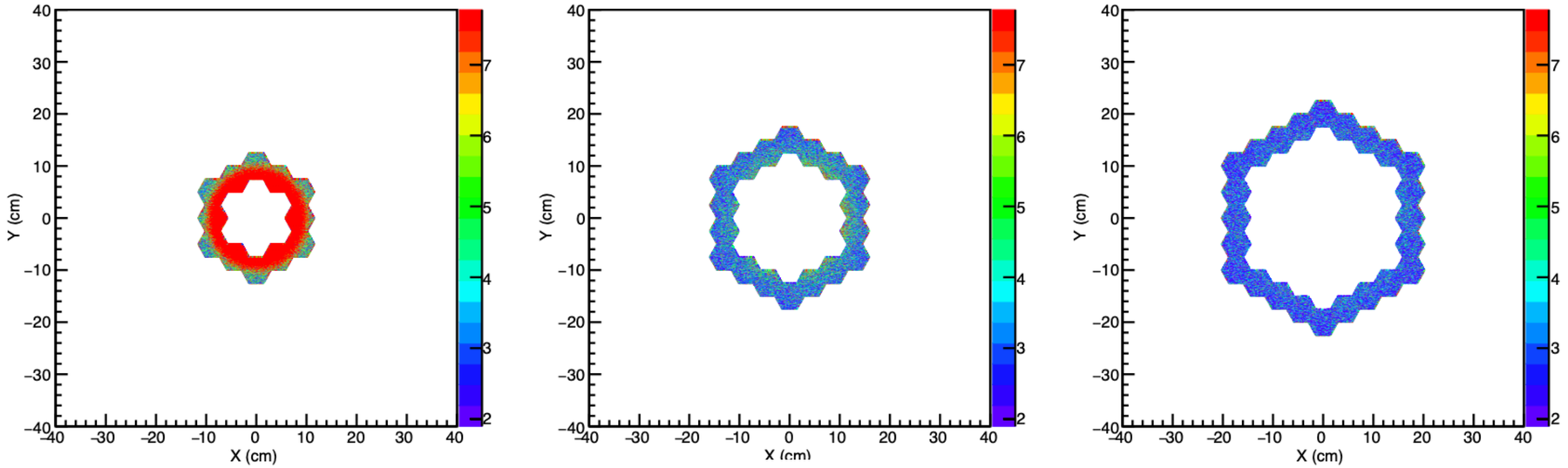


BeBe detector

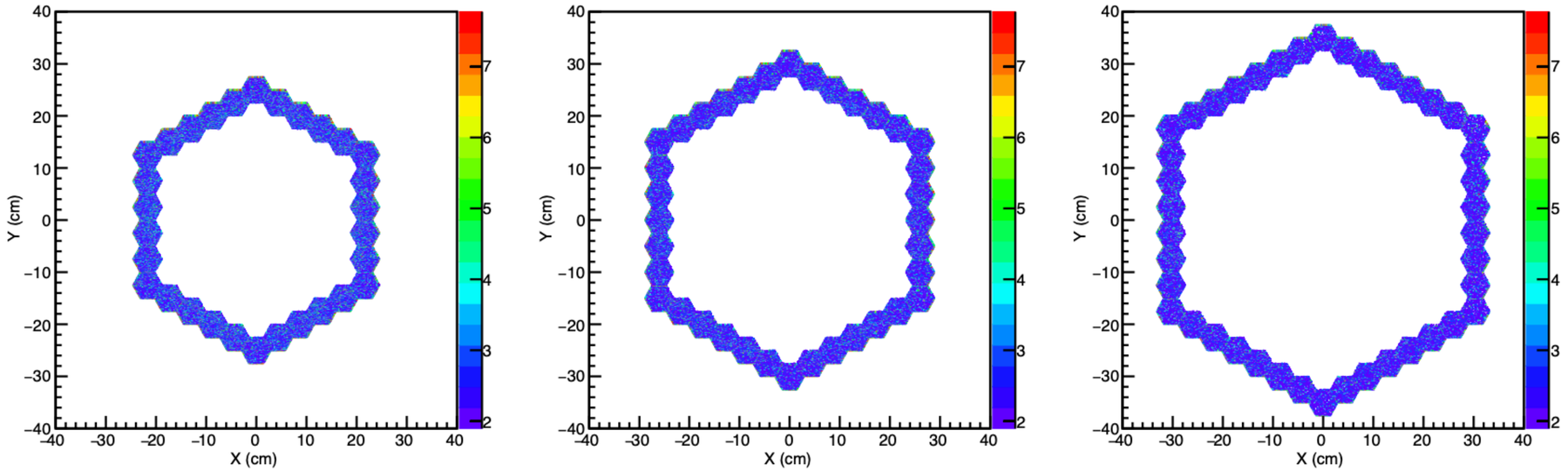
- 162 hexagonal cells (5 cm height, 1 cm width)
- six concentric “rings”
- plastic scintillator BC404
- $1.9 < |\eta| < 3.97$
- photosensors: SiPM or PMT (do be decided)



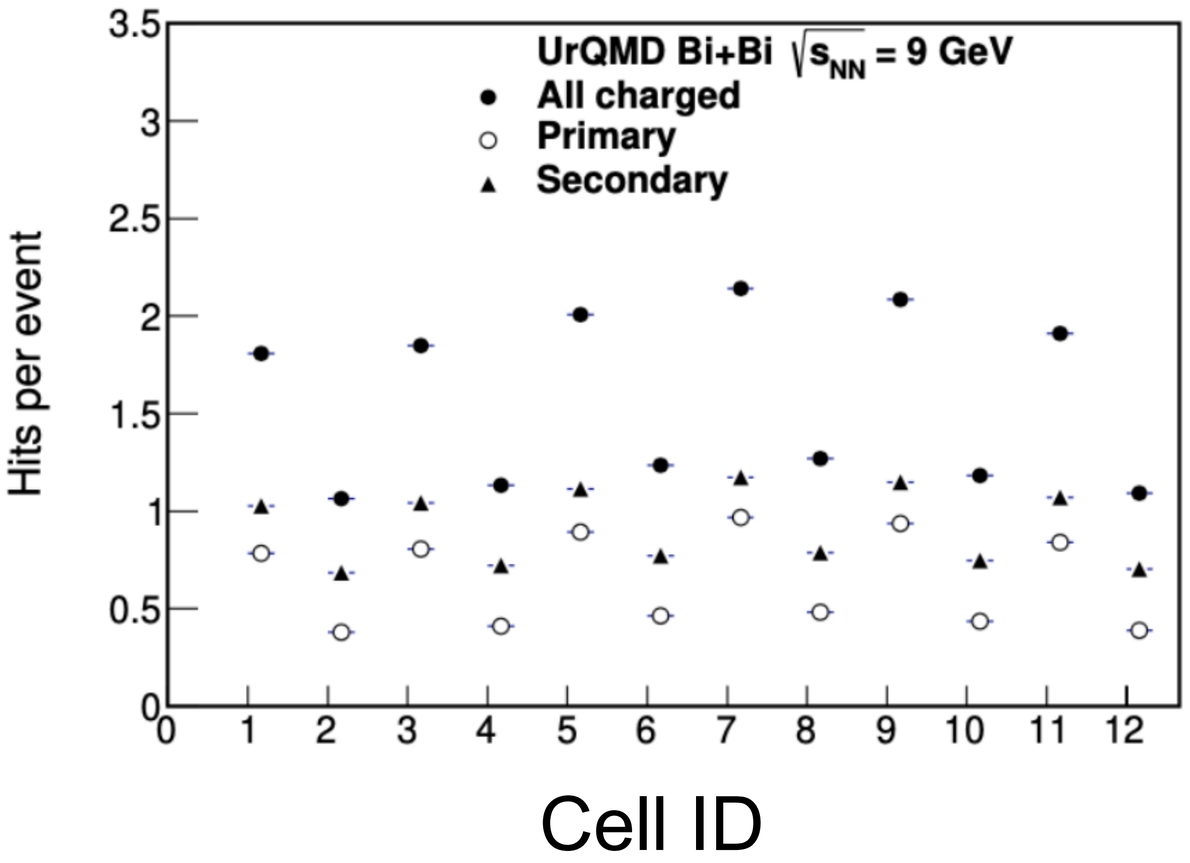
Simulation studies: hexagonal cells

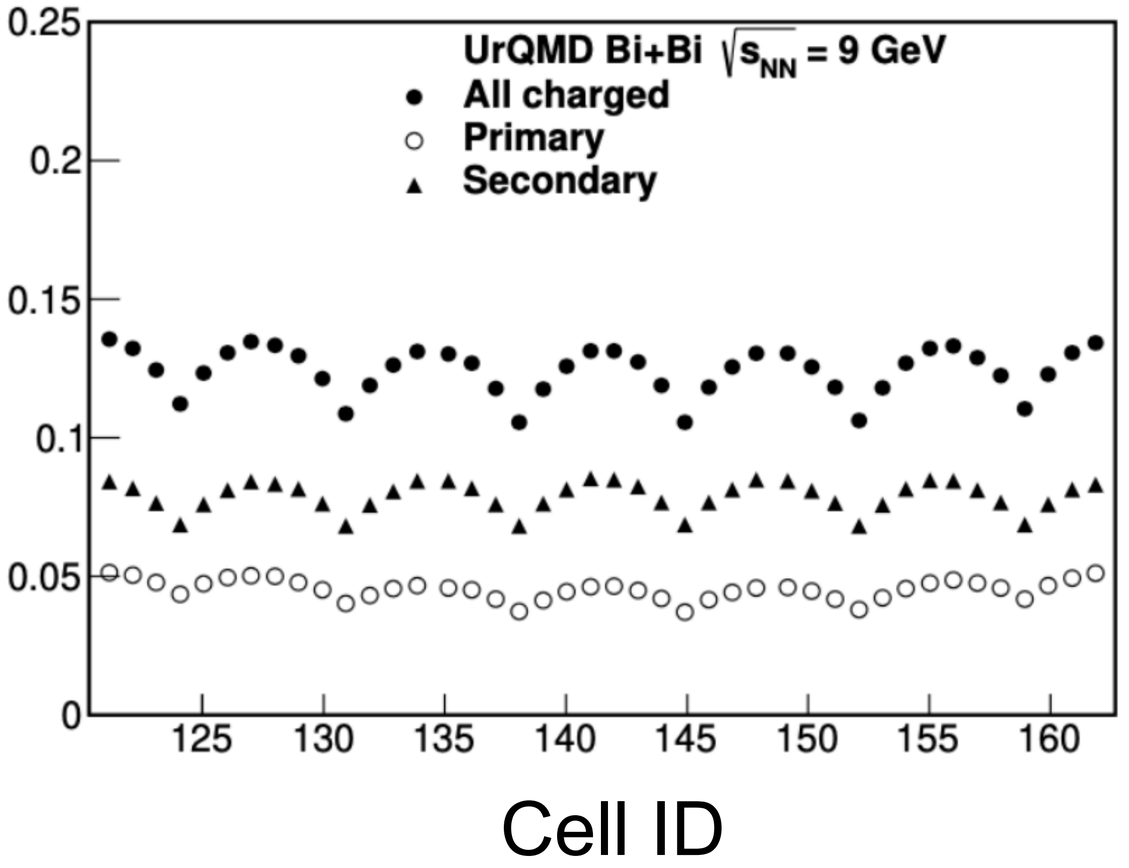


Internal Note 06-08-2020.v1 - MexNICA



Simulation studies: hexagonal cells

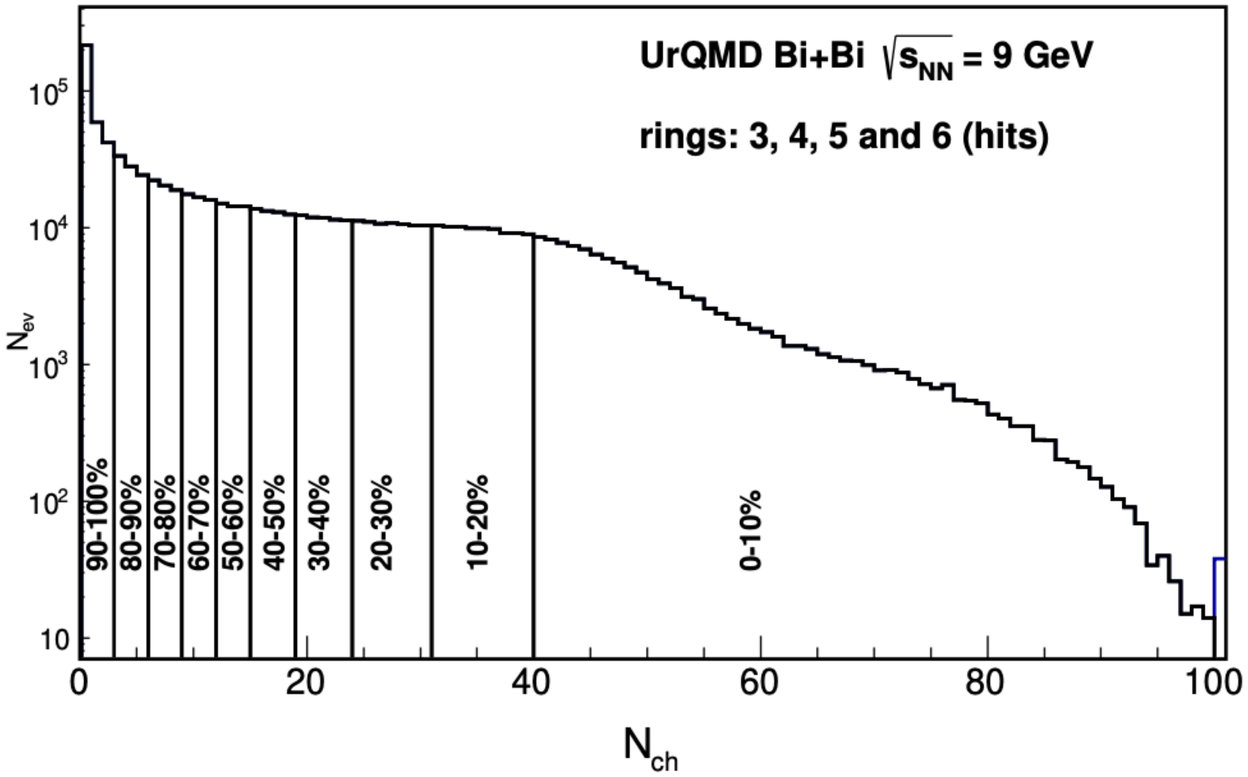


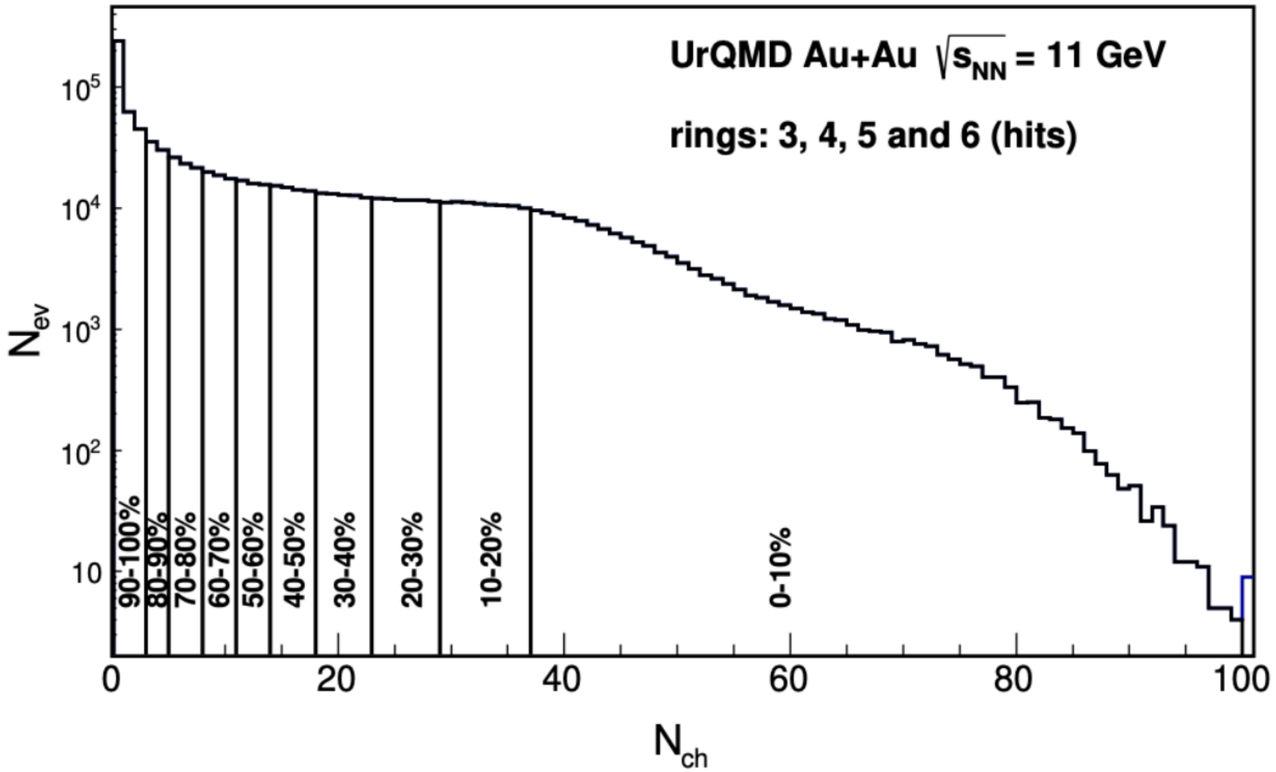


Internal Note 06-08-2020.v1 - MexNICA

Simulation studies: hexagonal cells

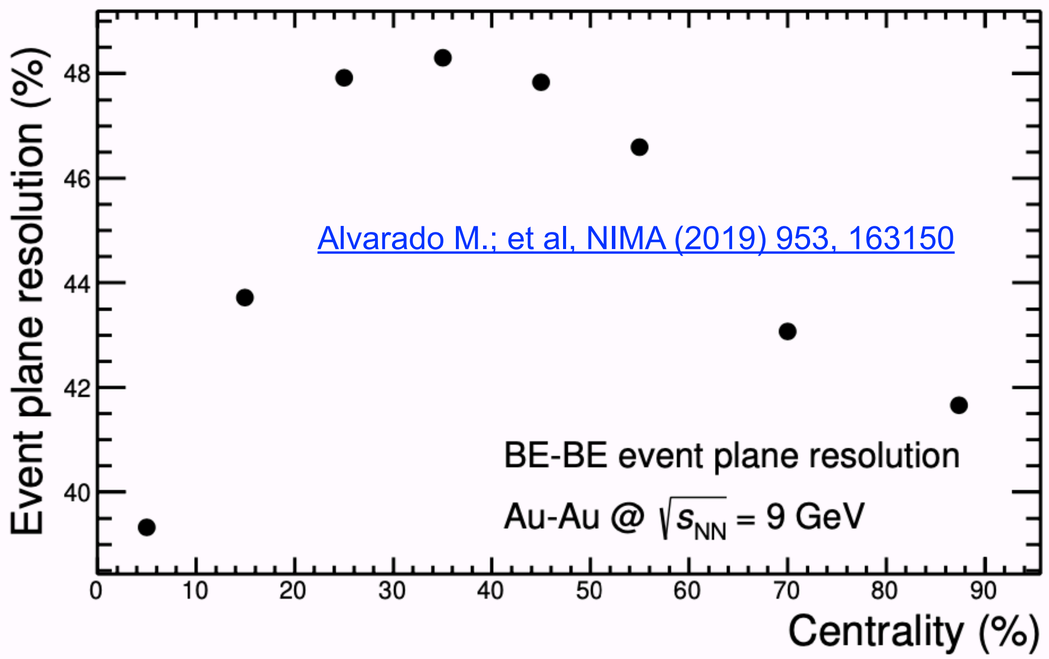
Internal Note 06-08-2020.v1 - MexNICA





With the BeBe information would be possible to construct centrality classes using rings 3, 4, 5 and 6.

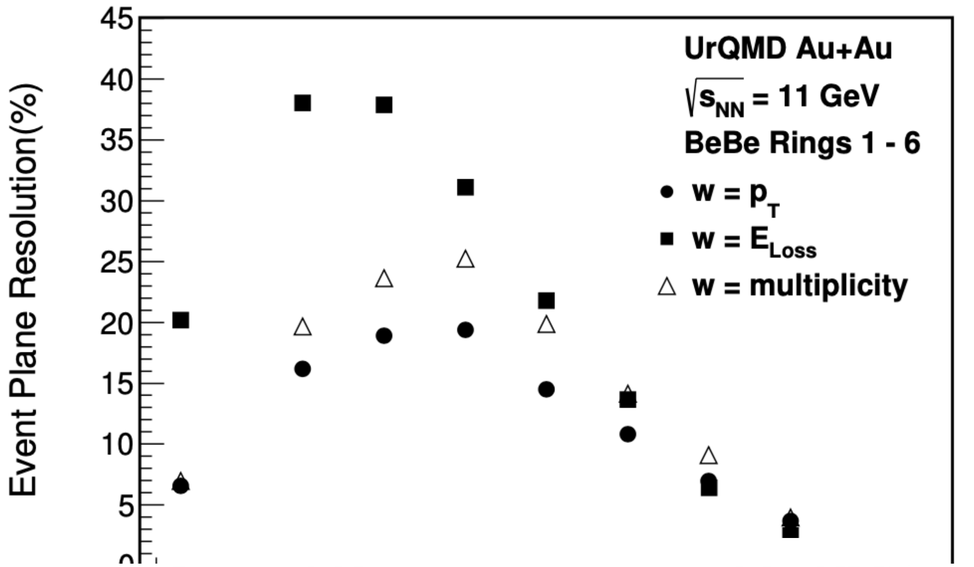
Simulation studies: hexagonal cells



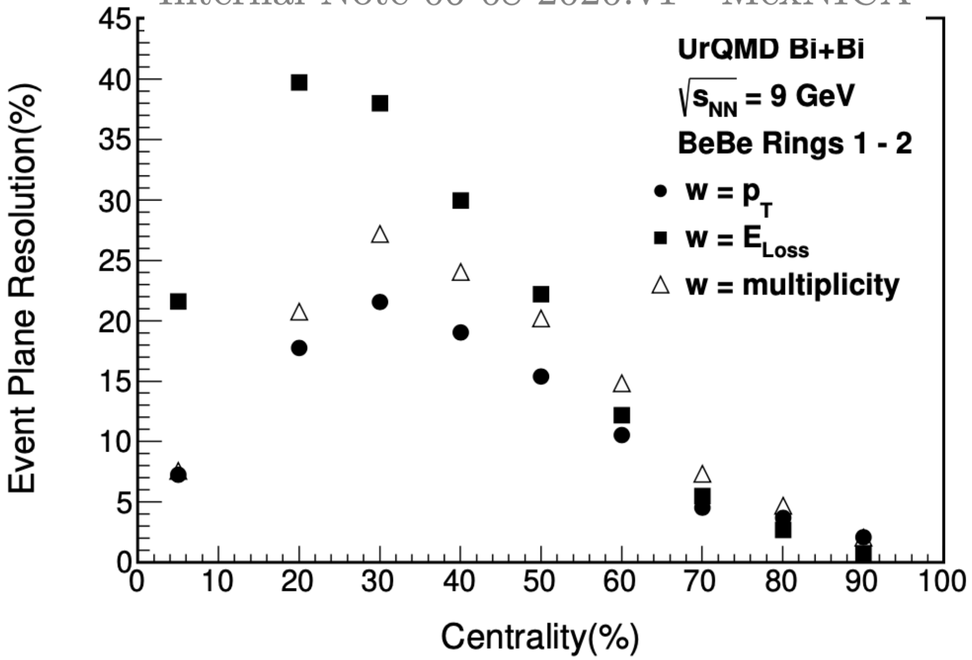
Alvarado M.; et al, NIMA (2019) 953, 163150

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

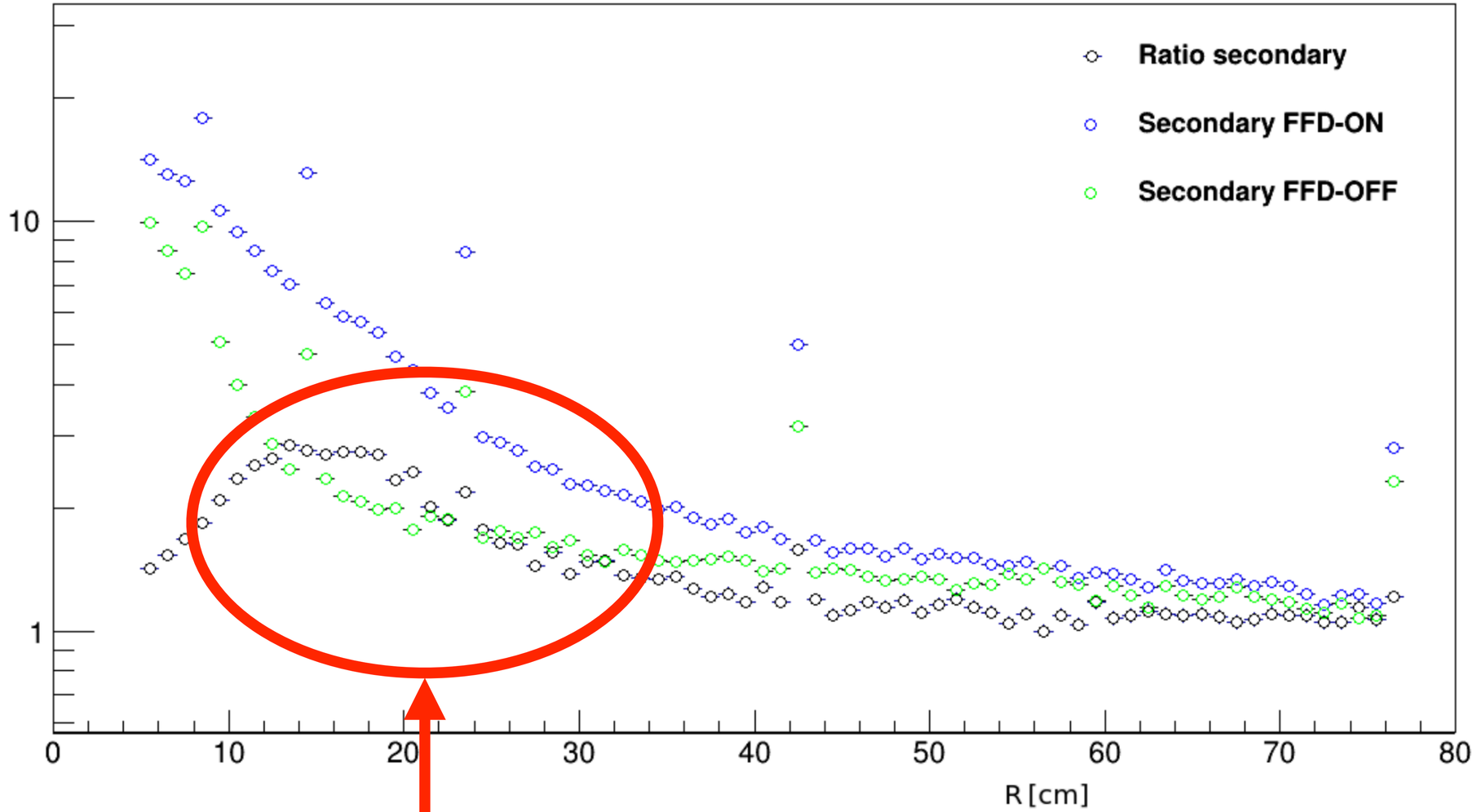
Maximum resolution between 25–45 % of centrality.



Internal Note 06-08-2020.v1 - MexNICA

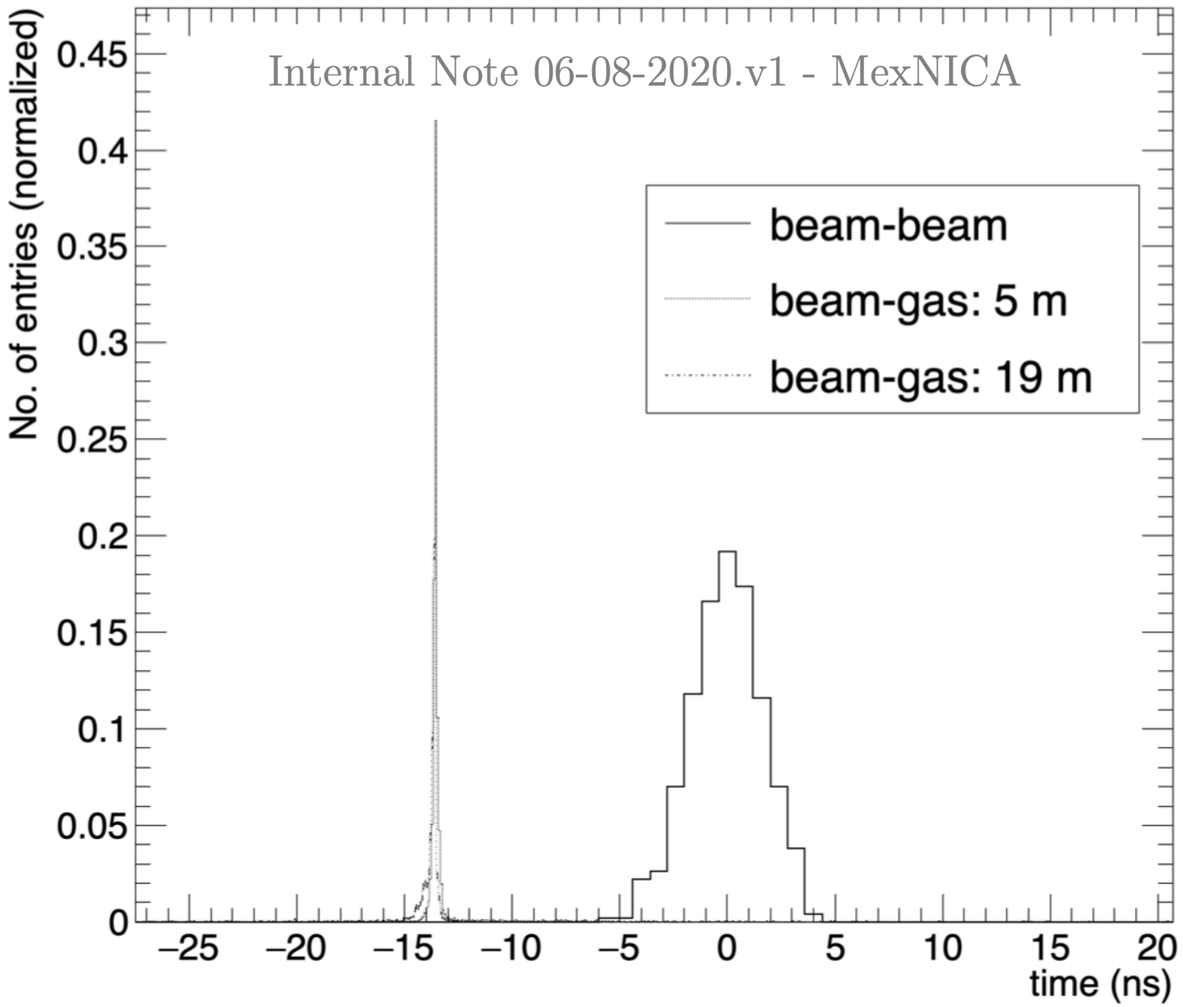


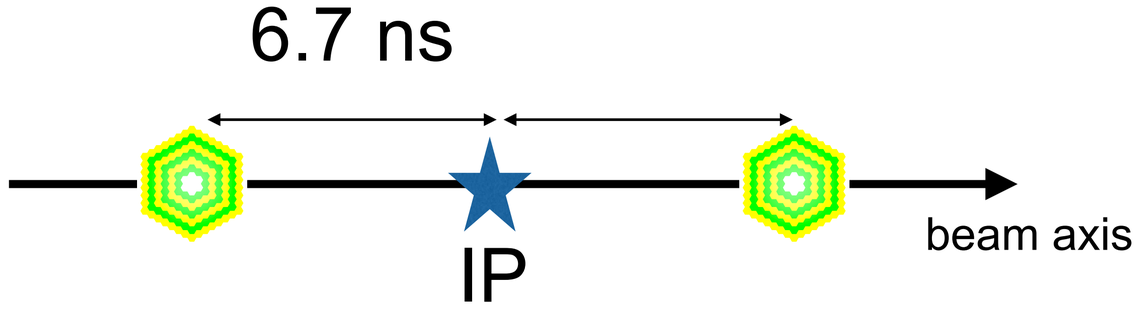
Simulation studies: hexagonal cells

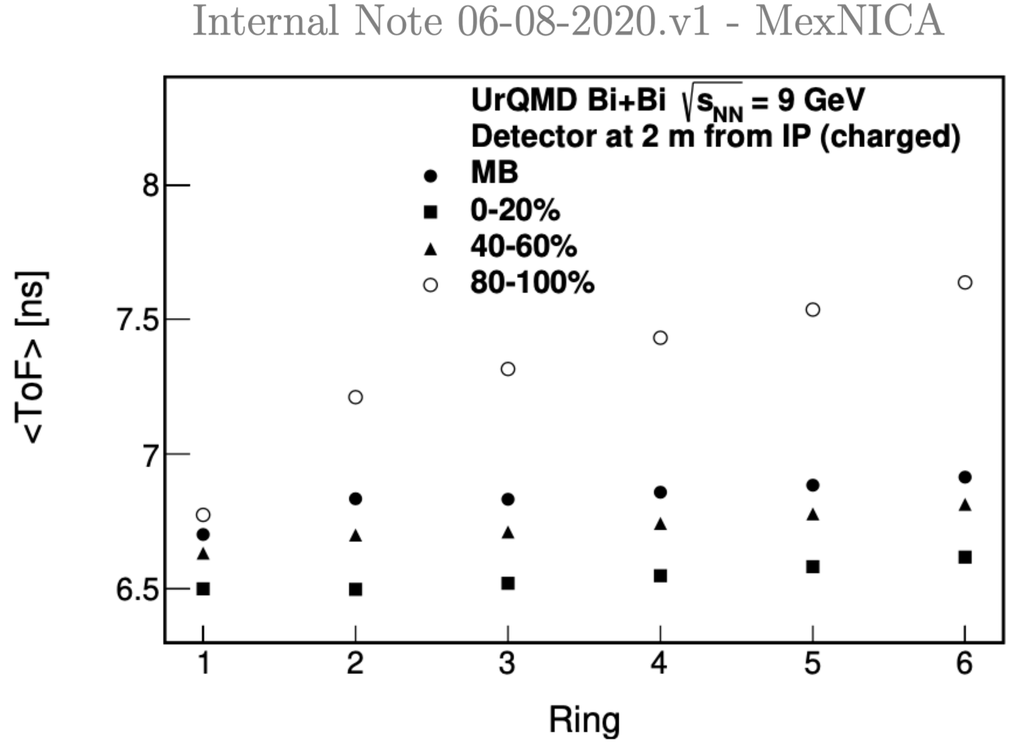


We may have a shadow from FFD

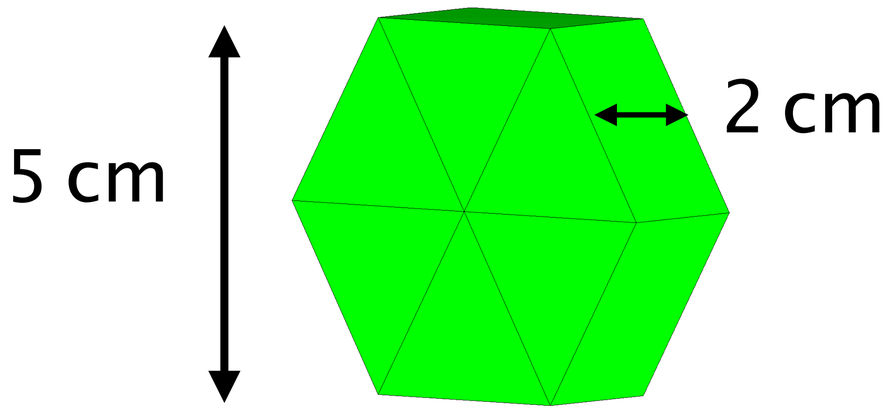
Simulation studies: hexagonal cells

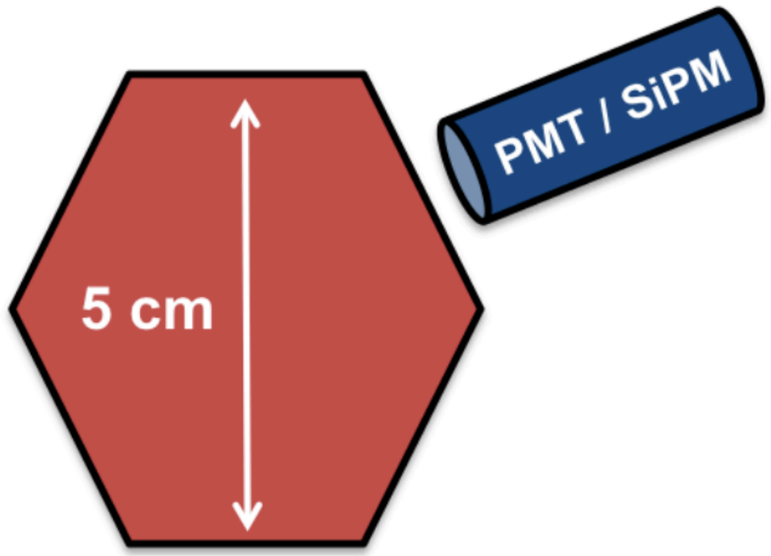






Time resolution studies: hexagonal cells



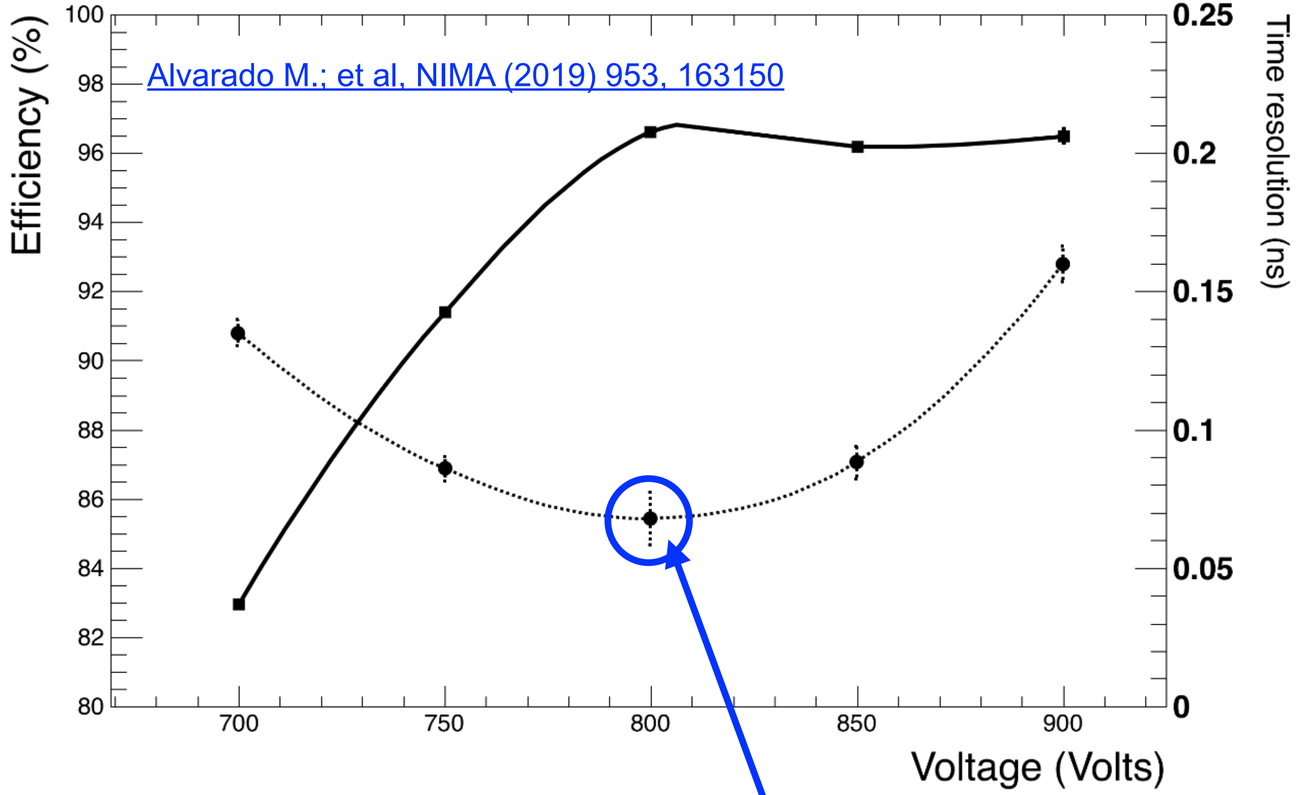


BE-BE prototype:

- hexagonal cell of 5 cm heigh and 2 cm width.
- BC-404 plastic scintillator
- evaluated at T10-CERN beam facilities (**May 2018**)
- DAQ provided by AD/VZERO ALICE groups. Same FEE as used in ALICE data taking.

Time resolution studies: hexagonal cells

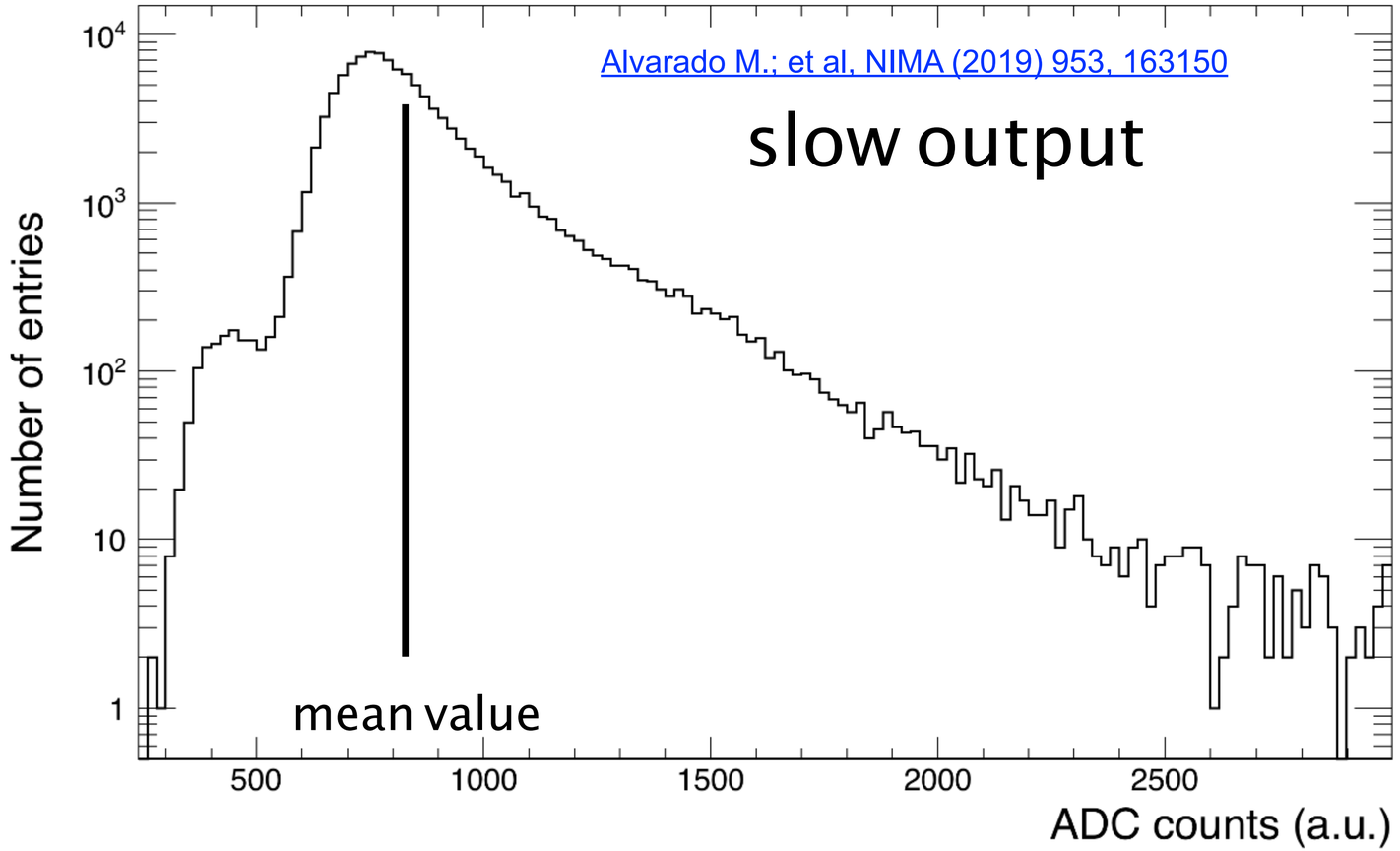
Time resolution of BE_BE prototype coupled to Hamamatsu PMT R6249



Voltage (V)	700	750	800	850	900
Time resolution (ps)	135 ± 5	86 ± 4	68 ± 5	88 ± 6	160 ± 7
χ^2/ndf	33.32/24	13.42/19	23.26/19	19.82/19	27.68/23

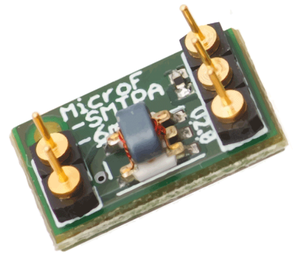
Time resolution studies: hexagonal cells

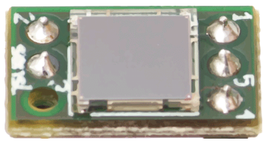
SensL (C-60035-4P-EVB) SiPM

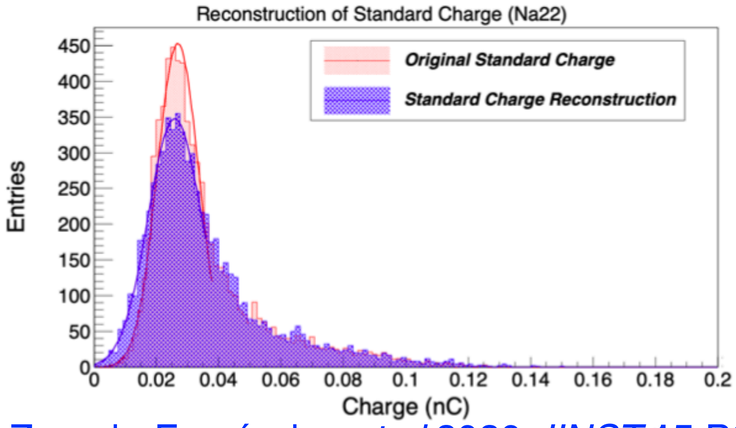


Several ADC ranges, for slow(charge) output, were considered to compute the time resolution of BB_{p2}

1. 850 - 870
2. 840-880
3. 830-880
4. 830-890
5. 800-920
6. 700-900





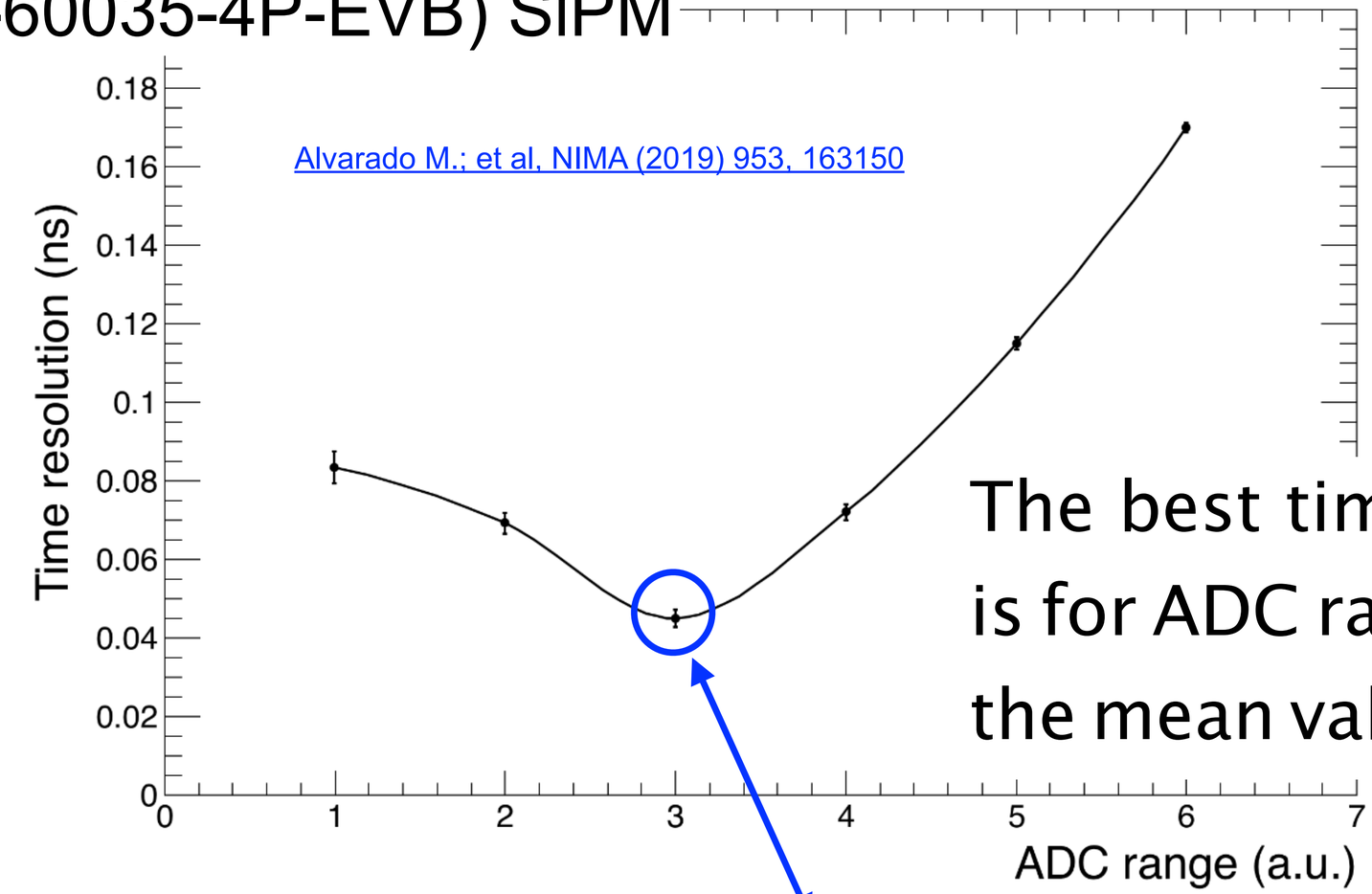


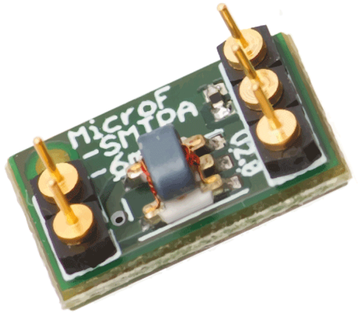
C.H. Zepeda-Fernández *et al* 2020 *JINST* **15** P09008

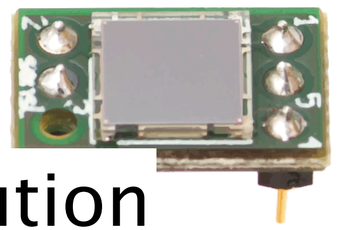
Two outputs: fast (timing) and slow (charge)

Time resolution studies: hexagonal cells

SensL (C-60035-4P-EVB) SiPM







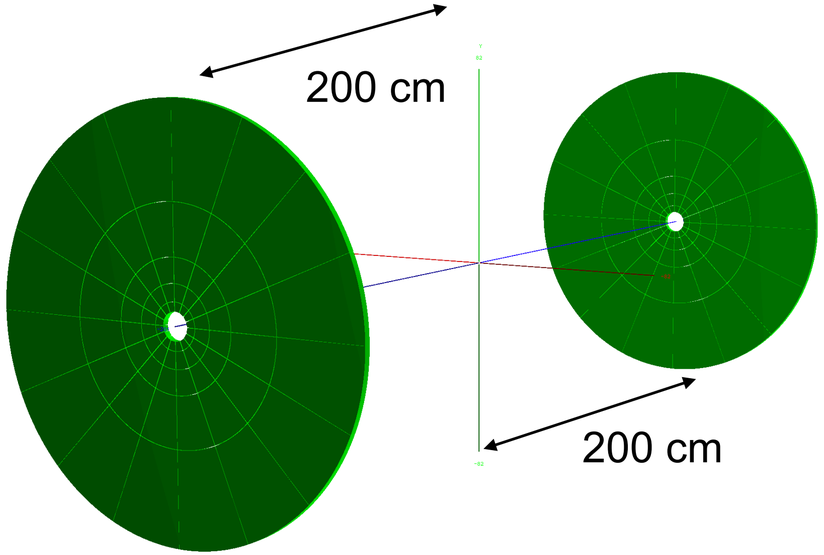
The best time resolution is for ADC ranges around the mean value

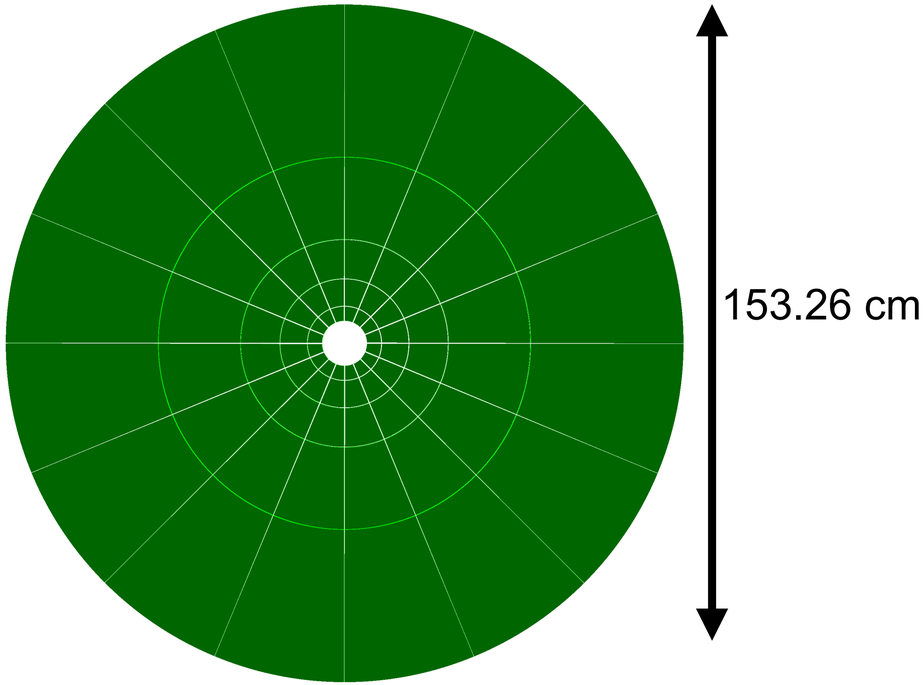
ADC range (a.u.)	850-870 (1)	840-880 (2)	830-880 (3)	830-890 (4)	800-920 (5)	700-900 (6)
Time resolution (ps)	83 ± 4	69 ± 3	45 ± 2	72 ± 2	115 ± 2	170 ± 1
χ^2/ndf	27.24/20	60.09/24	82.22/25	65.14/25	150.3/28	140.2/31

Detector concept: disk cells

BeBe detector

- 80 cells per side (1 cm width)
- five concentric rings
- plastic scintillator BC404
- $1.68 < |\eta| < 4.36$
- photosensors: SiPM or PMT (do be decided)

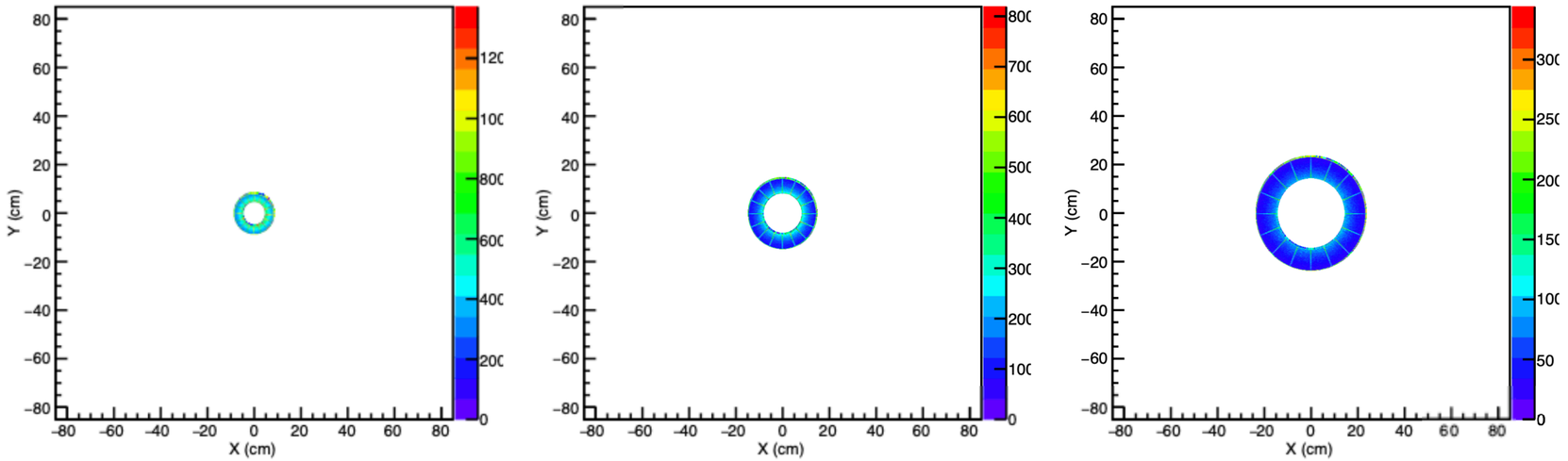


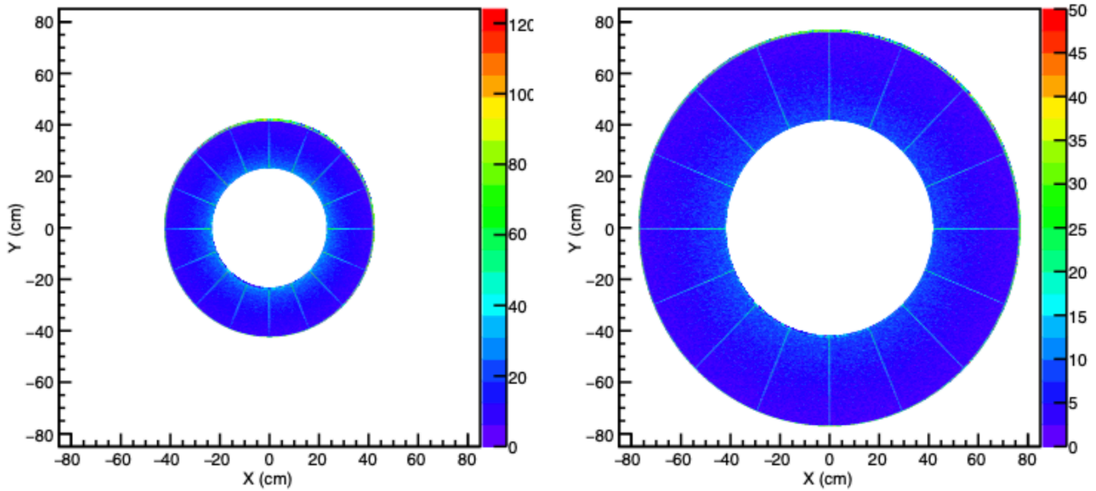


The construction of centrality classes and beam-gas studies with this geometry is a work in progress. A similar physics performance w.r.t. hexagonal geometry is expected.

Simulation studies: disk cells

inner most ring

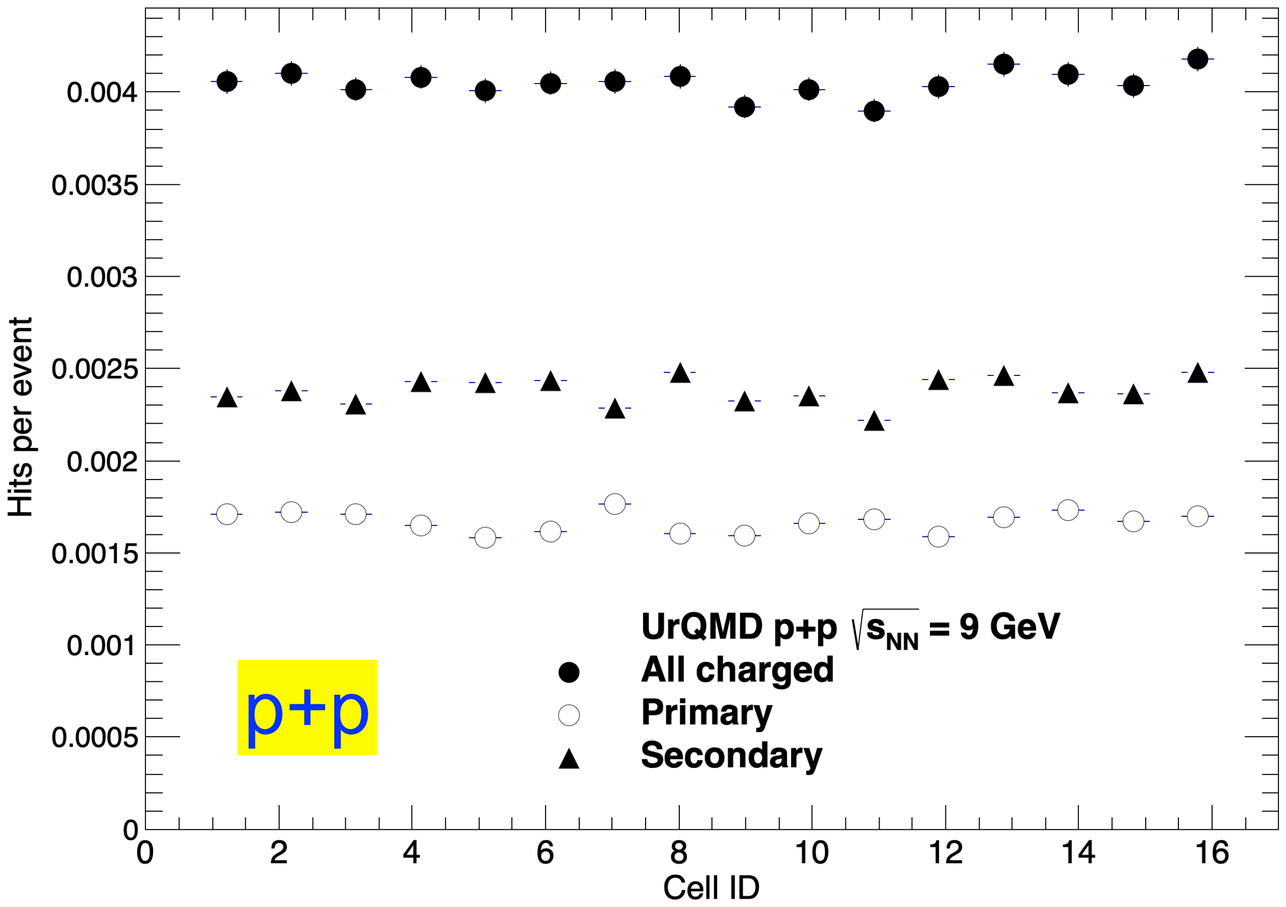


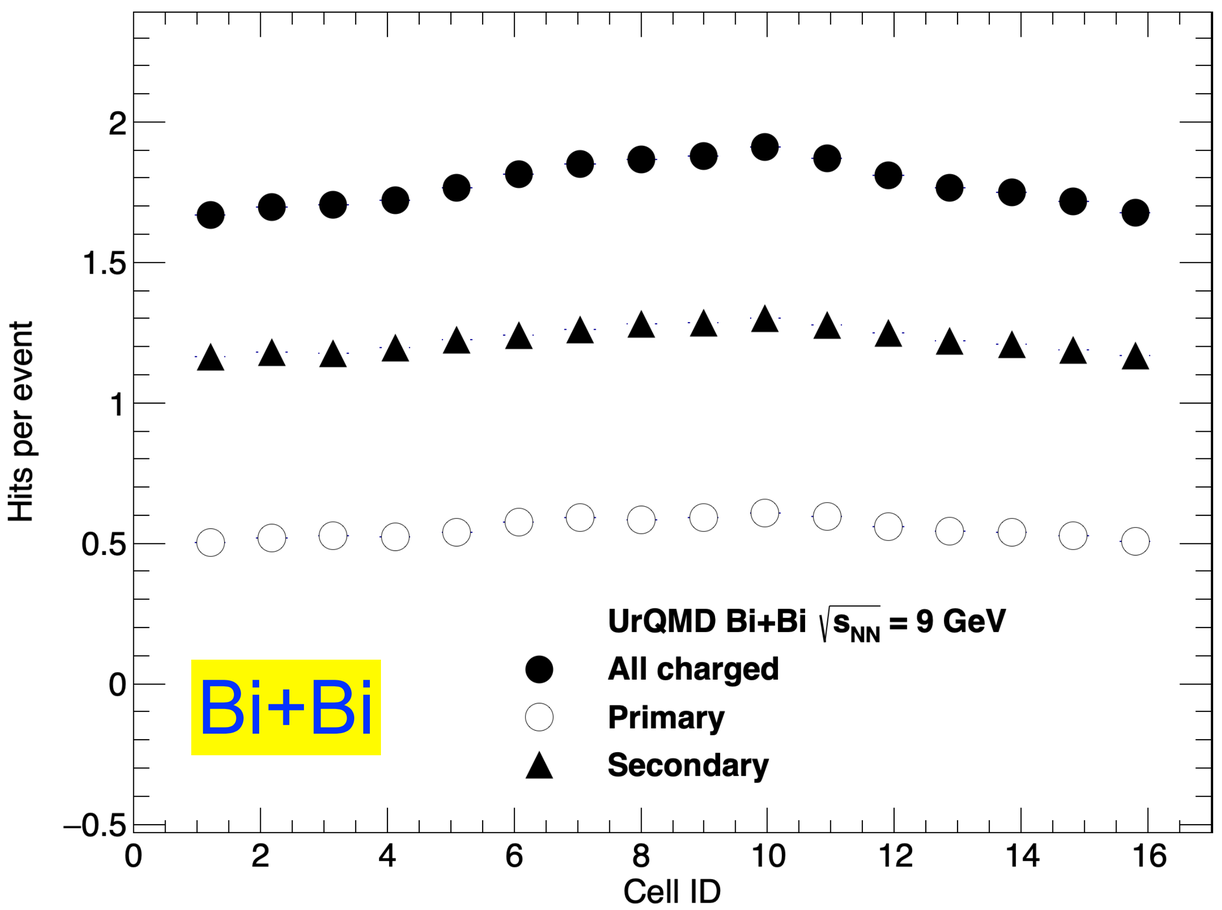


outer most ring

Simulation studies: disk cells

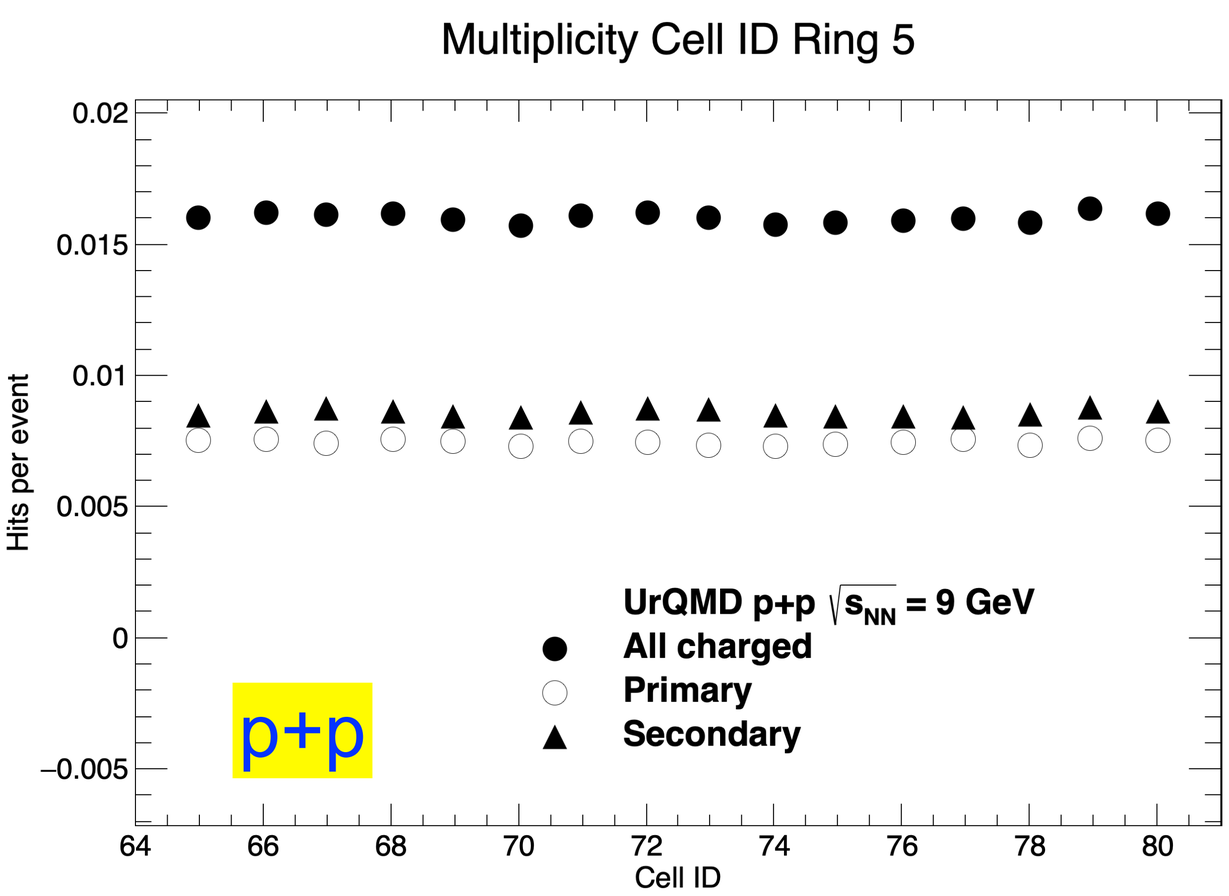
inner most ring

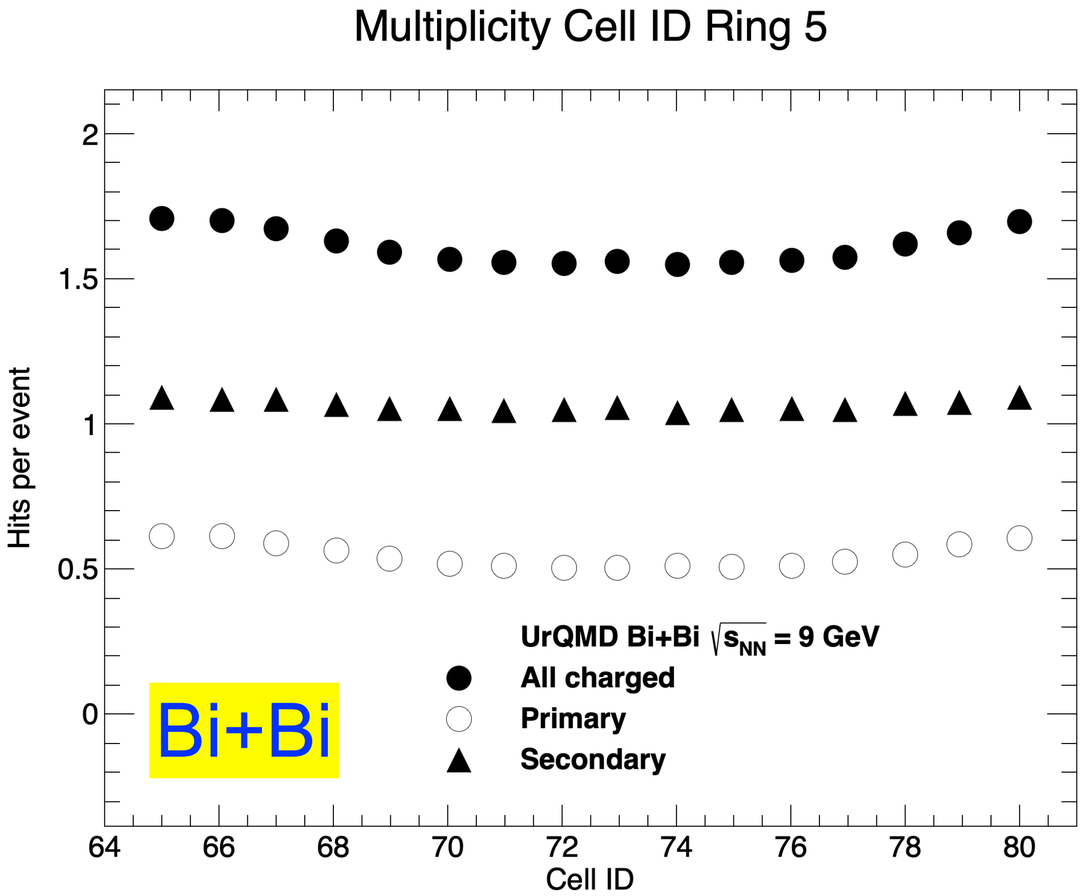




Simulation studies: disk cells

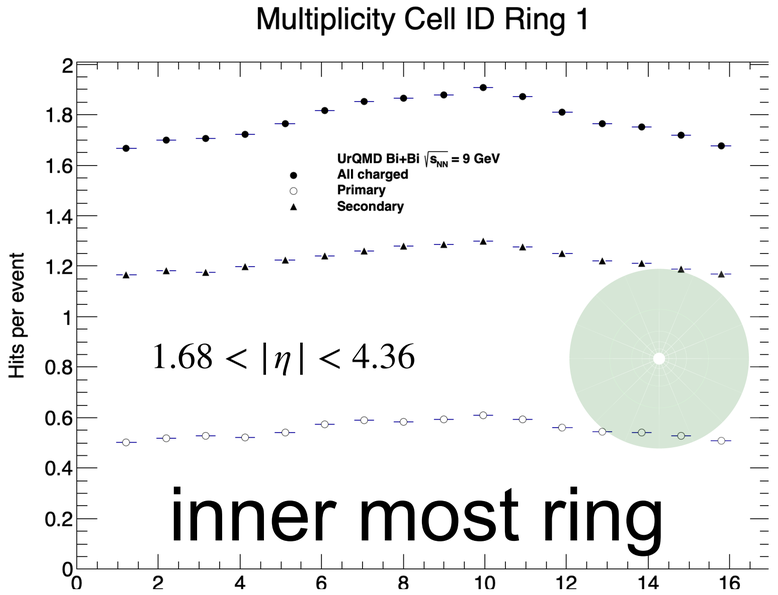
outer most ring



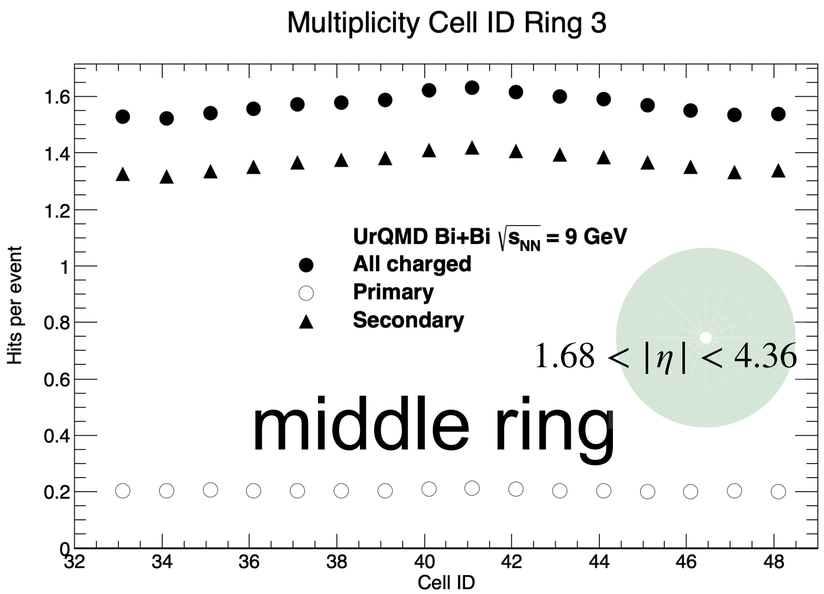


Simulation studies: disk VS hexagonal cells

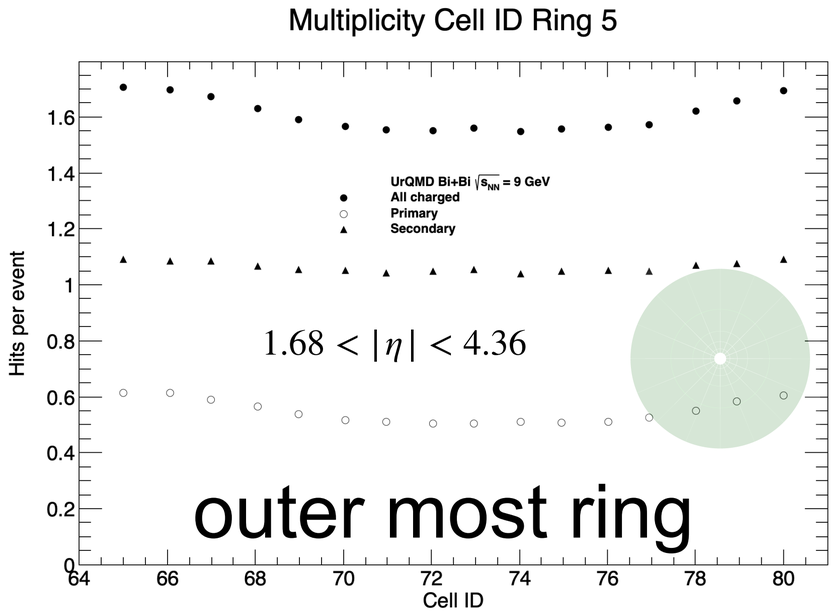
Bi+Bi



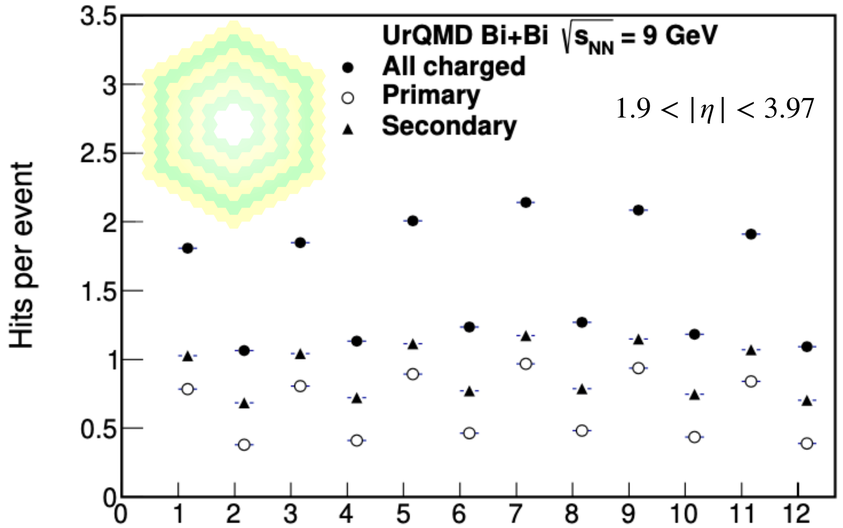
inner most ring



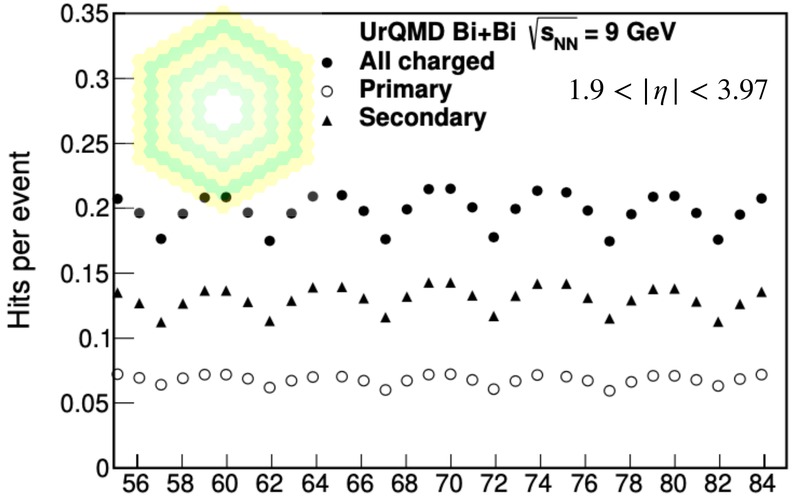
middle ring



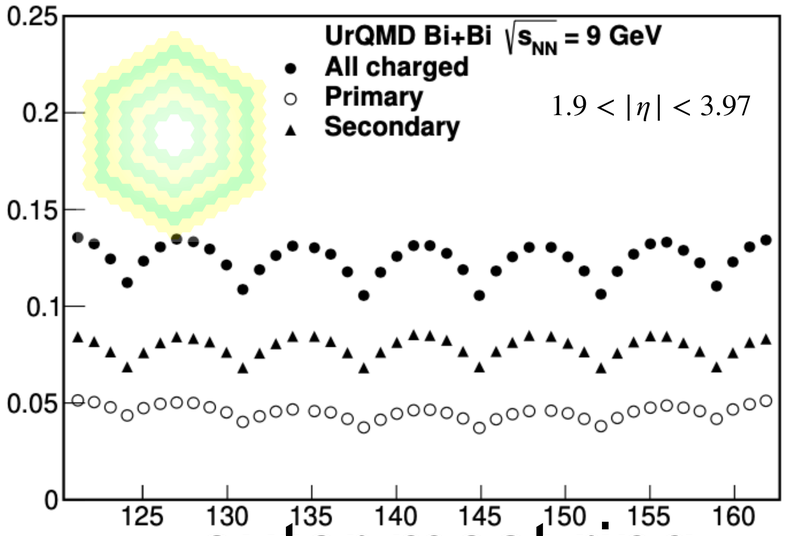
outer most ring



inner most ring

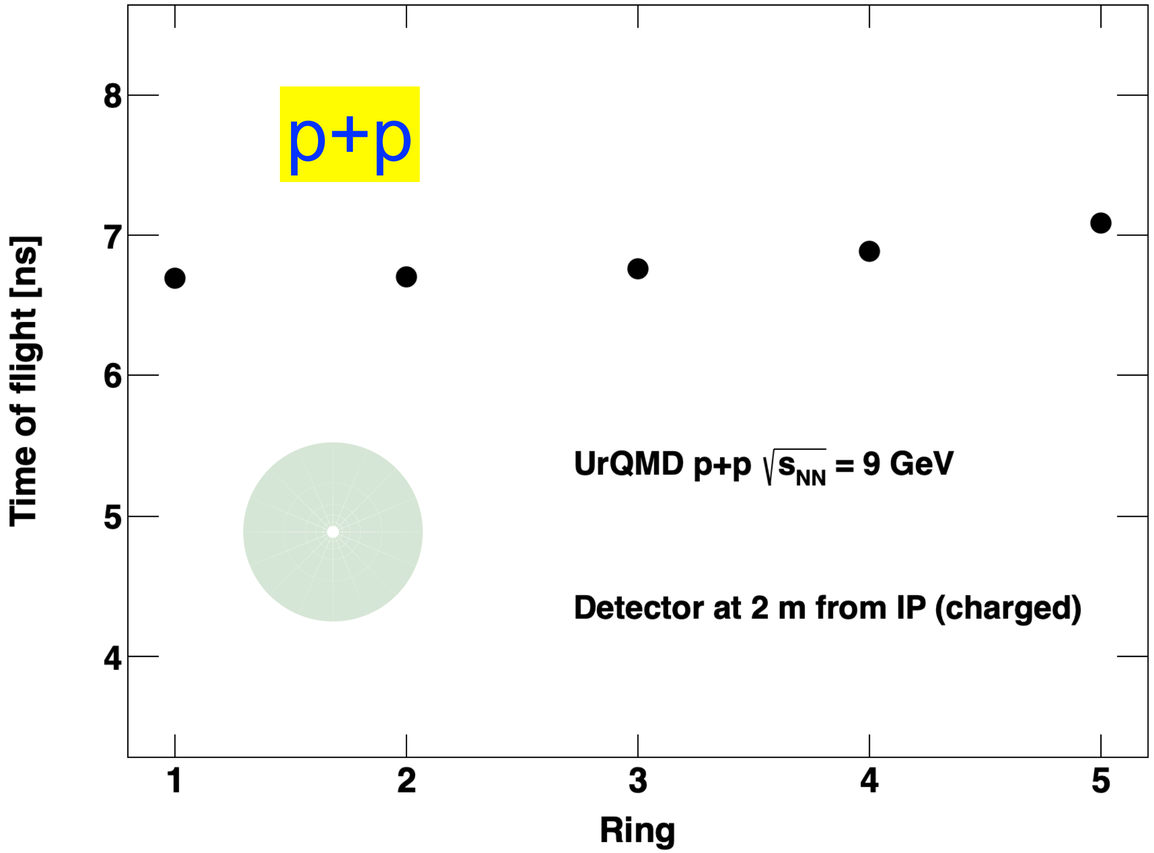


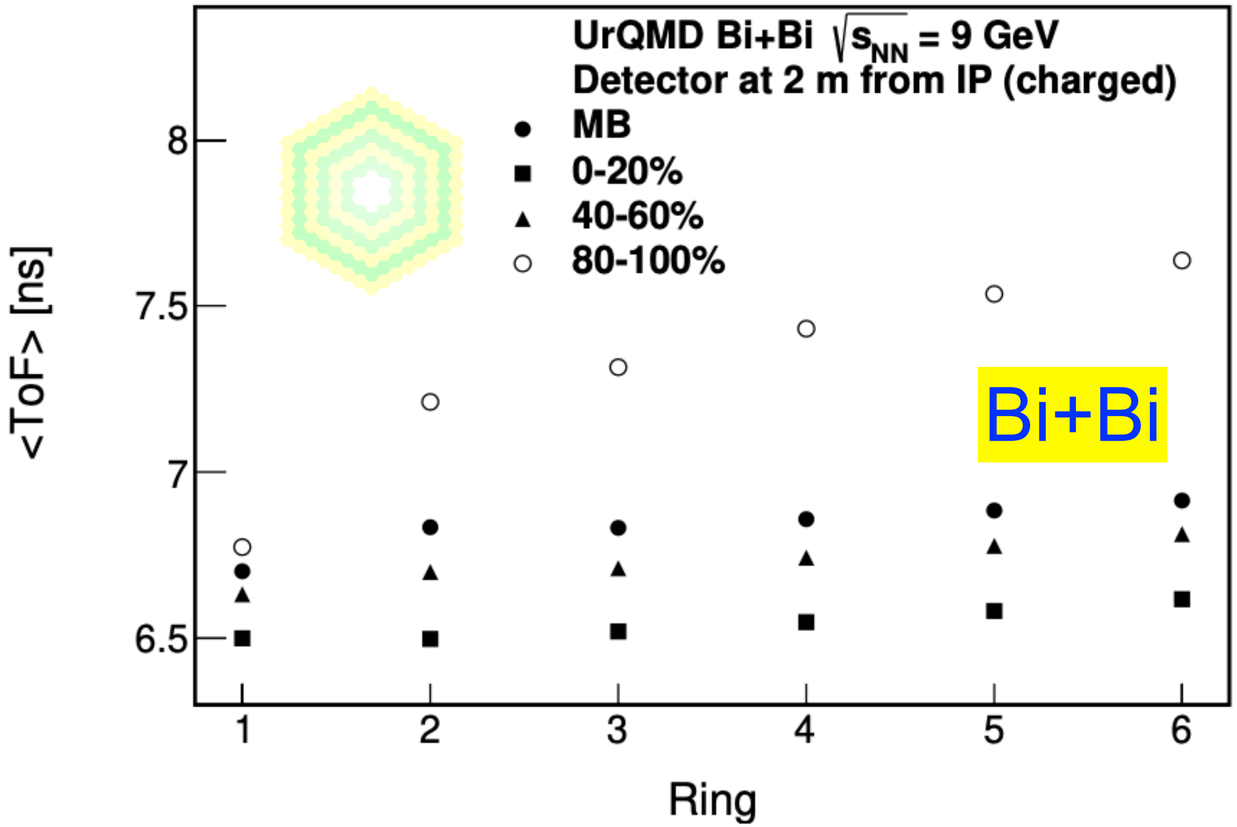
middle ring



outer most ring

Simulation studies: disk VS hexagonal cells

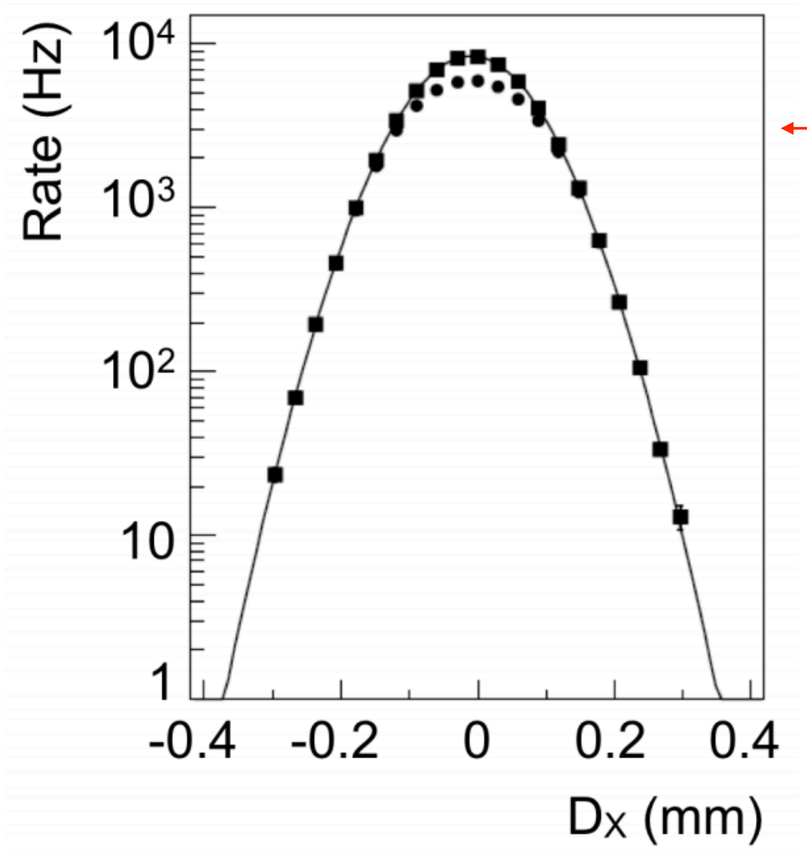




With the time information, either disks or hexagons, we can define a time window to set a beam-beam trigger (BB) for both BeBe hodoscopes (Z>0 and Z<0). This is crucial for beam monitoring tasks.

¿BeBe for luminosity measurements?

In ALICE, the on-line monitoring of the luminosity uses a time coincidence between the two VZERO arrays.



time resolution of VZERO system: 1 ns

The rate corresponding to the coincidence between VZERO-A and VZERO-C signals is named MBAND. The luminosity and therefore the rate of $MB_{AND}(Dx,Dy)$ are functions of the transverse displacements Dx and Dy of the beams.

$$\mathscr{L} = k_b f N_1 N_2 Q_x Q_y \quad \text{and} \quad \sigma_{\mathrm{MB_{AND}}} = \mathrm{MB_{AND}}(0,0)/\mathscr{L},$$

N_1 and N_2 beams intensities

k_b is the number of colliding bunches

$f = 11.2455$ kHz the LHC revolution frequency.

Key issue: trigger efficiency of the Minimum Bias trigger.

JINST 8 (2013) P10016

¿BeBe for luminosity measurements?

http://cds.cern.ch/record/1281333/files/ATLAS-CONF-2010-060.pdf

ATLAS

3.2 LUCID

Online luminosity values from LUCID measurements are obtained from the LUMAT card. At present there are four algorithms implemented in the LUMAT firmware:

- LUCID_Zero_AND, the number of events per BCID when no hits are found in either detector arm;
- LUCID_Zero_OR, the number of events per BCID when at least one of the two detector arms has no hits or when neither arm contains any hit;
- LUCID_Hit_AND, the number of hits when there is at least one hit in each of the two detector arms;
- LUCID_Hit_OR, the number of hits when there is at least one hit in the 32 tubes of both detector arms.

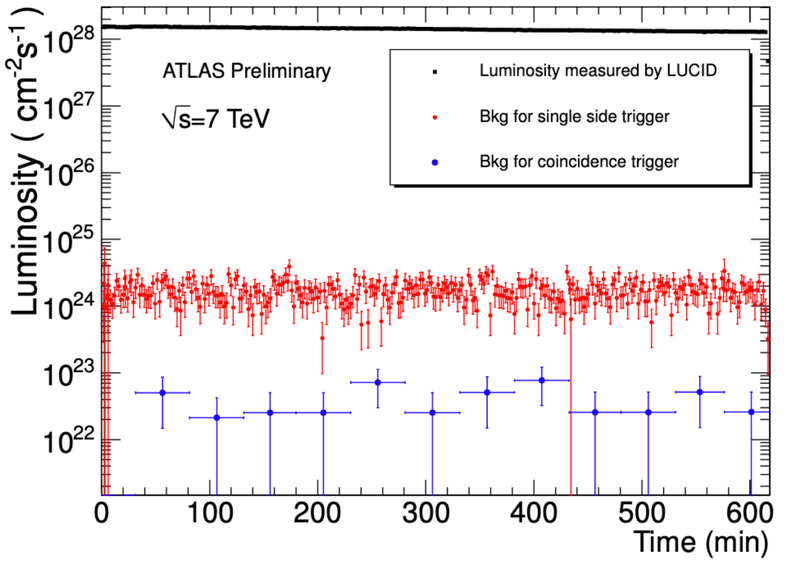
$$\mathscr{L} = \frac{\mu n_b f_r}{\sigma_{inel}} = \frac{\mu^{meas} n_b f_r}{\varepsilon \sigma_{inel}} = \frac{\mu^{meas} n_b f_r}{\sigma_{vis}}$$

- LUCID_Event_AND, the number of events with at least one hit in each detector arm. The LUCID_Event_AND probability per beam crossing $P^{\text{LUCID\_Event\_AND}}$ is related to the LUCID_Zero_OR probability per beam crossing $P^{\text{LUCID\_Zero\_OR}}$:

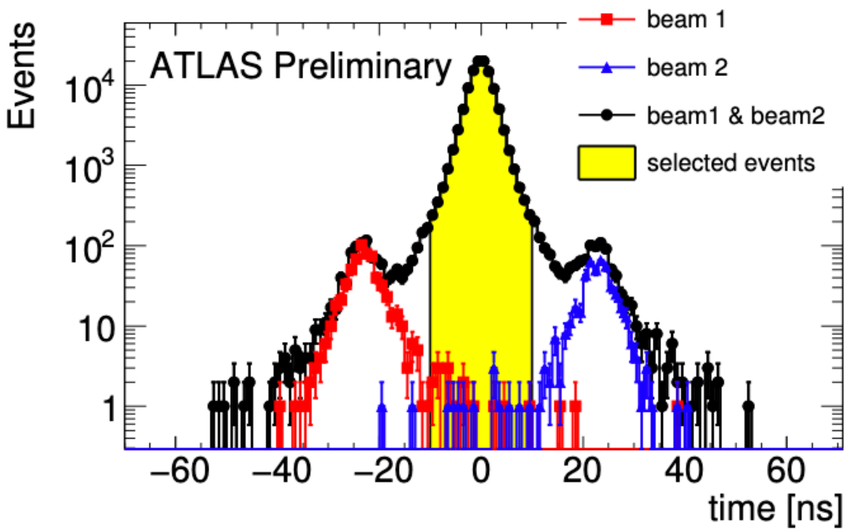
$$P^{\text{LUCID\_Event\_AND}} = 1 - P^{\text{LUCID\_Zero\_OR}}$$

- LUCID_Event_OR, the number of events for which the sum of hits in both detector arms is larger or equal to one. The LUCID_Event_OR probability per beam crossing $P^{\text{LUCID\_Event\_OR}}$ is related to the LUCID_Zero_AND probability per beam crossing $P^{\text{LUCID\_Zero\_AND}}$:

$$P^{\text{LUCID\_Event\_OR}} = 1 - P^{\text{LUCID\_Zero\_AND}}$$



Key issue: trigger efficiency of the Minimum Bias trigger.

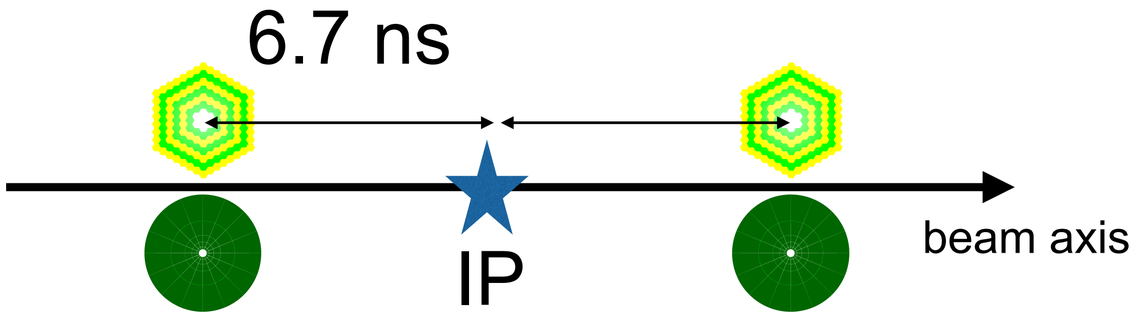


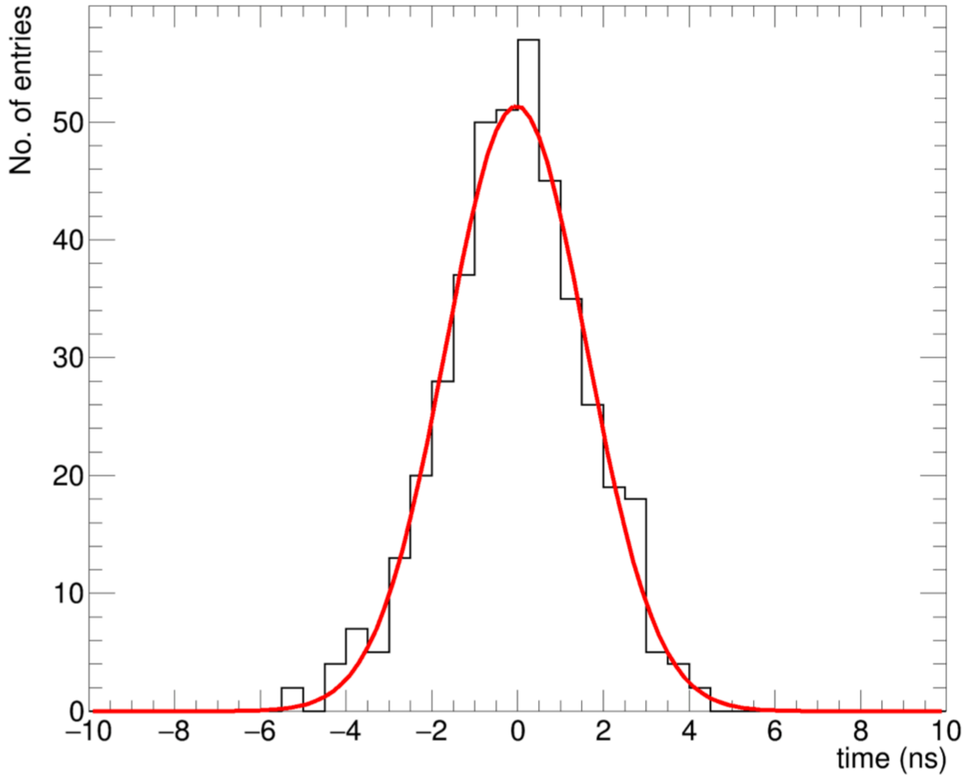
¿BeBe for luminosity measurements?

Particles created in p+p collisions will arrive at the BeBe hodoscopes around 6.7 ns after the primary collision. As a first approach, we centered the time window at 6.7 ns for both hodoscopes (see slide 26) and try to determine the BeBe trigger efficiencies.

BeBe triggers:

- A: BeBeLeft (Z>0)
- B: BeBeRight (Z<0)
- OR: BeBeLeft OR BeBeRight
- AND: BeBeLeft AND BeBeRight





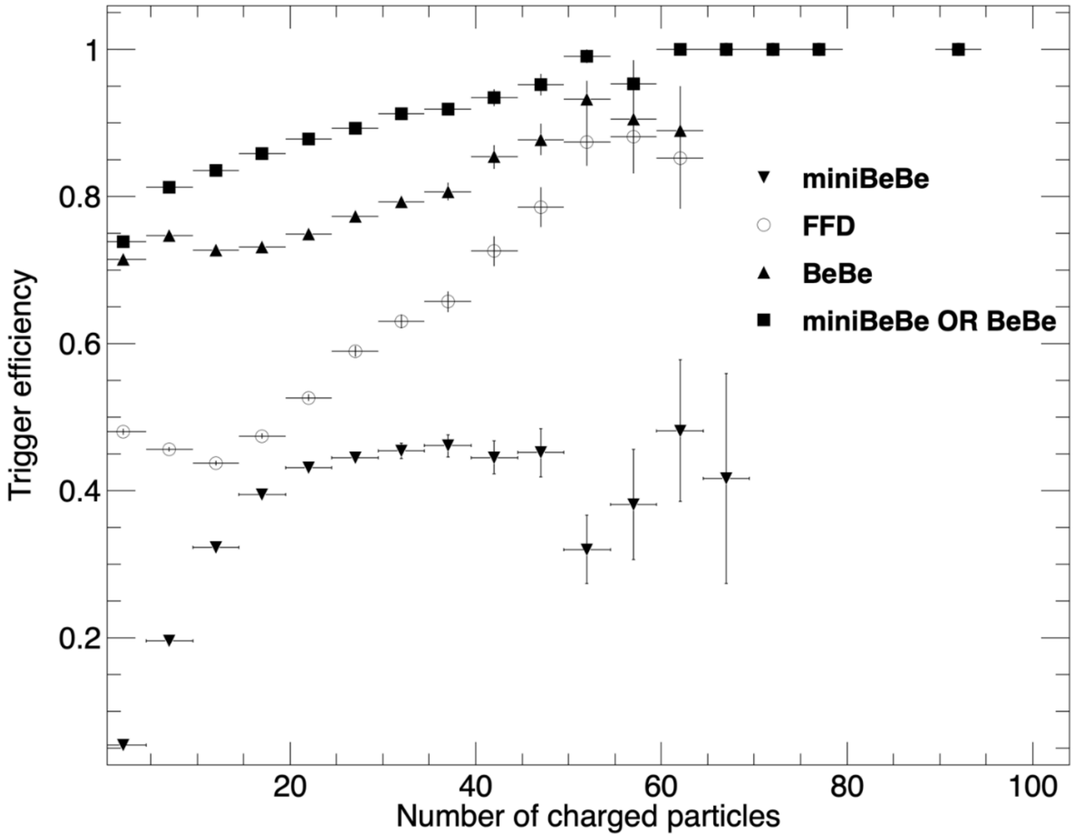
time difference BeBeLeft - BeBeRight

¿BeBe for luminosity measurements?

p+p @ 10 GeV / EPOS 1.99	BeBe trigger efficiencies (%)			
Time window (ns)	A	B	OR	AND
4 - 10	59.8	59.8	96.5	23
4.5 - 7.5	48.7	48.7	85.9	11.4
5.5 - 6.5	25.2	25	48.5	1.7

p+p @ 9 GeV / UrQMD	BeBe trigger efficiencies (%)			
Time window (ns)	A	B	OR	AND
4 - 10	55.9	56	95.1	16.8

BeBe detector may increase the trigger capabilities of MPD for low multiplicity p+p collisions events



See the talk of Maria Elena Tejeda of this session for more details of miniBeBe detector

¿BeBe for luminosity measurements?

Bi+Bi @ 9 GeV / UrQMD	BeBe trigger efficiencies (%)			
Time window (ns)	A	B	OR	AND
4 - 10	98.7	98.3	99.6	97.3
4.5 - 7.5	86.1	84.7	97.8	73.1
5.5 - 6.5	70.1	70	93.5	46.6

Au+Au @ 11 GeV / UrQMD	BeBe trigger efficiencies (%)			
Time window (ns)	A	B	OR	AND
4 - 10	100	100	100	100
4.8 - 8.8	99.6	99.7	99.9	99.4
5 - 9	99.7	99.7	99.9	99.5

Final comments

- The proposed BeBe detector can be used as a trigger for p+p and Bi+Bi collisions.

- The BeBe detector, either hexagonal or disks cells, can give valuable information for physics studies: centrality and event plane determination.

- The BeBe triggers can be used for beam luminosity measurements.

Back-up slides

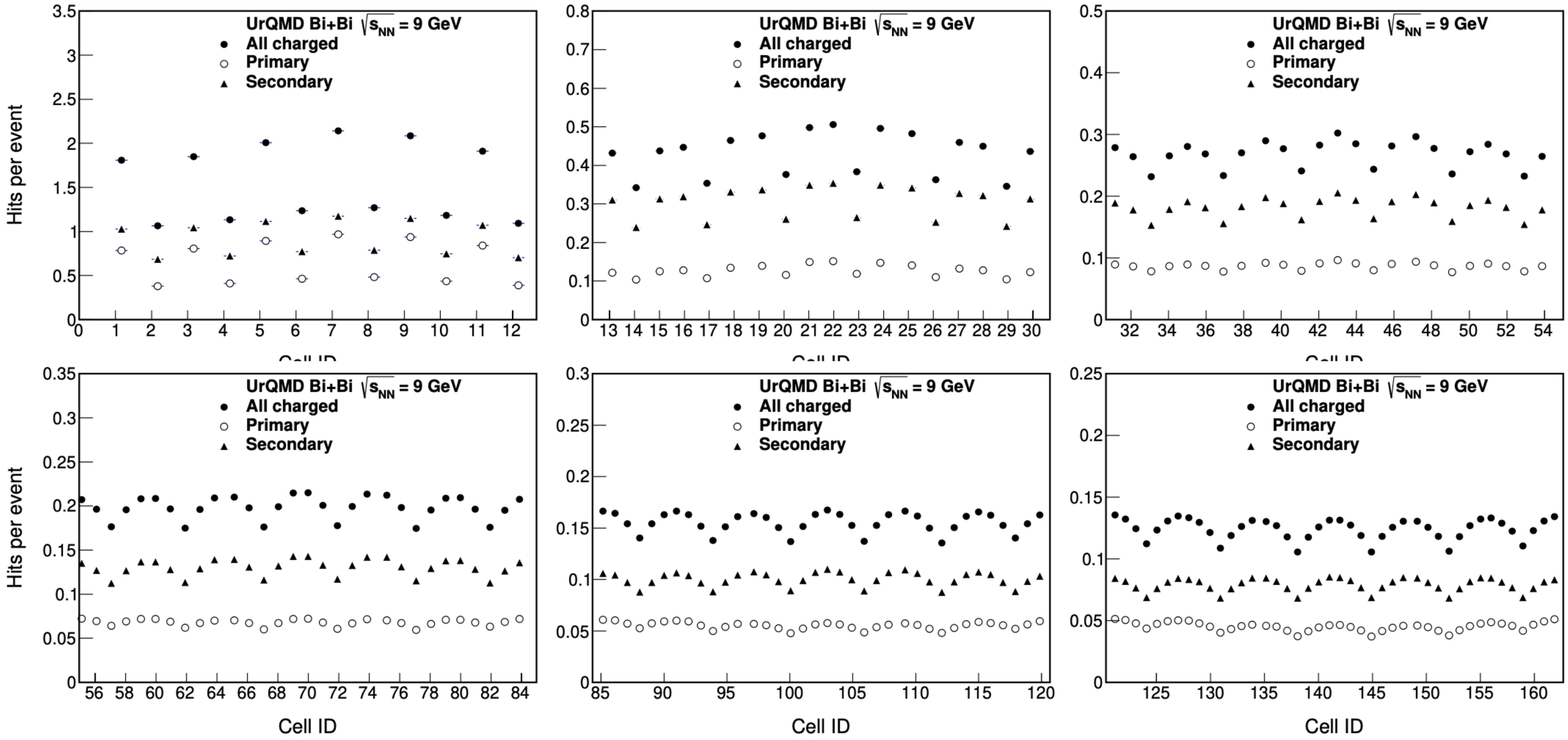
Simulation studies: hexagonal cells

Internal Note 06-08-2020.v1 - MexNICA

Bi+Bi@9GeV, 3-6 BeBe rings				
Class %	b min (fm)	b max (fm)	N_{ch} max	N_{ch} min
0-10	0	2.8395	100	40
10-20	2.8395	4.0705	40	31
20-30	4.0705	5.0795	31	24
30-40	5.0795	5.9805	24	19
40-50	5.9805	6.8405	19	15
50-60	6.8405	7.7105	15	12
60-70	7.7105	8.6095	12	9
70-80	8.6095	9.6405	9	6
80-90	9.6405	10.9605	6	3
90-100	10.9605	15.1705	3	0

Au+Au@11GeV, 3-6 BeBe rings				
Class %	b min (fm)	b max (fm)	N_{ch} max	N_{ch} min
0-10	0	2.7895	100	37
10-20	2.7895	4.0005	37	29
20-30	4.0005	4.9805	29	23
30-40	4.9805	5.8605	23	18
40-50	5.8605	6.9995	18	14
50-60	6.9995	7.5505	14	11
60-70	7.5505	8.4495	11	8
70-80	8.4495	9.4505	8	5
80-90	9.4505	10.7505	5	3
90-100	10.7505	14.9605	3	0

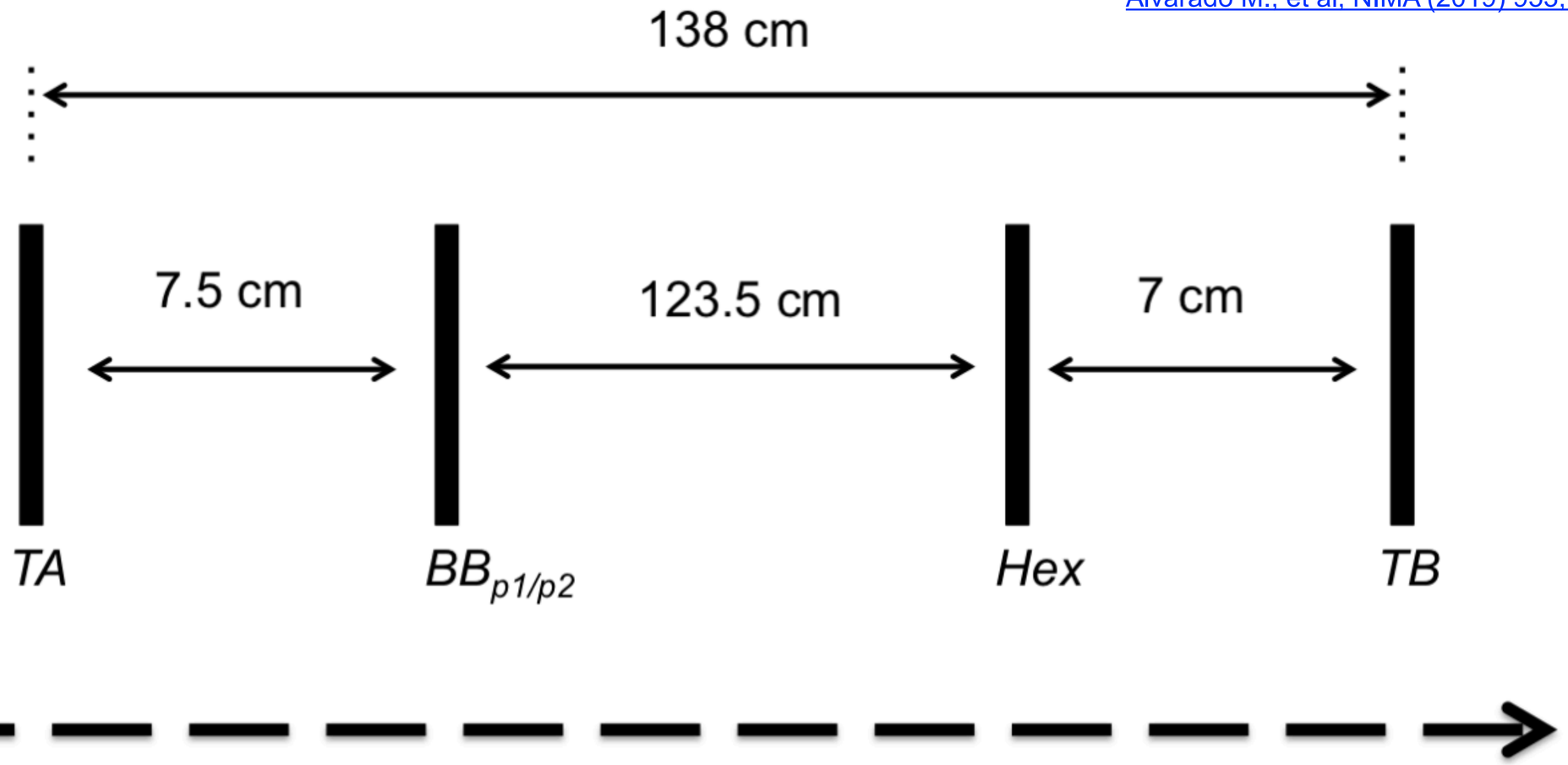
Simulation studies: hexagonal cells



Internal Note 06-08-2020.v1 - MexNICA

Time resolution studies: hexagonal cells

Alvarado M.; et al, NIMA (2019) 953, 163150



$$\sigma_{p1}^2 = \sigma_{BB_{p1}}^2 + \sigma_{TA}^2 + \sigma_{FEE}^2$$

Time resolution studies: hexagonal cells

Time difference between the TDC value from TA and BB_{p1}

Alvarado M.; et al, NIMA (2019) 953, 163150

Entries	2356
Mean	−19.44
Std Dev	0.3274
χ^2 / ndf	33.32 / 24
Constant	292.9 ± 7.6
Mean	−19.44 ± 0.01
Sigma	0.3098 ± 0.0048

Number of entries

Time (ns)

Hamamatsu PMT R6249

260 ps

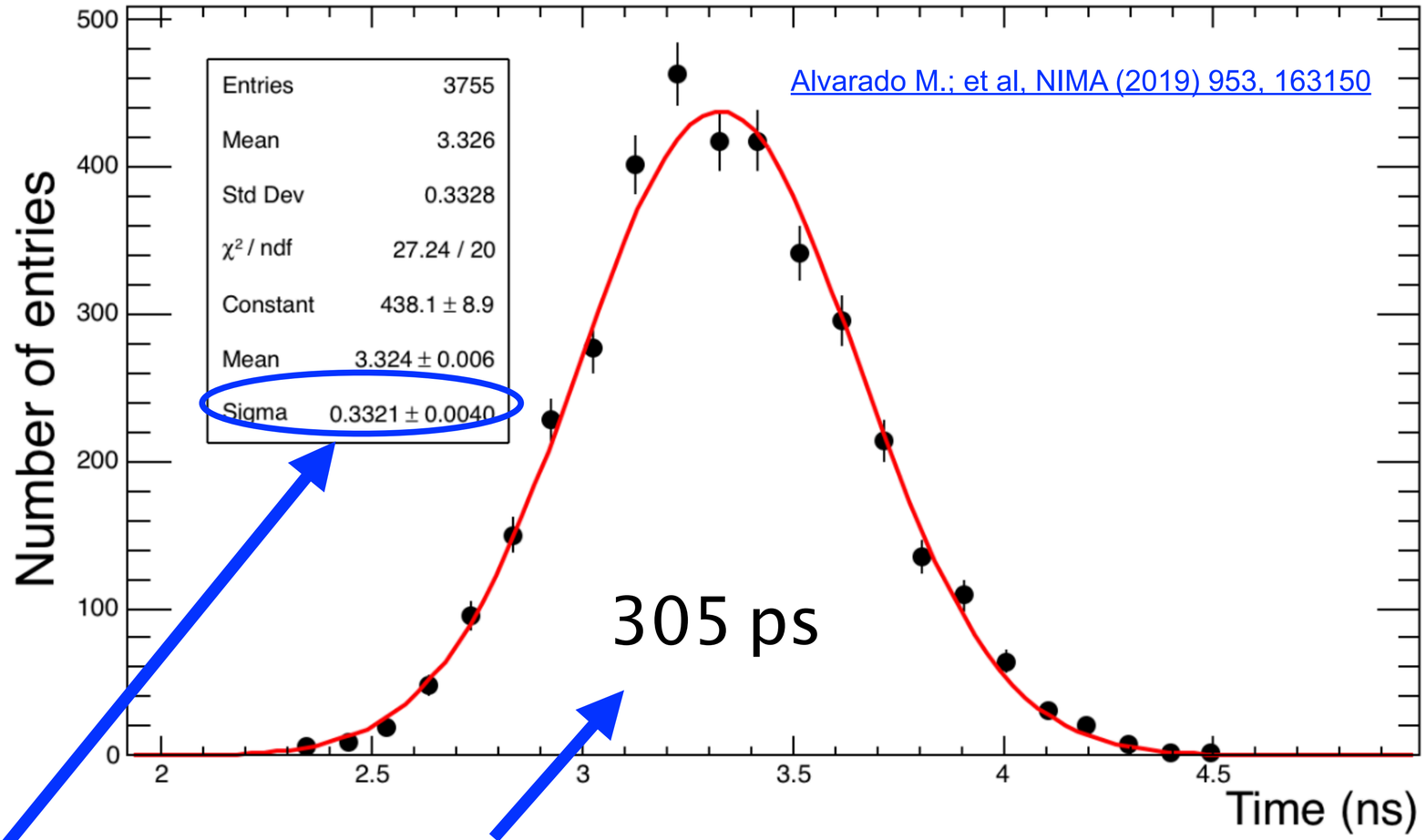
¿?

$$\sigma_{p1}^2 = \sigma_{BB_{p1}}^2 + \sigma_{TA}^2 + \sigma_{FEE}^2$$

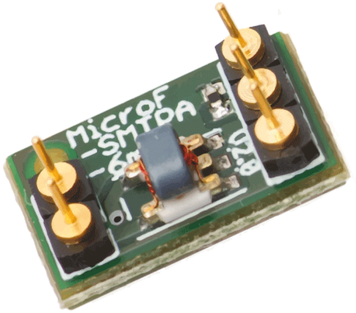
100 ps (Nucl. Instrum. Methods Phys. Res. A 626–627 (2011) 90–96)

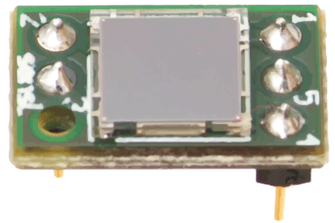
Time resolution studies: hexagonal cells

SensL (C-60035-4P-EVB) SiPM



Alvarado M.; et al, NIMA (2019) 953, 163150

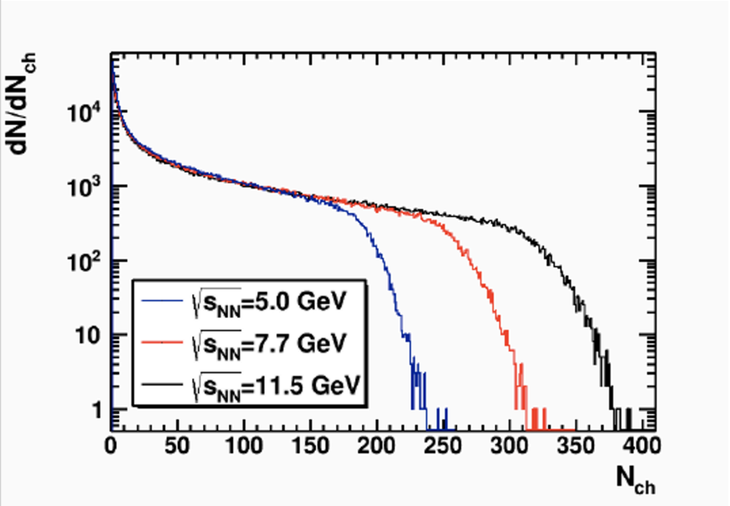




$$\sigma_{p2}^2 = \sigma_{BB_{p2}}^2 + \sigma_{TA}^2 + \sigma_{FEE}^2 \rightarrow$$ 100 ps (Nucl. Instrum. Methods Phys. Res. A 626-627 (2011) 90–96)

PWG1 G. Feofilov's report (this meeting)

Charged particle multiplicity in MPD



Reconstructed data:

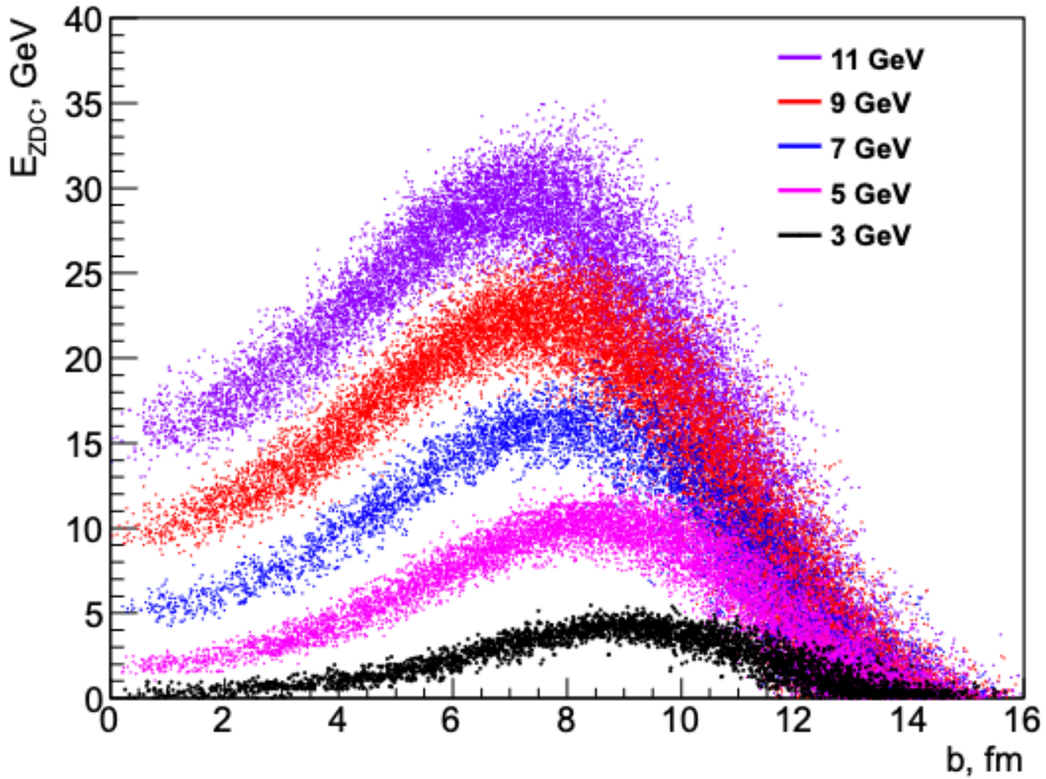
- UrQMD 3.4 simulation
  - Au+Au, N_{ev}=500k, $\sqrt{s_{NN}}$=5, 7.7, 11.5 GeV
- GEANT4 MPD detector simulation
- Reconstruction procedure:
  - Realistic tracking in TPC (Cluster Finder)

Used particle selection:

- $|\eta|<0.5$
- $p_T>0.15$ GeV/c

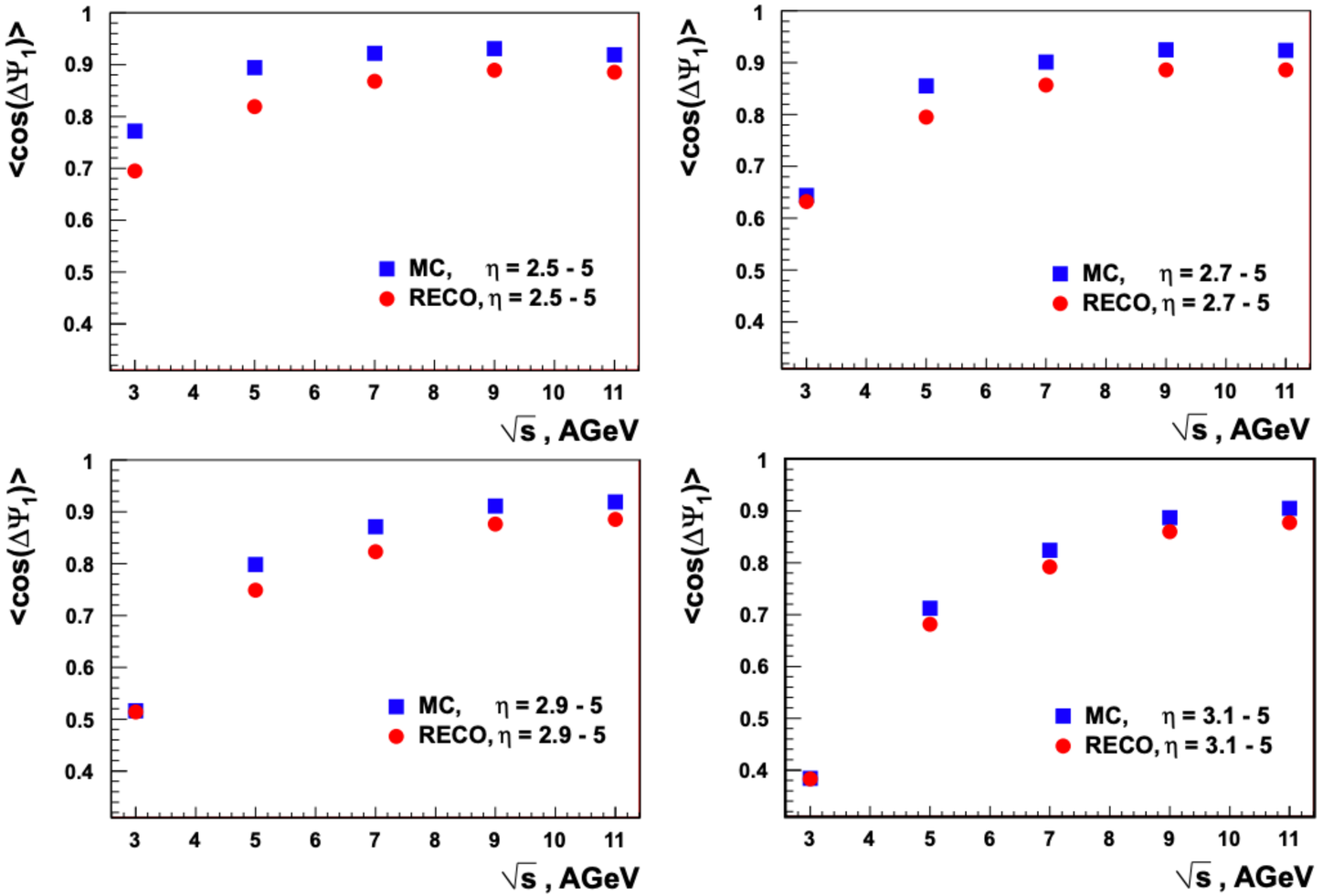
16.01.2020

8



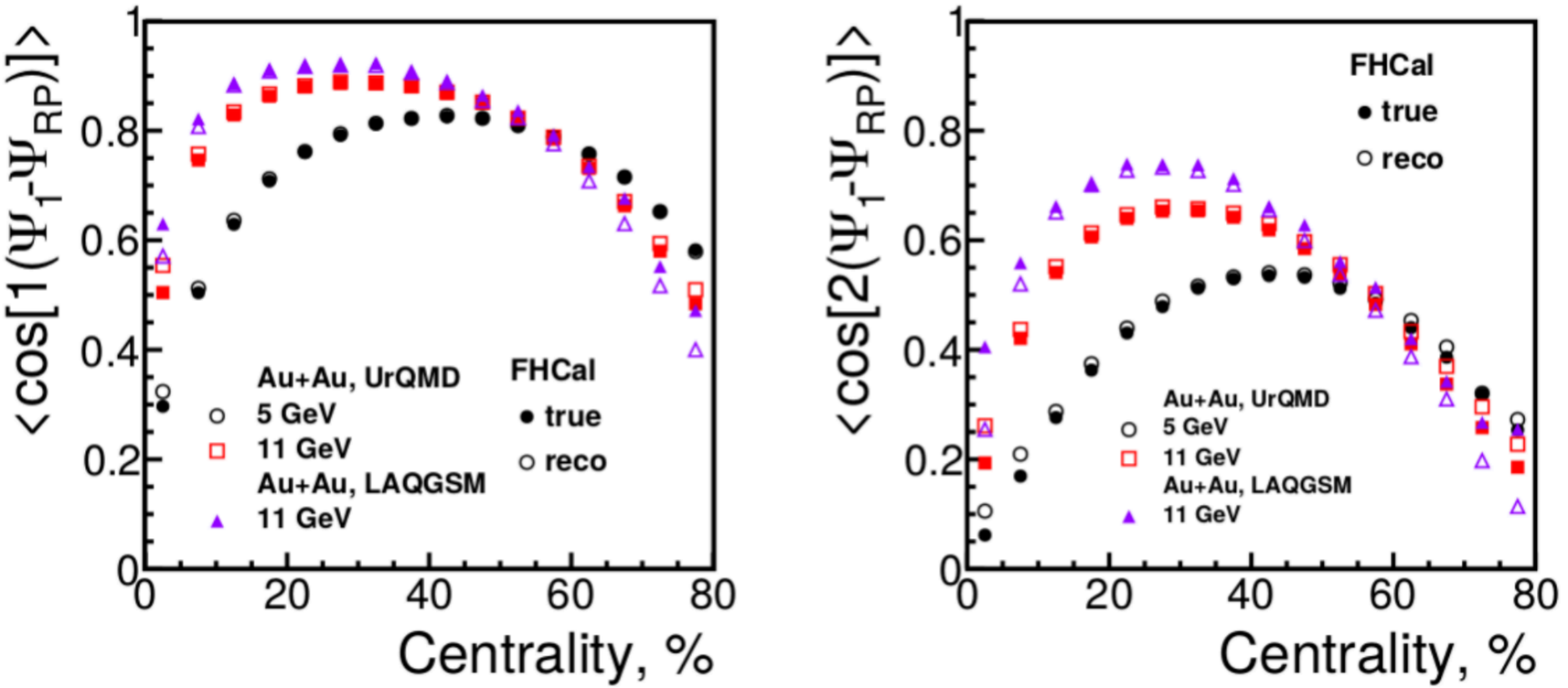
http://mpd.jinr.ru/data/presentations/notes/mpd_phys-002.pdf

http://mpd.jinr.ru/data/presentations/notes/mpd_phys-002.pdf



http://qfthep.sinp.msu.ru/talks2019/1569396682_QFTHEP_2019_Parfenov.pdf

Event plane resolution correction factors



Good performance in the centrality range 0-80% for NICA collision energy range

24.09.2019

10

https://arxiv.org/pdf/2006.14982.pdf

ALICE Diffractive single module tested at T10 CERN

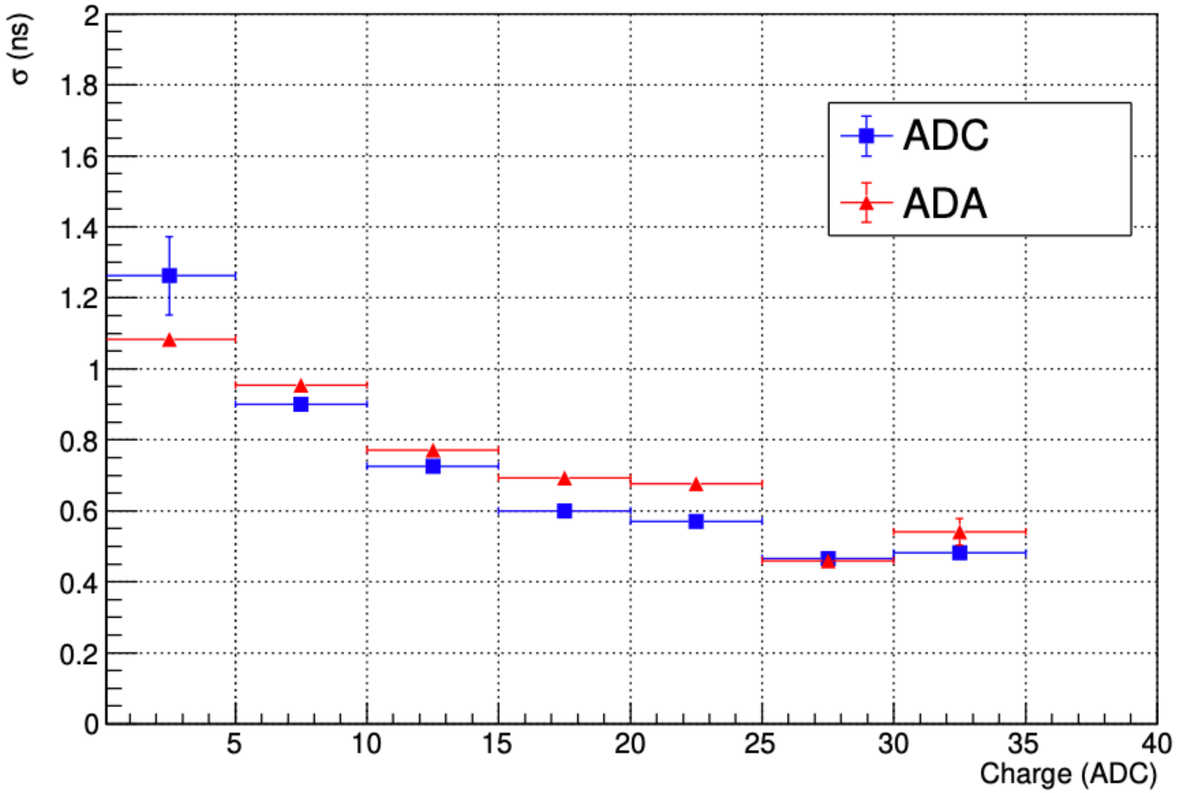


Figure 9: Time resolution as a function of the measured charge for the AD modules in the test beam.

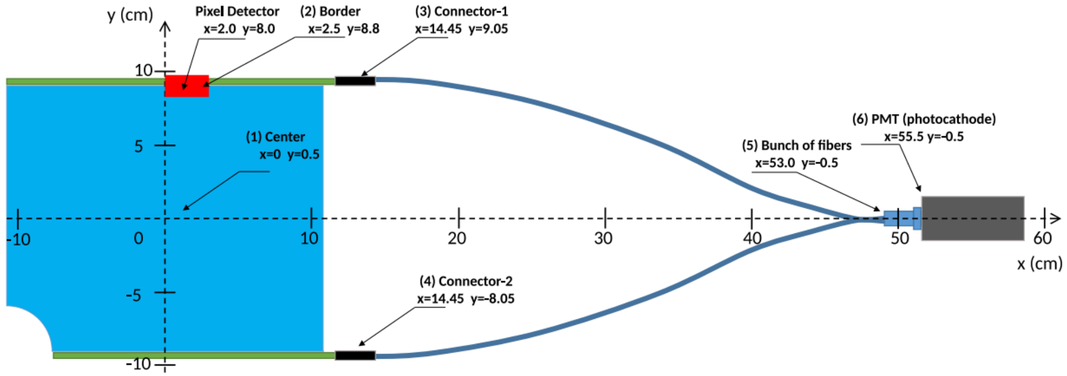


Figure 3: Location of the scintillator, the WLS bars, the fibres, the PMT, and the pixel detector, as well as the definition of the coordinate system whose origin lies at the centre of the plastic scintillator.