ITER Neutronics Modeling Using Hybrid Monte Carlo/Deterministic Techniques and CAD Based Monte Carlo

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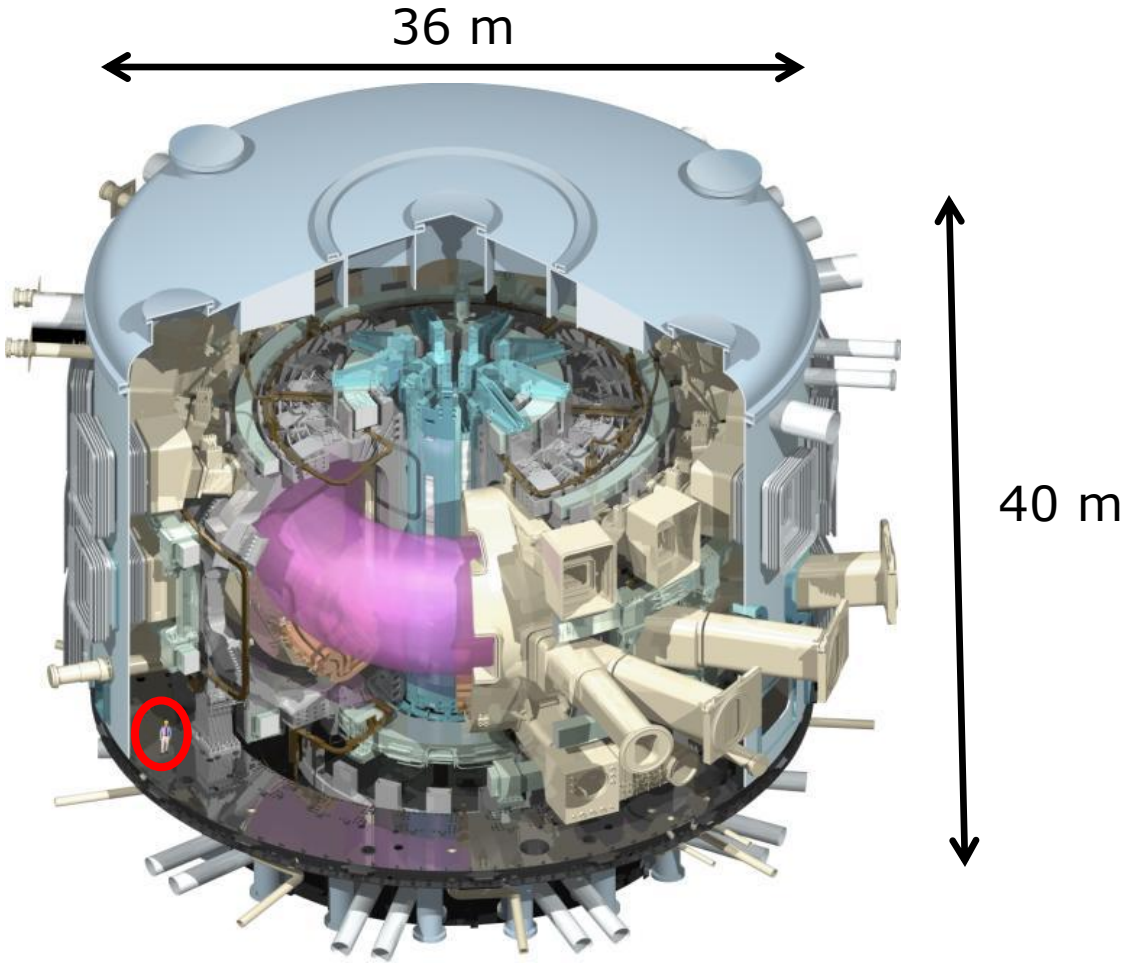
Outline

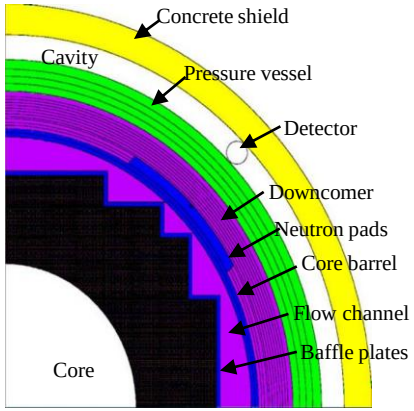
- Motivation for work
- Parameters calculated
  - Inboard (IB) toroidal field coils (TFC) nuclear heating
  - Prompt dose outside bioshield
  - Total neutron and gamma fluxes
- Conclusion

ITER

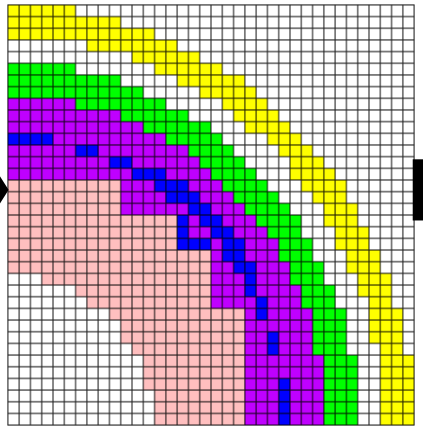


- Large size
- Complex geometry

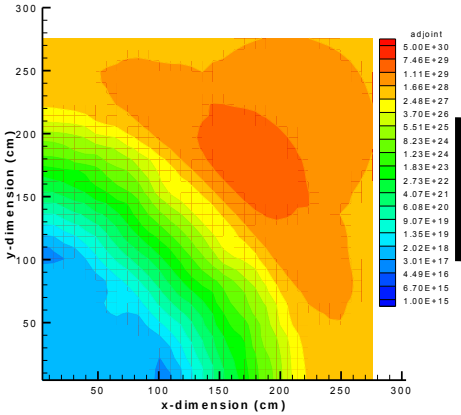
ADVATNG (CADIS, FW-CADIS) dramatically speeds up calculation



MC model



Deterministic model



Adjoint flux

CADIS calculation of VR parameters

Source biasing

$$\hat{q}(\bar{r},E) = \frac{\phi^{+}(\bar{r},E)\,q(\bar{r},E)}{R}$$

Weight windows

$$w_{\ell}(\bar{r},E) = \frac{R}{\phi^{+}(\bar{r},E)}$$

MC

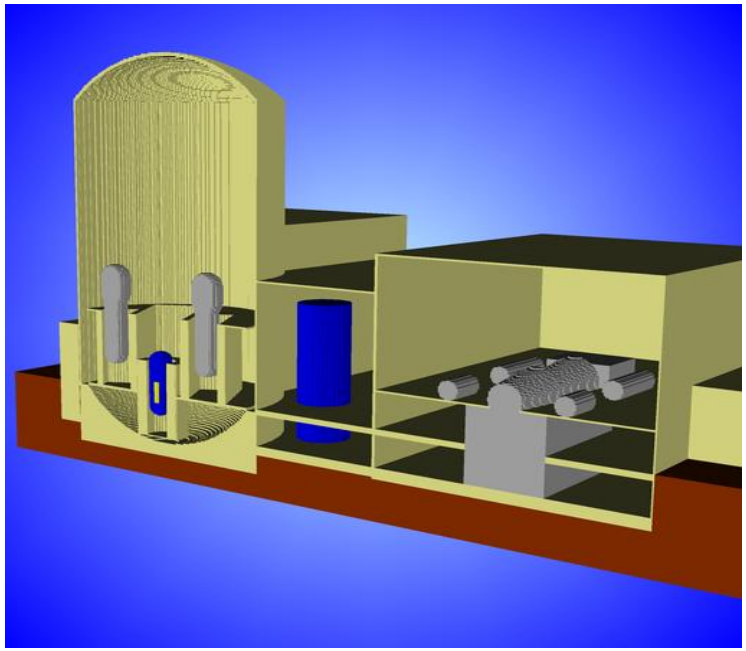
Results

Case	CPU time (hr) for 1% uncertainty	Speed up
No VR	8.86E+4 (10.1 yrs)	1
Manual VR	13.6	6500*
ADVANTG	**1.02**	**87000**

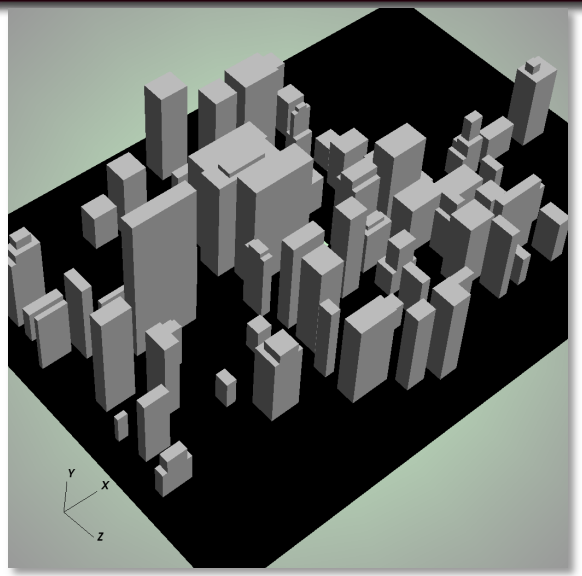
* Required ~3 weeks by an experienced MC practitioner using all applicable MCNP4C VR capabilities

Applications of CADIS and FW-CADIS

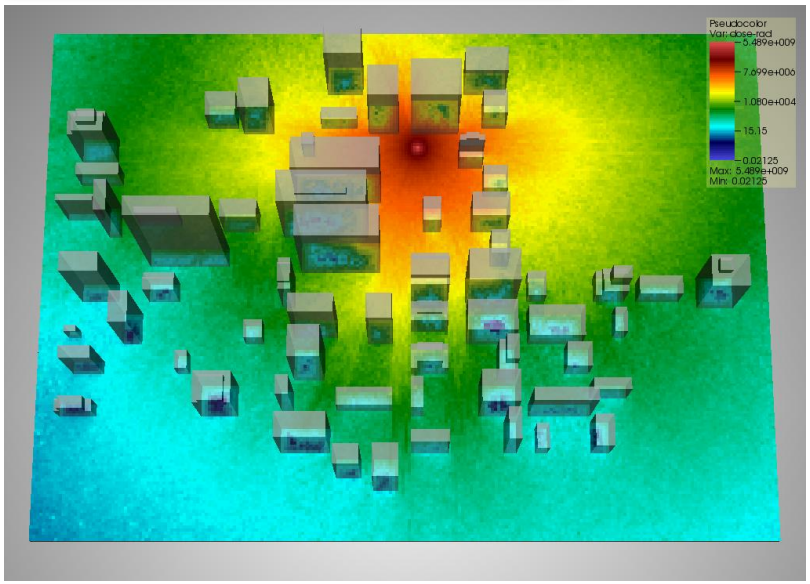
- Large systems



PWR facility
85 × 125 × 70 m



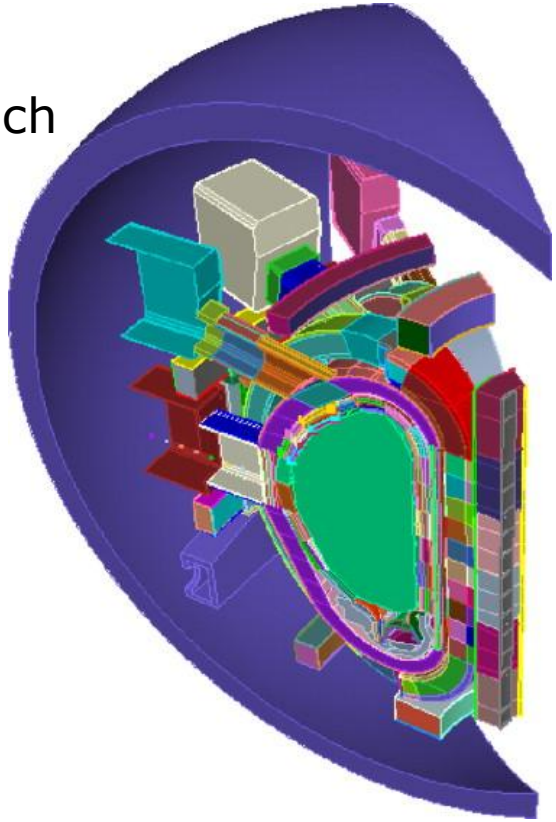
Times Square
NYC
1200m×540m
×860m



CAD based MC

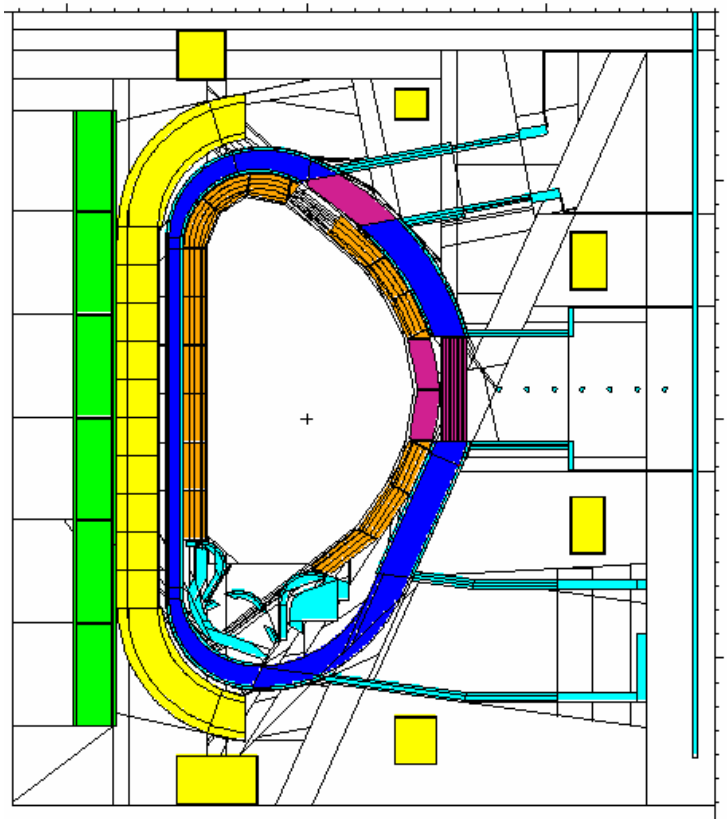
- Needed for complex geometries

Direct approach



UW CAD model
140 MB ACIS file

Translation approach

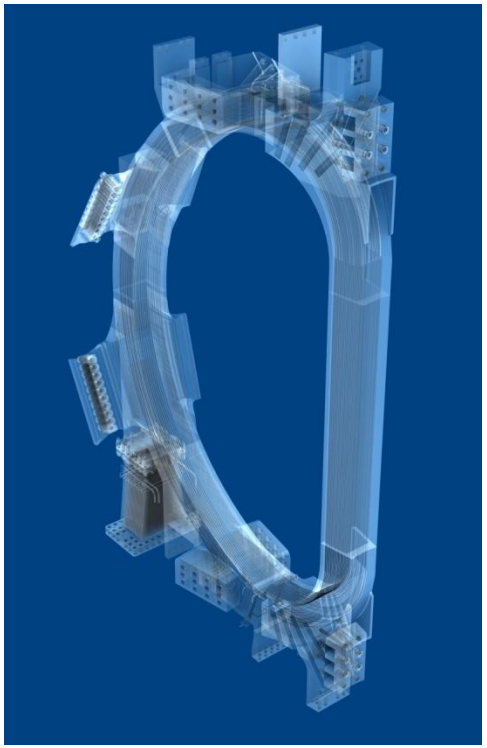


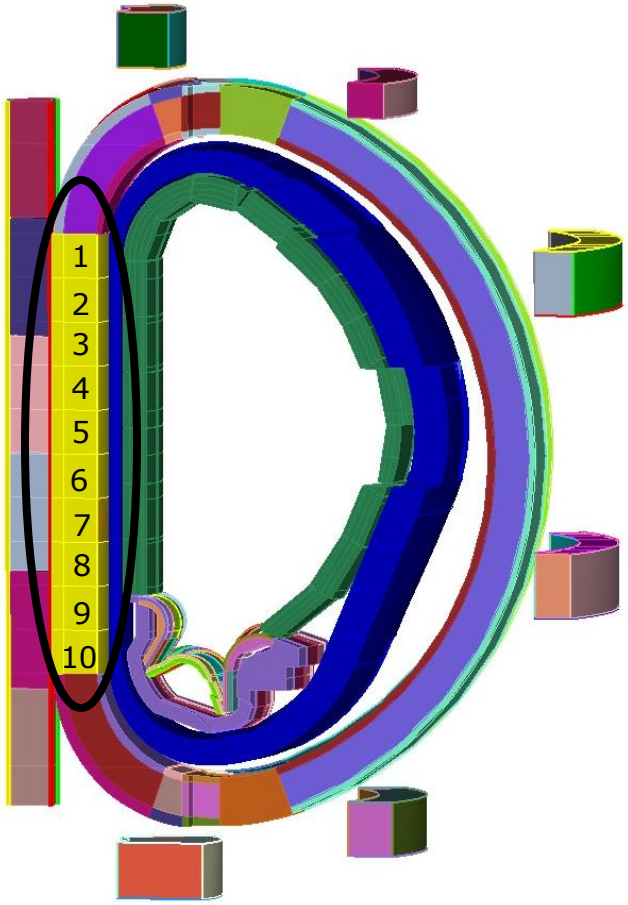
KIT MCNP model
30 000 lines geometry cards

Deterministic calculations only take few hours

	Number of cells (millions)	Forward calculation time (hr)	Adjoint calculation time (hr)
IB TFC	0.4	1.7	2.0
Dose	0.6	-----	1.9
Total flux	1.1	4.8	3.9

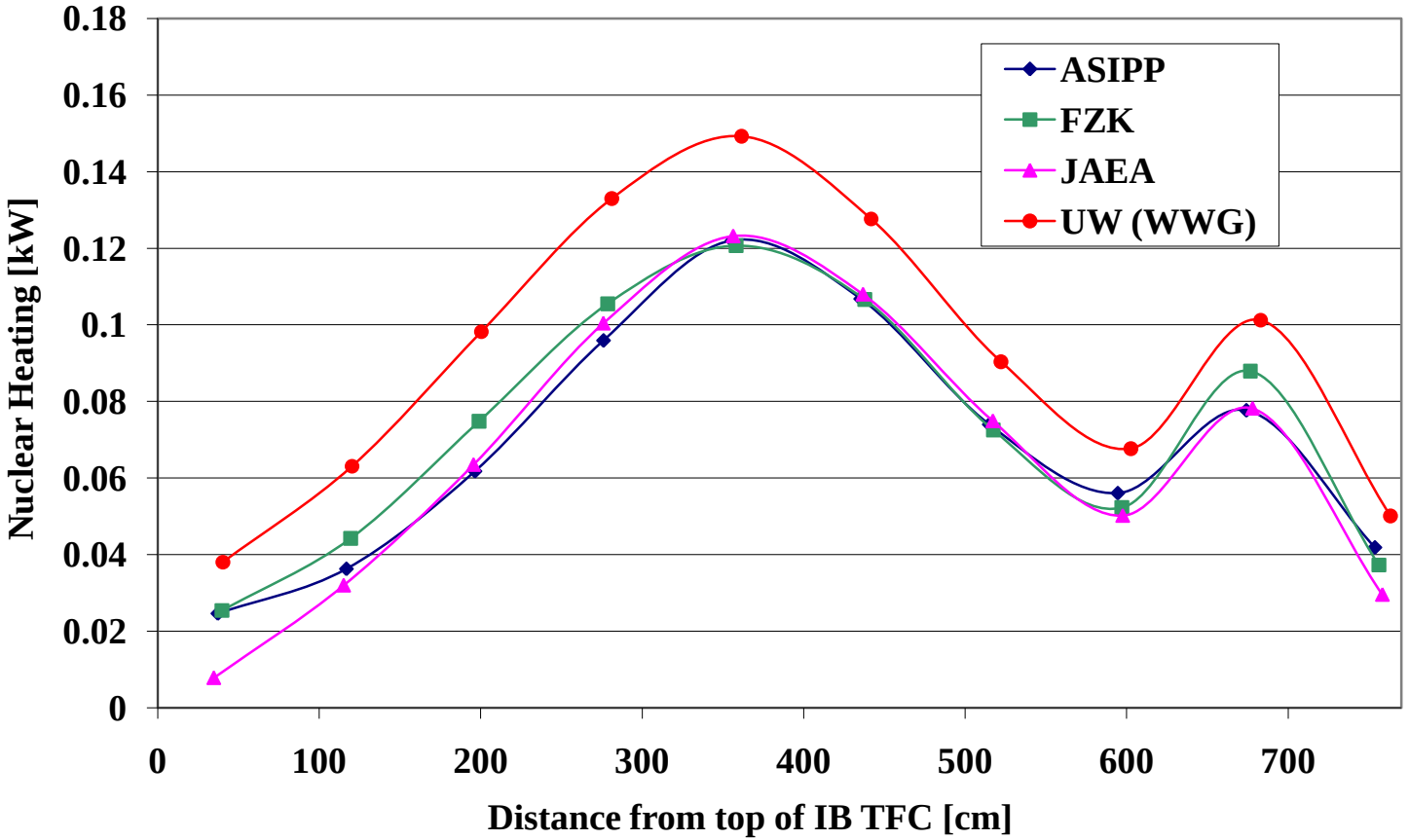
Inboard toroidal field coils (IB TFC)

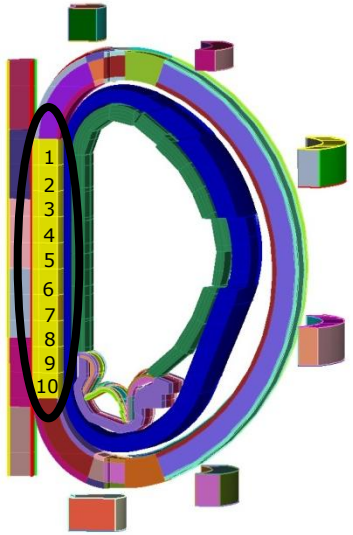




- Super conducting magnet operating at cryogenic temperatures
- Neutrons and photons heating has to be removed
- Shielded by blanket and vacuum vessel (VV)

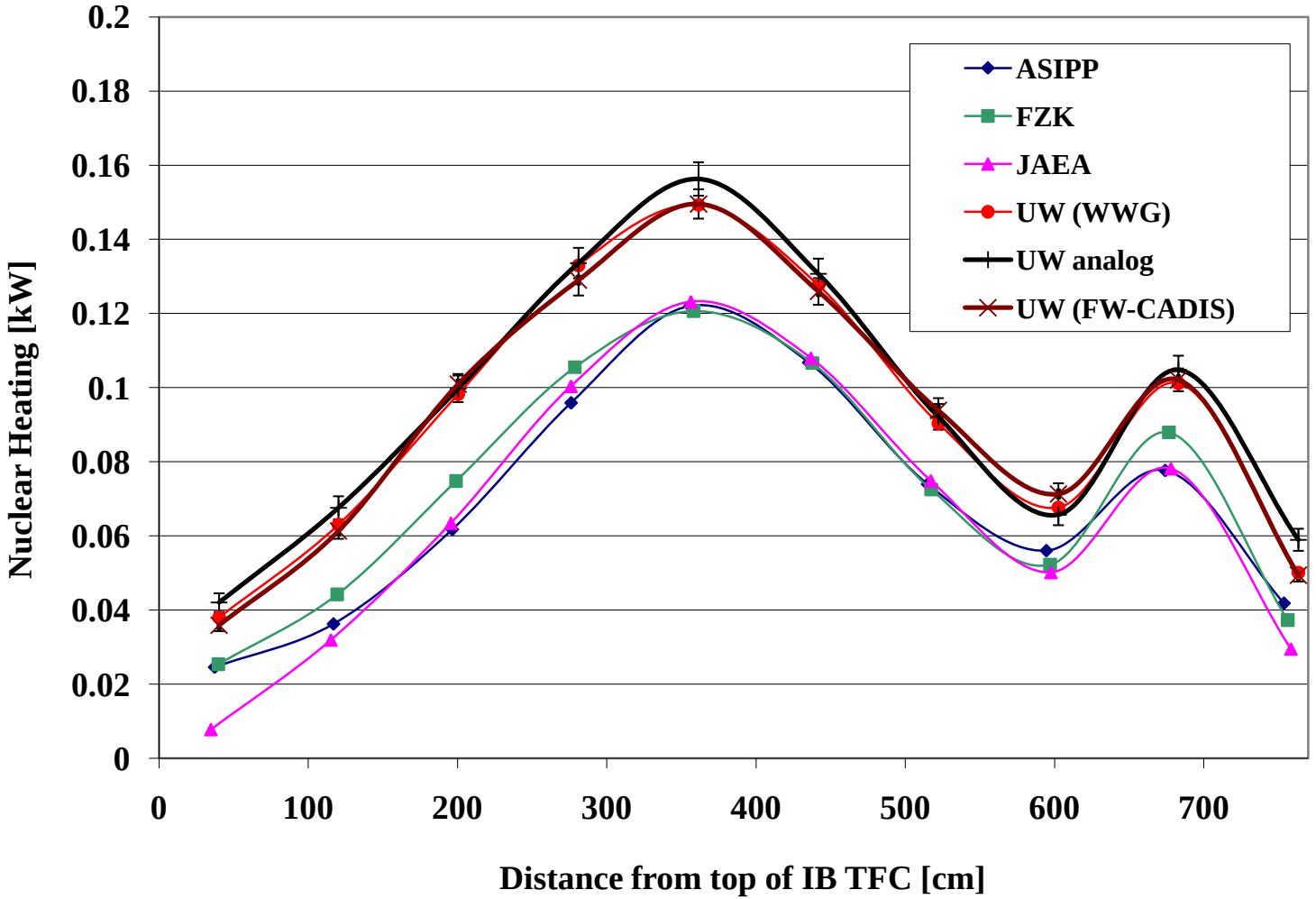
2006 CAD based MC benchmark





- UW results systematically higher
- Is it be because of MCNP WWG????

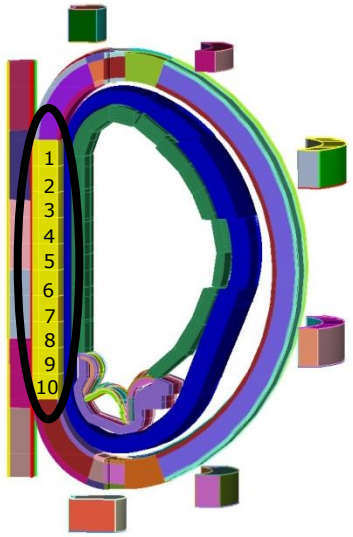
No bias due to variance reduction



MC running efficiency

MC figure of merit (FOM)

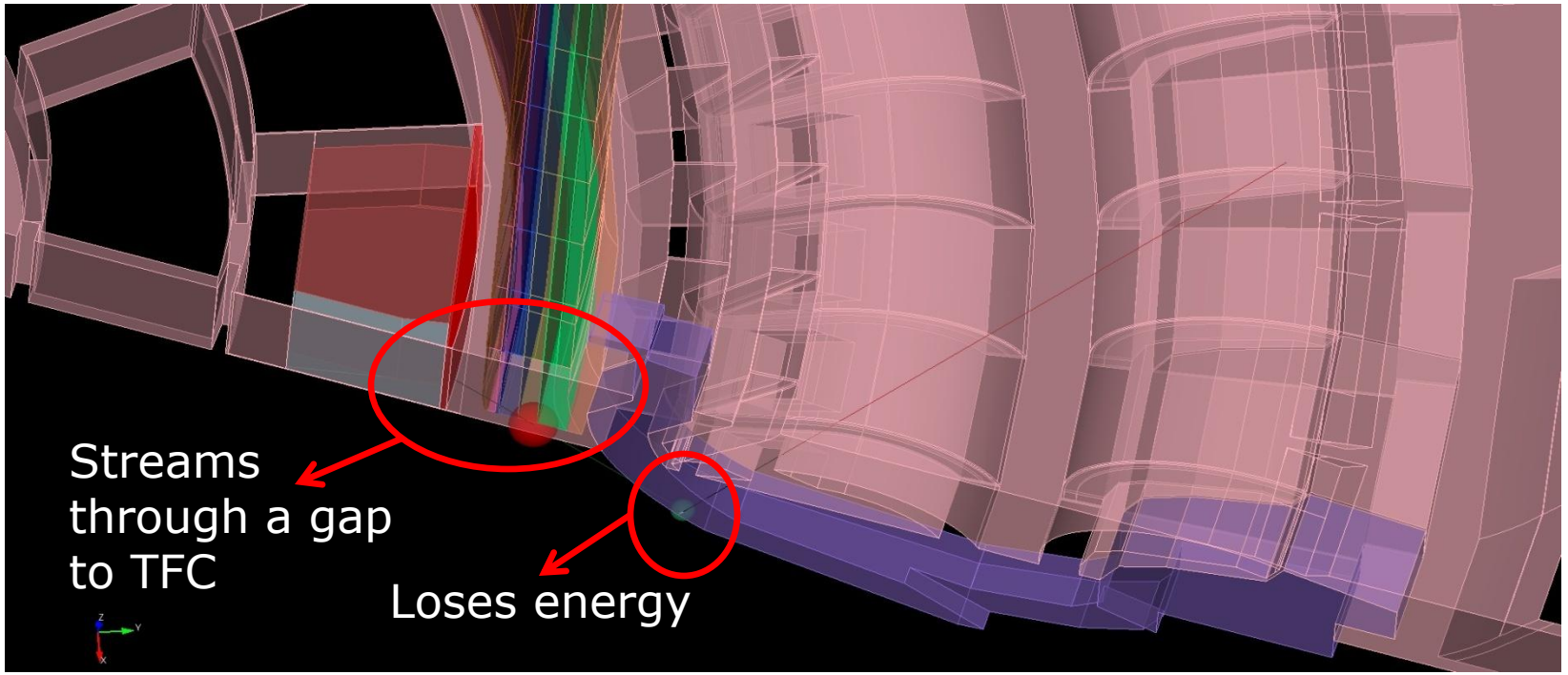
$$FOM = \frac{1}{(Max.\,uncertainty)^2 \times Time}$$



	Time (day)	Max. uncertainty	Normalized FOM
Analog	121	5.9%	1
WWG	11	3.6%	30
FW-CADIS	4	5.0%	42

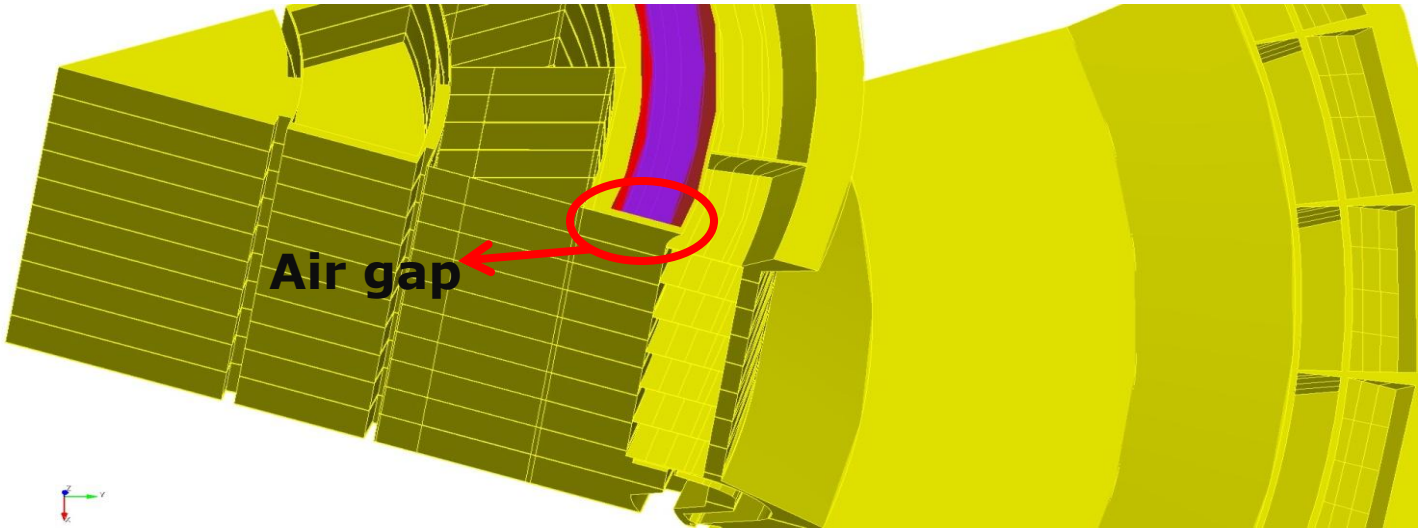
FW-CADIS controlled by occasional histories which took several minutes

What happened to this history?

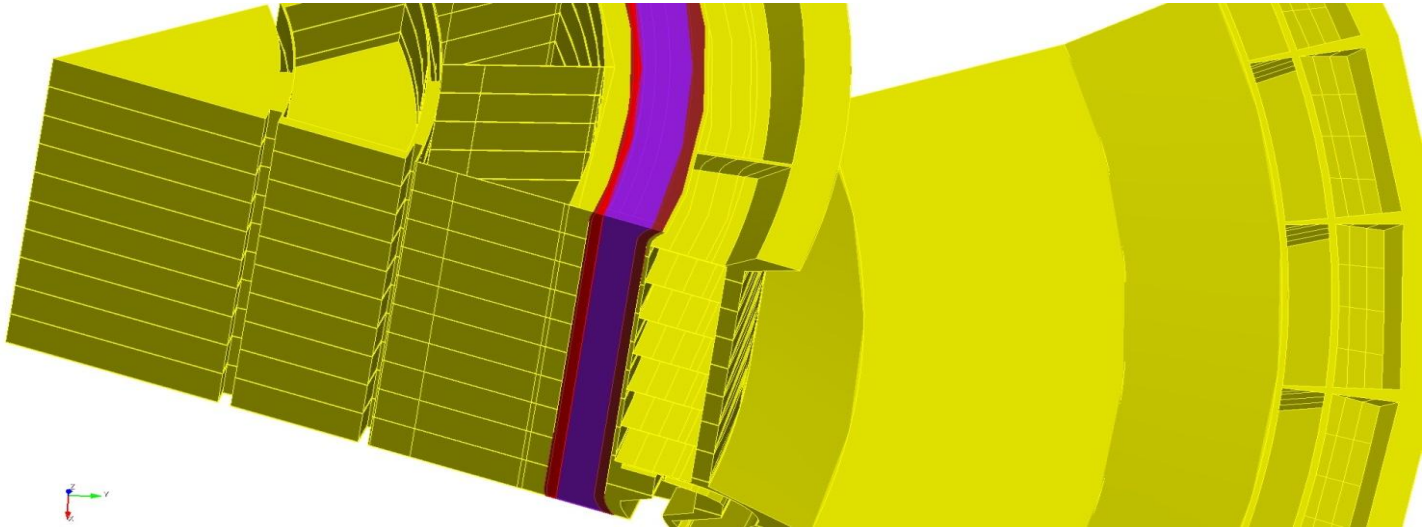


- Lost energy in front of VV
  - Acquired high weight
  - This region should be shielded from TFC by VV
- Streams directly to TFC where weights are very low
- A gap in VV

Fixing UW CAD model

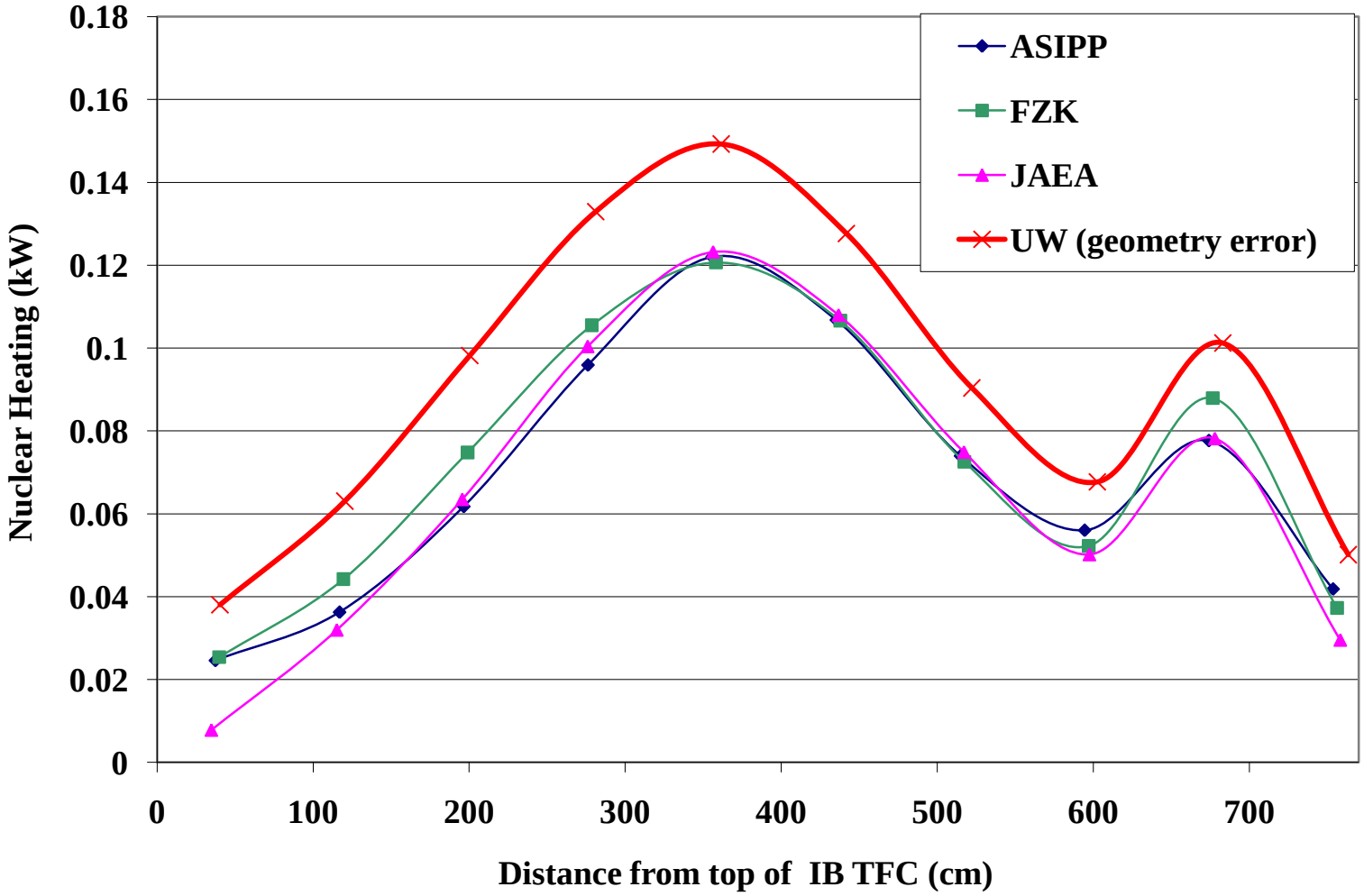


Before

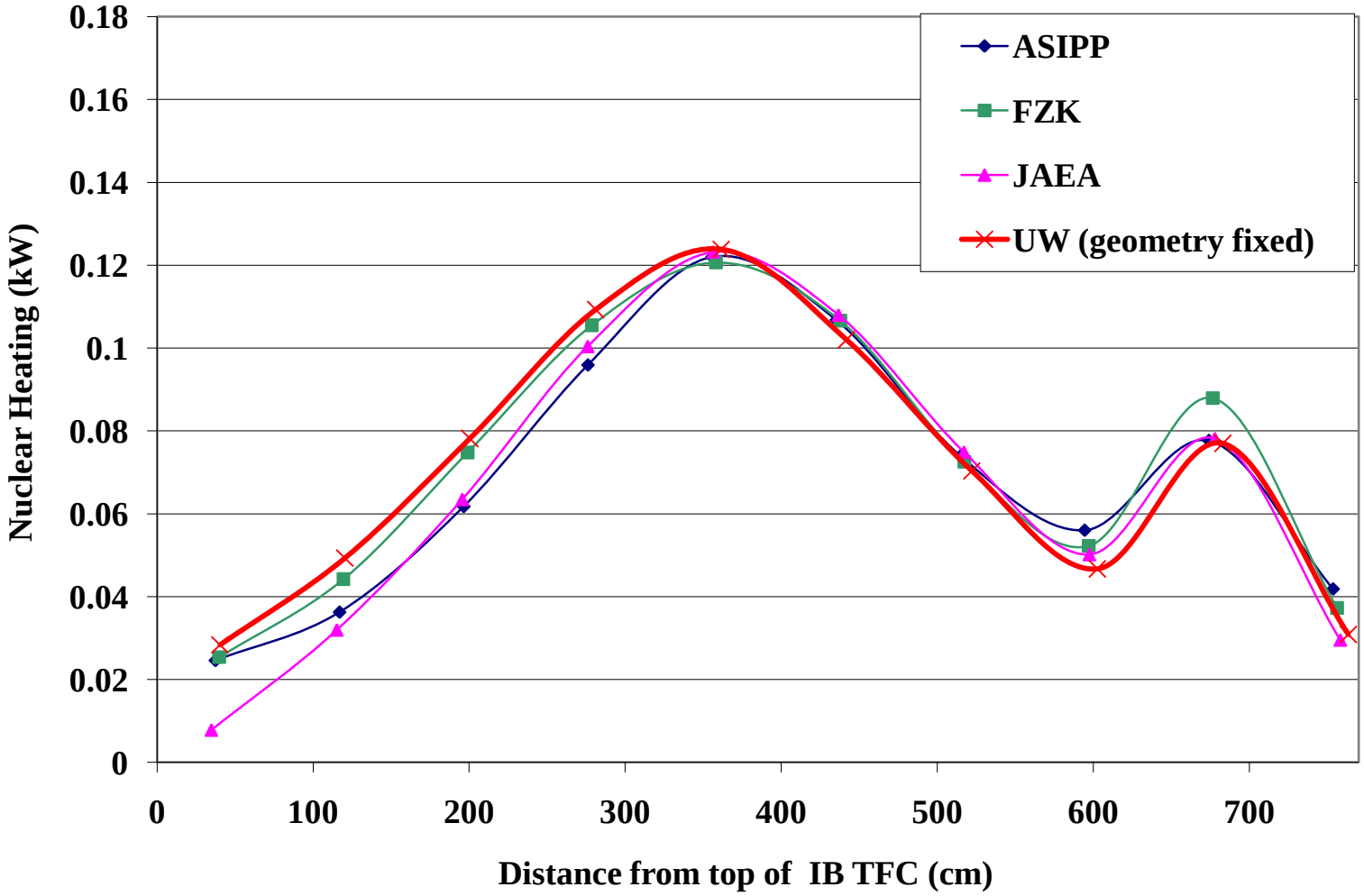


After

IB TFC heating after fixing geometry



IB TFC heating after fixing geometry



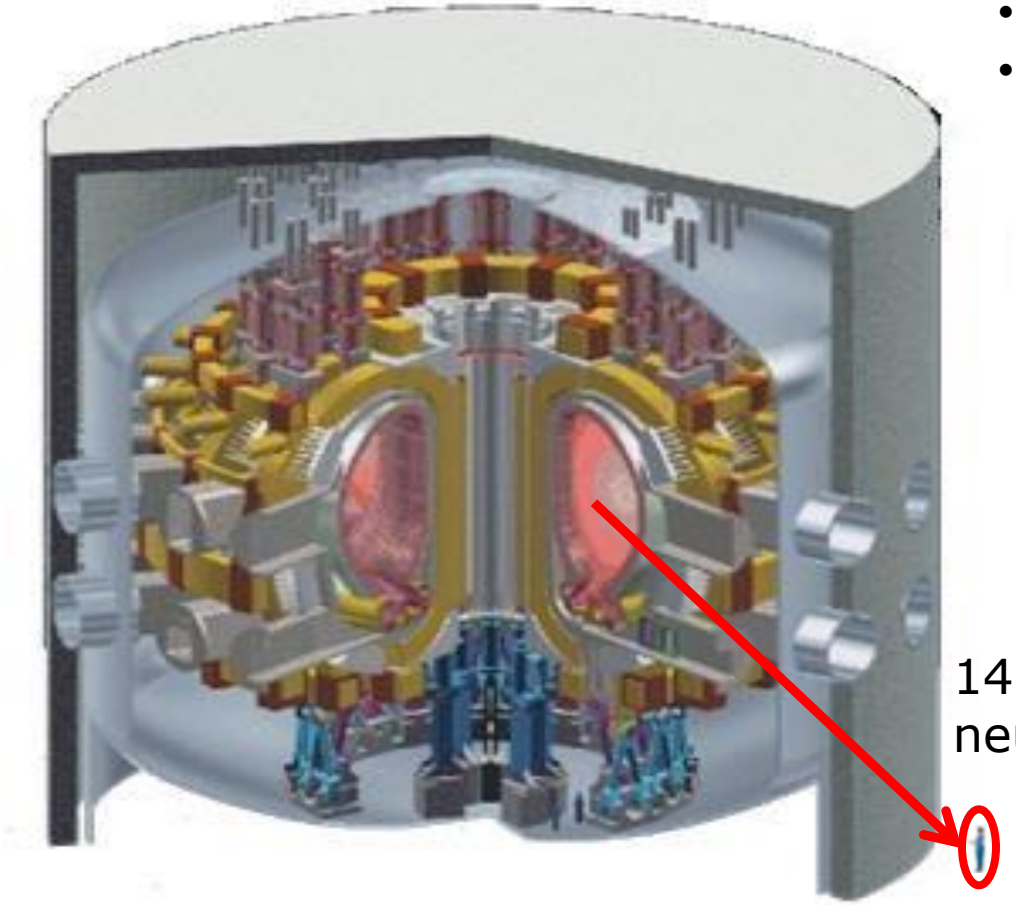
FOM after fixing geometry

	Time (day)	Max. uncertainity	FOM before fixing	FOM after fixing
Analog	121.3	5.9%	1	---
WWG	11.0	3.6%	30	---
FW-CADIS	0.8	4.5%	42	275

Disappearance of long histories increased FW-CADIS FOM

Prompt operational dose outside bioshield

- Source-detector problem
  - CADIS



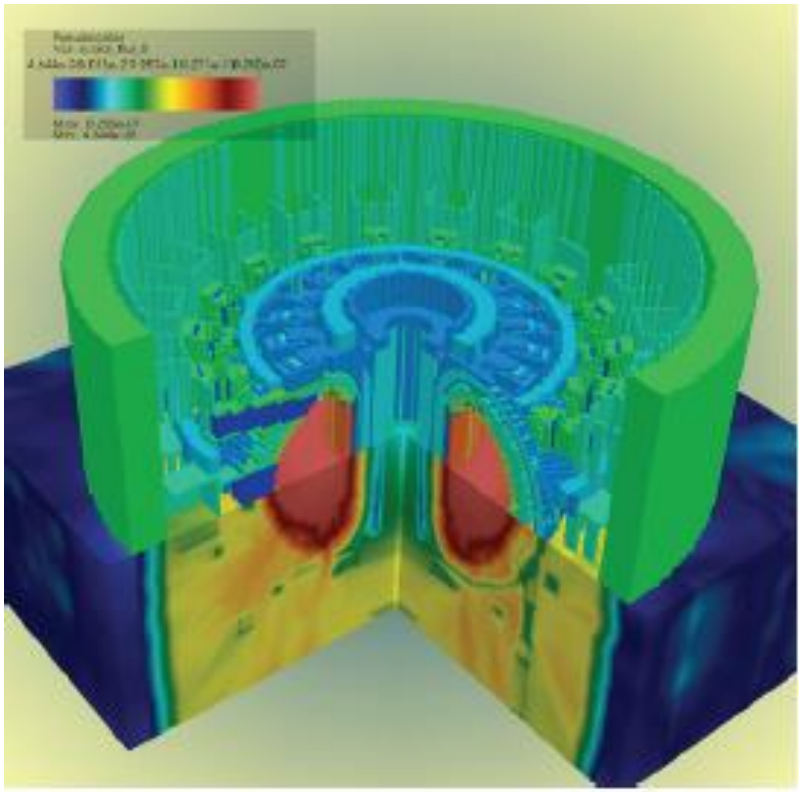
- Very challenging to MC
- Only tackled by combinations of (1-D, 2-D) and 3-D

14 orders of magnitude neutron flux attenuation

Dose calculation

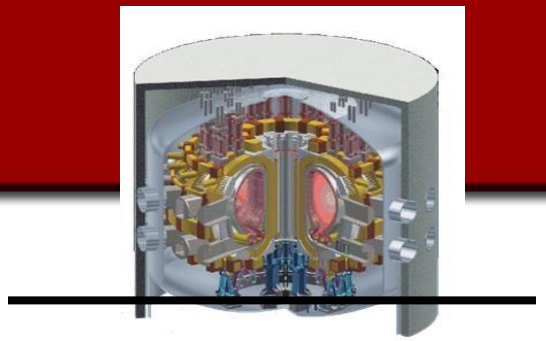
	Dose (mrem/hr)	Relative uncertainty	Time (day)	Normalized FOM
MC (No CADIS)	0.48	76.7%	610.0	1
MC (CADIS)	0.27	3.8%	8.6	10,566
Denovo	0.18	280 million cell 1 hr, 14 400 cores = 610 processors days		

Total neutron flux (Denovo)

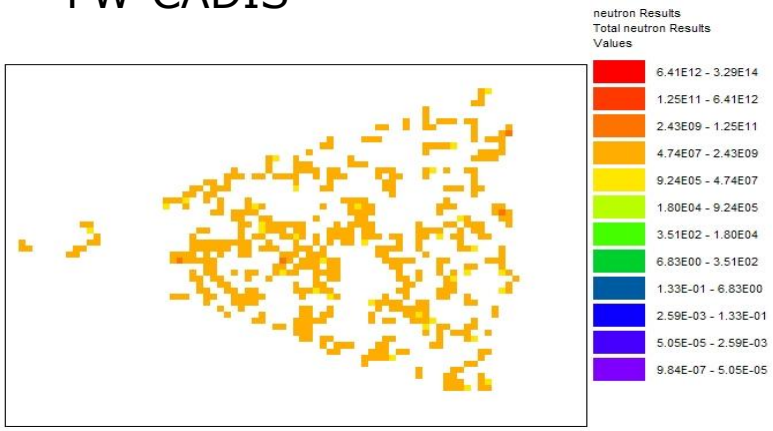


With CADIS even very challenging problems are doable in reasonable time

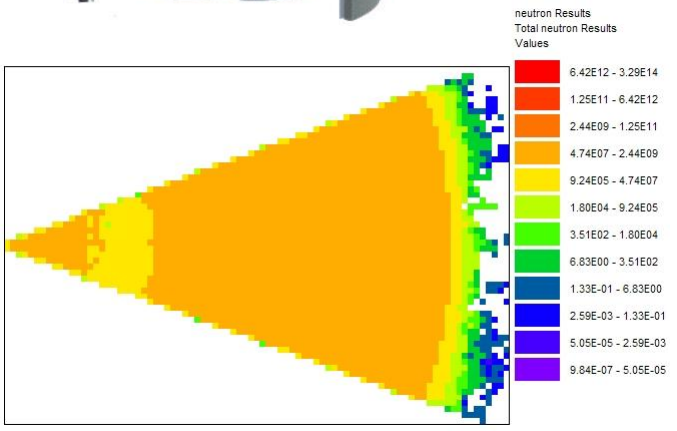
Total flux (4 days)



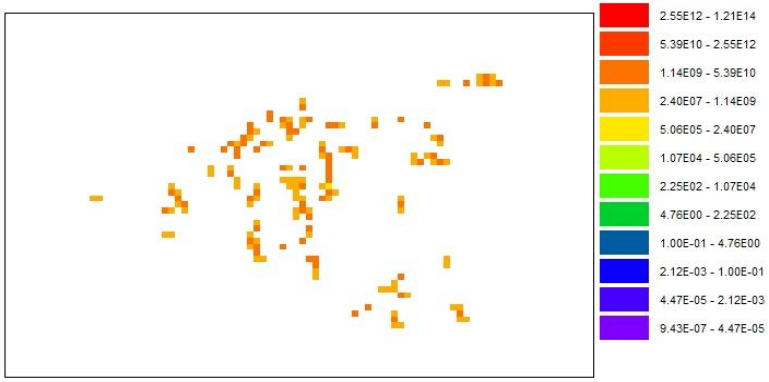
- Global problem
  - FW-CADIS



Neutrons

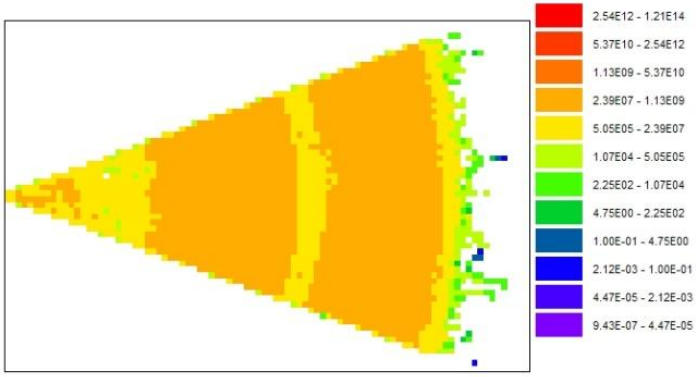


Analog

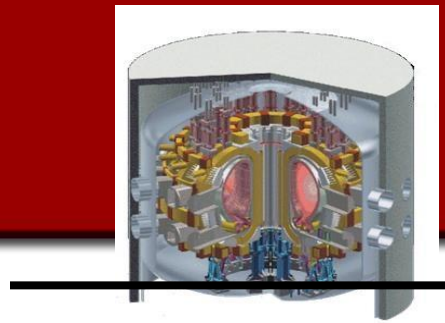


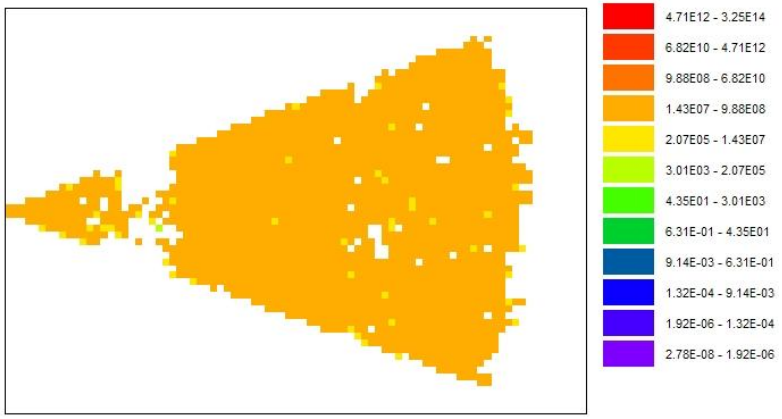
Photons

FW-CADIS

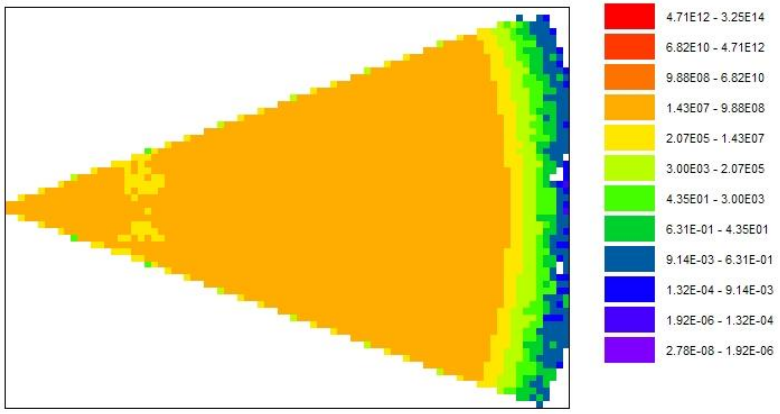


Total flux (50 days)



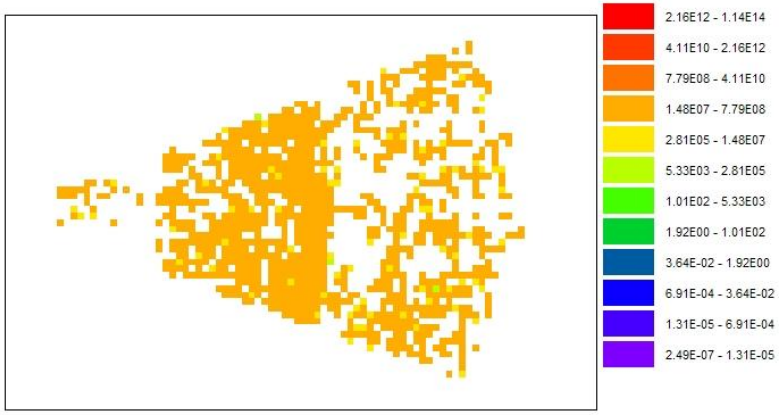


Neutrons

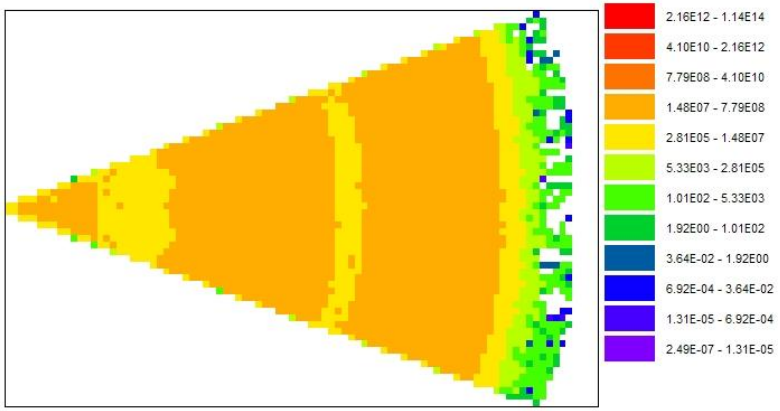


Analog

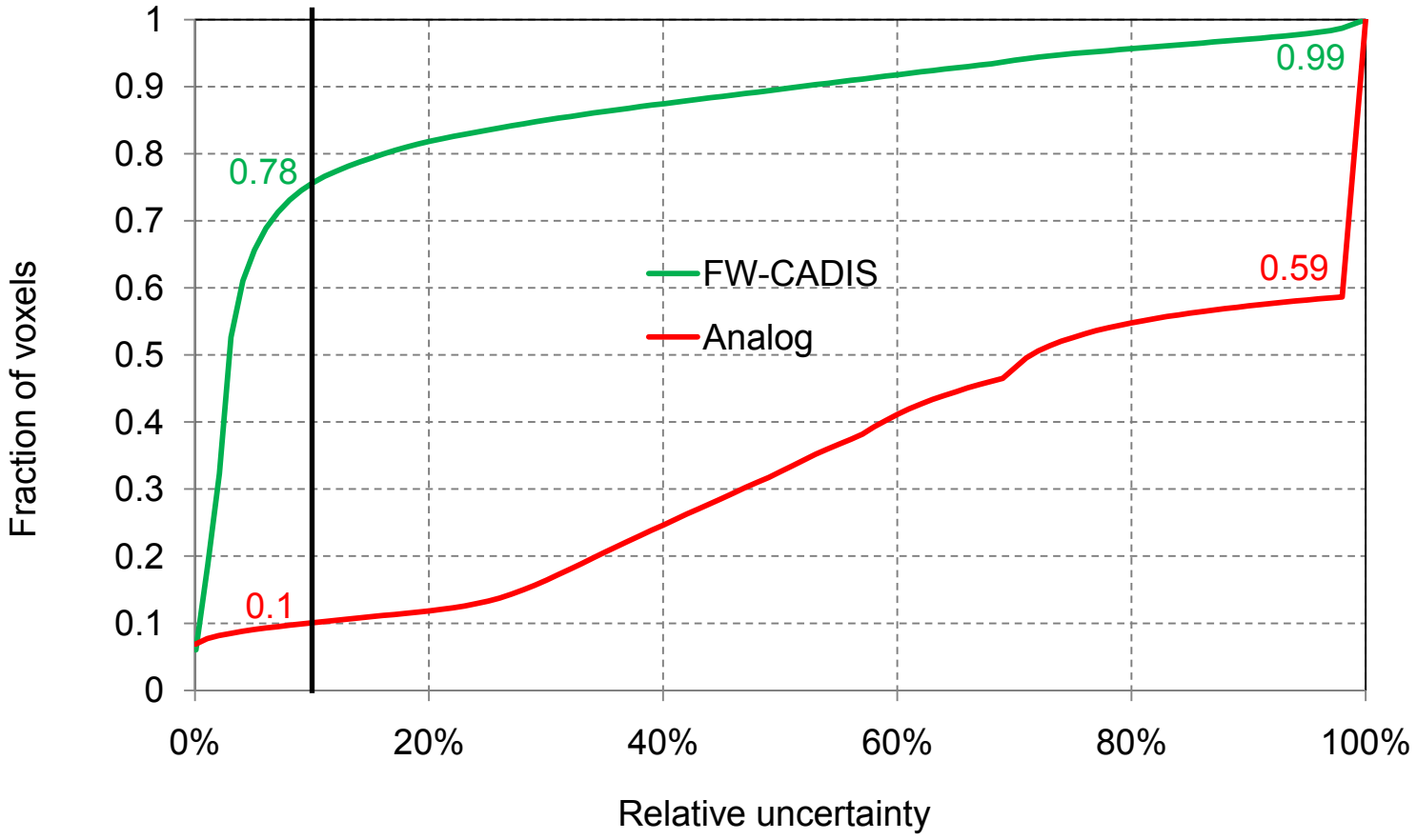
FW-CADIS



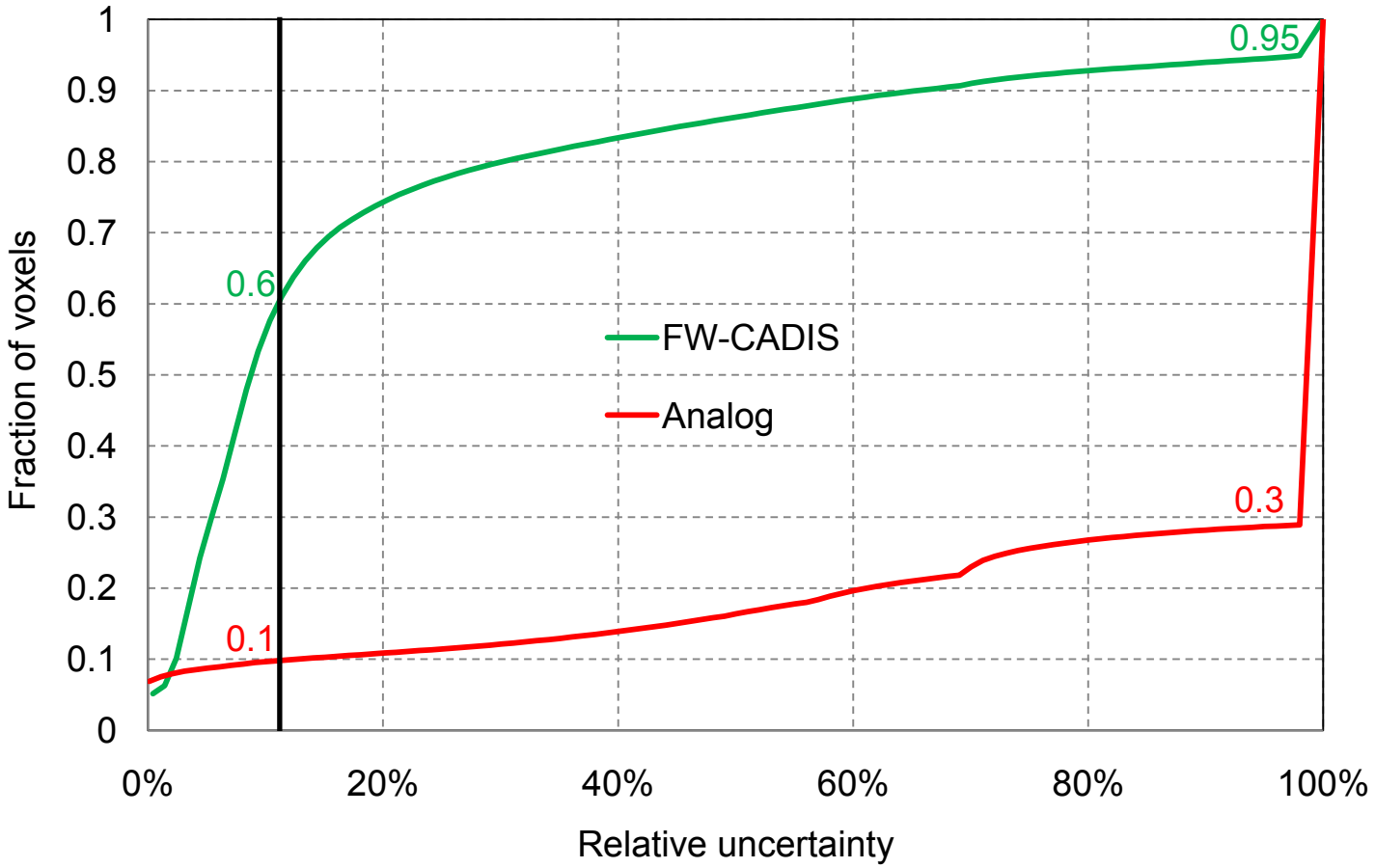
Photons



Total neutron flux cumulative distribution functions (50 days)



Total gamma flux cumulative distribution functions (50 days)



Conclusion

Coupling CAD based MC with hybrid techniques allows fast and accurate 3-D neutronics simulation of challenging and complex systems such as ITER