PETERSBURG NUCLEAR PHYSICS INSTITUTE
NAMED BY B.P. KONSTANTINOV
OF NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

Intermediate report:

Trigger studies in the collider mode

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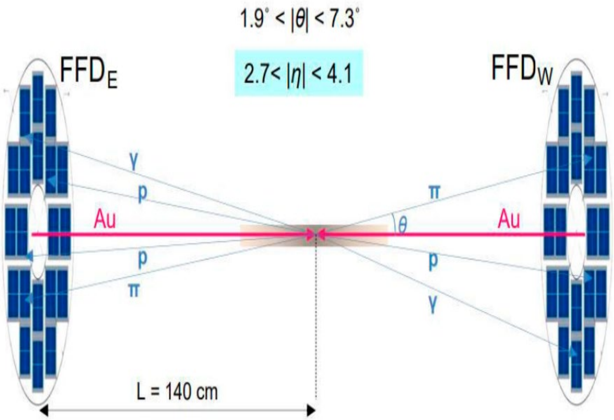
Project goals

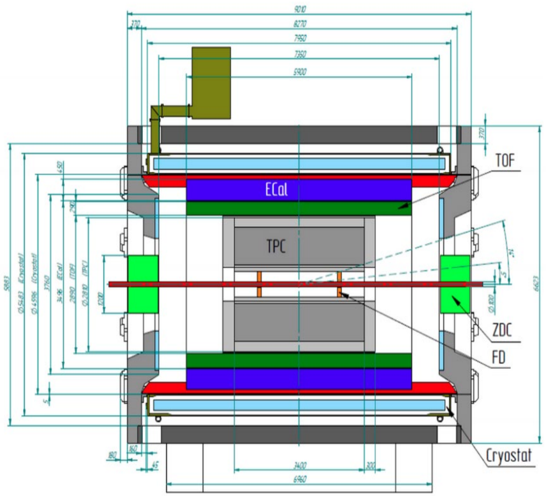
- Systematic study of the MPD trigger system (stage 1, collider mode) and T_0 measurement capability in p+p, p+Bi, C+C, Xe+Xe, Bi+Bi collisions at $\sqrt{s_{NN}} = 4 – 11$ GeV. What collisions can be measured and what trigger logic for event selection can be used.
- Full-scale simulation (DCM-QGSM-SMM, PYTHIA8 → MPDRoot) of the MPD detector in p+p, p+Bi, C+C, Xe+Xe, Bi+Bi collisions at $\sqrt{s_{NN}} = 4 – 11$ GeV.
- Optimization of trigger logic algorithms and determination of the maximum achievable characteristics of the MPD trigger system in p+p, p+Bi, C+C, Xe+Xe, Bi+Bi collisions at $\sqrt{s_{NN}} = 4 – 11$ GeV.
- Determination of the limits of the MPD trigger system for the purpose of efficient selection of events and the start time T_0 measurement depending on the size, energy and centrality of a colliding system.
- Adjustment of the trigger logic algorithms in accordance with the development of trigger electronics.

Trigger detectors

Fast forward detector (FFD)



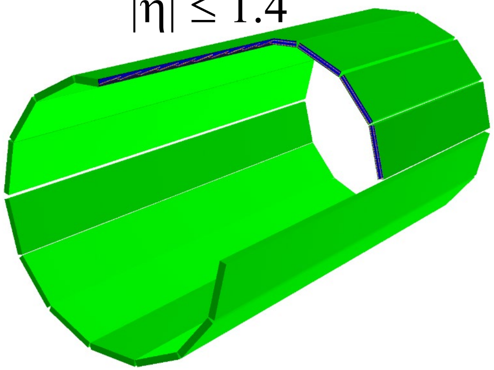
- 2×20 Cherenkov modules. 2×80 channels.
- Specially designed for event selection.
- Good time and vertex resolutions.
- Provides T_0 for TOF and ECal. Designed time resolution ≤ 50 ps.



Stage 1

Time of flight system (TOF)

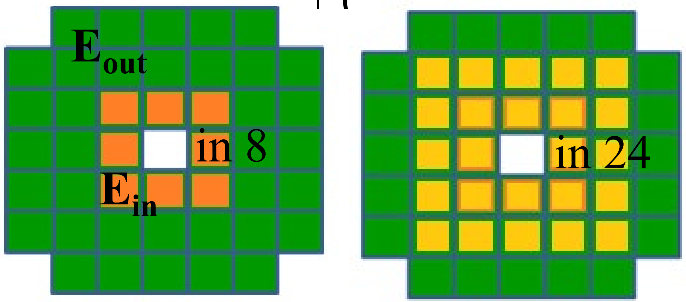
$|\eta| \leq 1.4$



- $14\times2\times10$ MRPC detectors.
- Fast enough for event triggering.

Forward Hadron Calorimeter (FHCal)

$2 < |\eta| < 5$



- 2×48 equivalent sampling lead/scintillator calorimeter modules.
- Time and event vertex resolutions are not good enough compared to FFD.
- Fast enough for event triggering.

MPD Trigger

FFD: $|\Delta\varphi| < 2\pi$, $2.7 < |\eta| < 4.1$

FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

TOF: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$

- Fast enough.
- Have suitable electronics.
- Cover different rapidity ranges.
- Measure different signals.
- Complement each other.

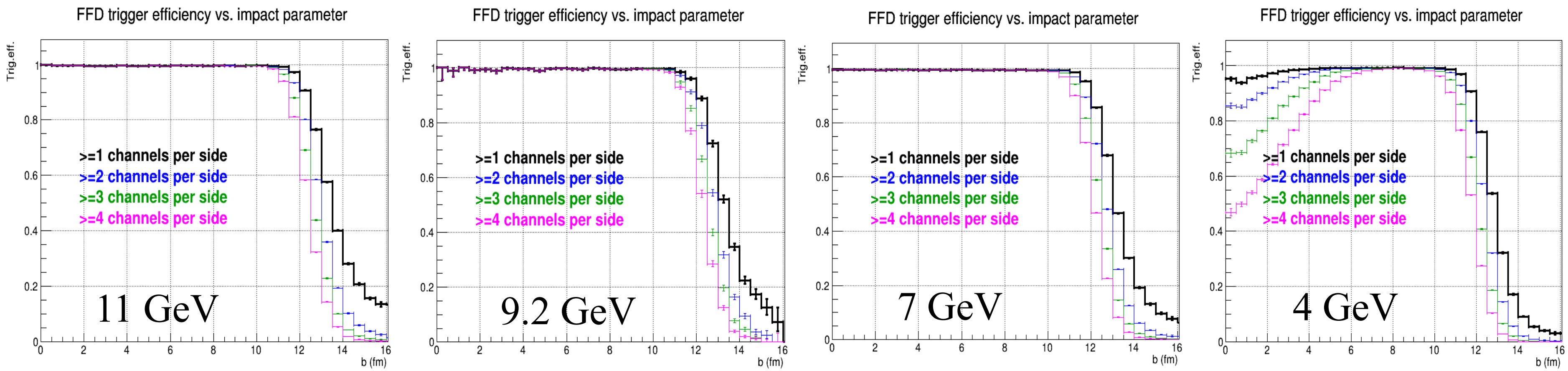
Full-scale simulation

- **Collision systems:**
  - p+p, p+Bi, C+C, Xe+Xe and Bi+Bi.
  - $\sqrt{s_{NN}}$ = 4, 7 and 11 GeV (9,2 GeV for results validation).
- **Event generators:**
  - DCM-QGSM-SMM for p+Bi, C+C, Xe+Xe, Bi+Bi.
    - realistic z-vertex distribution with $\sigma_z \sim 50$ cm.
    - inelastic collisions with b ~ 0–16 fm (~ 0.5×10^6 - 1×10^6 events for every collision system).
  - PYTHIA8 for p+p and p+Bi (TOF).
- **Particles propagation through MPD:**
  - Full event reconstruction with default MpdRoot.
  - Geant-4.
  - FFD, FHCal and TOF standard procedures as described in Victor Riabov presentations: (https://indico.jinr.ru/event/3448/contributions/18622/attachments/14091/23624/TriggerMassProductions.pdf)
- **Trigger configurations and definition:**
  - Different combinations of FFD, FHCal and TOF detectors
  - FFD
    - Default is ≥ 1 fired channel per side for symmetric and on one side for asymmetric collision system.
    - Optional: ≥ 2, 3 or 4 modules per or on one side.
    - |z-vertex| < 140 cm (should be wider by 10 – 20 cm during online selection).
  - FHCal:
    - Default is ≥ 1 fired module per side for symmetric and on one side for asymmetric collision system.
    - Optional (per or on one side): ≥ 2 modules, ≥ 1 module in inner region 8, ≥ 1 module in inner region 24.
    - Optional: ≥ 1 modules in 8, 24 or 44 inner region, ≥ 1 modules in 8 or 24 or 44 inner regions.
    - |z-vertex| < 150 cm (should be wider by 20 – 30 cm during online selection).
  - TOF:
    - Default ≥ 1 fired detector.
    - Optional: ≥ 2, 3, 4 fired detectors.

Bi + Bi at $\sqrt{s_{NN}}$ = 4 - 11 GeV

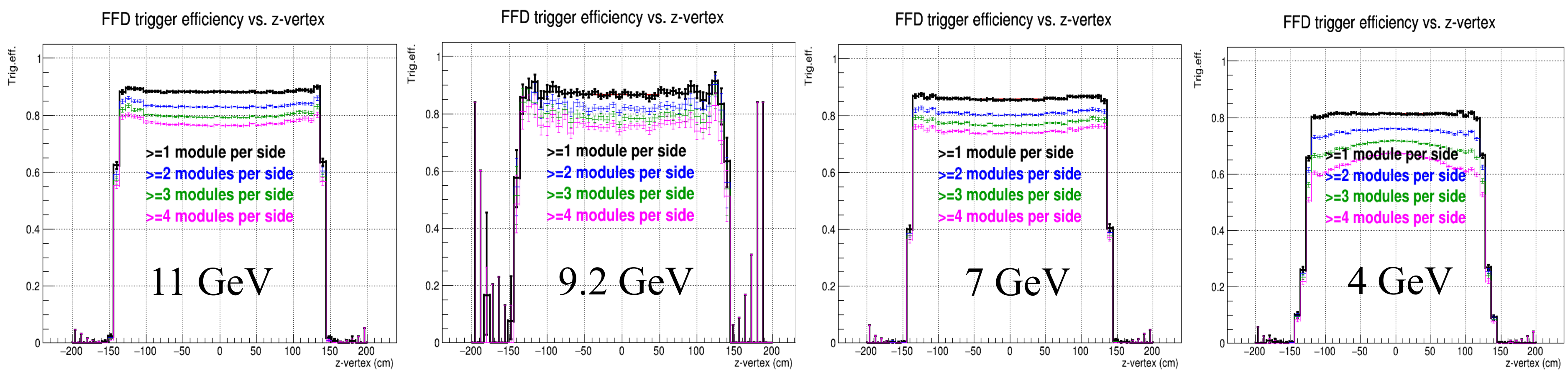
FFD

FFD trigger efficiency vs impact parameter b (fm)



100% from 0 to 11 fm | 100% from 0 to 11 fm | 100% from 0 to 10 fm | 100% from 5-8 to 10 fm

FFD trigger efficiency vs z-vertex (cm)

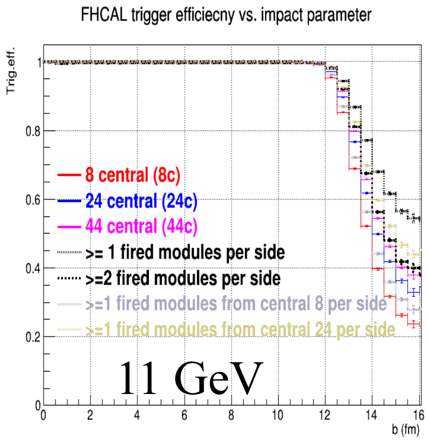


≈ 88 % | ≈ 87 % | ≈ 85 % | ≈ 81 %

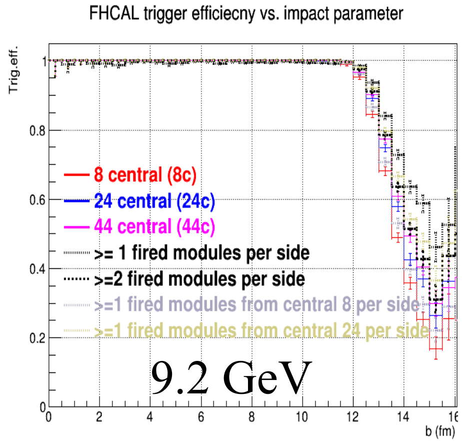
- Trigger efficiency is decreasing with decreasing $\sqrt{s_{NN}}$.
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

FHCal

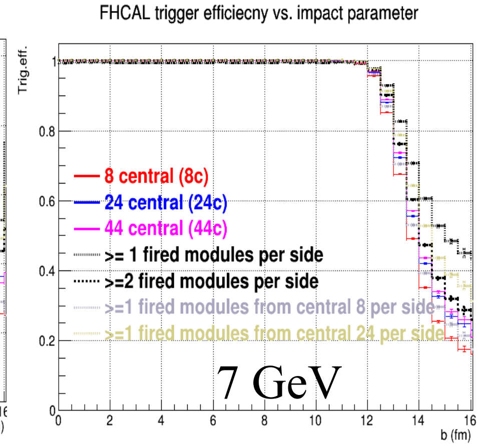
FHCal trigger efficiency vs impact parameter b (fm)



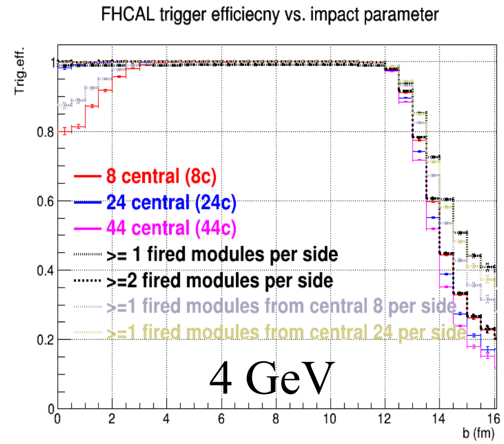
100% from 0 to 12 fm



100% from 0 to 12 fm

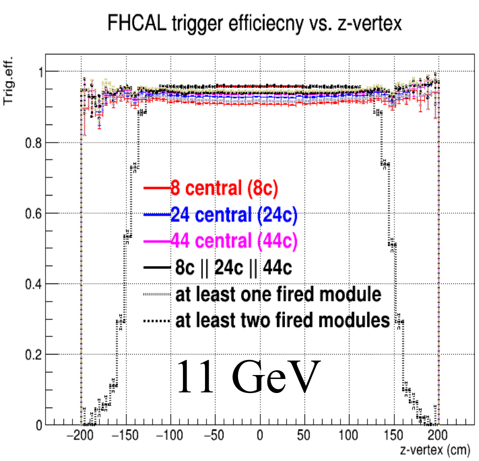


100% from 0 to 11 fm

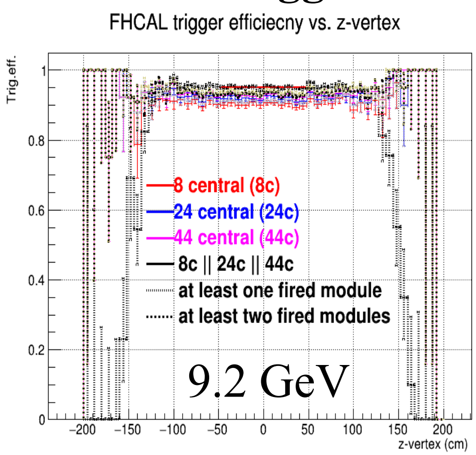


100% from 0 to 11 fm

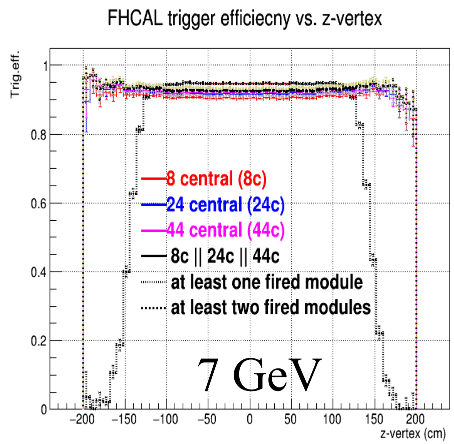
FHCal trigger efficiency vs z-vertex (cm)



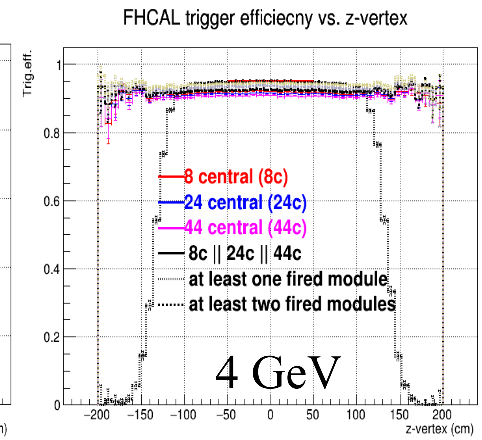
≈ 96 %



≈ 95 %



≈ 95 %

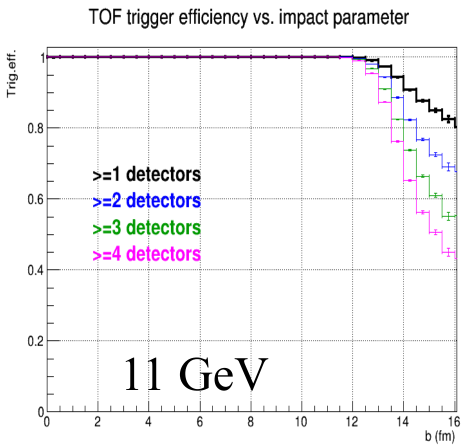


≈ 95 %

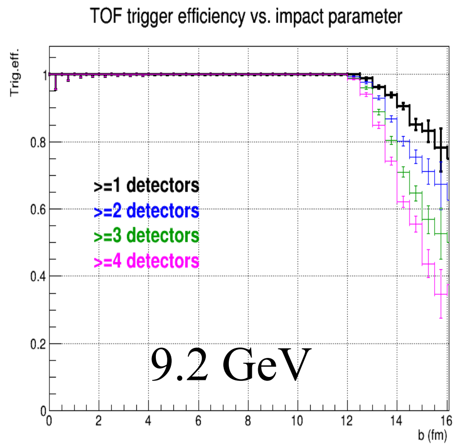
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

TOF

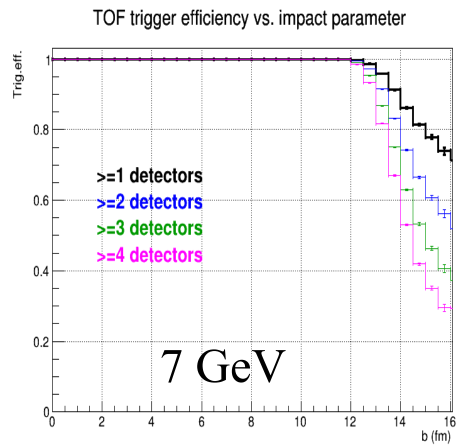
TOF trigger efficiency vs impact parameter b (fm)



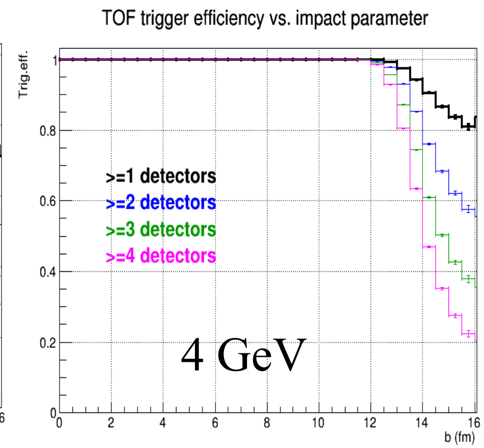
100% from 0 to 12 fm



100% from 0 to 12 fm

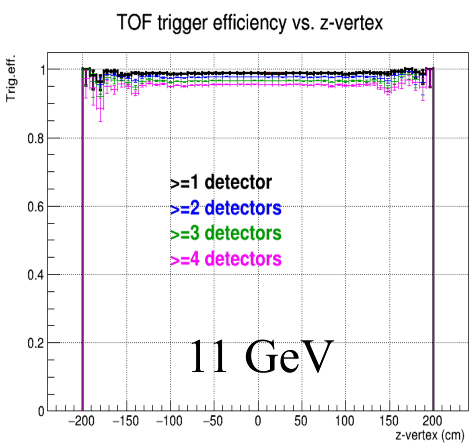


100% from 0 to 12 fm

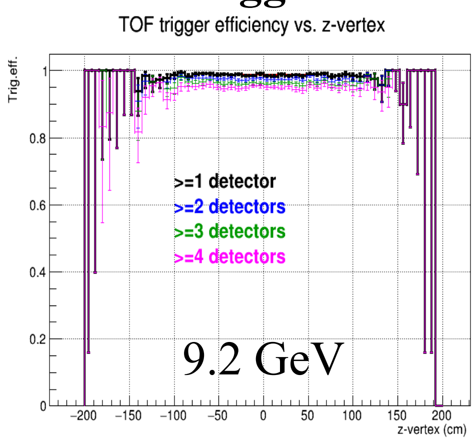


100% from 0-12 fm

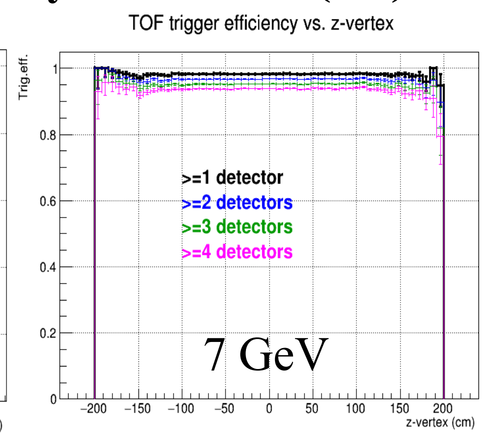
TOF trigger efficiency vs z-vertex (cm)



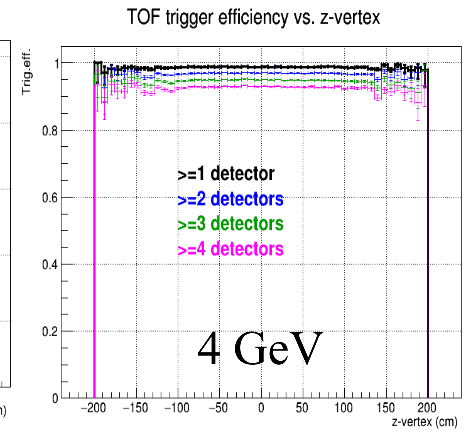
≈ 99 %



≈ 99 %



≈ 99 %

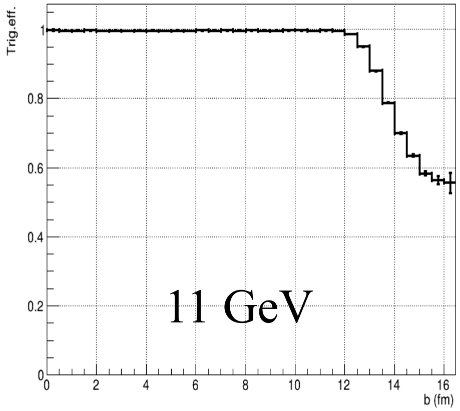


≈ 99 %

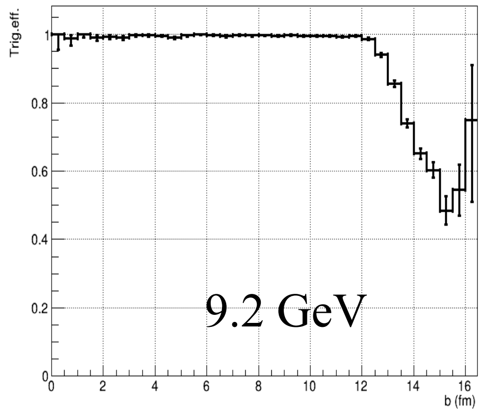
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±200 cm.

FFD and FHCal

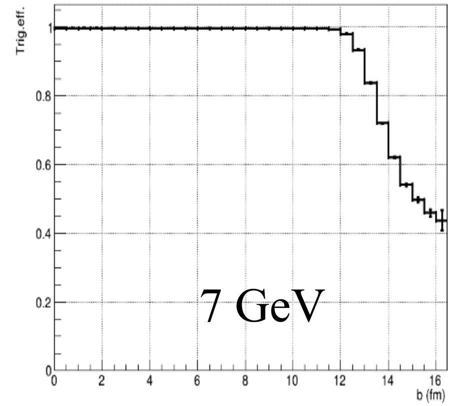
FFD || FHCal trigger efficiency vs impact parameter b (fm)



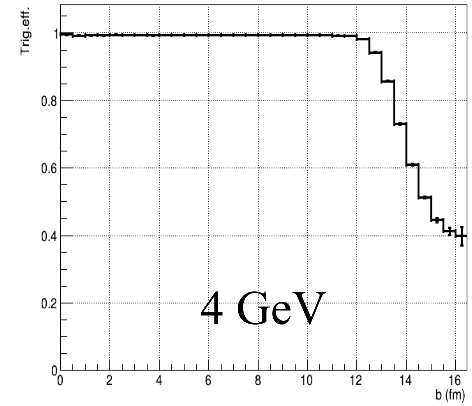
100% from 0 to 12 fm



100% from 0 to 12 fm

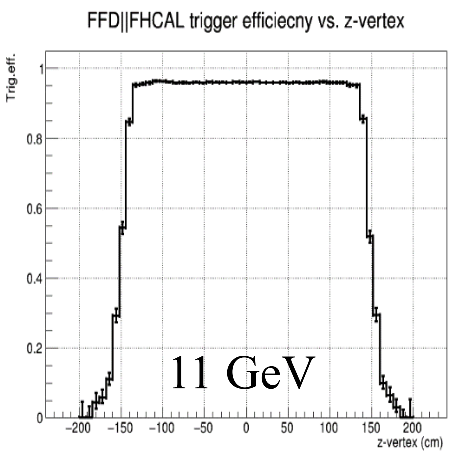


100% from 0 to 11 fm

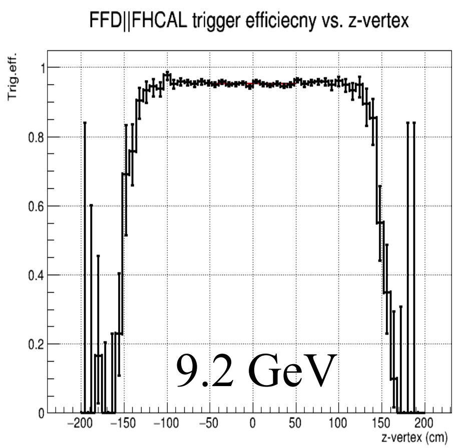


100% from 0 to 11 fm

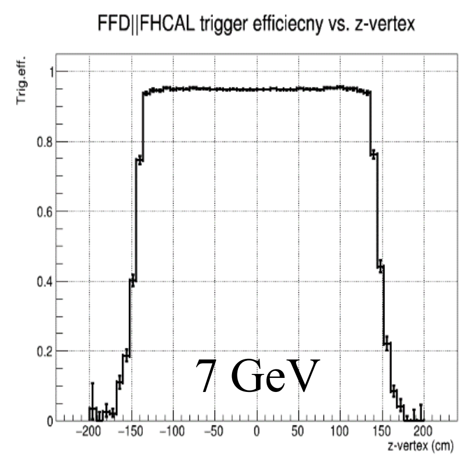
FFD || FHCal trigger efficiency vs z-vertex (cm)



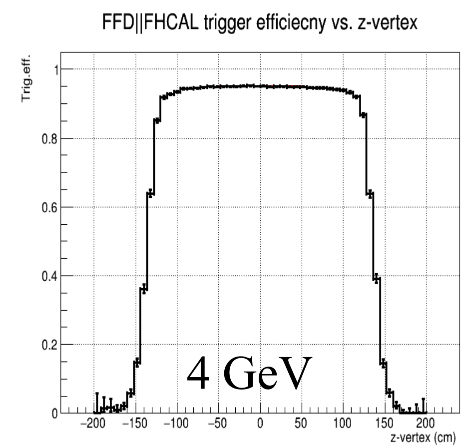
≈ 96 %



≈ 95 %



≈ 95 %

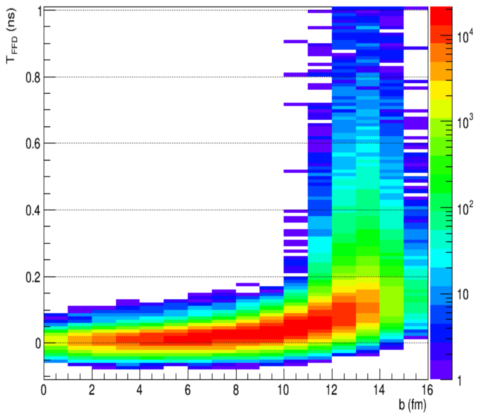


≈ 95 %

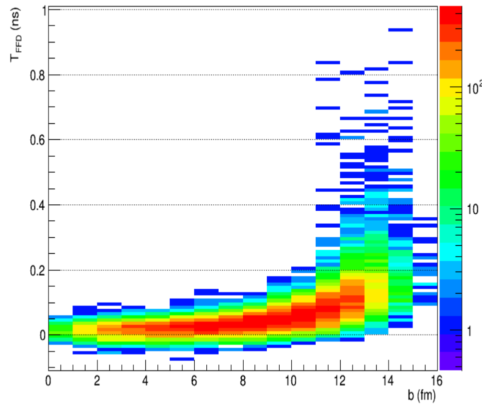
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

T_0 in FFD

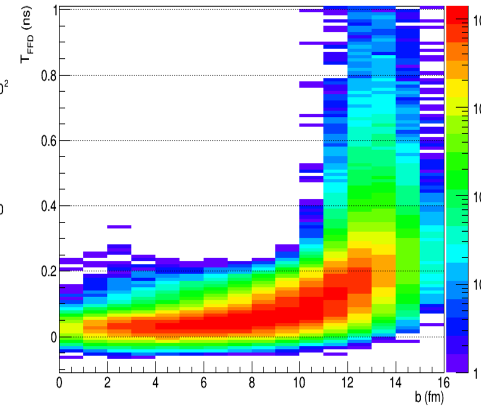
$$T_0 = (T_{FFDE} + T_{FFDW}) / 2 - L/c$$



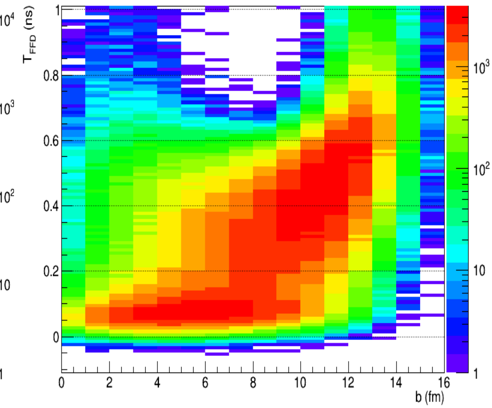
11 GeV



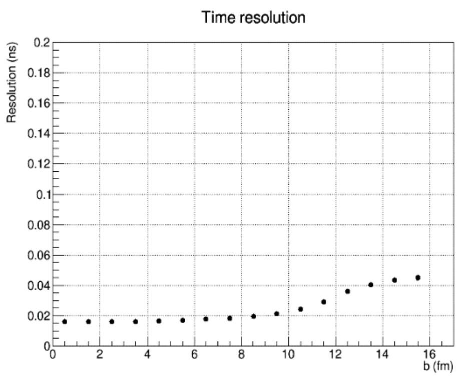
9.2 GeV

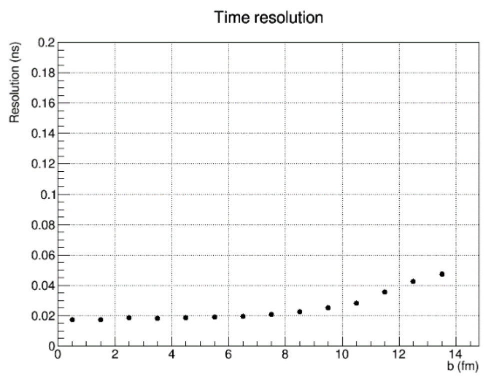


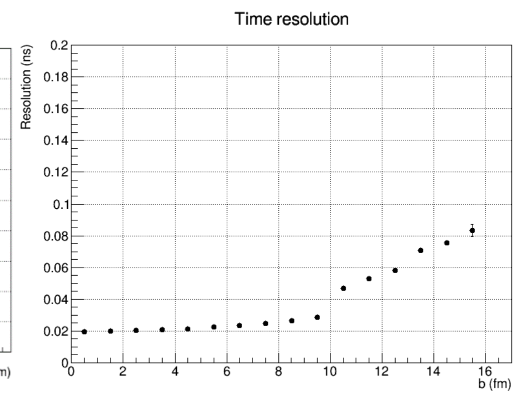
7 GeV

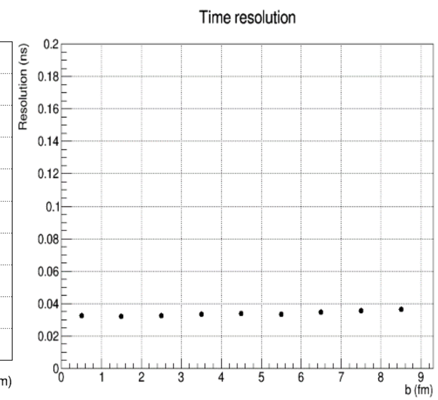


4 GeV





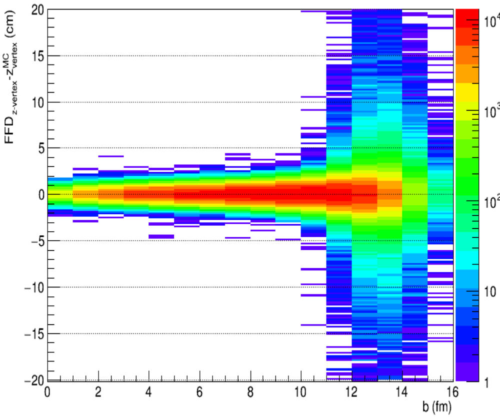




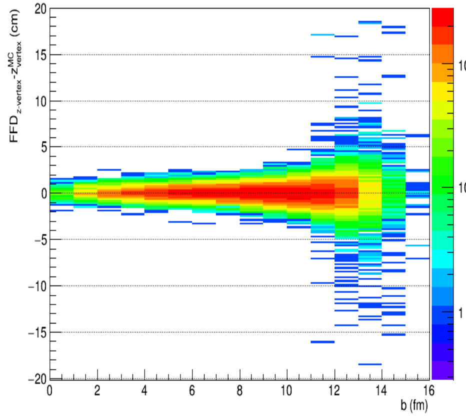
- Significant centrality bias for all studied $\sqrt{s_{NN}}$ especially for 4 GeV.
- Time resolution is degrading with decreasing $\sqrt{s_{NN}}$ and centrality (from 15-30 to 60-80 ps).

z-vertex in FFD

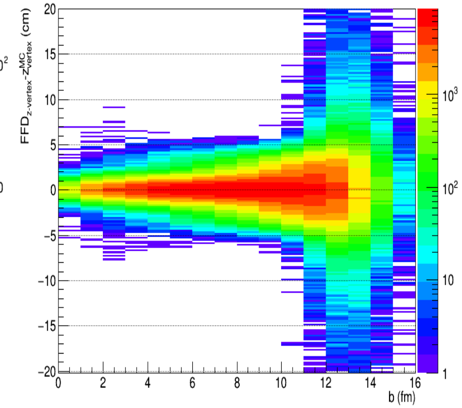
$$z\text{-vertex} = (T_{FFDW} - T_{FFDE})/2 \times c$$



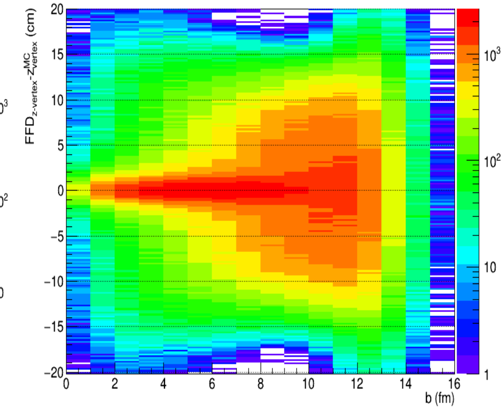
11 GeV



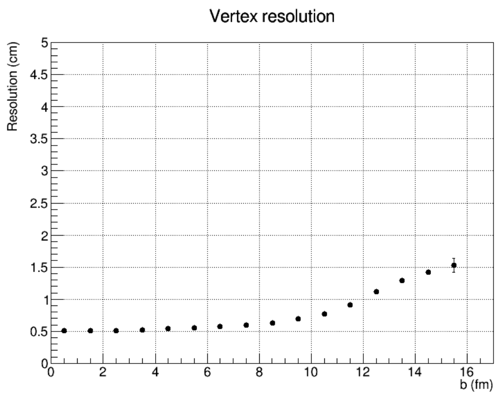
9.2 GeV

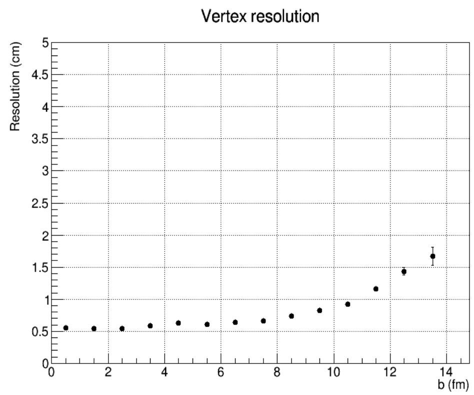


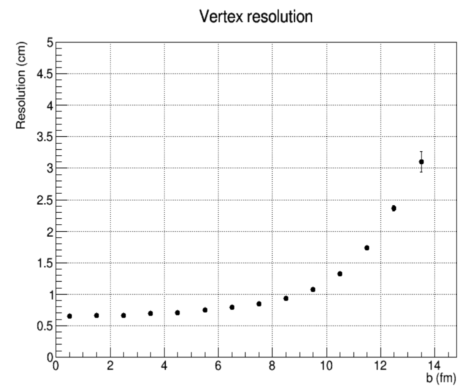
7 GeV

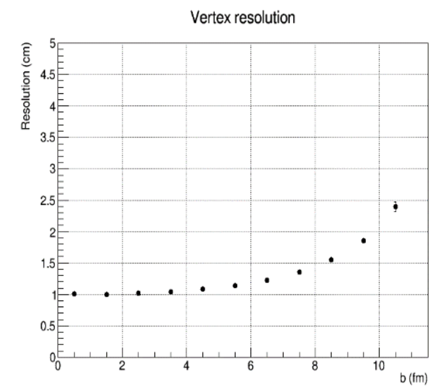


4 GeV





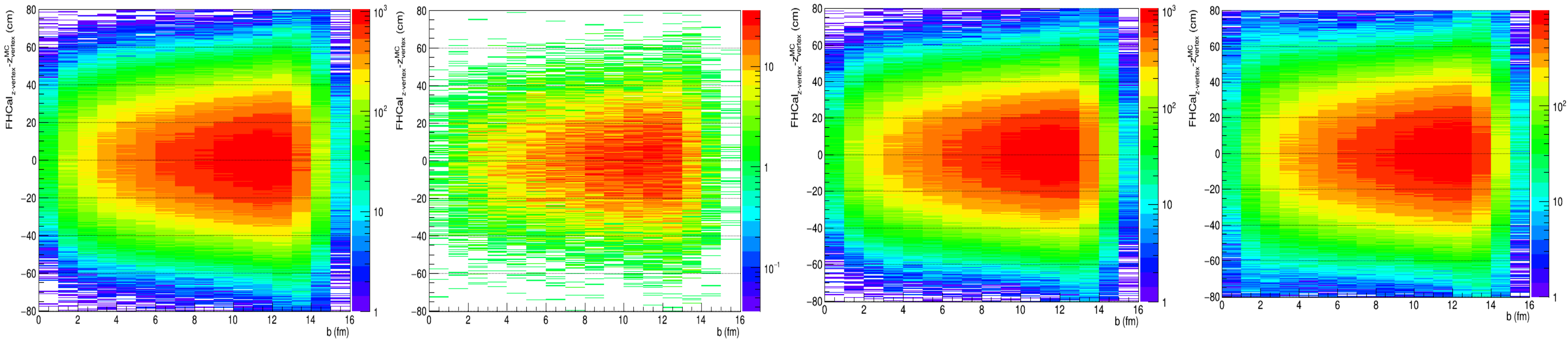




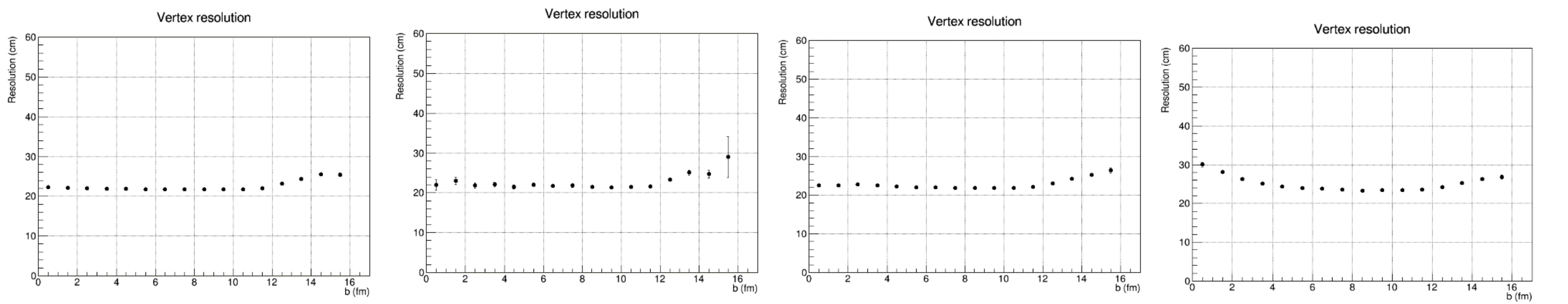
- z-vertex vs centrality distribution is not biased.
- z-vertex resolution is degrading with decreasing $\sqrt{s_{NN}}$ and centrality (from 0,5-1 to 1,5-3 cm).

z-vertex in FHCal

$$z\text{-vertex} = (T_{FHCALW} - T_{FHCALW})/2 \times c$$



11 GeV | 9.2 GeV | 7 GeV | 4 GeV



- z-vertex vs centrality distribution is not biased.
- z-vertex resolution is degrading with decreasing centrality (from 22 to 30 cm).
- z-vertex resolution is worse in central 4 GeV Bi+Bi collisions and has a recess shape.

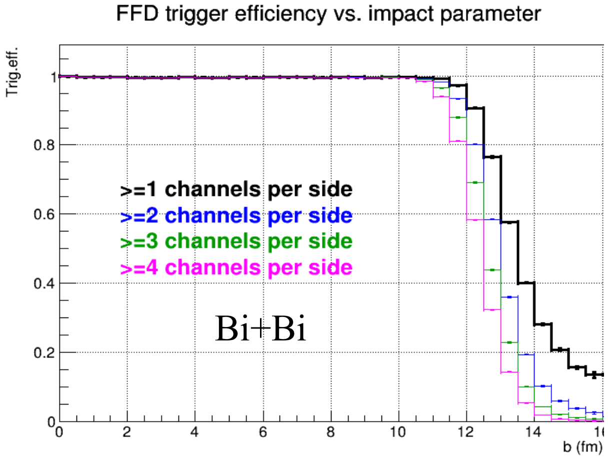
Summary, Bi + Bi at $\sqrt{s_{NN}}$ = 4 - 11 GeV

- Event selection of Bi+Bi collisions at $\sqrt{s_{NN}}$ = 4, 7, 9.2 and 11 GeV can be done with FFD, FHCal and TOF.
- Trigger efficiency vs b has a flat region with 100% efficiency.
- Trigger efficiency vs z-vertex is flat and wide (possible event selection with z-vertex > 120 cm).
- TOF has the greatest trigger efficiency (99%) > FFD (81 – 88%) and FHCal (95%).
- T_0 resolution study shows significant bias in T_0 vs centrality distribution especially for 4 GeV collisions.
- T_0 can be measured by FFD in a wide range of centrality with good enough resolution:
  - for the most central collisions: 15 – 30 ps (11 – 4 GeV).
  - for the most peripheral collisions: 60 – 80 ps (11 - 7 GeV).
- Z-position of the primary vertex can be measured by FFD with resolution of about:
  - for the most central collisions: 0.5 - 1 cm (11 – 4 GeV).
  - for the most peripheral collisions: 1.5 – 3 cm (11 – 7 GeV).
- Z-vertex is also can be measured by FHCal but the resolution is worse in this case and is about 20-30 cm depending on the centrality and the collision energy.

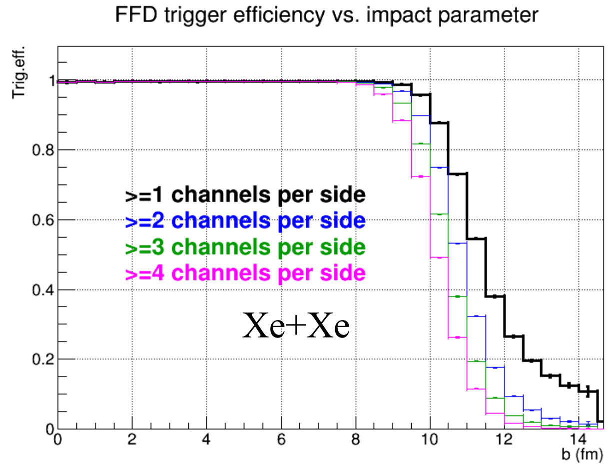
Bi+Bi, Xe+Xe, C+C, p+Bi and p+p at $\sqrt{s_{NN}}$ = 11 GeV

FFD

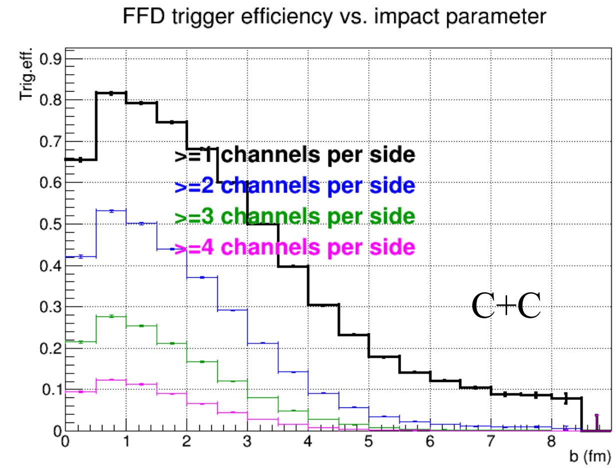
FFD trigger efficiency vs impact parameter b (fm)



100% from 0 to 11 fm

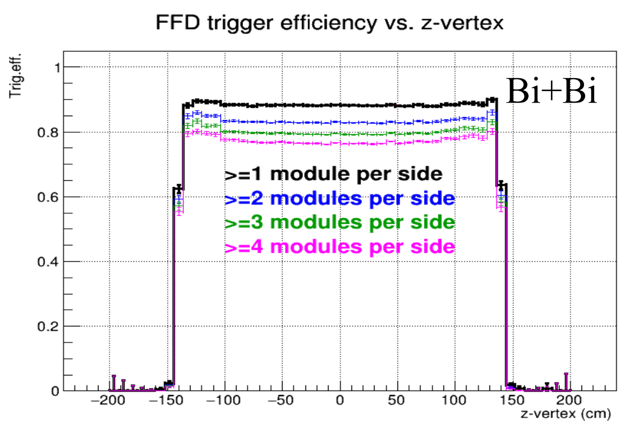


100% from 0 to 8 fm

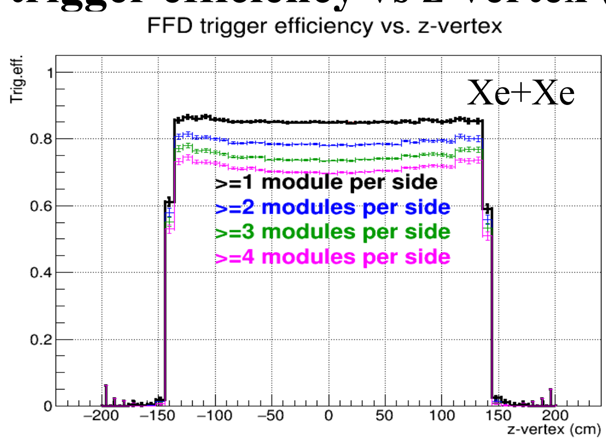


≈ 80 % max

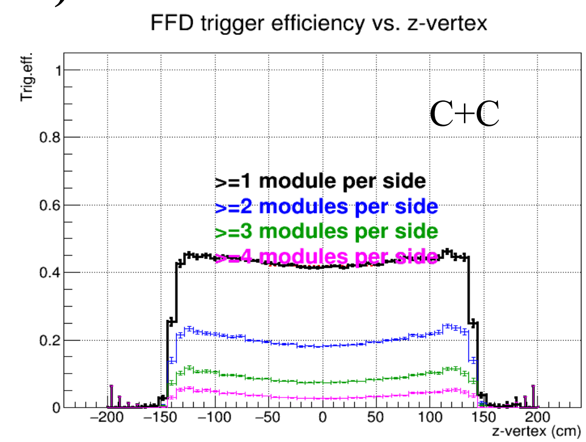
FFD trigger efficiency vs z-vertex (cm)



≈ 88 %



≈ 85 %

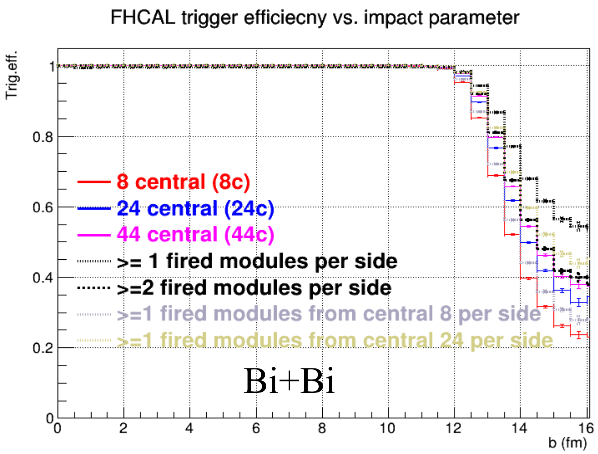


≈ 42 %

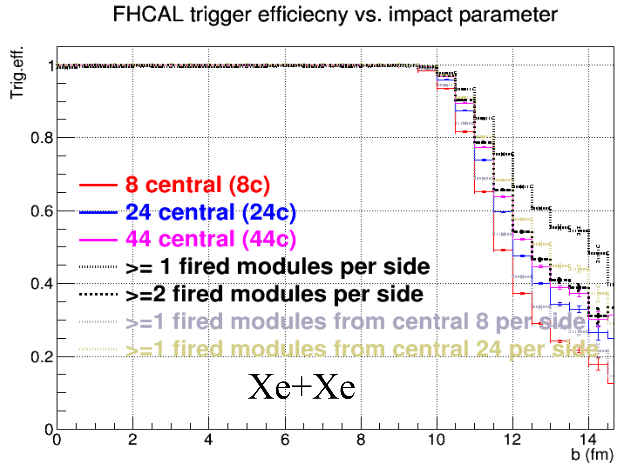
- Trigger efficiency is decreasing with decreasing size of the colliding system.
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

FHCal

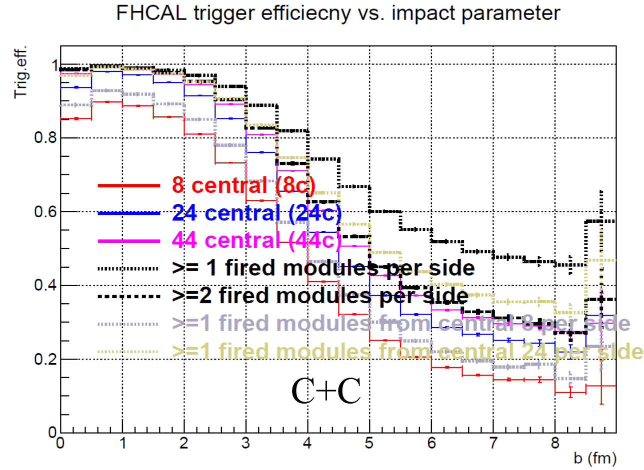
FHCal trigger efficiency vs impact parameter b (fm)



100% from 0 to 12 fm

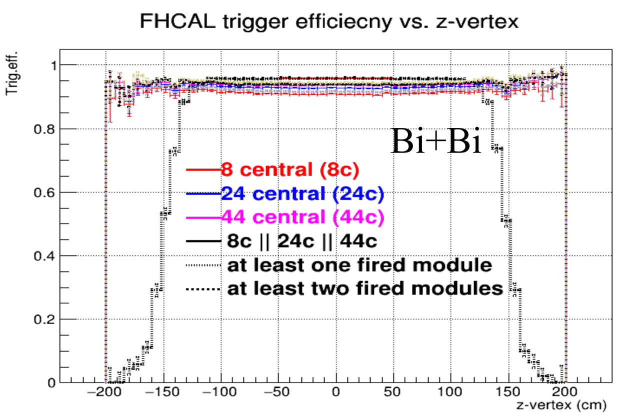


100% from 0 to 9 fm

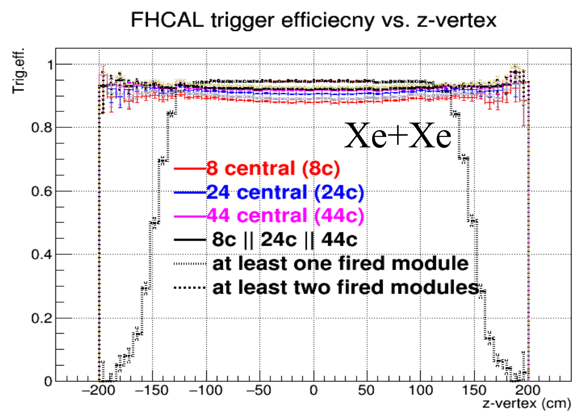


100 % around 1 fm

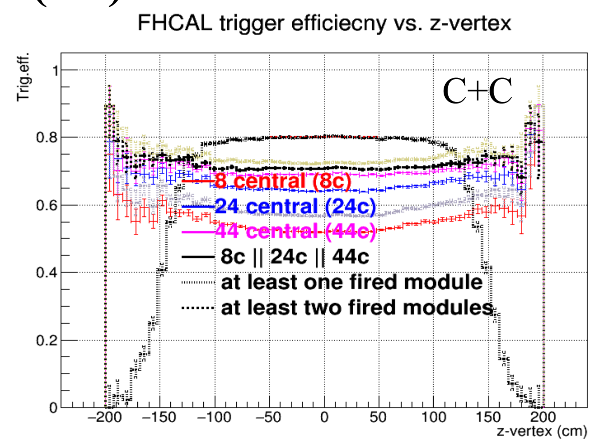
FHCal trigger efficiency vs z-vertex (cm)



≈ 96 %



≈ 94 %

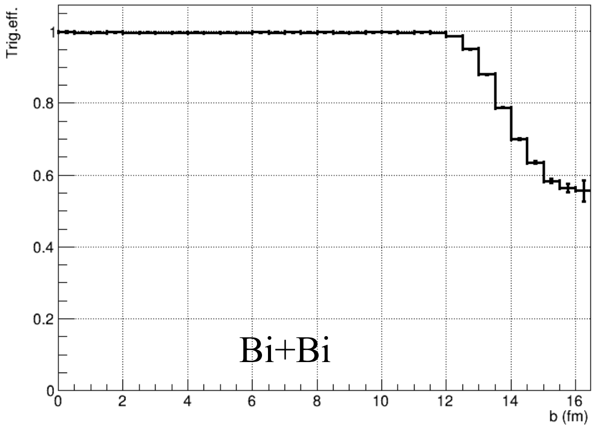


≈ 80 %

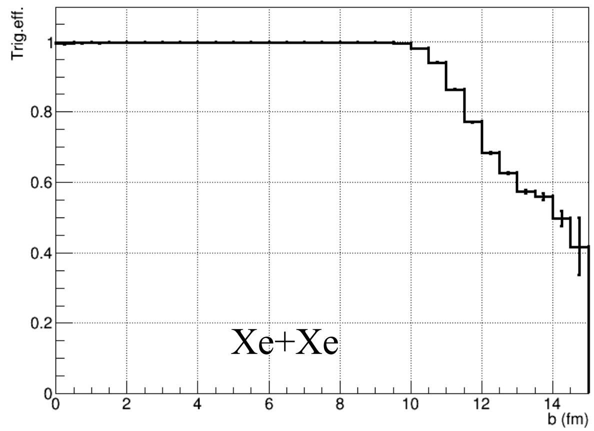
- Trigger efficiency is decreasing with decreasing size of the colliding system.
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

FFD and FHCal

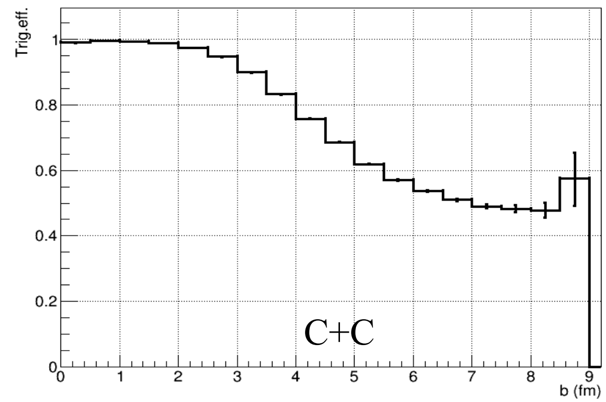
FFD || FHCal trigger efficiency vs impact parameter b (fm)



100% from 0 to 12 fm

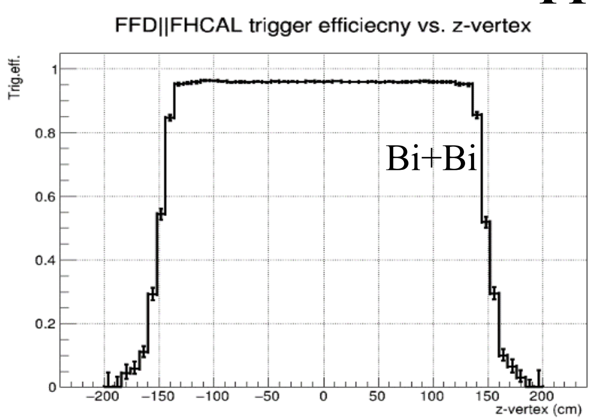


100% from 0 to 9 fm

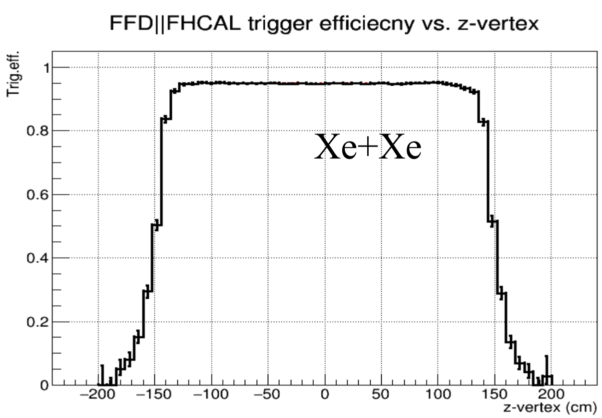


100 % around 1 fm

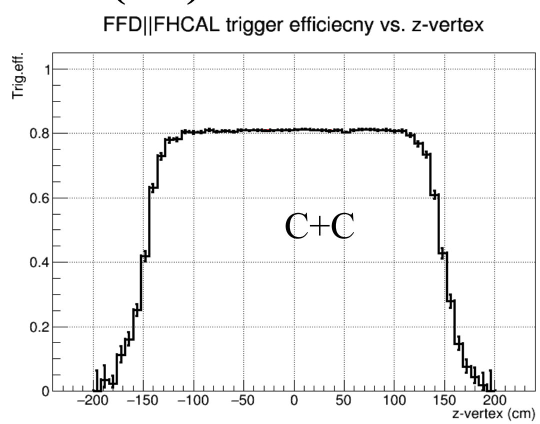
FFD || FHCal trigger efficiency vs z-vertex (cm)



≈ 96 %



≈ 95 %

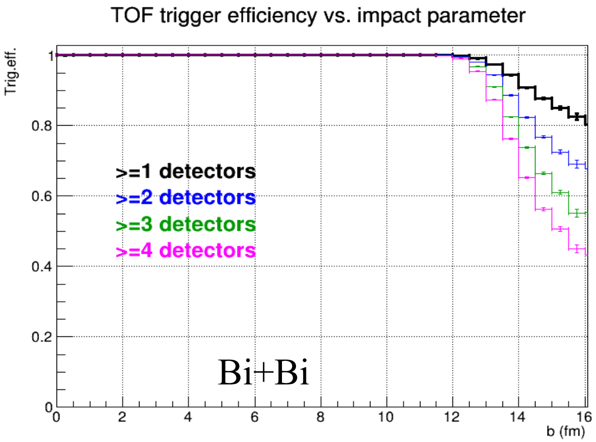


≈ 80 %

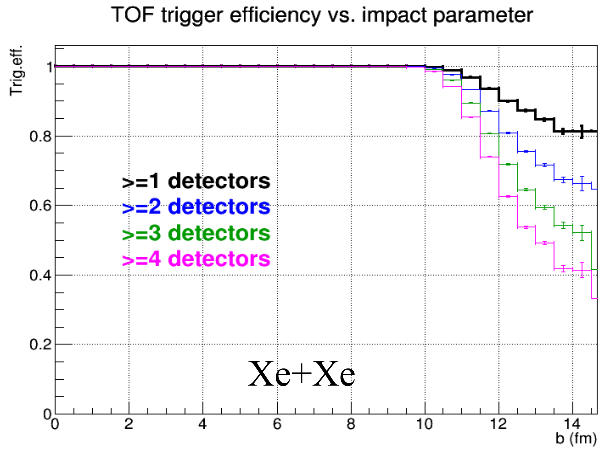
- Trigger efficiency is decreasing with decreasing size of the colliding system.
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±140(130) cm.

TOF

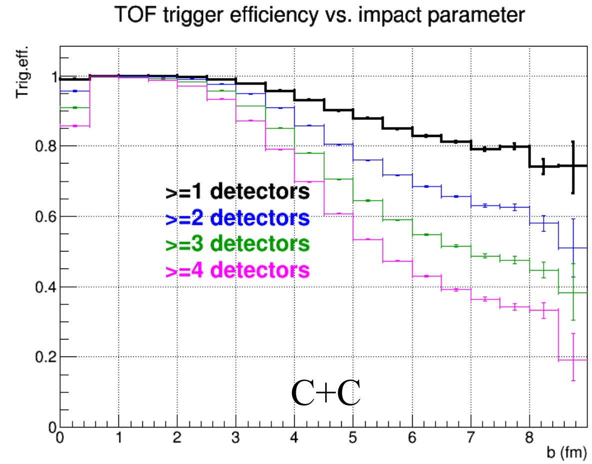
TOF trigger efficiency vs impact parameter b (fm)



100% from 0 to 12 fm

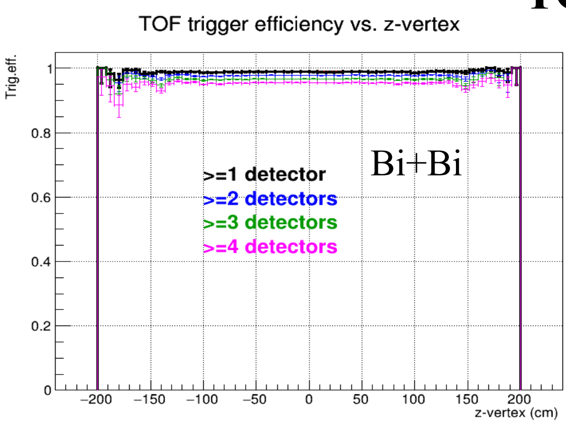


100% from 0 to 10 fm

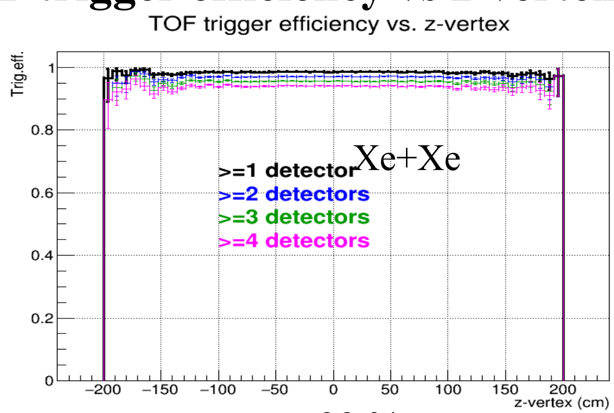


100 % from 0,5 to 2,5 fm

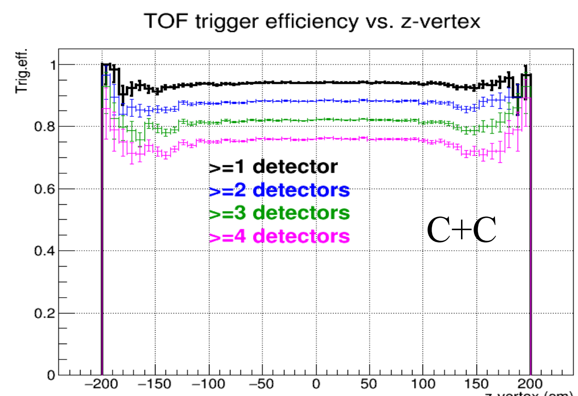
TOF trigger efficiency vs z-vertex (cm)



≈ 99 %



≈ 99 %

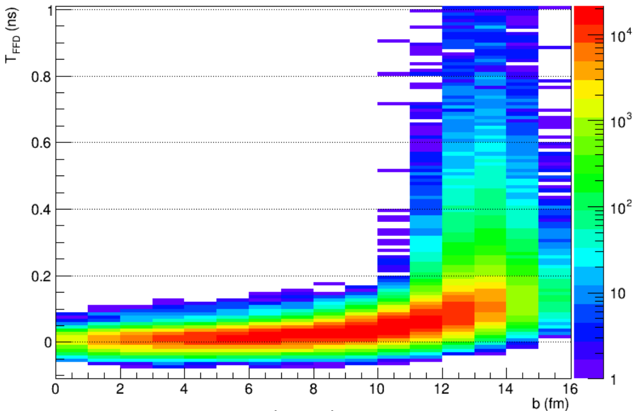


≈ 89 %

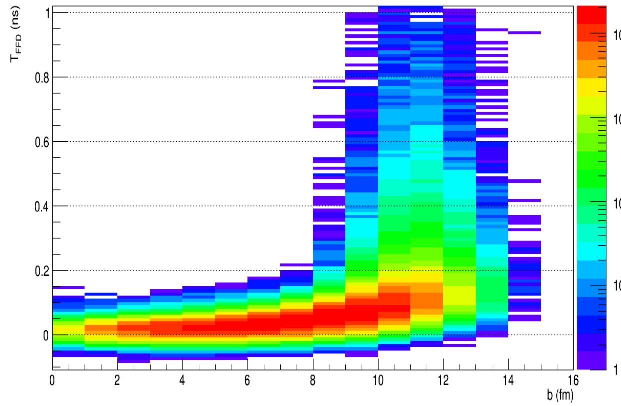
- Trigger efficiency is decreasing with decreasing size of the colliding system.
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±200 cm.
- TOF is crucial for event selection in C+C collisions and other light systems.

T_0 in FFD

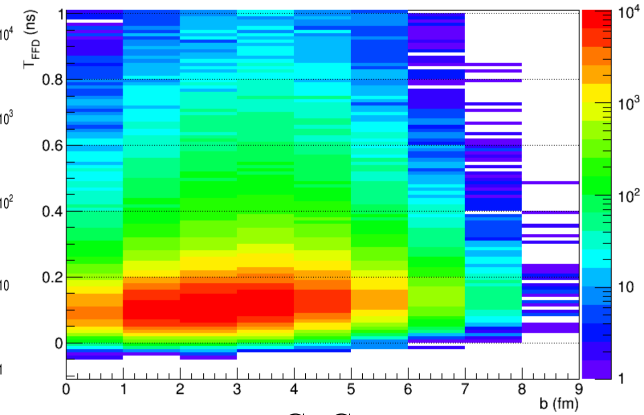
$$T_0 = (T_{FFDE} + T_{FFDW}) / 2 - L/c$$



Bi+Bi

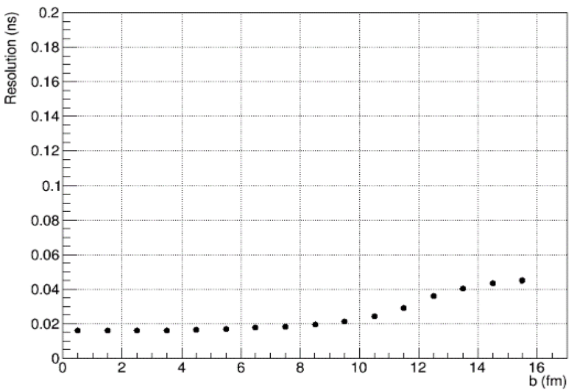


Xe+Xe

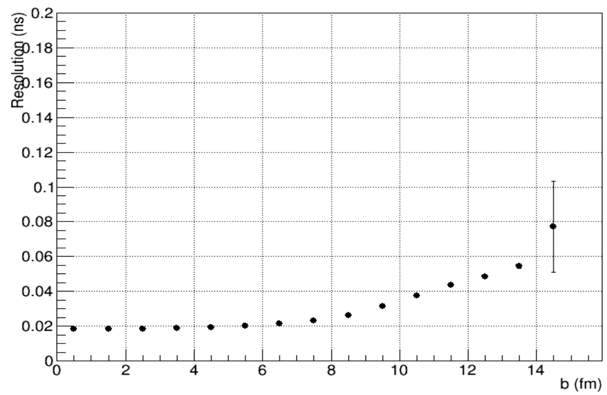


C+C

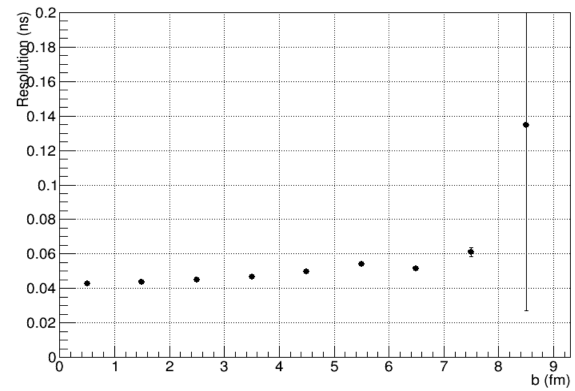
Time resolution



Time resolution



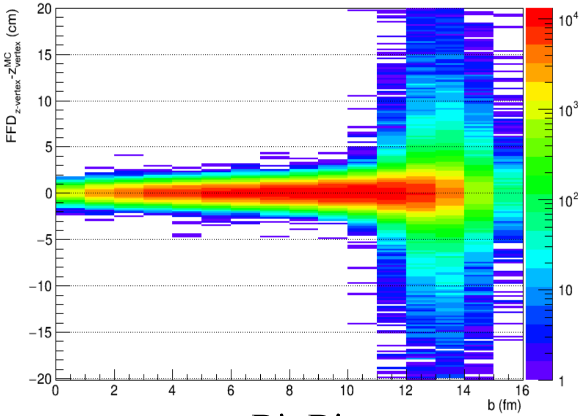
Time resolution



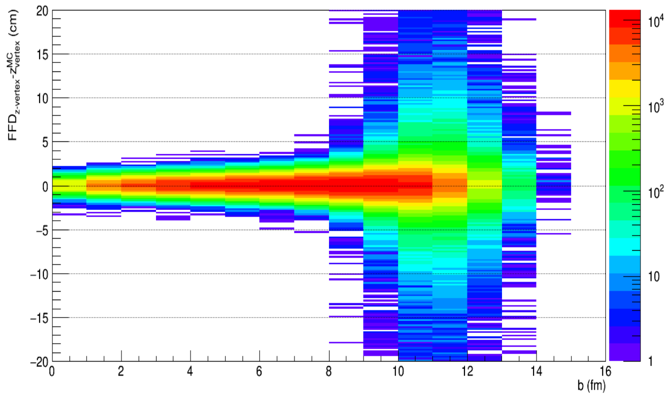
- Significant centrality bias for all studied collision systems.
- Time resolution is degrading with decreasing centrality and the size of the collision system:
  - 15 – 45 ps for Bi+Bi, 20-60 for Xe+Xe, $0 \leq b \leq 14$ fm.
  - 40 – 60 ps for C+C, $0 \leq b \leq 8$ fm.

z-vertex in FFD

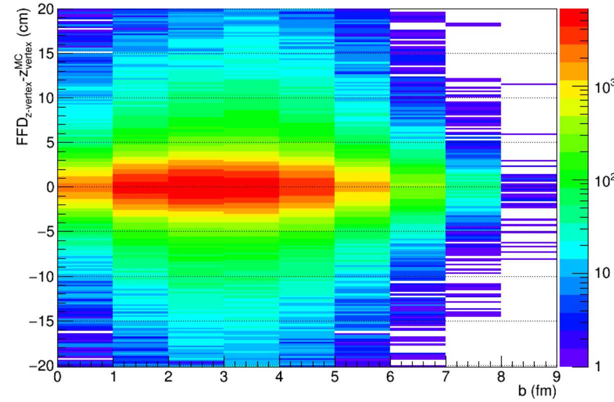
$$z\text{-vertex} = (T_{FFDW} - T_{FFDE})/2 \times c$$



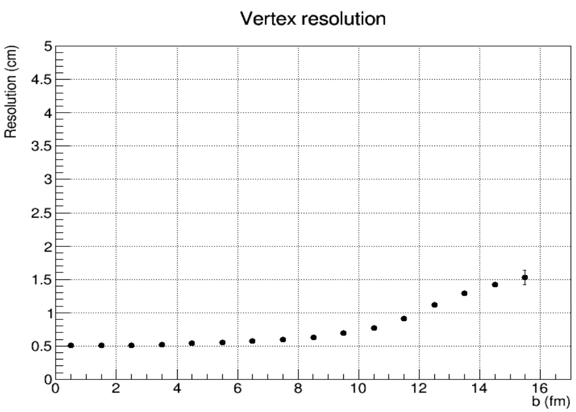
Bi+Bi

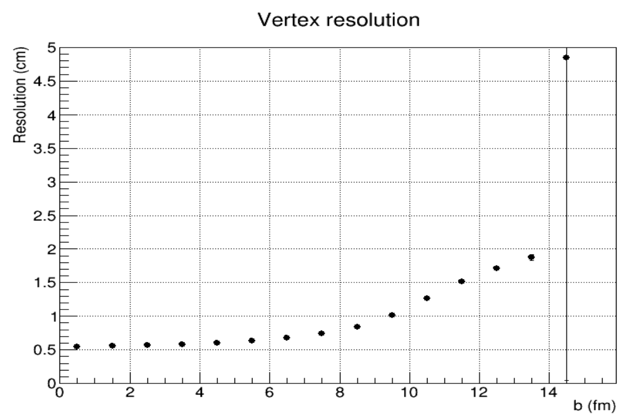


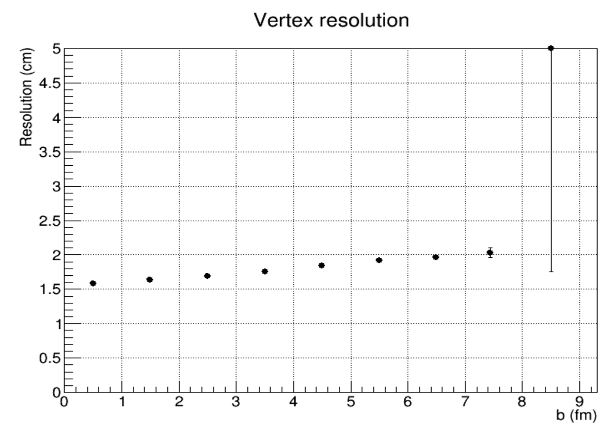
Xe+Xe



C+C



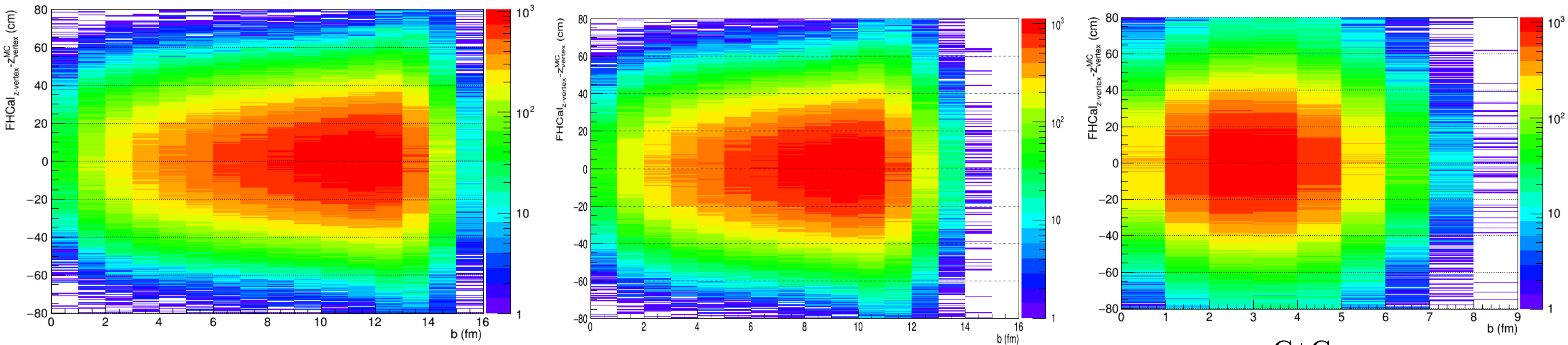




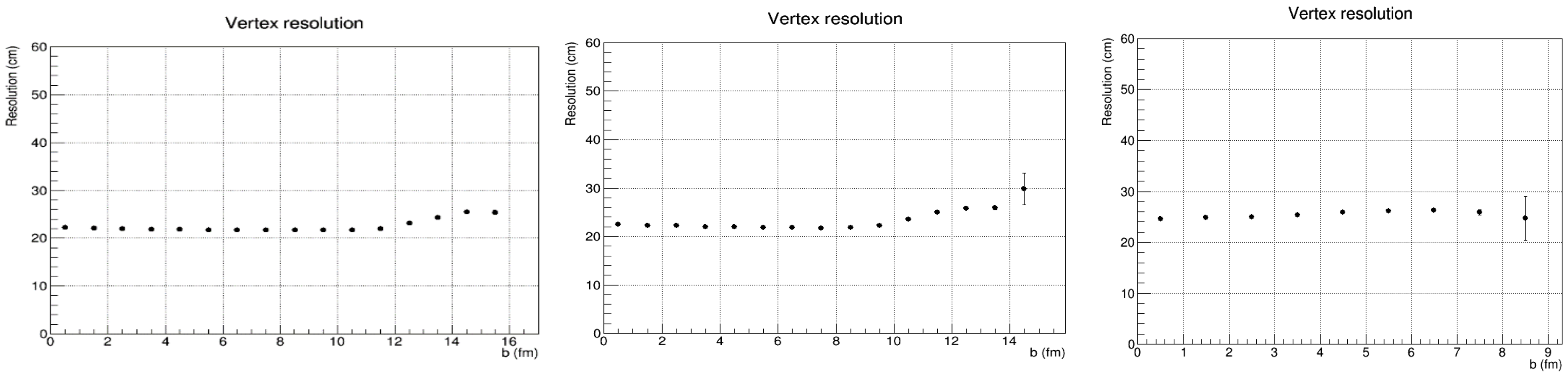
- z-vertex vs centrality distribution is not biased.
- z-vertex resolution is degrading with decreasing centrality and the size of the collision system:
  - 0.5 – 1.5-2 cm for Bi+Bi and Xe+Xe, $0 \leq b \leq 14$ fm.
  - 1.5 – 2 cm for C+C, $0 \leq b \leq 8$ fm.

z-vertex in FHCal

z-vertex = $(T_{FHCALW} - T_{FHCALW})/2 \times c$



Bi+Bi Xe+Xe C+C



- z-vertex vs centrality distribution is not biased.
- z-vertex resolution is degrading with decreasing centrality and the size of the collision system:
  - 22 – 26 cm for Bi+Bi and Xe+Xe, $0 \leq b \leq 14$ fm.
  - 25 cm for C+C, $0 \leq b \leq 9$ fm.

Summary, Bi+Bi, Xe+Xe, C+C at $\sqrt{s_{NN}}$ = 11 GeV

- Event selection of Bi+Bi, Xe+Xe and C+C collisions at $\sqrt{s_{NN}}$ = 11 GeV can be done with FFD, FHCal and TOF.
- Trigger efficiency vs b has a flat region with 100% efficiency except FFD in C+C.
- Trigger efficiency vs z-vertex is flat and wide (possible event selection with z-vertex > 120 cm).
- TOF has the greatest trigger efficiency of 99 % (Bi+Bi, Xe+Xe) and 89% (C+C) > FFD 88% (Bi+Bi), 85 (Xe+Xe), 42 % (C+C) and FHCal 96 % (Bi+Bi), 94 % (Xe+Xe), 80 % (C+C).
- T_0 resolution study shows significant bias in T_0 vs centrality distribution especially for C+C collisions.
- T_0 can be measured by FFD in a wide range of centrality with good enough resolution:
  - Bi+Bi and Xe+Xe: 20 – 60 ps, $0 \leq b \leq 14$ fm.
  - C+C: 40 – 60 ps, $0 \leq b \leq 8$.
- Z-position of the primary vertex can be measured by FFD with resolution of about:
  - Bi+Bi and Xe+Xe: 0.5 – 2 cm, $0 \leq b \leq 14$ fm.
  - C+C: 1.5 – 2 cm, $0 \leq b \leq 8$ fm.
- Z-vertex is also can be measured by FHCal but the resolution is worse in this case and is about 20-30 cm depending on the centrality and the size of the collision system.
- FFD and FHCal trigger performance is not good enough for event selection in light systems. TOF is crucial for event selection in light system collisions such as C+C.

Bi+Bi, Xe+Xe, C+C, *p+Bi and p+p* at $\sqrt{s_{NN}}$ = 11 GeV

FFD and FHCal trigger logic for p+Bi

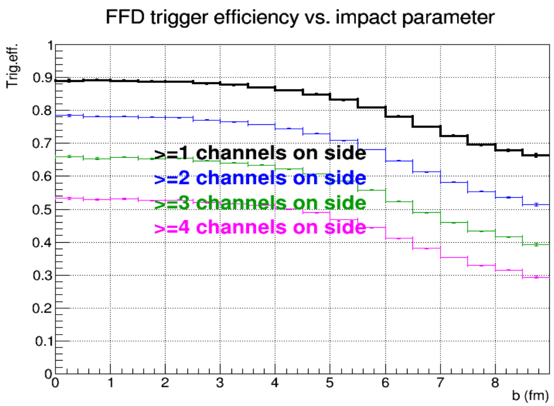
FFD and FHCal trigger efficiency vs impact parameter b (fm)

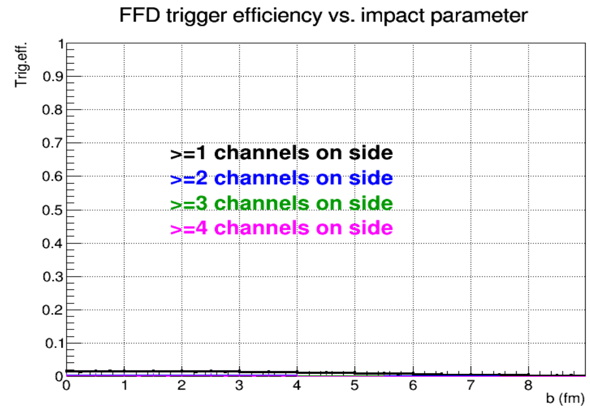
on one side in the direction of Bi beam

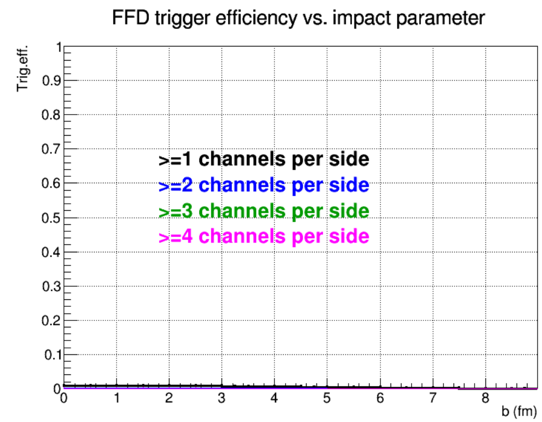
on one side in the opposite direction of Bi beam

per side

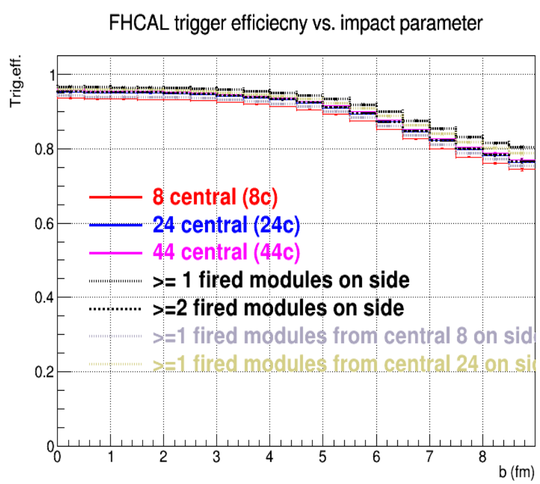
FFD

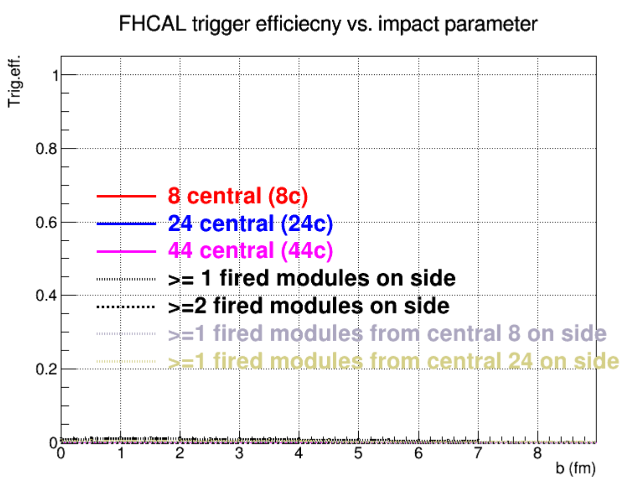


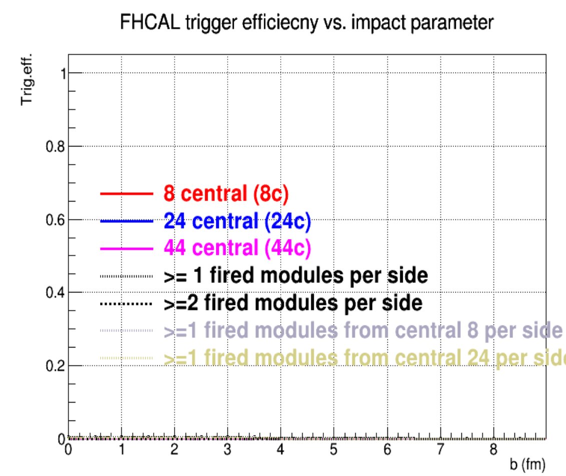




FHCal



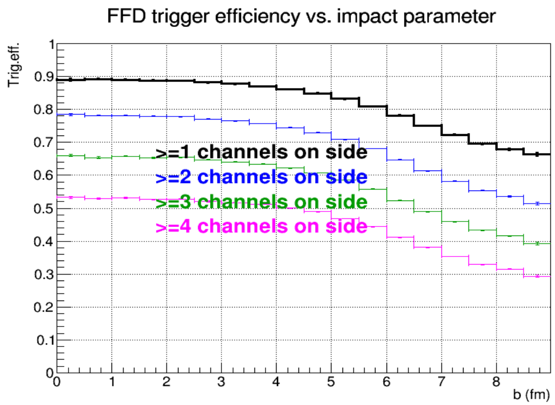




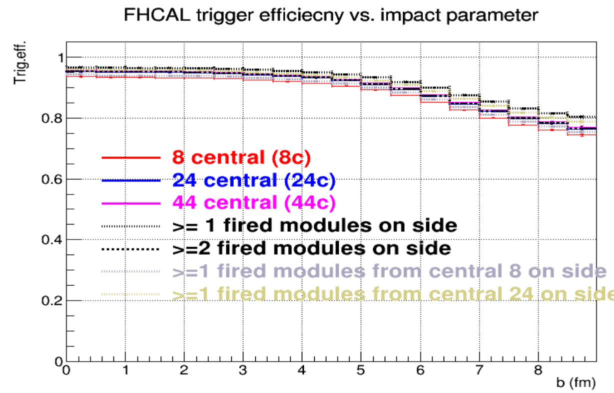
Default – at least one channel or detector is fired on only one side in the direction of the Bi beam

FFD and FHCal trigger efficiency for p+Bi

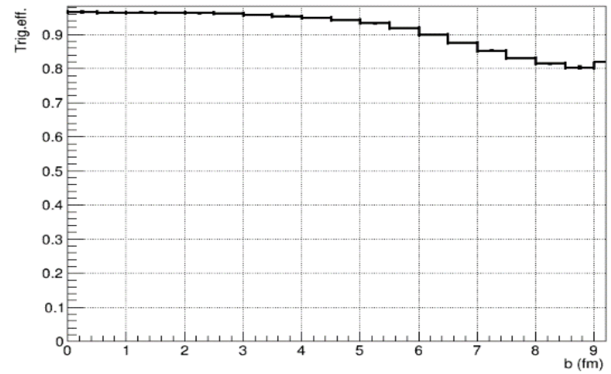
Trigger efficiency vs impact parameter b (fm)



≈ 90 % max

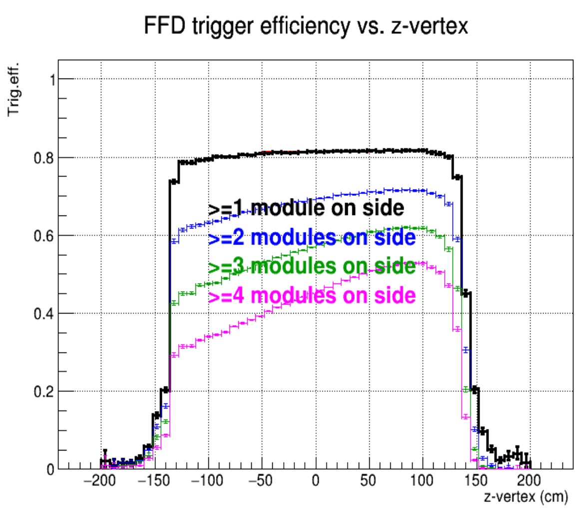


≈ 95 % max

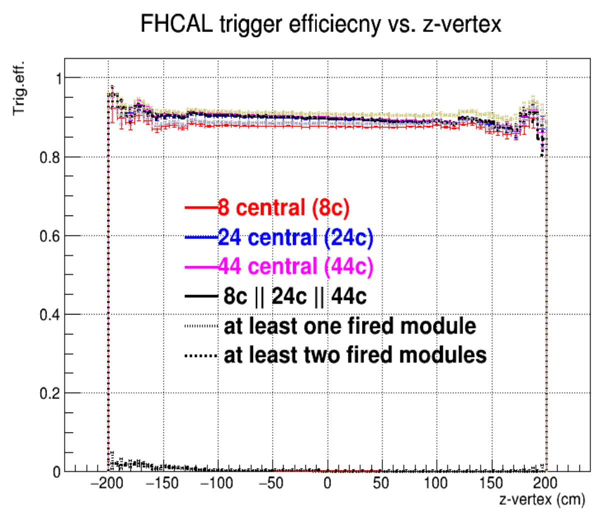


≈ 96 % max

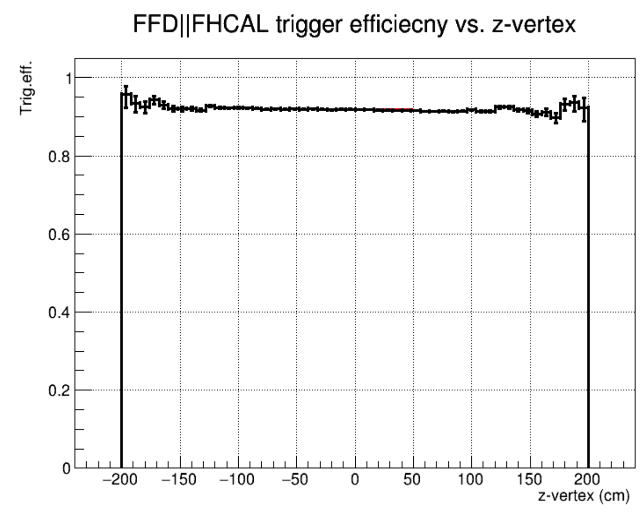
Trigger efficiency vs z-vertex (cm)



≈ 82 %



≈ 90 %

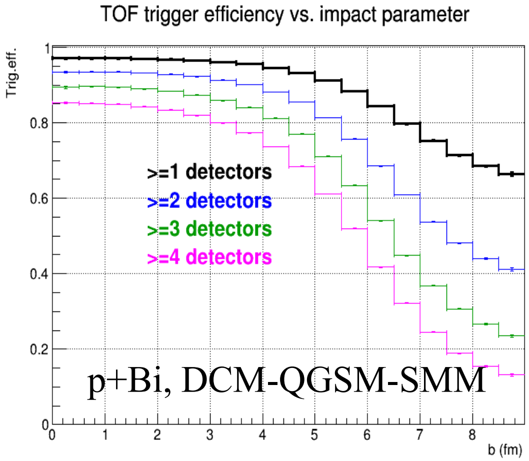


≈ 92 %

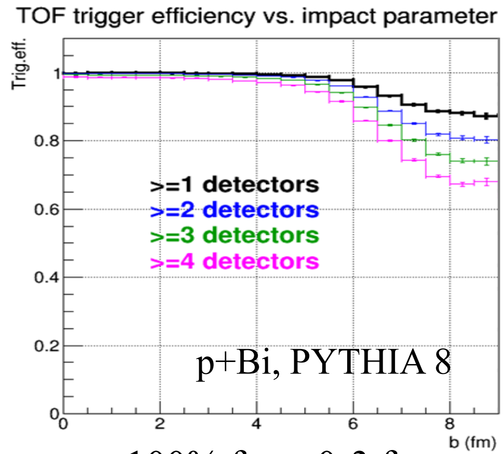
- Trigger efficiency vs z-vertex is flat.
- z-vertex region with acceptable trigger efficiency ±130 cm.

TOF trigger efficiency for p+Bi

TOF trigger efficiency vs impact parameter b (fm)

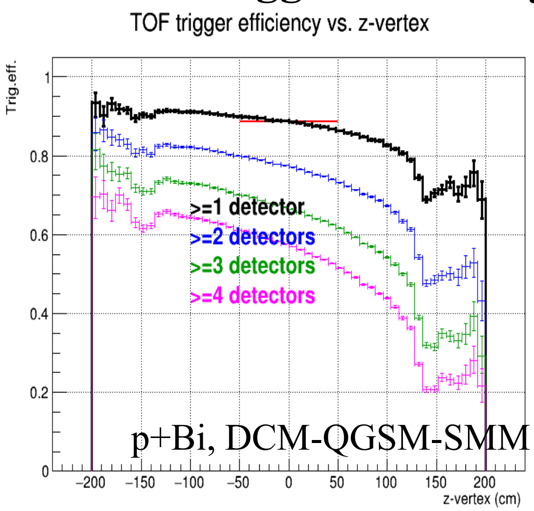


100% from 0-2 fm

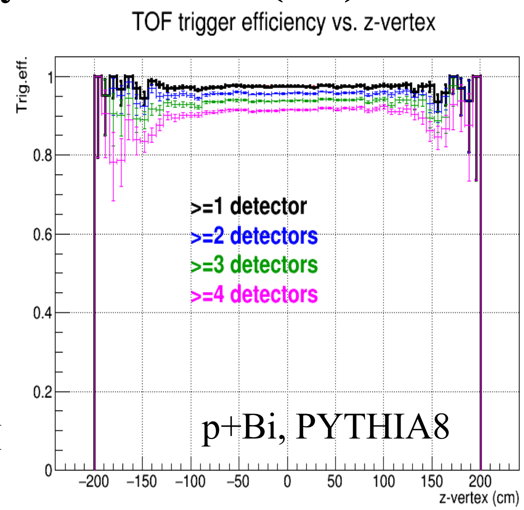


100% from 0-3 fm

TOF trigger efficiency vs z-vertex (cm)



≈ 80 – 90 %

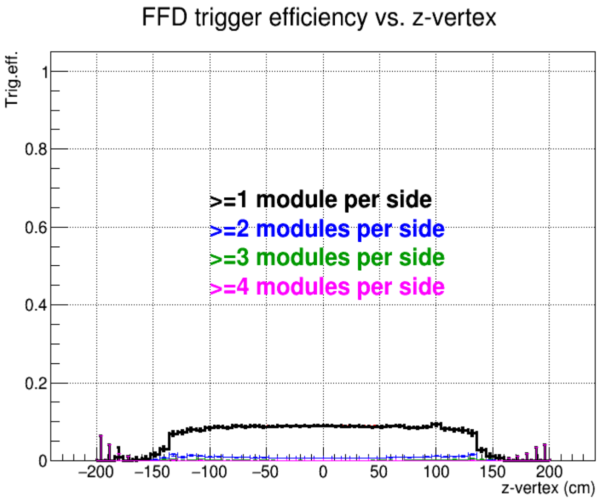


≈ 94 %

- DCM-QGSM-SMM or PYTHIA8 (Angantyr model)
- Trigger efficiency vs b, 100% region:
  - 100% region, DCM-QGSM-SMM: 0 – 2 fm.
  - 100% region, PYTHIA8: 0 – 3 fm.
  - DCM-QGSM-SMM – significant difference between default and optional trigger configurations.
- Trigger efficiency vs z-vertex:
  - DCM-QGSM-SMM – has a slope, 90 – 80%.
  - PYHITA – flat, 95 %.
- z-vertex region with acceptable trigger efficiency ±130 cm.
- TOF is crucial for event selection.

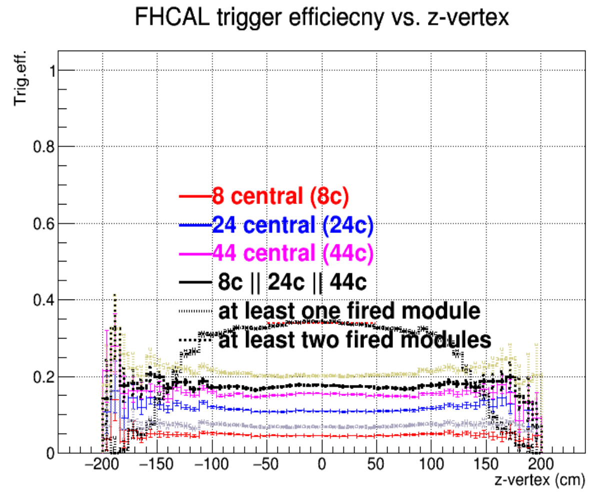
Trigger efficiency, p+p

FFD



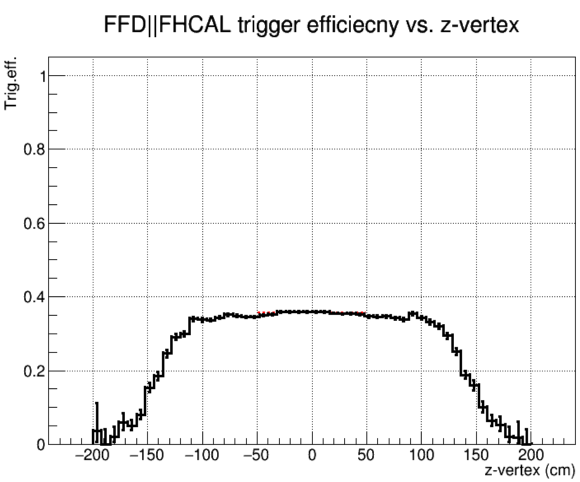
≈ 10 %

FHCal



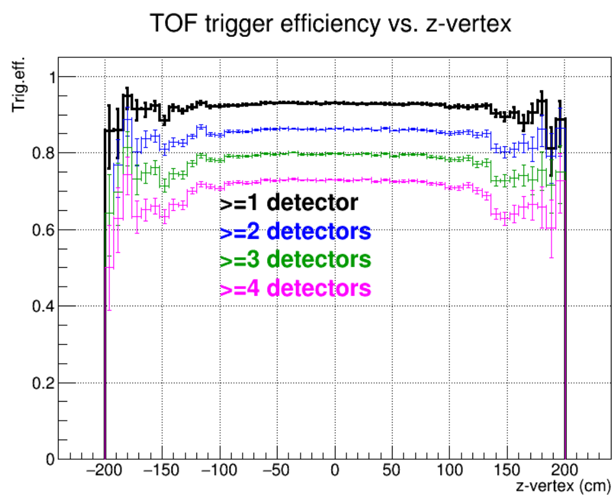
≈ 35 %

FFD||FHCal



≈ 37 %

TOF



≈ 93 %

- PYTHIA8 with default settings.
- Flat trigger efficiency vs z-vertex.
- FFD ≈ 10%.
- FHCal ≈ 35%.
- FFD||FHCal ≈ 37%.
- TOF ≈ 93 %.
- z-vertex region with acceptable trigger efficiency ±130 cm.
- TOF is crucial for event selection.

Summary, p+Bi and p+p at $\sqrt{s_{NN}}$ = 11 GeV

- Event selection of p+Bi and p+p collisions at $\sqrt{s_{NN}}$ = 11 GeV can be done with FFD, FHCal and TOF.
- Calculations are done using DCM-QGSM-SMM for p+Bi and PYTHIA8 for p+p and p+Bi (TOF) event generators.
- Event generator predictions for p+Bi are close but differs from each over.
- TOF Trigger efficiency vs b has a flat region with 100% efficiency in p+Bi collisions.
- Trigger efficiency vs z-vertex is wide (possible event selection with z-vertex > 120 cm).
- TOF has the greatest trigger efficiency of 80-95 % (p-Bi) and 93% (p+p) > FFD 82 % (p+Bi), 10 (p+p), and FHCal 90 % (p+Bi), 35 % (p+p) and FFD||FHCal 92 % (p+Bi), 37 % (p+p).
- T_0 and z-vertex resolution study will be done latter.
- TOF is crucial for event selection in p+Bi and p+p collisions.

Conclusions and outlook

- Recent result on the MPD trigger efficiency, T_0 and z-vertex systematic study in the collider mode in Bi+Bi collisions at $\sqrt{s_{NN}}$ = 4, 7, 9.2 and 11 GeV and Bi+Bi, Xe+Xe, C+C and p+p collisions at $\sqrt{s_{NN}}$ = 11 GeV were presented.

- Full-scale simulation of the MPD detector in p+p, p+Bi, C+C, Xe+Xe, Bi+Bi collisions at $\sqrt{s_{NN}}$ = 4 – 11 GeV was done using DCM-QGSM-SMM event generator for all collision systems except p+p and PYTHIA8 for p+Bi (TOF) and p+p collisions.

- Event selection in considered collision systems can be done with FFD, FHCal and TOF. FFD and FHCal trigger performance is not good enough for event selection in light and asymmetric collision systems.

- TOF is crucial for event selection in light and asymmetric collisions like p+p, p+Bi and C+C.

- To do list:

  ✓Trigger efficiency study in p+p, p+Bi, C+C and Xe+Xe at $\sqrt{s_{NN}}$ = 4, 7 GeV. T_0 and z-vertex study in p+p and p+Bi collisions at 11 GeV.

  ✓Optimization of trigger logic algorithms (FFD||TOF, FHCal||TOF, FFD||FHCal||TOF etc.).

  ✓Final report with main results.