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Karlsruhe Institute of Technology

Institute for Neutron Physics and Reactor Technology (INR)

Optimization of the deuteron beam profile for neutron irradiations in IFMIF-DONES

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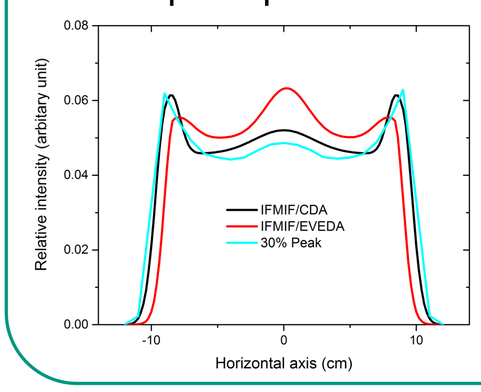
Introduction

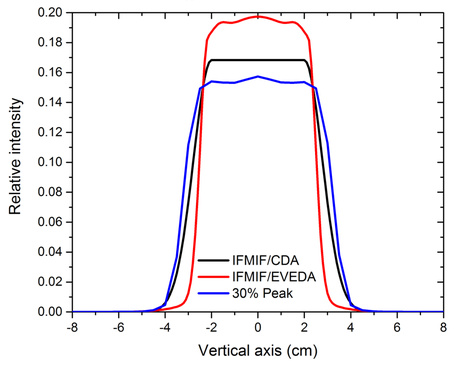
- IFMIF-DONES is a **D**EMO **O**riented **NE**utron **S**ource based on the IFMIF engineering design (IFMIF/EVEDA). Its deuteron beam is designed to impinge on the lithium target within an semi-rectangular area with a preferable profile.
- The goal of the deuteron beam profile optimization is to achieve, as much as possible, a uniform distribution of the damage dose (DPA) at the required level. Meanwhile, the profile must be realistically achievable by the beam dynamics.

Current available profiles

- IFMIF/CDA profile: analytic profile used in IFMIF/CDA phase
- IFMIF/EVEDA profile: tabular profile in IFMIF/EVEDA phase
- 30 % peak profile: tabular profile with 30% edge peak

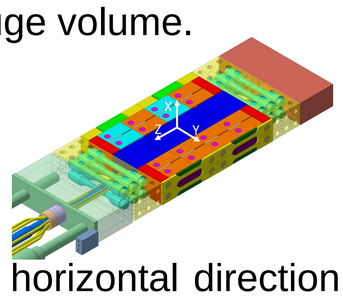


Beam profiles normalized to the area.



Optimization approachs and setup

- **Objective**: "Volume-DPA Product" (VDP). High level DPA (>10 dpa, VDP10) is preferred. Early target for the DEMO 1st phase : 10 ~ 20 dpa (VDP10-20).
- **Constraints**: DPA gradient <10% over gauge volume.
  - Beam direction X: d(DPA)/dx / DPA(x,y,z) * 4.6mm < 10%
  - Horizontal direction Y:
    - |Z| < 25mm : d(DPA)/dy / DPA(x,y,z) * 4mm < 10%
    - |Z| > 25mm : d(DPA)/dy / DPA(x,y,z) * 7.6mm < 10%
  - Vertical direction Z:
    - |Z| < 25mm : d(DPA)/dz / DPA(x,y,z) * 9mm < 10%
    - |Z| > 25mm : d(DPA)/dz / DPA(x,y,z) * 2mm < 10%



- **Variables**: McDeLicious analytic profile in horizontal direction (7 parameters.) (IFMIF/CDA vertical profile used).

Normalized Gaussian

$$G(y,y_0,\sigma)=\frac{1}{\sqrt{2\pi\sigma}}e^{-(y-y_0)^2/2\sigma}$$

$$\int_{-\infty}^{\infty}G(y,y_0,\sigma)dy=1$$

Basic distribution

$$I_0(y,y_0,\sigma_0,m_0)=\begin{cases}m_0G(y,-y_0,\sigma_0); & y<-y_0\\ G(0,0,\sigma_0); & -y_0\le y\le y_0\\ m_0G(y,y_0,\sigma_0); & y>y_0\end{cases}$$

1st correction

$$I_1(y,y_1,\sigma_1,m_1)=m_1[G(y,-y_1,\sigma_1)+G(y,y_1,\sigma_1)]$$

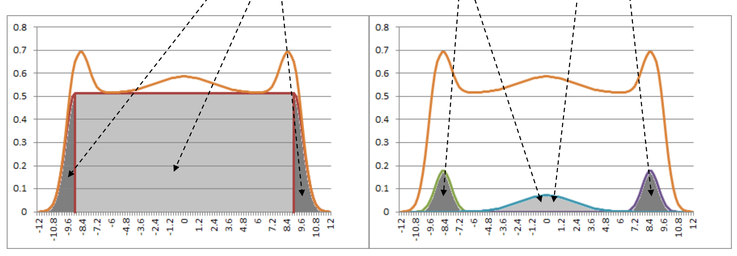
2nd correction.

$$I_2(y,y_2,\sigma_2,m_2)=m_2[G(y,0,\sigma_2)+G(y,0,\sigma_2)]$$

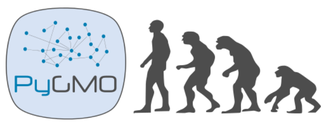
Upper-/ lower- bounds

y_i: center, σ_i: width,m_i: area

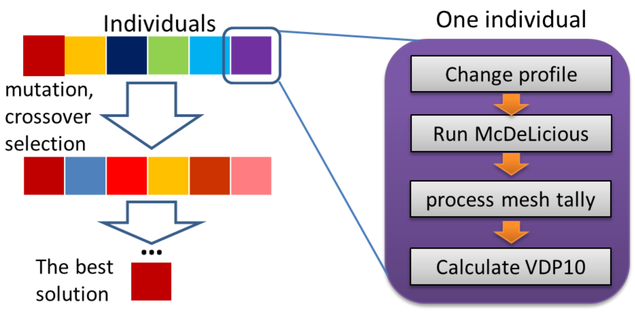
y_0 [1,9]	σ_0[0,10]	1
y_1[0.5,8.5]	σ_1[0,10]	m_1[0,1]
0	σ_2[0,10]	m_2[0,1]



- **Methods**: Genetic Algorithm implement in PyGMO library.

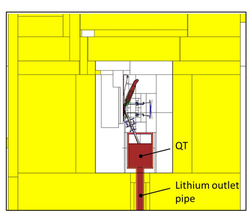


PyGMO (the Python Parallel Global Multiobjective Optimizer)

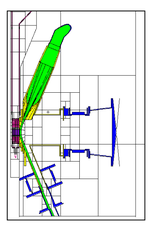


Sensitive studies

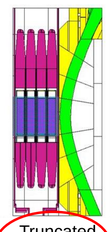
- Model sensitive study (McDeLicious code + FENDL-3.1b).



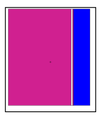
Full DONES model



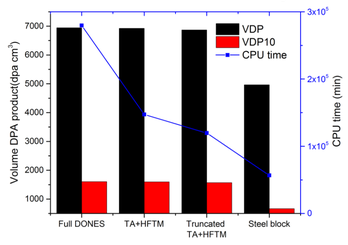
TA+HFTM



Truncated TA+HFTM

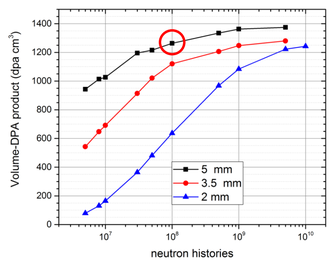


Steel block

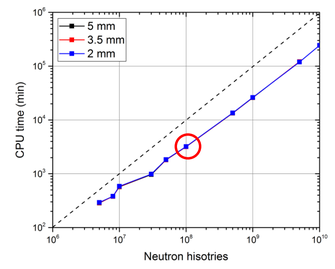


Comparison of results and CPU time

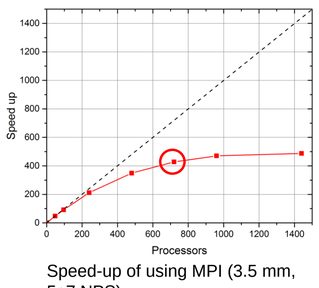
- Sensitive studies on mesh resolution and n histories (NPS).



Sensitivities of VPD10 to mesh and NPS



CPU time for different meshes and NPS (960 cores)

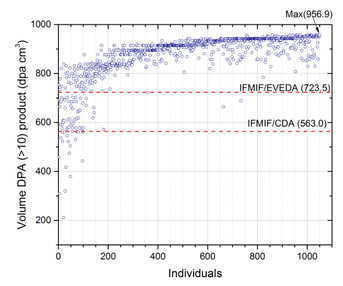


Speed-up of using MPI (3.5 mm, 5e7 NPS)

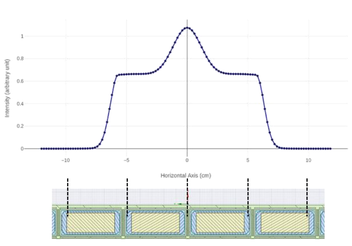
Optimization results

- Optimized profiles after 50 individuals × 20 generation.

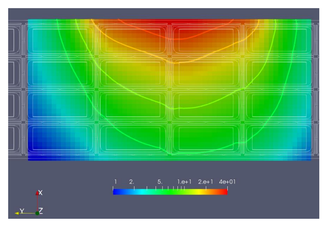
VDP10



Optimization evolution of VDP10

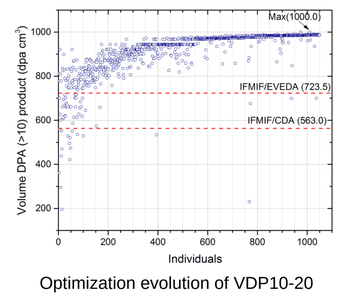


Optimized profile of VDP10 (**VDP10opt**)

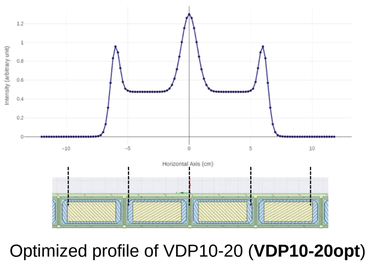


DPA calculated using profile VDP10opt

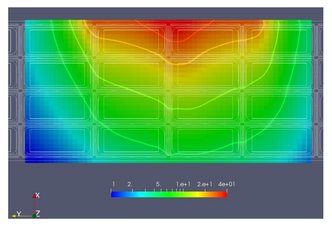
VDP10-20



Optimization evolution of VDP10-20

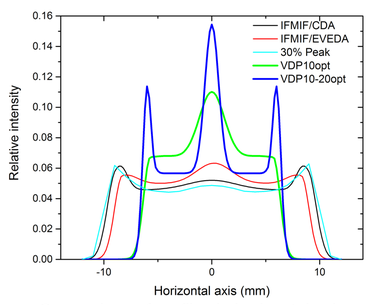


Optimized profile of VDP10-20 (**VDP10-20opt**)

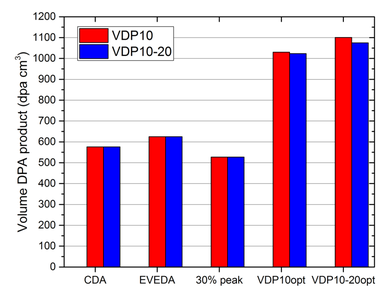


DPA calculated using profile VDP10-20opt

- Comparison of VDP from different profiles using same condition (3.5 mm mesh, 1e9 NPS).
- Optimized profiles have significant increases of VDP.



Comparison of profiles in horizontal axis (normalized by area)



Comparison of VDP10 and VDP10-20 from different profiles

	VDP10	VDP10-20
Comparing with IFMIF/EVEDA:		
VDP10opt	65%	63%
VDP10-20opt	75%	71%
Comparing with VDP10opt:		
VDP10-20opt	6.7%	5.0%

Gain of VDP from the optimized profiles

Conclusions

- The deuteron beam profile has been optimized to achieve higher irradiation performance.
- The optimized profiles have 60~70% gains of VDP10 and VDP10-20 comparing with the IFMIF/EVEDA profile.
- The optimized profiles have similar beam size of 14 cm, the gain from the edge peak is not significant (5-7%).
- The profiles have to be further optimized considering the final HFTM design and beam dynamics capability.