CAD-Based Shielding Analysis for ITER Port Diagnostics

A. Serikov[1], U. Fischer[1], D. Anthoine[2], L. Bertalot[3], M. De Bock[3], R. O'Connor[3], R. Juarez[4], V. Krasilnikov[3]

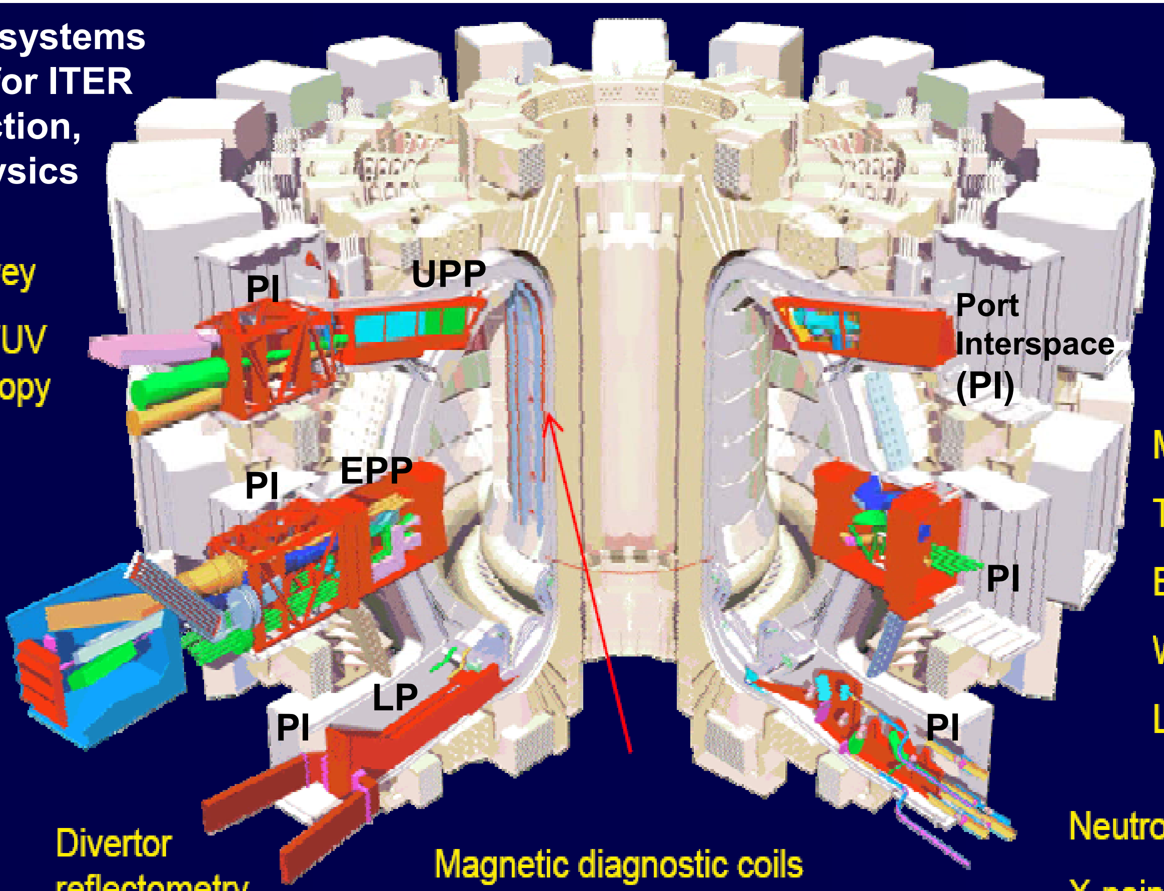
[1]Karlsruhe Institute of Technology (KIT), Institute for Neutron Physics and Reactor Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[2]Bertin Technologies, France
[3]ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France
[4]Departamento de Ingeniería Energética, ETSII-UNED, Calle Juan del Rosal 12, Madrid 28040, Spain

Email corresponding author: arkady.serikov@kit.edu

Content

Objectives – CAD-based MCNP Monte Carlo radiation transport and activation analyses for the Diagnostic Upper and Equatorial Port Plugs (UPP #3 and EPP #8, #17 – results presented)

~45 diagnostic systems to be installed for ITER machine protection, control and physics studies:



X-ray survey

Imaging VUV Spectroscopy

X-ray crystal spectroscopy

Divertor VUV spectroscopy

X-ray survey

Core VUV monitor

Divertor reflectometry

Magnetic diagnostic coils
Micro fission chambers

Edge Thomson scattering

Motional Stark effect

Toroidal interferometer

Electron cyclotron emission

Wide-angle viewing/IR

Lost alpha

Neutron Flux Monitor

X-point LIDAR

CAD-Based Monte Carlo Rad. Transport

3 modeling approaches of CAD-based Monte Carlo transport simulations:

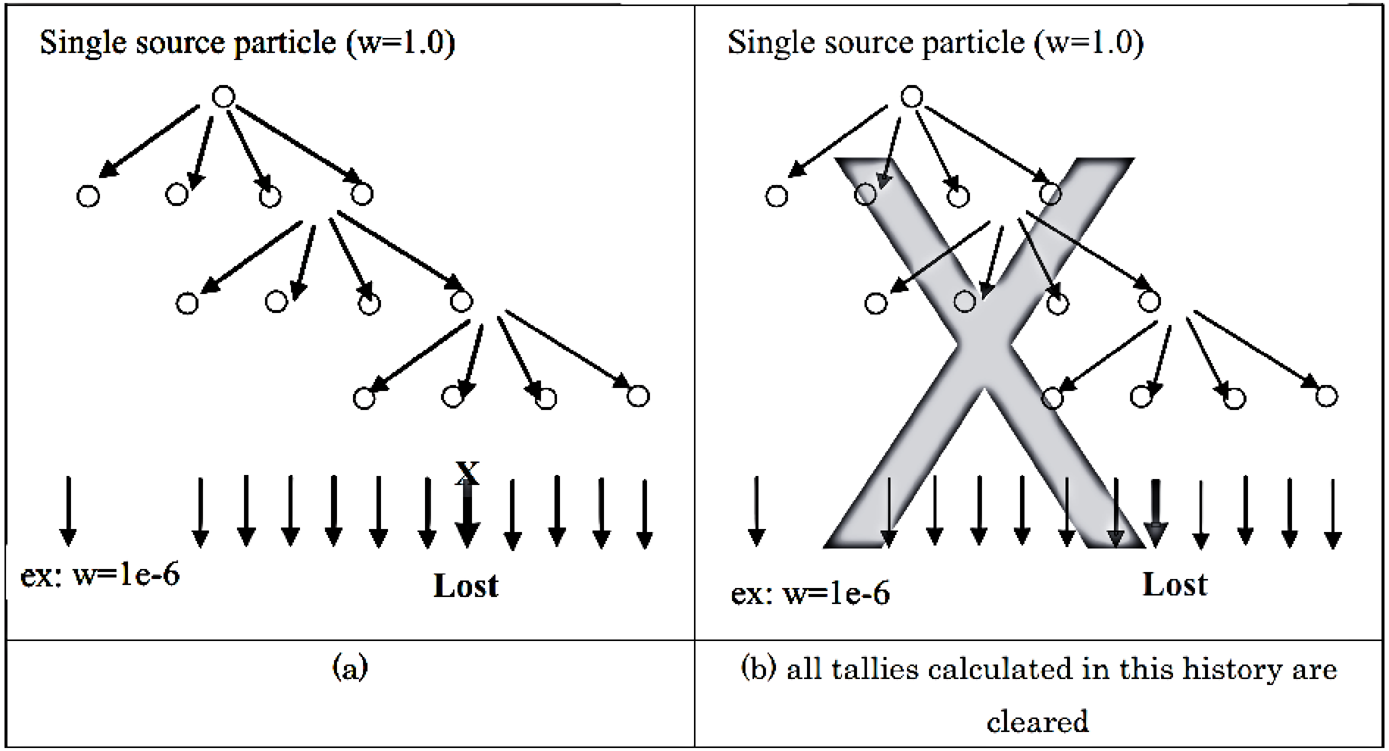
1. **Constructive Solid Geometry (CSG)** – tradiational approach with **CAD to Monte Carlo models conversion codes**:
   - MCAM (FDS team, China)
   - McCAD (KIT fusion neutronics group, Germany)
2. Unstructured Mesh (UM) geometry in MCNP6 (LANL, USA);
3. Direct particle tracking technique with Direct Accelerated Geometry Monte Carlo (DAGMC) library – developed by University of Wisconsin–Madison, USA.

Stages of CAD-to-MC models geometry conversion to CSG model of MCNP:

1) Geometry simplification – remove the unnecessary details
2) Approximation of free-form and spline surfaces to 1st and 2nd order surfaces of MCNP
3) Material definition with homogenization setting up the material mixtures for the simplified cells, such as steel-water shield 60 vol.% steel – 40 vol.% water.

Tallying procedure in MCNP models with lost particles

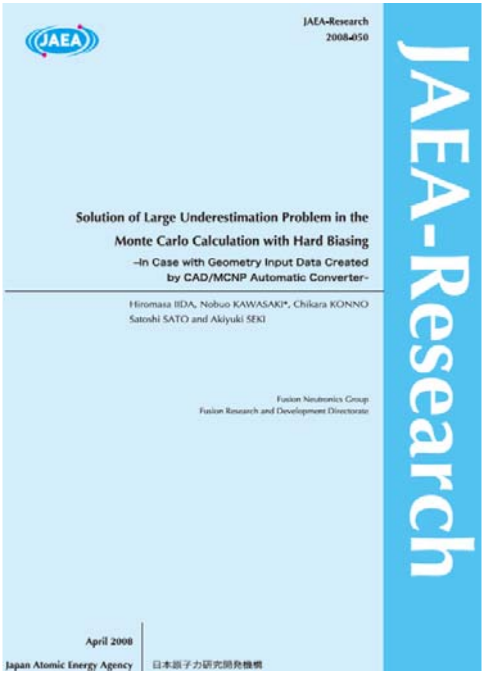
- CAD-to-MC geometry conversion of tokamaks (ITER, DEMO) with all their complex engineering and diagnostic systems is performed with some level of approximation. Approximations could couse geometry errors and as the consequence – lost paricles.
- **Big problem with lost particles:** If one of particles in a history is lost, MCNP cancels all tallies calculated during the history and all banked particles are erased.



(a)

(b) all tallies calculated in this history are cleared

Schematic explanation of MCNP lost particles handling procedure, from Ref. (*) JAEA report


JAEA-Research
2008-050

Solution of Large Underestimation Problem in the
Monte Carlo Calculation with Hard Biasing
-In Case with Geometry Input Data Created
by CAD/MCNP Automatic Converter-

Hiromasa IIDA, Nobuo KAWASAKI*, Chikara KONNO
Satoshi SATO and Akiyuki SEKI

Fusion Neutronics Group
Fusion Research and Development Directorate

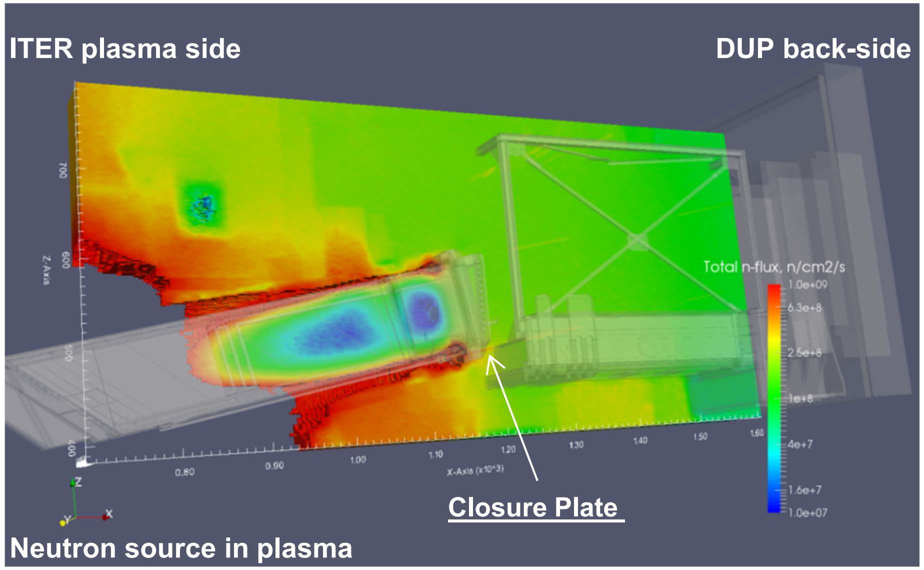
April 2008
Japan Atomic Energy Agency 日本原子力研究開発機構

JAEA-Research

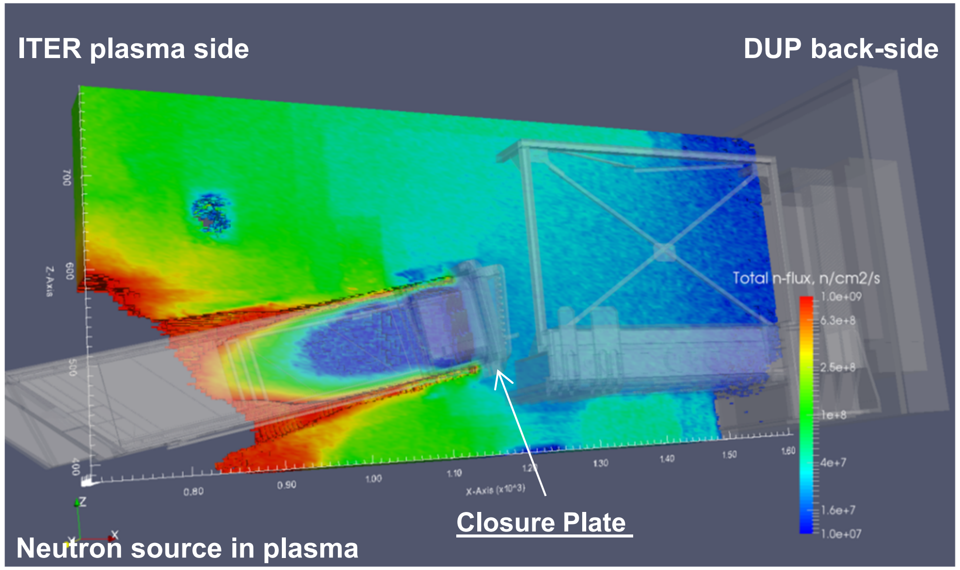
Ref. (*)

Example of lost paricles in ITER Upper Port with strong particle splitting

V1: Diagnostic Upper Port (DUP)



V2: Diagnostic Upper Port (DUP) with lost particles at the back-side



Neutron fluxes in DUP Closure Plate of 2 MCNP models
(the same neutron source, the same DUP model, just 10e-3 lost paricle rate at the DUP back-side)

Energy	V1: Diagnostic Upper Port (DUP), n/cm2/s	V2: Diagnostic Upper Port with lost particles at the back-side, n/cm2/s
0<E<0.1 MeV	1.76E+08	1.37E+06
0.1<E<1 MeV	1.04E+08	1.45E+05
1<E<20 MeV	8.06E+06	1.29E+03
Total	2.88E+08	1.52E+06

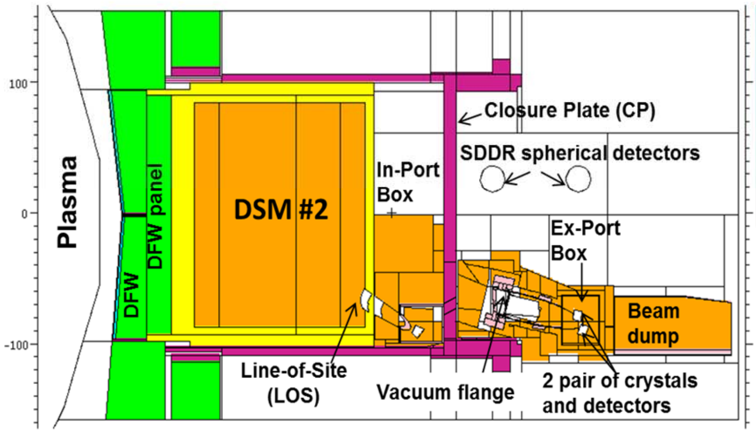
Conclusion: we must keep lost paricle rate at very low level of 10e-7 - 10e-9

Shielding Analysis for ITER Port Diagnostics

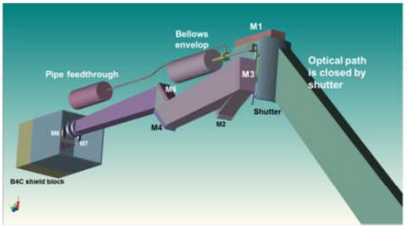
Example 1:

Tritium and Deposit Monitor (**T-monitor**) & Core-Imaging X-ray Spectrometer (**CIXS**) neutronics analysis with Local MCNP model of ITER **Equatorial Port Plug (EPP) #17**

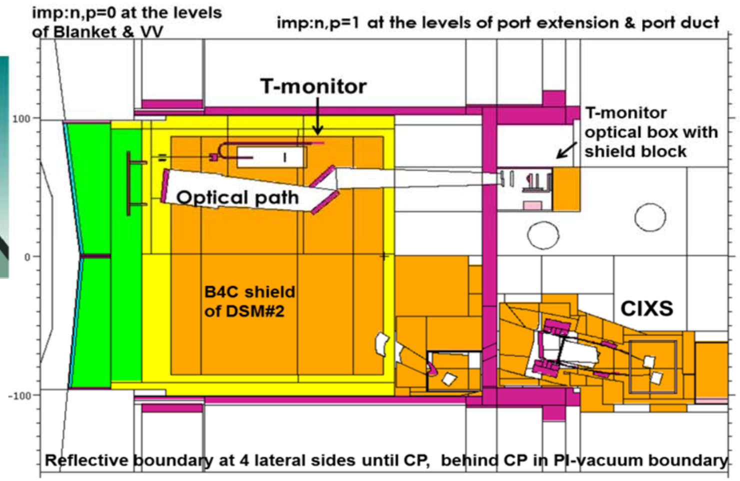
MCNP Local modeling approach for ITER neutronics



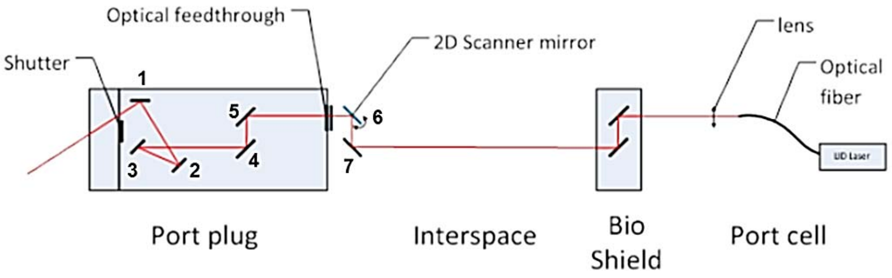
Initial MCNP local model of the **CIXS** Diagnostics apertures only



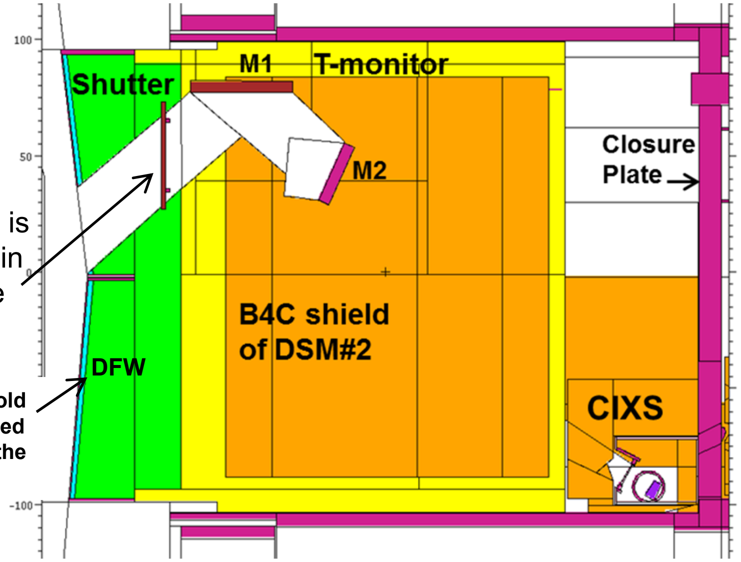
Converted CAD-to-MCNP T-monitor model is inserted in EPP17 Local MCNP model



Resulting MCNP local model with Diagnostics apertures of two systems: **Tritium (T) monitor & CIXS**



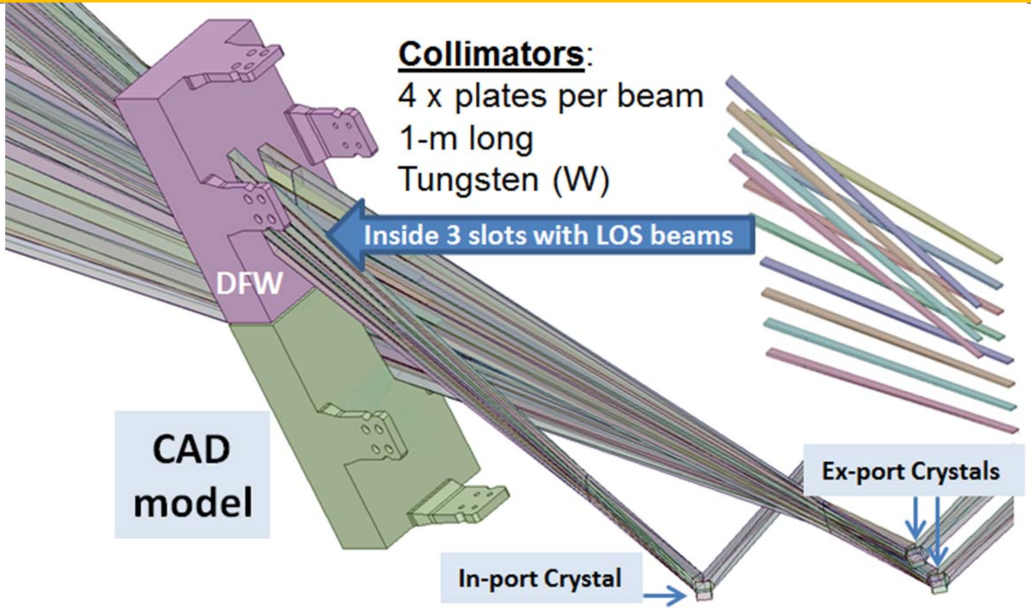
7 mirrors M1-M7 have been modelled - along the optical pathway, started from the front mirror M1, ended by M7 inside the optical box attached to the Closure Plate



Optical path is closed by thin shutter plate

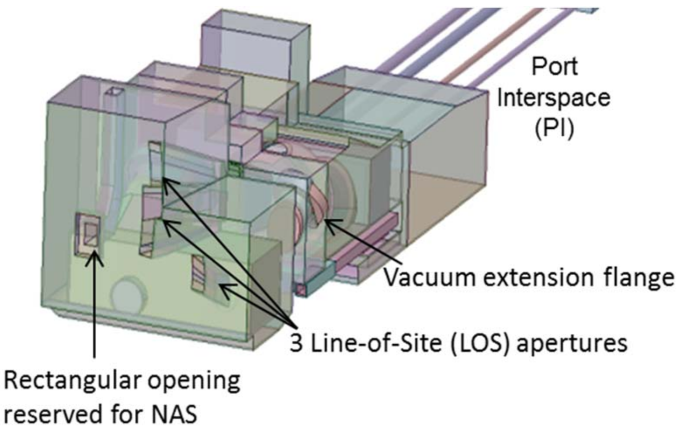
DFW "V" shape is the old version but we supposed this has no impact on the presented results

Total neutron flux for EPP17 with CIXS only

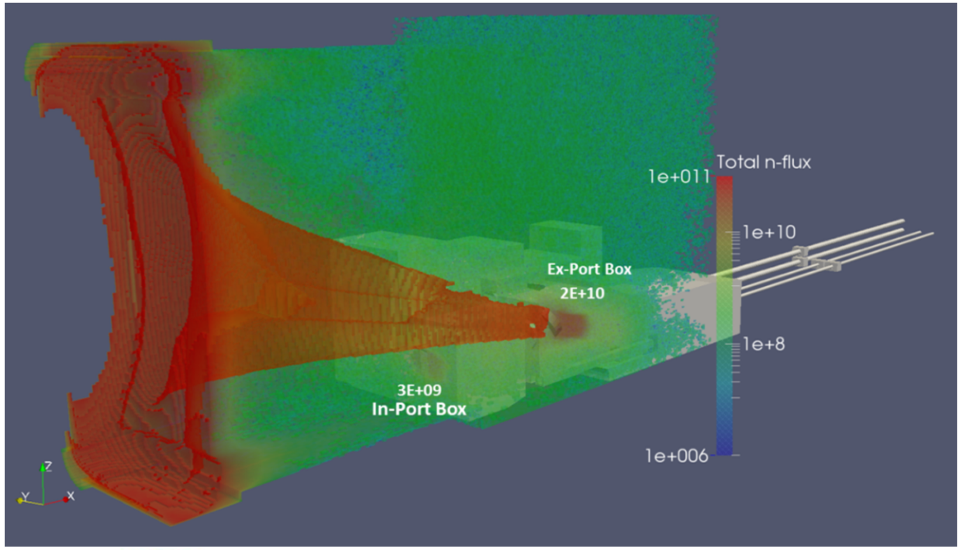


Collimators:
4 x plates per beam
1-m long
Tungsten (W)

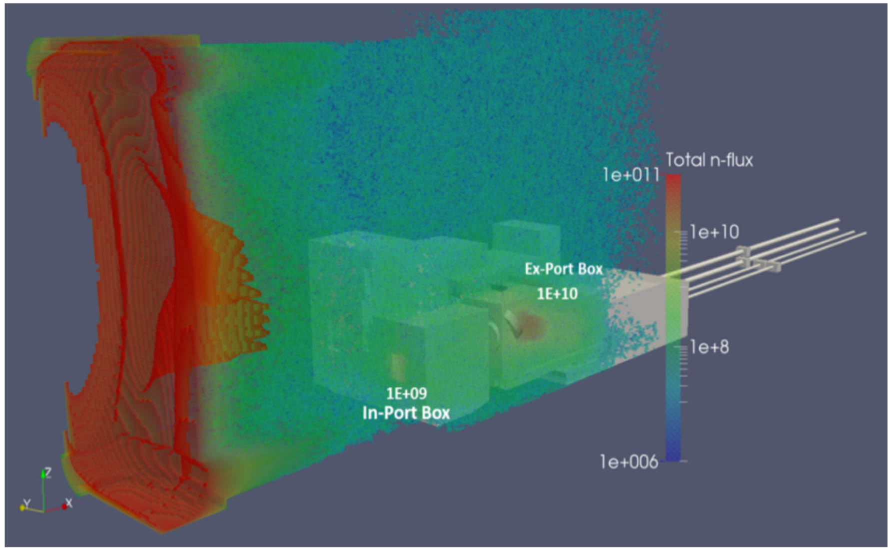
CAD model of the original CIXS shielding



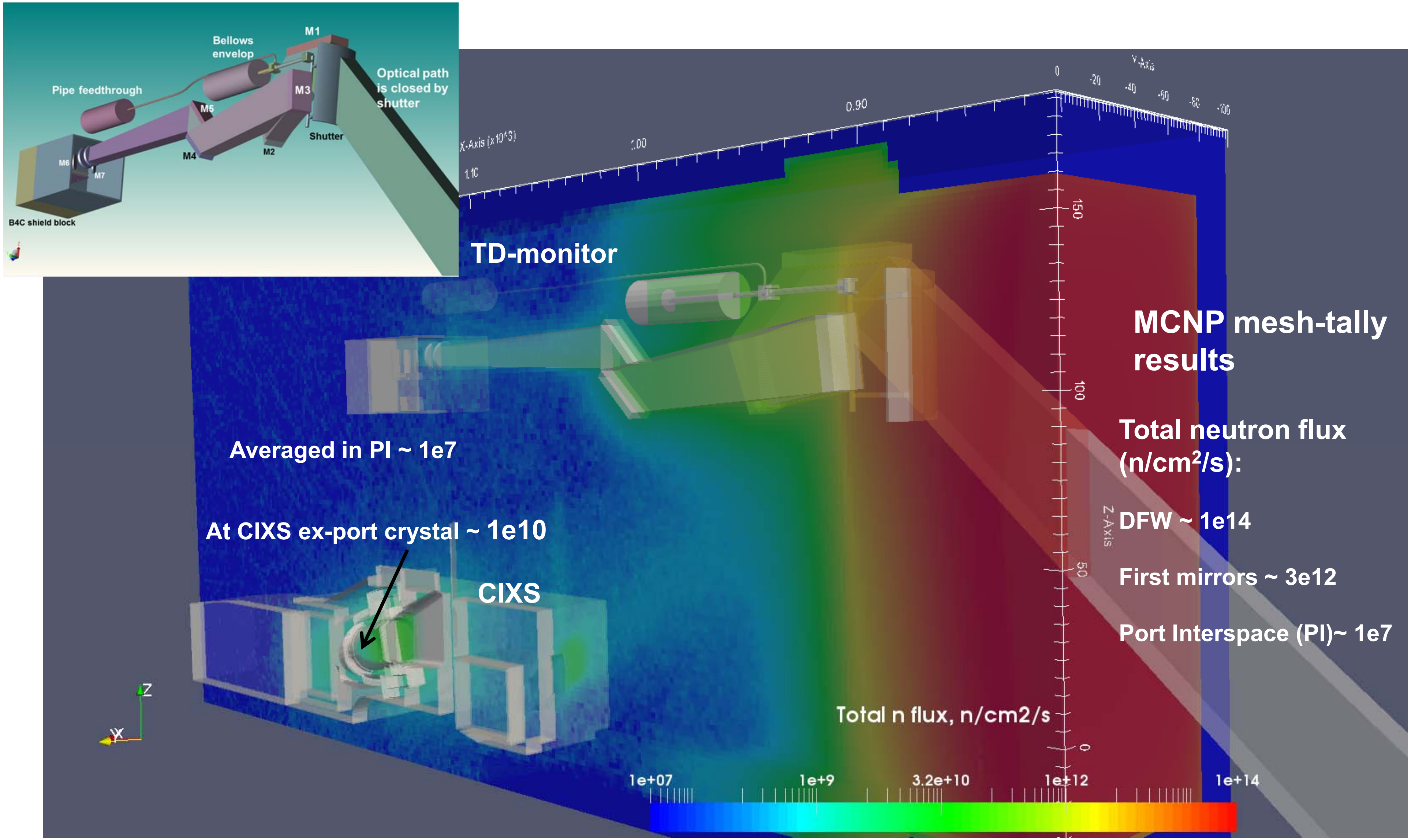
Map of total n-flux for the CIXS model having no-collimated LOS beams



Map of total n-flux for the CIXS model with collimated LOS beams



Total neutron flux for EPP17 with CIXS and TD-monitor



TD-monitor

Averaged in PI ~ 1e7

At CIXS ex-port crystal ~ 1e10

CIXS

MCNP mesh-tally results

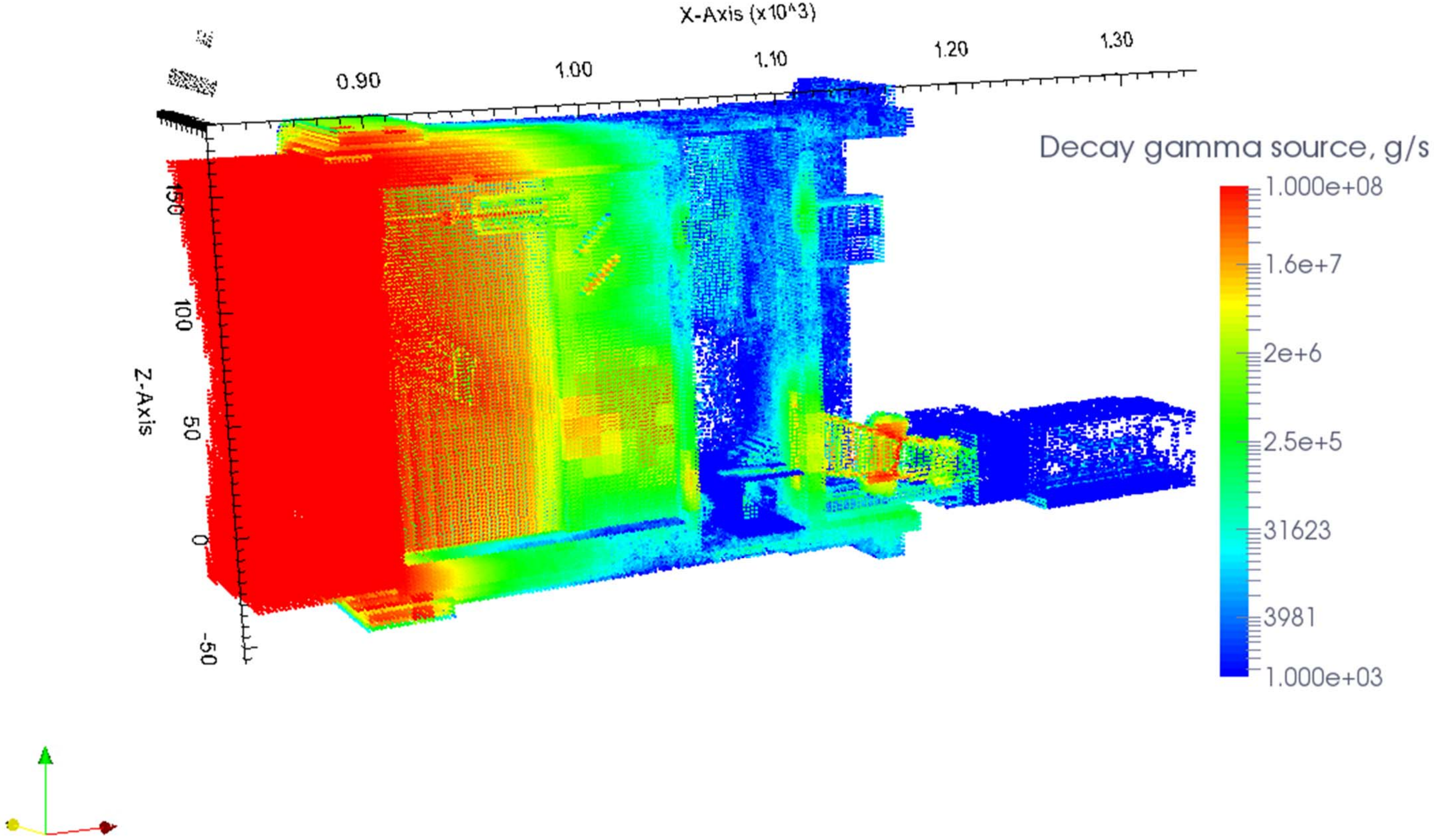
Total neutron flux ($n/cm^2/s$):

DFW ~ 1e14

First mirrors ~ 3e12

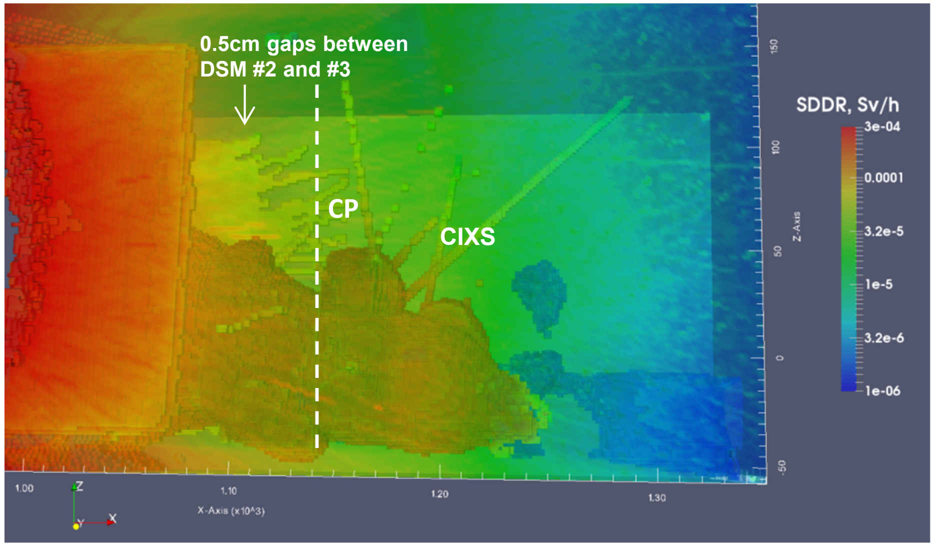
Port Interspace (PI)~ 1e7

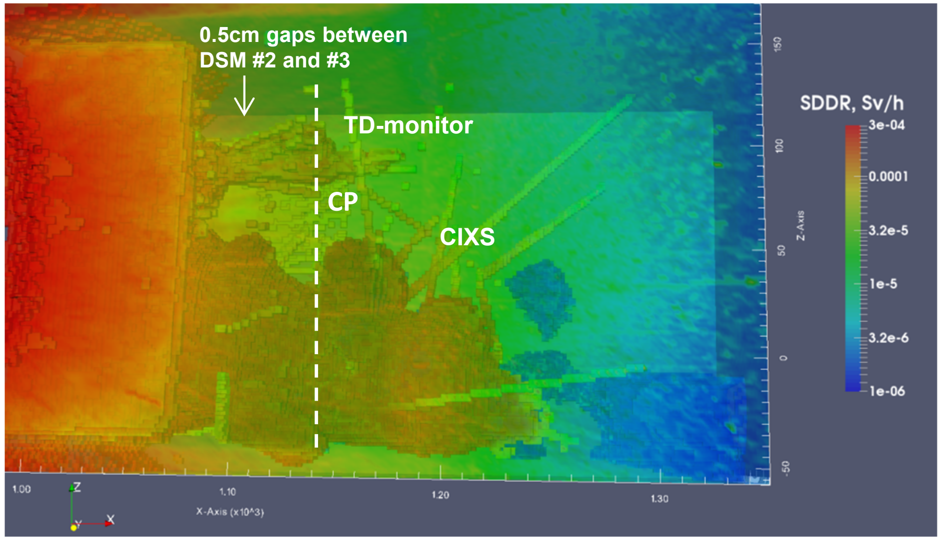
Distribution of decay gamma sources for SDDR



Comparison of the SDDR distributions in MCNP fine mesh

SDDR in CIXS-only model vs. **SDDR in TD-monitor & CIXS model**





Decay gamma streaming pathways:

1) 0.5 cm gaps between DSM #2 and #3
2) CIXS

Decay gamma streaming pathways:

1) 0.5 cm gaps between DSM #2 and #3
2) CIXS
3) TD-monitor

SDDR horizontal distributions and effect of TD-monitor on SDDR

Horizontal SDDR (microSv/h) distributions in spherical detectors of TD-monitor & CIXS model

Layer #	Detectors location in horizontal distribution	Left			Right
L1	Below the TD-monitor, at 30cm from CP	134	210	209	120
L2	Behind the TD-monitor, at 66cm from CP	27	59	78	69
L3	Far from TD-monitor, 100cm from CP	12	56	72	58

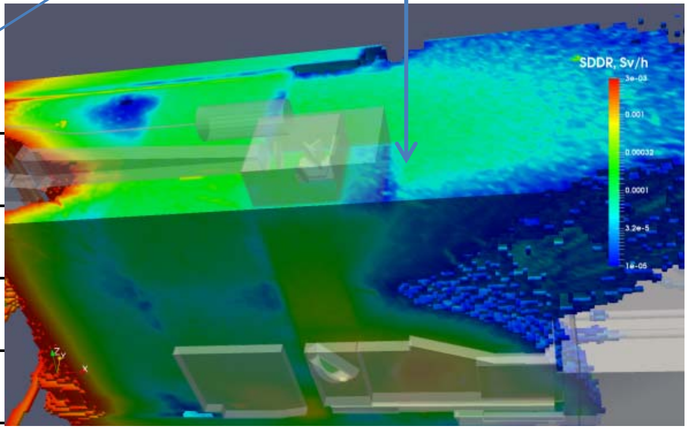
Horizontal SDDR (microSv/h) distributions in detectors of CIXS-only model

Layer #	Detectors location in horizontal distribution	Left			Right
L1	Below the TD-monitor, at 30cm from CP	121	193	194	117
L2	Behind the TD-monitor, at 66 cm from CP	32	66	74	63
L3	Far from TD-monitor, 100cm from CP	11	56	67	55

Gamma shadow effect for 2 detectors at L2 due to the shield of TD-mon box

Effect of TD-monitor on SDDR in spherical detectors. Difference of SDDR (microSv/h) in two models: (TD-mon & CIXS model) – CIXS-only model

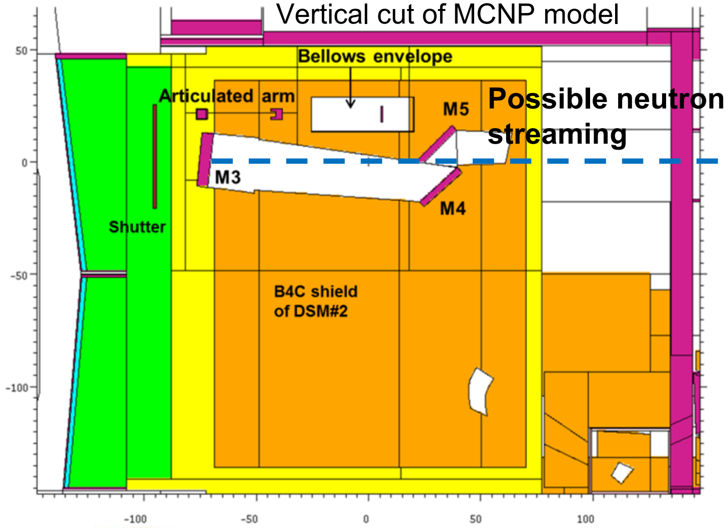
Layer #	Detectors location in horizontal distribution	Left			Right
L1	Below the TD-monitor, at 30cm from CP	13	17	15	3
L2	Behind the TD-monitor, at 66cm from CP	-5	-7	4	6
L3	Far from TD-monitor, 100cm from CP	1	0	5	3

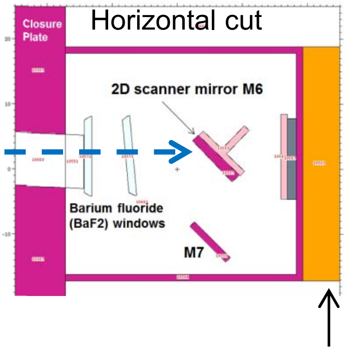


Summary and Recommendations

- Neutronics analysis was performed in the MCNP Local model of **EPP17** included only the apertures of two Diagnostics: TD-monitor and CIXS.
- The results include neutron and gamma fluxes and nuclear heating on **7 mirrors** of the TD-monitor, neutron fluxes and SDDR estimated in spherical detectors and with 3D distributions in EPP17:

  - Nuclear heating on mirrors is up to **0.77 W/cm^3** (cooling might be required).
  - SDDR in spherical detectors at the bottom of TD-monitor shield box (at 30 cm from Closure Plate) reaches **210 microSv/h**, with a contribution of **17 microSv/h from TD-monitor.**
  - Shield block behind the TD-monitor contribute to a decrease on **7 microSv/h** – gamma shadow effect.
  - These are relative SDDR values of Local MCNP model. Final values request inclusion of all the tenants of EPP17 (TD-monitor, CIXS, Vis/IR system, and Divertor Thermography) – future task of EPP17 port plug integration, with inclusion of all the sorts of the gaps, radiation cross-talks between the ports, and environmental effects in global MCNP C-lite model.





Recommendations for TD-monitor design improvement:

- Increase vertical shift (M4-M5) of the dog leg inside the port plug - to prevent possible direct neutron streaming.

- Shield block behind the TD-monitor optical box appears as a “neutronic relevant option”.

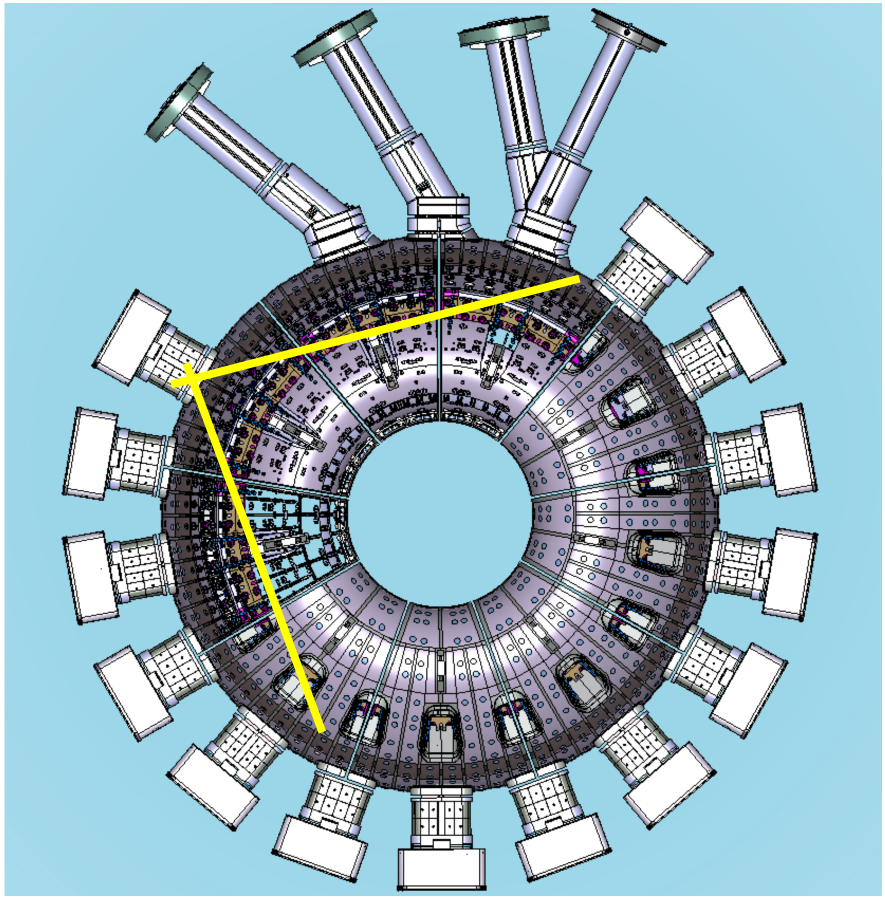
In-port radiation cross-talks

Example 2:

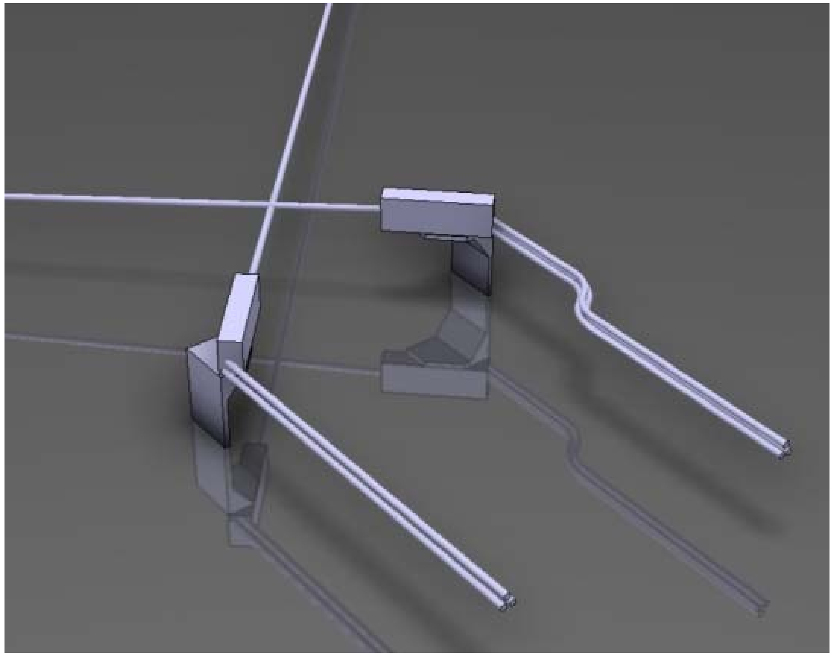
Tangential Neutron Spectrometer (TNS) inside the **EPP #8** with 7 Diagnostics in C-lite v.2

Tangential Neutron Spectrometer (TNS) integrated inside the Diagnostic Equatorial Port Plug (EPP) #8

Diamond detectors and fission chambers are instaled in TNS as neutron detectors. High fluxes (10^9 n/cm^{2}s – 10^{10} n/cm^{2}s) will allow at least 100 ms spectroscopy time resolution.



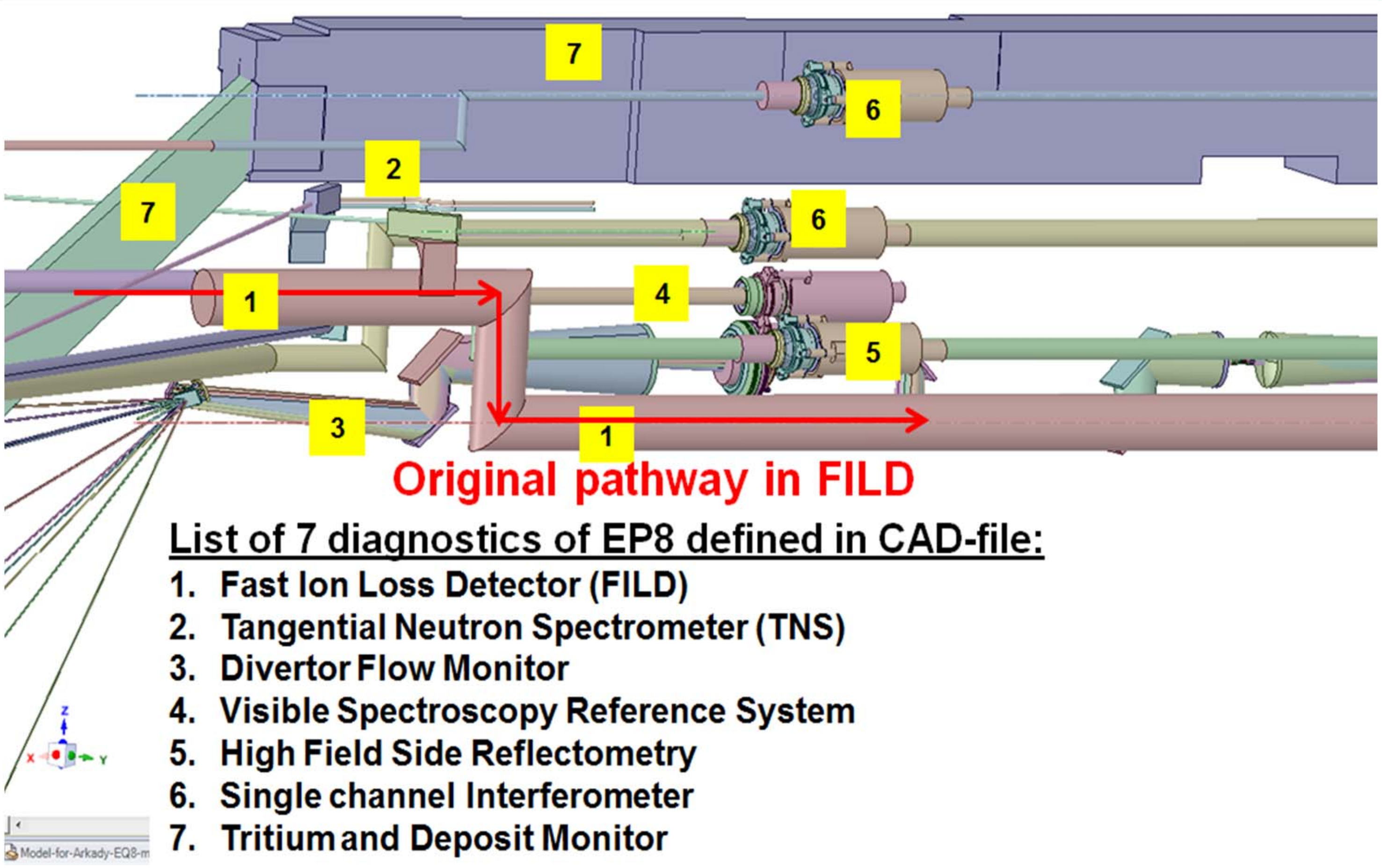
Top view on ITER vacuum vessel



2 neutron detectors of Tangential Neutron Spectrometer (TNS)

Task: eliminate radiation cross-talk from the Fast Ion Loss Detector (FILD or Lost Alpha - LAM) to Tangential Neutron Spectrometer (TNS) in EPP #8

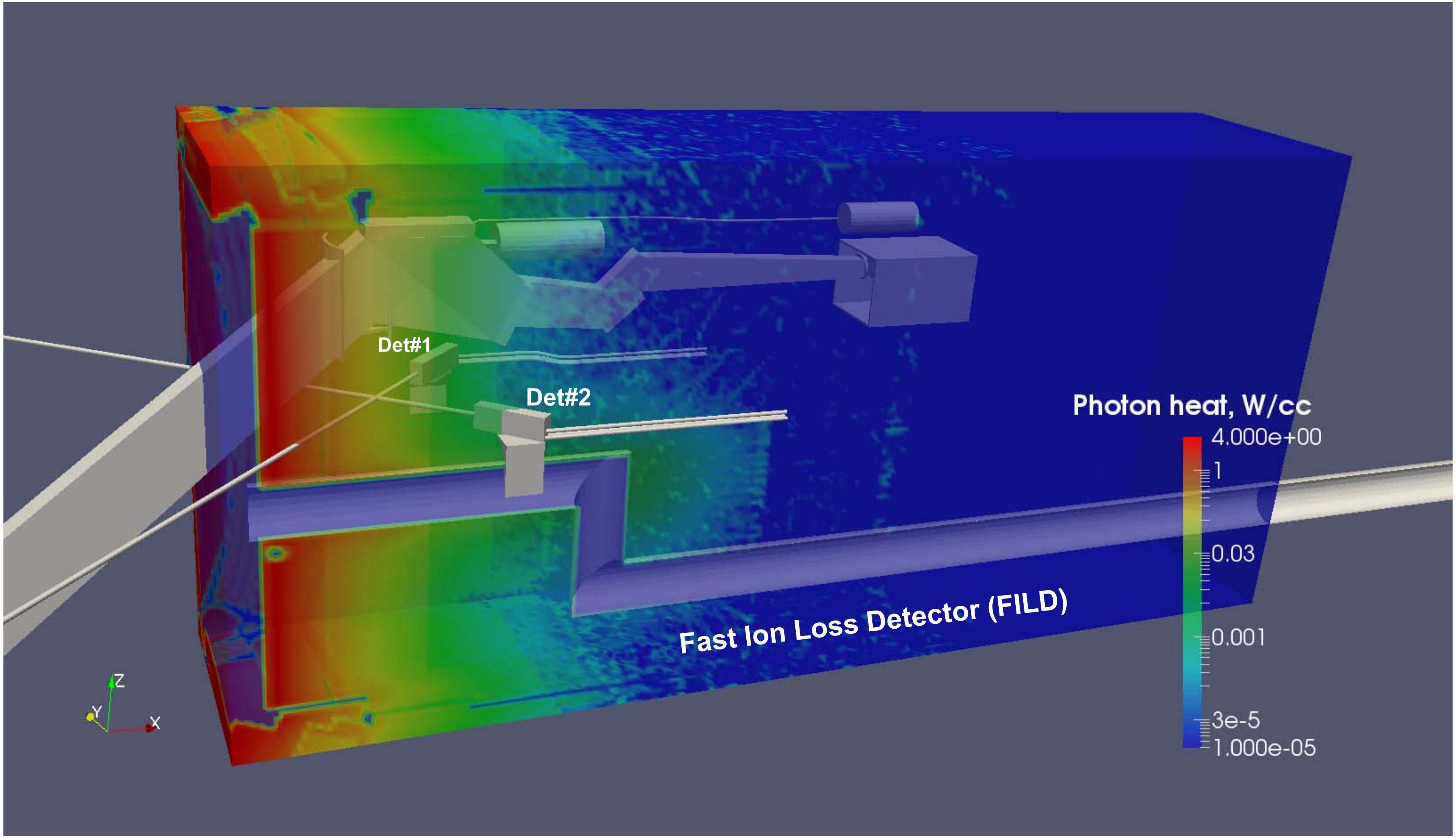
The purpose of TNS spectrometer is to measure spectra of neutrons flying in tangential direction as a collective D-T plasma rotation. In result to estimate the Doppler energy shift of the neutron spectrum emission. **Problem** was noise of neutrons coming from other Diagnostics.



List of 7 diagnostics of EP8 defined in CAD-file:

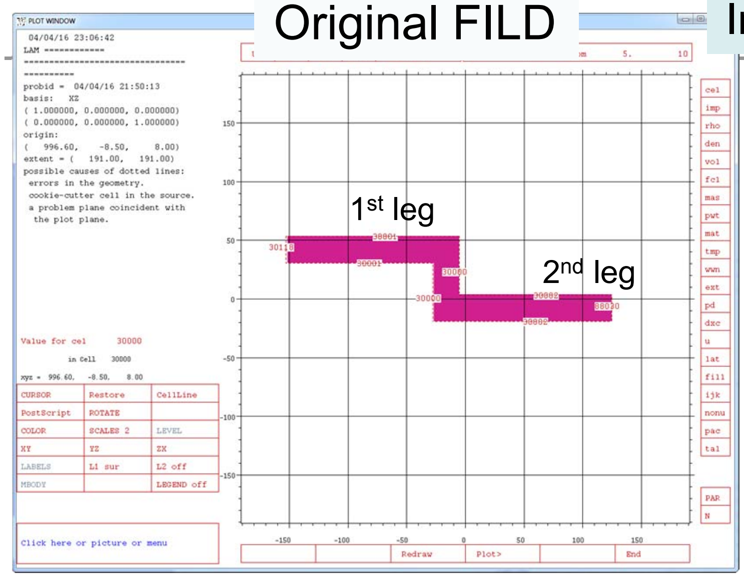
1. Fast Ion Loss Detector (FILD)
2. Tangential Neutron Spectrometer (TNS)
3. Divertor Flow Monitor
4. Visible Spectroscopy Reference System
5. High Field Side Reflectometry
6. Single channel Interferometer
7. Tritium and Deposit Monitor

Photon heating (W/cm^3) for EPP8 (7 diagnostics included in EPP#8) – impact of Lost Alpha Monitor (LAM) on neutron energy spectrrum in two Detectors of TNS



Impact of FILD on TNS

Original FILD



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( 0.000000, 0.000000, 1.000000)
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possible causes of dotted lines:
 errors in the geometry.
 cookie-cutter cell in the source.
 a problem plane coincident with
  the plot plane.

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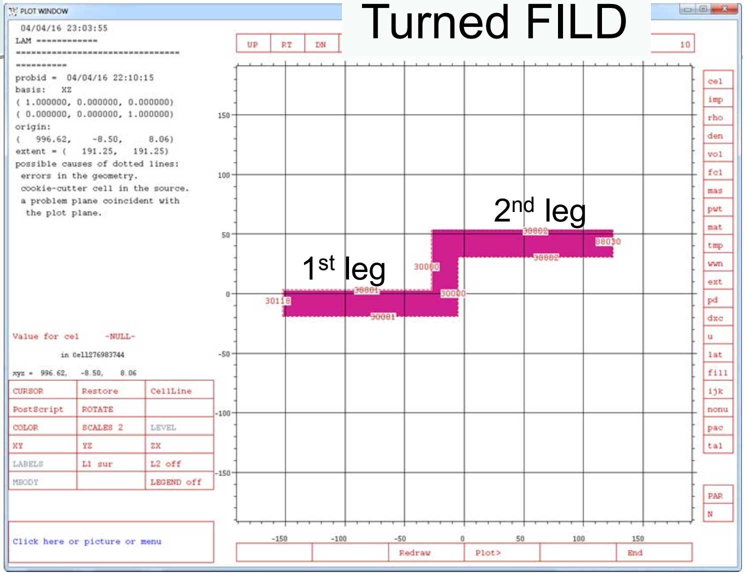
xyz =  996.60,   -8.50,    8.00
```

Modification of the FILD pathway

Turned FILD



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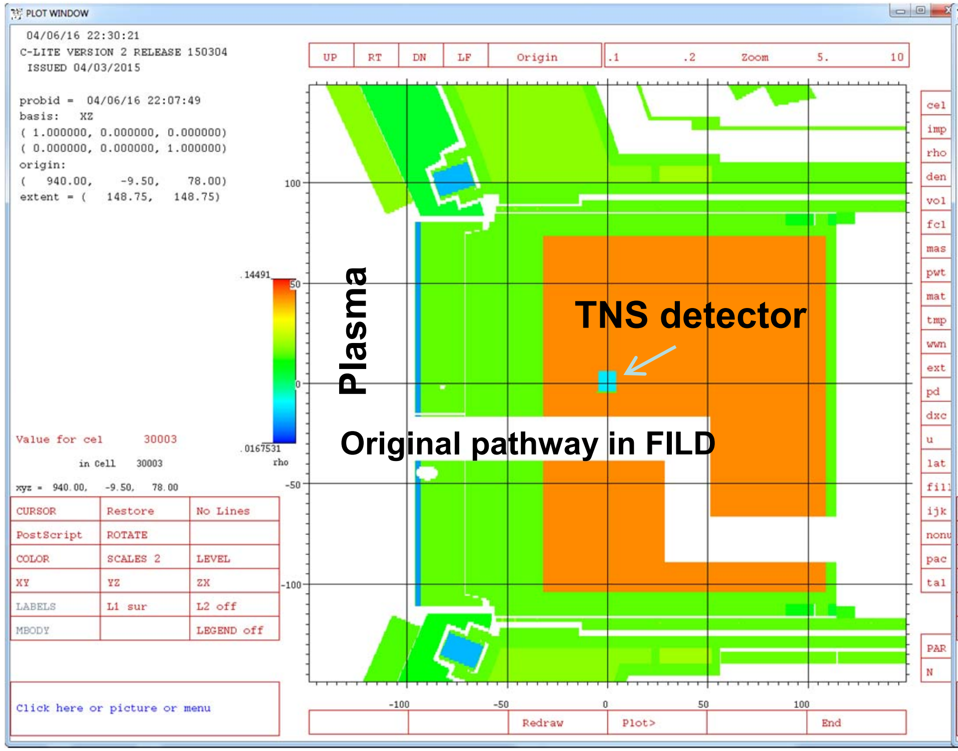

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C-LITE VERSION 2 RELEASE 150304
 ISSUED 04/03/2015

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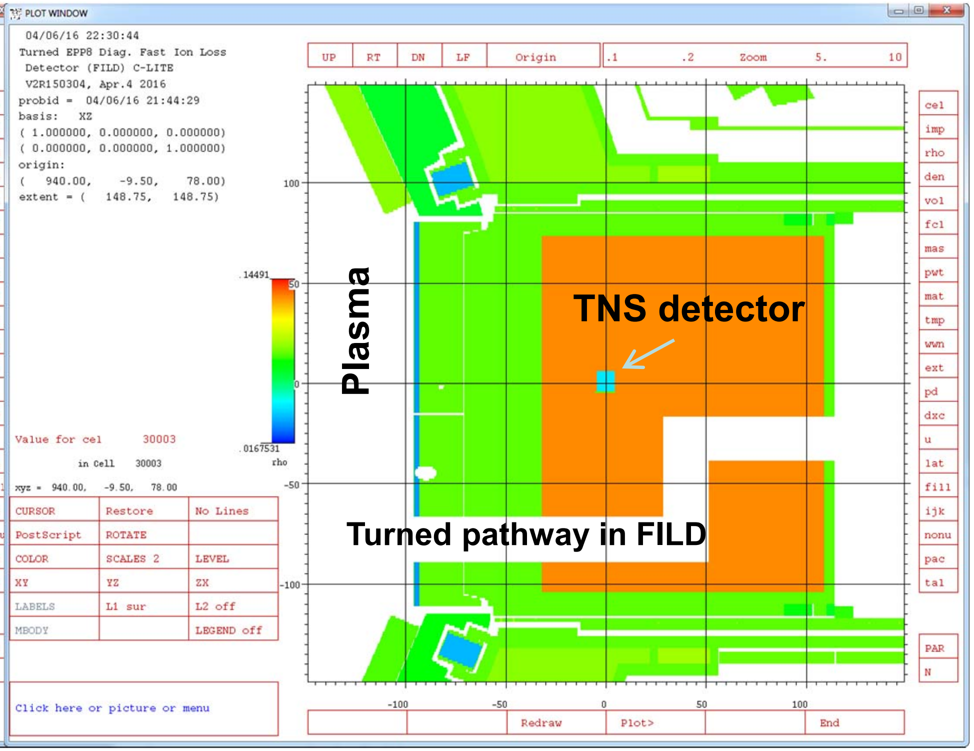

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 Detector (FILD) C-LITE
 V2R150304, Apr.4 2016
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( 0.000000, 0.000000, 1.000000)
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xyz =  940.00,   -9.50,   78.00
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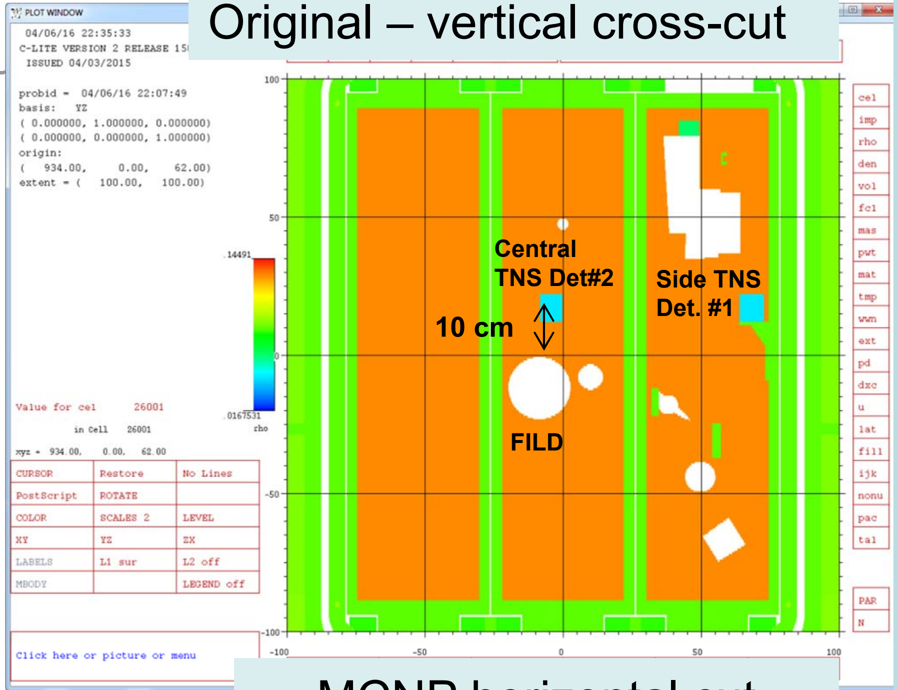
Original – vertical cross-cut



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C-LITE VERSION 2 RELEASE 15
ISSUED 04/03/2015

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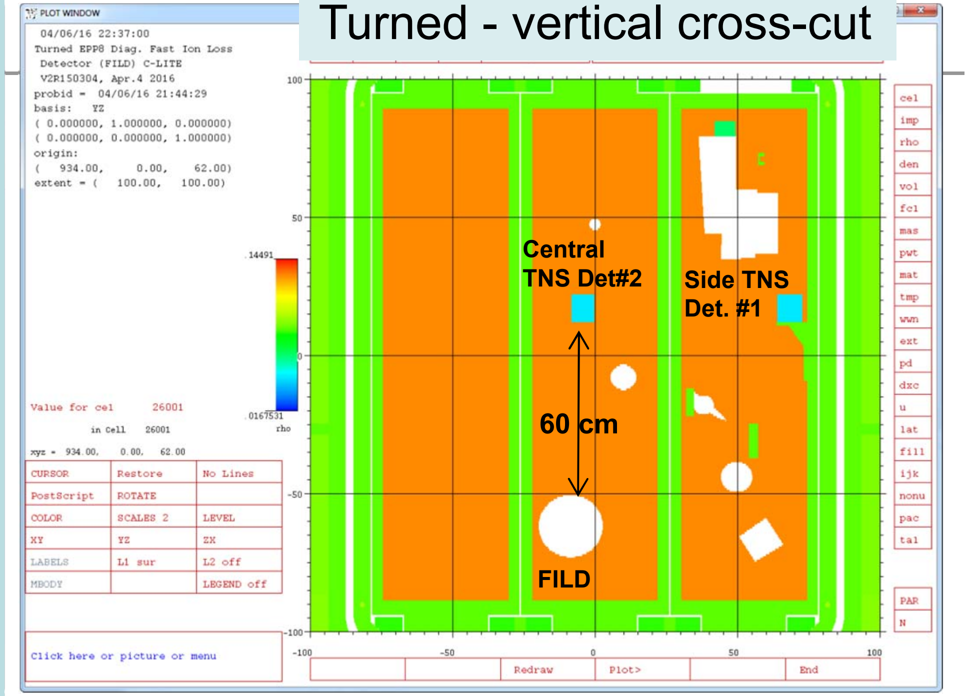
xyz =  934.00,   0.00,  62.00
```

Turned - vertical cross-cut



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Detector (FILD) C-LITE
V2R150304, Apr.4 2016
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origin:
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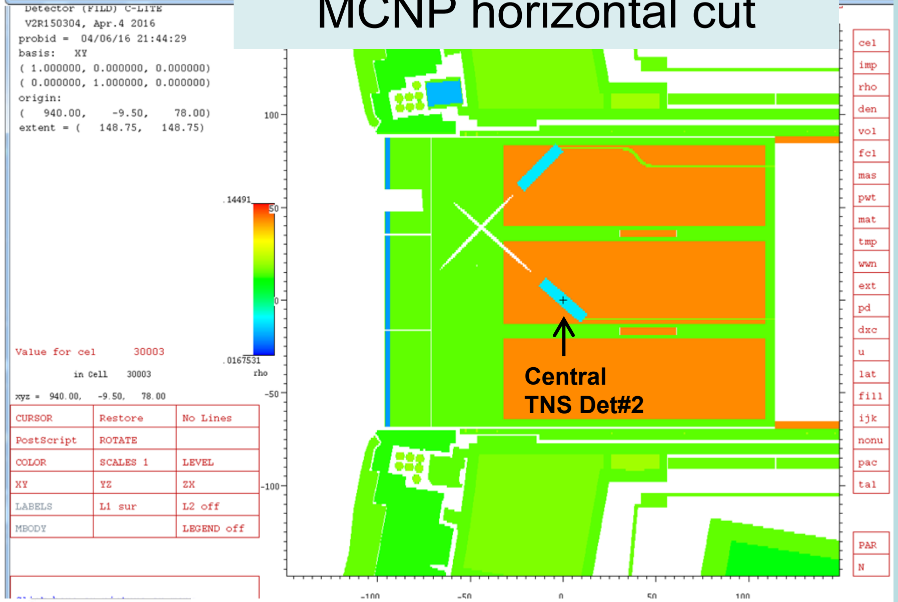
MCNP horizontal cut



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Detector (FILD) C-LITE
V2R150304, Apr.4 2016
probid =  04/06/16 21:44:29
basis:   XY
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( 0.000000, 1.000000, 0.000000)
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extent = (   148.75,   148.75)

Value for cel      30003
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xyz =  940.00,  -9.50,  78.00
```

Investigation was carrying on for the Central TNS detector. In the original EPP #8 model the distance between TNS and 1st leg of FILD was 10 cm, in the turned model it is 60 cm.

Turning upside-down of the FILD pathway helps to increase the 14-MeV peaking factor in energy resolution of the central TNS detector.

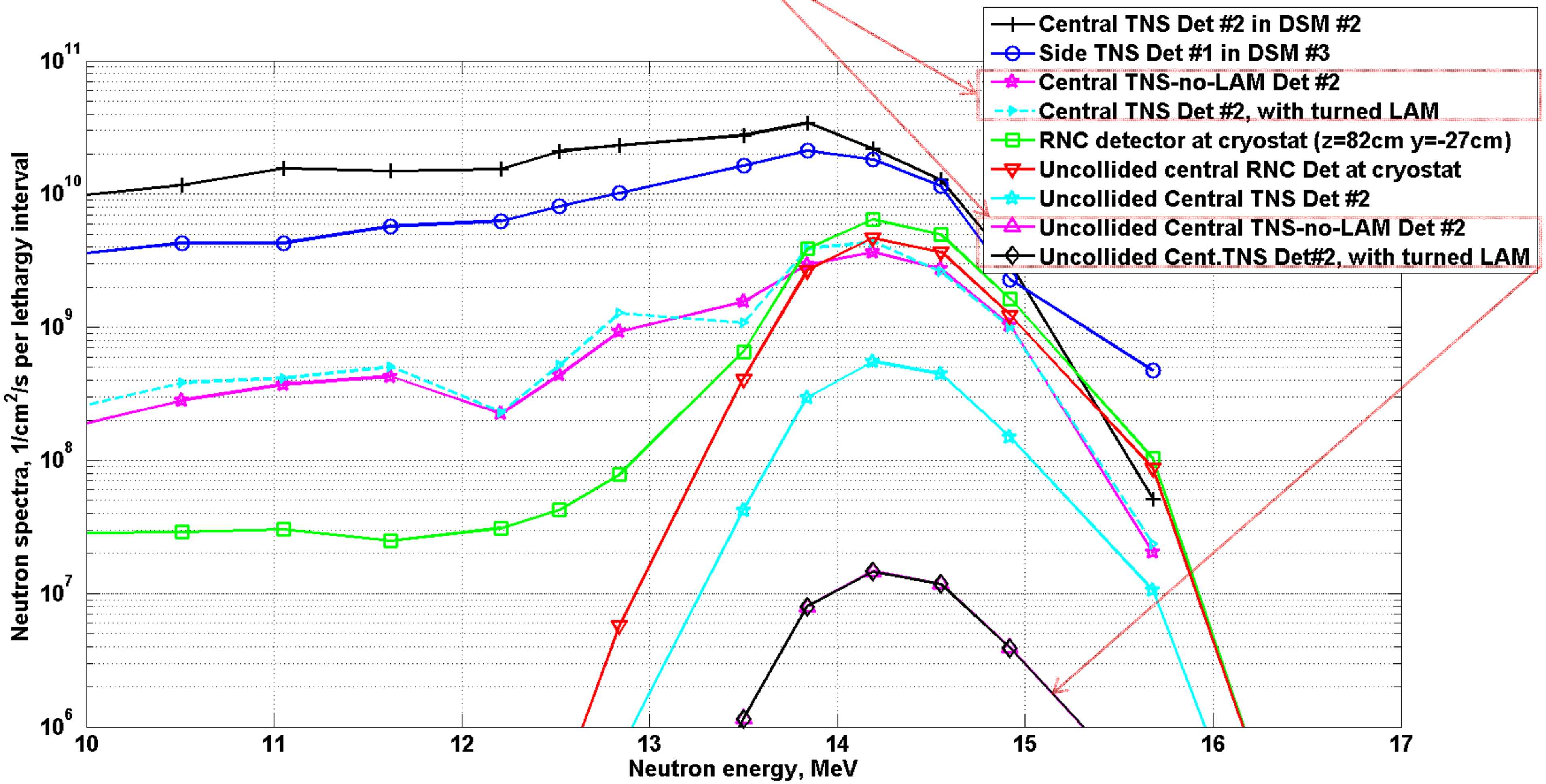
Turned FILD configuration stops neutron streaming from the FILD pathway to the Central TNS detector.

For measuring of n-spectrum in Central Det. #2 the turned FILD option is an equivalent to one of its absence – option of totally filled FILD (LAM – as FILD called before): "TNS-no-LAM" case on the spectra plots next slide.

Eliminating cross-talks between TNS and LAM (FILD)

In Central TNS Detector #2 the neutron spectra are coincided for two cases:

1) Totally removed LAM (FILD)
2) Turned upside-down LAM (FILD)

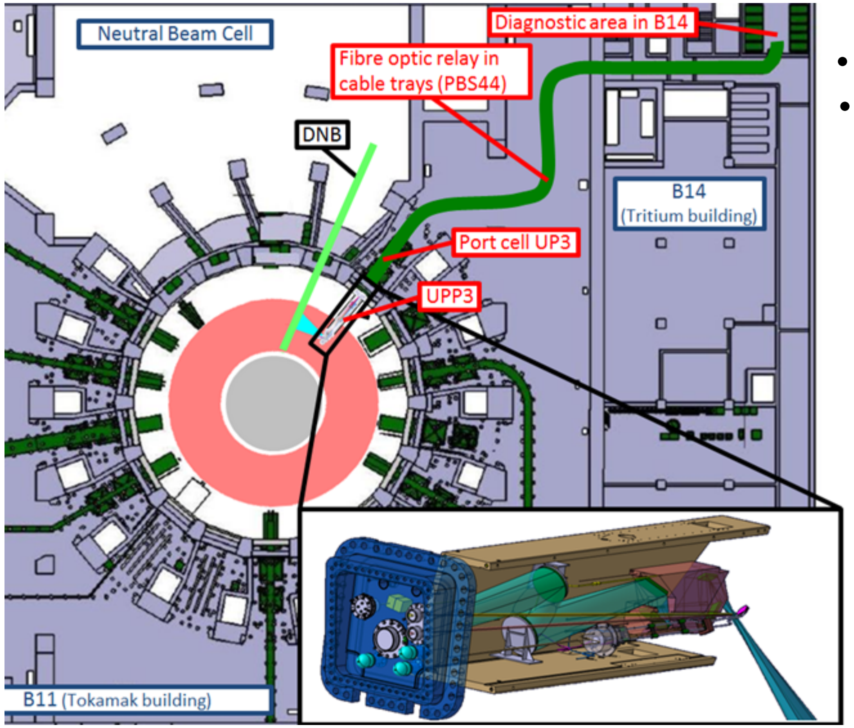


In-port radiation cross-talks

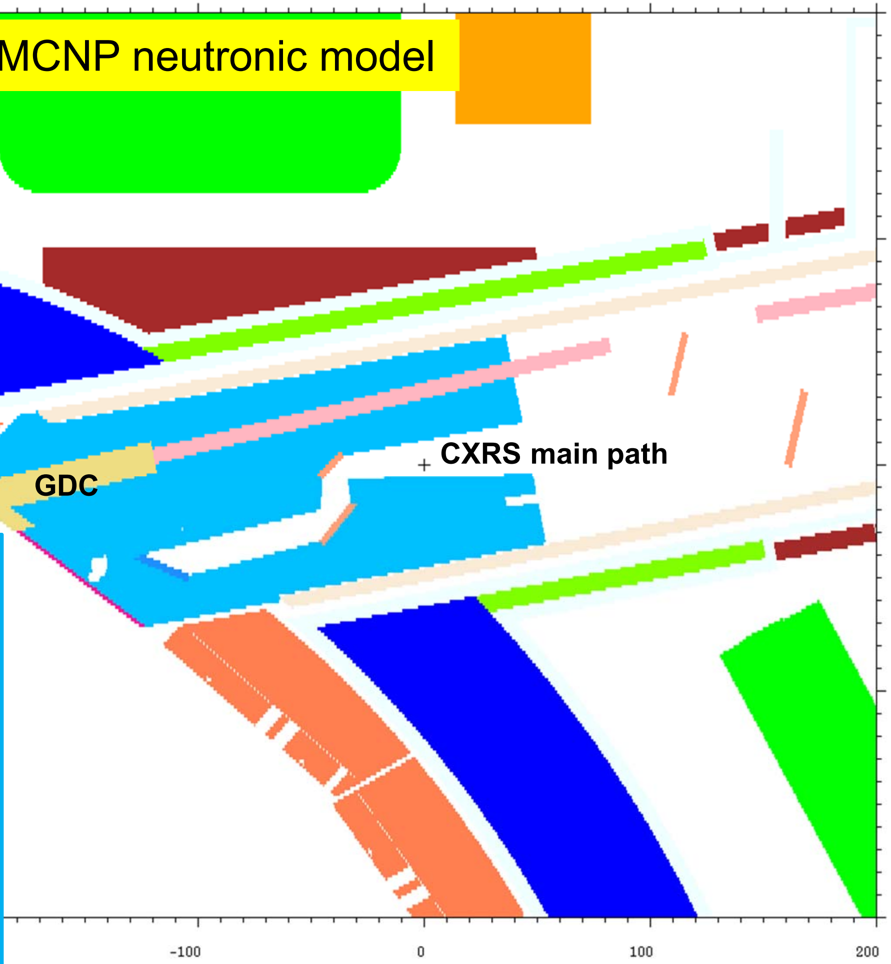
Example 3:

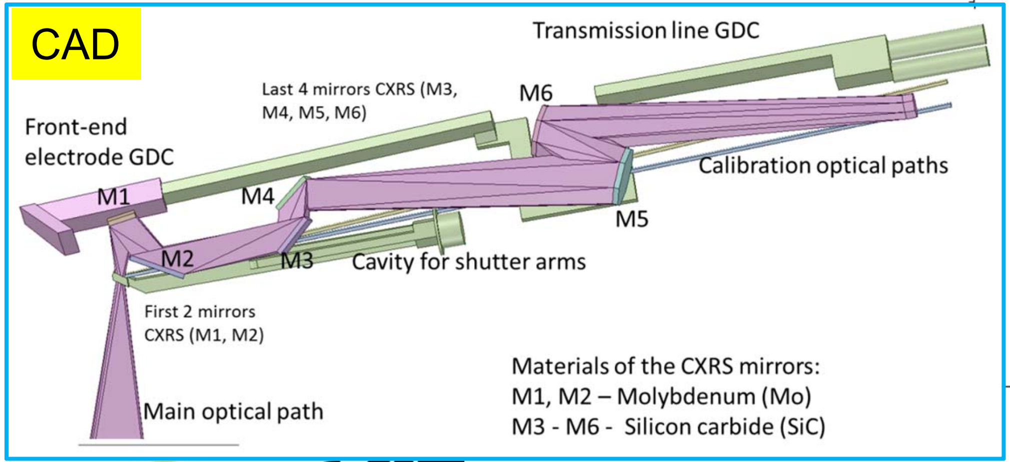
Shutter and the main Diagnostic path of the Charge eXchange Recombination Spectroscopy (CXRS) in **UPP #3**

Upper Port Plug #3 with Charge eXchange Recombination Spectroscopy (CXRS)



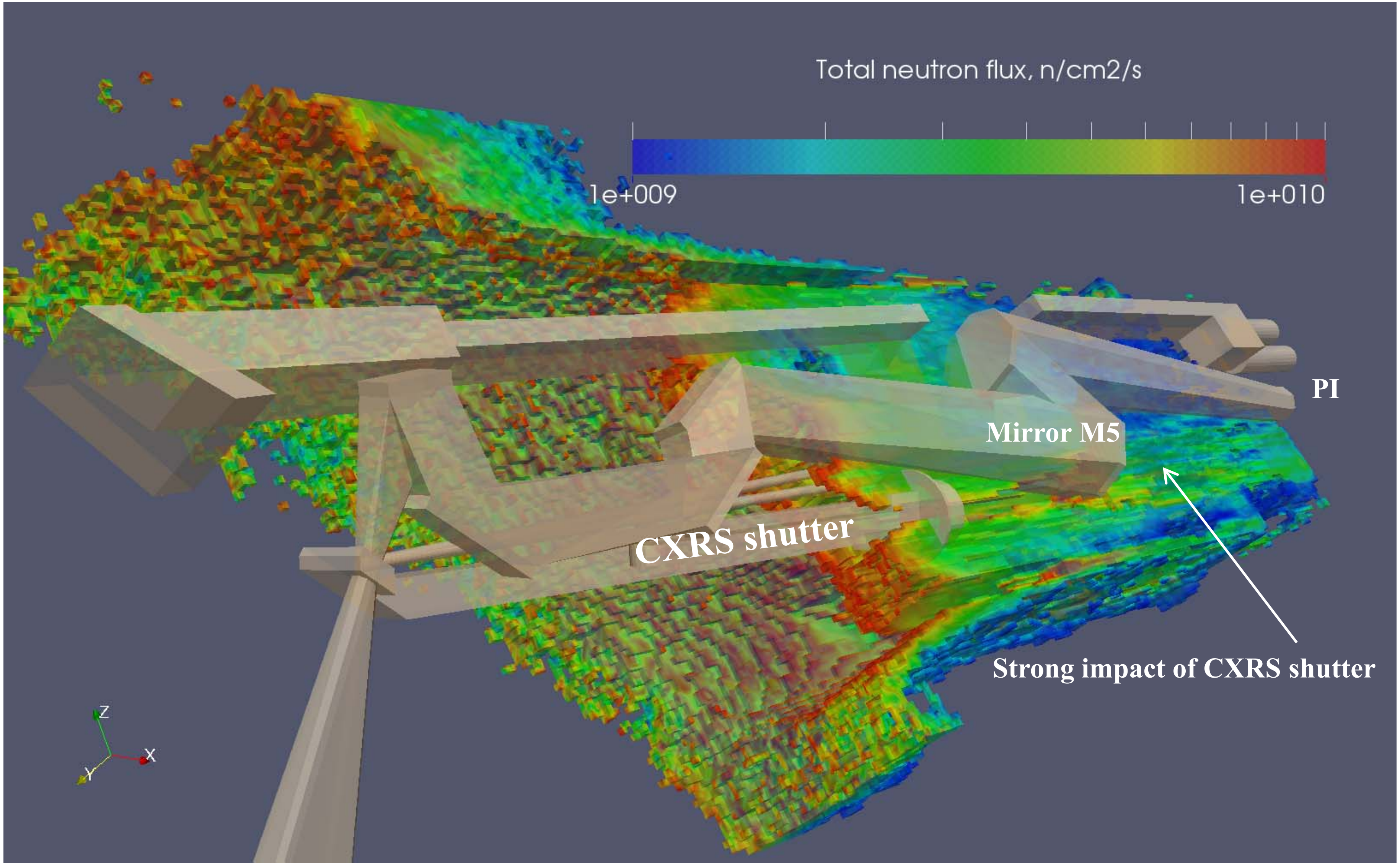
- Collects visible light emitted by Diag. Neutral Beam (DNB)
- Analyses the light ➔ Ion Temp., Plasma Rotation, Impurities





Materials of the CXRS mirrors:
M1, M2 – Molybdenum (Mo)
M3 - M6 - Silicon carbide (SiC)

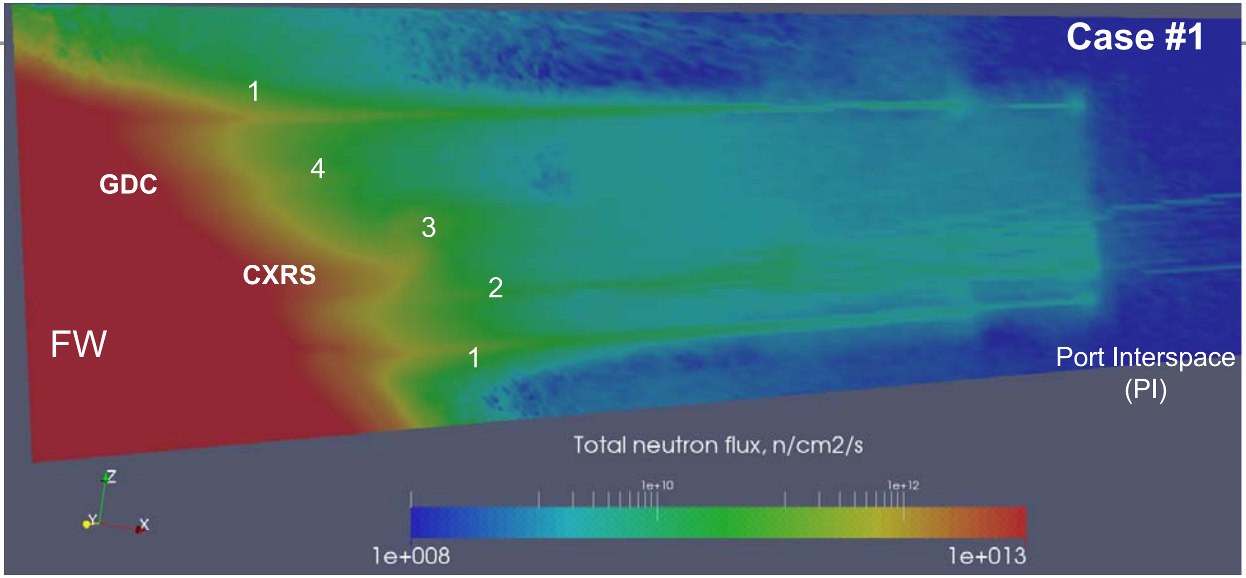
Impact of CXRS shutter – on neutron flux streaming



Strong impact of CXRS shutter

Case #1:
UPP-CXRS with GDC
4 pathways of neutron streaming :

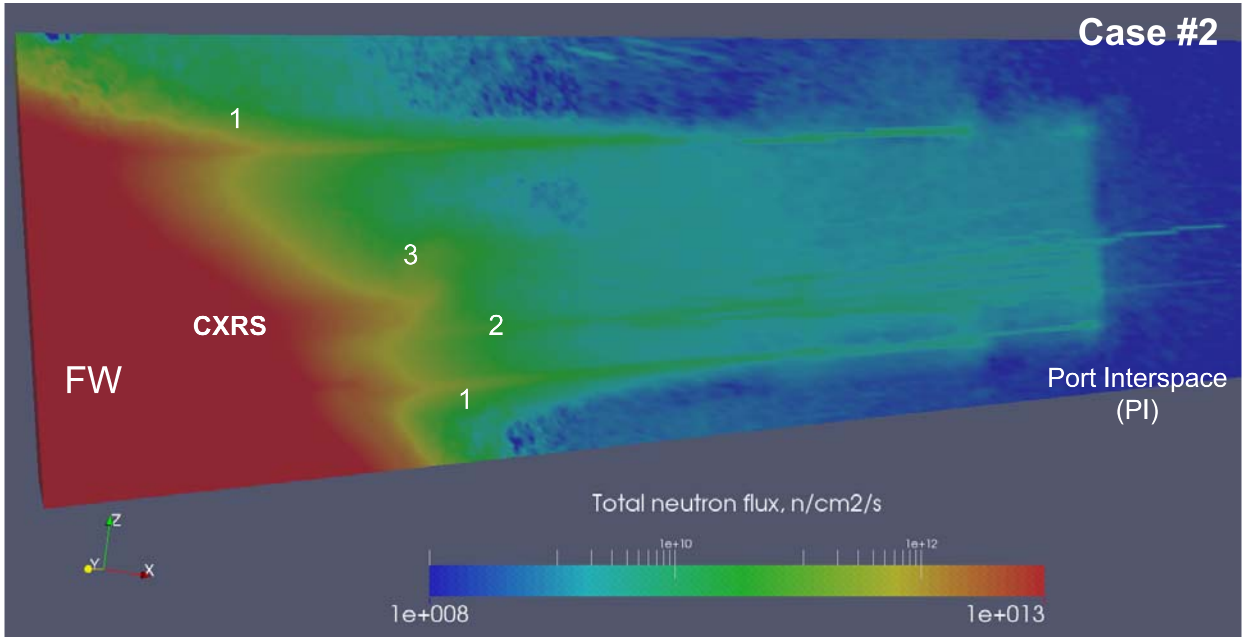
- **1 – Gaps all-round the UPP**
- **2 – CXRS shutter**
- **3 – CXRS main optical path**
- **4 – GDC electrode**



Neutron pathway analysis: Case #1 vs. Case #2:

Case #2:
UPP-CXRS except GDC
3 pathways of neutron streaming :

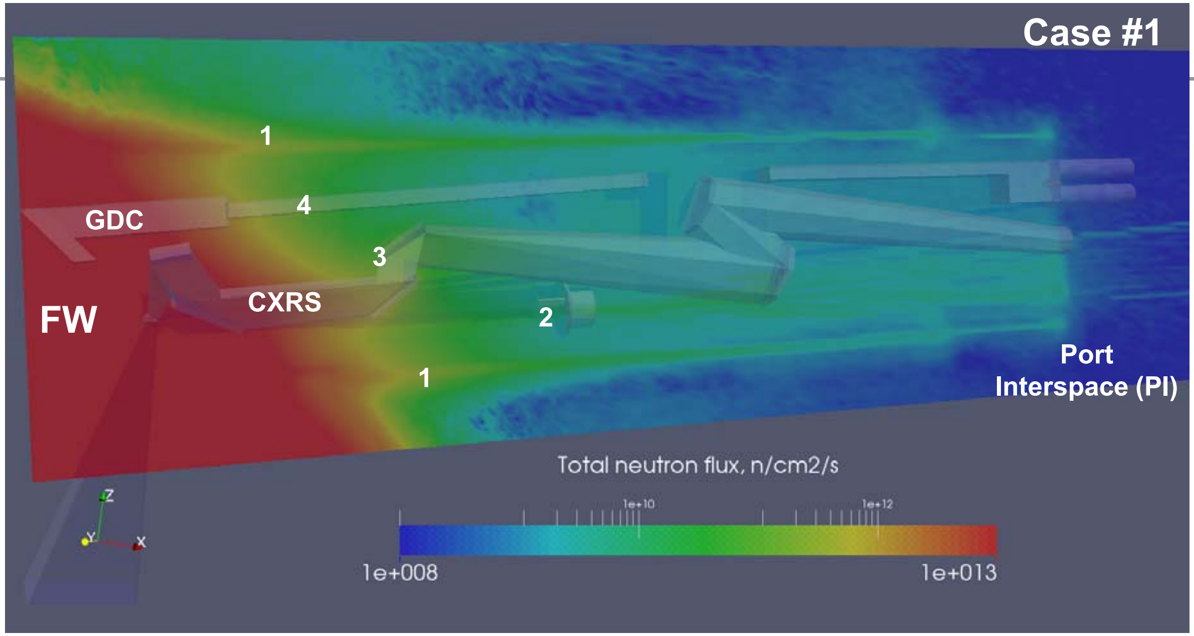
- **1 – Gaps all-round the UPP**
- **2 – CXRS shutter**
- **3 – CXRS main optical path**



Neutron pathway analysis: Case #1 vs. Case #3:

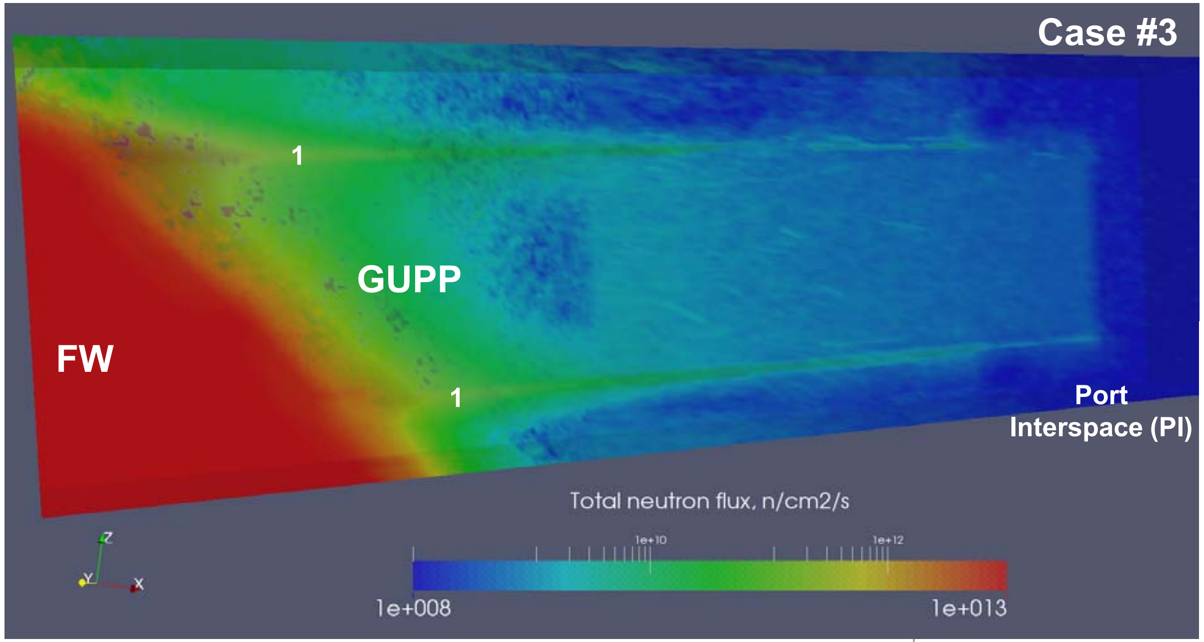
Case 1:
UPP-CXRS with GDC
4 pathways of neutron streaming :

- **1 – Gaps all-round the UPP**
- **2 – CXRS shutter**
- **3 – CXRS main optical path**
- **4 – GDC electrode**



Case 3:
Generic UPP
1 pathway of neutron streaming :

- **1 – Gaps all-round the GUPP**



Conclusions

- The phenomenon of in-port cross-talk was investigated for the diagnostic systems deployed in two Equatorial Port Plugs (EPP) #17 and #8, and for the components of Upper Port Plug (UPP) #3.
- The T-monitor & Core-Imaging X-ray Spectrometer (CIXS) inside the Diagnostic Generic EPP are analysed in EPP#17 local MCNP model of ITER. While EPP#8 and UPP#3 are modelled globally with C-lite v2 and B-lite v3 models, respectively.
- Multiple sets of diagnostic equipment inserted inside the same Port Plug create additional pathways for radiation streaming along the diagnostic channels and labyrinths (e.g. optical pathways) – the reason of in-port radiation cross-talk between different diagnostic systems.
- Demonstrated that in order to take advantage of particular shielding improvements in full extent, we should also assess the mutual influence of every Diagnostic system installed inside the same port.
- **This subject is important for Diagnostics designing at the stage of port integration to ensure engineering and maintenance solutions for the Diagnostic tenant systems.**