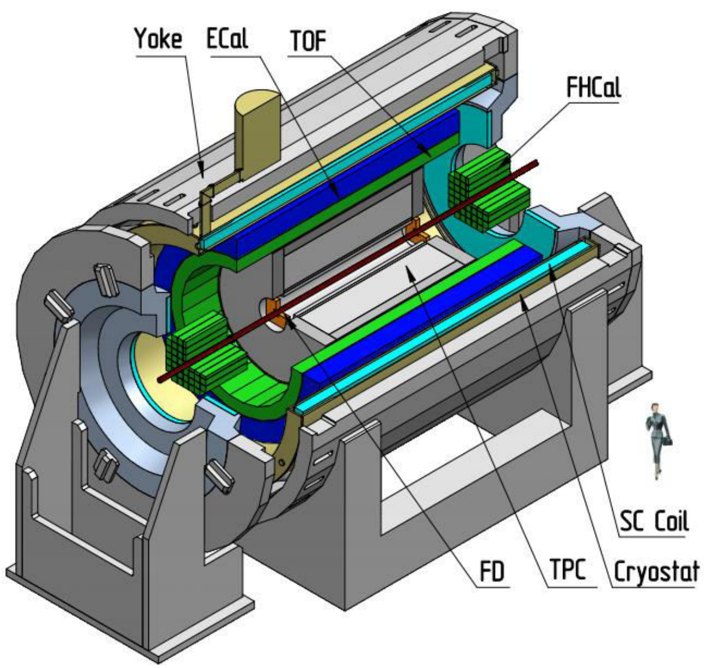
# Simulation of the MPD trigger – II

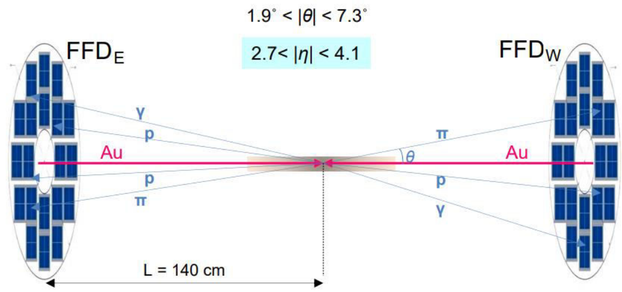
V. Riabov for the MPD

- ❖ A follow-up of my previous PF presentation on 17.06.2021
- ❖ Joint effort of many groups:
  - ✓ PHQMD event generator: V. Kireyeu
  - ✓ Centrality determination: P. Parfenov, D. Idrisov, V. Luong, A. Taranenko
  - ✓ FFD operation and simulation: S. Lobastov, V. Yurevich
  - ✓ FHCAL operation and simulation: M. Golubeva, A. Ivashkin

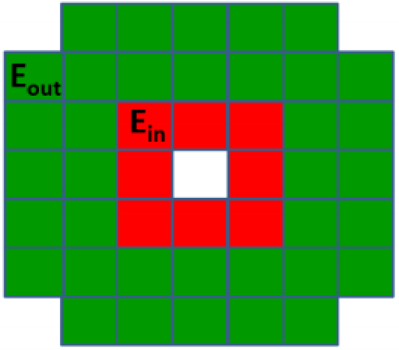
# Trigger detectors at forward rapidity




- FFD (Fast Forward Detector):
  - ✓ fast event triggering
  - ✓ $T_0$ for time measurements in the TOF and ECAL




- FHCAL (Forward Hadron Calorimeter) – detector for event centrality and reaction plane measurements with potential for event triggering




$2 < |\eta| < 5$

$\sim 1\text{x}1\ \text{m}^2$

- MPD challenges at NICA energies:
  - ✓ low multiplicity of particles produced in heavy-ion collisions
  - ✓ particles are not ultra-relativistic (even the spectator protons)

# Simulation chain and results

- Event generators: DCM-QGSM-SMM* (GSI version) and PHQMD:
  - ✓ 150 k events, realistic z-vertex with $\sigma \sim 24$ cm, minbias b = 0-16 fm
  - ✓ simulation of hadron production at midrapidity → event multiplicity/centrality
  - ✓ simulation of hadron and fragment production at forward rapidity → acceptance of FFD & FHCAL
- All detectors are simulated in the framework of the MpdRoot (Geant-4)
- Centrality determination following report by P. Parfenov at Physics Forum from April, 15:
  - ✓ used looser track selections in the TPC: nHits > 10, $|\eta| < 1$, $p_T > 50$ MeV/c, $|DCA| < 5$ cm
- Predictions for trigger efficiency show model dependence. However basic performance parameters and trends are predicted to be the same:
  - ✓ FFD || FHCAL trigger provides high trigger efficiency, $\varepsilon > 95\%$
  - ✓ Very weak z-vertex dependence of efficiency within $|Z_{vrtx}| < 50$ cm
  - ✓ $T_0$ can be measured with $\sigma \leq 50$ ps in AuAu@11 at all centralities and in AuAu@5 at 0-30%
  - ✓ Mean value of $T_0$ shows rather strong multiplicity dependence (physics, not a detector effect)
  - ✓ z-vertex can be measured with resolution < 5 and 25 cm with the FFD and FHCAL, respectively

* Statistical Multifragmentation Model (**SMM**)

# Questions asked

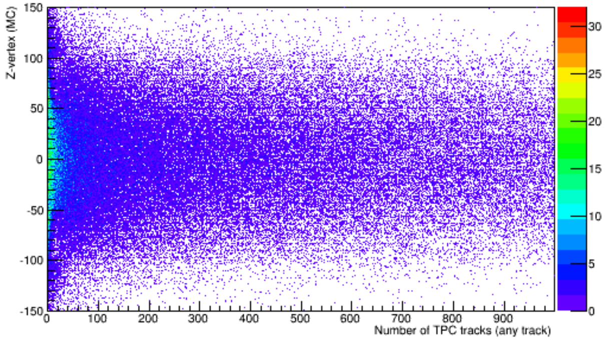
- What could be expected for trigger efficiency in Au+Au@5-11 with a wider z-vertex distribution, which is a possible experimental situation, $\sigma$ = 50 cm
- What could be expected for BiBi@9.2, the most probable first-beam configuration?
- What could be expected for light nuclei collisions?

# Au+Au collisions with wide z-vertex distribution

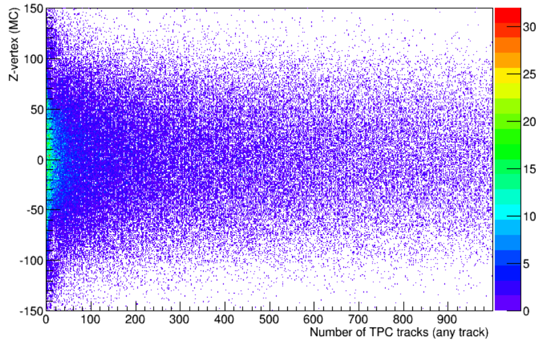
# Simulation framework - I

- Event generators: DCM-QGSM-SMM* (GSI version) and PHQMD:
  - ✓ 150 k events, realistic z-vertex with σ = 50 cm, minbias b = 0-16 fm
  - ✓ full chain of event simulation and reconstruction using MpdRoot with Geant-4
- Event selection:
  - ✓ some event generators generate events with zero activity at large values of impact parameter (b)
  - ✓ selected events that have at least one primary generated particle at |η| < 1.0
- Z-vertex reconstruction:
  - ✓ meaningful vertex can be reconstructed at $|Z_{vrtx}| < 100$ cm
  - ✓ lower efficiency of track reconstruction at small number of tracks

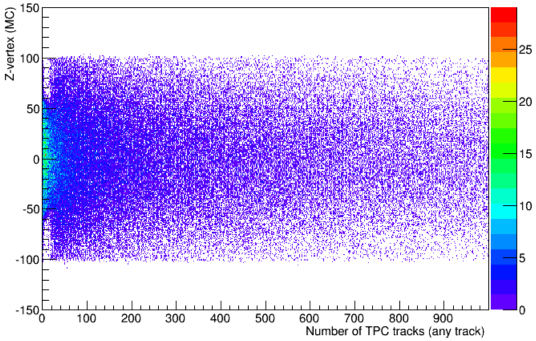
**Generated: Zvrtx vs. $N_{tr}^{TPC}$**




**Vertex is reconstructed (any value)**




**Vertex is reconstructed (within 5σ from true value)**

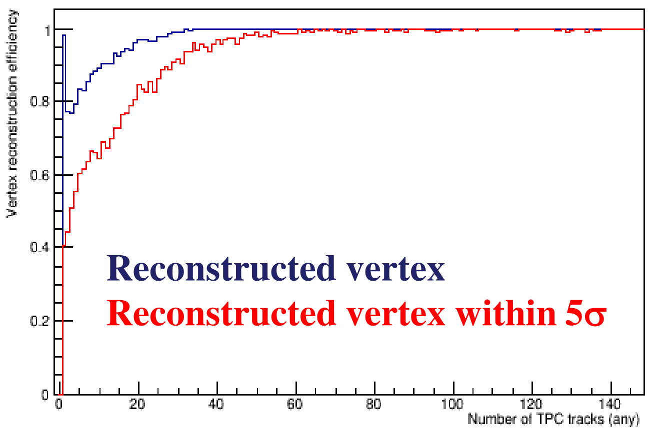


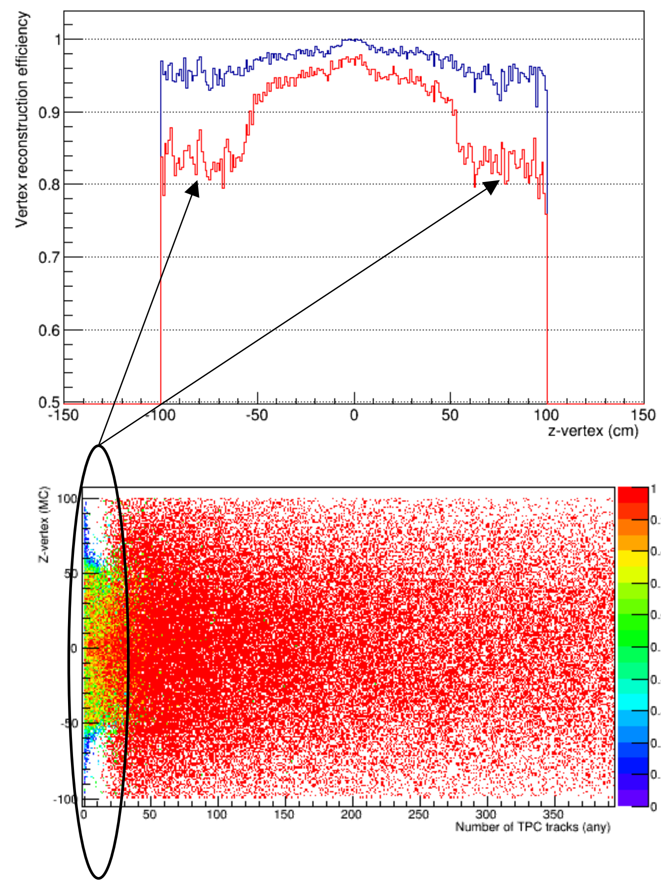

* Statistical Multifragmentation Model (**SMM**)

# Simulation framework - II

- Z-vertex reconstruction:
  - ✓ vertex can be reconstructed at $|Z_{vrtx}| < 100$ cm
  - ✓ lower efficiency of track reconstruction at small number of tracks
  - ✓ distribution $\left(z_{vrtx}^{reco} - z_{vrtx}^{gen}\right)$ is not Gaussian, long tails beyond 5σ
  - ✓ significant $Z_{vrtx}$ dependence at low multiplicities

**Generated: |Zvrtx| < 100 cm**



# Simulation framework - III

- Problems with centrality determination:
  - ✓ low TPC multiplicity in peripheral collisions

**AuAu@11, $|Z_{vrtx}| < 50$ cm**

| Centrality class | $N_{tracks}^{TPC}$ |
|---|---|
| 90-100% | 1-4 |
| 80-90% | 5-12 |
| 70-80% | 12-24 |
| 60-70% | 24-44 |
| 50-60% | 44-73 |
| 40-50% | 73-114 |
| 30-40% | 114-170 |
| 20-30% | 170-245 |
| 10-20% | 245-349 |
| 0-10% | 349-587 |

**AuAu@5, $|Z_{vrtx}| < 50$ cm**

| Centrality class | $N_{tracks}^{TPC}$ |
|---|---|
| 90-100% | 1-3 |
| 80-90% | 4-10 |
| 70-80% | 10-21 |
| 60-70% | 21-37 |
| 50-60% | 37-61 |
| 40-50% | 61-93 |
| 30-40% | 93-137 |
| 20-30% | 137-195 |
| 10-20% | 195-273 |
| 0-10% | 273-445 |

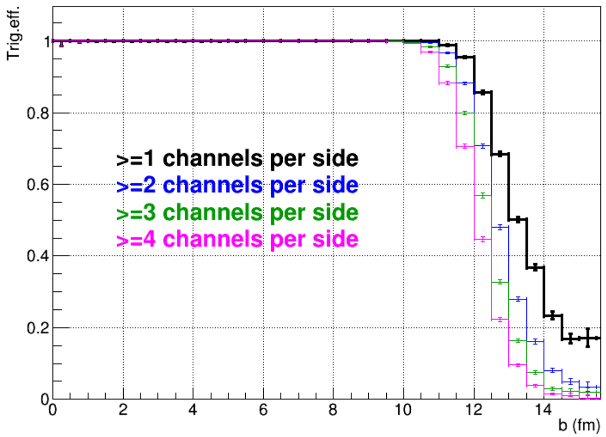
  - ✓ at large values of $|Z_{vrtx}|$ the TPC multiplicity drops → zero efficiency for peripheral collisions

- Inability to characterize peripheral events by centrality at large values of $|Z_{vrtx}|$
  + dependence of z-vertex reconstruction efficiency on multiplicity and vertex
  + no vertex reconstruction at $|Z_{vrtx}| > 100$ cm:

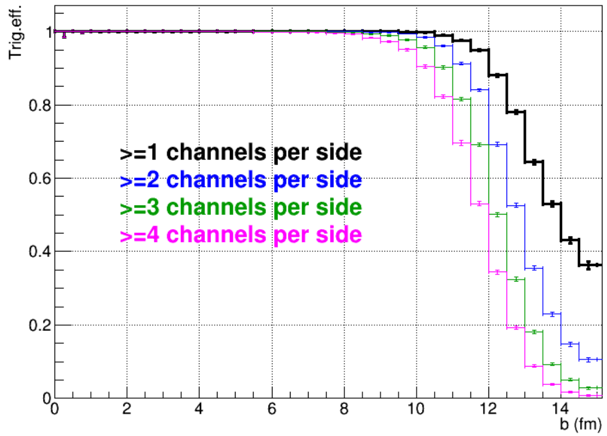
  → no framework for centrality determination at large $|Z_{vrtx}|$
  → further results will be presented as a function of impact parameter only
  → **NO CUT on z-vertex in the following studies (used |Zvrtx| < 50 cm in previously)**

# FFD trigger efficiency

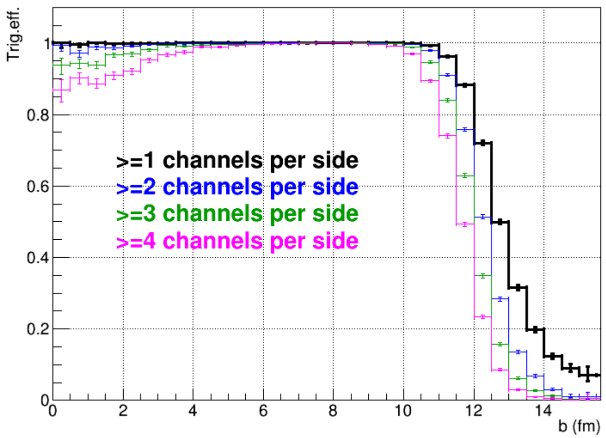
- DCM-QGSM-SMM, AuAu@11



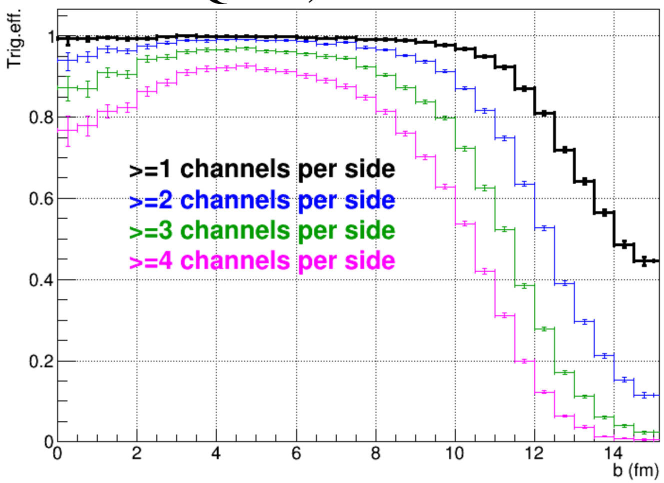

- PHQMD, AuAu@11




- DCM-QGSM-SMM, AuAu@5



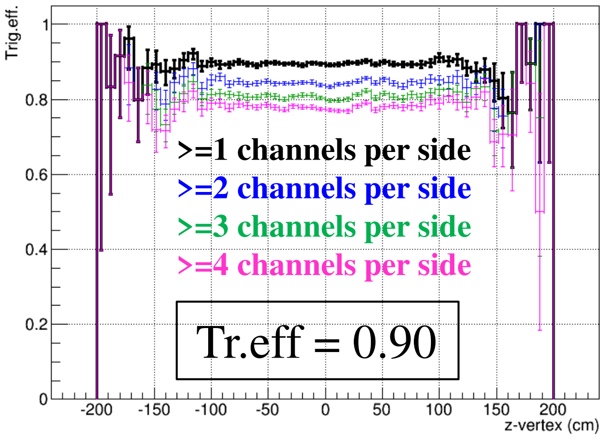

- PHQMD, AuAu@5



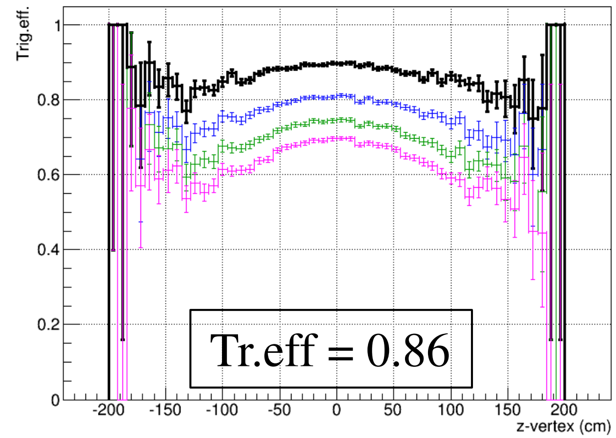

- Efficiency is ~ 100% in central and semicentral collisions
- " at least one-channel per side" is a preferred option for FFD triggering

# FFD efficiency vs. true z-vertex

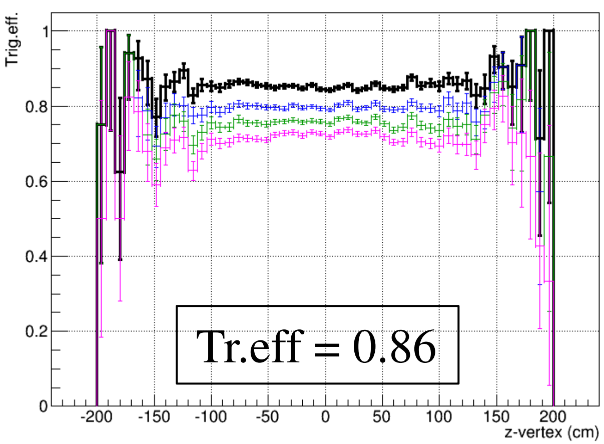
DCM-QGSM-SMM, AuAu@11



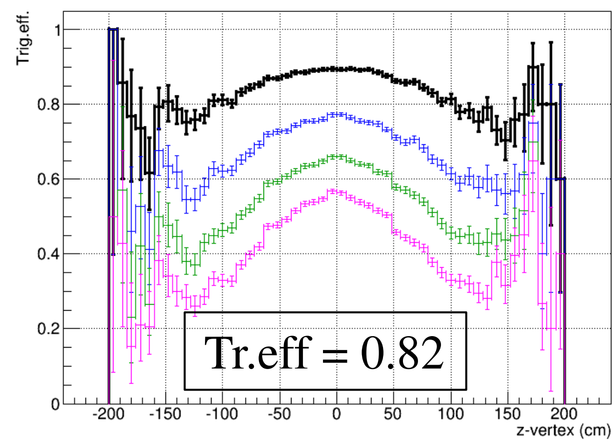

PHQMD, AuAu@11




DCM-QGSM-SMM, AuAu@5




PHQMD, AuAu@5

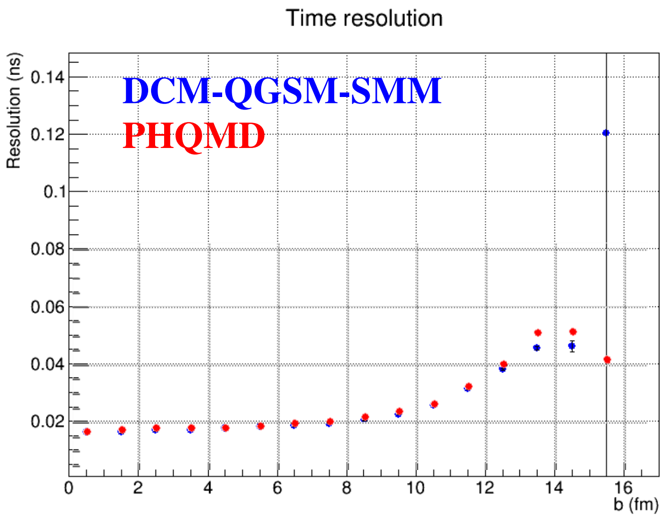



- FFD trigger efficiency does not show z-vertex dependence in DCM-QGSM-SMM
- FFD trigger efficiency shows strong z-vertex dependence in PHQMD, more prominent at lower $\sqrt{s}$

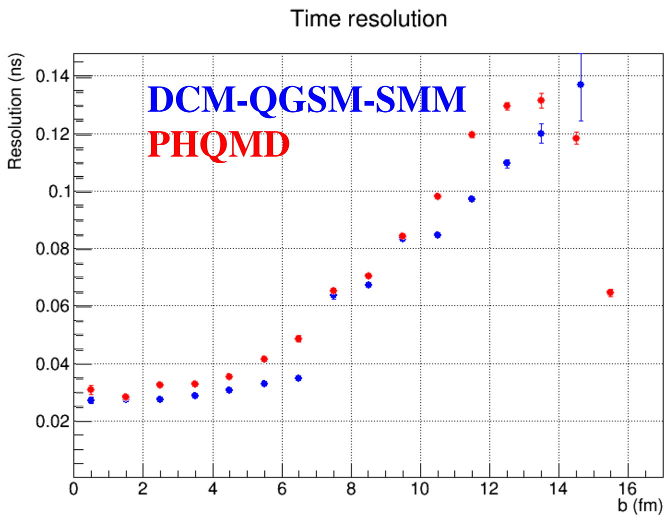
# FFD, $T_0$ resolution

- $T_0 = (T_{FFDE} + T_{FFDW}) / 2 - L/c$

- AuAu@11, $T_0$ resolution vs. centrality



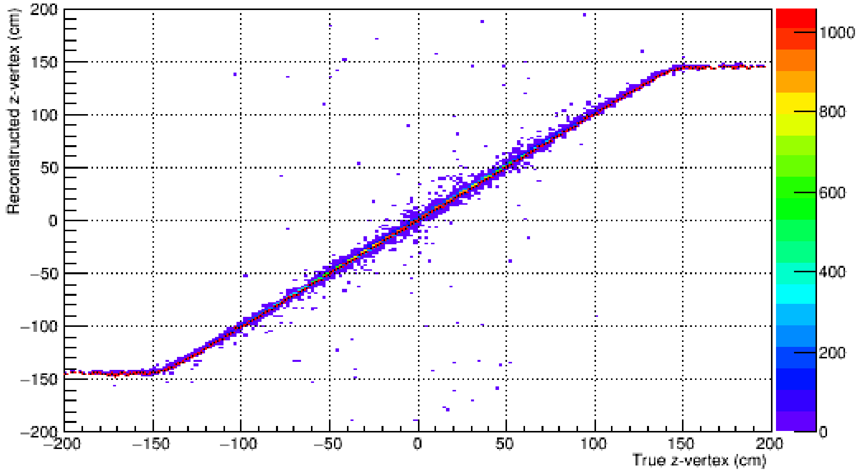

- AuAu@5, $T_0$ resolution vs. centrality



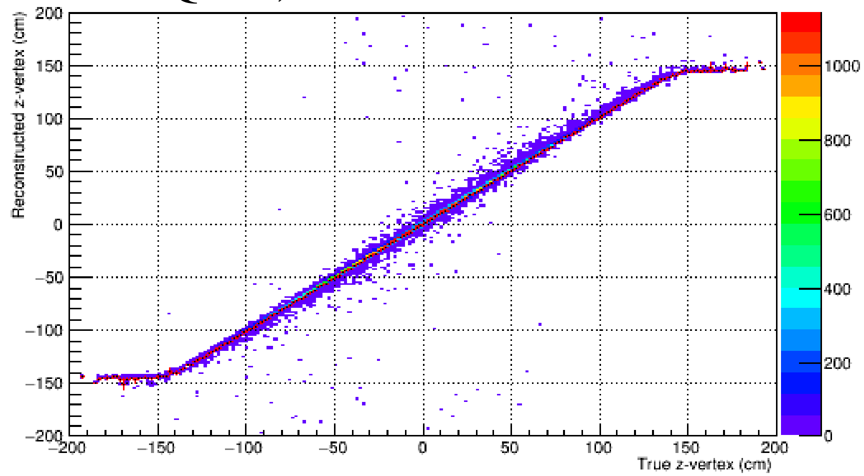

- With TOF resolution of 80-100 ps, the $T_0$ resolution is required to be ~ 50 ps
- The condition is satisfied in AuAu@11 at all centralities
- The condition is satisfied only in central AuAu@5; $T_0$ resolution becomes comparable to TOF resolution at centralities > 50-70%
- Time resolution is comparable to that with option $|Z_{vertex}| < 50$ cm
- Similar $T_0$ centrality bias is preserved (dependence of $<T_0>$ on multiplicity)

# FFD, z-vertex vs. true vertex

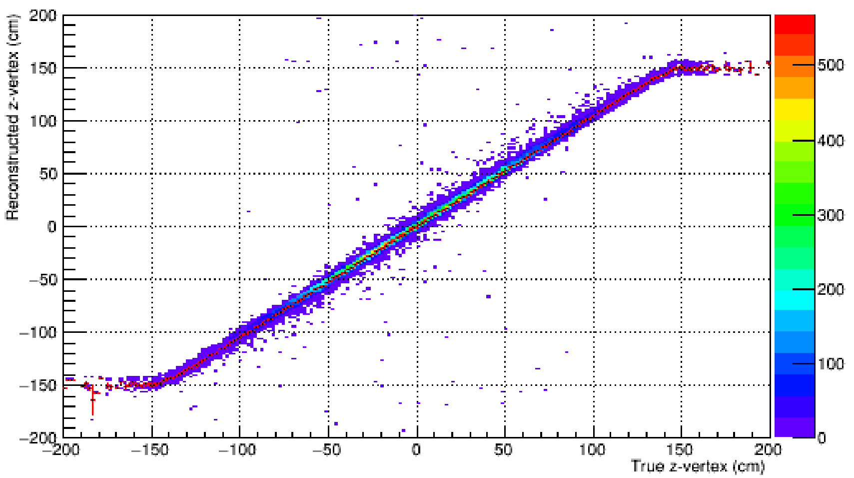
- $Z = (T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]
- DCM-QGSM-SMM, AuAu@11



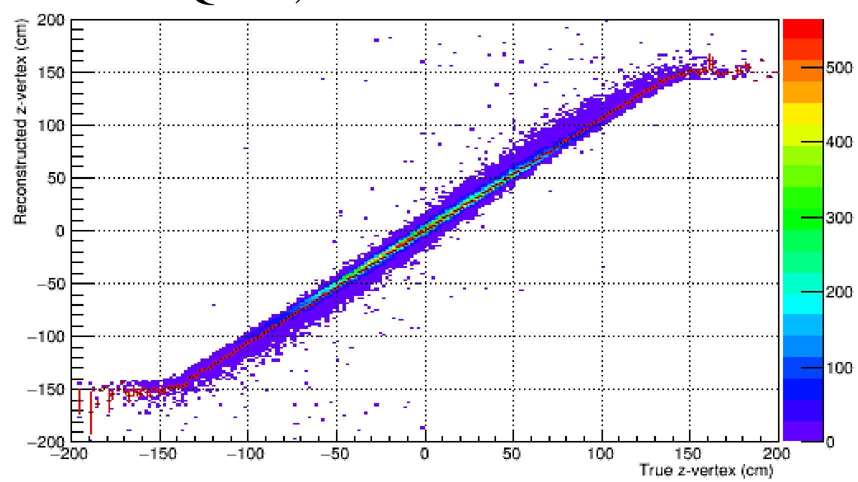

- PHQMD, AuAu@11




- DCM-QGSM-SMM, AuAu@5



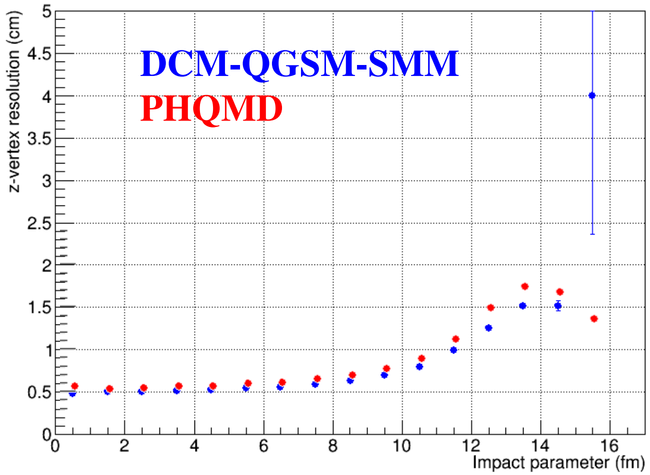

- PHQMD, AuAu@5



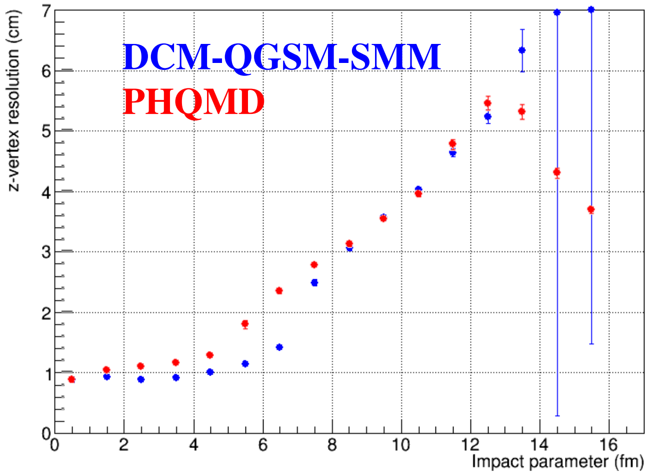

- Z-vertex can be reconstructed up to 140 cm; bias at lower energy (z-reconstructed > z-true)

# FFD, z-vertex resolution

- $Z = (T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]
- AuAu@11, z-resolution vs. centrality




- AuAu@5, z-resolution vs. centrality



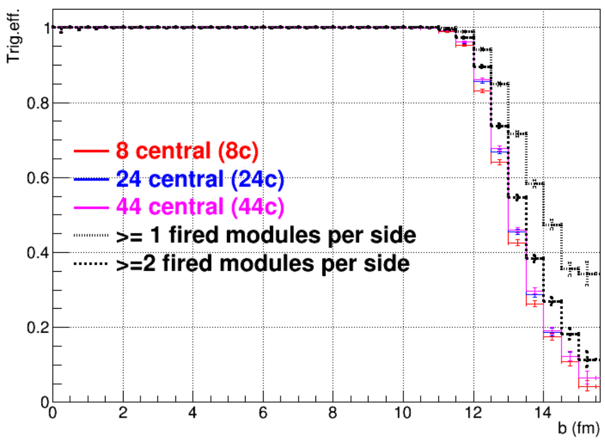

- Z-vertex resolution is < 2 cm and < 6 cm in AuAu@11 and AuAu@5, respectively
- Z-vertex resolution is comparable to that with $|z_{vertex}| < 50$ cm

# FFD: Summary

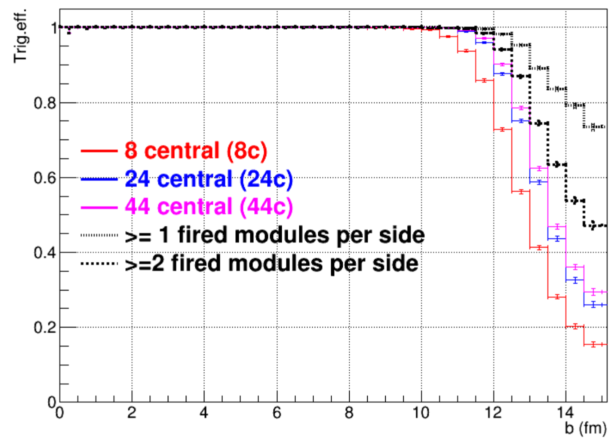
- FFD trigger efficiency can have a strong z-vertex dependence at $|Z_{vrtx}| > 50$ cm (predicted by PHQMD but not confirmed by DCM-QGSM-SMM). The dependence is more prominent at lower collision energy
- Z-vertex can be reconstructed within $|zvertex| < 140$ cm with a resolution < 2(6) cm in AuAu@11(5)
- $T_0$ and z-vertex resolutions are comparable to that with a cut of $|Z_{vertex}| < 50$ cm

# FHCAL trigger efficiency

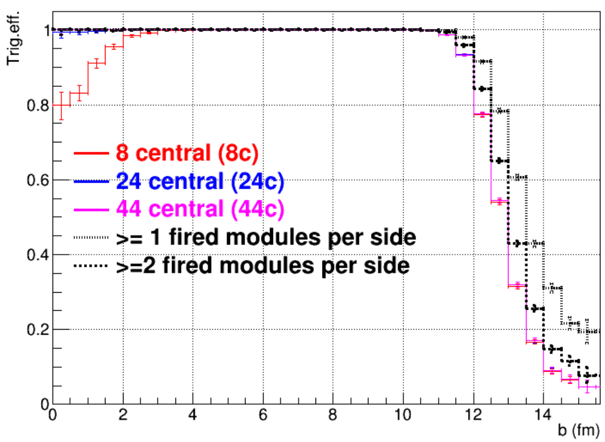
- DCM-QGSM-SMM, AuAu@11



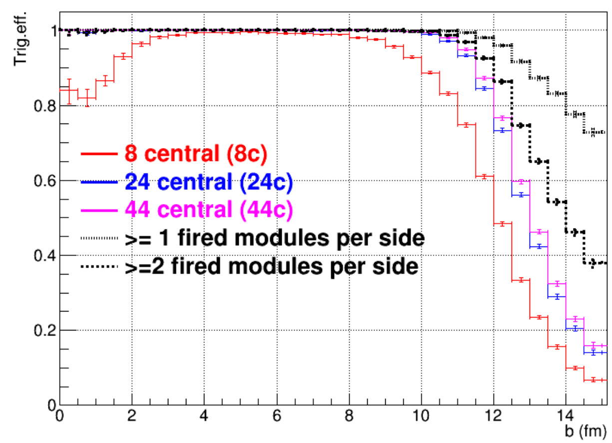

- PHQMD, AuAu@11




- DCM-QGSM-SMM, AuAu@5



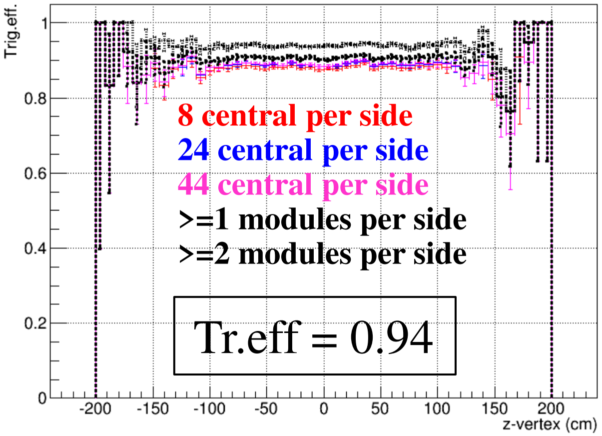

- PHQMD, AuAu@5



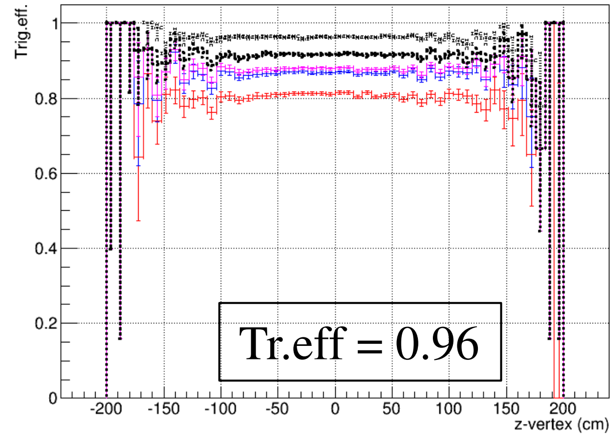

- Efficiency is ~ 100% in central and semicentral collisions
- “ at least one-module per side” is a preferred option for FHCAL triggering

# FHCAL efficiency vs. true z-vertex

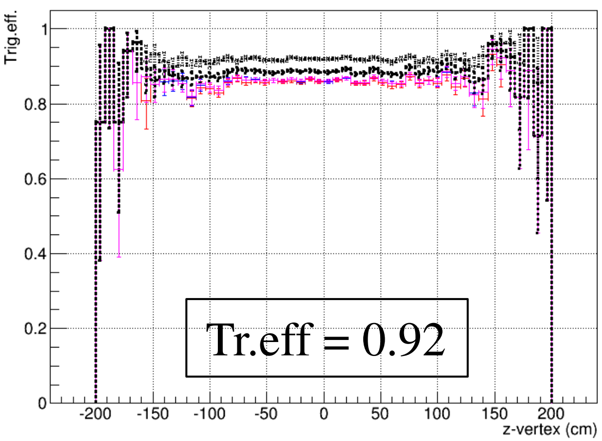
DCM-QGSM-SMM, AuAu@11



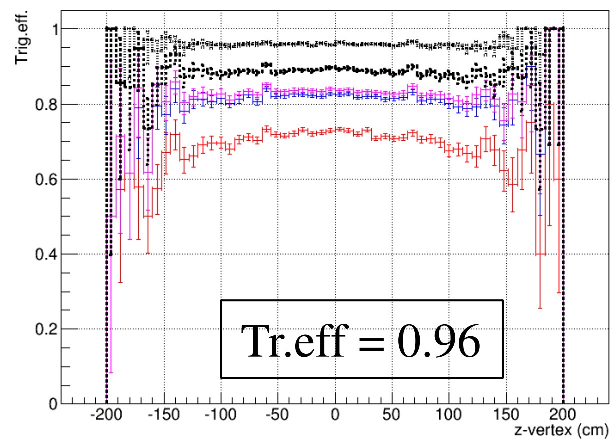

PHQMD, AuAu@11




DCM-QGSM-SMM, AuAu@5



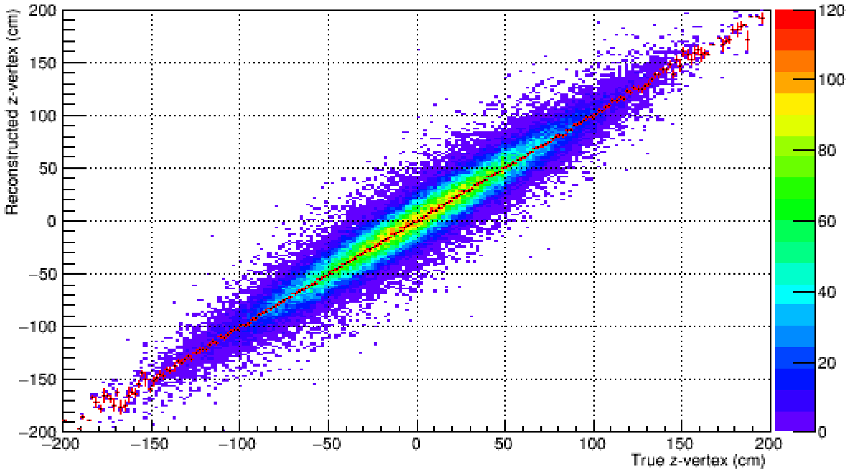

PHQMD, AuAu@5



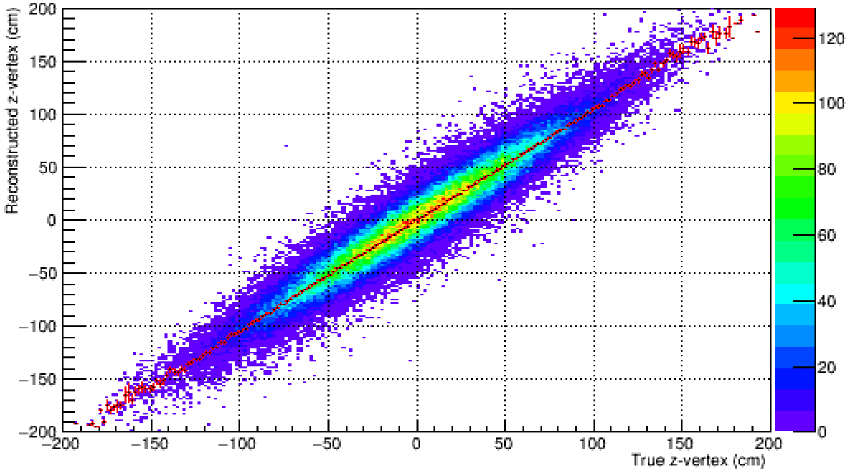

- FHCAL trigger efficiency does not show z-vertex dependence (any selections)
- FHCAL trigger efficiency is ~ 0.93 in all systems predicted by two event generators

# FHCAL, z-vertex vs. true vertex

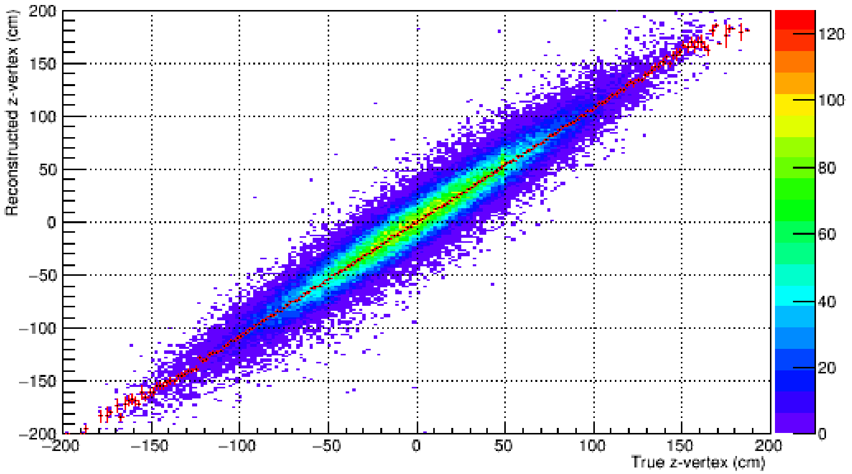
- Z = $(T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]
- DCM-QGSM-SMM, AuAu@11



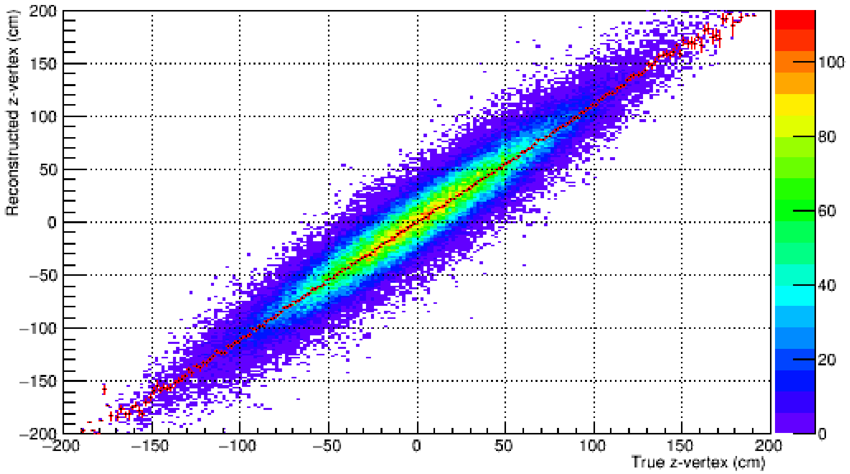

- PHQMD, AuAu@11




- DCM-QGSM-SMM, AuAu@5



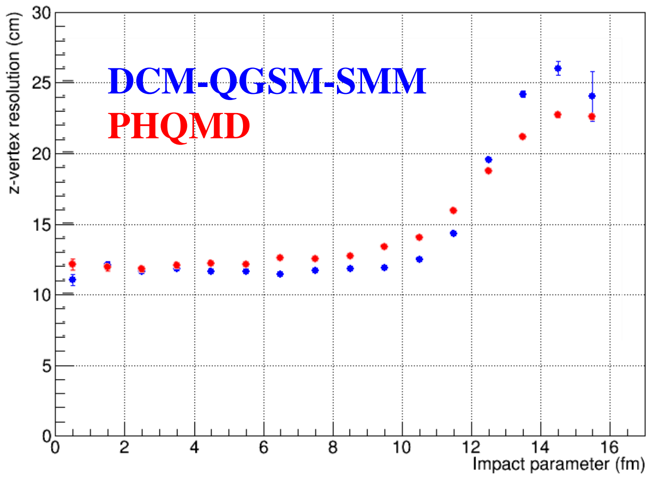

- PHQMD, AuAu@5



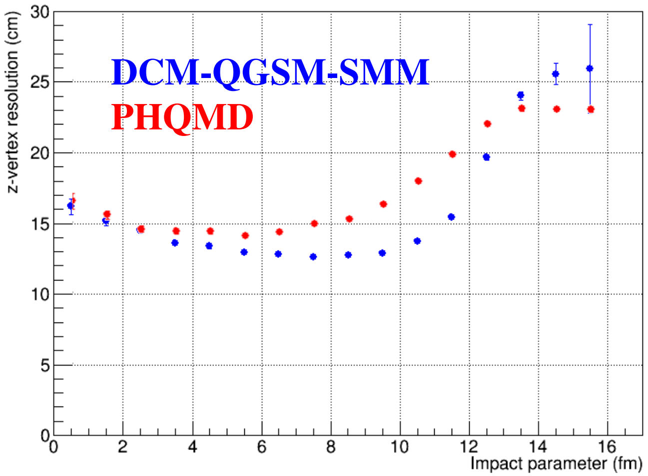

- Z-vertex can be reconstructed in the whole range
- Observe energy-dependent distortions at lower energies (z-reconstructed > z-true)

# FHCAL, z-vertex resolution

- $Z = (T_{FHCALW} - T_{FHCALE}) / 2 * 30$ [cm]
- AuAu@11, z-resolution vs. centrality




- AuAu@5, z-resolution vs. centrality



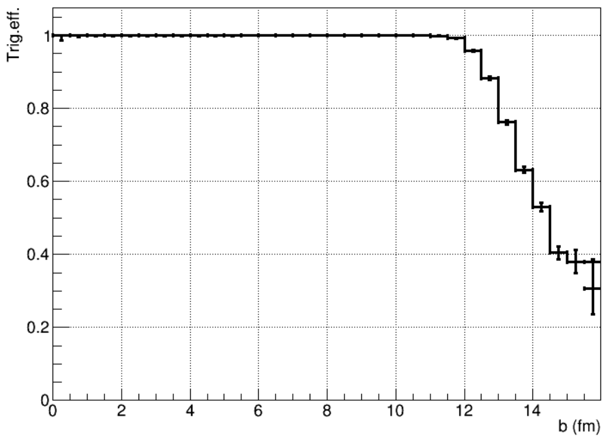

- Z-vertex resolution is < 25 cm in AuAu@5,11; weak collision energy dependence
- Z-vertex resolution is comparable to that with a cut of $|z_{vertex}| < 50$ cm

# FHCAL: Summary

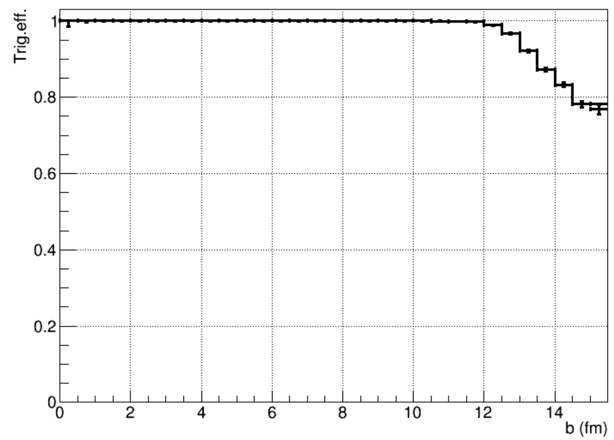
- FHCAL continues to show higher trigger efficiency compared with the FFD
- FHCAL trigger efficiency is predicted to be z-vertex independent
- FHCAL efficiency is comparable to that with a cut of $|Z_{vrtx}| < 50$ cm
- z-vertex can be reconstructed in the whole range of measurements; reconstructed z-vertex is biased towards larger values compared with true z-vertex; the bias becomes more prominent at lower collision energies and larger z-vertex values
- z-vertex resolution is comparable to that with a cut of $|Z_{vertex}| < 50$ cm

# FFD||FHCAL trigger efficiency

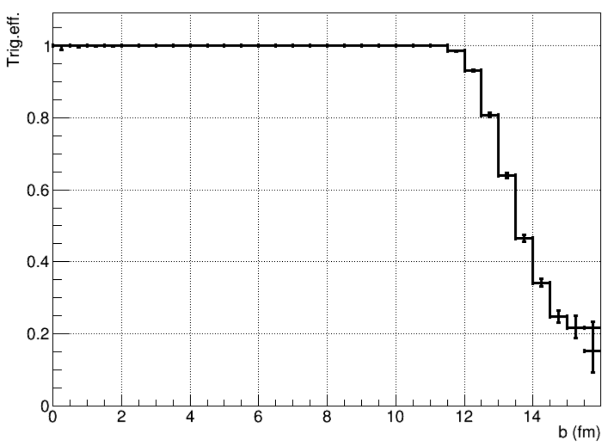
- DCM-QGSM-SMM, AuAu@11



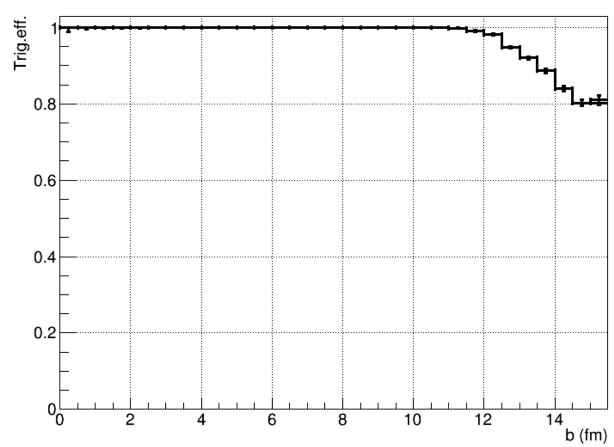

- PHQMD, AuAu@11




- DCM-QGSM-SMM, AuAu@5



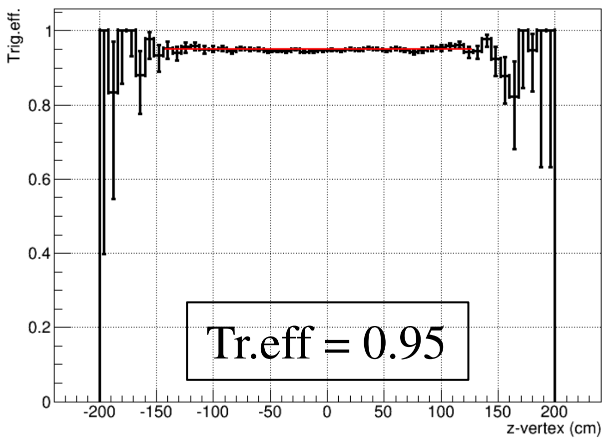

- PHQMD, AuAu@5



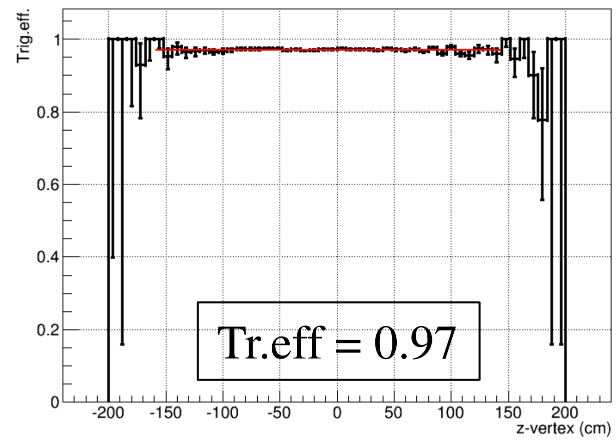

- Efficiency is ~ 100% in central and semicentral collisions
- FFD||FHCAL efficiency is larger than that for the FFD or FHCAL alone

# FFD || FHCAL vs. true z-vertex

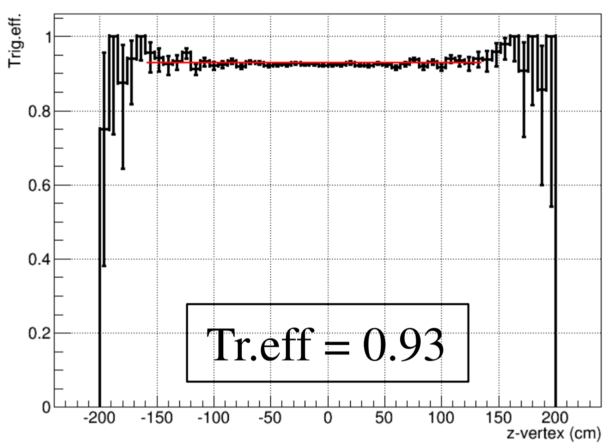
DCM-QGSM-SMM, AuAu@11



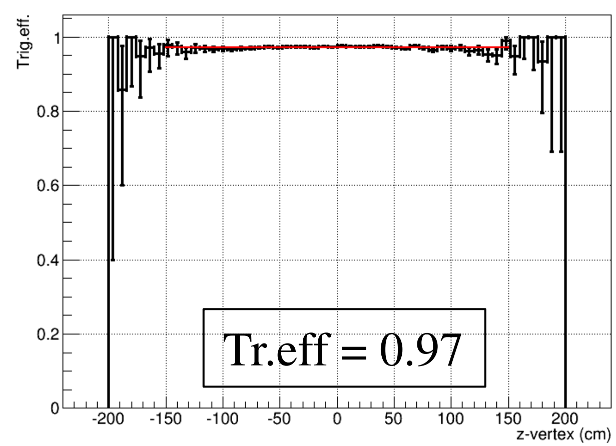

PHQMD, AuAu@11




DCM-QGSM-SMM, AuAu@5




PHQMD, AuAu@5




- FFD || FHCAL trigger efficiency does not show z-vertex dependence
- FFD || FHCAL trigger efficiency is ~ 0.95 predicted by two event generators

# Summary, wide z-vertex distribution

- FHCAL and FFD||FHCAL trigger efficiencies obtained with a wide z-vertex selection are very similar to those evaluated with a vertex cut of 50 cm
- Mean trigger efficiencies are also comparable
- $T_0$ and z-vertex resolutions are comparable; observe biases

→ FFD may have problems with triggering at large z-vertex (PHQMD)

→ FHCAL, FFD||FHCAL show good performance for event triggering in a wide z-vertex range

→ Have a remaining task of event centrality categorization at large values of z-vertex

# Trigger efficiency in BiBi@9.2

# Simulation framework

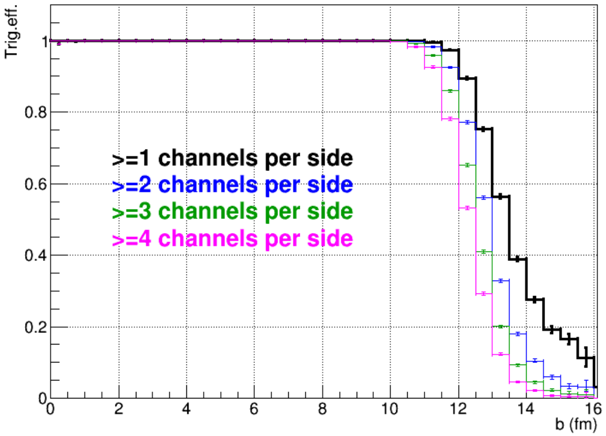
- Event generators: DCM-QGSM-SMM* (GSI version) and PHQMD:
  - ✓ 150 k events, realistic z-vertex with $\sigma$ = 23 cm, minbias b = 0-16 fm
  - ✓ full chain of event simulation and reconstruction using MpdRoot with Geant-4

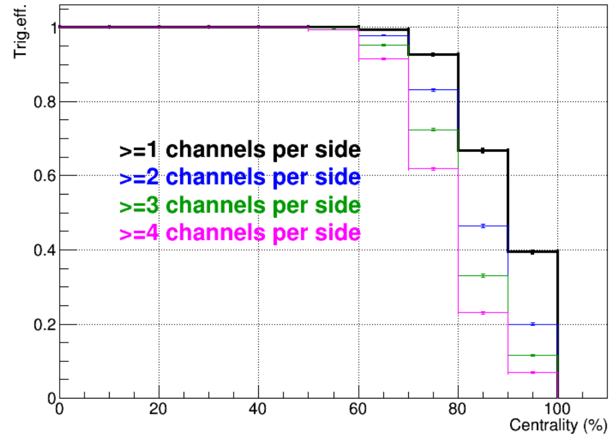
- Event selection:
  - ✓ some event generators generate events with zero activity at large values of impact parameter (b) → selected events that have at least one primary particle at $|\eta| < 1.0$
  - ✓ reconstructed z-vertex cut, $|Z_{vrtx}| < 50$ cm
  - ✓ event has at least one reconstructed track (for centrality measurements in the TPC)

* Statistical Multifragmentation Model (**SMM**)

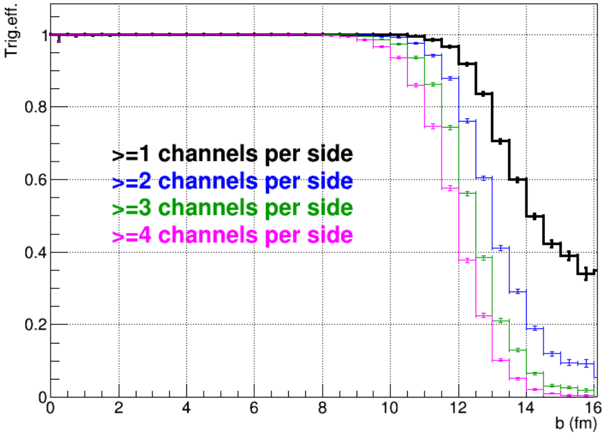
# FFD

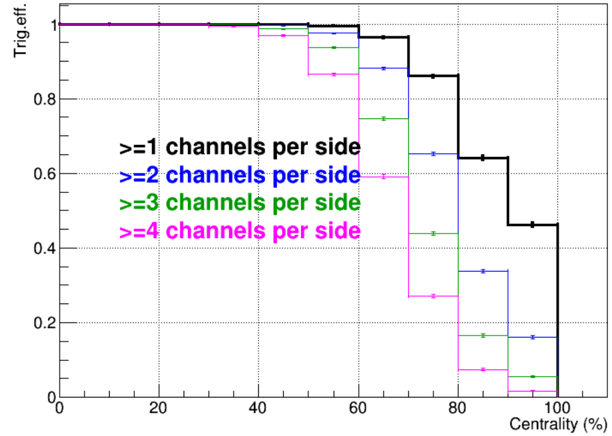
- DCM-QGSM-SMM, BiBi@9.2, trigger efficiency vs. impact parameter and centrality




- PHQMD, BiBi@9.2, trigger efficiency vs. impact parameter and centrality

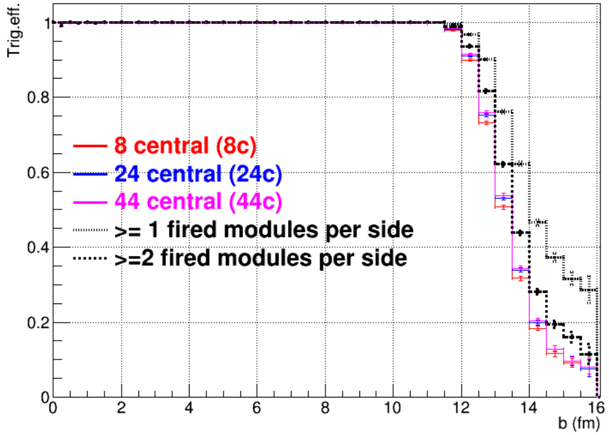


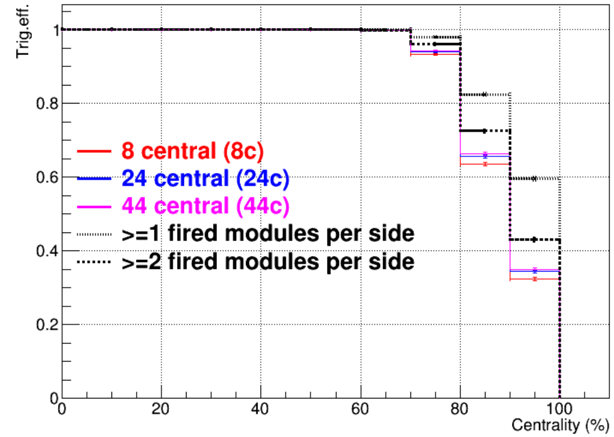




- Efficiency is ~ 100% in central and semicentral collisions and rapidly drops towards peripheral collisions → " at least one-channel per side" is a preferred option
- Similar centrality dependence for two event generators

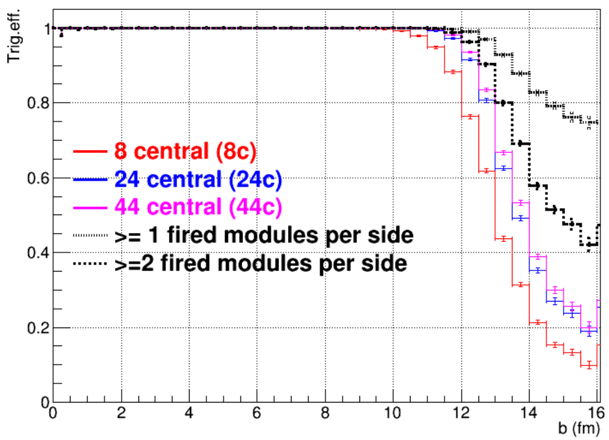
# FHCAL

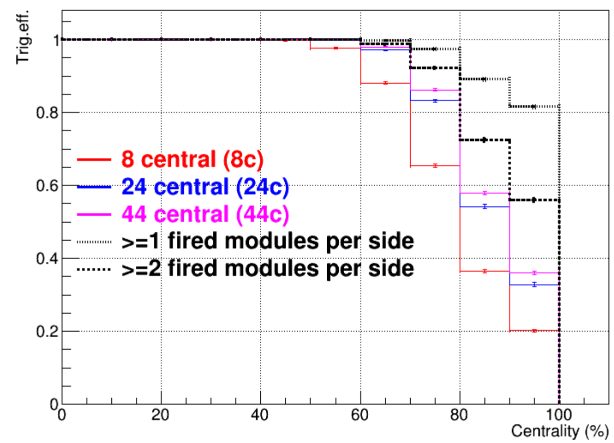
- DCM-QGSM-SMM, BiBi@9.2, trigger efficiency vs. impact parameter and centrality




- PHQMD, BiBi@9.2, trigger efficiency vs. impact parameter and centrality

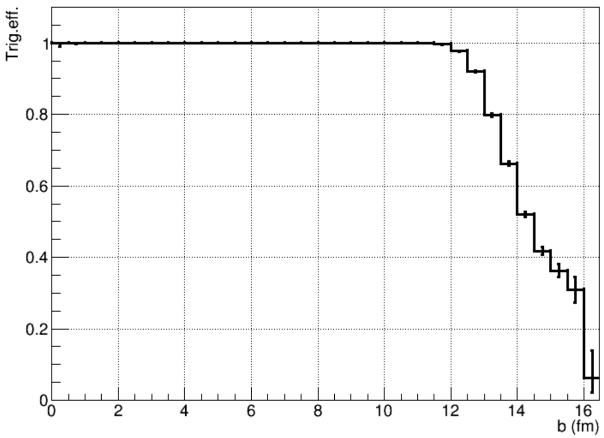


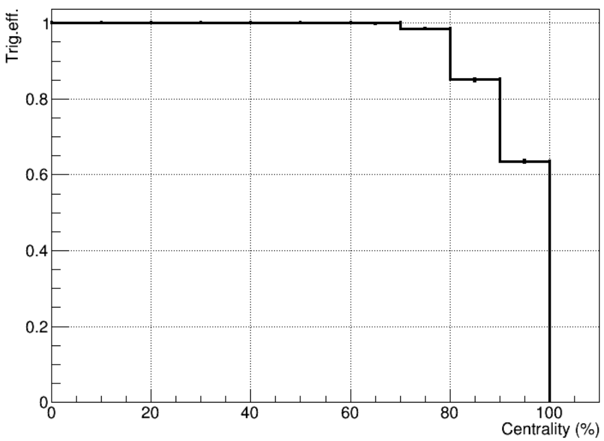




- Efficiency is ~ 100% in central and semicentral collisions and rapidly drops towards peripheral collisions → " at least one-channel per side" is a preferred option
- FHCAL efficiency > FFD efficiency in peripheral collisions
- PHQMD predicts higher efficiency

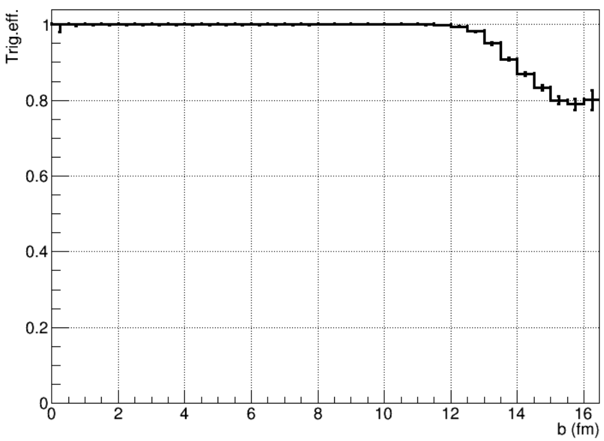
# FFD || FHCAL

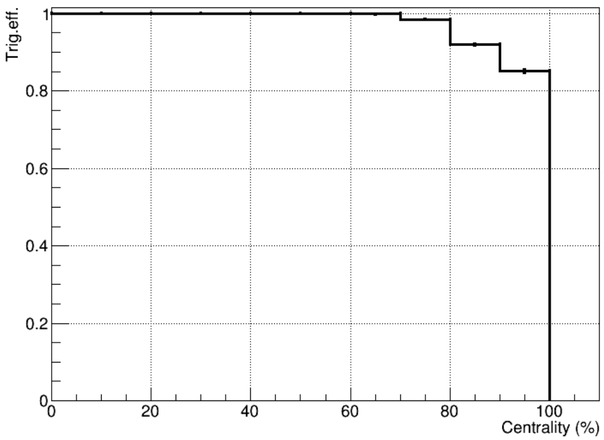
- DCM-QGSM-SMM, BiBi@9.2, trigger efficiency vs. impact parameter and centrality




- PHQMD, BiBi@9.2, trigger efficiency vs. impact parameter and centrality

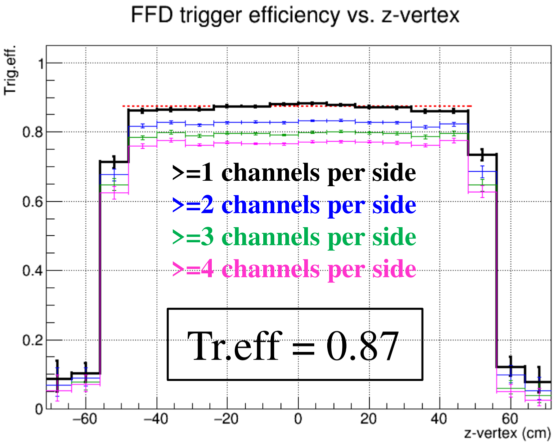


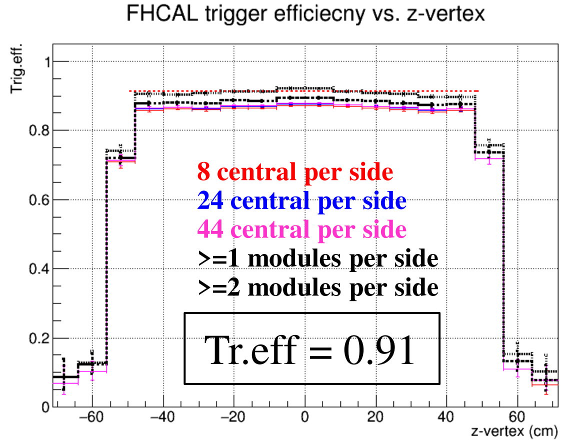



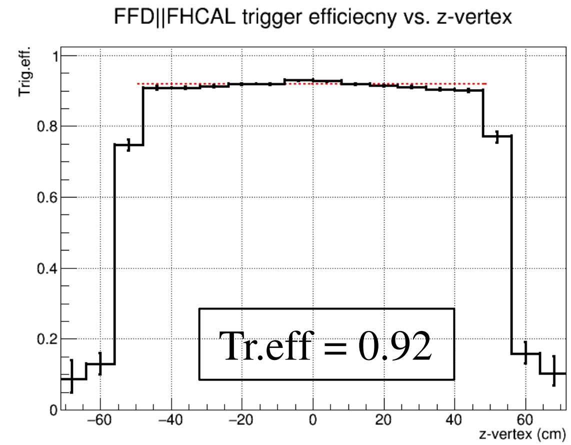

- FFD||FHCAL shows the highest efficiency
- PHQMD predicts higher efficiency

# Trigger efficiency vs. reconstructed z-vertex

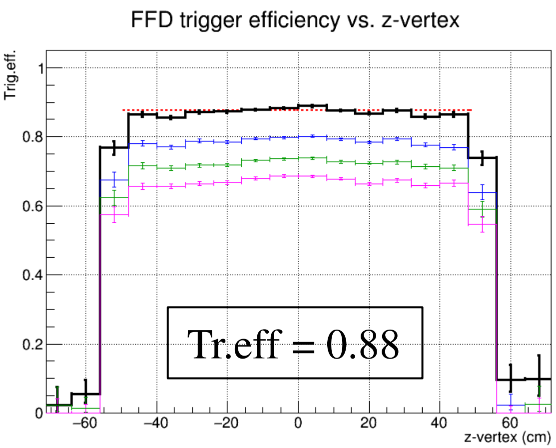
DCM-QGSM-SMM, BiBi@9.2

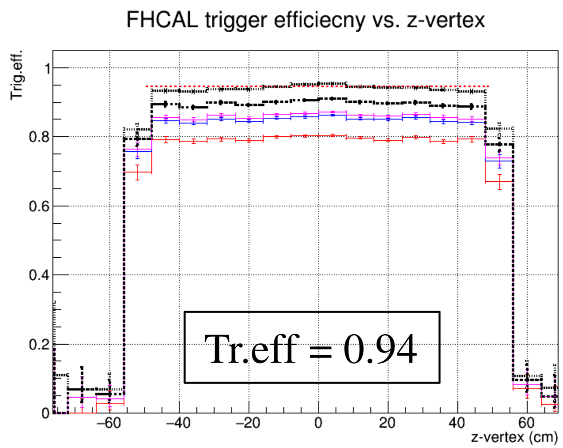


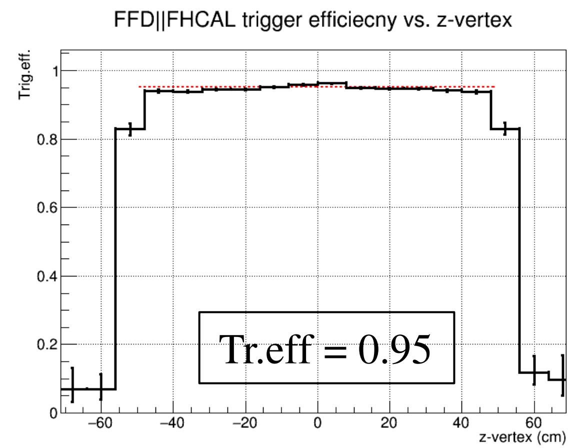




PHQMD, BiBi@9.2



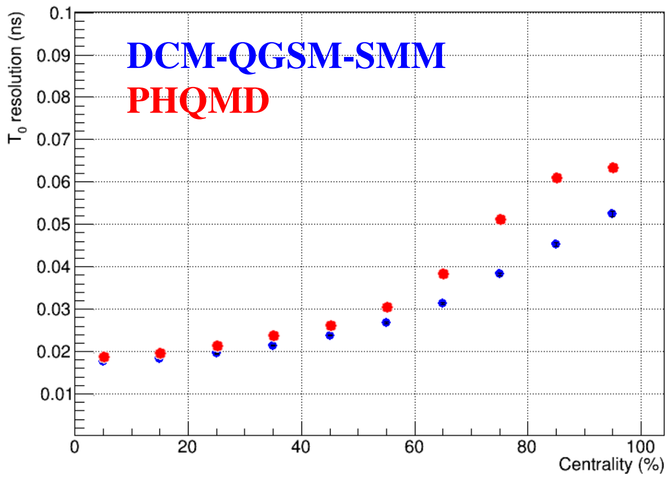



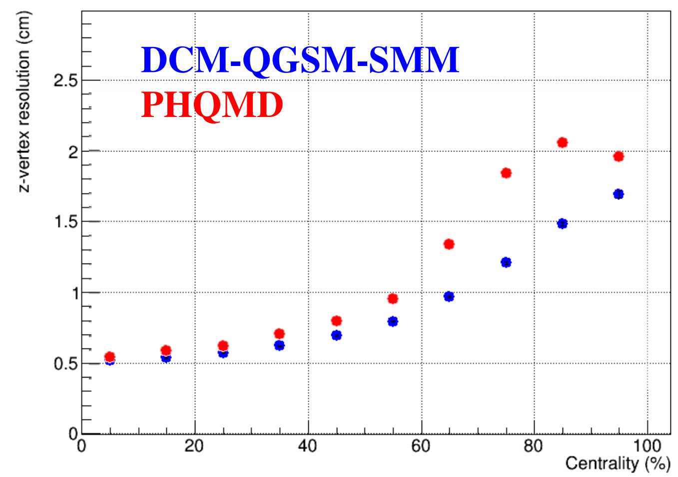

- Efficiencies do not depend on z-vertex within $|Z_{vrtx}| < 50$ cm
- FFD efficiency ~ 87-88%, FHCAL efficiency ~ 91-94 %, FFD||FHCAL efficiency ~ 92-95%

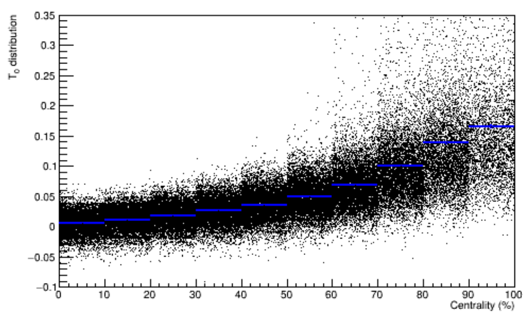
# FFD, $T_0$ and z-vertex resolution

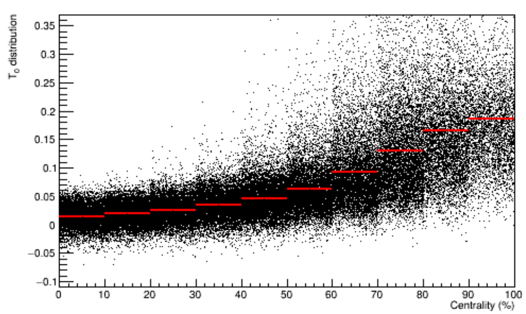
$T_0$ resolution: $T_0 = (T_{FFDE} + T_{FFDW}) / 2 - L/c$




Z-resolution: $Z = (T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]



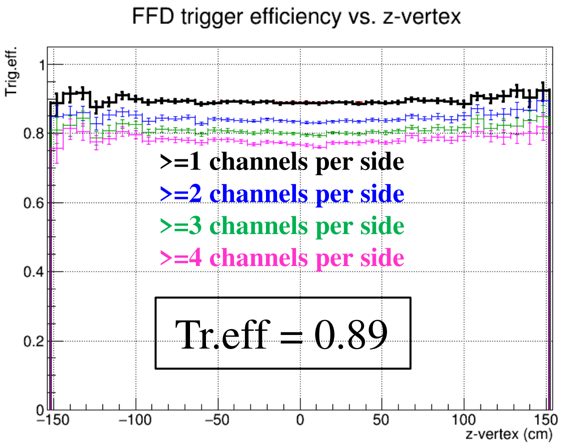



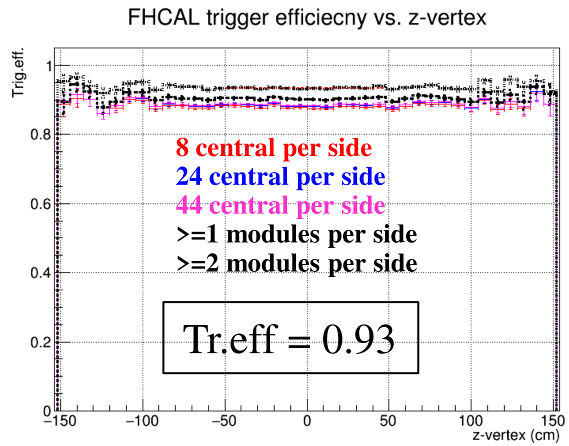



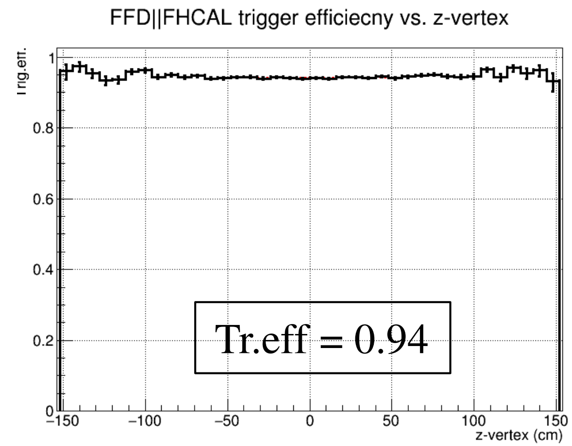

- $T_0$ resolution < 60 ps at all centralities
- z-vertex resolution < 2 cm
- Strong $T_0$ multiplicity bias (shift of mean values + non-Gaussian tails in peripheral collisions)

# Trigger efficiency vs. true z-vertex

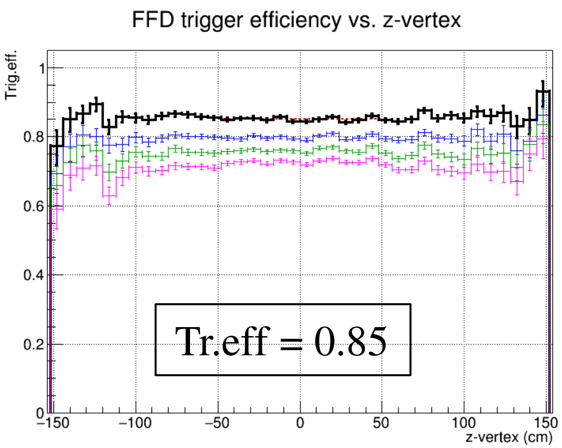
DCM-QGSM-SMM, BiBi@9.2

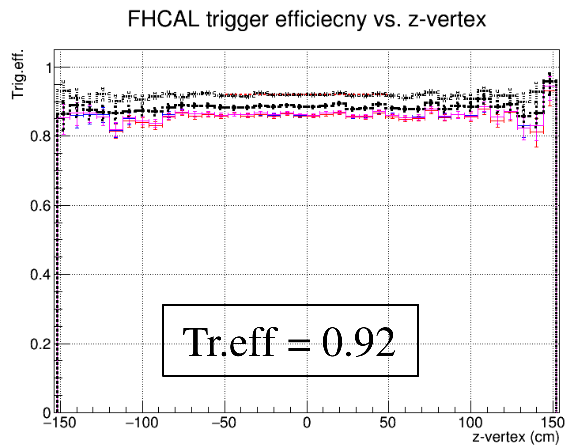


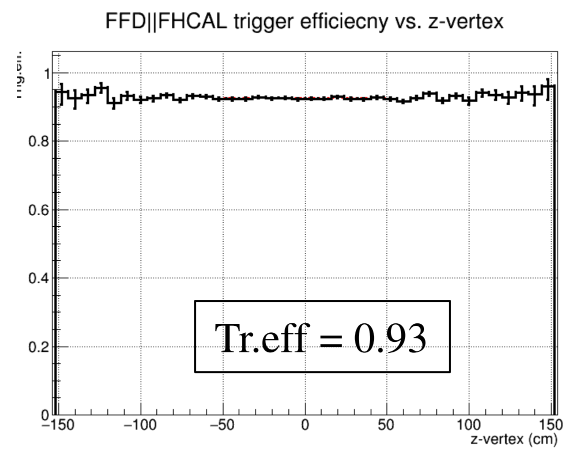




PHQMD, BiBi@9.2




- FFD, FHCAL and FFD||FHCAL efficiencies do not depend on z-vertex
- Comparable efficiencies from two event generators
- Problem of centrality event categorization at large values of z-vertex remains …

# Summary for BiBi@9.2

- Trigger performance in BiBi@9.2 is closer to that in AuAu@11 rather than in AuAu@5
  - ✓ quite high mean trigger efficiency with the FFD (~87%) and FHCAL (~93%)
  - ✓ weak z-vertex dependence of the FFD, FHCAL and FFD||FHCAL efficiencies
  - ✓ $T_0$ resolution < 60 ps, mind the multiplicity bias though
  - ✓ z-vertex resolution < 2 cm, ~ 3% bias at large values of z-vertex (non-linearity of z-reco vs. z-gen)
- FFD && FHCAL preserve high efficiency in a wide z-vertex range, up to ±150 cm. However, a framework for centrality measurements in the wide z-vertex range has yet to be established

→ FFD & FHCAL will cover the triggering needs in BiBi@9.2

# Collisions of light nuclei

# Simulation framework

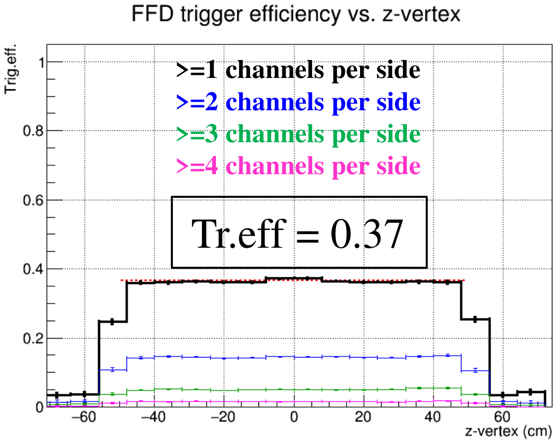
- Event generator: DCM-QGSM-SMM* (GSI version):
  - ✓ C+C @ 9.2 GeV, 600 k events, realistic z-vertex with $\sigma$ = 23 cm, minbias b = 0-8 fm
  - ✓ full chain of event simulation and reconstruction using MpdRoot with Geant-4

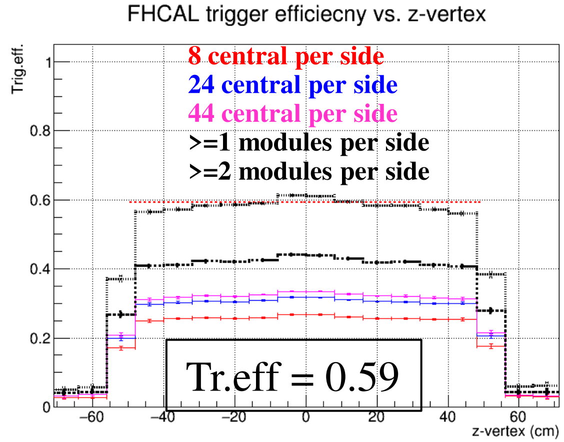
- Event selection:
  - ✓ selected events that have at least one primary generated particle at $|\eta| < 1.0$
  - ✓ reconstructed z-vertex cut, $|Z_{vrtx}| < 50$ cm
  - ✓ event has at least one good reconstructed track (for centrality measurements in the TPC)

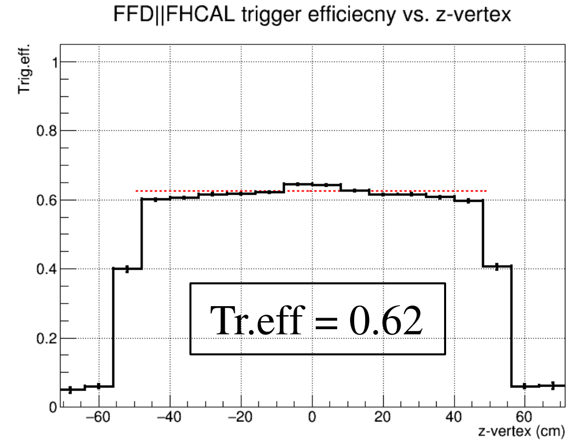
* Statistical Multifragmentation Model (**SMM**)

# Mean trigger efficiency, CC@9.2

DCM-QGSM-SMM, CC@9.2



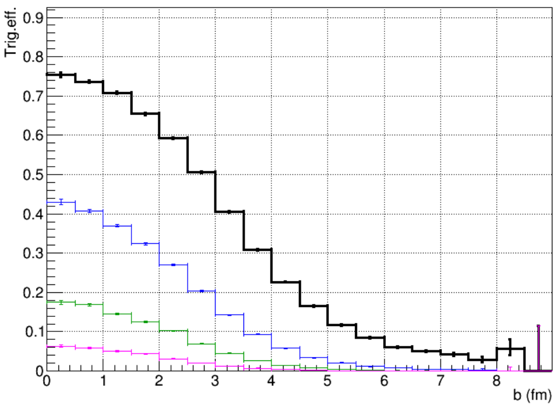



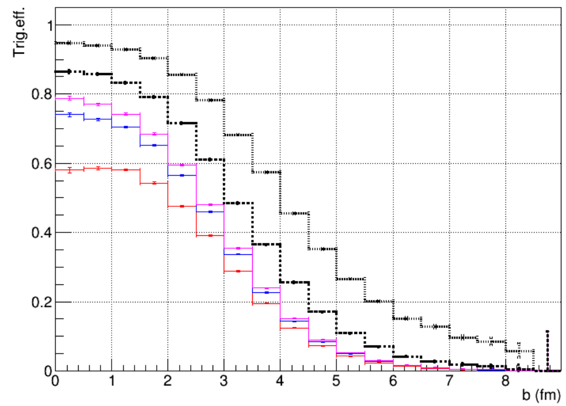

- FFD, FHCAL and FFD||FHCAL efficiencies show modest dependence on z-vertex
- Much lower efficiencies are observed …

# FFD, FHCAL and FFD||FHCAL, CC@9.2

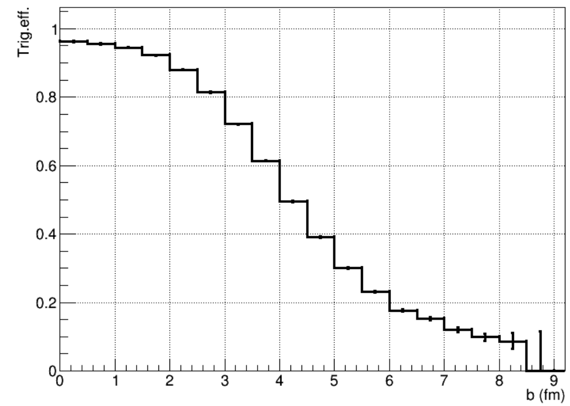
FFD



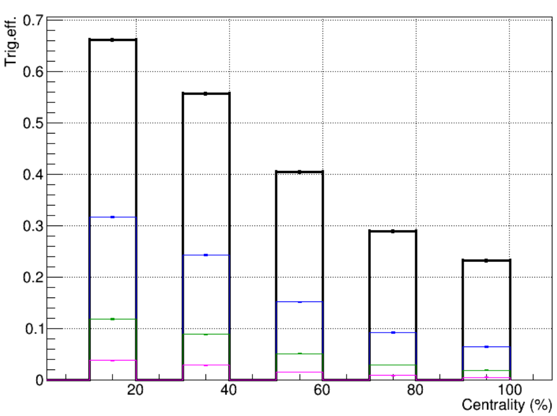

FHCAL



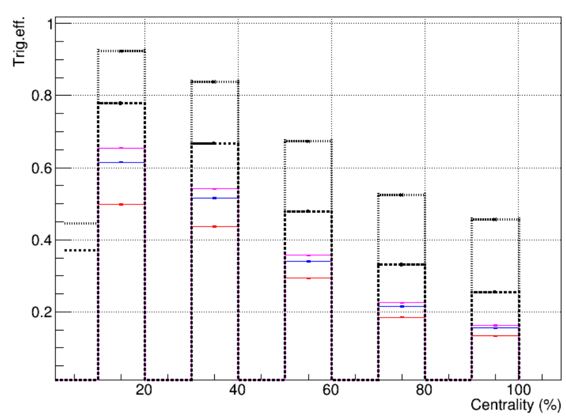

FFD || FHCAL

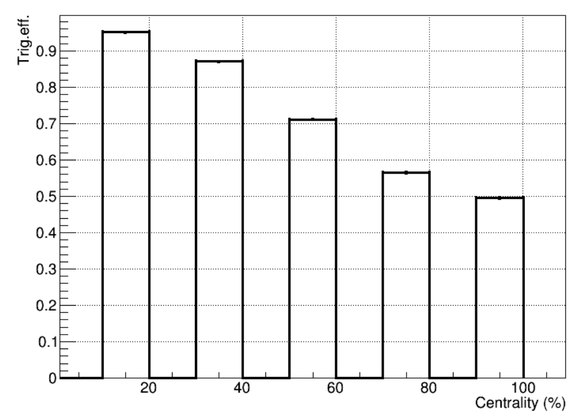



FFD trigger efficiency vs. centrality




FHCAL trigger efficiency vs centrality

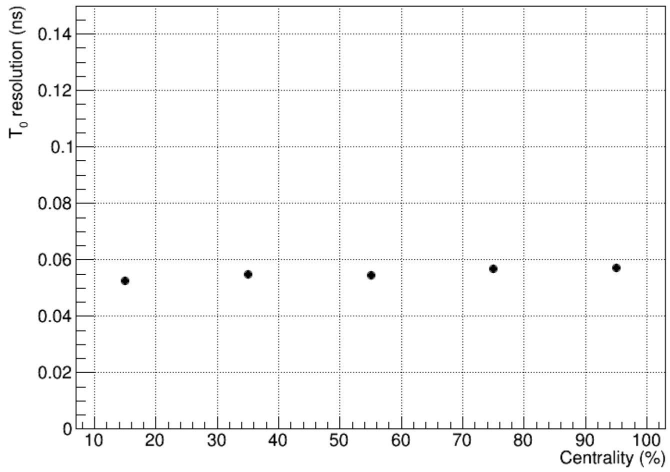


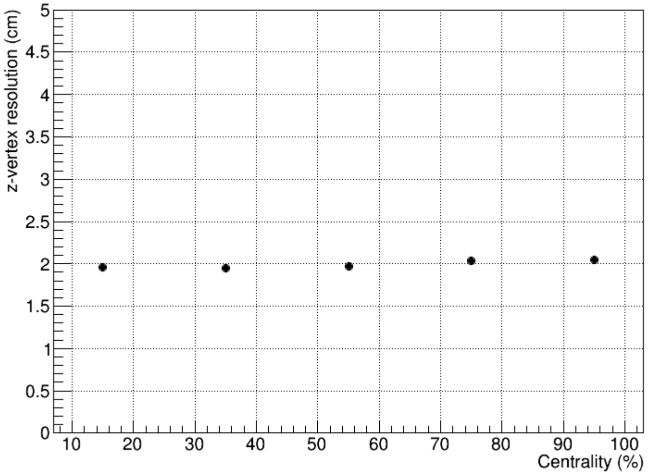

- Maximum efficiency of ~ 95% is achieved in 0-20% collisions, never reaches a level of 100%
- Trigger efficiency rapidly drops in peripheral collisions

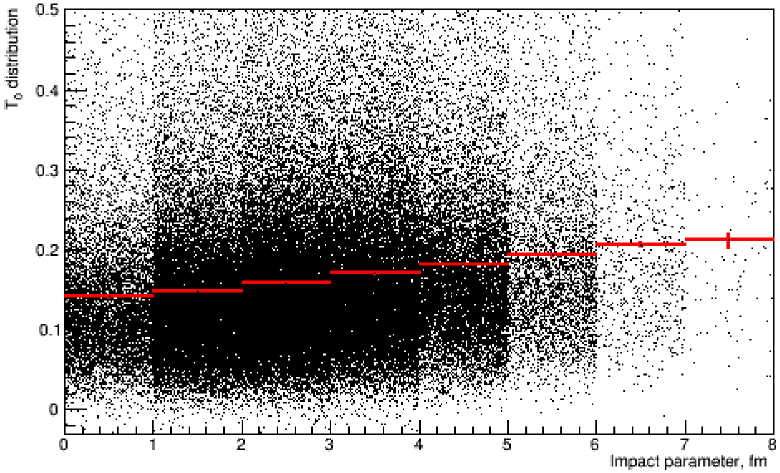
# FFD, $T_0$ and z-vertex resolution

$T_0$ resolution: $T_0 = (T_{FFDE} + T_{FFDW}) / 2 – L/c$




Z-resolution: $Z = (T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]




$T_0$ resolution ~ 60 ps at all centralities

z-vertex resolution ~ 2 cm (FFD) ~ 20 cm (FHCAL)

$T_0$ multiplicity bias (shift of mean values + non-Gaussian tails at all centralities)

# Summary for CC@9.2

- FFD and FHCAL trigger on ~40% and ~60% of CC@9.2 collisions
- Trigger efficiency never reaches a 100% level, even in most central collisions
- Time resolution (FFD) ~ 60 ps
- Z-vertex resolution (FFD) ~ 2 cm (FHCAL) ~ 20 cm

→ FFD & FHCAL have obvious deficiencies for triggering in CC@9.2

# BACKUP