D0 note 3530

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Choice of Better Shielding Materials for D0 Detector Upgrade

V. Sirotenko

Department of Physics
Northern Illinois University
DeKalb, IL 60115

ABSTRACT

It is shown that replacing polyethylene-lead outer cover in D0 shielding design by borated polyethylene-steel sandwich can provide the same shielding effect. The use of heavy polyconcrete shielding instead of polyethylene and lead may even improve shielding properties against neutrons and gammas by the factor of two.

1. Introduction

As a result of the extensive calculations [1] made for the last several years with such programs as GCALOR and MARS [2], the final design for the neutron shielding for the D0 detector has been made. This design incorporates sandwich-like shielding covering both beam regions: between calorimeter and forward toroid and after forward toroid to the end of the experimental hall. It has three layers of the different materials: inner layer made from steel with thickness of 18", middle layer of 6" polyethylene (PE) and outer layer is lead with thickness of 2". Thick steel layer absorbs and dumps hadronic cascades, polyethylene slows down and captures neutrons, lead absorbs gammas. The layout of the D0 detector with such a shielding, referring here as Bset3-50-0, is shown in Fig. 1.

The main disadvantage of such a design is the use of the lead plates on the top of the shielding. Lead is costly, rather untechnological from the construction point of view, produces additional spallation neutrons. That's why additional studies have been done with the goal to find alternative materials which can be used to replace lead without degradation in the shielding efficiency.

Below in this note we consider two supplementary options for the choice of materials which may be used in the outer two layers of the neutron shielding. Results presented here are based on the calculations done with GCALOR simulation program along, but basic results were confirmed by the MARS calculations [3]

2. Bset3-50-12: BPE + Steel

The idea to replace ordinary polyethylene (PE) by borated polyethylene (BPE) and lead by steel was proposed by S.Pospisil [4] and it is based on the following: the absorption cross sections is much higher in BPE while energy of the resulting gammas is almost twice as low, so steel of the same thickness as lead can be used to absorb those gammas. Such a shielding (Bset3-50-12) was calculated with GCALOR, the chemical content of both ordinary PE and borated polyethylene BPE is given in Table 1. Results of the calculations are shown in Fig. 2 and Fig. 3 as ratios of the neutron and γ fluences for the Bset3-50-12 setup with BPE-Steel outer layer to the Baseline Setup Bset3-50-0 with ordinary PE-Lead outer layer as a function of radius R for different Z positions: center, forward muon A, B and C stations. The thickness of the BPE and steel layers in Bset3-50-12 configuration was exactly the same as the thickness of ordinary PE and lead in the Baseline Setup Bset3-50-0. One can see from those figures that in the forward region after toroid, at Z = 665 cm (B) and Z = 950 cm (C), the BPE-Steel shielding is 20% better for neutrons and roughly the same for gammas.

So the conclusion here is that one can consider to replace PE+Lead shielding with BPE+Steel shielding without loosing the shielding power against neutrons and gammas. And the only factor which may affect such a design is the price of the BPE when compared with the price of the ordinary PE, but there is information that it is not much higher in case of placing order for BPE in Czech Republic [5].

3. Bset3-50-13: Heavy Polyconcrete PCOPB

There is another way to avoid usage of the open lead on top of the shielding: replace last two layers of the baseline shielding, PE and Lead, by one layer of so called heavy polyconcrete, doped with Lithium. Such polyconcrete will slow down neutrons, capture of thermal neutrons by Lithium in addition to H and provide effective shielding against gammas. Polymerconcretes were extensively studied in Dubna/ITEP (Russia) and it was shown that such materials have high radiation resistance, sufficient strength, low induced radioactivity, excellent mechanical properties and can be produced in blocks of any desired size and shape [6]. Another important feature of this material is its price: one can hope that it can be about 15% lower that traditional PE and Lead shielding [7].

Sample of heavy polyconcrete, PCOPB, has been provided to us by Russian manufacturer [7] and it's chemical content is shown in Table 2. We simulated this material PCOPB using Bset3-50-13 geometry setup where we took the Baseline Setup Bset3-50-0 and replace 6" PE and 2" Lead by 8" of PCOPB. Results of this calculations are quite impressive and are shown in Fig. 4 and Fig. 5 as ratios of the neutron and γ fluences for the Bset3-50-13 setup with PCOPB shielding to the Baseline Setup Bset3-50-0 as a function of radius R for different Z positions: center, forward muon A, B and C stations. One can see from those figures that in the region of forward muon spectrometer, at Z = 665 cm (B) and Z = 950 cm (C), the PCOPB shielding is 40% better for neutrons and 50% better for gammas. This factor of 2 reduction of the most dangerous γ background fluxes is very important from the point of view of muon triggering and muon reconstruction efficiency.

Another interesting result from the study of BPE-Steel and PCOPB shieldings is that the energy spectra of neutrons coming out of the shielding differs from neutron spectrum in case of PE-Lead shielding. As can be seen from Fig. 6 , the thermal peak of neutrons with energies less than 10 ev is missing for both BPE-Steel and PCOPB designs. This may be good since the sensitivity of the muon drift tubes to neutrons grows in this energy range with decreasing neutron energy.

4. Conclusion

It was shown by simulations that replacement of the outer D0 shielding structure made from ordinary polyethylene and lead by other materials may improve the shielding properties. In particular, the use of heavy polyconcrete may give factor of two reduction of neutron and gamma fluxes without increasing the size of the shielding and the shielding cost. The obtained results may be interesting for the shielding optimizations of such detectors as ATLAS and CMS at CERN, fixed target detectors at Fermilab and for other applications at accelerators and reactors.

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References

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   N.Mokhov, ”The MARS Code System User’s Guide, Version 13 (95)“, Fermilab FN-628, 1995.
3. N.V.Mokhov, private communication.
4. C.Leroy,S.Pospisil,I.Stekl,,J.Sodomka, ”Remarks on a Concept of the ATLAS Forward Region Shielding“, Atlas-Tech-32, 24 March 1998.
5. S.Pospisil, private communication.
6. L.N.Zaitsev,I.A.Sergeyev,S.L.Zaitsev, ”Polymerconcrete for Radiation Background Shielding of Detectors at Hadron Colliders“, Proc, of EPAC-98, Stockholm, 22-26 June 1998.
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Table 1: Chemistry of the ordinary and borated polyethylene used in the calculations

Polyethylene Type	Density in g/cm^3	Composition, % by weight			
		H	B	C	O
PE	0.93	14.4	-	85.6	-
BPE	0.99	12.7	3.0	71.0	13.3

Table 2: Chemistry of the heavy polyconcrete PCOPB

Density in g/cm^3	Composition, % by weight								
	H	Li	C	F	O	Al	Si	Ca	Pb
3.58	1.4	2.6	10.1	7.1	12.0	1.8	0.3	1.6	63.1

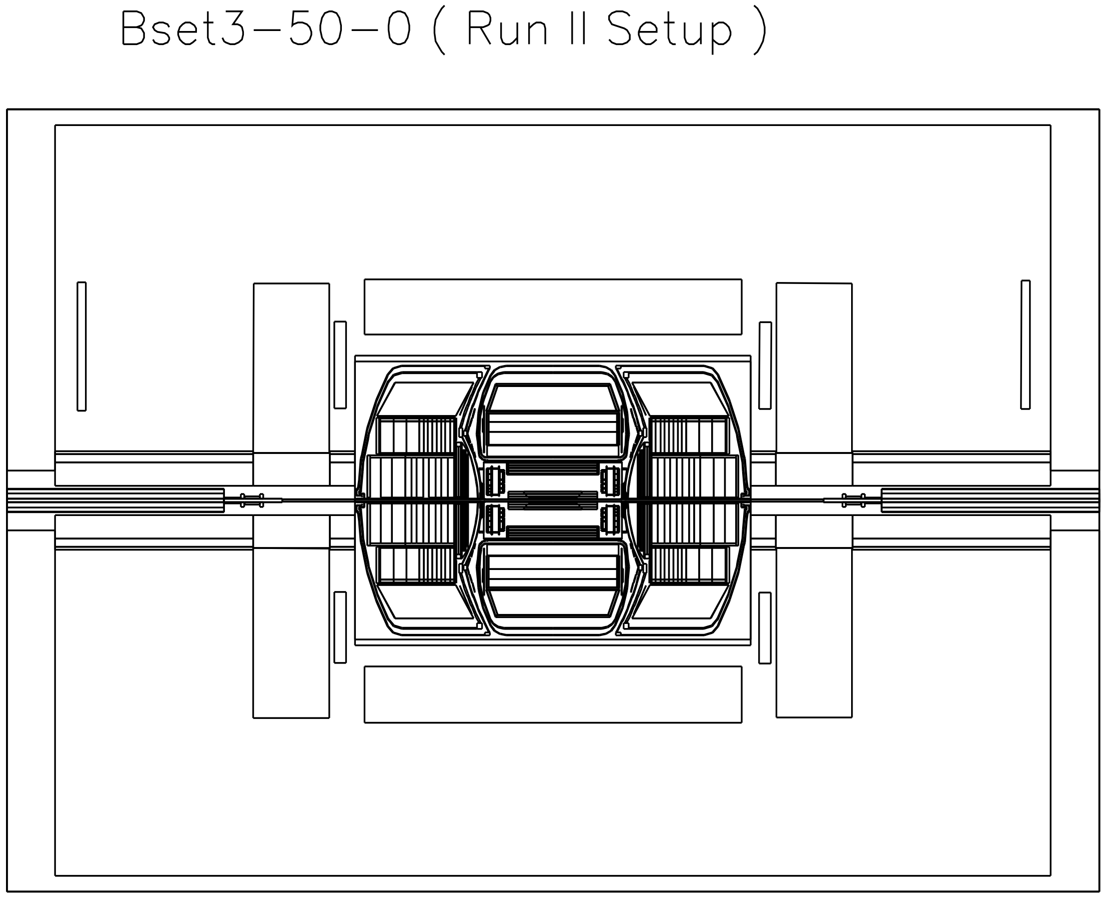

Figure 1: D0 detector with baseline shielding geometry Bset3-50-0

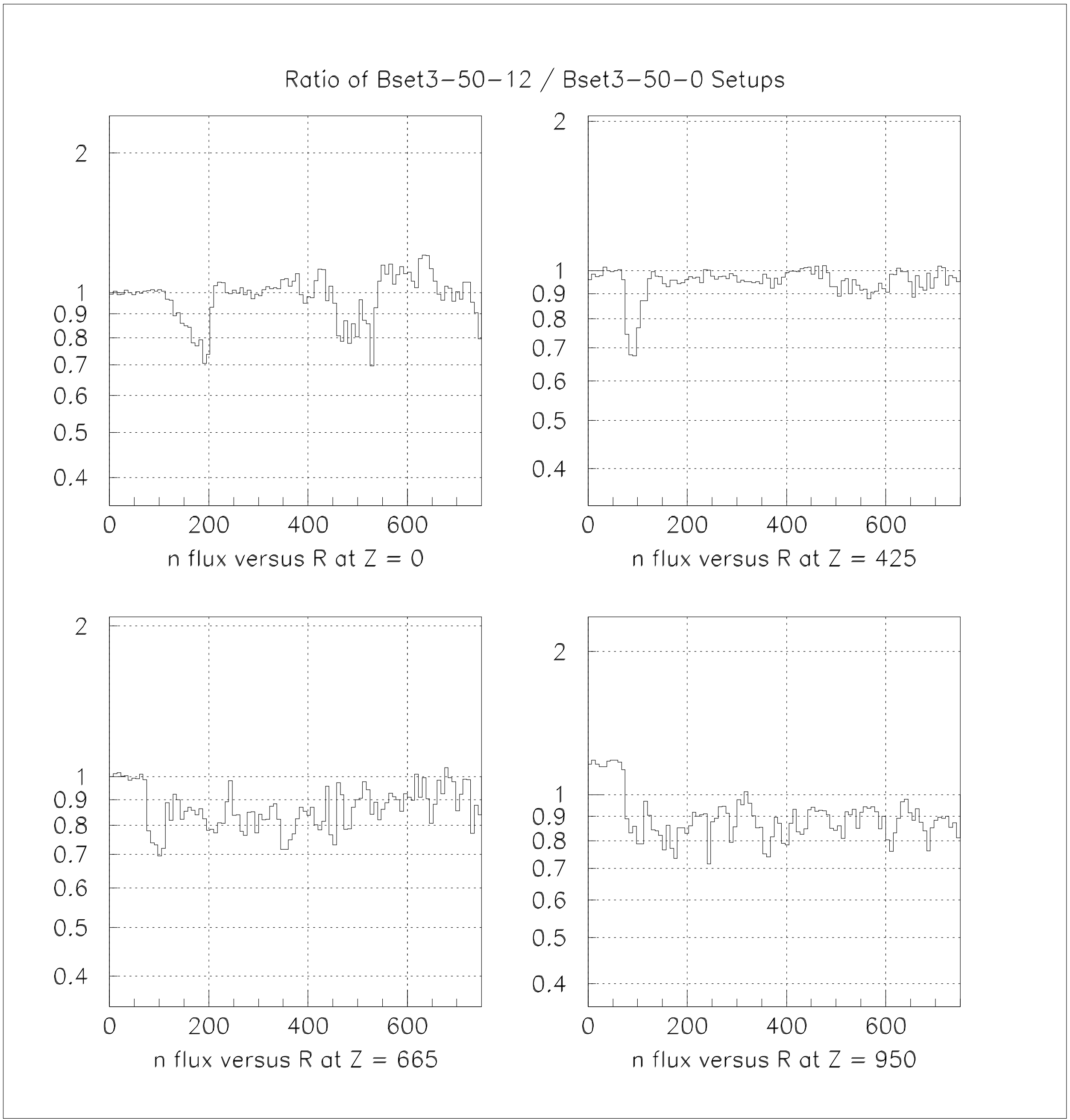

Figure 2: Ratio of the neutron fluences for the Bset3-50-12 setup with BPE-Steel outer layer to the Baseline Setup Bset3-50-0 as a function of radius R for different Z positions (center, muon A, muon B, muon C)

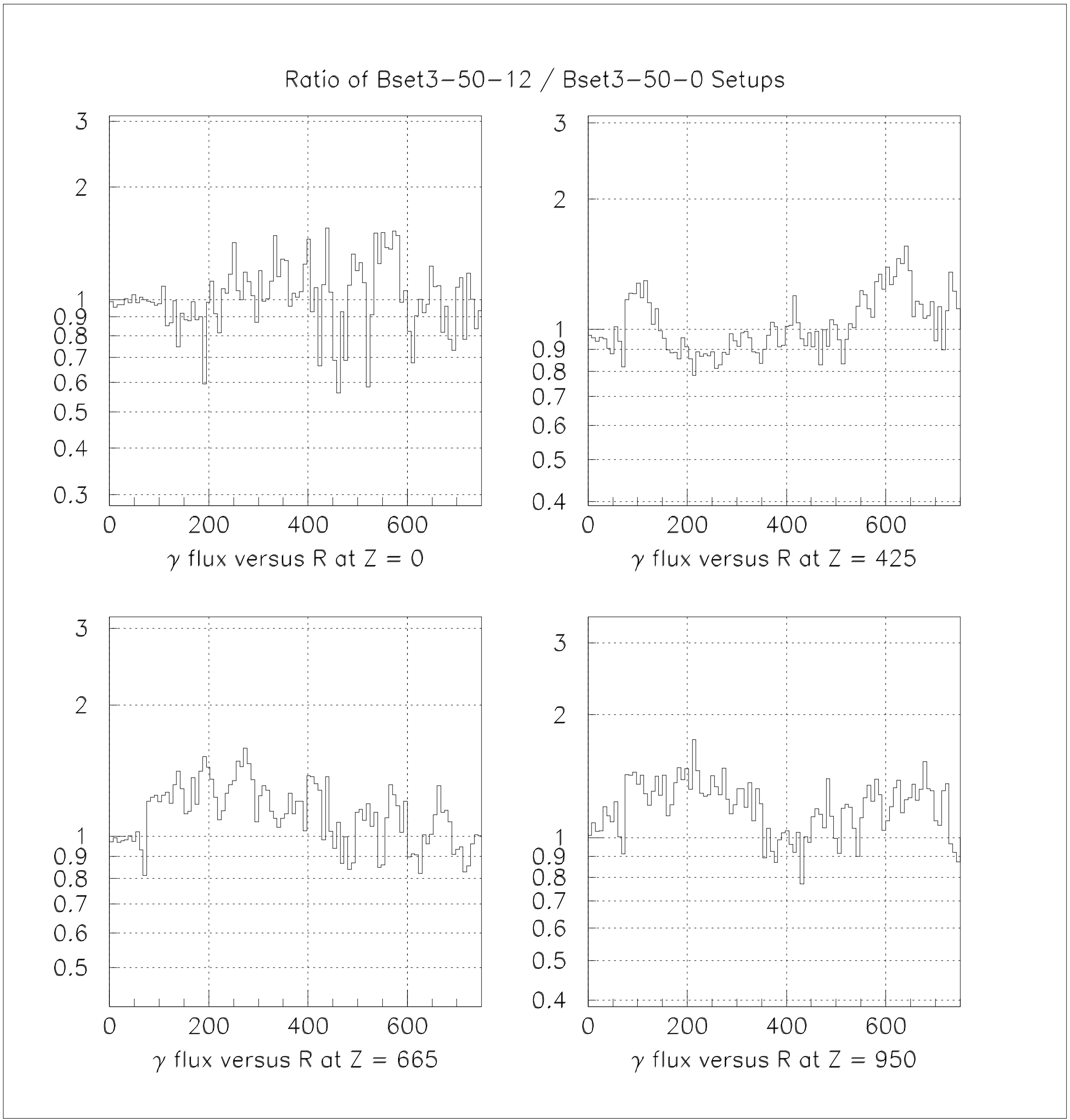

Figure 3: Ratio of the γ fluences for the Bset3-50-12 setup with BPE-Steel outer layer to the Baseline Setup Bset3-50-0 as a function of radius R for different Z positions (center, muon A, muon B, muon C)

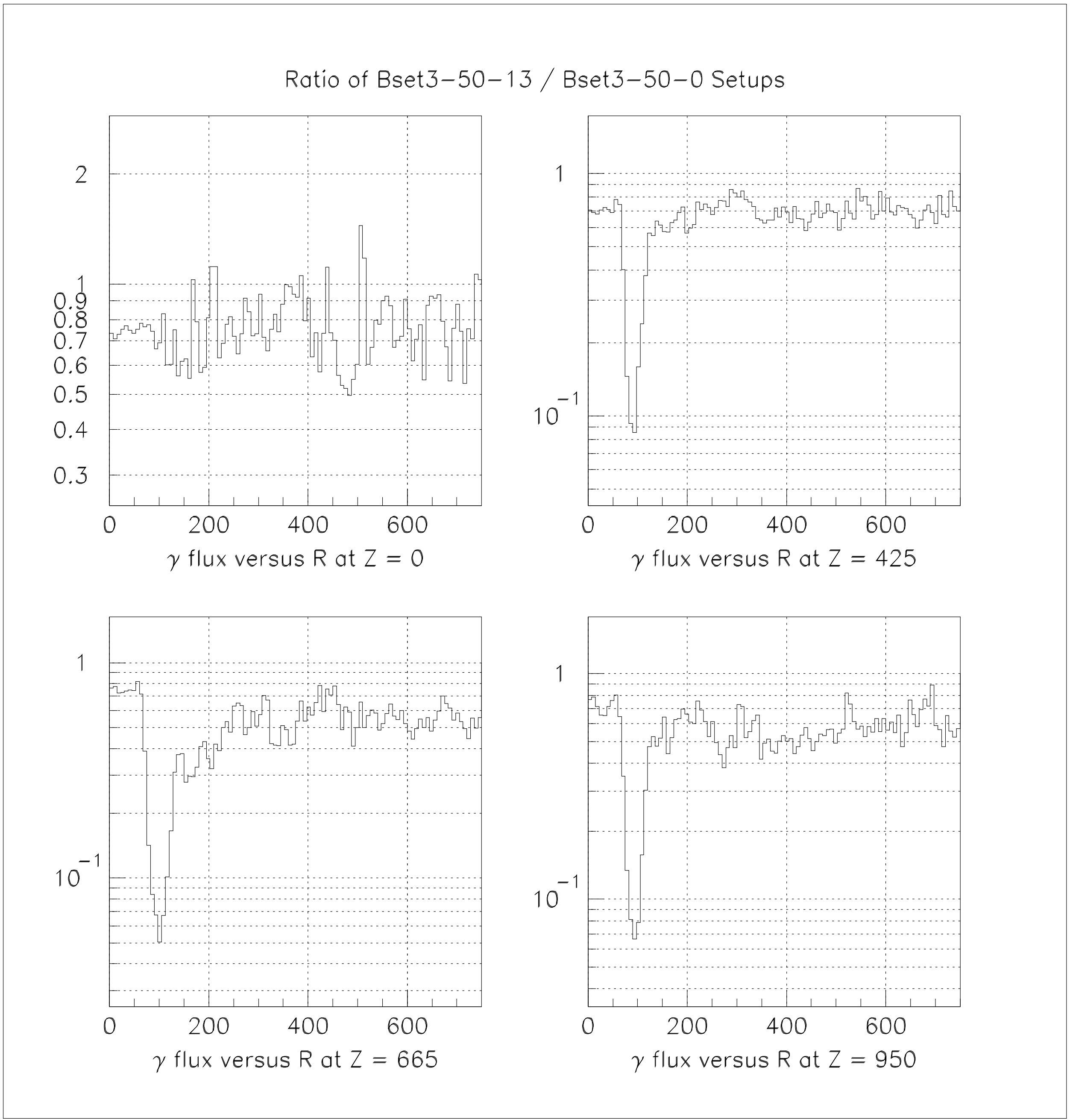

Figure 4: Ratio of the neutron fluences for the Bset3-50-13 setup with PCOPB polyconcrete outer layer to the Baseline Setup Bset3-50-0 as a function of radius R for different Z positions (center, muon A, muon B, muon C)

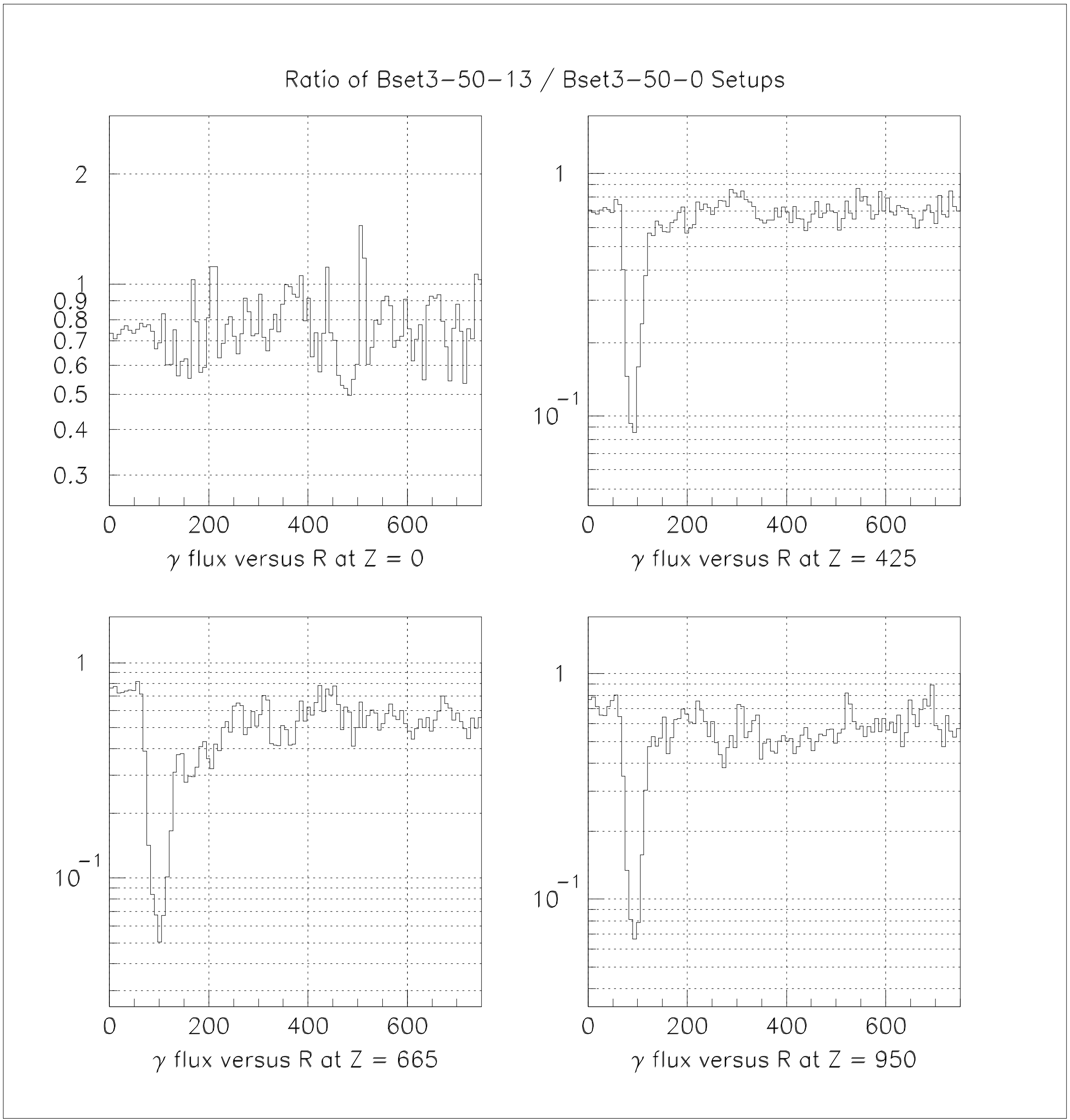

Figure 5: Ratio of the γ fluences for the Bset3-50-13 setup PCOPB polyconcrete outer layer to the Baseline Setup Bset3-50-0 as a function of radius R for different Z positions (center, muon A, muon B, muon C)

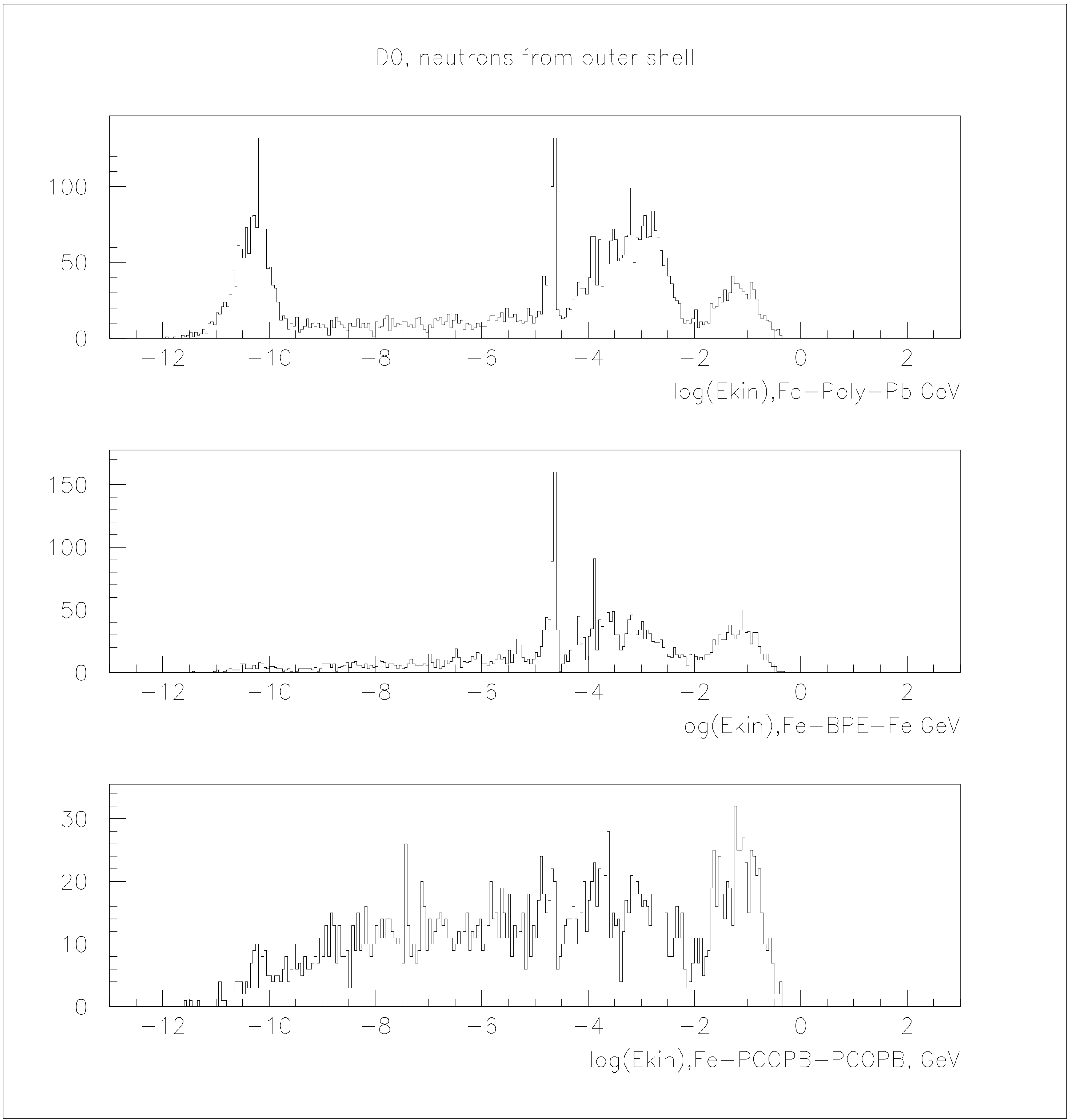

Figure 6: Energy spectra from neutrons coming from the outer shielding shell for three cases: (a) Baseline shielding PE+Lead; (b) BPE+Steel; (c) PCOPB polyconcrete