

Digital Twin Tech for Fusion Plant Flight Simulator

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on behalf of V-KSTAR Development Team

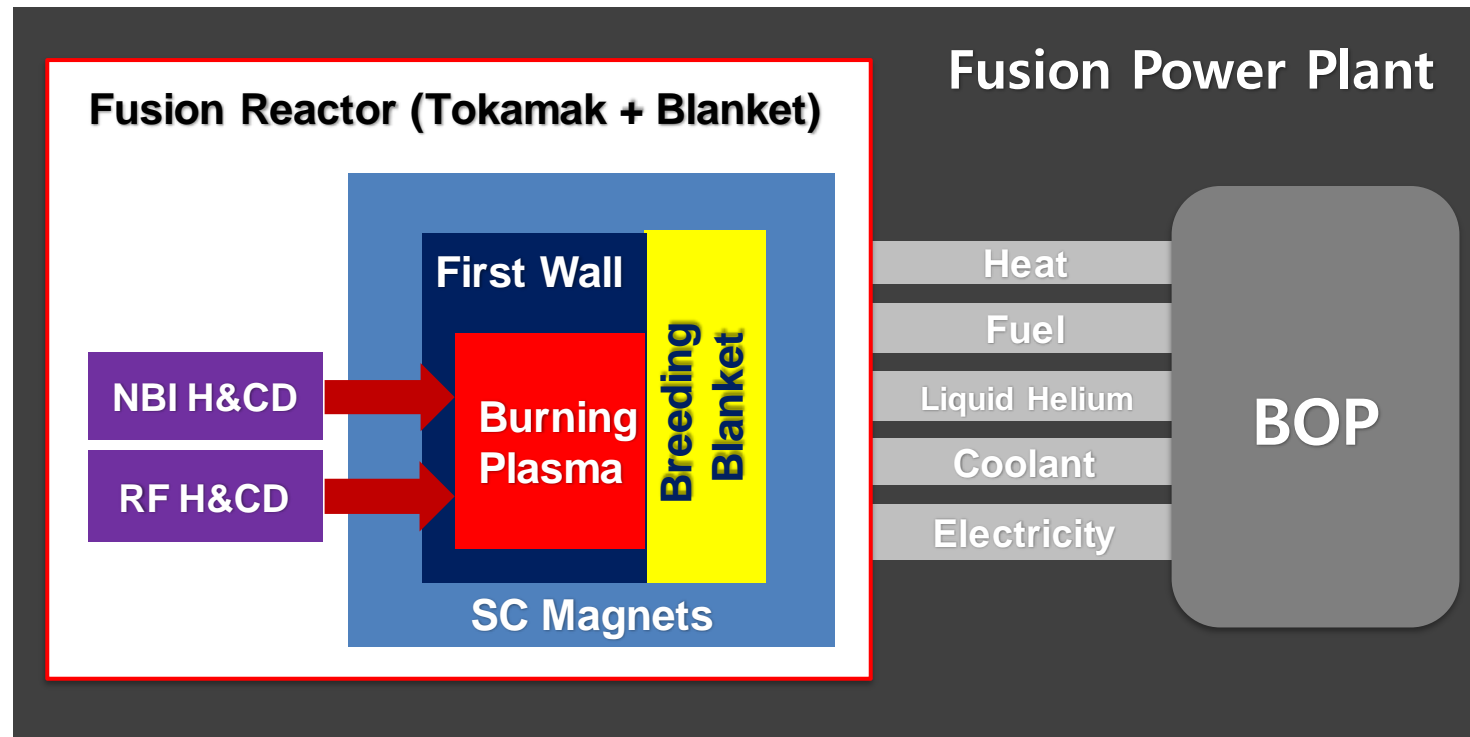
8th IAEA DEMO Workshop

Aug. 30 ~ Sep. 2 2022, Vienna, Austria



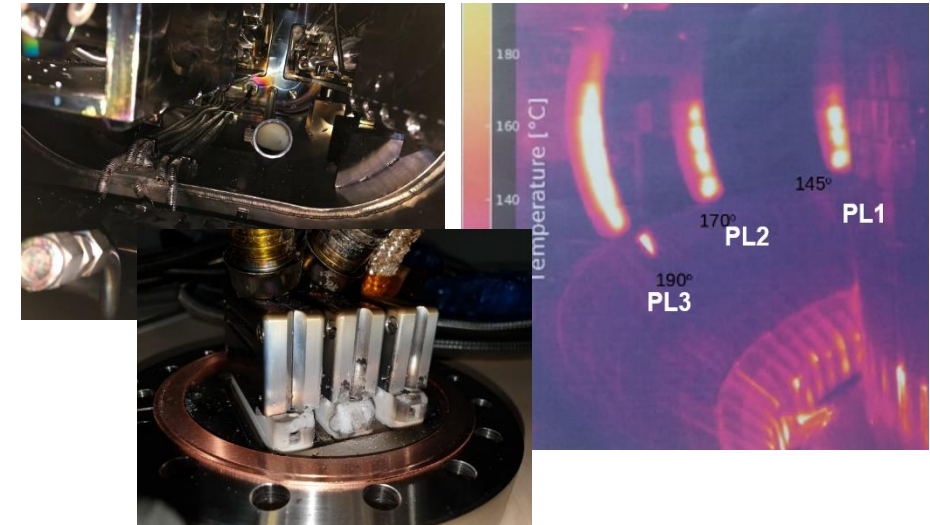
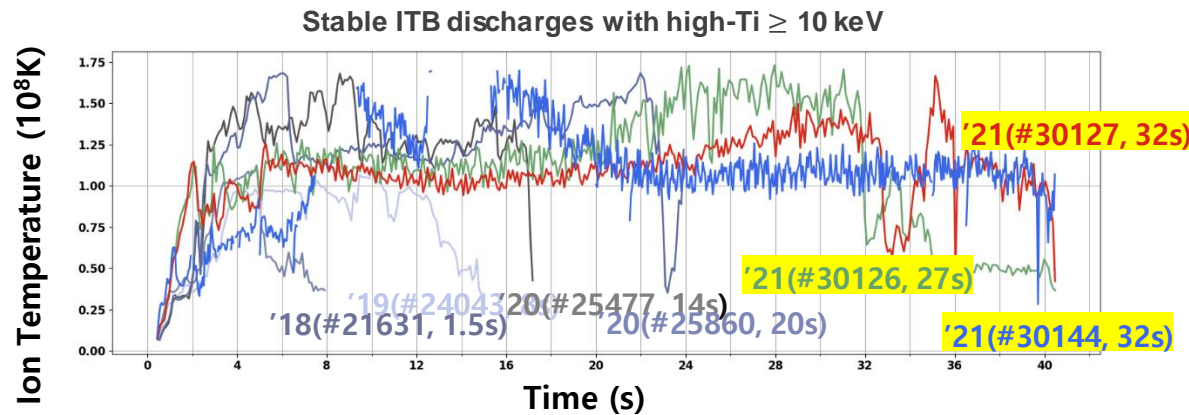
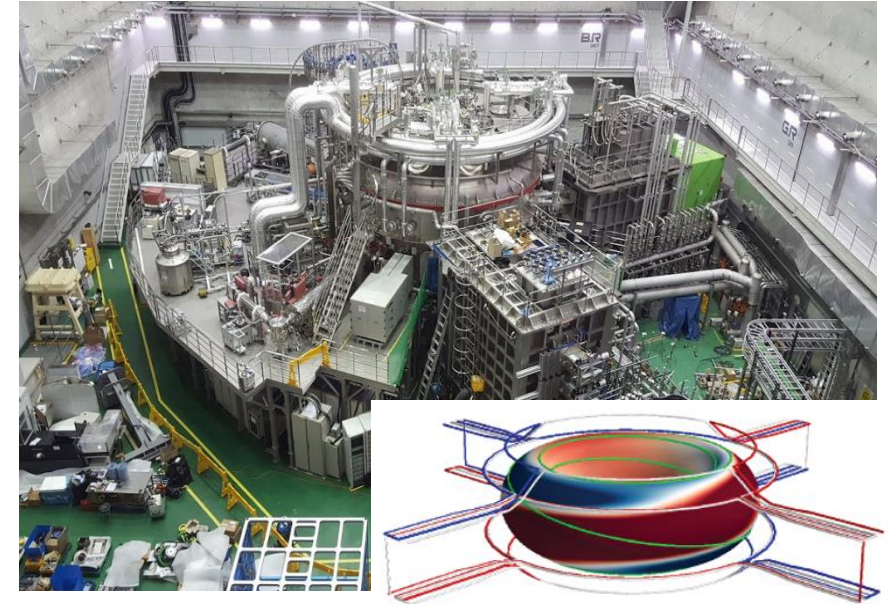
Fusion Power Plant Flight Simulator

- Integrated simulation of components consisting fusion power plant in connection with control algorithm
- Very challenging long term project – How to proceed? How to build and keep development momentum?
- ➔ By facilitating interaction between on-going simulation development efforts and KSTAR experiment

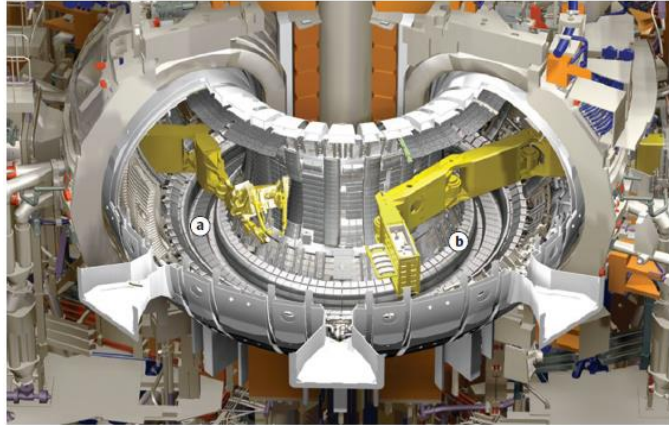


Challenges for long pulse experiment on KSTAR

- Even in present day machines like KSTAR, long pulse operation of high performance plasma is very challenging
 - Formation of hot spots by anisotropic losses of energetic particles
 - Errant reflections of RF beams
 - Heat exhaust control on divertor etc
 - More tricky for W-divertor (under upgrade now)
 - In fusion power plant, these and related issues would be addressed in much more challenging conditions
- ➔ Digital Twin is chosen as a platform to integrate and analyze relevant simulations, which will be evolved into comprehensive tokamak simulation in future



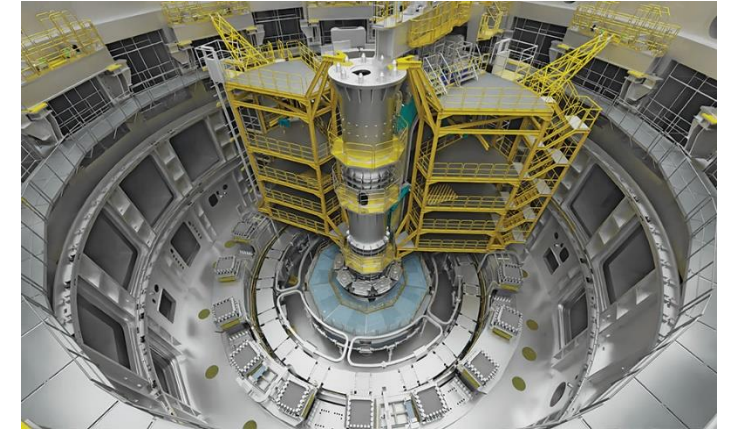
Digital Twin for Fusion Research



Remote Maintenance System on JET
(Rob Buckingham et al, Nature Phys. 2016)

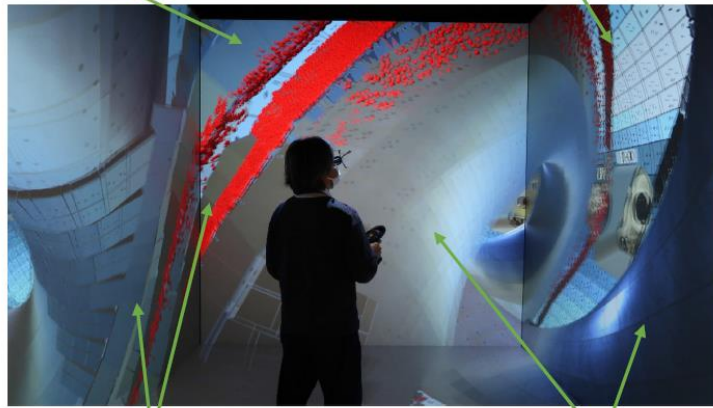


Virtual Room and Digital Twin for ITER Construction
(D. Keller et al, FED 2013)

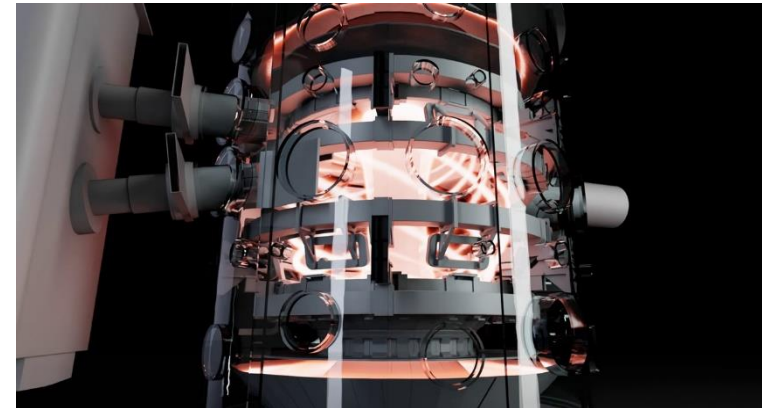


Triangle dome structure

Open divertor plates



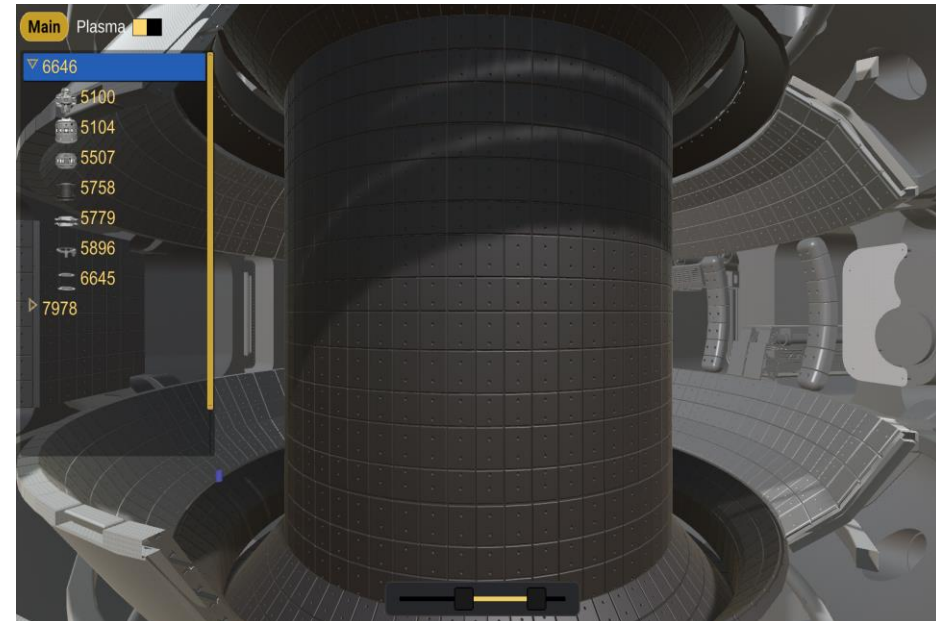
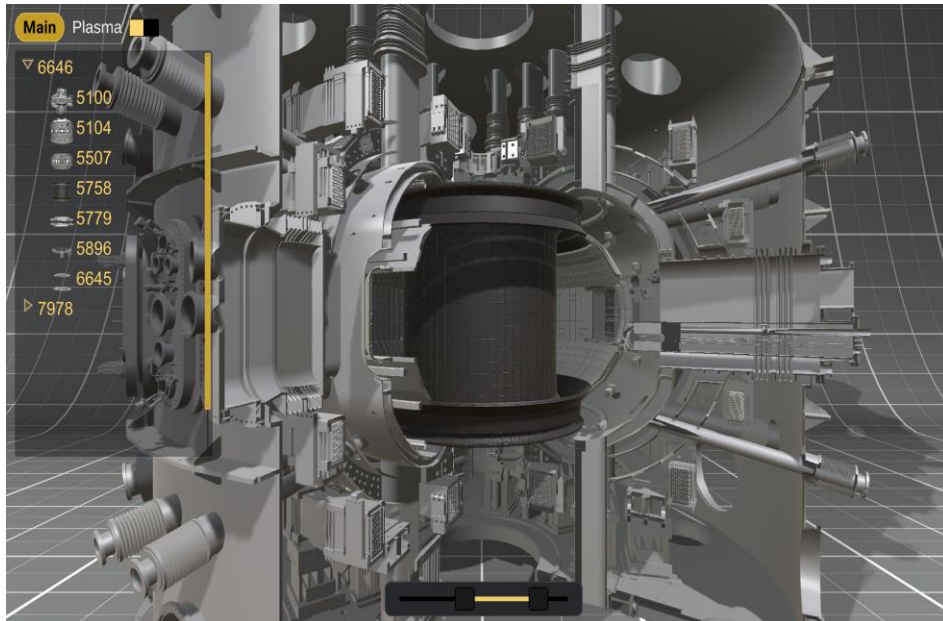
Closed divertor plates
VR System on LHD
(Hiroaki Ohtani et al, J. Vis. 2022)



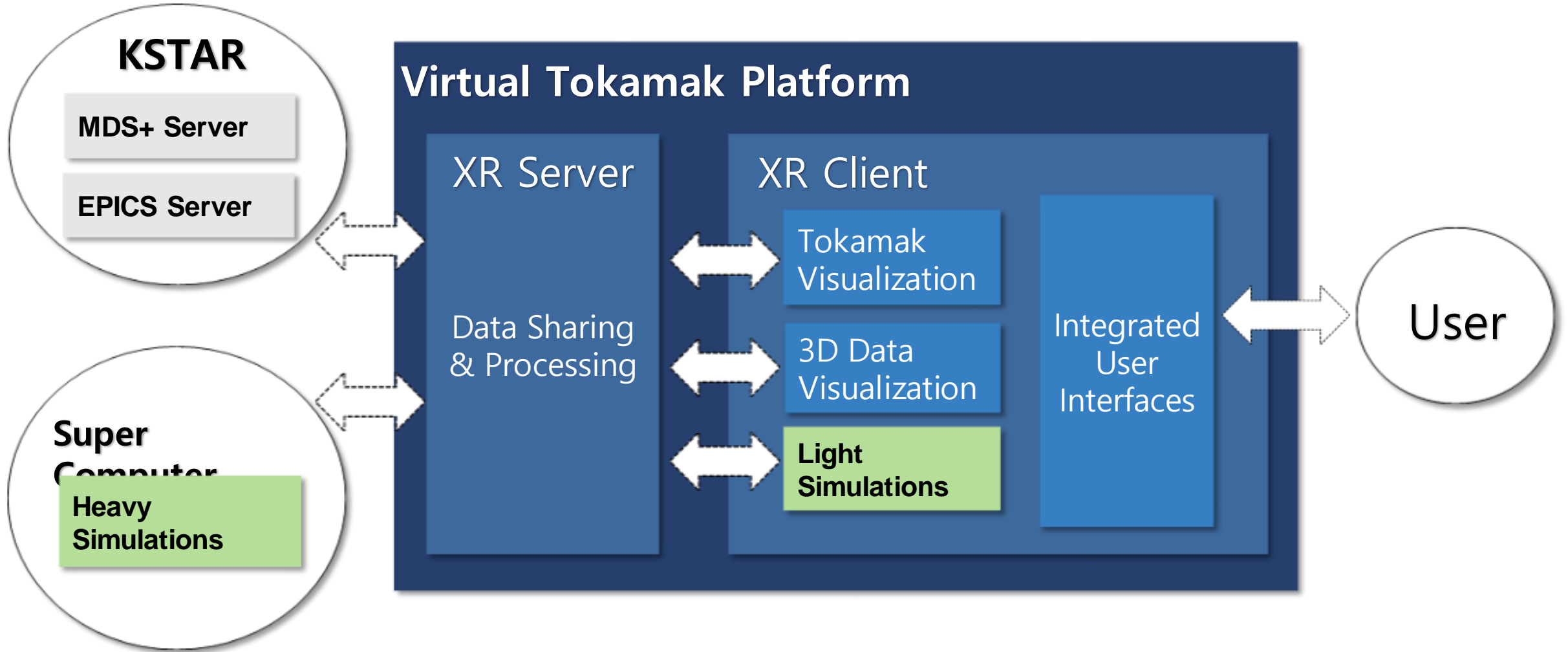
Digital Twin for Fusion Reactor Design
(<https://blogs.nvidia.com/blog/2022/05/30/ukaea-digital-twins-omniverse/>)

Virtual KSTAR – Key Features

- Development based on Unity Graphic Engine
- Customizable virtualization according to user's needs
 - Components, viewing angle & depth
- Fast enough to be running on laptop or PC (e.g. 10 FPS with RTX 2070 GPU)
- Data framework to systematically process various fusion data based on HDF5 format

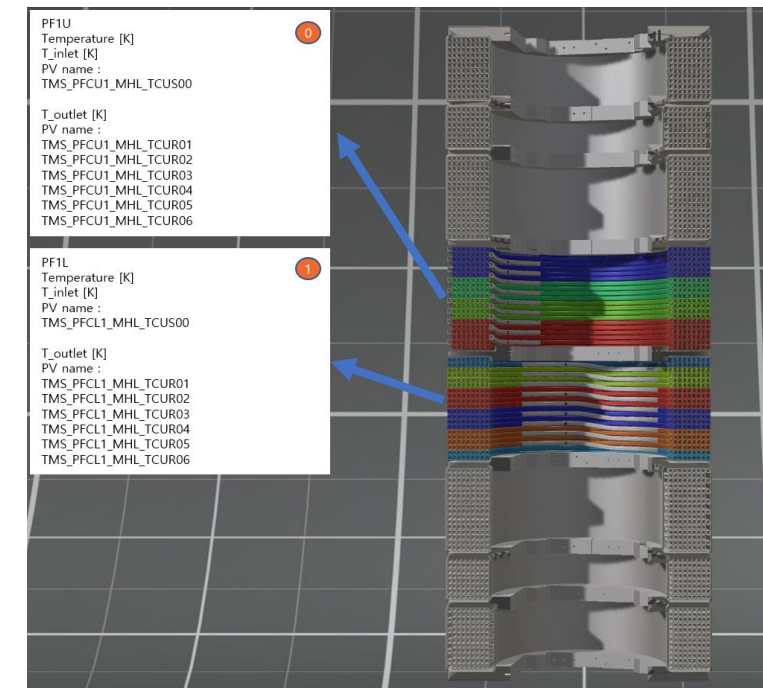
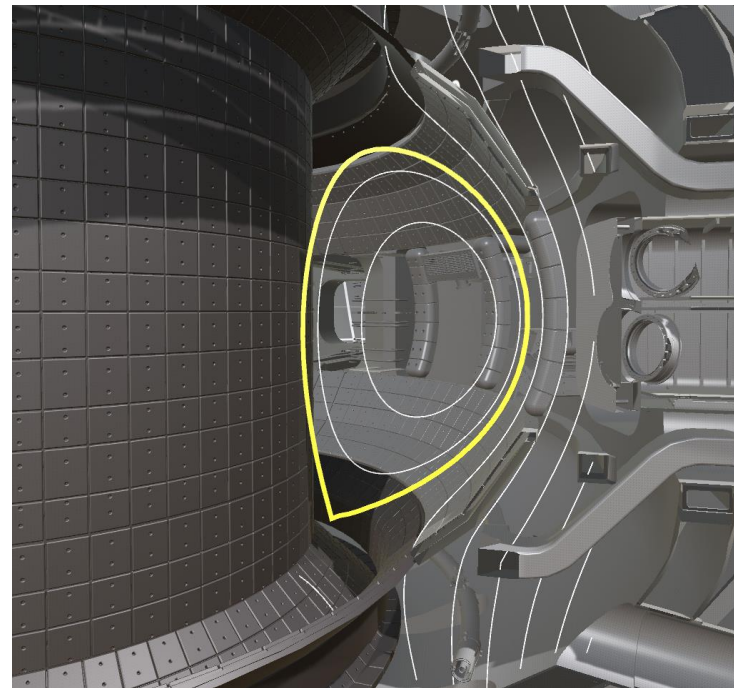
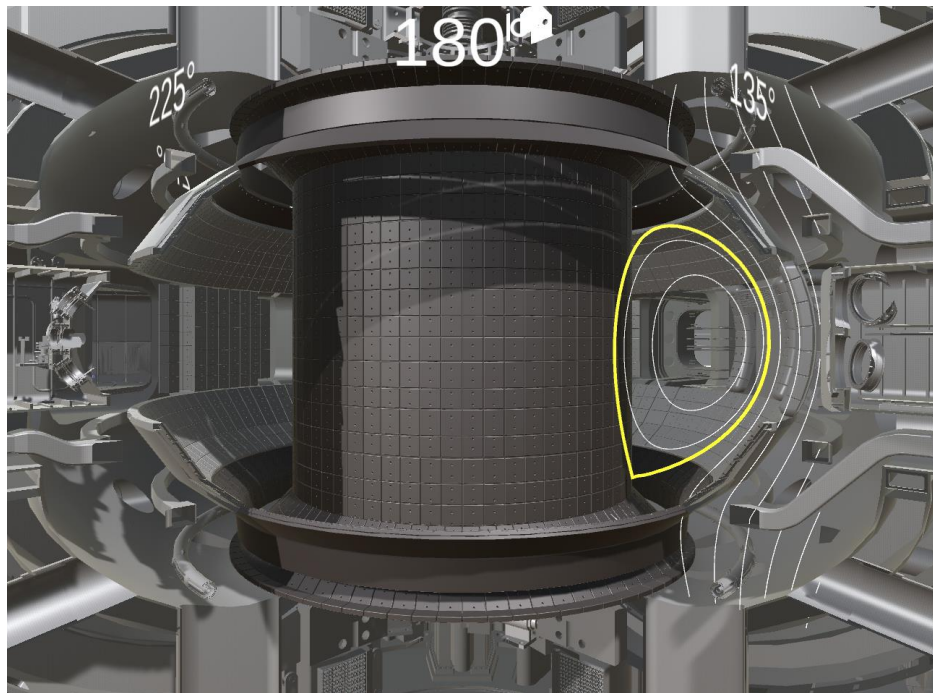
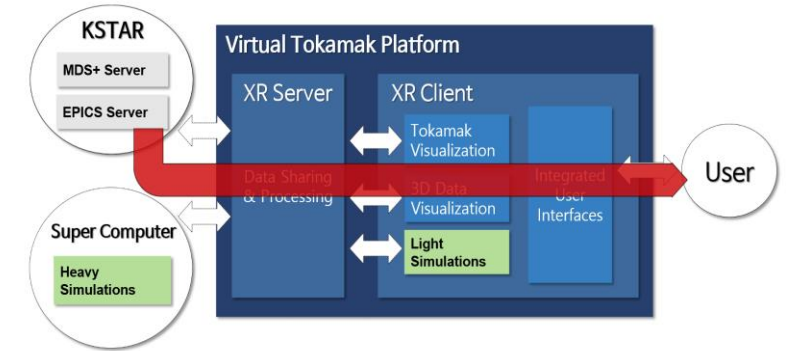


Virtual KSTAR – Overall Structure



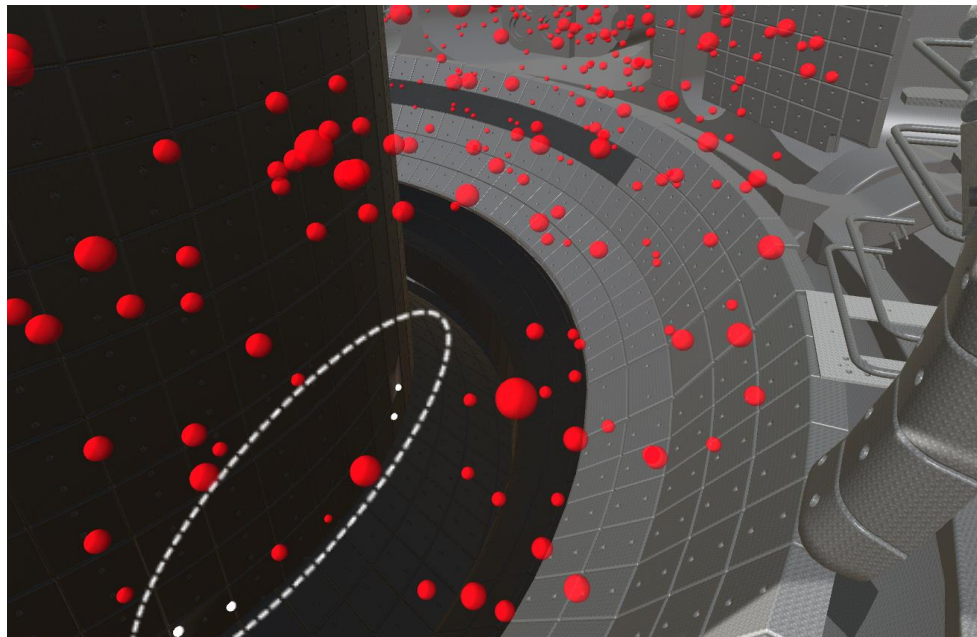
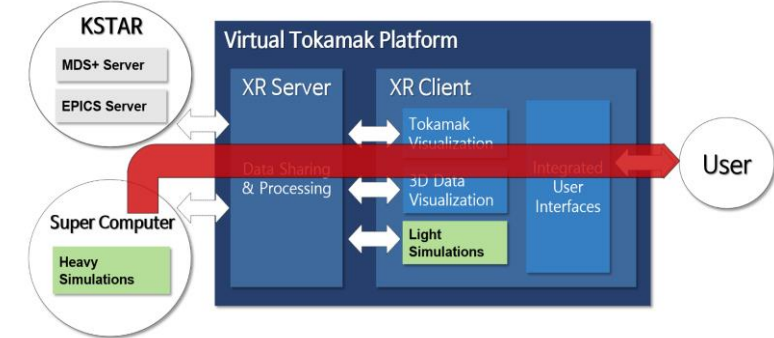
Virtual KSTAR – Real Time Monitoring of Machine Operation

- Real time visualization of EFIT magnetic equilibrium reconstruction
- Other data can be incorporated for real time monitoring of machine operation – PFC temperature, SC magnetic info etc.

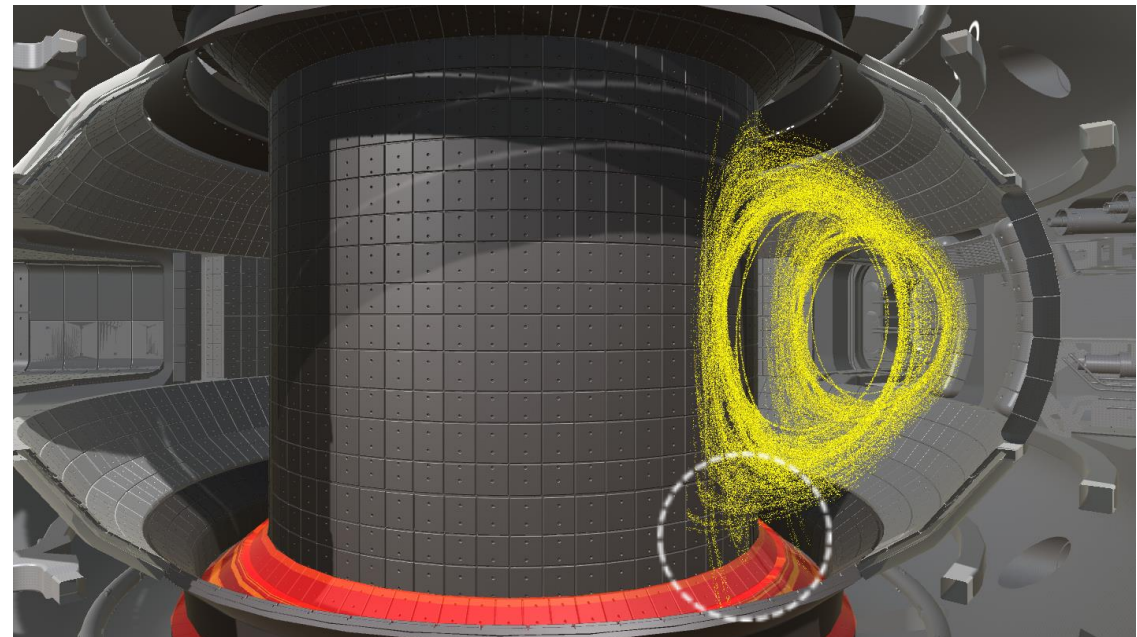


Virtual KSTAR – Post-Analysis of Simulation and Experiment

- NBI, RMP simulation data can be visualized for detailed assessment of their impacts on long pulse operation



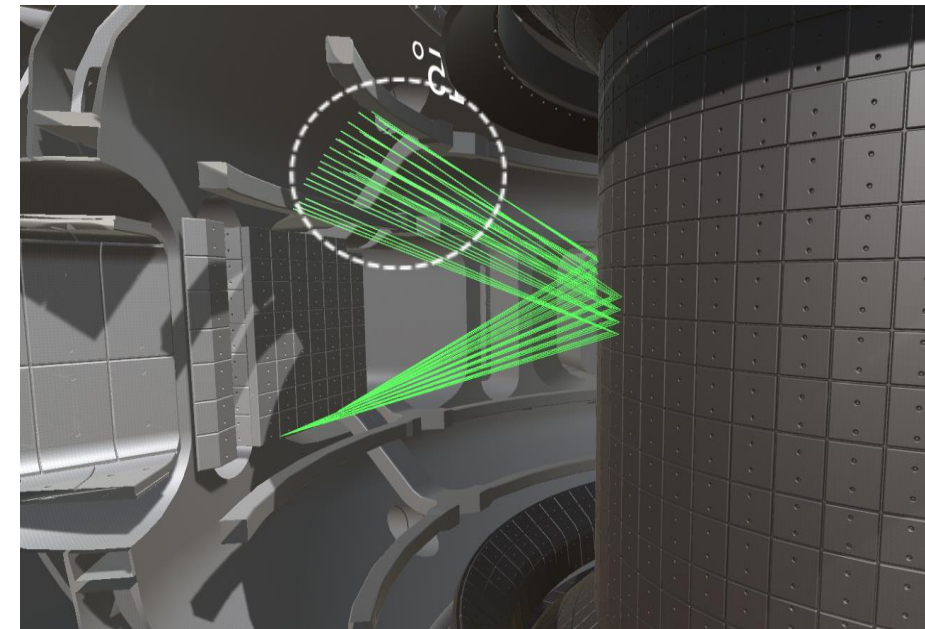
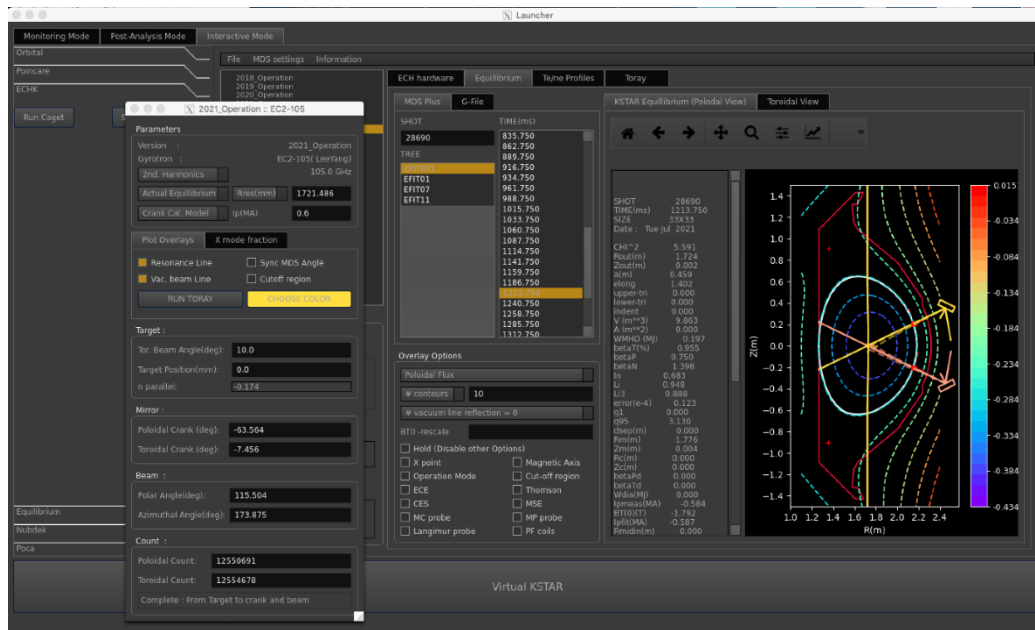
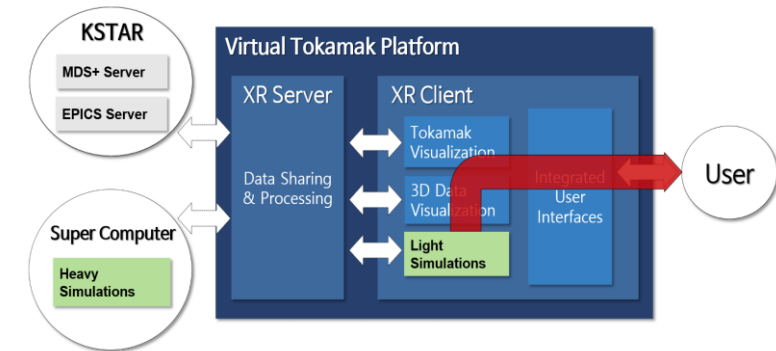
Tongnyeol Rhee, et al Phys. Plasmas 26 (2019) 112504



Kimin Kim et al, Phys. Plasmas 19 (2012) 082503
Kimin Kim et al, Phys. Plasmas 24 (2017) 052506

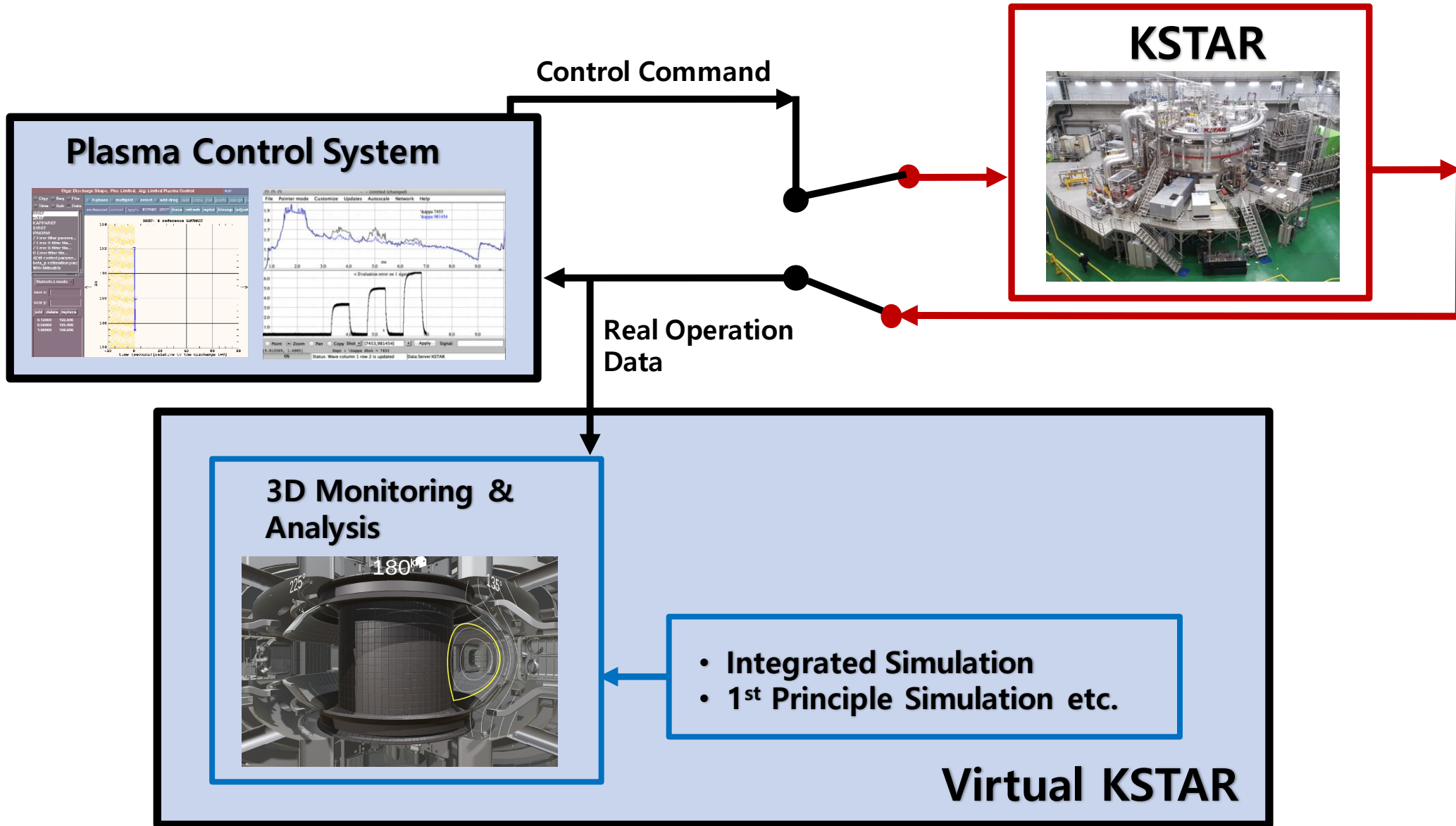
Virtual KSTAR – Interactive Simulation

- For light simulations, V-KSTAR can be working as interactive simulation platform
- In-between shot ECH ray tracing for machine operator
- ➔ Fusion flight simulator as a natural extension

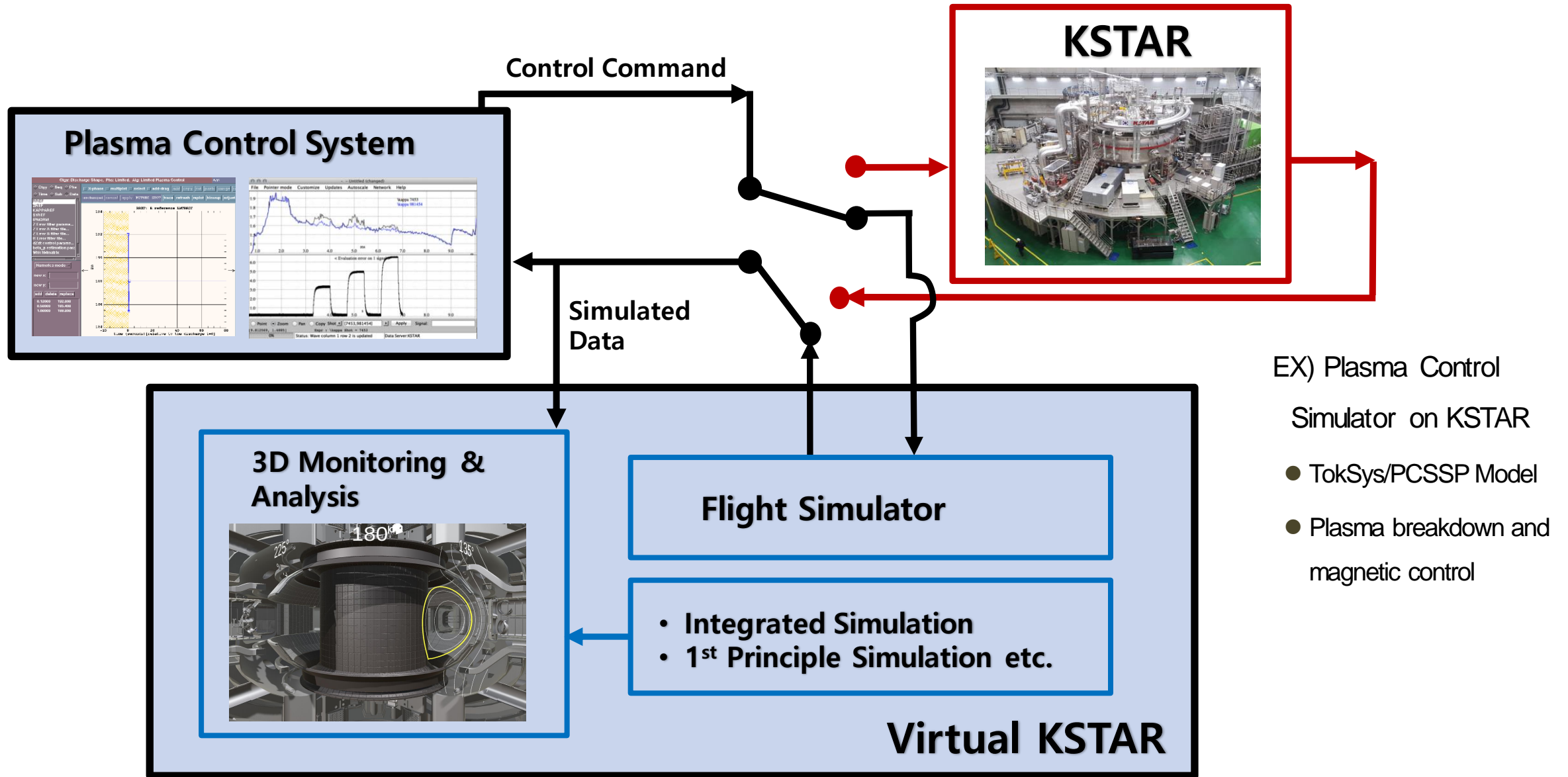


R. Prater et al, Phys. Plasmas 11 (2004) 2349
Minho Woo (KFE), 2021

Overall Data Flow for Machine Operation – Present

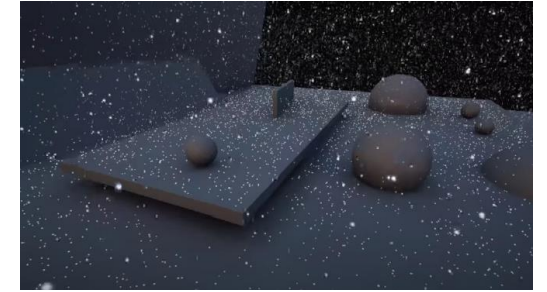
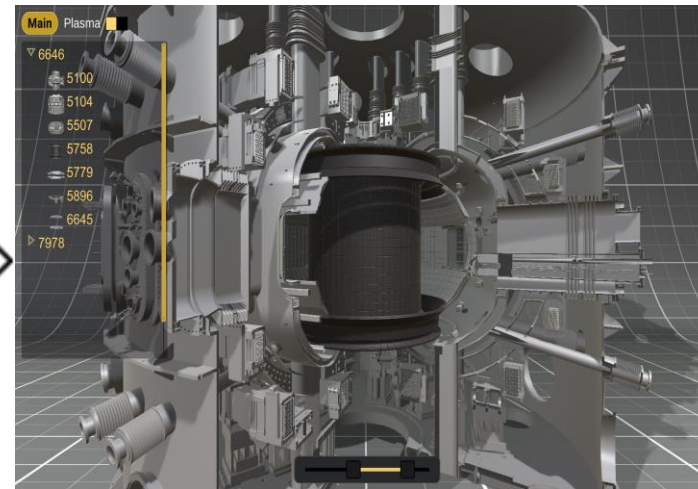
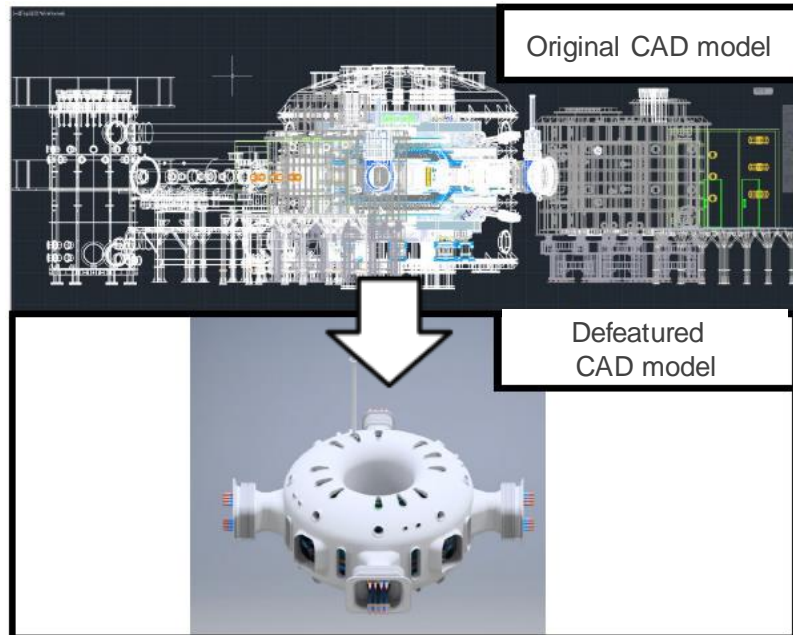


Overall Data Flow for Machine Operation – Future

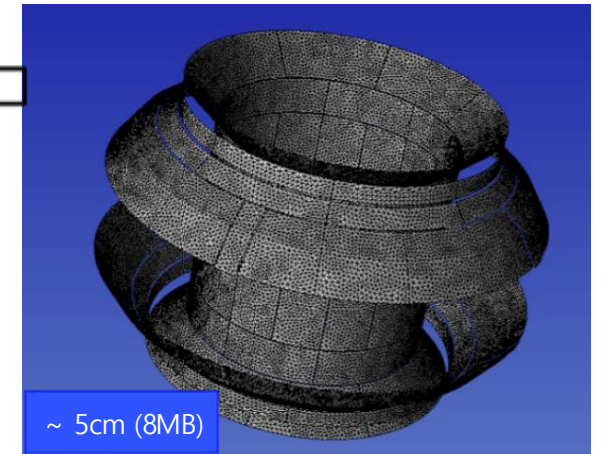


On-Going Developments

- Technologies to efficiently quantify 2D/3D impacts of plasma operation on machine components
 - Efficient 3D collision detection based on game graphic technology
 - Fast query on unstructured grid



Efficient collision detection algorithm
(ex: Snow falling animation by Unreal Engine)



Unstructured mesh covering plasma facing components

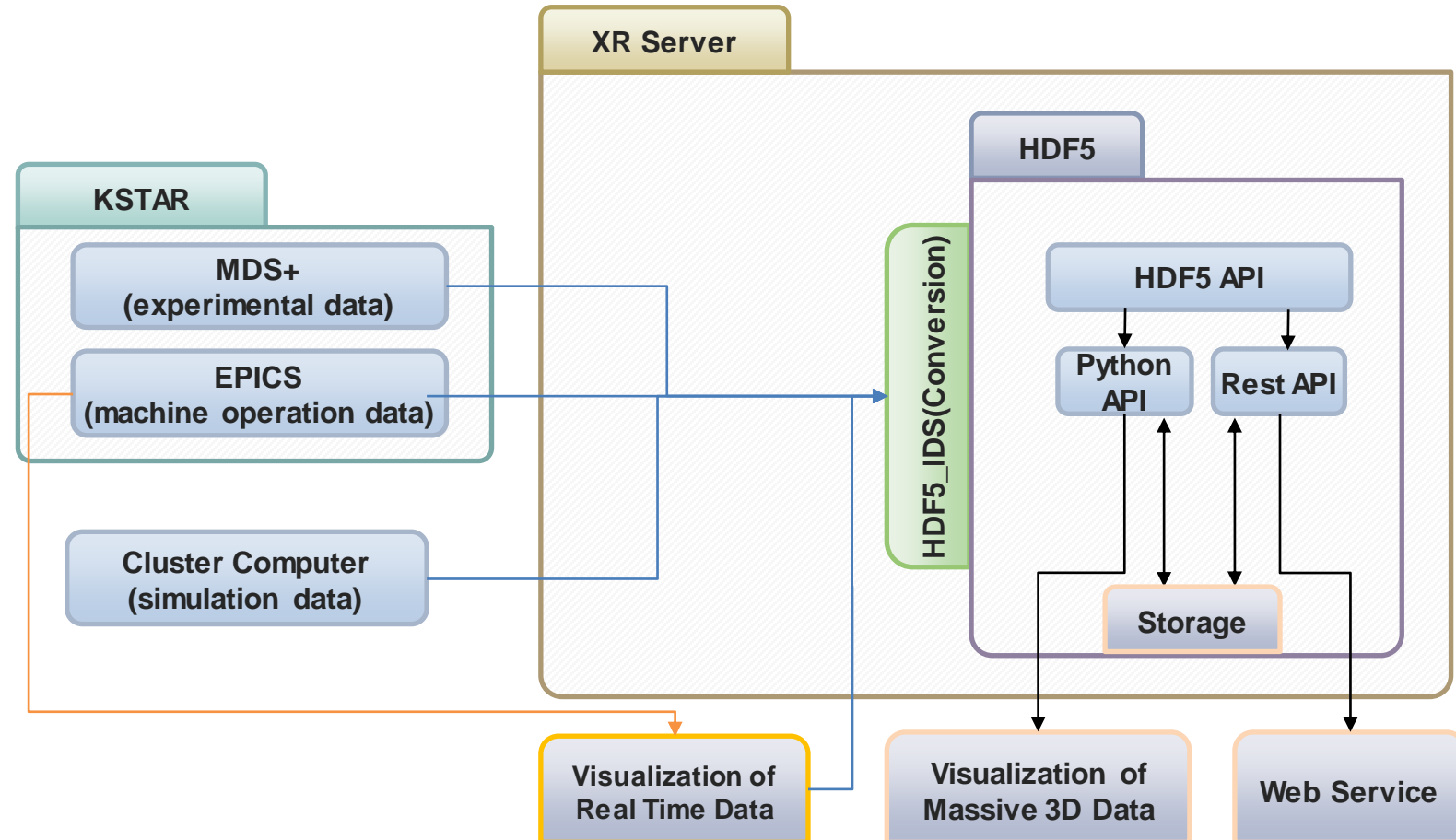
Summary & Discussion

- Digital Twin as a platform to integrate simulation modules for fusion plant flight simulator
 - Development platform allowing systematic test and validation on existing device
 - Natural connection to machine operation/control
- On-going and planned developments for more advanced Digital Twin
 - Efficient collision detection and grid mapping for analysis of fusion data in virtual environment
 - Incorporation of synthetic diagnostics
 - ML technologies for more efficient simulation
- Future development directions (eventually converging)
 - Continuing developments as validation and analysis platform
 - More control-oriented developments integrating (proto-type) flight simulator

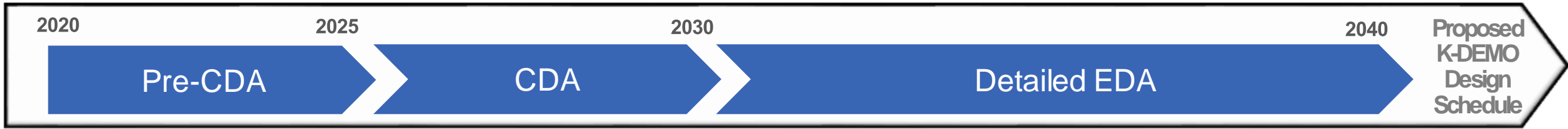
**Many Thanks for
Your Attention!**

Data Sharing & Processing

- Simulation and experimental data processing for integrated visualization
- Many different types and varying sizes... How to implement unified interface?
- HDF5 based APIs for different services
 - APIs for MDS+, EPICS, IMAS, etc.
 - Services for different sizes, speeds



Road Map for Virtual DEMO



1st Step ('21~'27)

V-KSTAR

- Mid-size tokamak simulations and virtualization
- Tokamak simulation validation

2nd Step ('28~'31)

V-ITER

- Burning plasmas & large – size tokamak simulations and virtualization
- AI applications

3rd Step ('32~'35)

V-BBS

- Blanket simulations and virtualization
- Fuel cycles and auxiliary system simulations

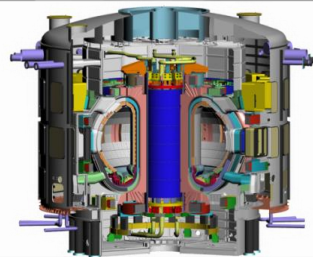
4th Step ('36~'40)

V-DEMO

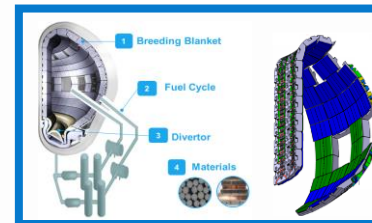
- K-DEMO design data integration → **V-DEMO**
- K-DEMO design verification and optimization



KSTAR



ITER



Blanket

Fusion experimental facilities