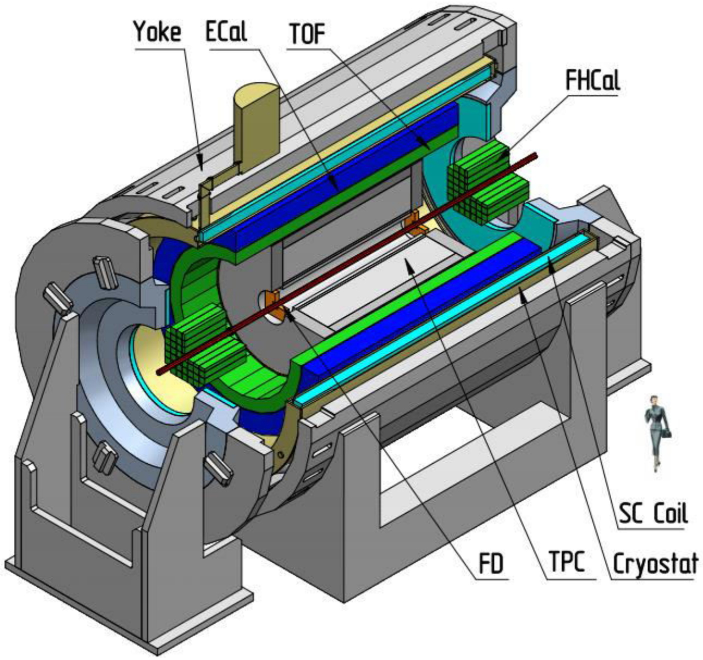
Simulation of the MPD trigger

V. Riabov for the MPD

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



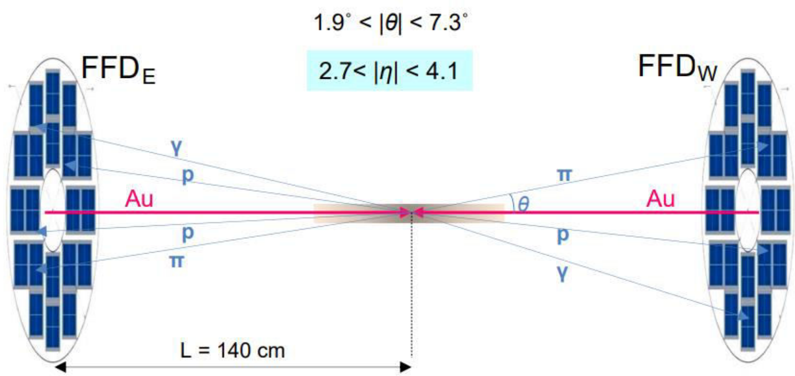
- FFD (Fast Forward Detector) – dedicated trigger detector:
  - ✓ fast event triggering
  - ✓ T_0 for time measurements in the TOF and ECAL

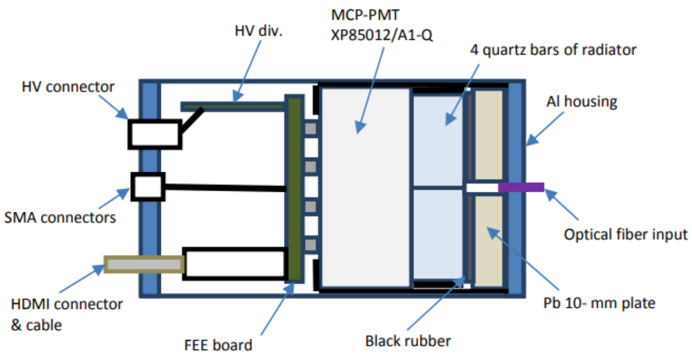
- FHCAL (Forward Hadron Calorimeter) – detector for event centrality and reaction plane measurements with potential for event triggering

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

FFD (see TDR for details)

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



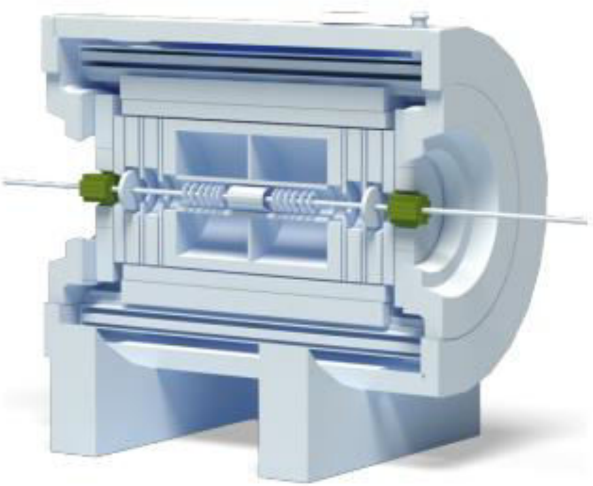


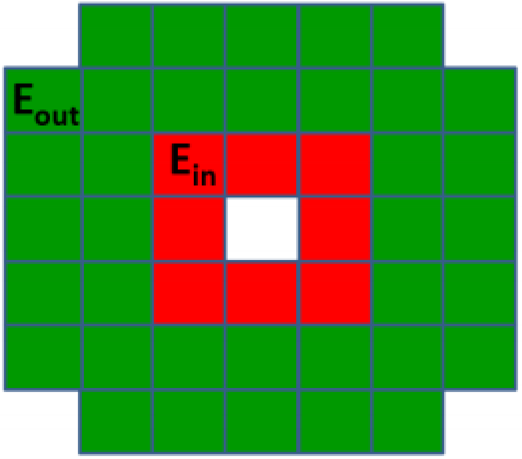
Experiment	Detector	Active area* (cm^2)	Number of channels*	Distance from IP (cm)	|η|-interval	Photodetector	Time resolution** σ_t (ps)
MPD/NICA	**FFD** Cherenkov	**625**	**80**	**140**	**2.7 – 3.9**	Photonis MCP-PMTs XP85012/A1	**44**

- Detects Cerenkov light from decay photons (mostly from $\pi^0 \to \gamma\gamma$ decays) and fast hadrons

FHCAL (see TDR for details)

- FHCAL (Forward Hadron Calorimeter) – event centrality and reaction plane measurements:
  - ✓ has a potential for event triggering
  - ✓ T_0 measurements are not possible





- Detects projectile nuclei fragments (spectators) and forward going particles produced close to the beam, $2 < |\eta| < 5$:
  - ✓ large transverse area, 1x1 m^2
  - ✓ energy resolution: $\sigma(E)/E < 60\% / \sqrt{E(GeV)}$
  - ✓ Time resolution for mip ~ 1 ns
  - ✓ good uniformity of the detector response
  - ✓ high transverse segmentation

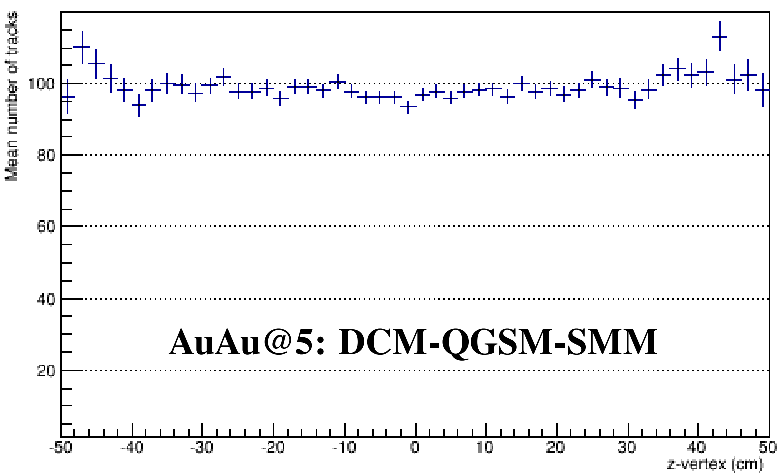
Simulation chain

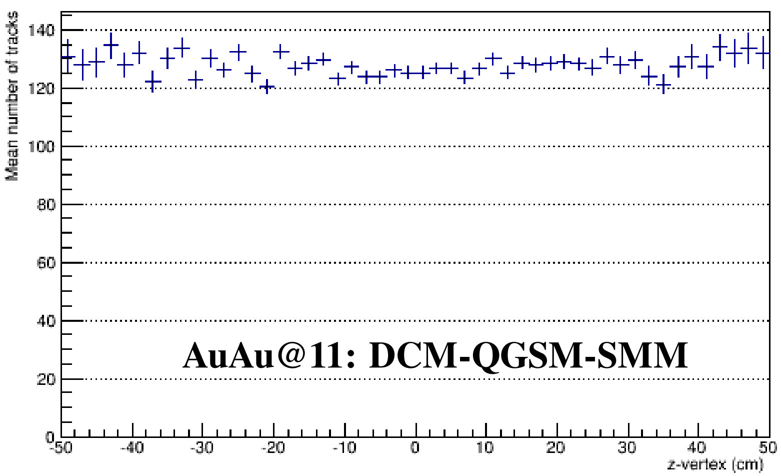
- Event generators: DCM-QGSM-SMM* (GSI version) and PHQMD:
  - ✓ 150 k events, realistic z-vertex with σ ~ 24 cm, minbias b = 0-16 fm
  - ✓ simulation of hadron production at midrapidity → event multiplicity/centrality
  - ✓ simulation of hadron and fragment production at forward rapidity → acceptance of FFD & FHCAL
- All detectors are simulated in the framework of the MpdRoot (Geant-4)
- FFD simulation :
  - ✓ modified version of the code originally committed by S. Lobastov (about a month ago)
  - ✓ particle transport → showers in Pb converter → Cerenkov light generation in the quartz radiator
  - ✓ generation of photoelectrons in photocathode taking into account its quantum efficiency, loss of photons due to reflection and absorption (~ 50%), times of photoelectrons are simulated as arrival times of Cerenkov photons to the photocathode surface
  - ✓ channel is fired once number of collected photoelectrons exceeds a limit of ~1/3 mip
  - ✓ photoelectrons sorted by time are integrated to exceed the same threshold → time of the channel
  - ✓ times are additionally smeared by 40 ps to account for the effects of electronics, cabling etc.
- FHCAL simulation :
  - ✓ modified version of the original code committed Marina long ago
  - ✓ particle transport → showers in Pb tiles → simulation of light in scintillator tiles (dE/dx → photons) → simulation of total signal, times of photoelectrons are simulated taking into account the photon formation times and photon transport to the last scintillator tile in the module
  - ✓ channel is fired once total signal in the module exceeds a limit of ~1 mip
  - ✓ photoelectrons sorted by time are integrated to exceed the same threshold → time of the channel
  - ✓ times are additionally smeared by ~ 1 ns to match the measured resolution

* Statistical Multifragmentation Model (**SMM**)

Event generators and centrality

- Centrality determination following report by P. Parfenov at Physics Forum from April, 15:
  - ✓ BUT used looser track selections in the TPC: nHits > 10, |η| < 1, p_T > 50 MeV/c, |DCA| < 5 cm
- Even with looser track selection cuts ~ 6% of inelastic Auau@11 events do not have reconstructed tracks in the TPC → no centrality categorization (dropped)
- Wider rapidity selection (|η| < 1.0) diminishes z-vertex dependence of centrality
- Number of $< N_{tracks}^{TPC} >$ vs. true z-vertex (events after reconstructed z-vertex cut of 50 cm):

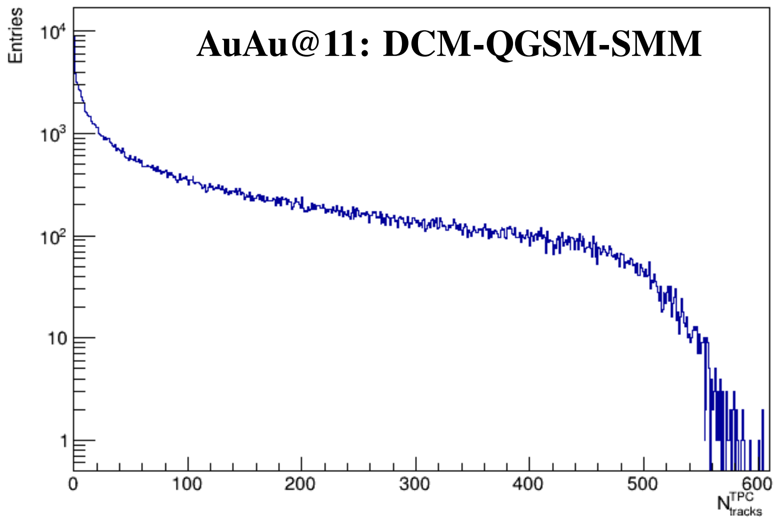




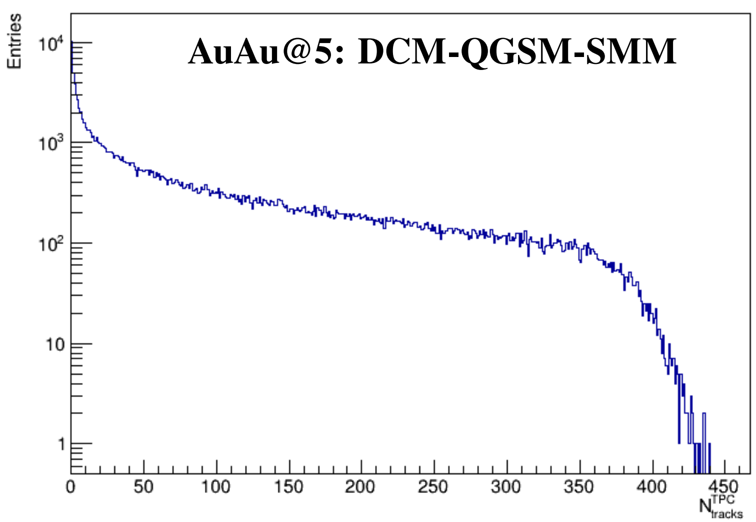
- Similar flatness of the distributions is observed in different multiplicity/centrality intervals
- The same distributions are depleted by up to 15-20% at z~0 with a narrower cut of |η| < 0.5

Multiplicity and centrality

- Multiplicity distributions and centrality classes after reconstructed z-vertex cut of 50 cm and assuming 100%-efficient event selection (100% trigger efficiency)



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



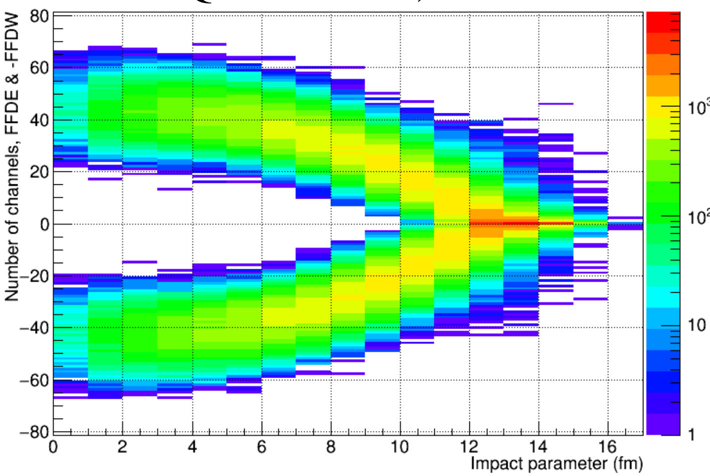
Centrality class	N_{tracks}^{TPC}
90-100%	1-3
80-90%	4-10
70-80%	10-21
60-70%	21-37
50-60%	37-61
40-50%	61-93
30-40%	93-137
20-30%	137-195
10-20%	195-273
0-10%	273-445

FFD

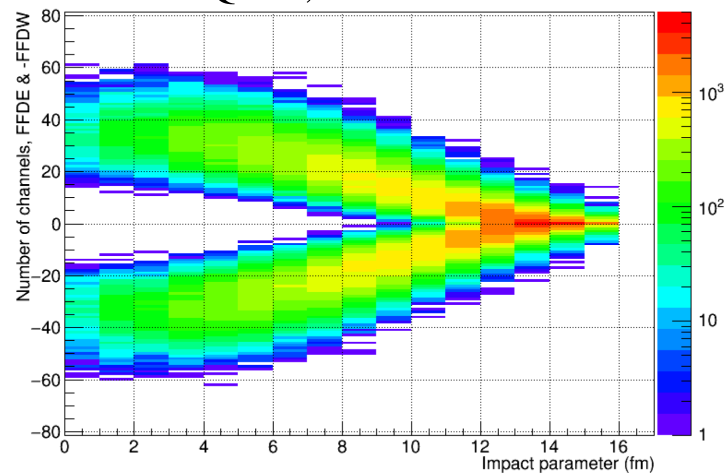
FFD, number of fired channels

- FFD-E (FFD-W) consists of 20 modules; each module has 4 read-out channels

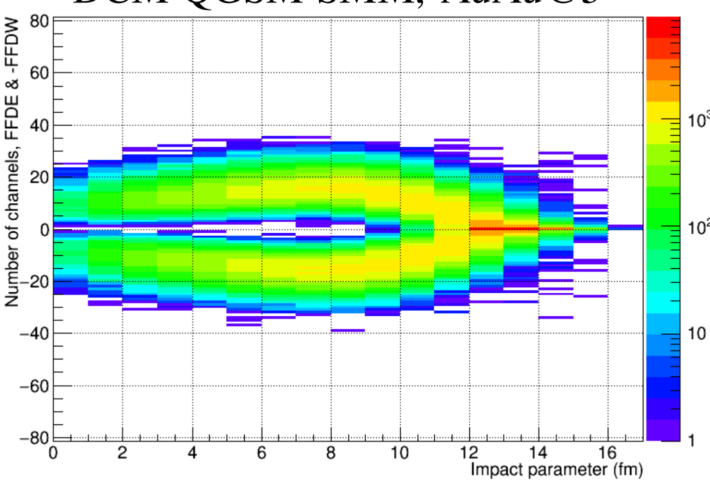
DCM-QGSM-SMM, AuAu@11



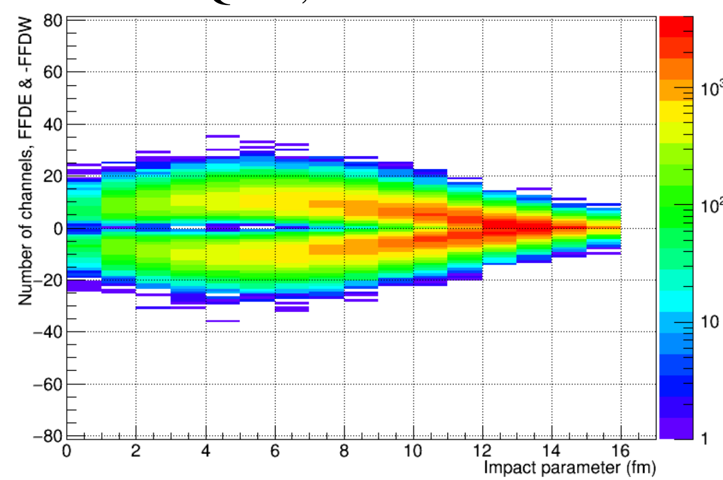
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5



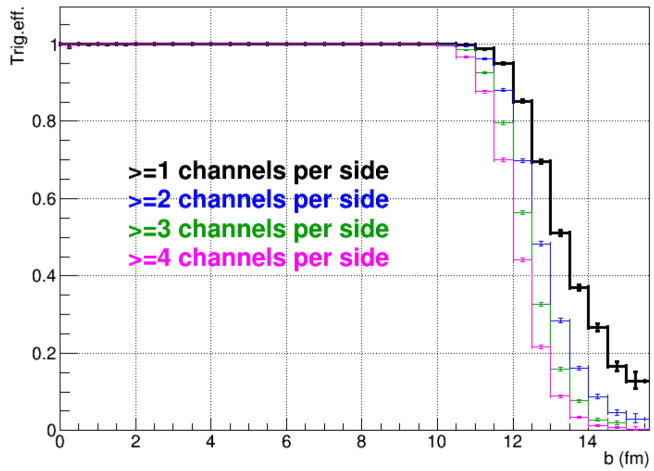
PHQMD, AuAu@5

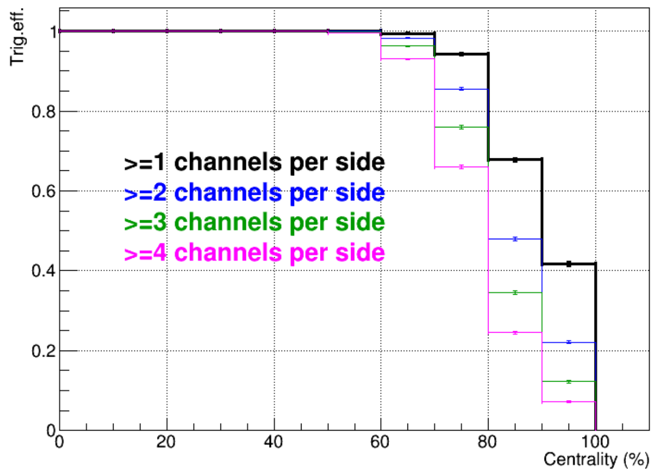


- Detector occupancy shows strong collision energy and centrality dependence

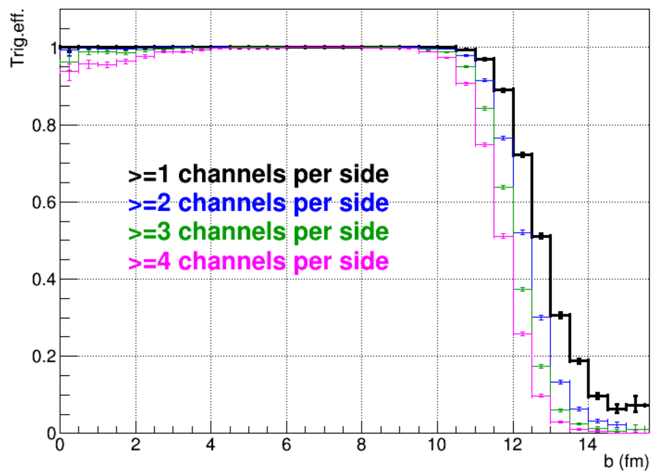
FFD with DCM-QGSM-SMM

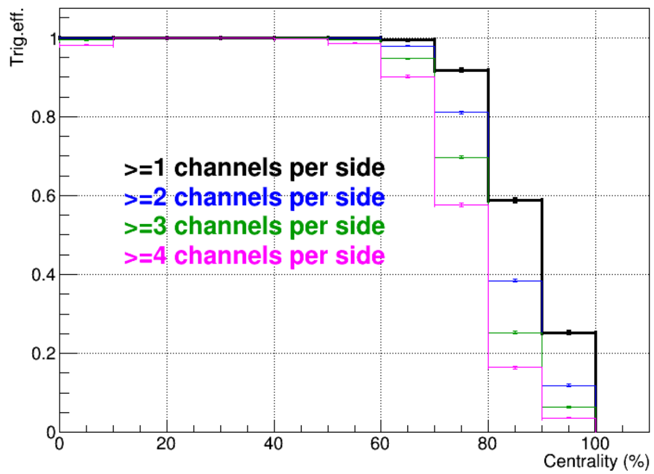
- DCM-QGSM-SMM, AuAu@11, trigger efficiency vs. impact parameter and centrality





- DCM-QGSM-SMM, AuAu@5, trigger efficiency vs. impact parameter and centrality

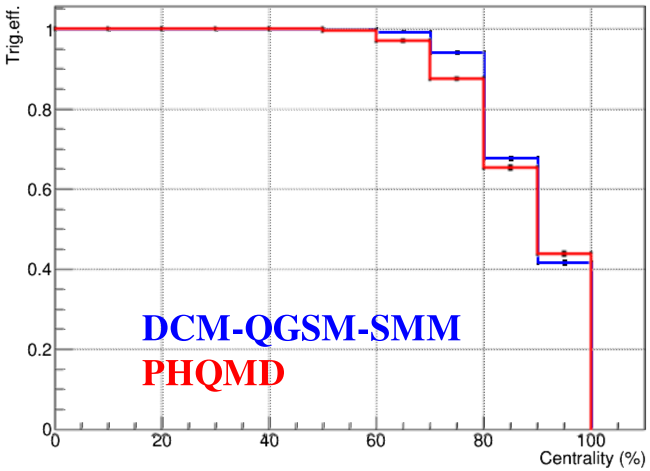




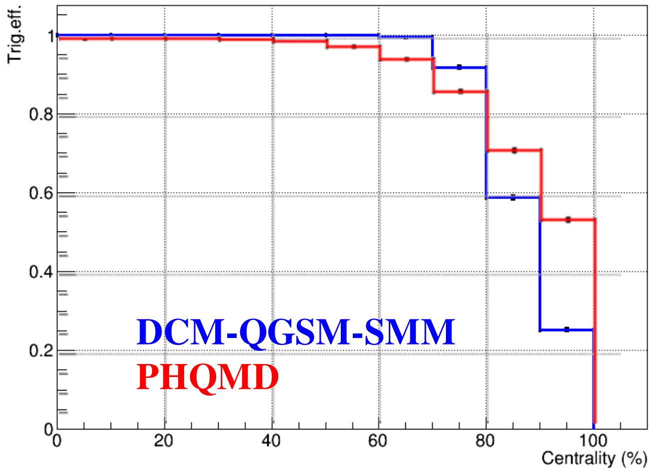
- Efficiency is ~ 100% in central and semicentral collisions and rapidly drops towards peripheral collisions → " at least one-channel per side" is a possible and preferred option for FFD triggering

FFD, model dependence

- AuAu@11, efficiency vs. centrality



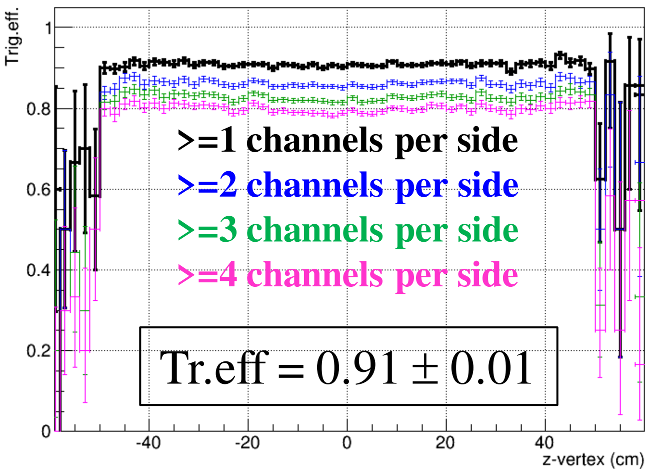
- AuAu@5, efficiency vs. centrality



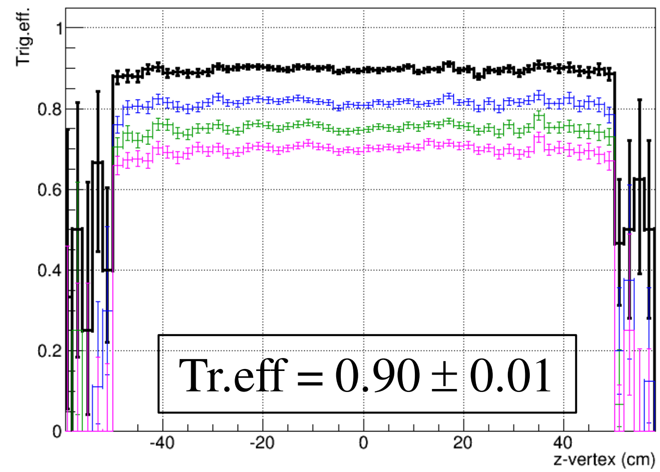
- Trigger condition: >= 1 fired channel per side
- Efficiency shows model dependence, especially at lower collision energy
- DCM-QGSM-SMM predicts lower FFD efficiency at lower collision energy in peripheral collisions, while PHQMD predicts higher efficiency

FFD efficiency vs. true z-vertex

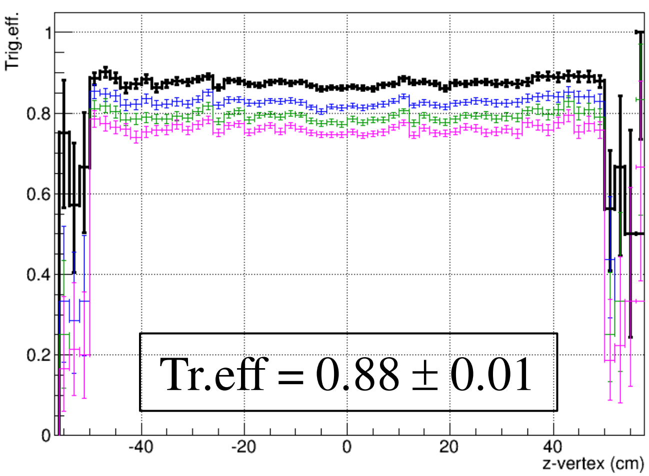
DCM-QGSM-SMM, AuAu@11



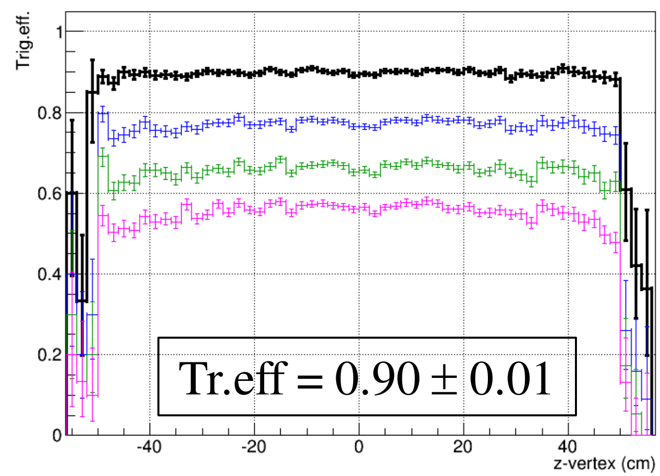
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5



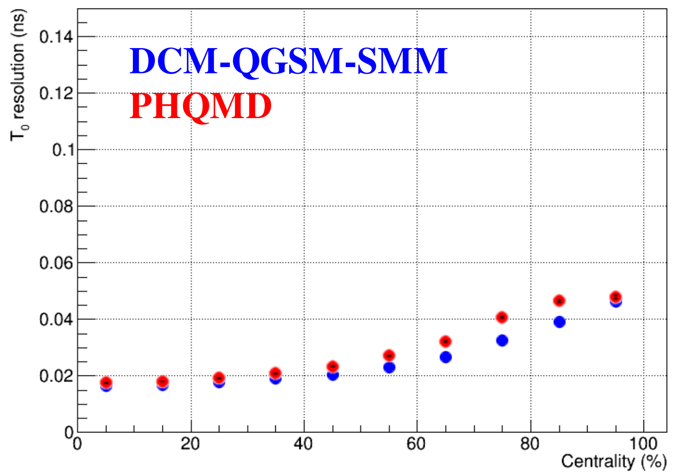
PHQMD, AuAu@5



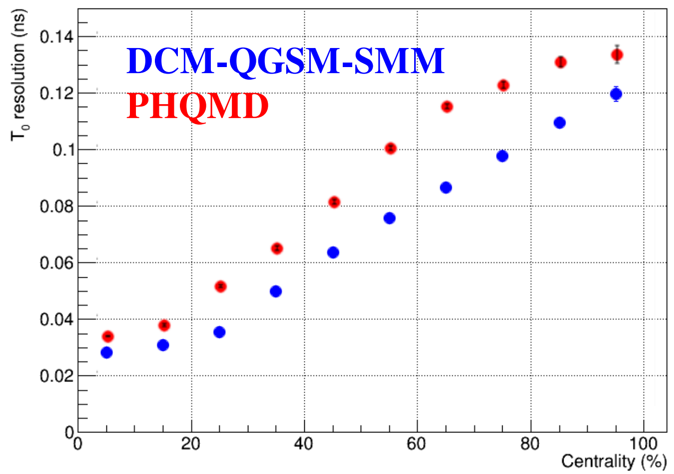
- FFD trigger efficiency does not show z-vertex dependence (at least with >=1 requirement)
- FFD trigger efficiency is ~ 0.9 in all systems consistently predicted by two event generators

FFD, offline T_0 resolution

- $T_0 = (T_{FFDE} + T_{FFDW}) / 2 - L/c$
- AuAu@11, T_0 resolution vs. centrality



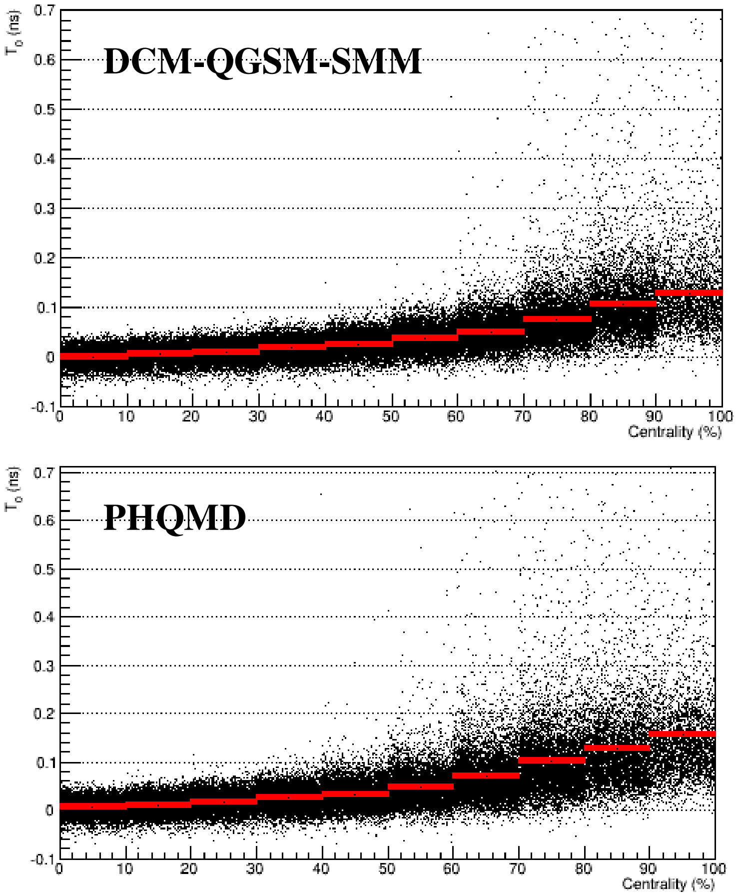
- AuAu@5, T_0 resolution vs. centrality



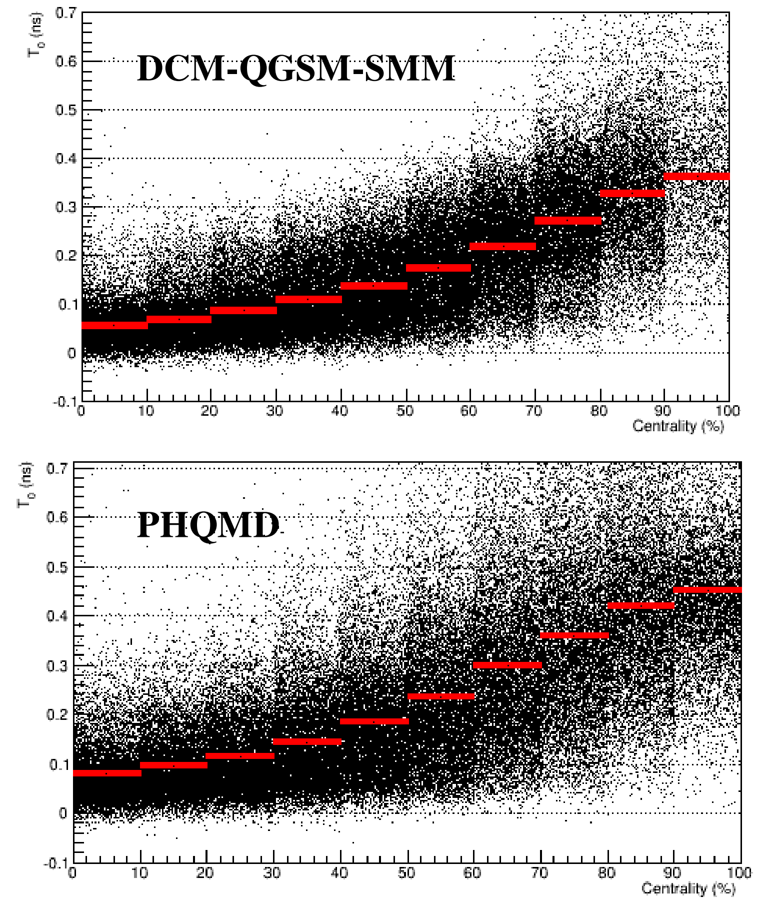
- With TOF resolution of 80-100 ps, the T_0 resolution is required to be ~ 50 ps
- The condition is satisfied in AuAu@11 at all centralities
- The condition is satisfied only in central AuAu@5; T_0 resolution becomes comparable to TOF resolution at centralities > 50-70%
- The problem is not in the intrinsic time resolution of the FFD, but in the time spread of arriving particles → <u>study of the TOF performance for T_0 measurements is needed!</u>

FFD, offline T_0 bias

- AuAu@11, T_0 resolution vs. centrality



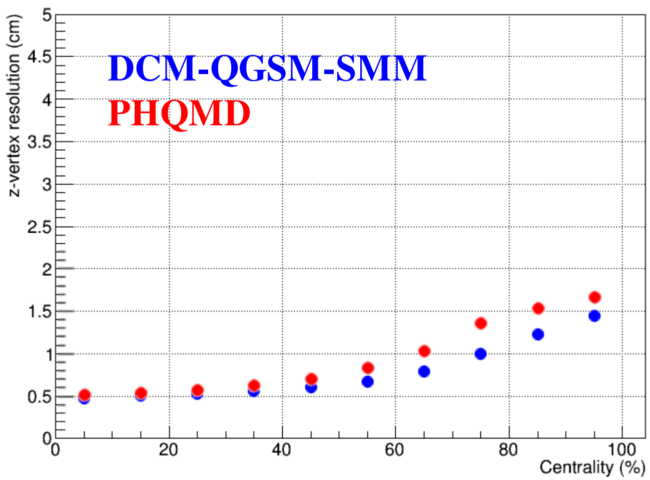
- AuAu@5, T_0 resolution vs. centrality



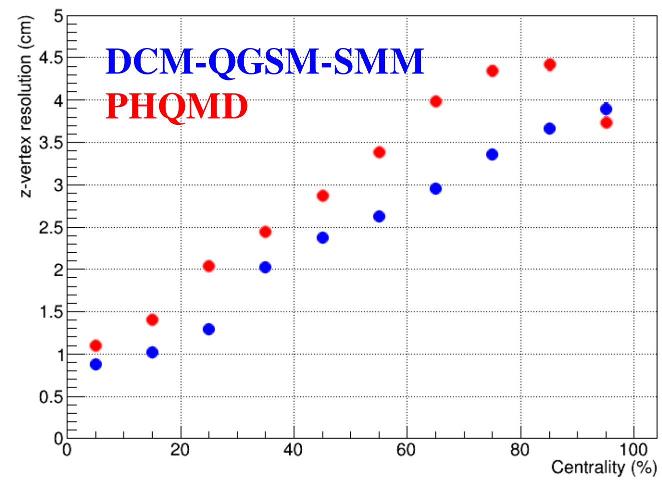
- Appearance of the tail in T_0 distribution at low multiplicities → non Gaussian distributions
- Mean of T_0 distribution shifts from zero at lower multiplicities (even in most central AuAu@5)
- The shift/bias is large → a strong effect (2-4 σ)
- The shift can be corrected by tuning the TOF-reconstructed proton masses to PDG value as a function of centrality → additional source of systematic uncertainties

FFD, offline z-vertex resolution

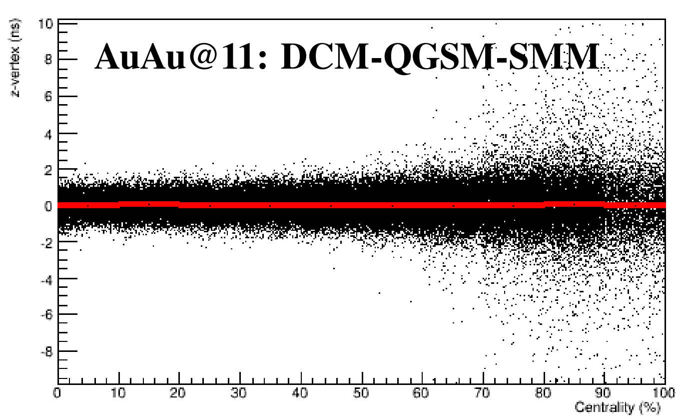
- $Z = (T_{FFDW} - T_{FFDE}) / 2 * 30$ [cm]
- AuAu@11, z-resolution vs. centrality

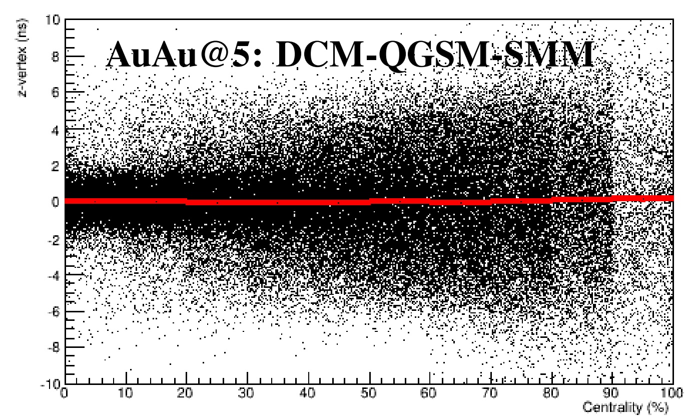


- AuAu@5, z-resolution vs. centrality



- Z-vertex resolution is < 2 cm and < 5 cm in AuAu@11 and AuAu@5, respectively
- No centrality bias for z-vertex is observed





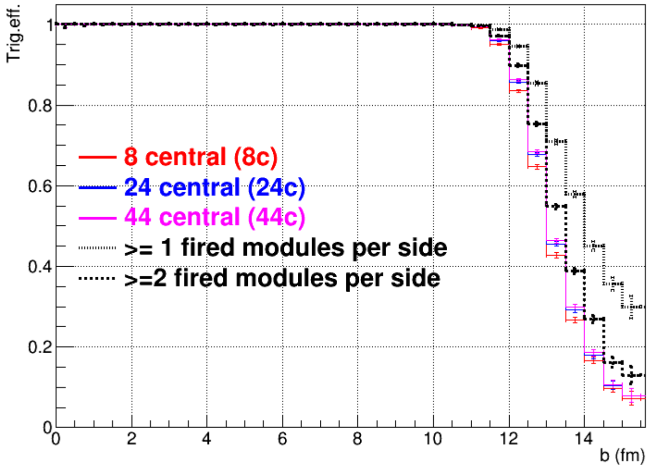
FFD: Summary

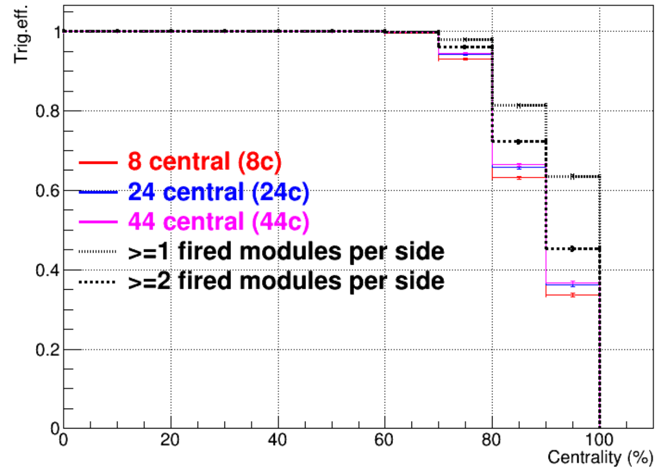
- FFD is a dedicated detector for AuAu event selection with superb performance (single channel efficiency of 100% for mip and time resolution of ~ 40 ps)
- Specifics of AuAu collisions in the collider mode at low energies puts some limitation on the trigger performance
- Predictions for FFD performance show model dependence; however basic performance parameters and trends are predicted to be the same
- FFD, trigger efficiency in Au-Au:
  - ✓ ~ 100% in central and semicentral collisions at all energies
  - ✓ rapidly drops in peripheral collisions; ~ 50% in centrality interval 80-100%
  - ✓ overall efficiency is ~ 90%, no collision energy dependence, no z-vertex dependence
- FFD, T_0 and z-vertex in Au-Au:
  - ✓ offline z-vertex resolution is < 2 cm and < 5 cm in AuAu@11 and AuAu@5, respectively
  - ✓ online z-vertex resolution is < 5 cm (no averaging)
  - ✓ T_0 resolution is < 50 ps in AuAu@11 and in central AuAu@5
  - ✓ T_0 resolution rapidly deteriorates in semi-central and peripheral AuAu@5 → TOF studies???
  - ✓ T_0 shows strong centrality bias; can be corrected by mass measurements in the TOF but should be considered as a source of systematic uncertainties
  - ✓ T_0 shows tail (non-Gaussian) in low-multiplicity events → lower efficiency and systematic unc.

FHCAL

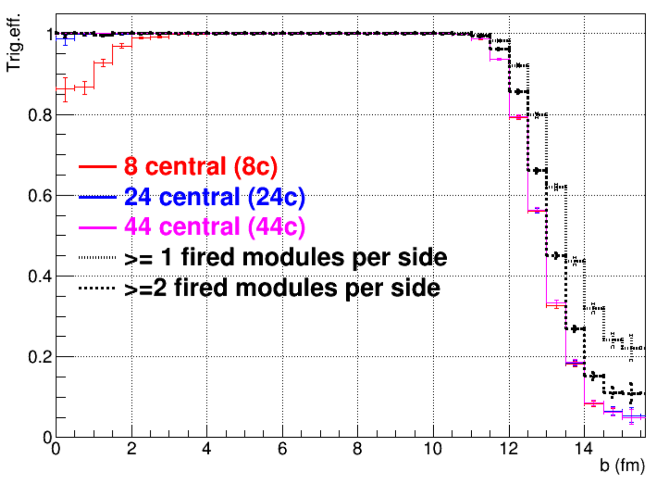
FHCAL, DCM-QGSM-SMM

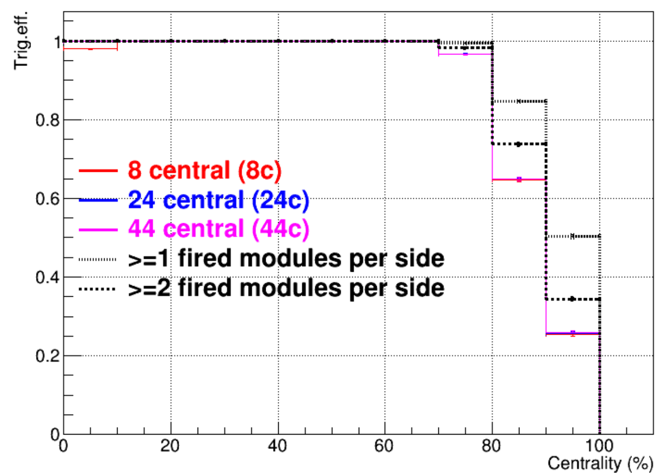
- DCM-QGSM-SMM, AuAu@11, trigger efficiency vs. impact parameter and centrality





- DCM-QGSM-SMM, AuAu@5, trigger efficiency vs. impact parameter and centrality

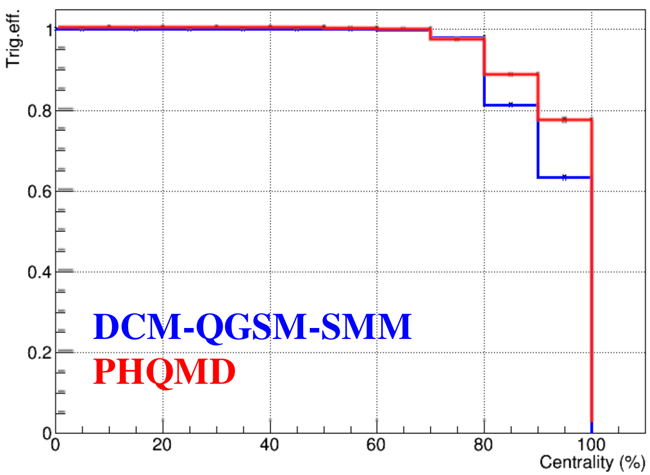




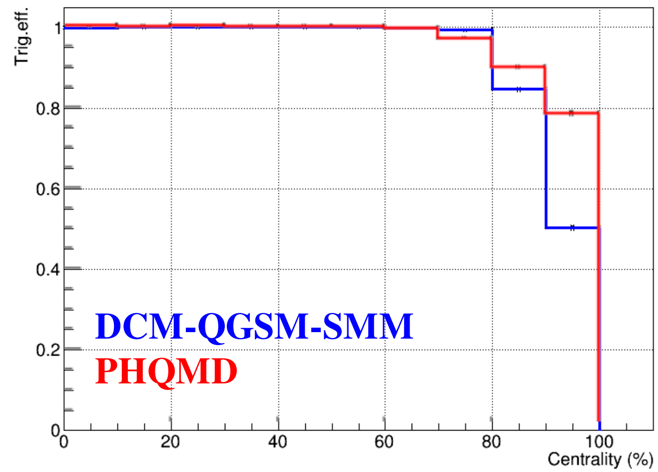
- Efficiency is ~ 100% in central and semicentral collisions and drops towards peripheral ones
- |Option “ at least one-module per side” provides the highest efficiency for FHCAL triggering

FHCAL, model dependence

- AuAu@11, efficiency vs. centrality



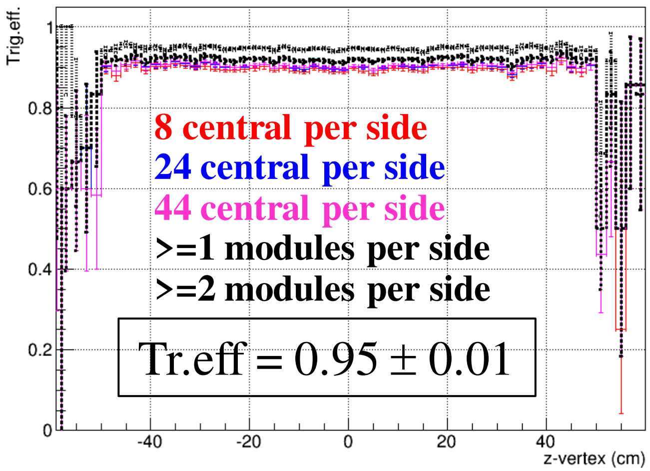
- AuAu@5, efficiency vs. and centrality



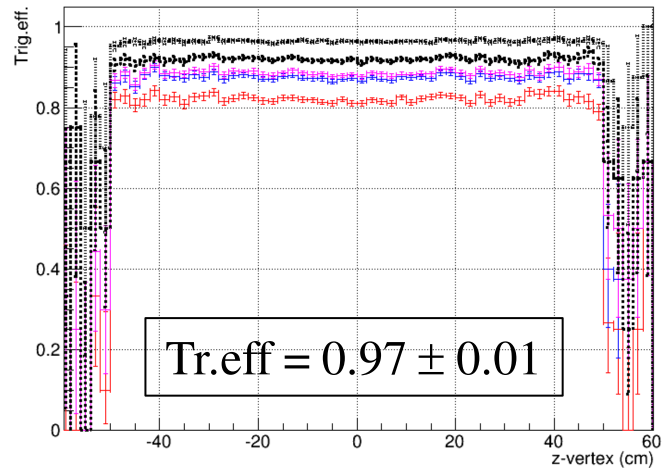
- Trigger option: at least one fired module per side
- Efficiency shows model dependence
- DCM-QGSM-SMM predicts lower FHCAL efficiency at lower collision energy in peripheral collisions; PHQMD predicts no collision energy dependence

FHCAL efficiency vs. true z-vertex

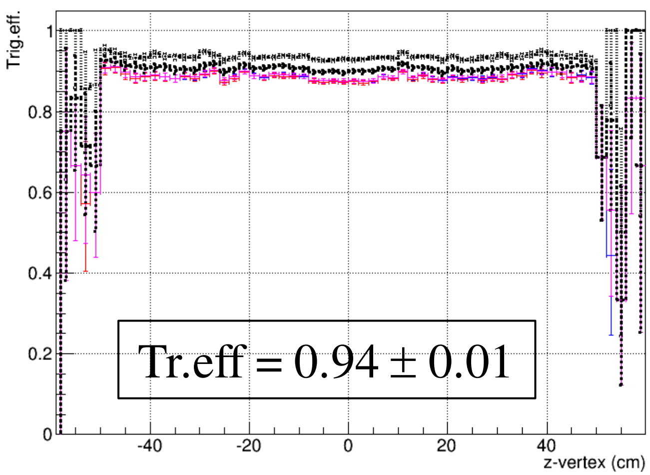
DCM-QGSM-SMM, AuAu@11



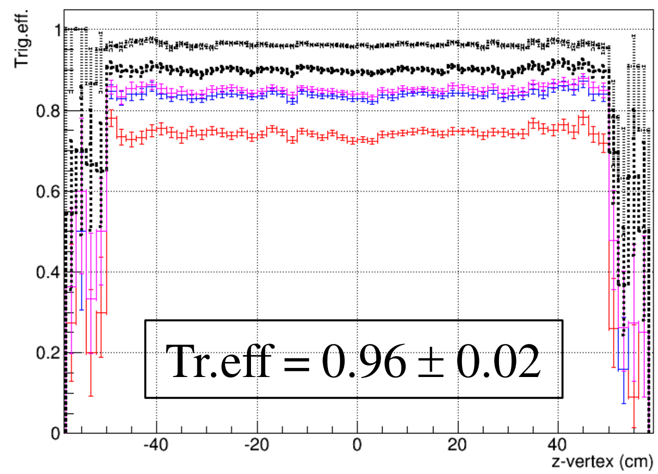
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5



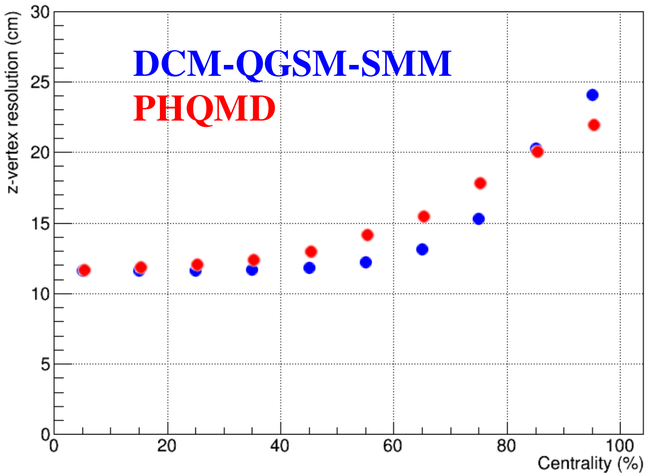
PHQMD, AuAu@5

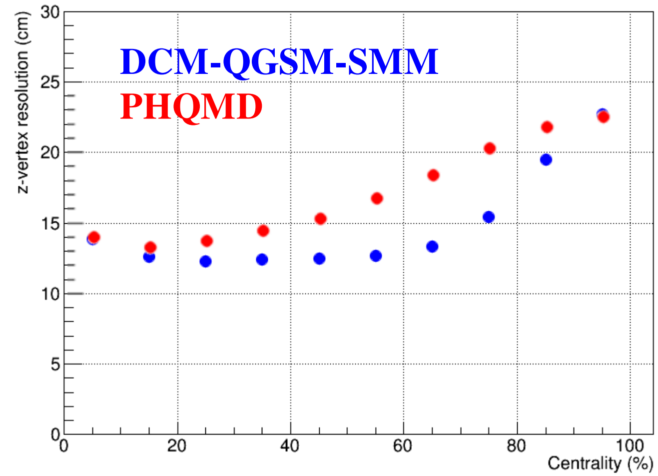


- FHCAL trigger efficiency does not show z-vertex dependence (any selections)
- FHCAL trigger efficiency is ~ 0.95 in all systems predicted by two event generators

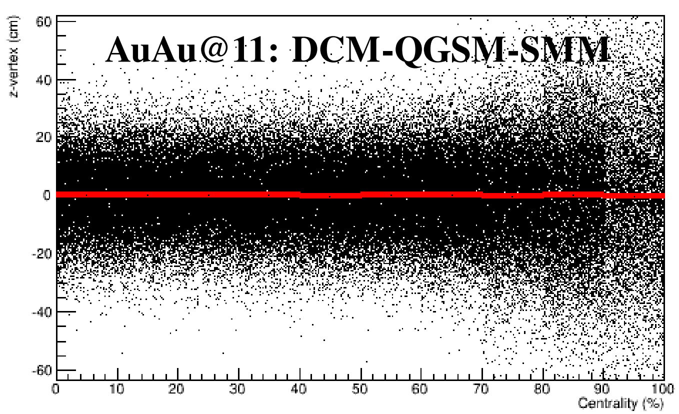
FHCAL, offline z-vertex resolution

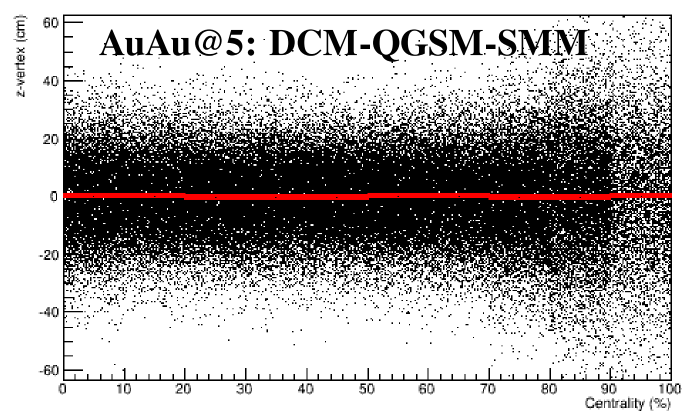
- $Z = (T_{FHCALW} - T_{FHCALE}) / 2 * 30$ [cm]
- AuAu@11, z-resolution vs. centrality
- AuAu@5, z-resolution vs. centrality





- Z-vertex resolution is < 25 cm in AuAu@5,11; weak collision energy dependence
- No centrality bias for z-vertex is observed





FHCAL: Summary

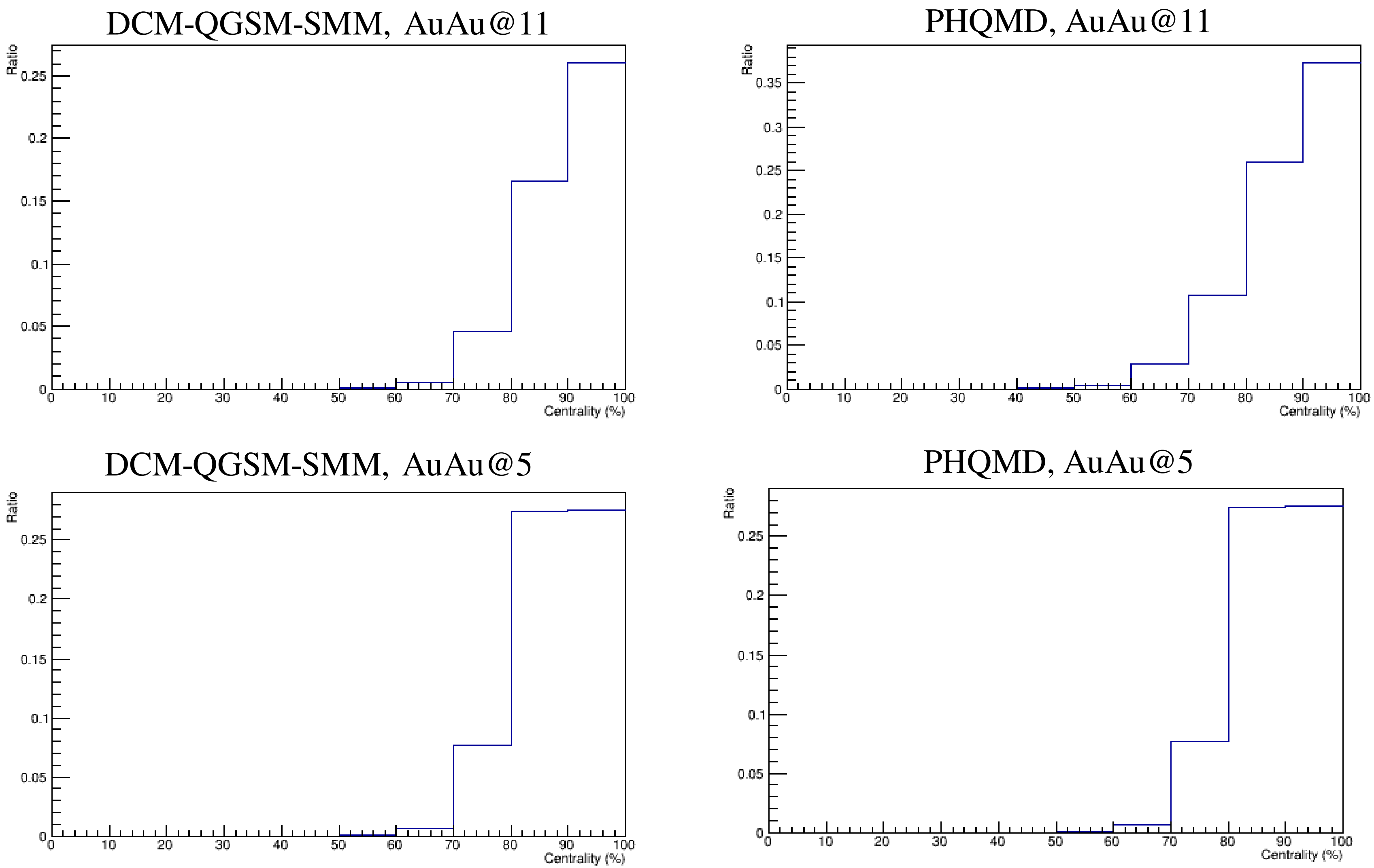
- FHCAL shows very encouraging performance for event triggering in AuAu
- Predictions for FHCAL performance show model dependence; however basic performance parameters and trends are predicted to be the same
- FHCAL, trigger efficiency in Au-Au:
  - ✓ higher efficiency in peripheral collisions in comparison with FFD
  - ✓ overall efficiency is ~ 95%, weak collision energy dependence, no z-vertex dependence
- FHCAL, T_0 and z-vertex in Au-Au:
  - ✓ offline z-vertex resolution is < 25 cm in AuAu@5,11; weak collision energy dependence
  - ✓ online z-vertex resolution is 20-25 cm in AuAu@5,11 (no averaging for modules, highest energies)
  - ✓ T_0 measurements are meaningless
- FHCAL is not a substitute for FFD, both detectors should be used together to enhance trigger performance in peripheral collisions

FFD or FHCAL

Best options are used for the FFD and FHCAL:

- ✓ FFD: >= 1 channels per side
- ✓ FHCAL: >=1 modules per side

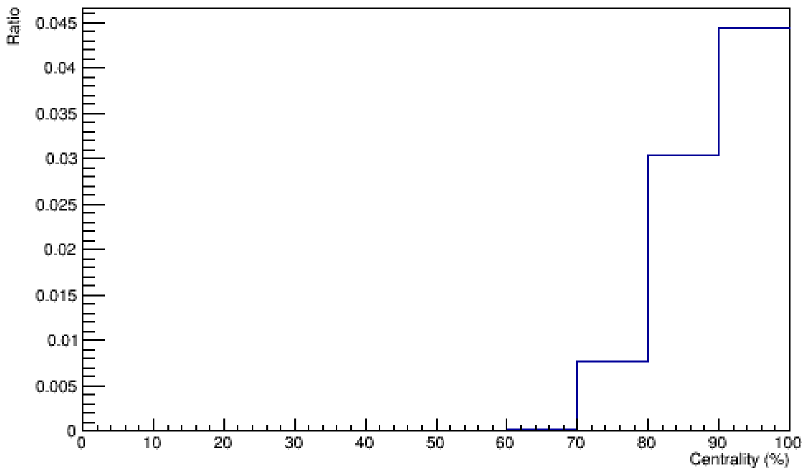
!FFD && FHCAL



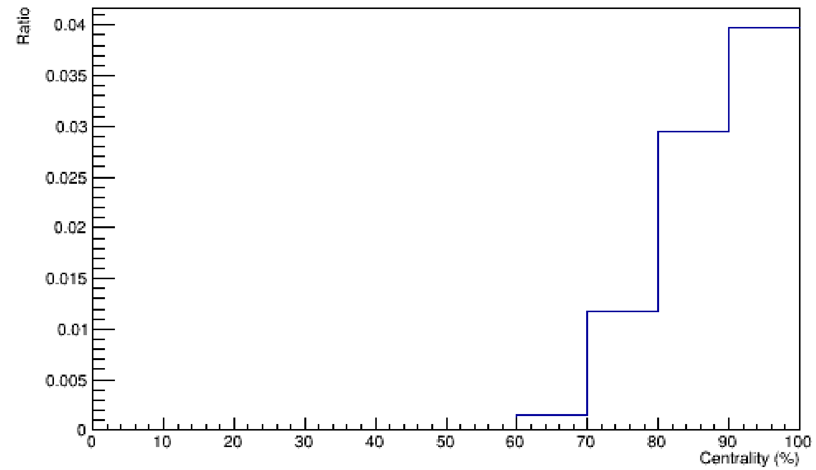
- 20-35% collisions in centrality interval 80-100% fire the FHCAL but not the FFD

FFD && !FHCAL

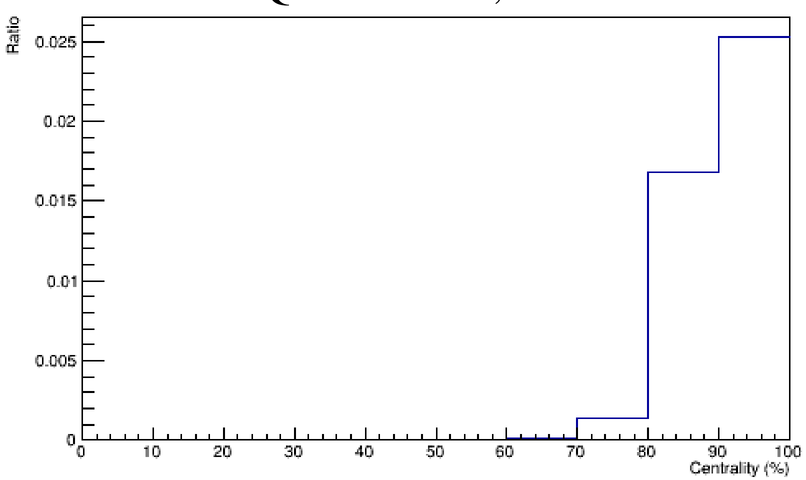
DCM-QGSM-SMM, AuAu@11



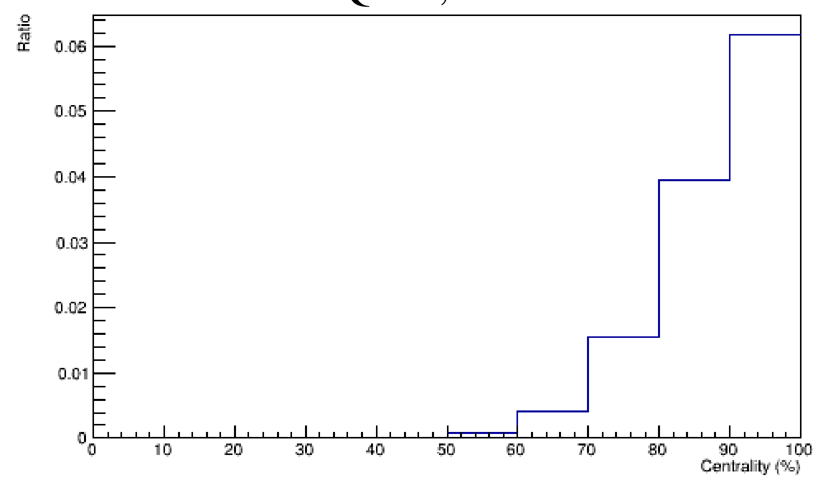
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5

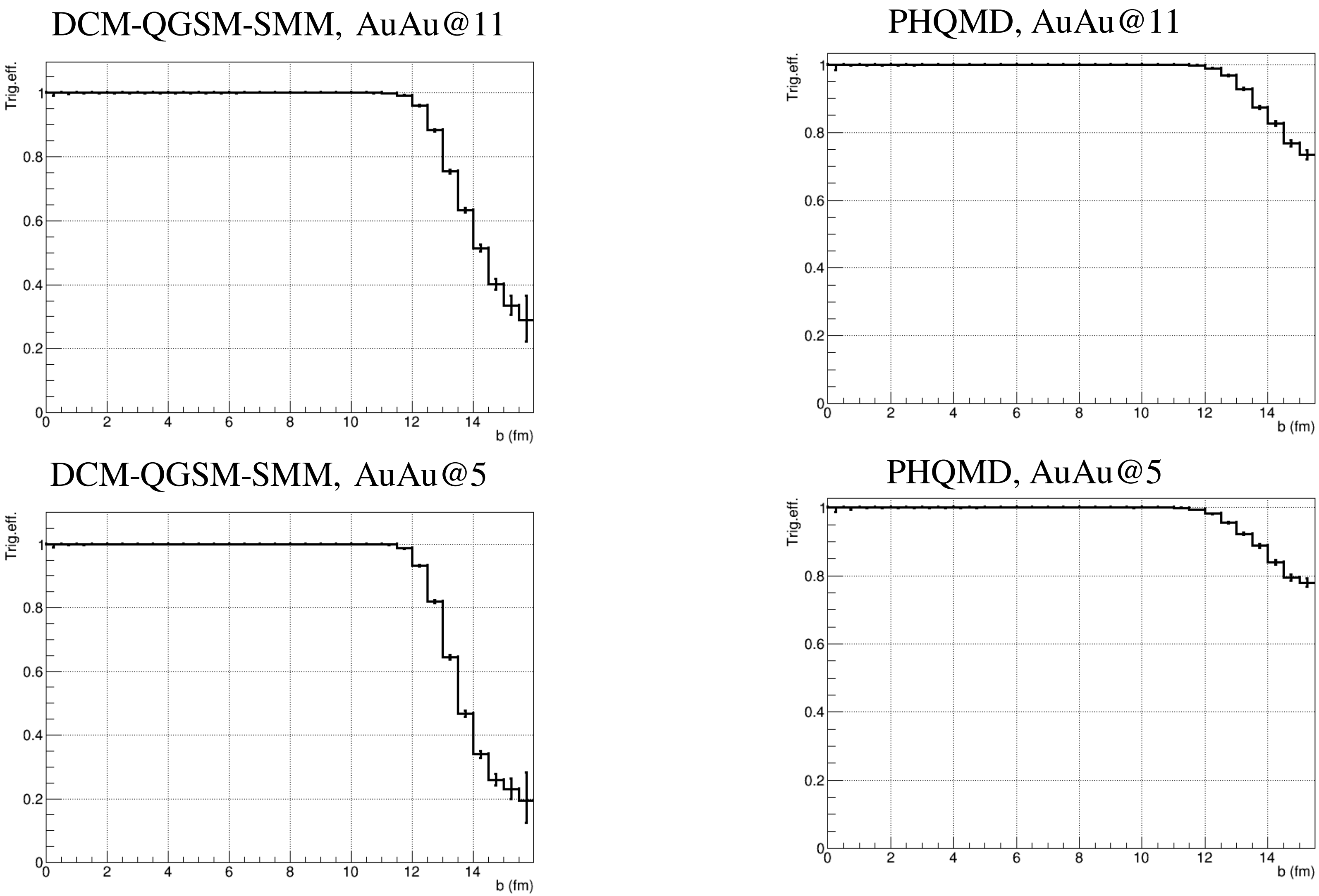


PHQMD, AuAu@5



- Only 2-6% peripheral collisions fire the FFD but not the FHCAL
- Trigger option FFD || FHCAL can take advantage of the two subsystems

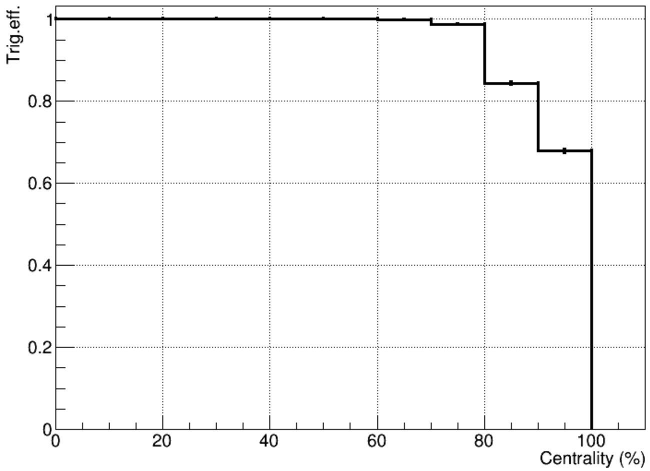
FFD || FHCAL vs. impact parameter



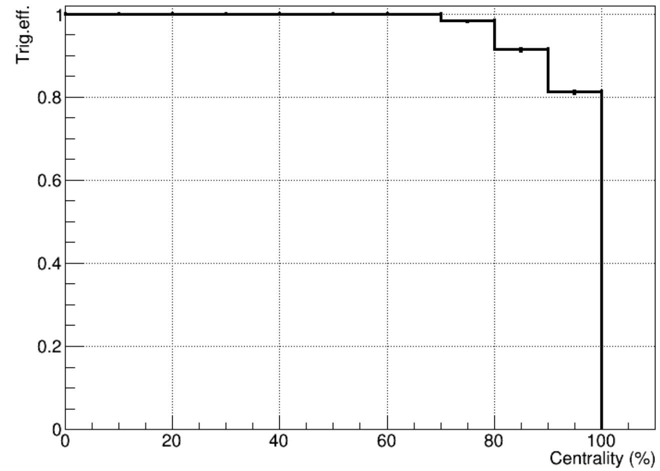
- Observe quite significant model dependence for trigger efficiency.

FFD || FHCAL vs. centrality

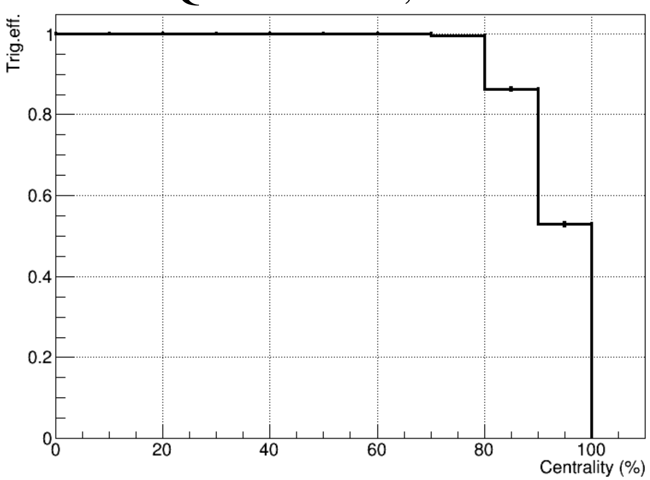
DCM-QGSM-SMM, AuAu@11



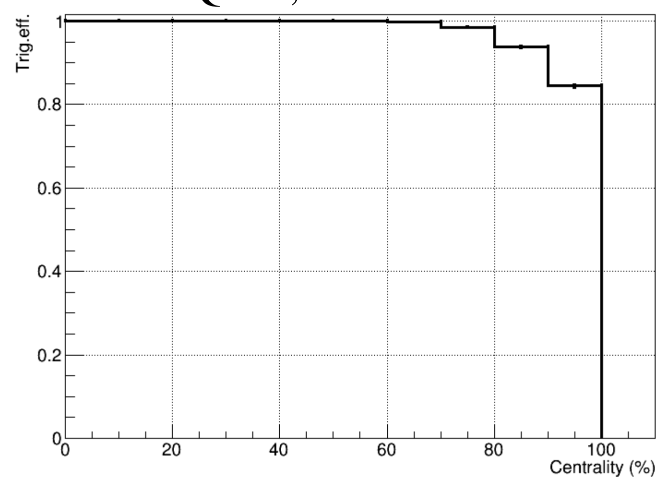
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5



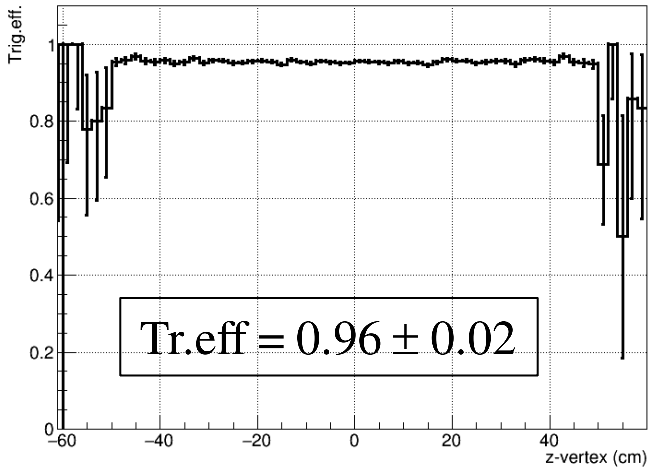
PHQMD, AuAu@5



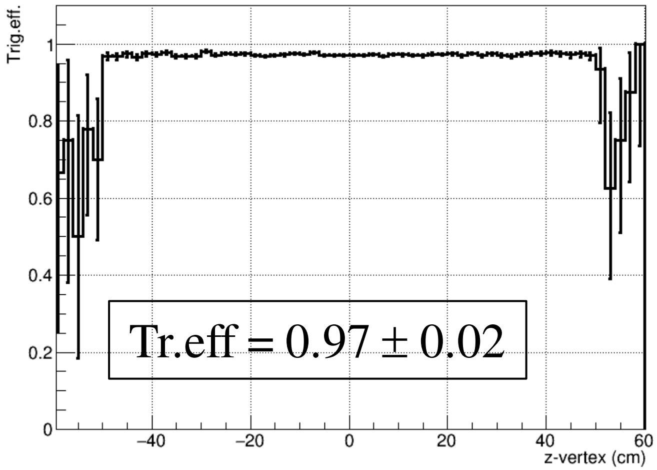
- Observe quite significant model dependence for trigger efficiency
- Weak collision energy dependence

FFD || FHCAL vs. true z-vertex

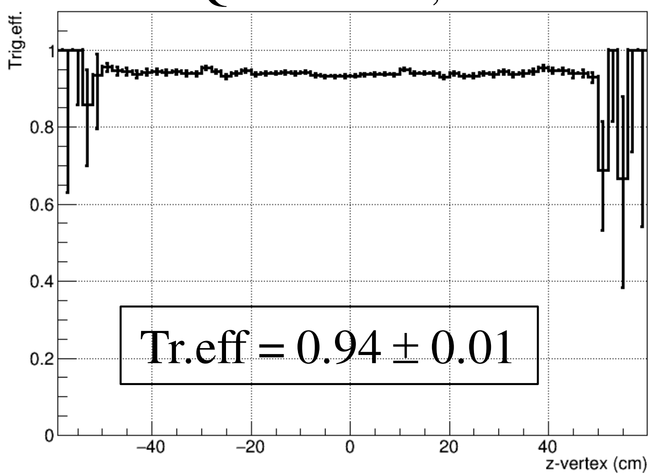
DCM-QGSM-SMM, AuAu@11



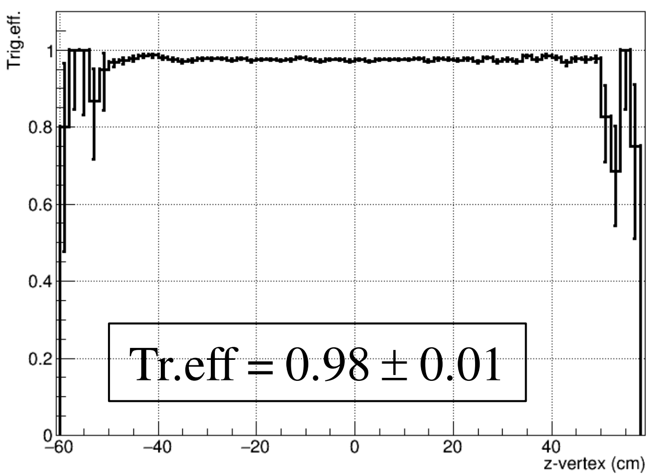
PHQMD, AuAu@11



DCM-QGSM-SMM, AuAu@5



PHQMD, AuAu@5



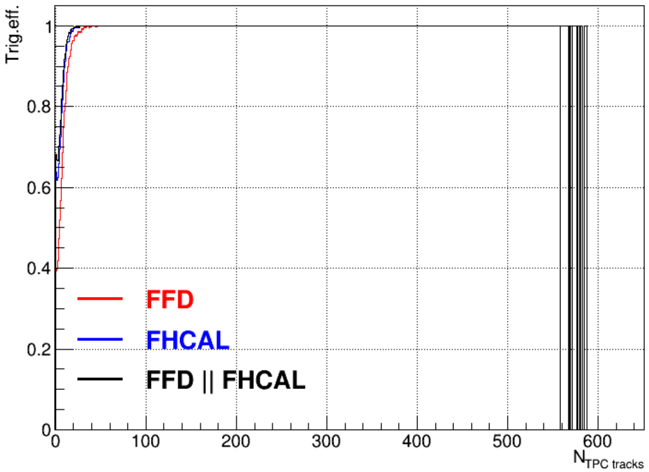
- FFD || FHCAL trigger efficiency does not show z-vertex dependence
- FFD || FHCAL trigger efficiency is ~ 0.94-0.98 predicted by two event generators

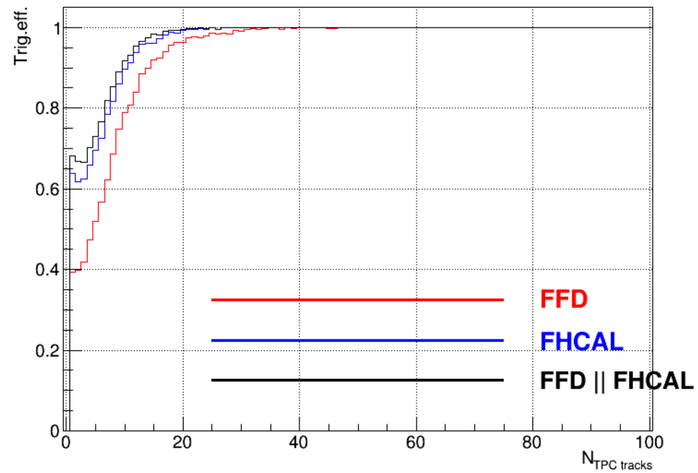
Track efficiency

Reconstructed track multiplicity is a measure of centrality !!!

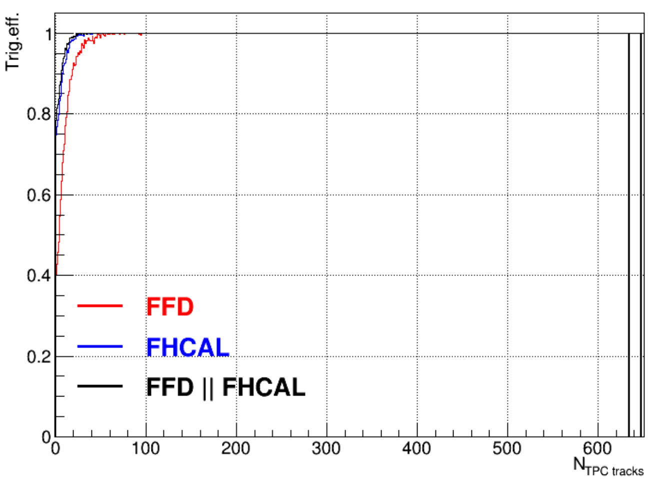
Track “trigger efficiency”, AuAu@11

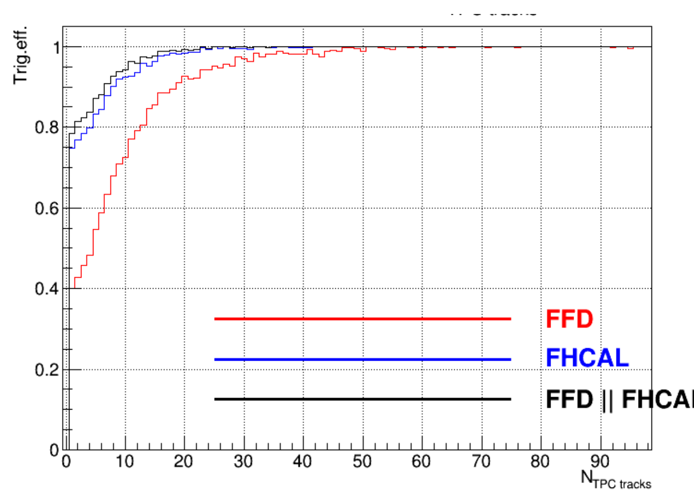
- DCM-QGSM-SMM, AuAu@11





- PHQMD, AuAu@11

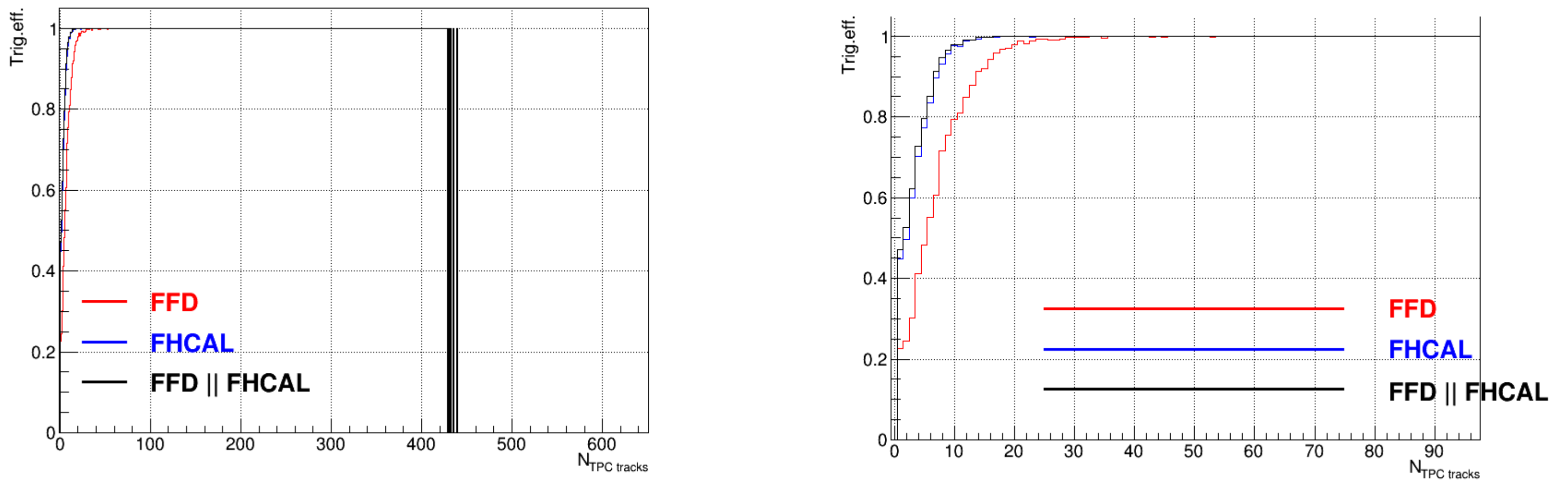




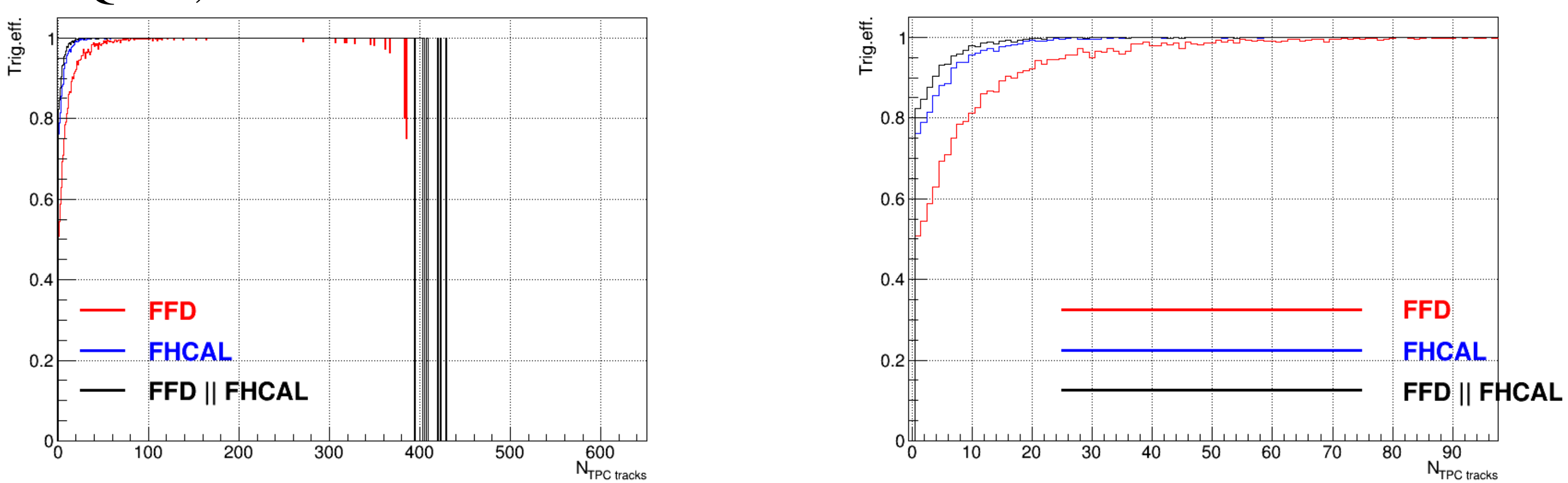
- As expected, efficiency drops in peripheral collisions
- The efficiency shows rather small model dependence → source of systematics

Track “trigger efficiency”, AuAu@5

- DCM-QGSM-SMM, AuAu@5



- PHQMD, AuAu@5



- As expected, efficiency drops in peripheral collisions
- The efficiency shows strong model dependence → source of systematics

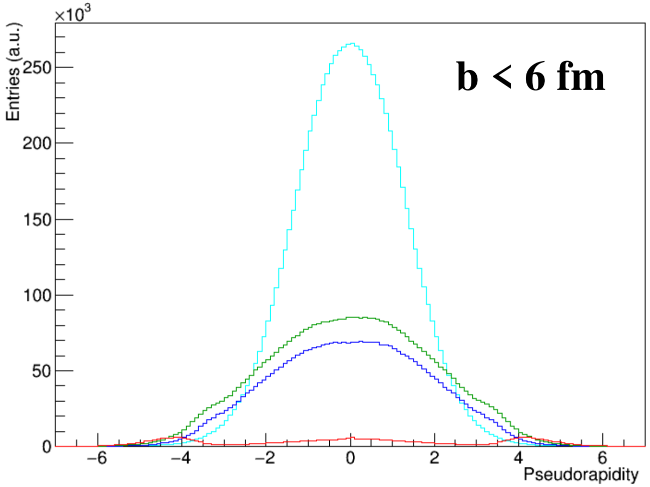
Summary

- FFD and FCAL, especially when taken together, provide rather high efficiency
- The best results are achieved with FFD || FHCAL logic
- Do not observe z-vertex dependence of trigger efficiency
- Only events triggered by FFD will have meaningful T_0 measurements, alternatives for T_0 measurements should be considered (TOF???)
- T_0 can be measured with $\sigma \leq 50$ ps in AuAu@11 at all centralities
- T_0 can be measured with $\sigma \leq 50$ ps in AuAu@5 at centrality values 0-30%; at higher centralities T_0 resolution rapidly drops → alternatives???
- z-vertex can be measured with resolution < 5 and 25 cm with the FFD and FHCAL, respectively
- Bias and uncertainties for centrality determination using N_{ch} reconstructed in the TPC should be evaluated

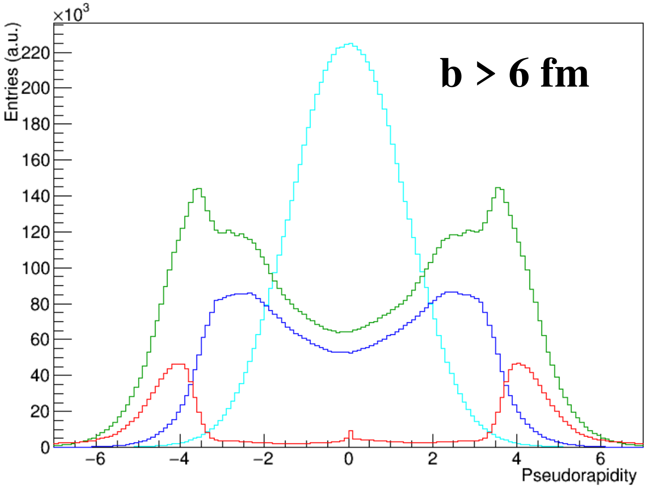
BACKUP

DCM-QGSM-SMM

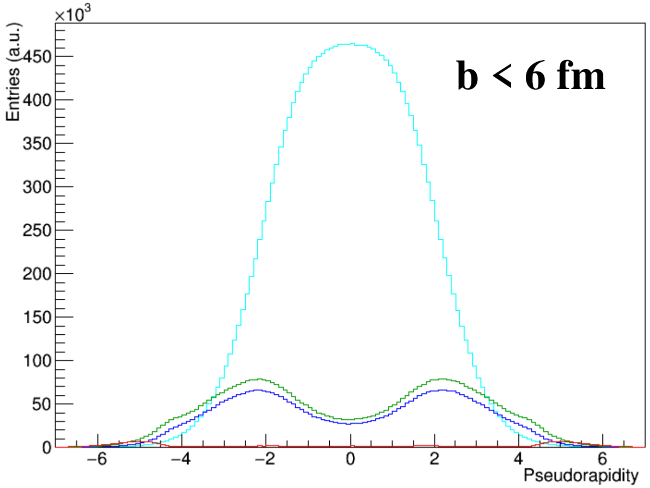
- AuAu@5

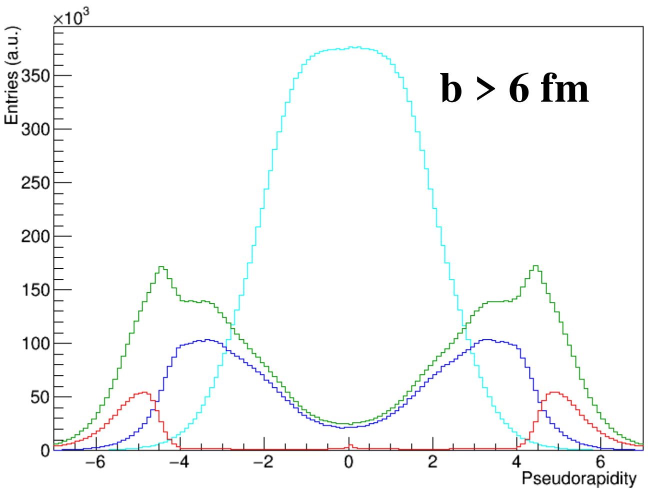


$\pi^+ + \pi^-$
$p + \overline{p}$
n
ions



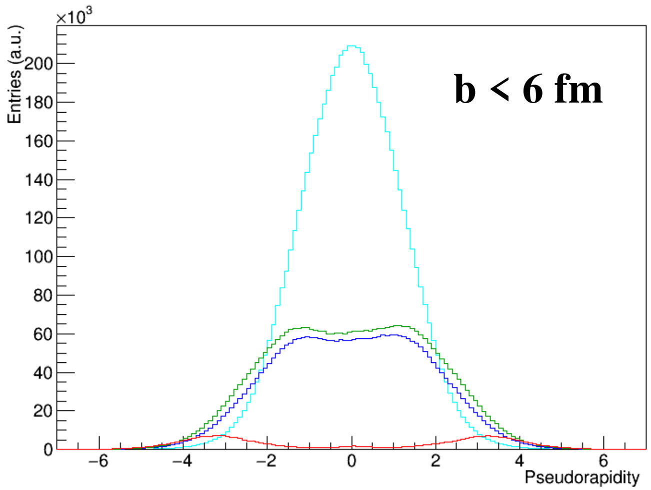
- AuAu@11





PHQMD

- AuAu@5

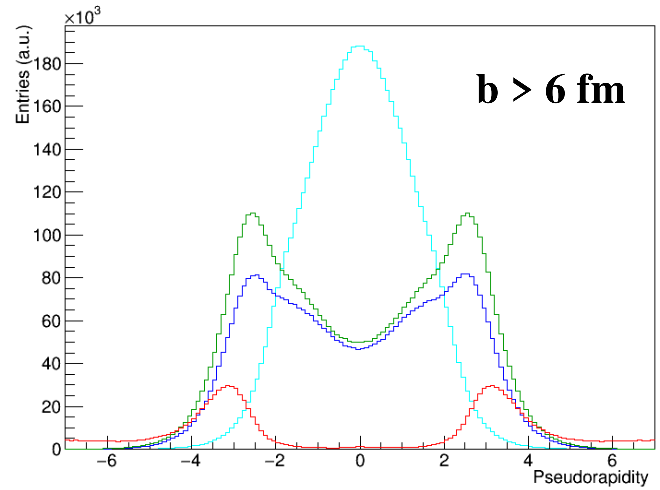


$\pi^+ + \pi^-$

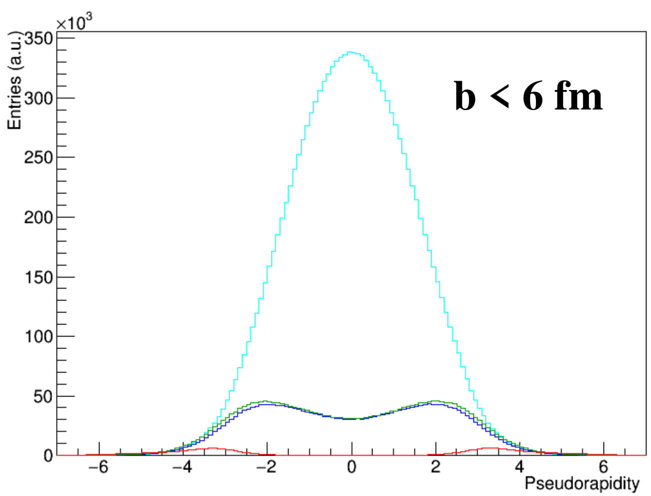
$p + \bar{p}$

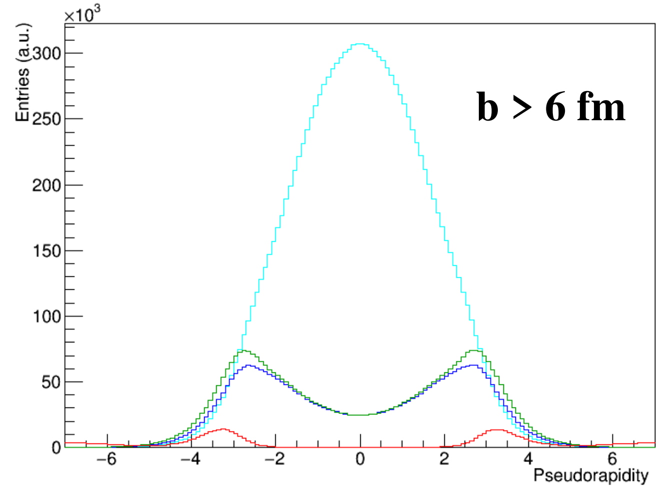
n

ions



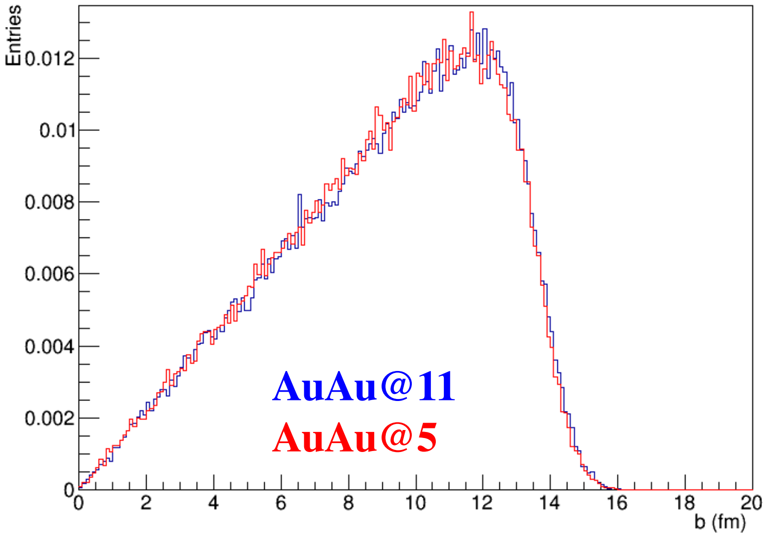
- AuAu@11



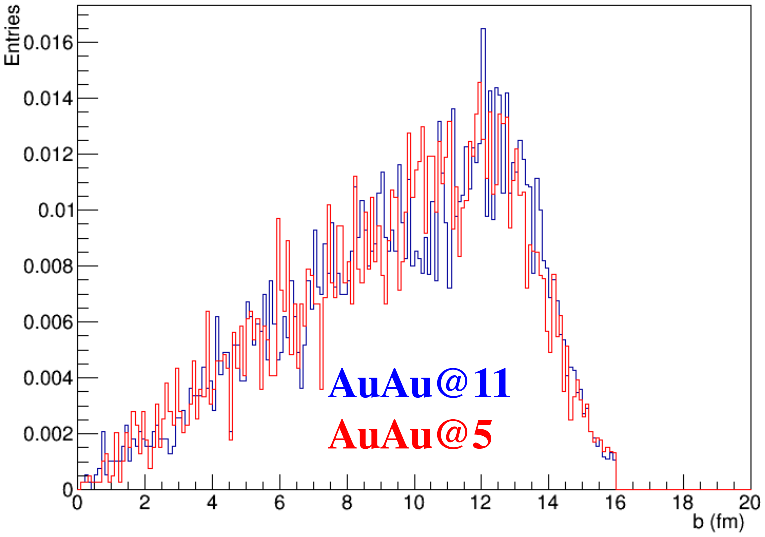


Impact parameters (N_{tracks}^{TPC}>0)

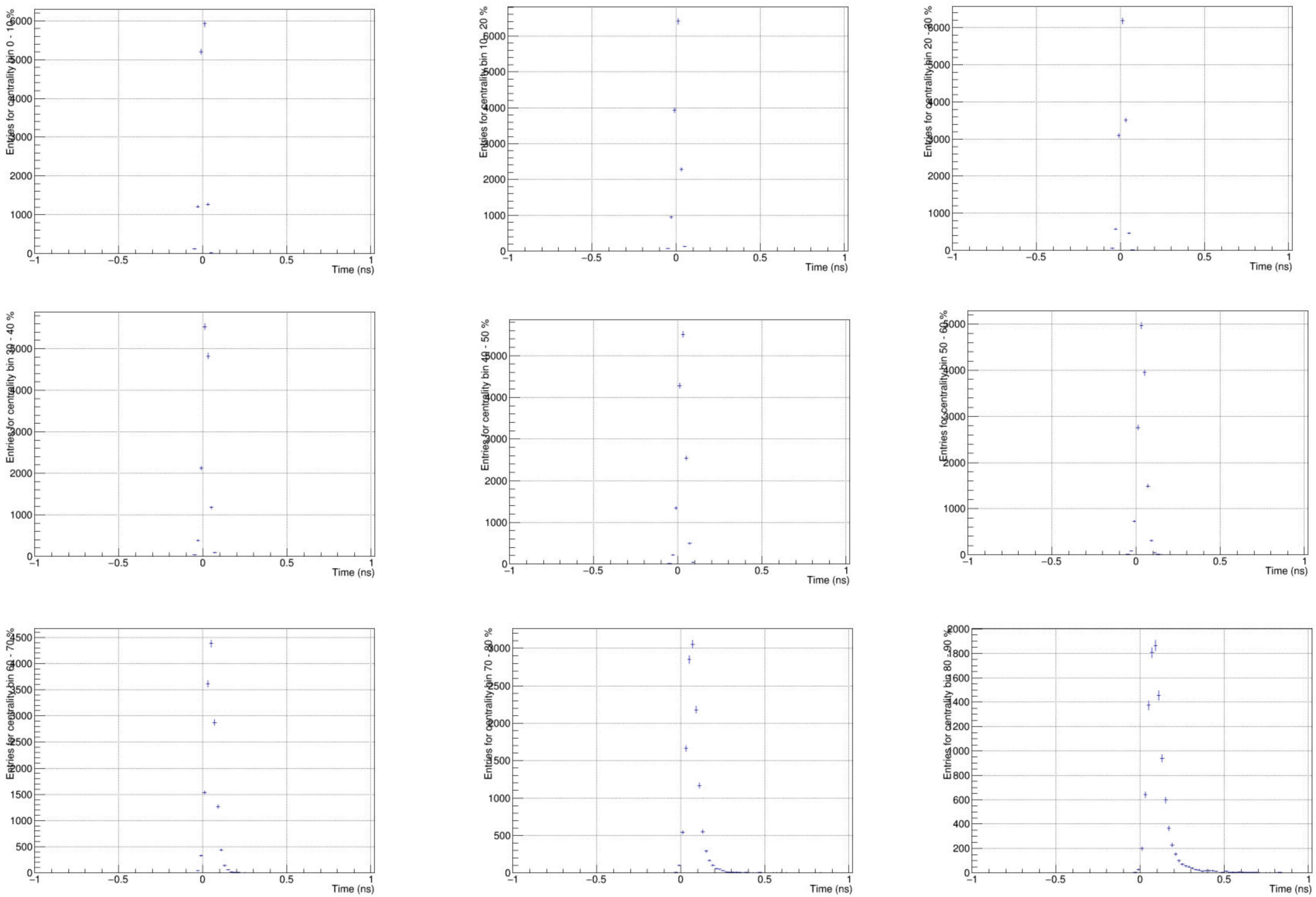
DCM-QGSM-SMM



PHQMD



Slices from slide 14, AuAu@11



Slices from slide 14, AuAu@5