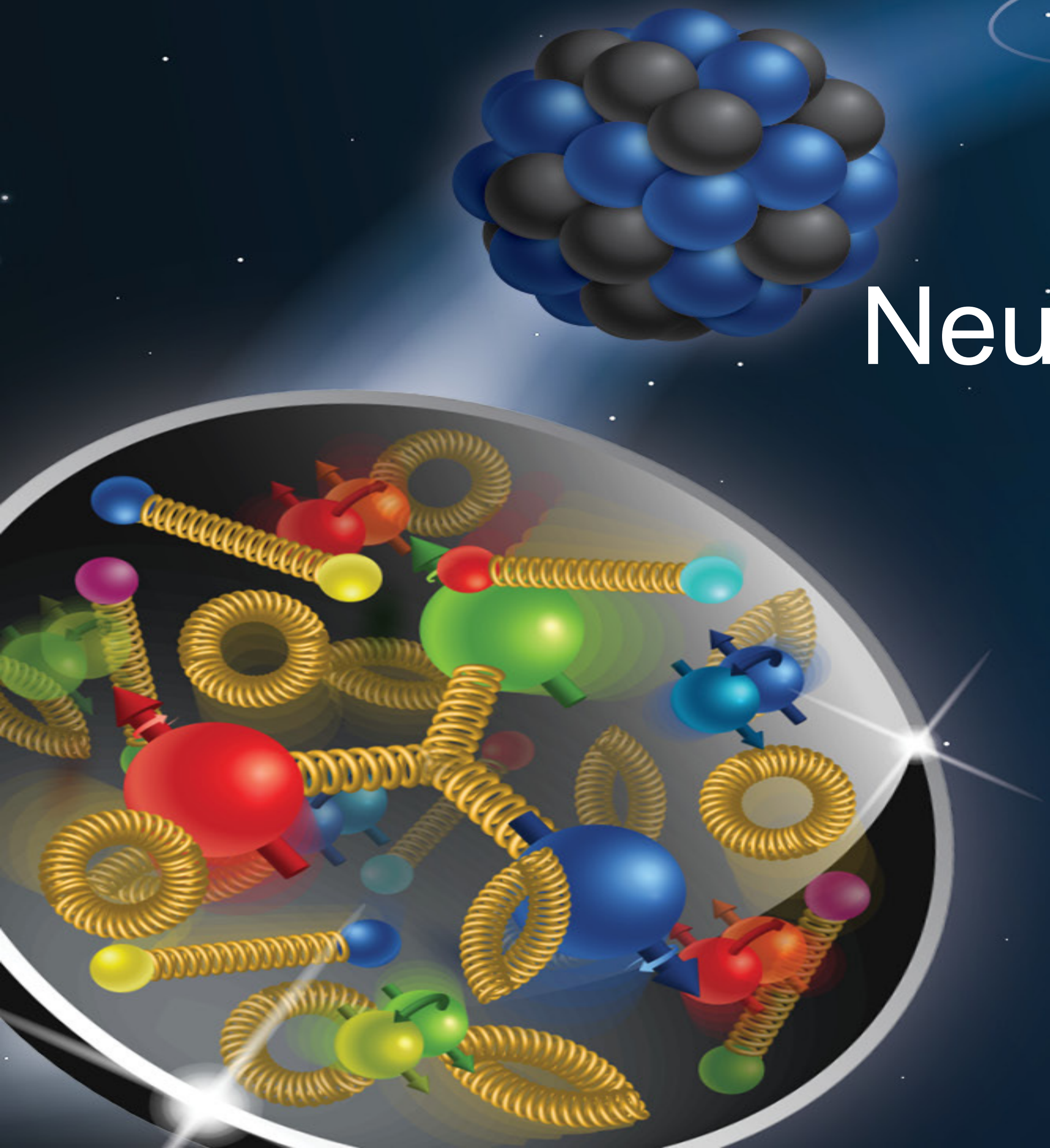


Neutron Fluences for the ZDC: update

Alex Jentsch, *Brookhaven National Lab*
ajentsch@bnl.gov

ePIC TIC Meeting
December 18th, 2023

BROOKHAVEN NATIONAL LABORATORY Jefferson Lab U.S. DEPARTMENT OF ENERGY Office of Science

General Information About Simulations

https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses → All information related to radiation simulations placed here.

- Radiation simulations carried out using the Starsim environment, using Geant3 + GCALOR (and FLUKA, for comparison) for hadronic transport - validated with measurements of neutron fluxes from the STAR IR.
  - Details of the studies performed to validate the simulations can be found at the following reference: Yuri Fisyak, Oleg Tsai, Flemming Videbæk, Zhangbu Xu, Thermal neutron flux measurements in the STAR experimental hall, Nucl. Inst. Methods A, Volume 756, 21 August 2014, Pages 68-72 (https://arxiv.org/abs/1310.2495)

- Calculations of the 1 MeV neutron equivalent fluence are carried out using the NIEL scaling hypothesis (detailed here: https://rd50.web.cern.ch/NIEL/), using the damage function for silicon collected by:
  - P.J. Griffin et al., SAND92-0094 (Sandia Natl. Lab.93), priv. comm. 1996: E = 1.025E-10 - 1.995E+01 MeV
  - A. Konobeyev, J. Nucl. Mater. 186 (1992) 117: E = 2.000E+01 - 8.000E+02 MeV
  - M. Huhtinen and P.A. Aarnio, NIM A 335 (1993) 580 and priv. comm.: E = 8.050E+02 - 8.995E+03 MeV and compiled by: A. Vasilescu (INPE Bucharest) and G. Lindstroem (University of Hamburg), "Displacement damage in silicon, on-line compilation".

Summary of Fluences (November 2023)

ZDC Configurations:

- 2021: 20cm Pb-Glass + 26.2cm W/Si + 78.6cm Pb/Si + 52.4cm Pb/Scintillator
- Present baseline (FOCAL): 7cm $PbWO_4$ + 5.64cm W/Si(10 layers W+Si+glue, 3.5mm W) + ~38.5cm Pb/Si (12 layers Pb+Si+glue, 3cm Pb) + 96cm Pb/Scintillator (15 layers Pb + Scintillator, 3cm Pb – x2)
- OLD DD4HEP ZDC: 10cm W/ScFi EMCAL + 96 layers of 1.0cm Pb + 0.25cm scintillator
- SiPM-on-tile ONLY (no crystal EMCAL)

All fluences assume 1e7 seconds runtime (6 months @ 60% machine efficiency)

Events	Simulation code	Beam pipe material	Pipe thickness	ZDC + Main Detector	Peak Fluence [neut./cm2]
Unknown generator: e+p 10x275	Pure FLUKA	Aluminum	2mm	2020-2021 configuration with assumptions	7.1e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	Stainless Steel	1cm	OLD DD4HEP ZDC (included in BryceCanyon)	0.2e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	Stainless Steel	1cm	Present baseline	0.31e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	Stainless Steel	2mm	Present baseline	0.95e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	Stainless Steel	2mm	SiPM-on-tile	0.23e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	Aluminum	2mm	Present baseline	1.1e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + FLUKA (2013)	Aluminum	2mm	Present baseline	0.54e12
e+p PYTHIA 10x275 GeV Q2 < 1 GeV2	G3 + GCALOR	None	N/A	Present baseline	1.2e12

Some Issues to be solved after November meeting

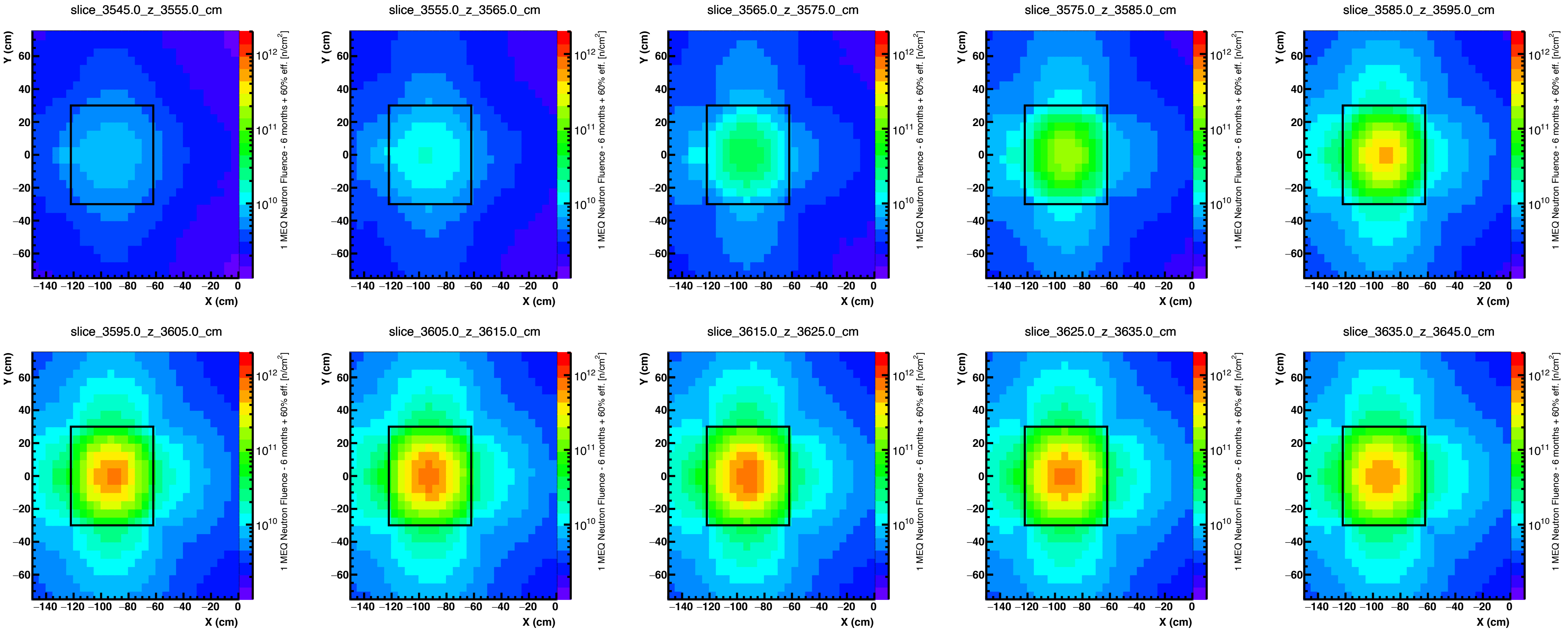
- Magnetic fields for beamline had not been working in the G3 + GCALOR simulations (not easy to import)
  - This was noted on the Wiki page.
  - **Now fixed → lowers fluence in ZDC by ~ x10**
- In the process of fixing this, found that MARCO field not properly imported (STAR field was overriding). → Now fixed, along with inclusion of FF fields.
  - New results for main detector to be uploaded soon (minimal overall impact).
- Radial normalization issue pointed out by Jin Huang.
  - ZDC does not have symmetry around axis used in simulations – previous normalization assumes it does.
  - **Now fixed → increases fluence in ZDC by ~x10 (see backup).**
- PYTHIA sample used will have MAJOR impact on the eventual rates in the ZDC.
  - See Elke's message regarding the PDFs used on MM – can affect total cross section by over a factor of 3!!!

Correct Cartesian Normalization + FF magnets – FOCAL

- Calculate fluence in proper 3D bins on (x,y,z), normalize by the 3D cell size. →Show in z-slices to more readily investigate the fluence impact.

Peak 1MEQ neutron fluence ~ 1e12 n/cm²

FOCAL ZDC entrance → Toward center in **10cm steps**

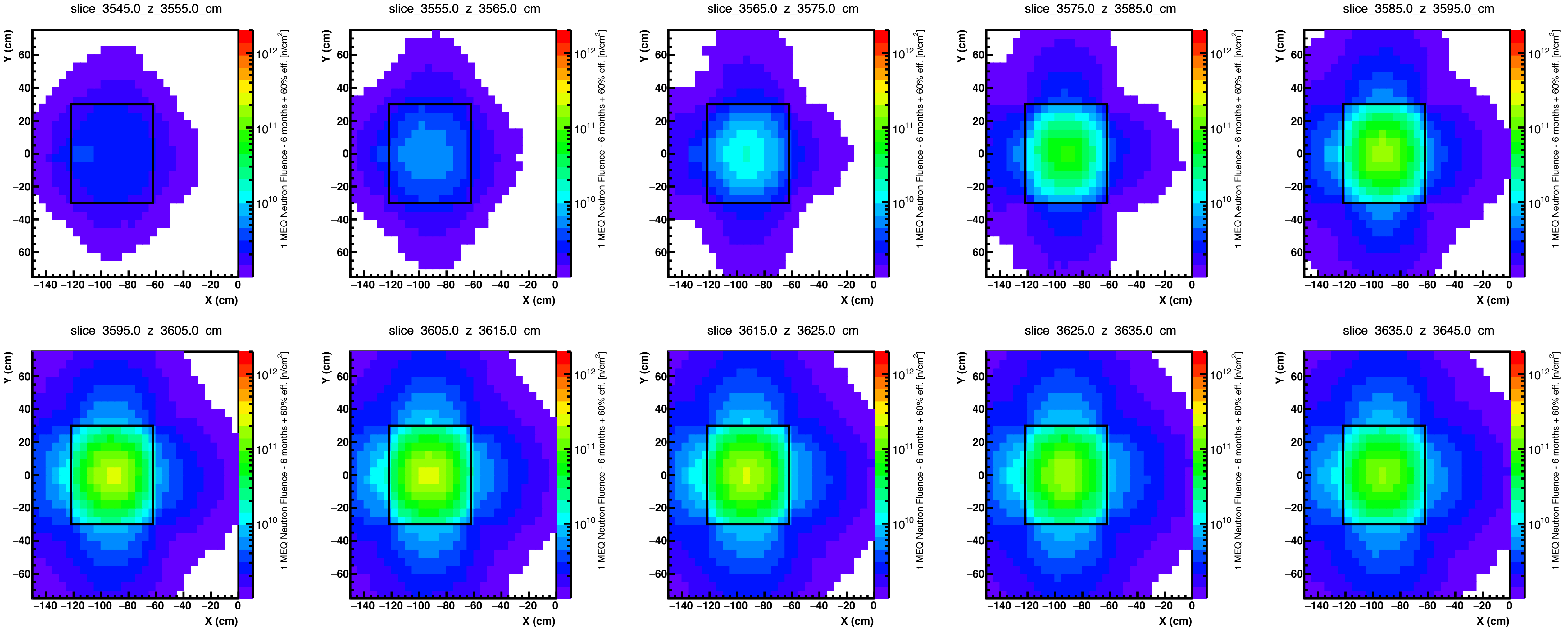


Correct Cartesian Normalization + FF magnets – SiPM-on-Tile

- Calculate fluence in proper 3D bins on (x,y,z), normalize by the 3D cell size. →Show in z-slices to more readily investigate the fluence impact.

Peak 1MEQ neutron fluence ~ 3e11 n/cm²

SiPM-on-tile ZDC entrance → Toward center in **10cm steps**



Summary + next steps

- Peak 1 MEQ neutron fluences in center of ZDC ~ 1e12 n/cm^2 for FOCAL (Pb absorber); ~ 3e11 n/cm^2 for SiPM-on-Tile (Fe absorber)
  - Using G3 + GCALOR, validated against measurements @ STAR.
- **Next Steps:**
  - Setup fluence codes in DD4HEP using the MCNP neutron tables (should perform similarly to FLUKA).
    - ➢ Requires setting up a plugin to access the G4 stepping action during event processing to extract GEANT steps needed to calculate fluences.
    - ➢ This will ensure future reproducibility and enable updated simulations to be performed as the geometry description advances.
  - Note: these simulations are VERY intensive, **with neutron thresholds set to the thermal range** → not something to setup as a benchmark unless requested by management.

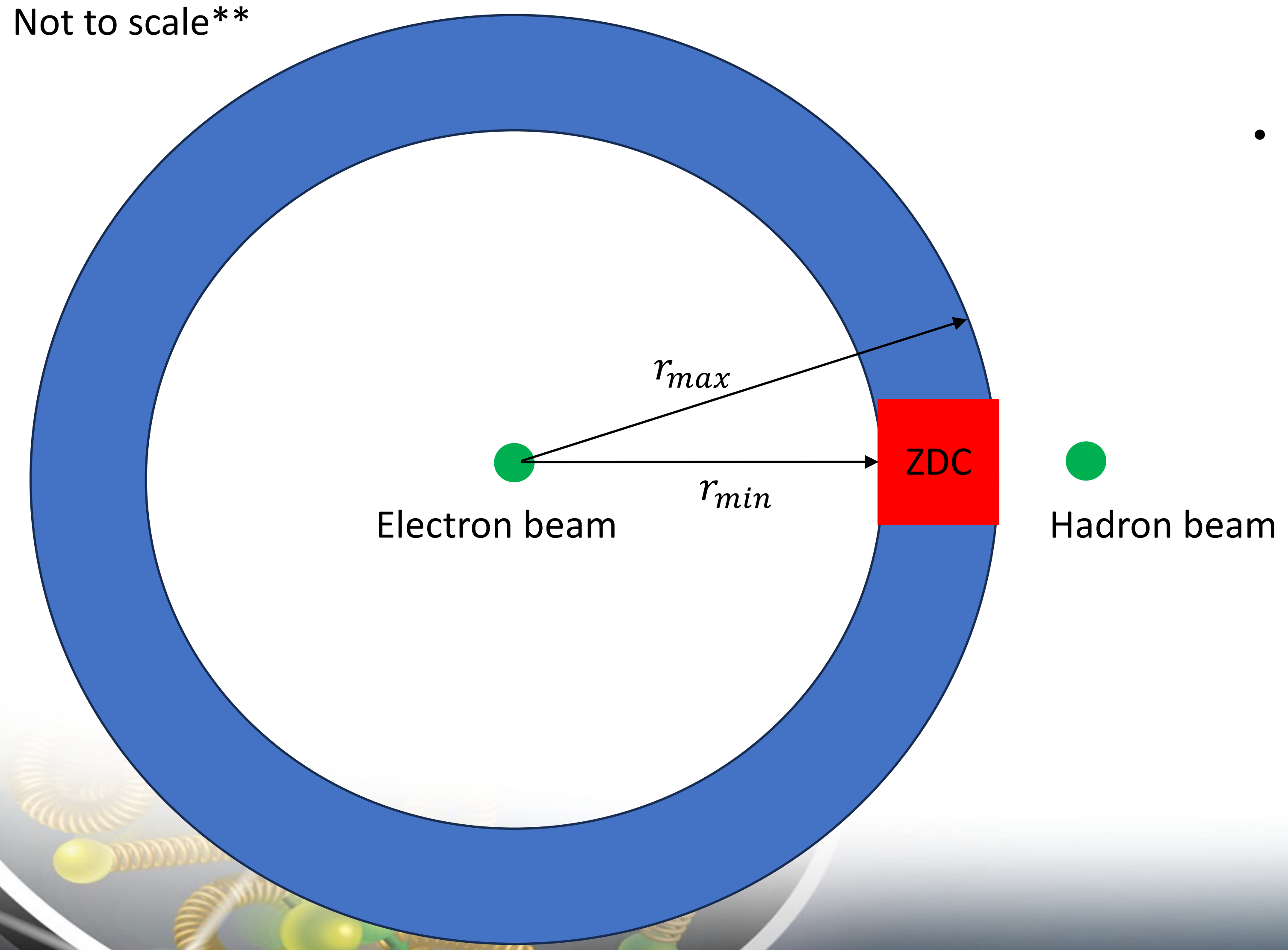
Some Comments

- Simulations of neutron fluences highly-dependent on accuracy of geometry description.
  - Support infrastructure, electronics platforms, tunnel walls, etc. all can play a major role, especially for thermal neutrons.
- Studies which compare data with Monte-Carlo commonly show a disagreement on the order 20% – 50% (higher or lower, depending on sub-component location).
  - Different MC approaches handle aspects of neutron transport differently, especially for low energies.
  - Incomplete description of geometry in the simulations.
  - Some additional references which are particularly useful:
    - https://cds.cern.ch/record/1544435/files/ATL-GEN-PUB-2013-001.pdf
    - https://cds.cern.ch/record/2764325/files/129-122-PB.pdf
    - ➢ "Today, a factor 1.5 on simulated predictions of fluence and dose is used in HL-LHC upgrade studies…the reliability and accuracy of the simulation results are highly dependent on the geometry and material description of the experiment implemented in the simulations."
- There are several currently-used setups for radiation studies, including GEANT4, FLUKA, MARS, GCALOR, etc. → Each has established credibility in the field.
  - They each do things a bit differently, and making comparisons between them can be a rabbit hole. The goal is to use a setup which facilitates inclusion and maintenance of correct geometry.

Normalization issue pointed out by Jin

- Simulations currently take advantage of (approximate) radial symmetry around beamline for central ePIC detector.
  - Oversight for ZDC!
- Coordinate system aligned with electron beamline – there is not a radially symmetric ZDC geometry w.r.t. to the electron beamline!
  - Fluence is calculated in (Z, R) bins, weighted by the GEANT step size →So for the (Z,R) bins @ the ZDC, ANYTHING propagated at that radius $\left(\mathrm{r} = \sqrt{x_{step}^2 + y_{step}^2}\right)$ is then stored in the bin (overcounting).
  - BUT, then the fluence is normalized by the volume of the radial shell, $\mathrm{V} = \pi(r_{max}^2 - r_{min}^2)dz_{step}$
  - So, ultimately, you are counting up more total "hits" in the bin, but then dividing by a shell which assumes evenly distributed fluence, which washes out the amount of fluence in the bins of interest, bringing the reported fluence DOWN.

Normalization issue pointed out by Jin



- ZDC centered on a radius of ~ 120cm, so r_min to r_max for whole ZDC is ~ 90cm to 150cm.
  - Volume of radial shell encompassing ZDC transverse size and 10cm longitudinal section is $V = \pi(r_{max}^2 - r_{min}^2)dz_{step} = \pi(150^2 - 90^2) * 10cm^3 = 4.52e5\ cm^3$
  - Volume of actual ZDC region is ~ 3.6e4 cm^3
  - **Wrong normalization can reduce the fluence by ~ x10.**

FF magnet issue

- Up to now, FF magnets were not working in the STARSIM environment.
  - No easy way to include magnets the way we do in DD4HEP or EICROOT.
  - Needed to generate “field maps” (just constant dipole fields, really) and import them all at once as a “global” field in TGeant3.
- Had been simply ignoring proton fluences at the ZDC, but of course the protons hitting the ZDC generate LOTS of neutrons.
- Pretty much every event has a high-energy proton at small angle.
  - All of these were hitting the ZDC.
- **Now fixed.**

Correct Cartesian Normalization (without FF magnets)

- Calculate fluence in proper 3D bins on (x,y,z), normalize by the 3D cell size. →Show in z-slices to more readily investigate the fluence impact.

RIKEN ZDC entrance → Toward center in 10cm steps