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Slow neutron flux measurements in STAR Wide Angle Hall.

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Abstract

We report on measurements of slow neutron fluxes at different locations in the STAR Experimental Hall during pp $\sqrt{s} = 510$ GeV Run 13 at RHIC. We compared these measurements with calculations based on pythia as minimum bias events generator and the detailed GEANT3 simulation with GCALOR as neutron transport code. A fairly good (within $\approx 20\%$) agreement was found at locations near ($\approx$1m) and very far ($\approx$10m) from the beam pipe. For intermediate locations ($\approx$ 5m) the simulation overestimates neutron flux by a factor of $\approx$3.

Keywords: slow neutrons, measurements, simulation.

1. Introduction

Since SSC time [1, 2] it has been understood that the main source of background in a detector at modern colliders is collisions at interaction point. The contribution from other sources (beam gas interactions, beam halo particles, etc.) was estimated to be below 10%[3]. Extensive simulations of background conditions were part of detectors optimizations for SSC and LHC experiments. ATLAS[4] and CMS have made simulations for all types of backgrounds including neutrons. All estimations of the neutron fluxes in experimental areas were based on simulations only, without support from experimentally measured data. Only recently ATLAS-MPX collaboration[5] published results of absolute background measurements including thermal neutrons and made a comparison with results of simulations (GEANT3+GCALOR[6] and Fluka). Their conclusion is [5] :

"Measured thermal neutron fluxes are found to be largely in agreement with the original simulations, mostly within a factor of two. Significant deviations are observed in the low radiation regions of ATLAS cavern, where measured thermal neutron fluxes are found to be lower than predicted by Monte Carlo simulations."

For the purpose of future discussions we will classify neutrons as follows:

- Intermediate energy neutrons with kinetic energy 100 keV – 1 MeV, which are most damaging for electronics and Silicon detectors, and
- Slow neutrons with kinetic energy below 250 meV. This definition includes cold ($< 25meV$), thermal ($25meV$), and part of epithermal ($25meV < E_{kin} < 400meV$) neutrons. The slow neutrons generate $\gamma-$quanta producing noise in detector elements.

STAR is planning series of upgrades in near future with detectors using different type of silicone sensors. Reliable estimations of neutron background at STAR are required to evaluate different technologies for these upgrades. This requirement and lack of experimental results for neutron background estimates were our motivations for this work. Exactly the same questions have been raised in context of ongoing detector R&D for proposed Electron Ion Collider (EIC):

- What are neutron background conditions at STAR detector will be at EIC?
- How reliable can we estimate these conditions ?

To answer these questions we:

- made measurement of the absolute thermal neutron flux at different locations in the STAR[7] Wide Angle Hall (WAH) during RHIC Run XIII[8],
- compared experimental results with simulations in order to understand how reliable this simulations are, and
- estimated fluxes of the medium energy neutrons using simulation results.

2. He^3 counter

We use a He^3 filled proportional counter [9] (loaned to us by BNL Instrumentation Division) to measure fluxes of slow neutrons in STAR WAH.

- The slow neutron are detected via reaction: $n + He^3 \rightarrow H^1 + H^3 + 764keV$,
  with cross section : $\sigma = 5.4\sqrt{(}25.3\ meV/E_{kin})$ [kbarn][10]. The simulated kinetic energy spectrum of neutron in STAR and the spectrum convoluted with the above cross section are presented in Fig.1.
- The counter specification gives the neutron sensitivity 100 ± 10 counts per $1Hz/cm^2$ of slow neutron flux[12]. This sensitivity was measured with calibrated isotropic thermal neutron flux at temperature 25^0C.
- The signal has been shaped, the threshold has been set to 20% of maximum signal (764 keV), which corresponds unambiguous slow neutron registration (contamination of γ and charged particles is only due to multiple hits during signal collection time of the detector $\approx 5\ \mu sec$ and neglected herein).
- During the run the counter positioned at 6 locations[11] of WAH (Fig.2)
  1. South (x = 428 cm, y = 183 cm, z= 0 cm, Fig.3), (during period 03/01/13 - 04/03/13),
  2. West (x = 183 cm, y = 0 cm, z = 676 cm,Fig.4), (04/03/13 - 04/17/13),
  3. East (x = 135 cm, y = -20 cm, z = -686 cm,Fig.4), (04/17/13 - 05/03/13),
  4. North (x = -442 cm, y = 202 cm, z = 0 cm, Fig.3), (05/08/13 - 05/22/13),
  5. Bottom (x = 15 cm, y = -390 cm, z = 53 cm, Fig.5 and Fig.6), (05/23/13 06/05/13),
  6. Far Away (x = -970 cm, y = -390 cm, z = -750 cm, Fig.6), (06/06/13 06/10/13).

3. Measurements

3.1. He^3 counter

The shaped signal from He^3 counter was fed to so called STAR RICH scalers (channel 16), and the rate of the scaler (Hz) recorded in STAR online data base (with frequency 15 seconds) and in STAR daq stream (with frequency 1 second) together with others scalers (for example, ZDC West, ZDC East, and ZDC West and East coincident rates). The He^3 counter rate versus time for different counter locations is shown in Fig.7.

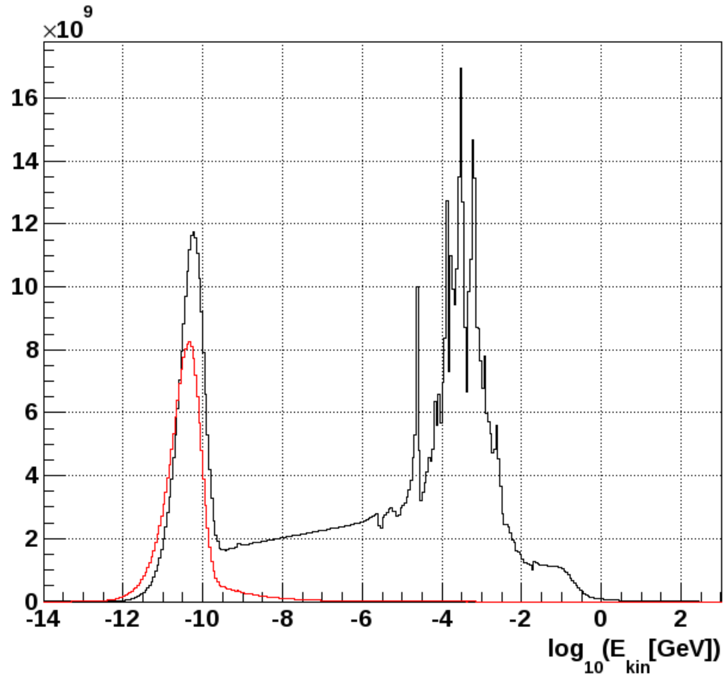

Figure 1. The neutron kinetic energy spectrum in STAR and result of convolution (red line) of this spectrum with He^3 neutron cross section. The integral of the convoluted spectrum corresponds to 87% of the total spectrum integral in region $< 250meV$.

3.2. Event rate

STAR has two detector systems to measure rate of inelastic interaction at beam-beam crossing:

- East and West Zero Degree Calorimeters (ZDC), and
- East and West Beam-Beam Counters (BBC).

There are two mode to count rates from these detectors:

- without killer (nokiller), i.e. dead time of the detectors corresponds to RHIC frequency ($\approx$ 9.4 MHz $\rightarrow$ 106 nsec), but in this mode counter can be affected "after pulses", and
- with killer, i.e. dead time of the detector is set to 1 μsec. This mode is used for ion-ion interaction with large signals in both detectors which can cause the above "after pulses".

In this study we used ZDC nokiller scalers. In order to estimate event rate the following approach[13, 14] used:

- $N_{BC} = 9.383 \times 111/120$: no. of bunch crossings [MHz],
- N_{EW}: no. of crossings that contain a coincidence West and East counters with probability $P_{EW} = N_{EW}/N_{BC}$,
- N_E: no. of crossings that contains a hit in East counter, $P_E = N_E/N_{BC}$,
- N_W: no. of crossings that contains a hit in West counter, $P_W = N_W/N_{BC}$,
- P_A: a probability to produce an East hit,
- P_B: a probability to produce a West hit,

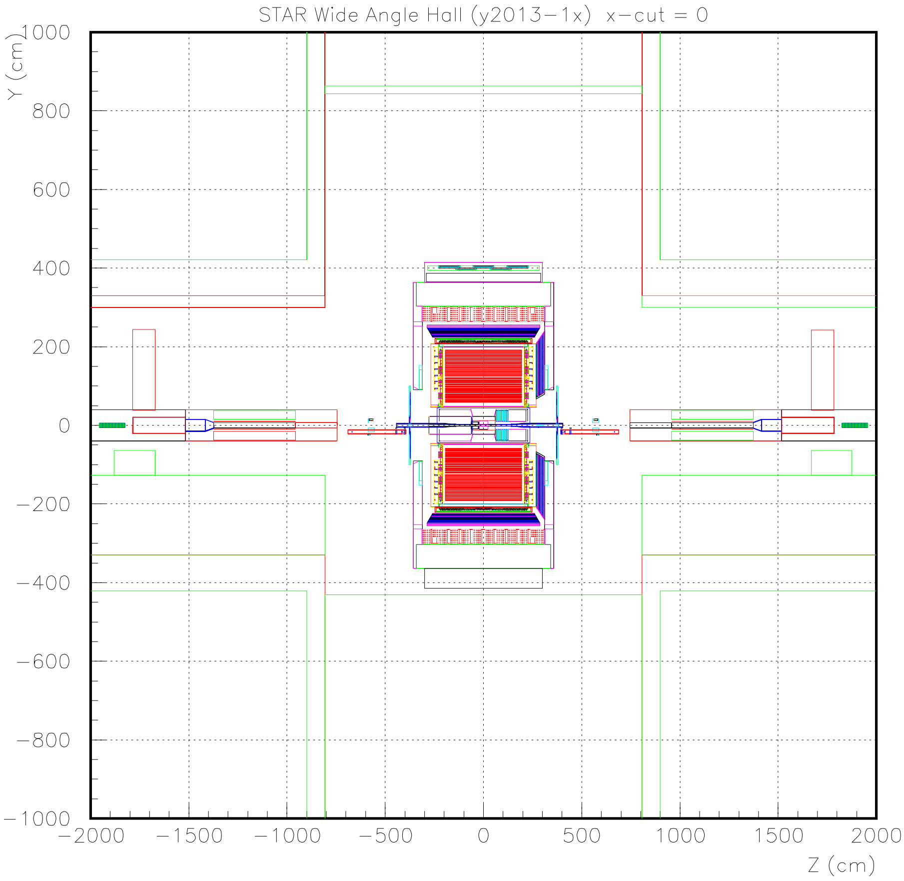

Figure 2. STAR Wide Angle Hall GEANT3 geometry model (version y2013-1x) including building elements (floor, roof, and walls), tunnel, shielding, and detector itself.

- P_{AB}: a probability to produce an East and West coincidence.

Then we have 3 equations:

$$P_E = P_A + P_{AB} \times (1 - P_A)$$
$$P_W = P_B + P_{AB} \times (1 - P_B)$$
$$P_{EW} = P_A \times P_B + P_{AB} \times (1 - P_A \times P_B)$$

and solving them with respect to P_{AB}

$$P_{AB} = \frac{P_{EW} - P_E P_W}{1 + P_{EW} - P_E - P_W}$$

and coincidence rate (AB) corrected for random coincidence for A and B is

$$N_{AB} = \mu \times N_{BC} = -ln(1 - P_{AB}) \times N_{BC}.$$

The coincidence rate in ZDC corresponds to $\sigma = 2.81$ mb[13] from 50 mb of pp[15] inelastic cross section at $\sqrt{s} = 510$ GeV. Thus total event rate

$$Rate = 50/2.81 \times N_{AB}$$

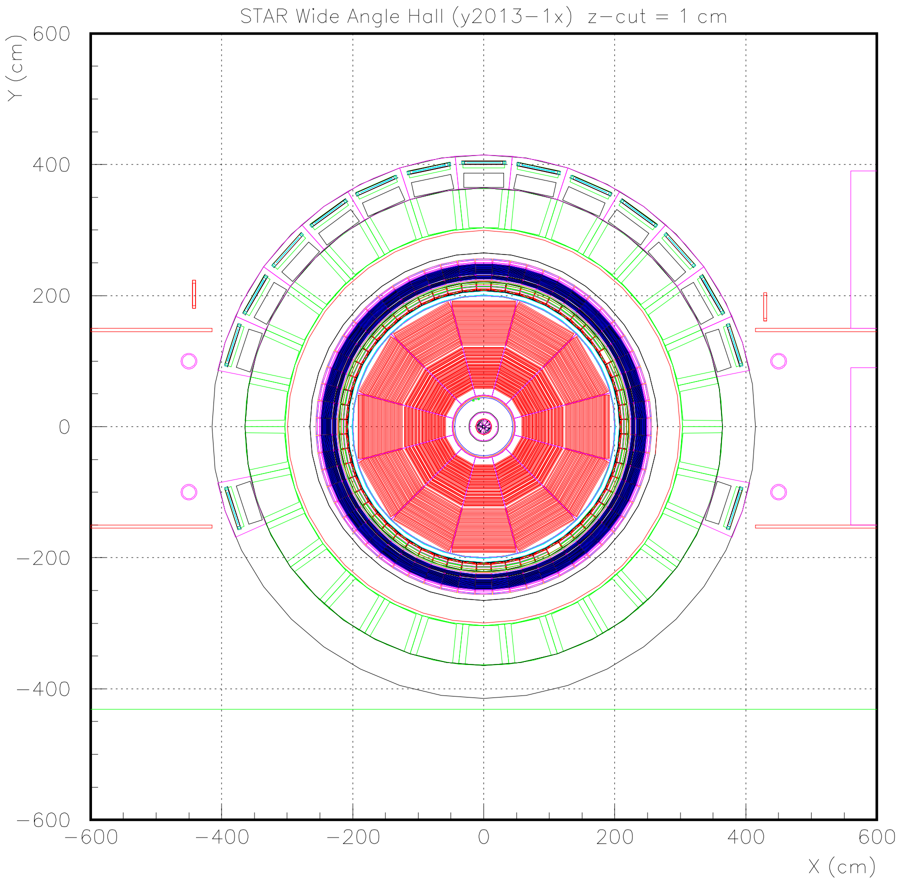

Figure 3. South (x = 428 cm) and North (x = -442 cm) locations (y ≈ 200 cm) of the counter in STAR WAH.

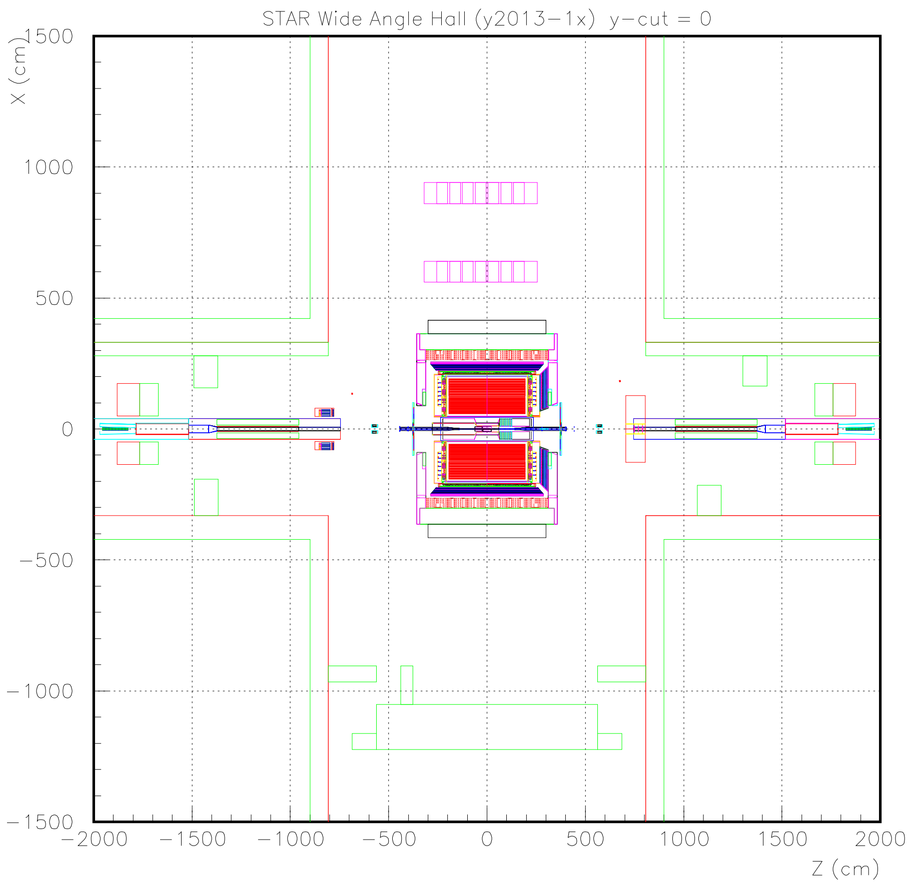

Figure 4. West (x = 183 cm, z = 676 cm) and East (x = 135 cm, z = -686 cm) locations (y ≈ -10 cm) of the counter in STAR WAH.

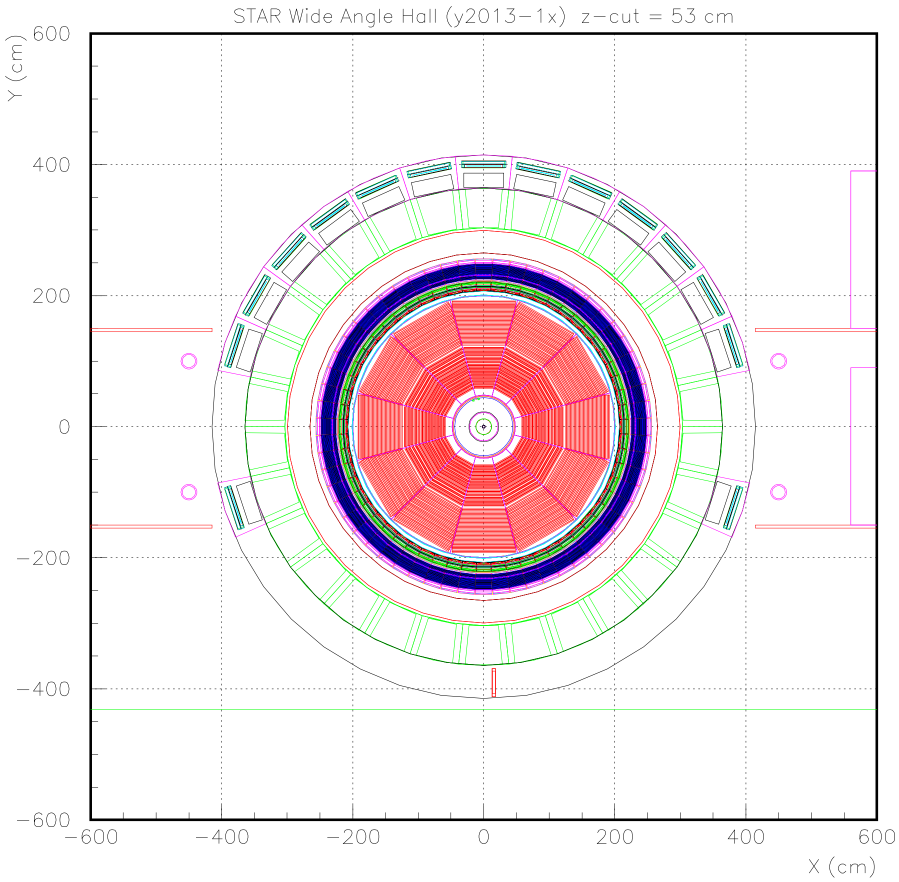

Figure 5. Bottom (x = 15 cm, y = -390 cm, z = 53 cm) location of the counter in STAR WAH.

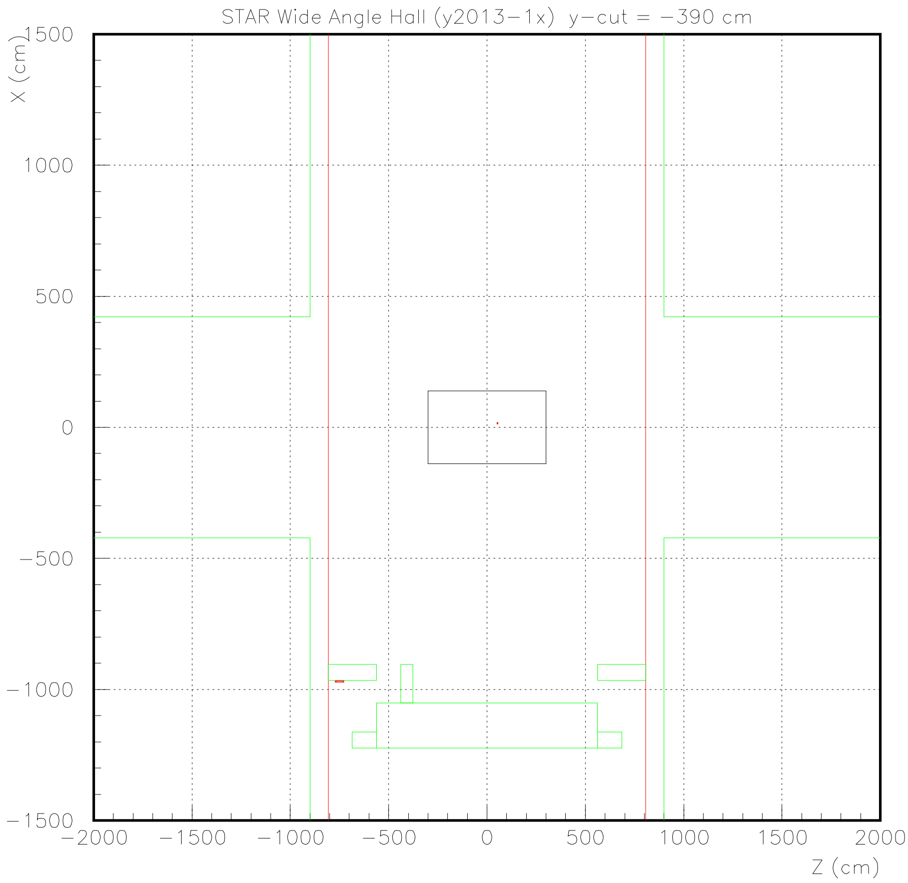

Figure 6. Bottom (x = 15 cm, y = -390 cm, z = 53 cm) and Far Away (x -970 cm, y = -390 cm, z = -750 cm) locations of the counter in STAR WAH.

3.3. Fluxes

The measured fluxes obtained from the He^3 counter rate using its sensitivity. In Fig.8 dependences of the measured slow neutron fluxes (F) at the different locations are shown. In order to normalize the flux to 1 MHz of pp interaction (F_0) and also account saturation effects in He^3 counter due to its dead time the dependences were approximated by

$$F = Rate \times (F_0 + Rate \times F_1)$$

with F_0 as corrected measured flux.

4. Simulation

To estimate fluxes pythia version 6.4.26 as pp 510 GeV minimum biased event generator and GEANT+GCALOR for propagation particles in STAR WAH used:

- The STAR detector and Wide Angle Hall geometry description was taken as version $y2013\_1x$.
- GEANT cuts:

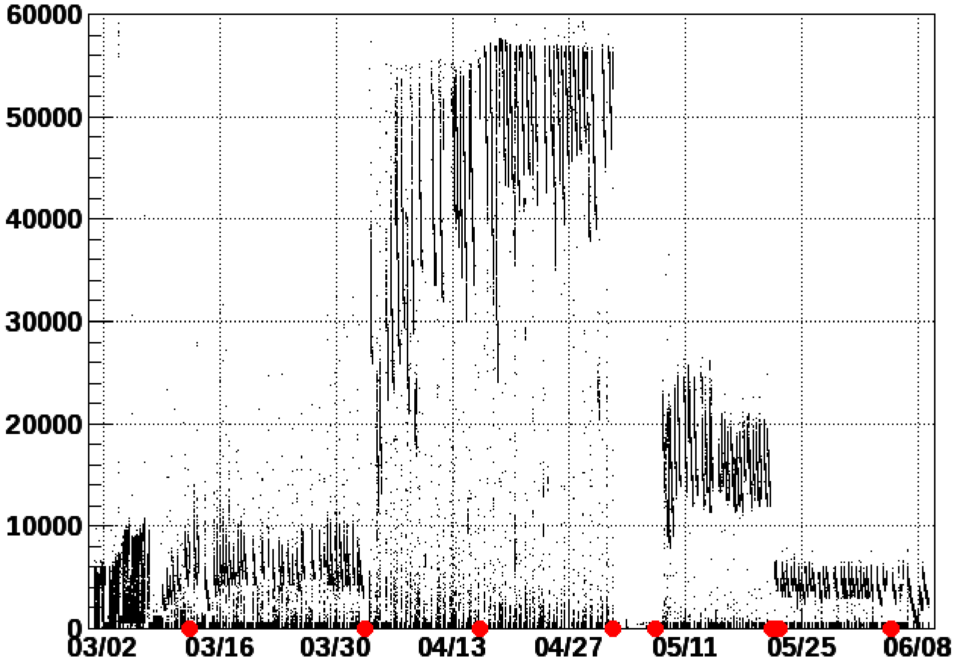

Figure 7. Measured He^3 counter rate (Hz) versus date at different counter locations. The location change is marked as red dots.

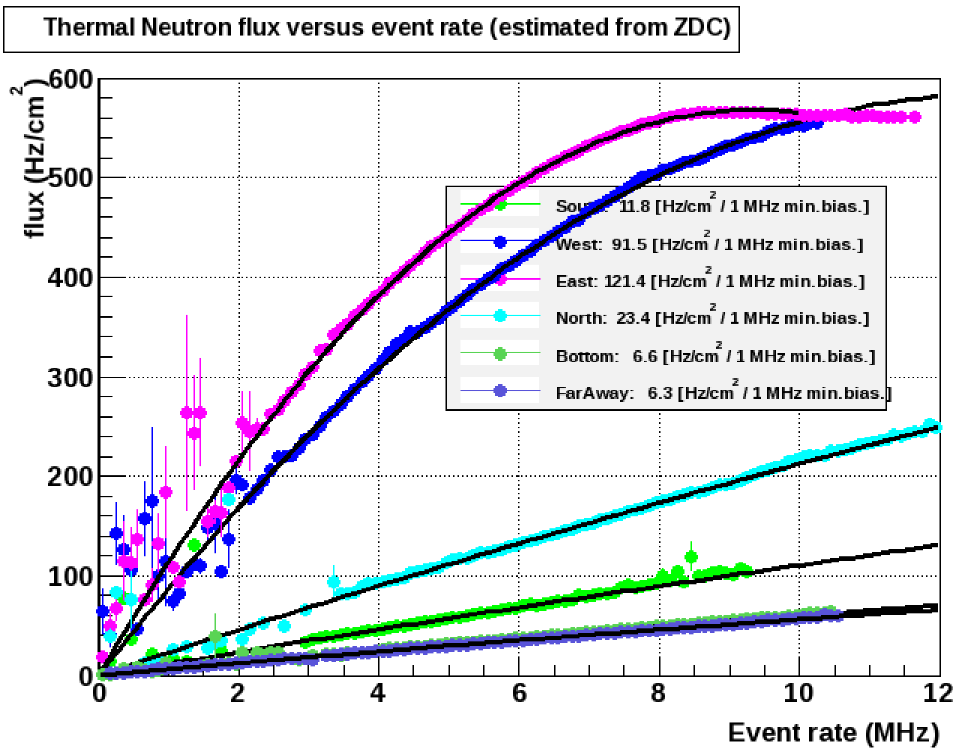

Figure 8. The measured slow neutron fluxes (F_0) versus event rate for different counter locations.

  - e, $\gamma = 10$ keV,
  - neutron $= 10^{-13}$ GeV,
  - charged hadrons = 1 MeV,
  - Maximum time of flight = 10 seconds.

- Flux defined as sum of track length of a particle collected in a given volume in unit time divided by the volume size.
- The fluxes normalized to 1 MHz rate of pp 510 GeV inelastic events.
- Fluxes for all neutron and neutron with $E_{kin} < 250meV$ are show in Fig.9 and Fig.10, respectively.
- The He^3 counter rate was estimated as the sum of neutron track lengths in the He^3 counter active volume weighted with $\sqrt{(}25.3meV/E_{kin})$ (to account cross section drop as inverse velocity) divided by the counter active volume (see Fig.11).

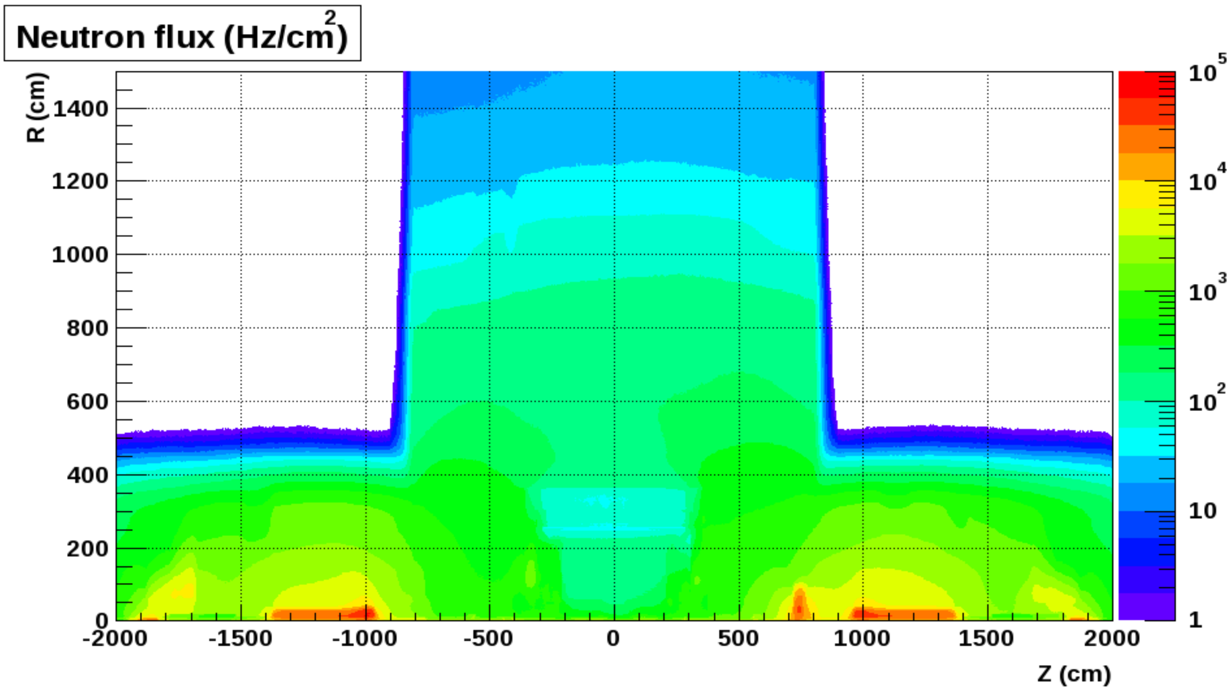

Figure 9. Neutron flux in STAR WAH for pp interaction at $\sqrt{s} = 510$ GeV with rate 1 MHz

5. Conclusions

Our general conclusion is that we can estimate neutron background for STAR detector with rather good precision. The results of measurements and calculation are presented for absolute values and their ratio in Fig.12 and Fig.13. The comparison is good for West, East and Far Away locations. But for South, North and Bottom locations the simulation overestimate flux by a factor of ≈ 3. We can now guess that problems that arise due to neutron dissipation from the interaction region could be caused by the geometry make up of WAH as well as WHA's materials. These problems could also be related to the neutron transport parameters.

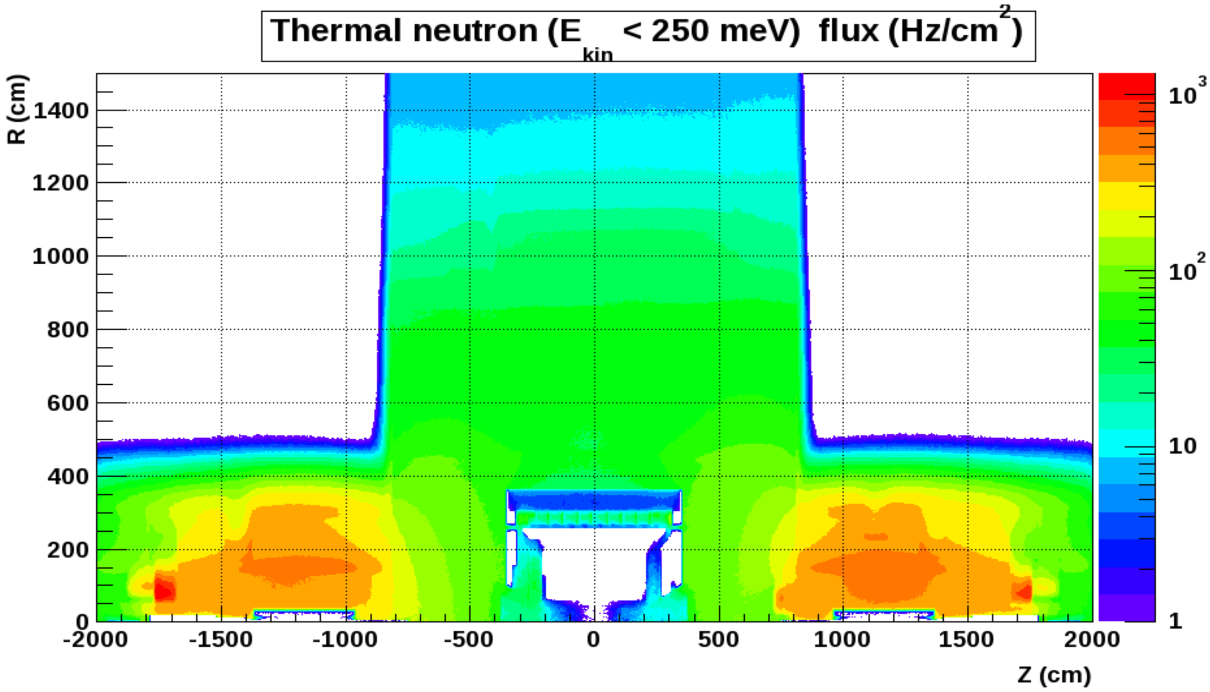

Figure 10. Slow neutron ($E_{kin} < 250meV$) flux in STAR WAH for pp interaction at $\sqrt{s}$ = 510 GeV with rate 1 MHz

6. Acknowledgments

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[10] `http://www.nndc.bnl.gov/exfor/servlet/E4sGetTabSect?SectID=13235&req=61079&PenSectID=872`
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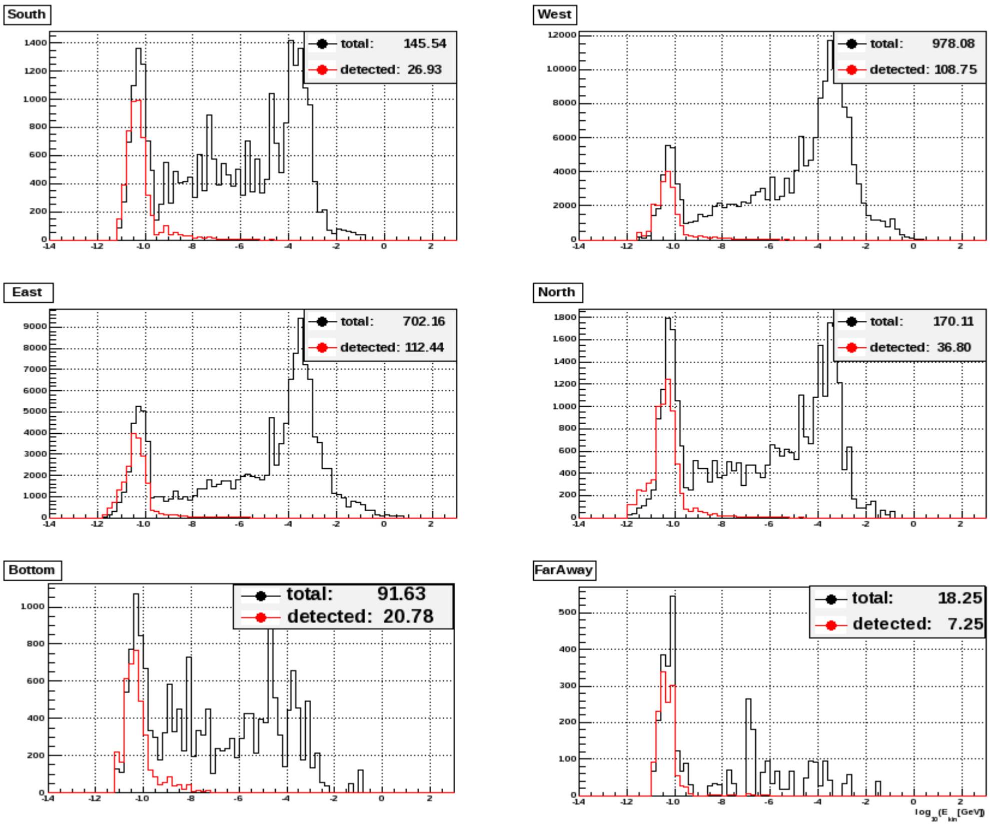

Figure 11. Kinetic energy spectrum of neutrons ($log_{10}(E_{kin}[GeV])$) at different location and the spectrum weighted with $\sqrt{(25.3meV/E_{kin})}$ to account detection efficiency. Total and detected numbers correspond to total neutron flux(Hz/cm^2) in the counter and counted one normalized to 1 MHz pp interaction rate.

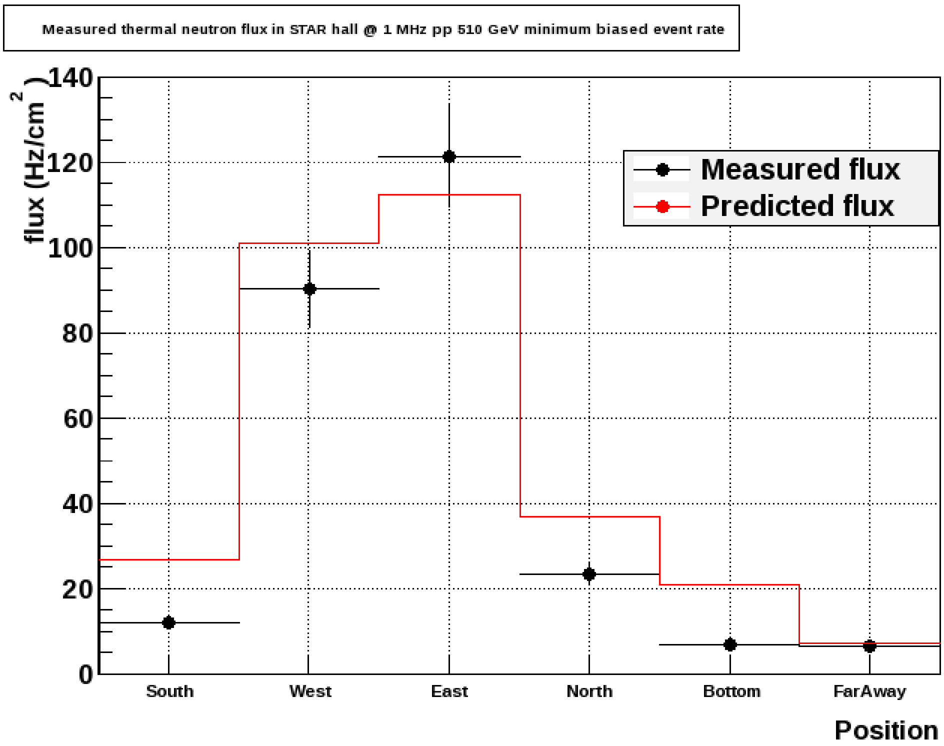

Figure 12. The measured slow neutron flux and predicted one from simulation for different counter locations.

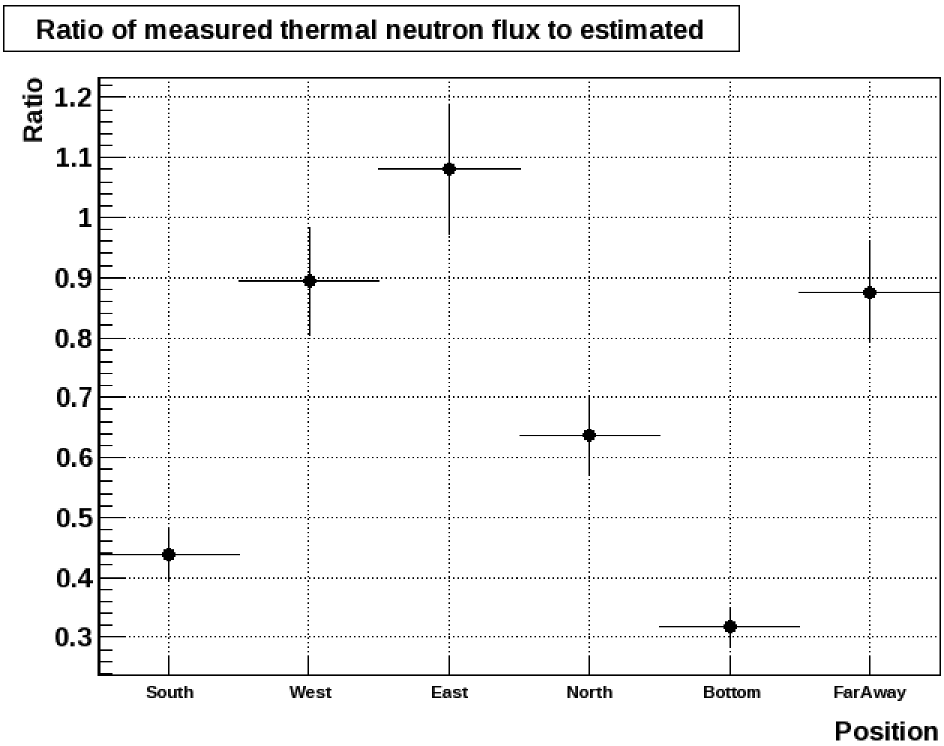

Figure 13. The ratio of measured slow neutron flux to predicted one from simulation for different counter locations.