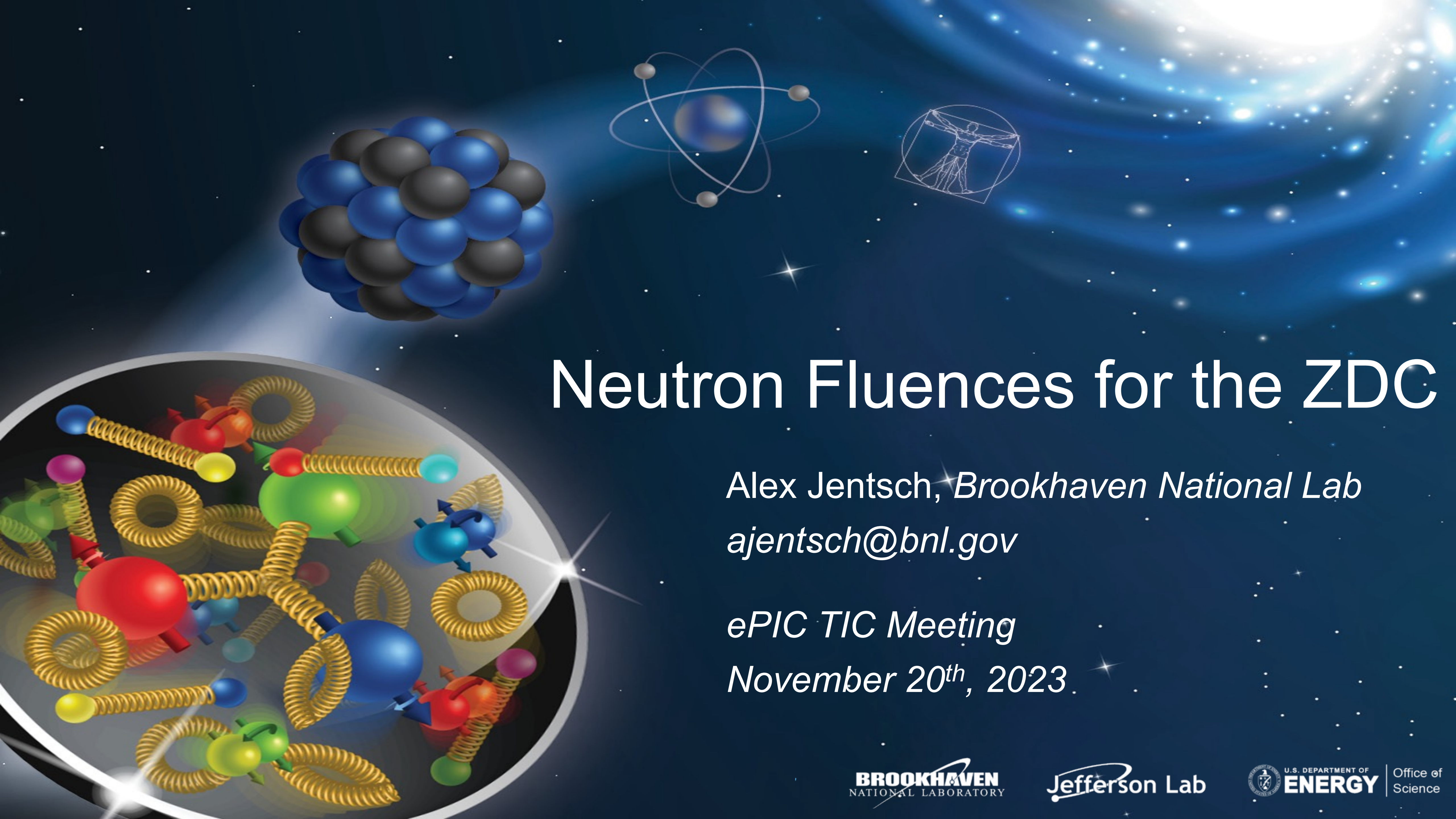

Neutron Fluences for the ZDC

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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 area.
  - 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 (and proton) 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".

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.

Introduction of setups

➢ ~2021 FLUKA study

- YR-era version of detector geometry and support structure (last update to generic R&D March 2021).
- Assumptions for material in magnet support, flux returns, cryostats, etc. (based on reasonable general assumptions, not machine design).
- Assumed residual gas pressure in beam-line of 10^{-9} mbar.
- Operational year assumed to be 1e7 seconds.
- Assumed small radius beam pipe (<7cm) made of 2mm thick Al through entire beamline (including magnets).
- ZDC comprised of 2 layers of Pb-Glass (20cm thickness, total), 22.5cm deep W/Si EMCAL, 78.6cm deep Pb/Silicon HCAL, 52.4cm deep Pb/Scint. HCAL.
- PAs have been contacted regarding event sample used for primary e+p interactions.

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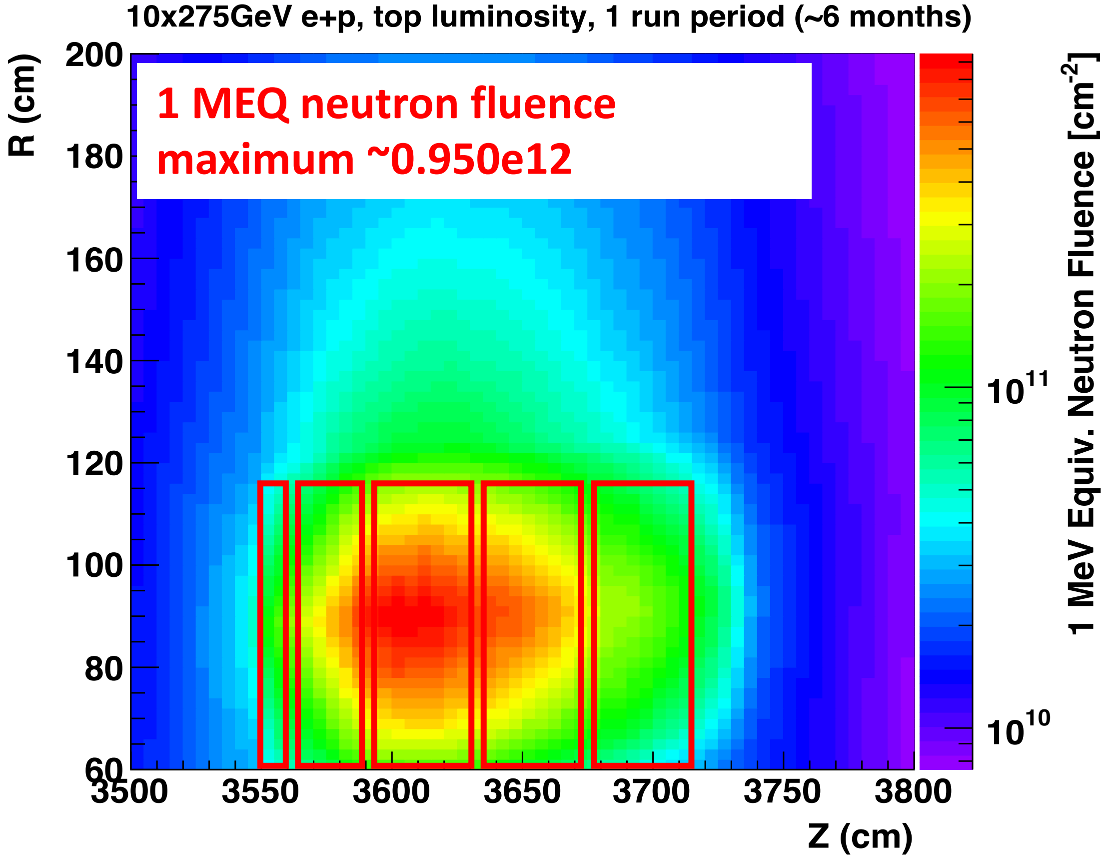
- **Modern GCALOR study**
  - Up-to-date ePIC detector geometry exported from full description in DD4HEP framework (TGeo).
  - Magnet yokes assumed to be pure iron – no assumptions made for cryostats/support structure.
  - Assumed conservative vacuum in the beamline (~ 1e-6 mbar). → this was not on purpose, the "vacuum" in the DD4HEP geometry was discovered to be set to this pressure value for an unknown reason.
  - Operational year assumed (here) to be 1e7 seconds to match previous study.
  - Assumed large radius beam pipe (~40cm, tapering to 10cm near ZDC) made of 1cm/2mm thick stainless steel (no exit window). Pipe inside magnets is aperture size of magnet bore.
  - ZDC geometry assumed to be what is in DD4HEP, with changes made to study impact on fluences (e.g. comparing ATHENA EMCAL vs. PbWO4 to assess impact of material in front of the HCAL).
  - PYTHIA6 with Q2 < 1 GeV2 used for primary interactions (beam+gas also modeled, and is available online – sub-dominant for ZDC rates).

ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Stainless Steel Beam Pipe, 2mm wall thickness

6 months @ ~60% machine efficiency = 1e7 seconds. → different from Wiki



ePIC CraterLake Geometry → exported in Tgeo format and input into Starsim setup.

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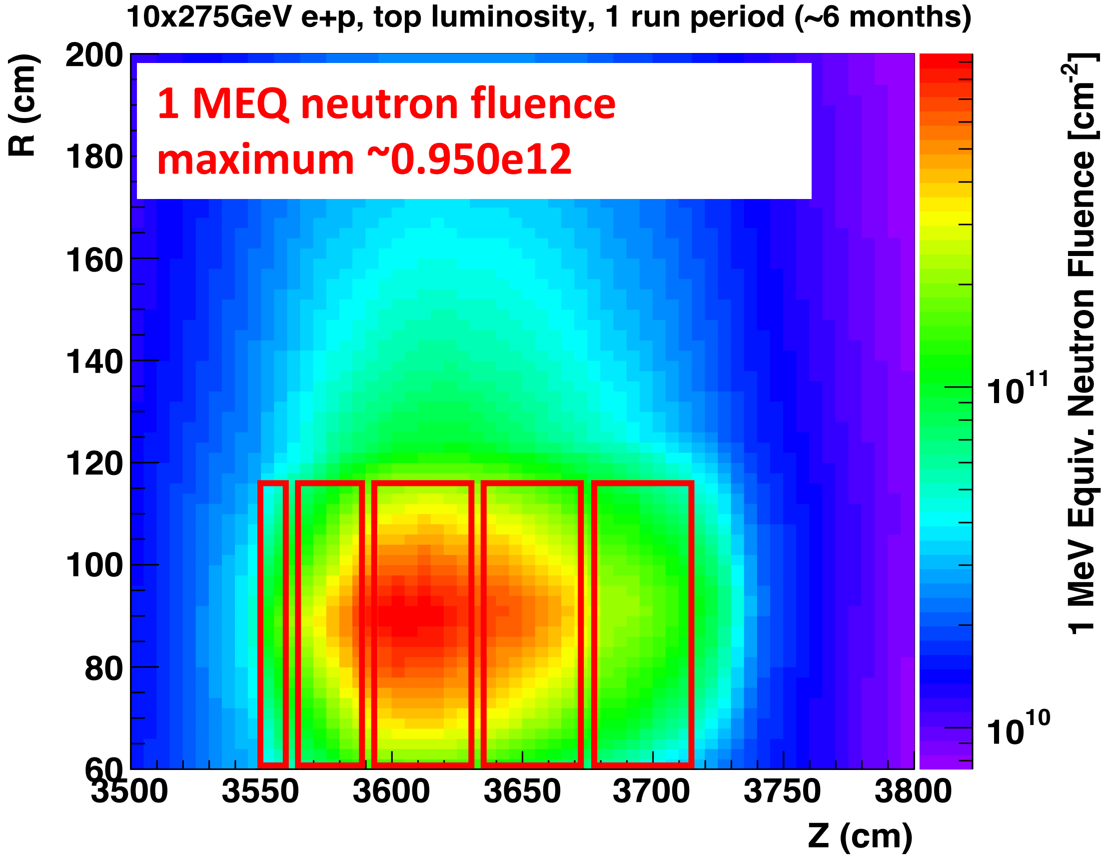
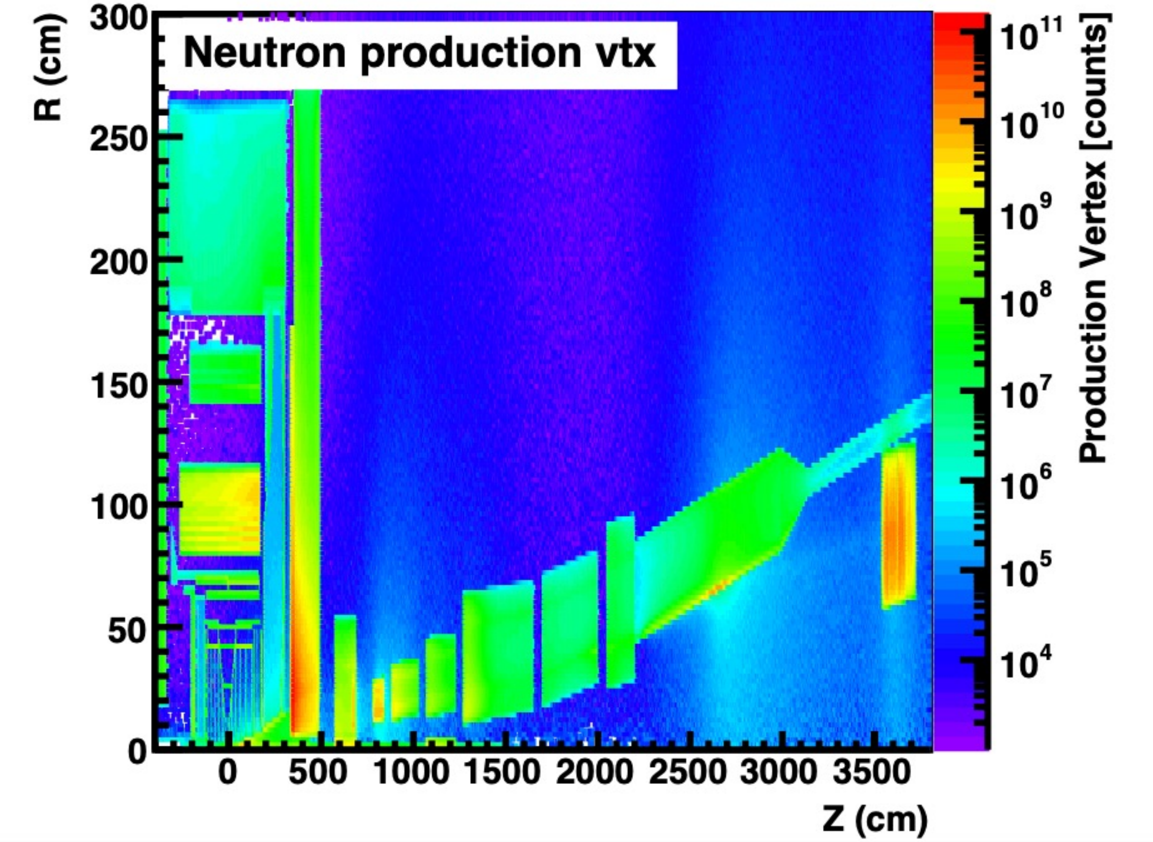

10x275GeV e+p, top luminosity, 1 run period (~6 months)

1 MEQ neutron fluence maximum ~0.950e12

ePIC CraterLake Geometry → exported in Tgeo format and input into Starsim setup.



Dense material (e.g. absorber in HCALs) largest source of neutrons – service and support components will have a large influence on…fluence.

Summary of Fluences

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

ZDC Configurations:

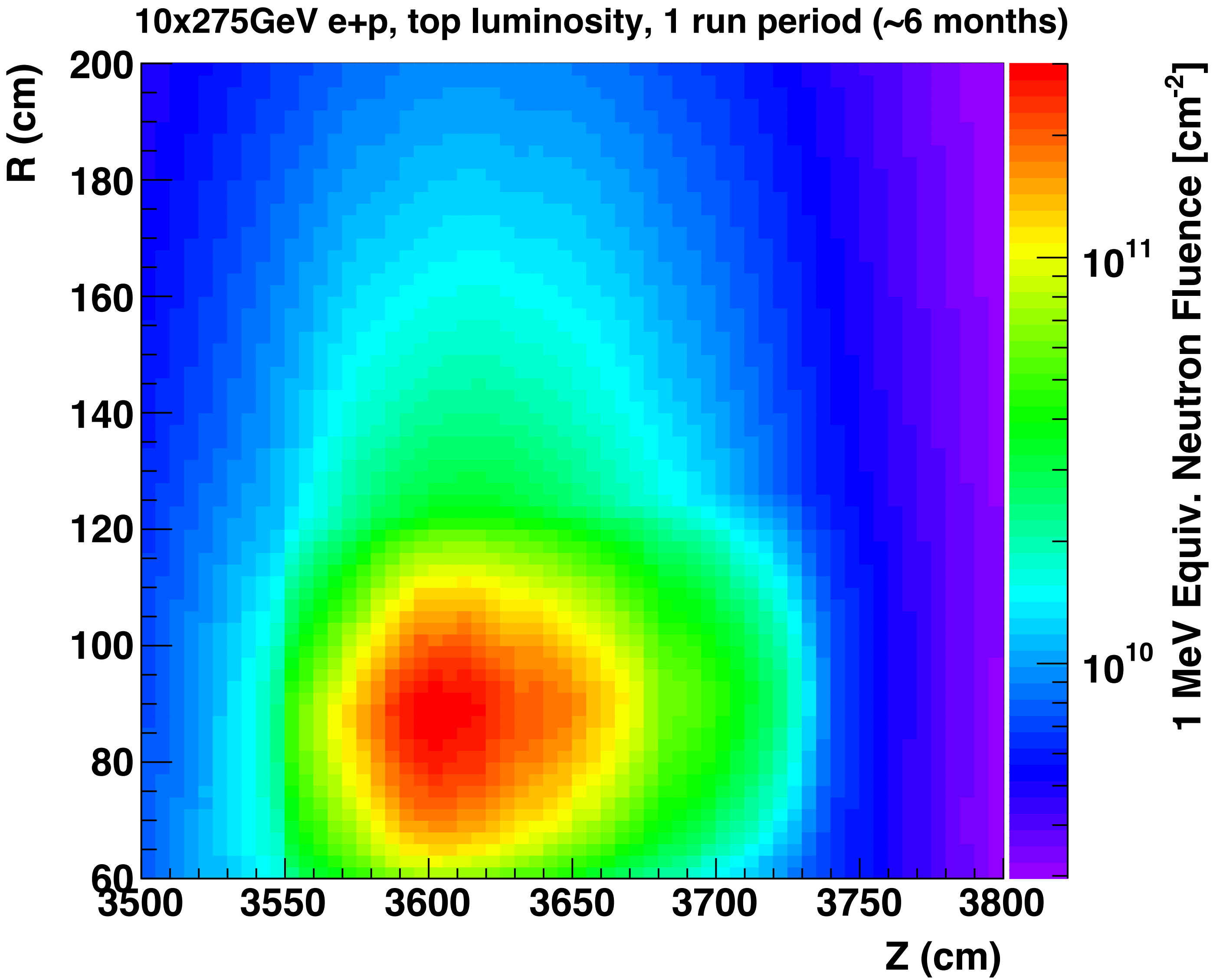
- 2021: 20cm Pb-Glass + 26.2cm W/Si + 78.6cm Pb/Si + 52.4cm Pb/Scintillator
- Present baseline: 7cm PbWO4 + 5.64cm W/Si(10 layers W+Si+glue, 3.5mm W) + ~38.5cm Pb/Si (12 layers Pb+Si+glue, 3cm Pb) + 96cm Pb/Scintillator (15 layers Pb + Scintillator, 3cm Pb – x2)
- OLD DD4HEP ZDC: 10cm W/ScFi EMCAL + 96 layers of 1.0cm Pb + 0.25cm scintillator
- SiPM-on-tile ONLY (no crystal EMCAL)

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

Summary + next steps

- Very difficult to do a real apples-to-apples comparison between previous study and current one.
  - Pure FLUKA vs. GEANT + GCALOR/FLUKA.
  - Not clear what was used for primary interaction simulations in previous study (PYTHIA6 with Q2 < 1 GeV2 used in current study).
  - Different geometries, services, tracking (TPC vs. modern silicon disks), assumptions for beam pipe, etc.
- **<u>Next Steps:</u>**
  - Setup fluence codes in DD4HEP using the MCNP neutron tables.
    - ➢ 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 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.

ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Stainless Steel Beam Pipe, 1cm wall thickness

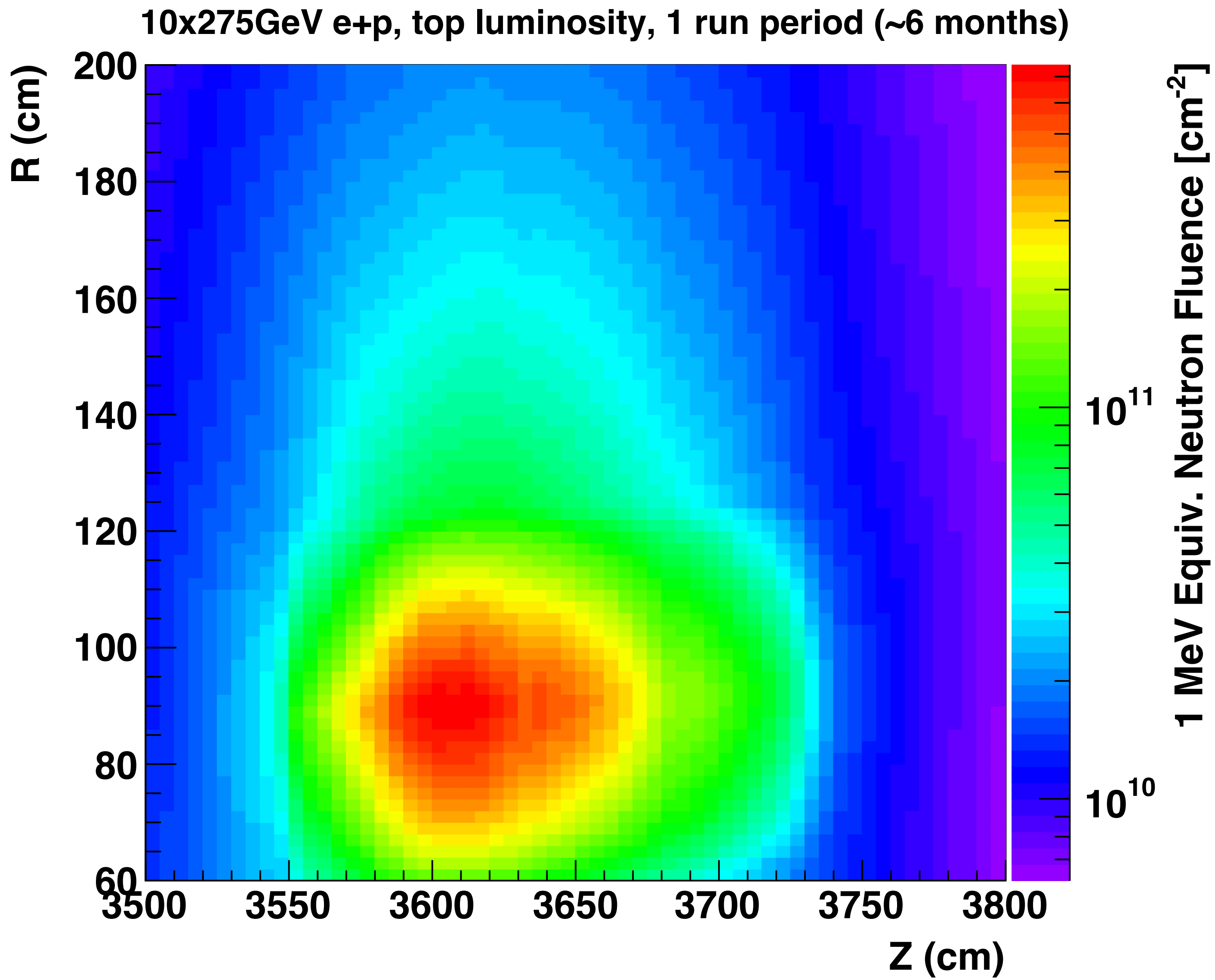


6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~0.3e12

BryceCanyon

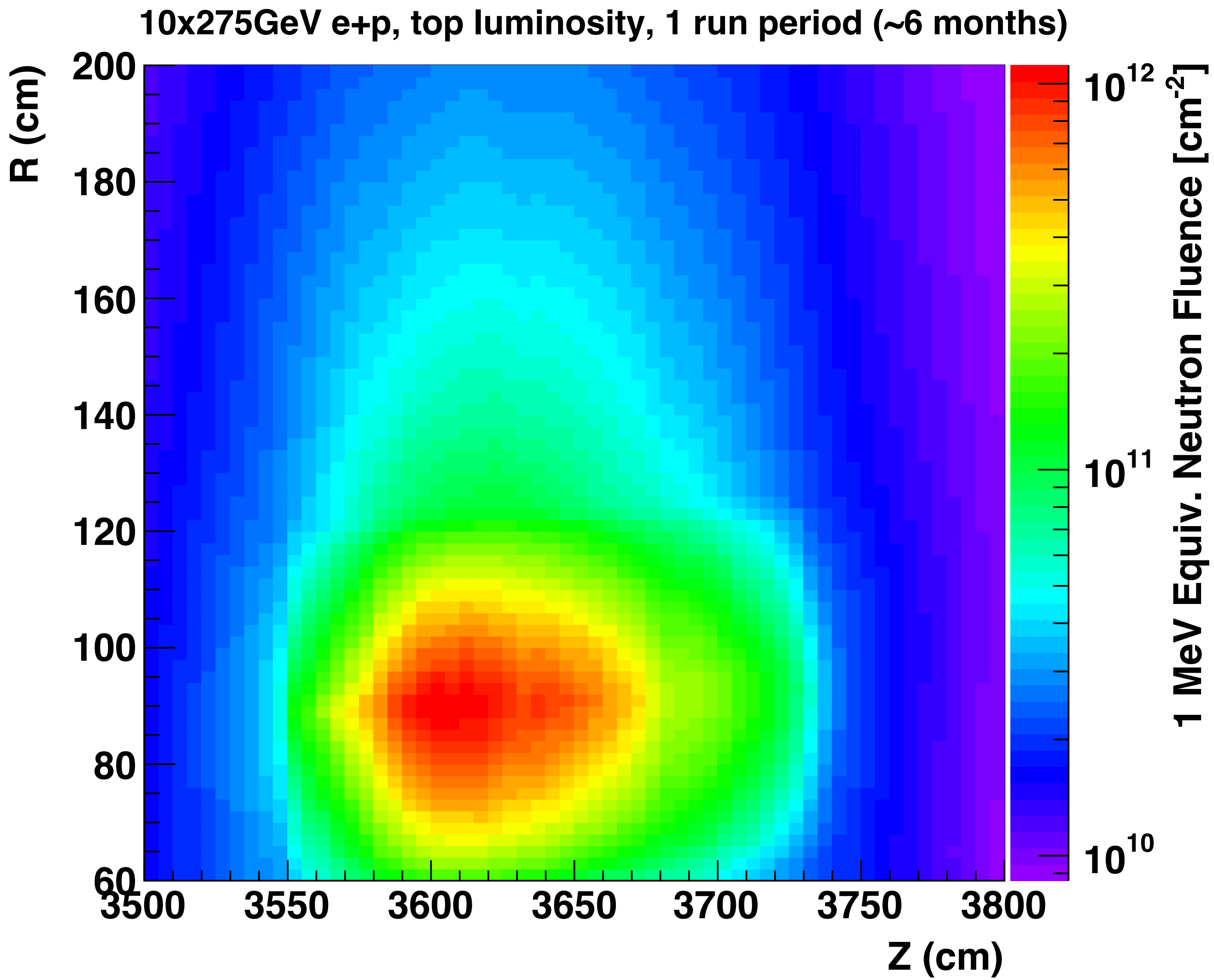
ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Aluminum Beam Pipe, 1cm wall thickness



6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~0.75e12

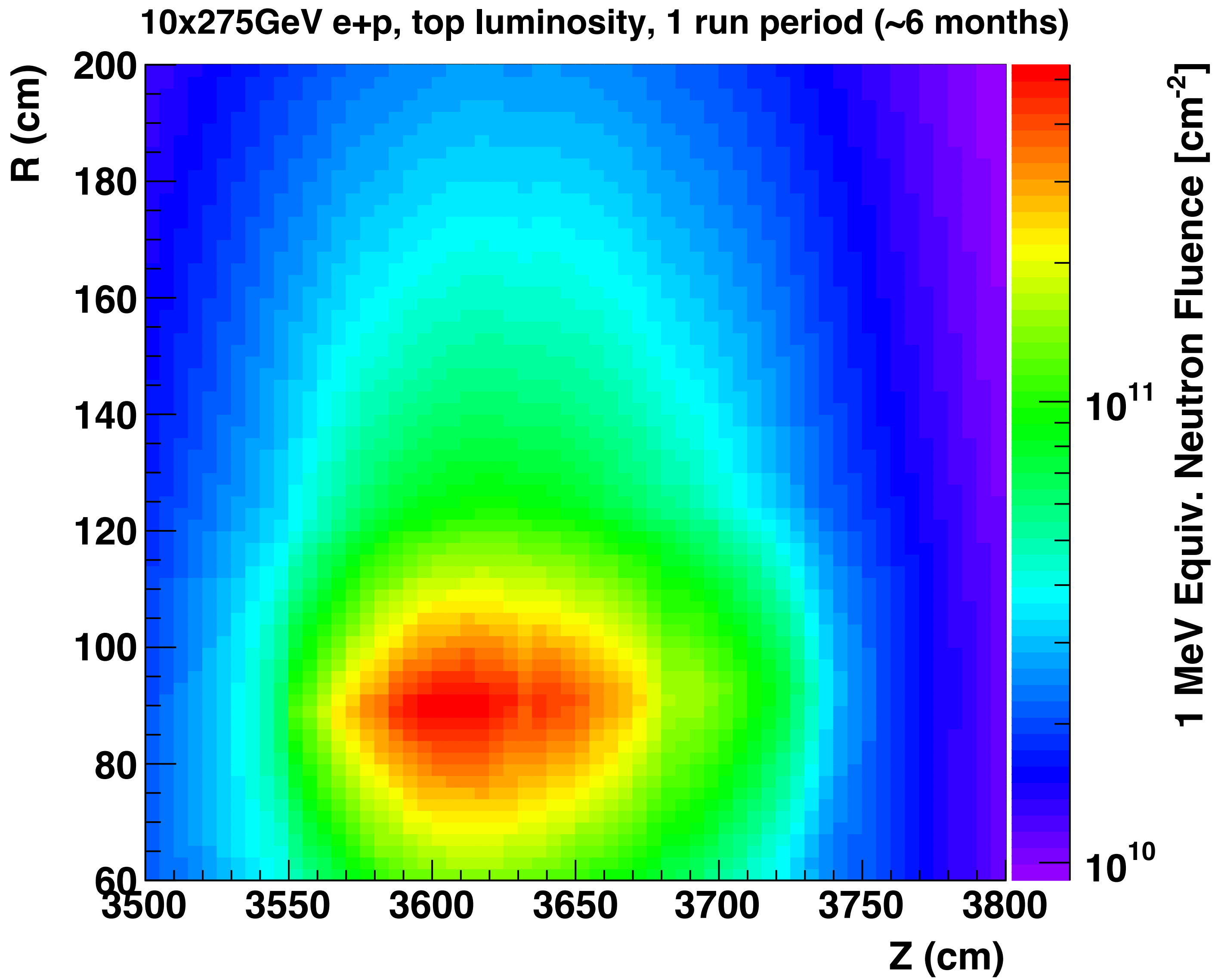
ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Aluminum Beam Pipe, 2mm wall thickness



6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~1.1e12

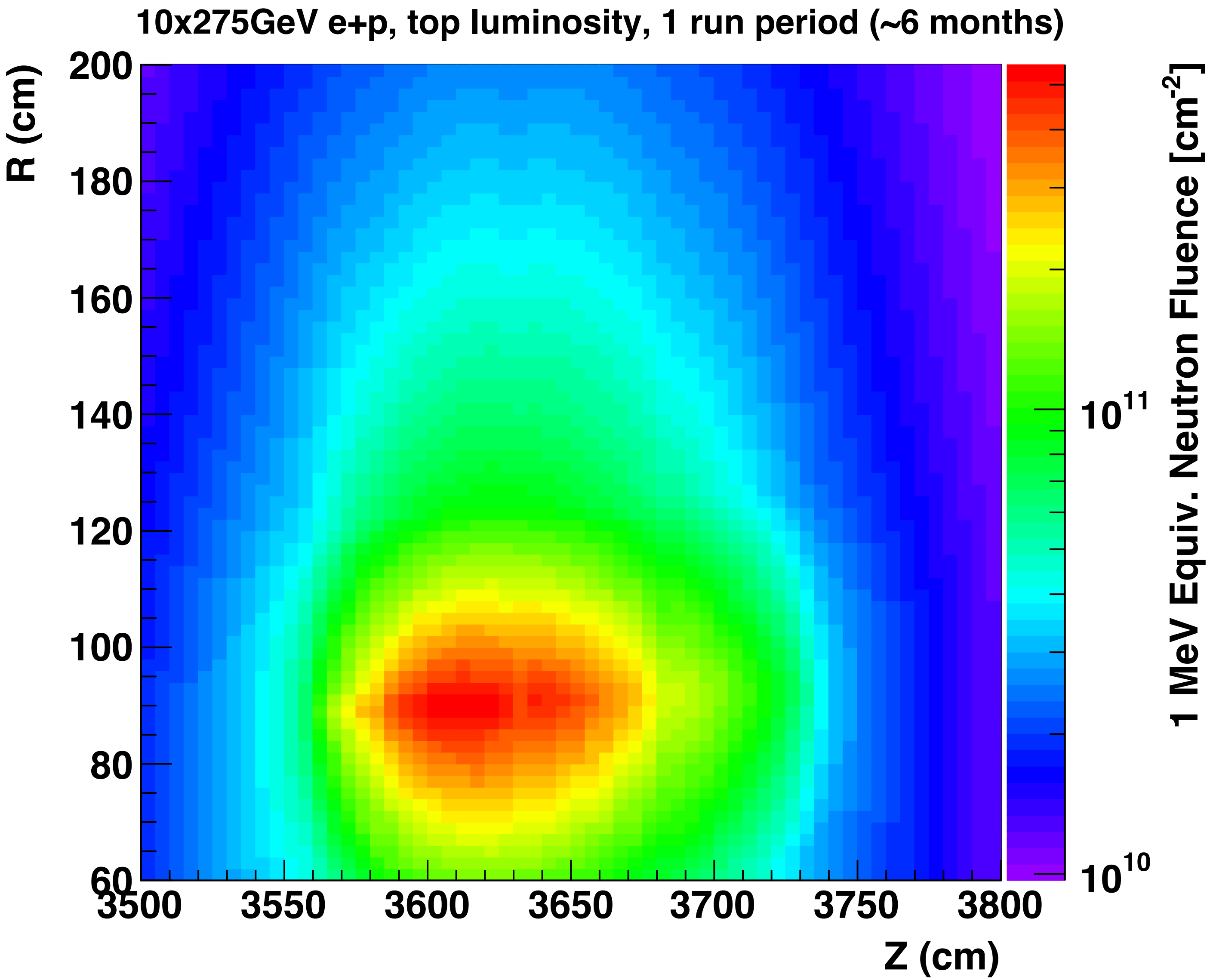
ePIC **FLUKA** ZDC 1 MEQ Neutron Fluence – Aluminum Beam Pipe, 2mm wall thickness



6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~0.538e12

ePIC **FLUKA** ZDC 1 MEQ Neutron Fluence – Aluminum Beam Pipe, 2mm wall thickness, No PbWO4

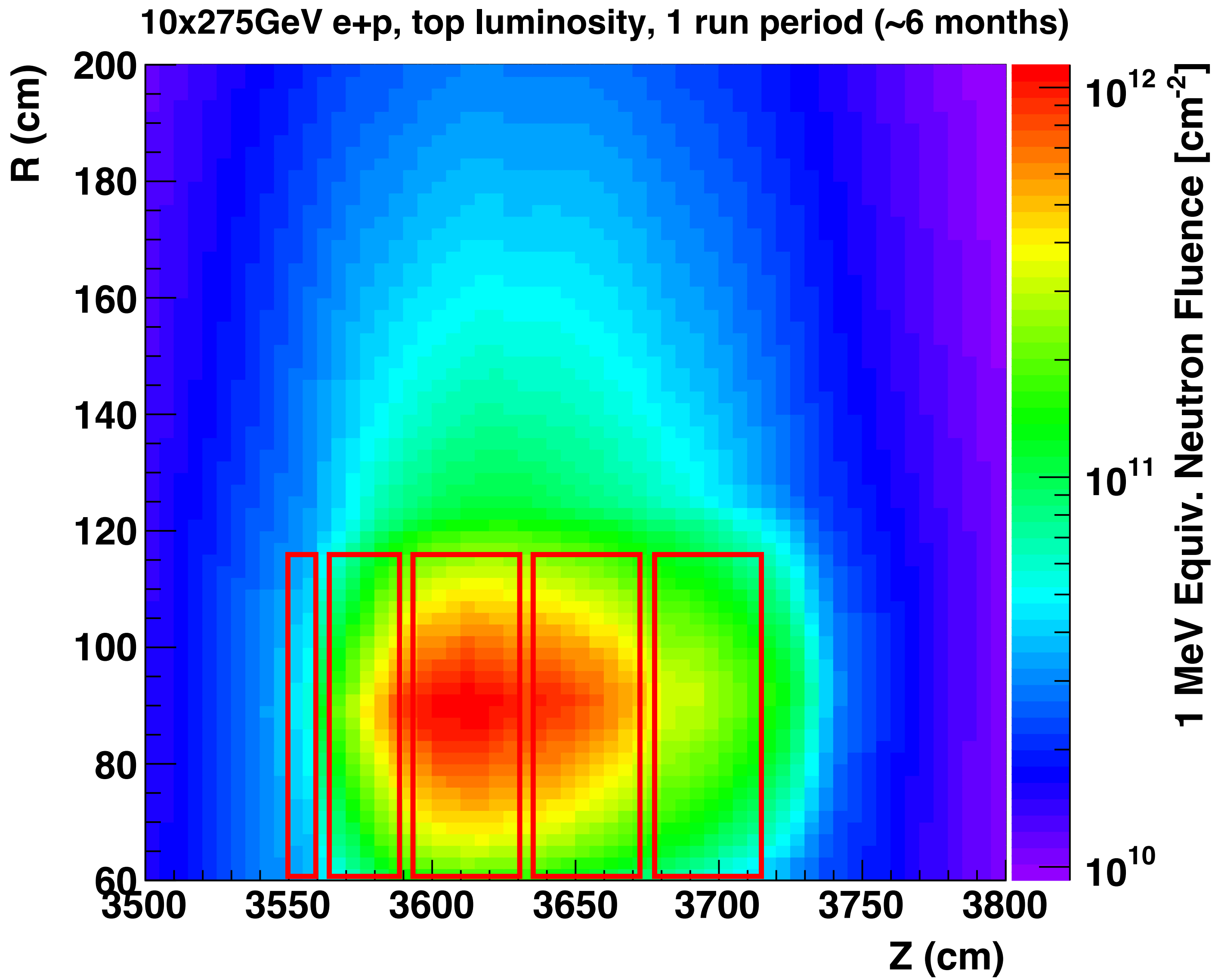


6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~0.55e12

Peak is a little deeper in the ZDC – makes sense, no PbWO4 to slow down some neutrons.

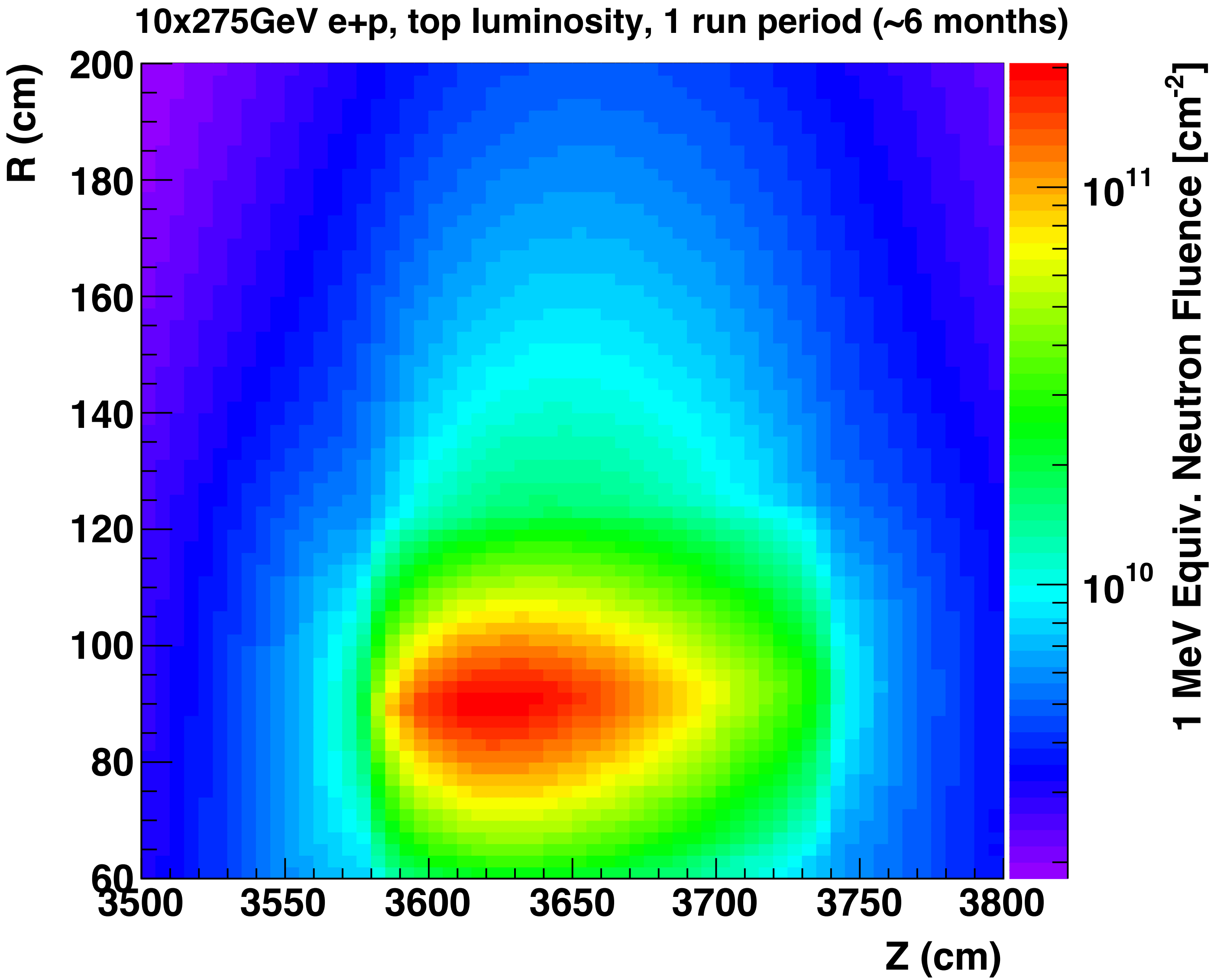
ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Aluminum Beam Pipe, 2mm wall thickness, No PbWO4



6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~1.14e12

ePIC **GCALOR** ZDC 1 MEQ Neutron Fluence – Steel Beam Pipe, 2mm thickness, SiPM-on-Tile



6 months @ ~60% machine efficiency = 1e7 seconds.

1 MEQ neutron fluence maximum ~0.23e12