

FPL

Fusion and Plasma application
research Laboratory

Workshop on Digital Engineering for Fusion Energy Research | Cambridge MA USA | Dec. 10, 2025

Special thanks to ... **RPI SCOREC & Simmetrix in USA.**

Mesh & 3D Data Analysis Technology for Digital Twin

Department of Nuclear Engineering, UNIST, South Korea

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On behalf of

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LEE, Jae-seok^{2,4}, FIGUERA MICHAL, Darian¹, LEE, Chokang³, KANG, Minjun³, LEE, Jeonggeun³,
KANG, Kyoung-O², KIM, Juhyung², KI, Jae-sug³, GHIM, Y.-c.⁴, KWON, Jae-Min²

¹Ulsan National Institute of Science and Technology (UNIST)



³Tritech corp.



²Korea Institute of Fusion Energy (KFE)



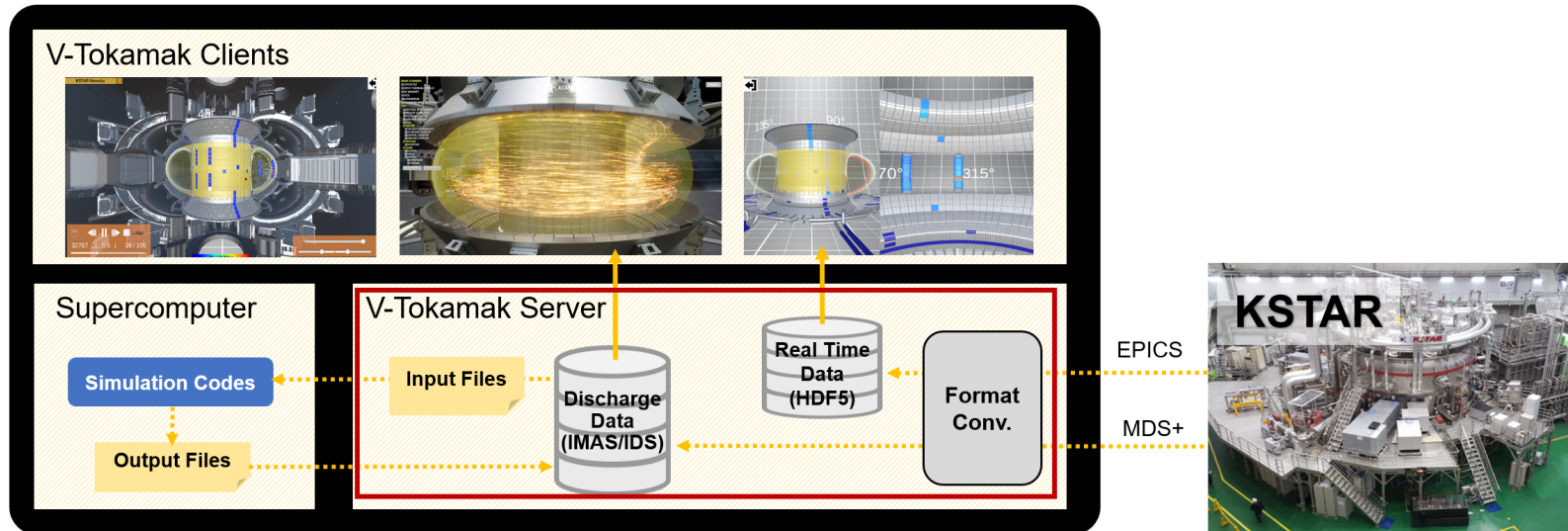
⁴Korean Advanced Institute of Science and Technology (KAIST)



- **Mesh in Digital Twin of a Fusion Reactor in South Korea**
- **Various Mesh Use Cases for High Fidelity Codes, 3D Analysis, Visualization, and Reactor Design**
 - Gyrokinetic codes: gKPSP2 & gKPSP3 - 2D or 3D mesh for reactor cross-section and volume, resp.
 - Eddy current code: ERRHAI – 3D mesh for Vacuum Vessel
 - Particle Orbit code for Neutron Beam Injectors: NuBDeC – 2D surface mesh of plasma facing components in 3D
 - Particle Orbit Code for Anisotropic pressure: POCA – 2D surface mesh of plasma facing components in 3D
 - Ly-alpha diagnostics – 2D surface mesh of plasma facing components in 3D
 - Unreal - Mesh application for visualization
 - Automated Fusion Reactor Designer: AutoFRD – CAD-Mesh-Sim. workflow

Motivation

- Virtual Tokamak Platform - WILL (Versatile Virtual platform for Integrated fusion simuLation and anaLysis)
 - Key component is the data framework to handle various data (operation, experiment, simulation etc.)
 - Targeted on existing operational machines with little 3D model changes → limitation for machine in design phase



Jae-Min Kwon et al, Fusion Eng. Des. 184, 113281 (2022)
Jae-Min Kwon et al, IEEE Trans. Plasma Sci. 52, 3910 (2024)

- Discrete space to solve governing equations for high fidelity code
- 3D visualization of physics quantities on CAD design through tessellation
- Data transfer platform for multi-physics codes to interact
- Reactor design optimization by physics simulators : A bridge between Engineering and Physics



[Thu. 2:00 pm (Talk)] Dr. Chanyoung Lee (to be presented by [Dr. Jae-Min Kwon](#))

Virtual Tokamak for Integrated Physics and Engineering Analysis

PUMI (Parallel Unstructured Mesh Infrastructure)



RPI SCOREC

Scientific Computation Research Center

21 followers

<http://www.scorec.rpi.edu/>

<https://scorec.rpi.edu/>

<https://github.com/SCOREC/core>

Overview Repositories 107 Projects Packages People 1

Pinned

core Public

for CPU

parallel finite element unstructured meshes

C++ 190 65

pumi-pic Public

support libraries for unstructured mesh particle in cell simulations on GPUs and CPUs

C++ 41 16

omega_h Public

for GPU

Forked from [sandialabs/omega_h](#)

Simplex mesh adaptivity for HPC

C++ 2 11

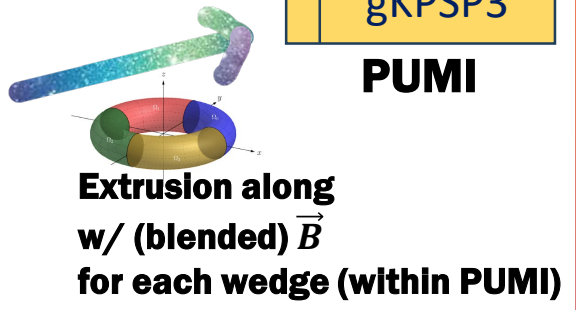
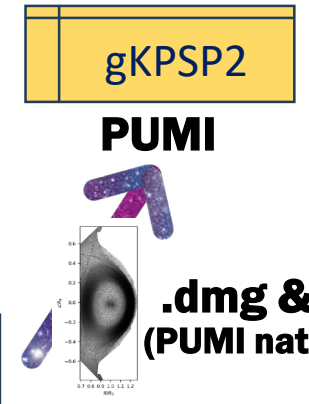
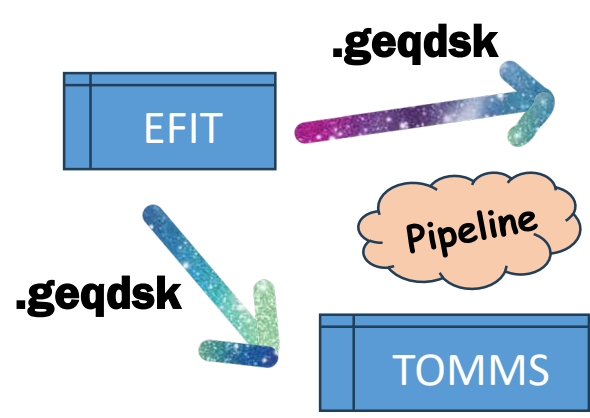
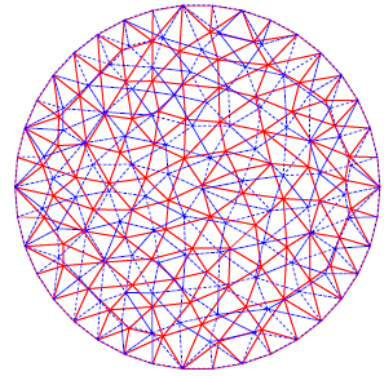
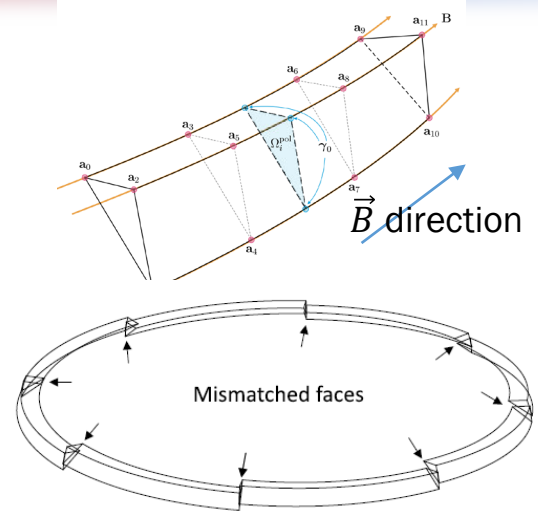
CPU-based highly performant unstructured mesh handler for parallel computing

Denoted with below figure in this talk

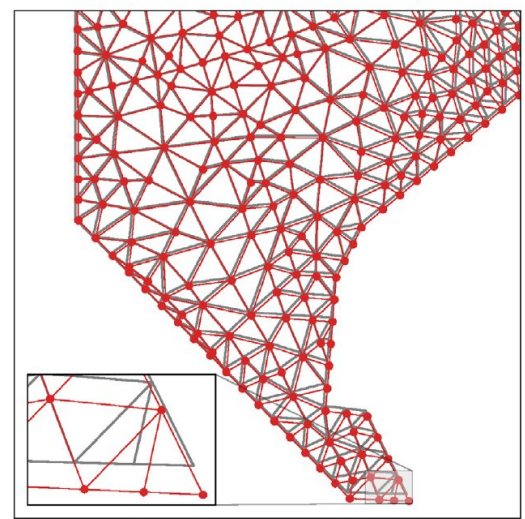


[Fri. 11:20 am (Talk)] Prof. Mark Shephard

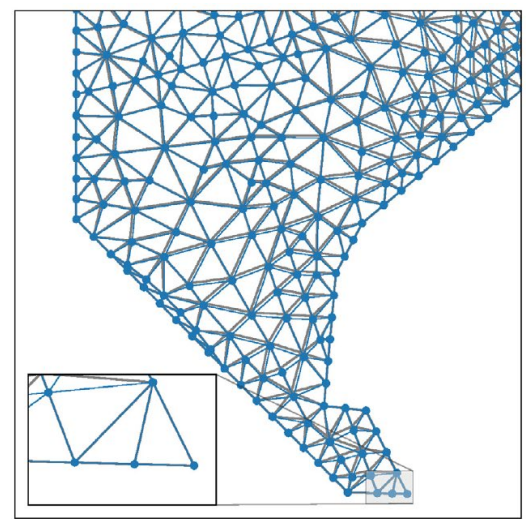
Tools to Support Geometry and Meshing Needs for Fusion Energy System Simulation Codes



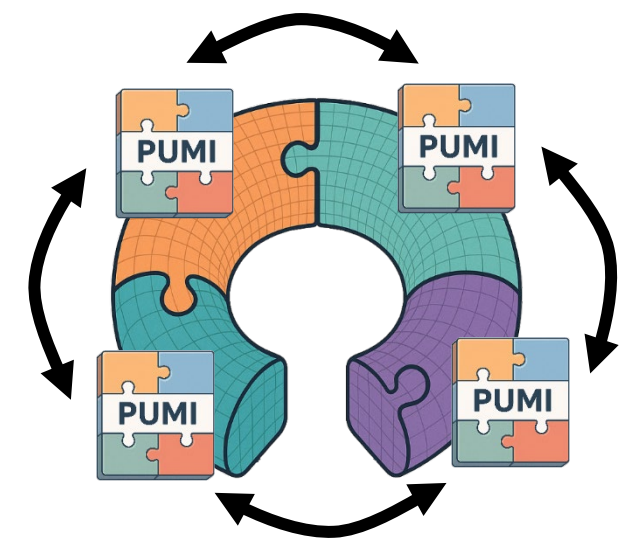
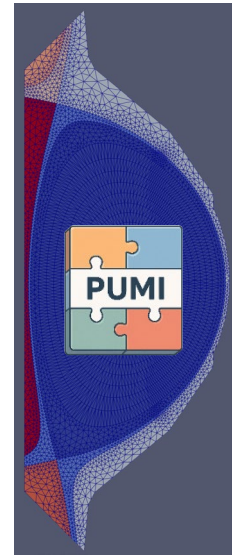
PUMI & SimModeler Suite



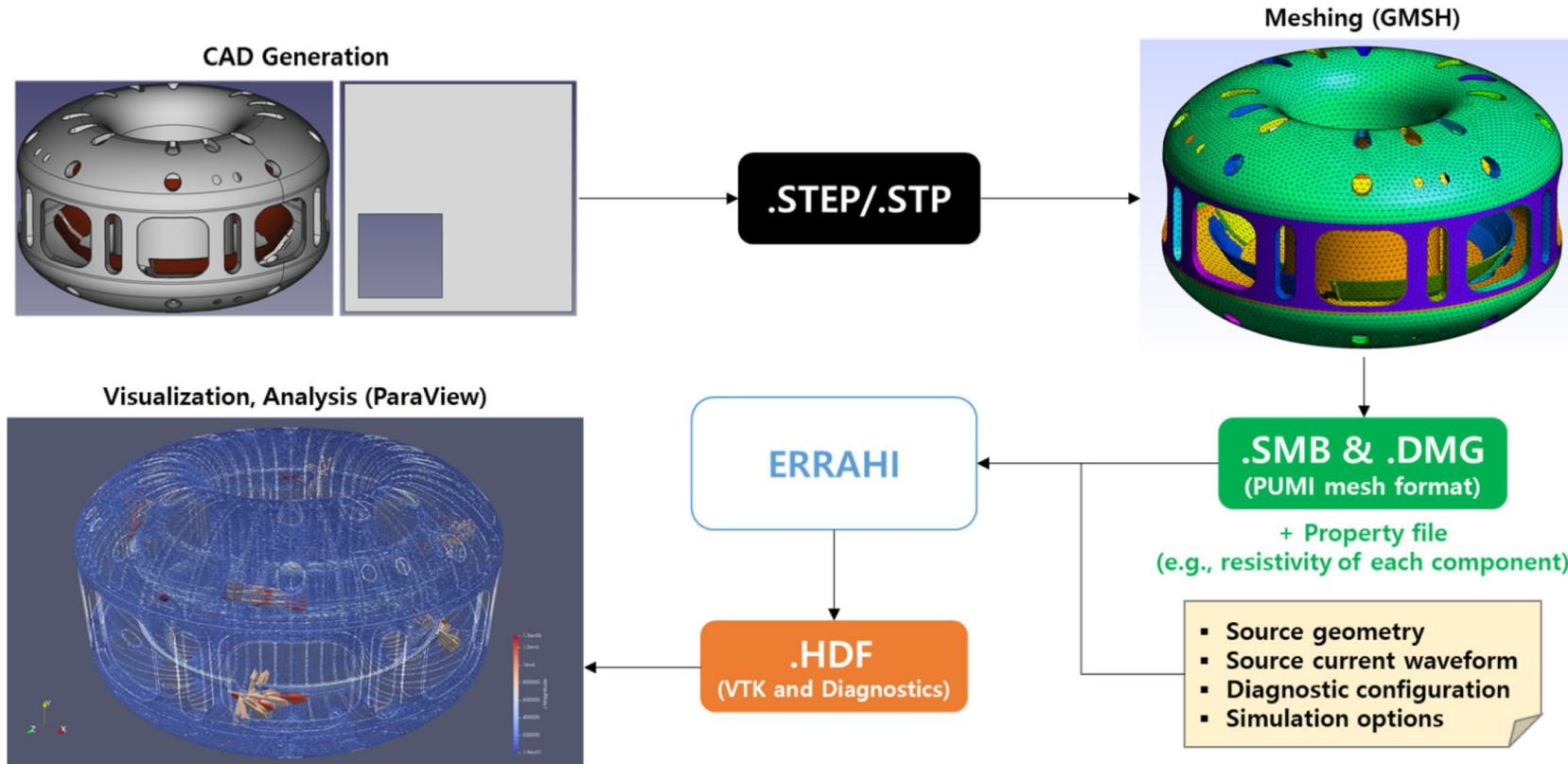
Field-following mesh blended with boundary geometry



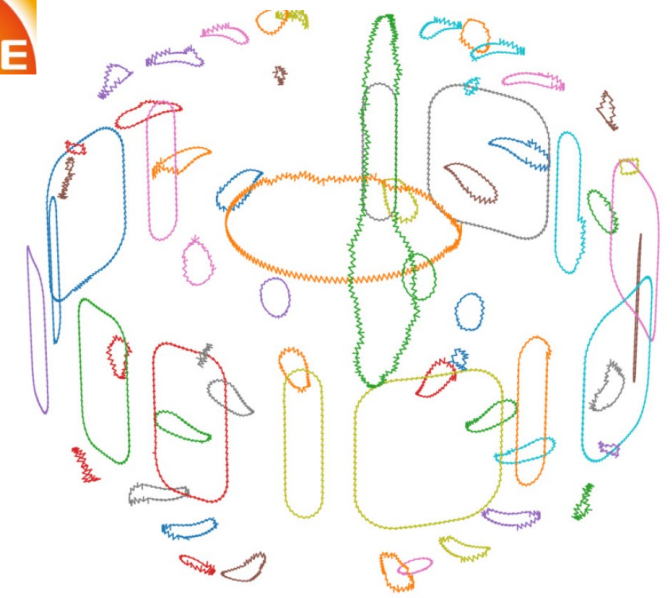
Single mesh-Integrity
Multiple Domains
(gKPSP2)



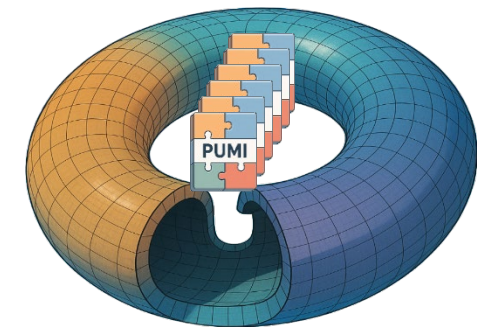
Multiple mesh-Integrities
Multiple Domains
(gKPSP3)



Pipeline of ERRHAI mesh creation and utilization



Finding short cycles in parallel for a given mesh



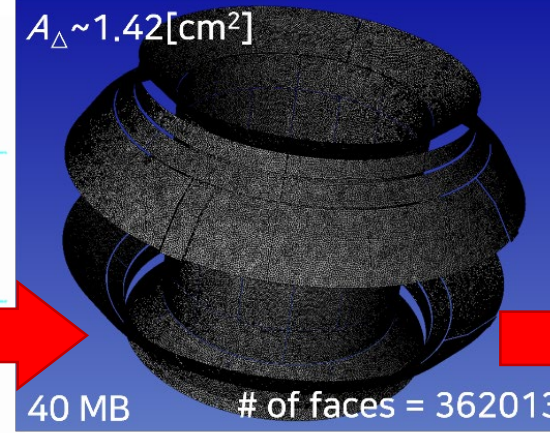
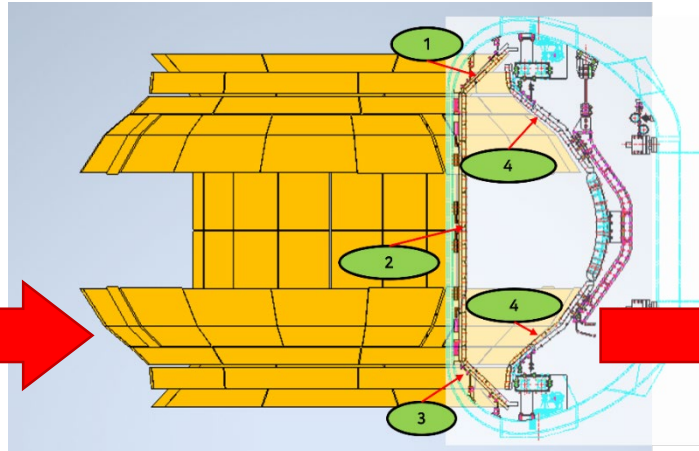
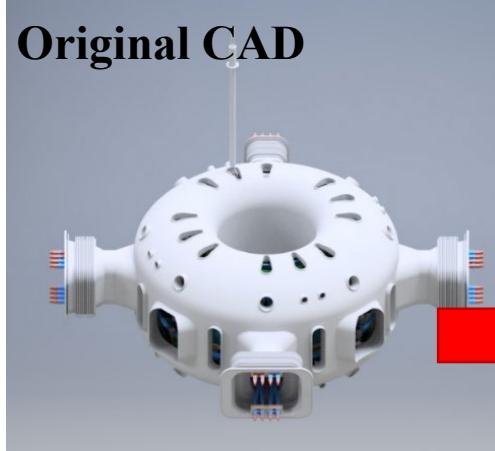
**Multiple mesh-Integrities
Single Domain**

3D simulation & analysis with CAD model - Tally with Fast Collision Detection

Taeuk Moon et al., Comput. Phys. Comm. 309, 109490 (2025)



Visualization: Kitware ParaView
@NuBDeC



AUTODESK Inventor
Defeaturing

Simmetrix
Simmodeler

Grid construction

SCOREC
Mesh handling API PUMI

C++ mesh handling library

Collision detection

Broad phase

Exclude non-collision case

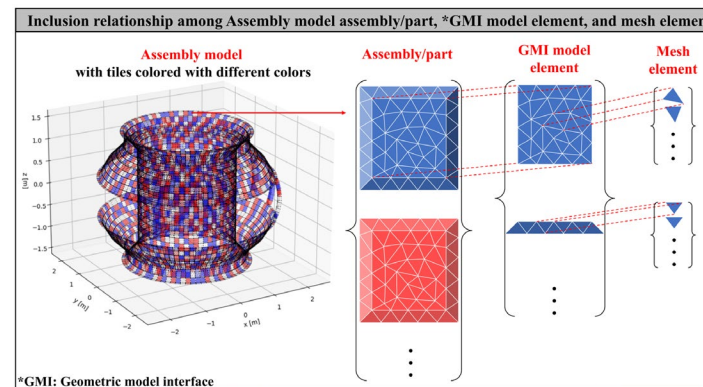
1. Analytic inside-outside routine
2. Uniform grid for data structure



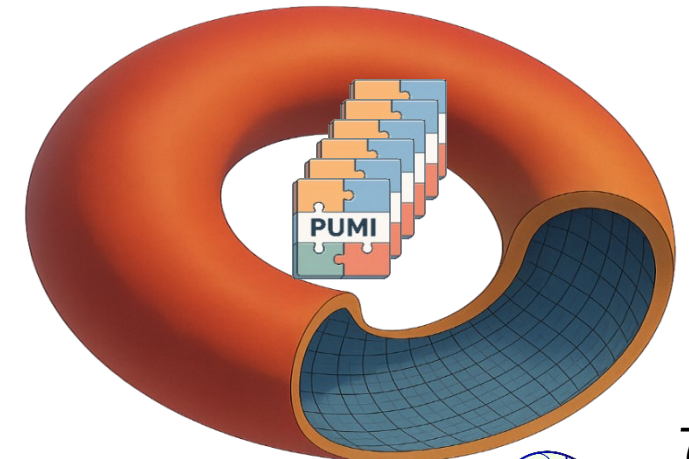
Narrow phase

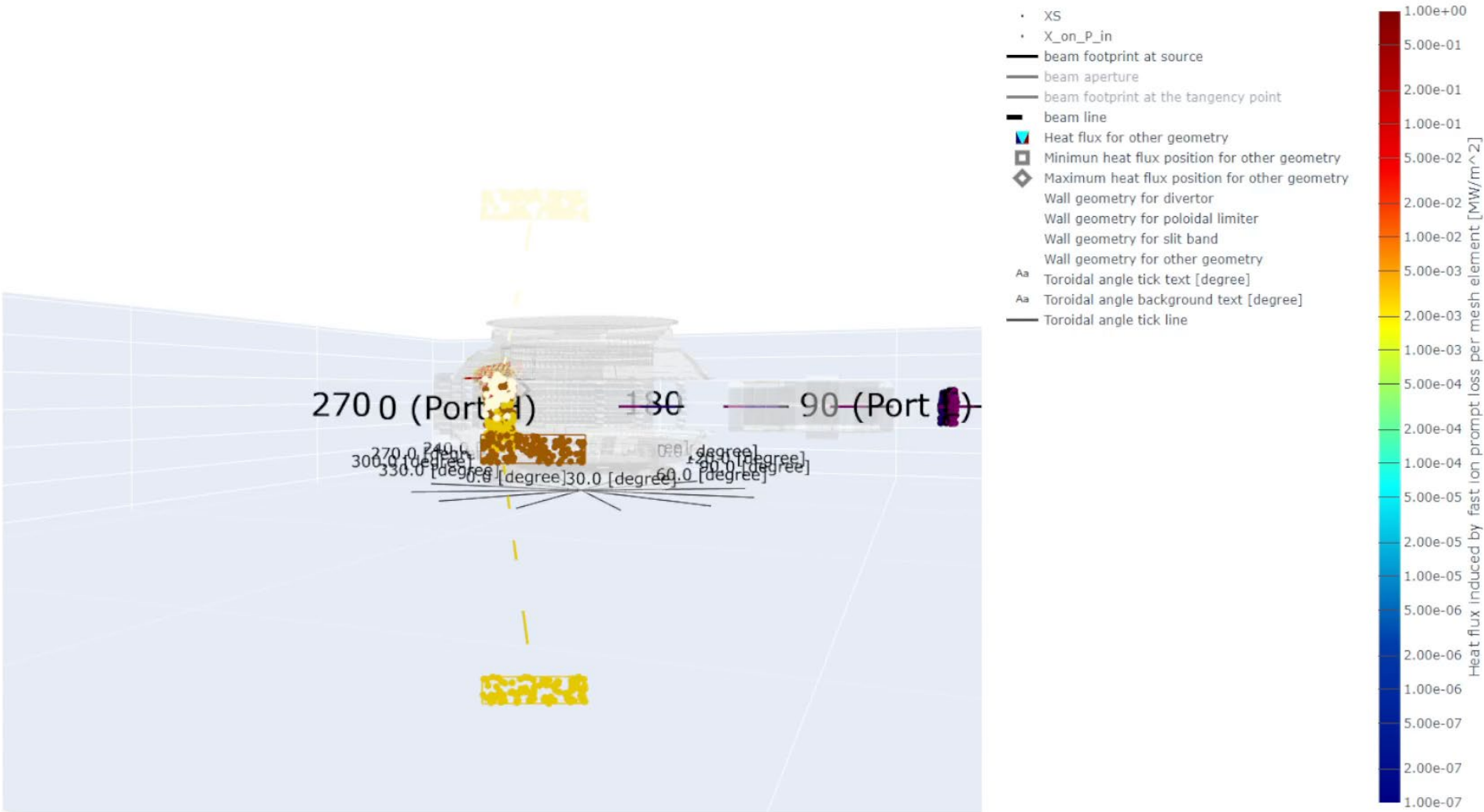
Detect collision point

- Ray-casting

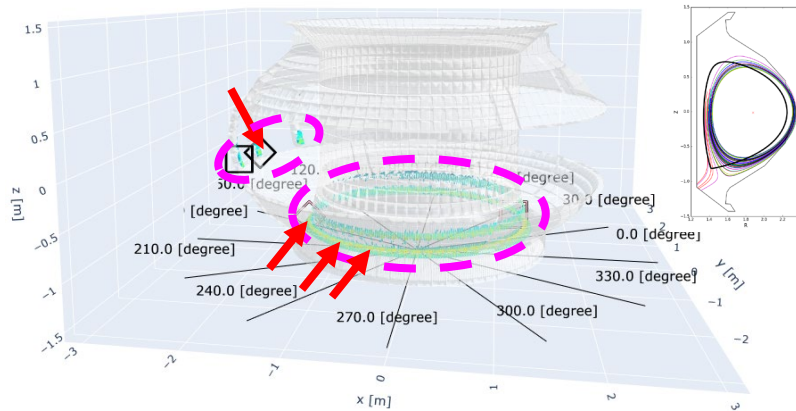
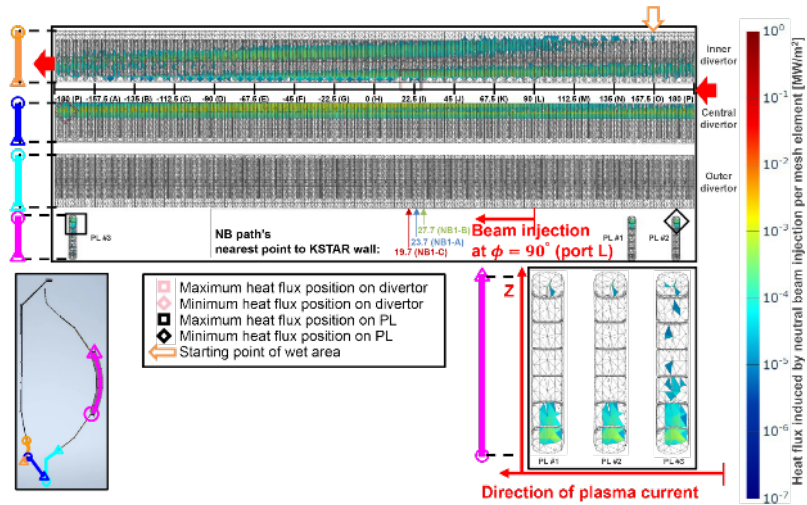


**Geometric classification
for per-tile counting**



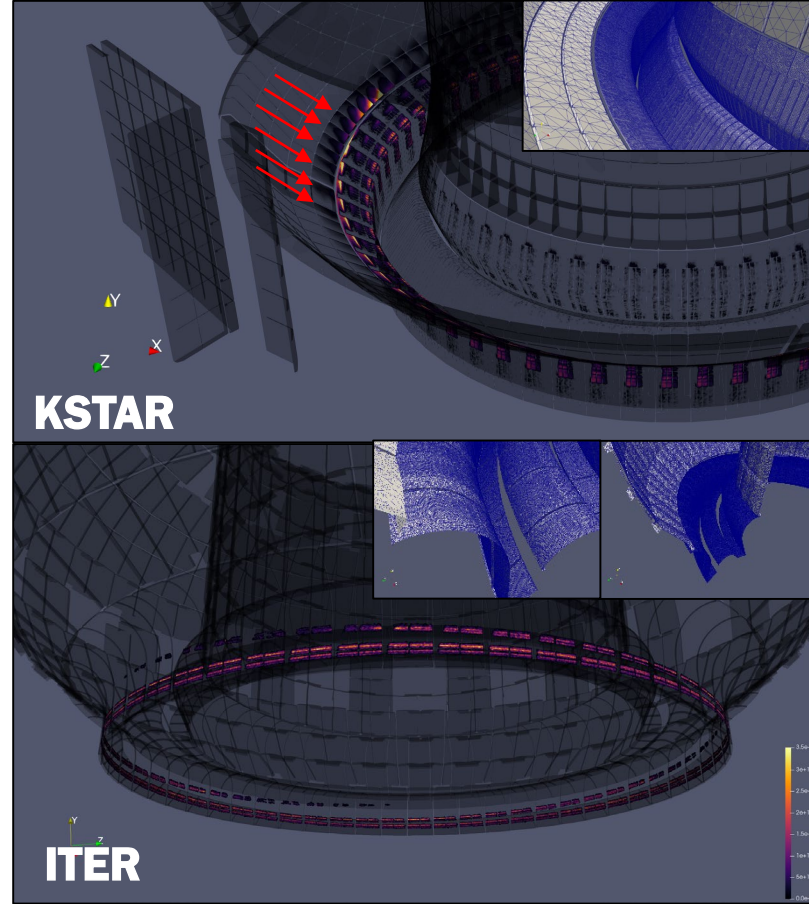


NuBDeC / POCA / Lyman- α diagnostics



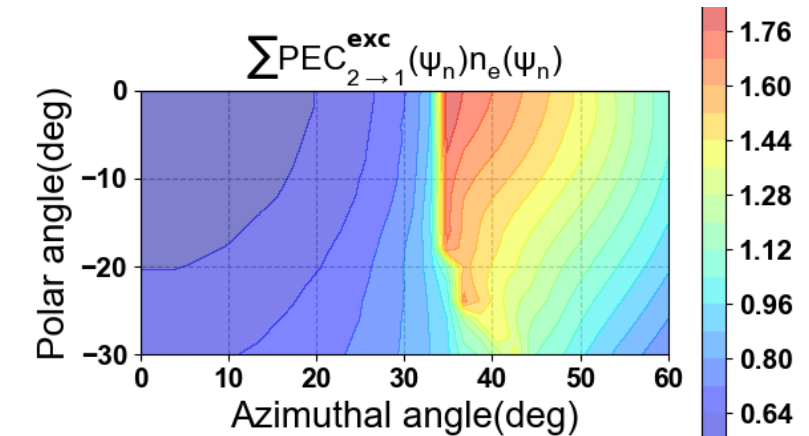
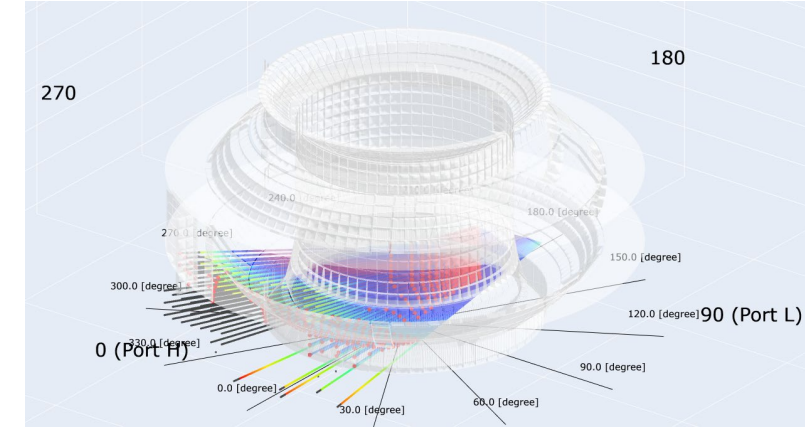
NuBDeC: Prompt Loss of Fast Ions generated by NBI

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



POCA : striation footprints by 3D magnetic perturbation

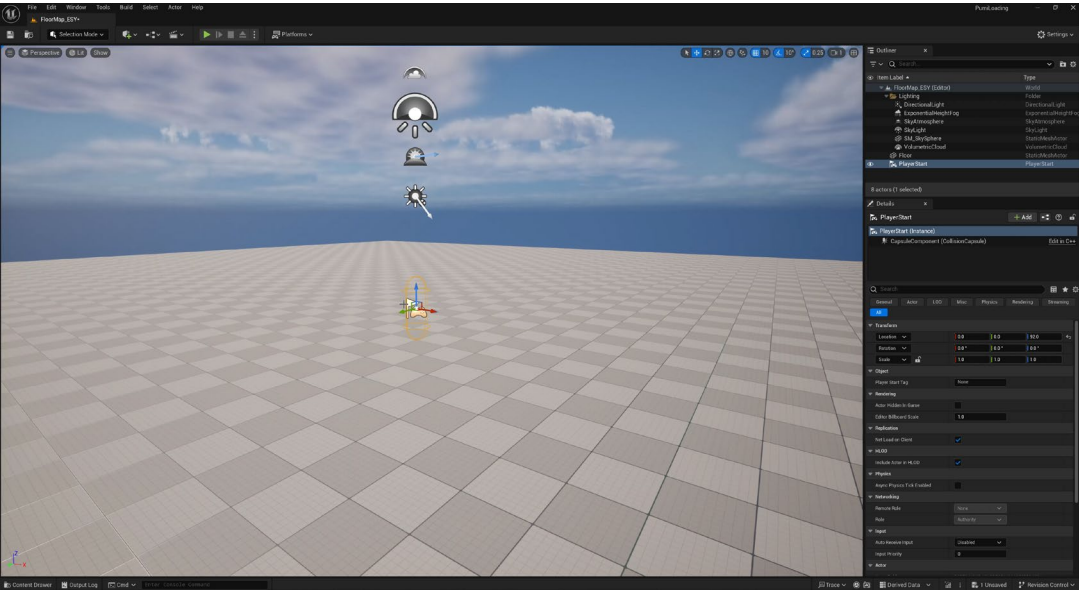
Kimin Kim et. al., Physics of Plasmas 19, 082503 (2012)



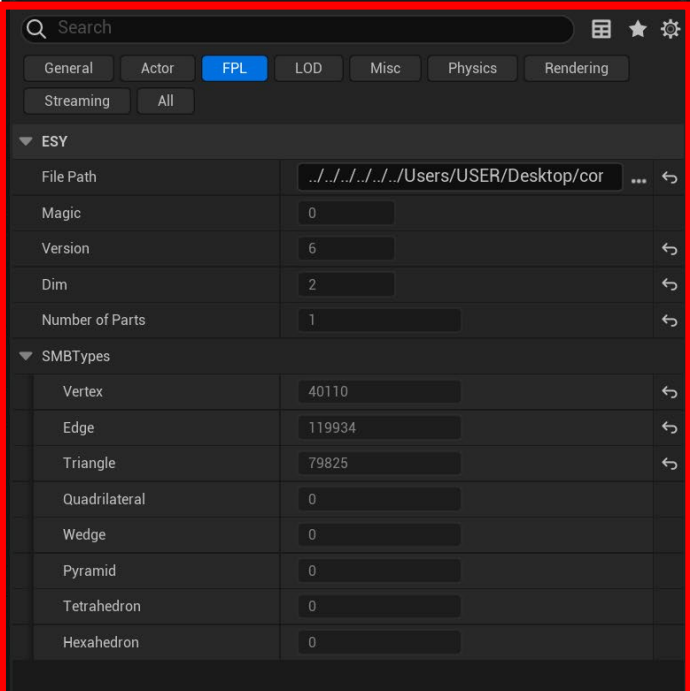
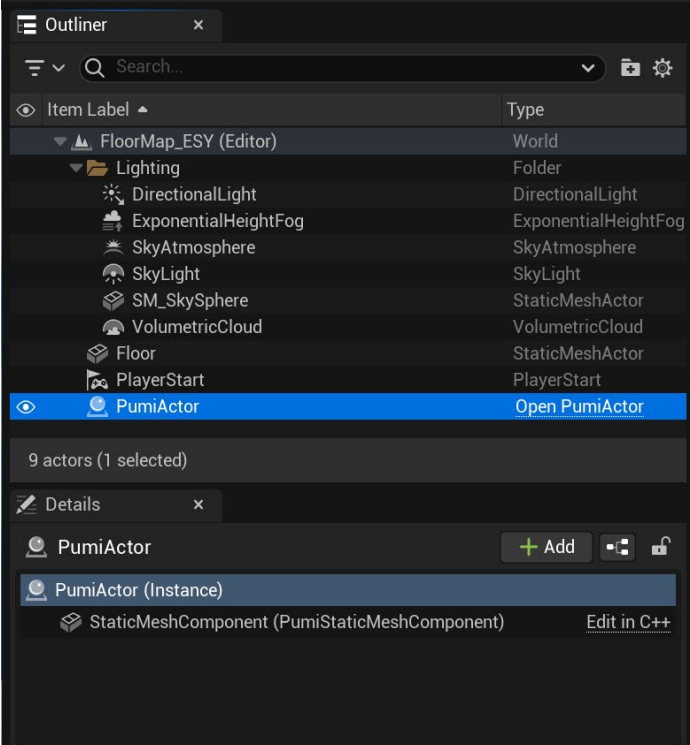
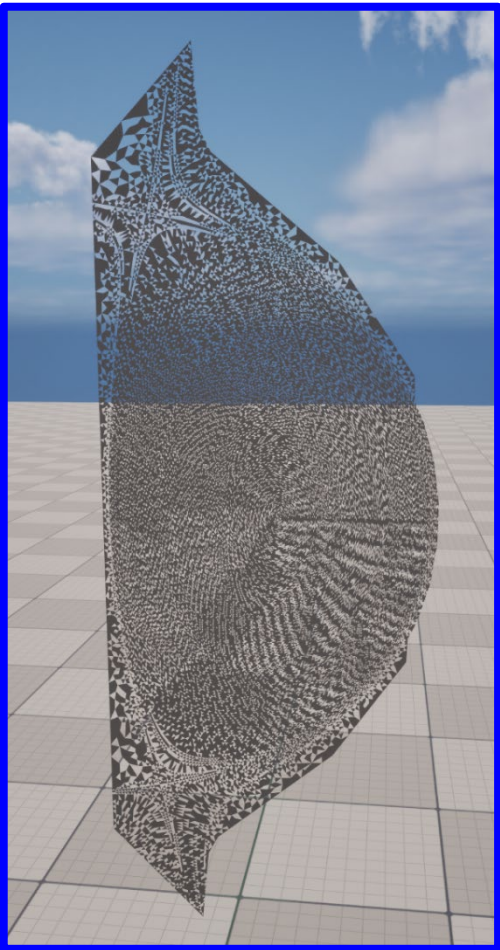
Ly- α (upper) signal line scan and (lower) image of scan

Lee, Jae-seok, et al. APS-DPP 2025

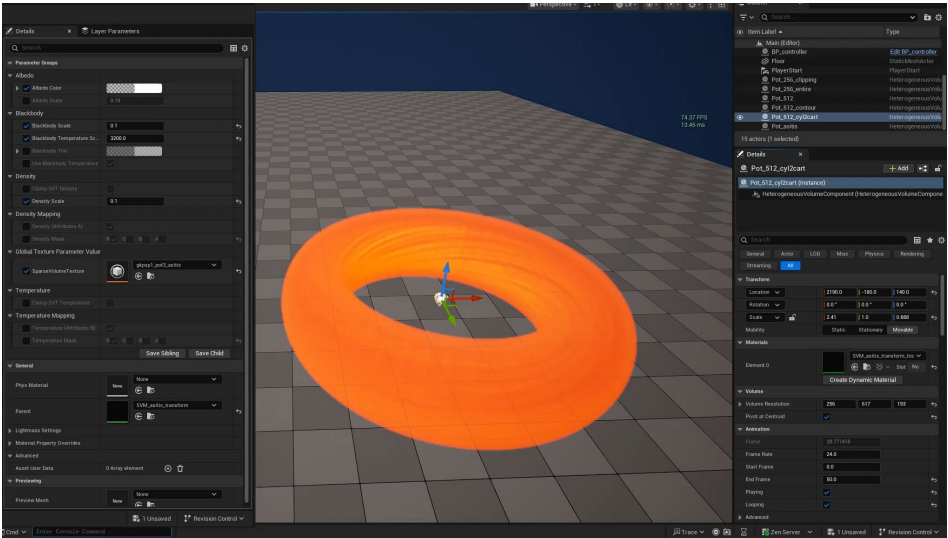
Interactive 3D analysis with Unreal



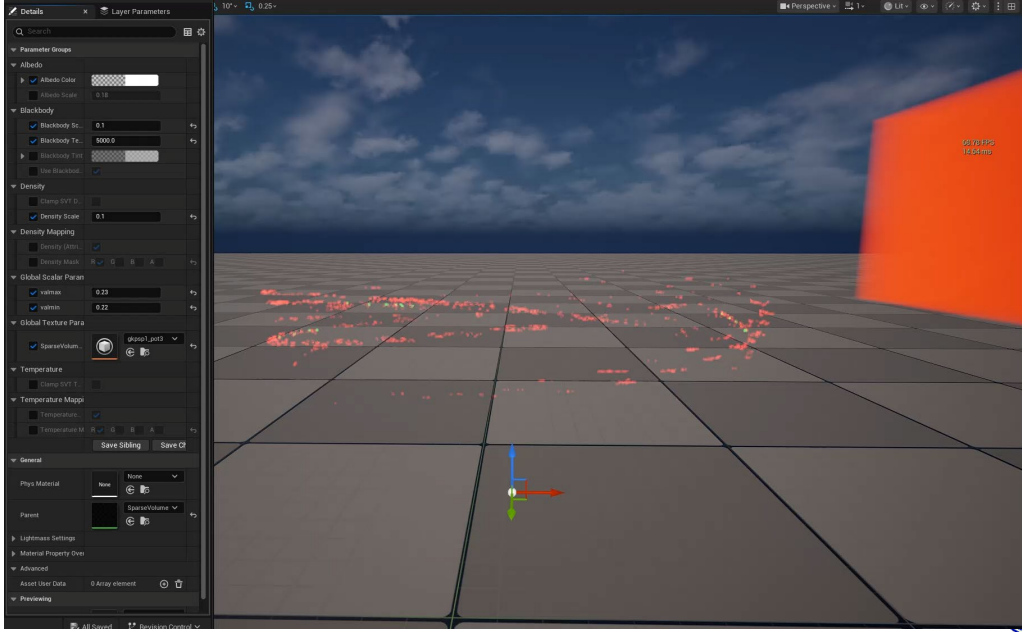
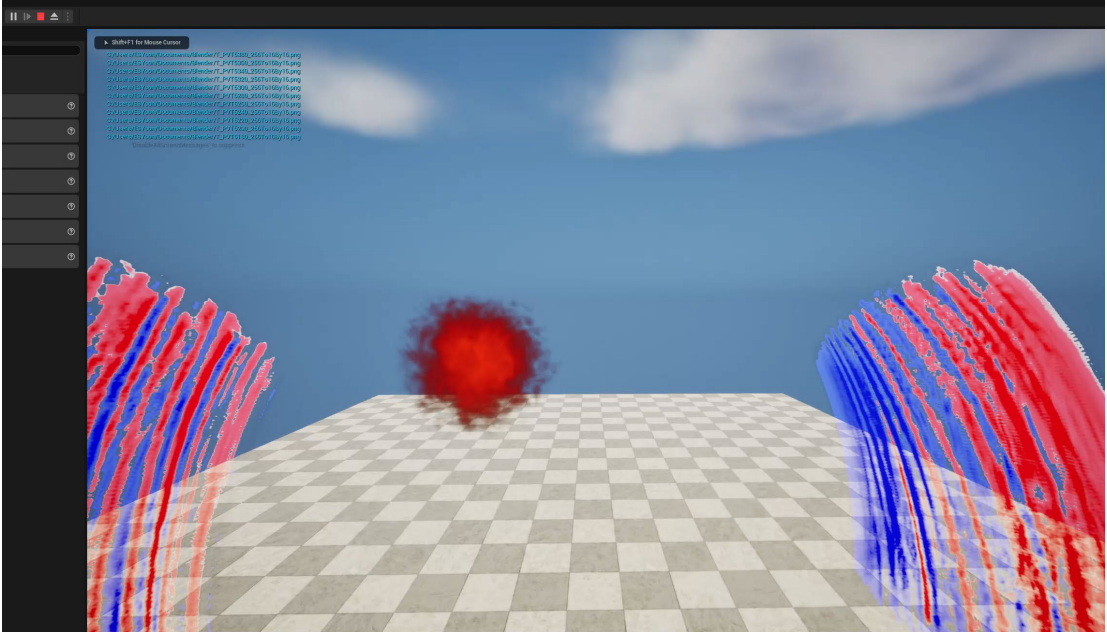
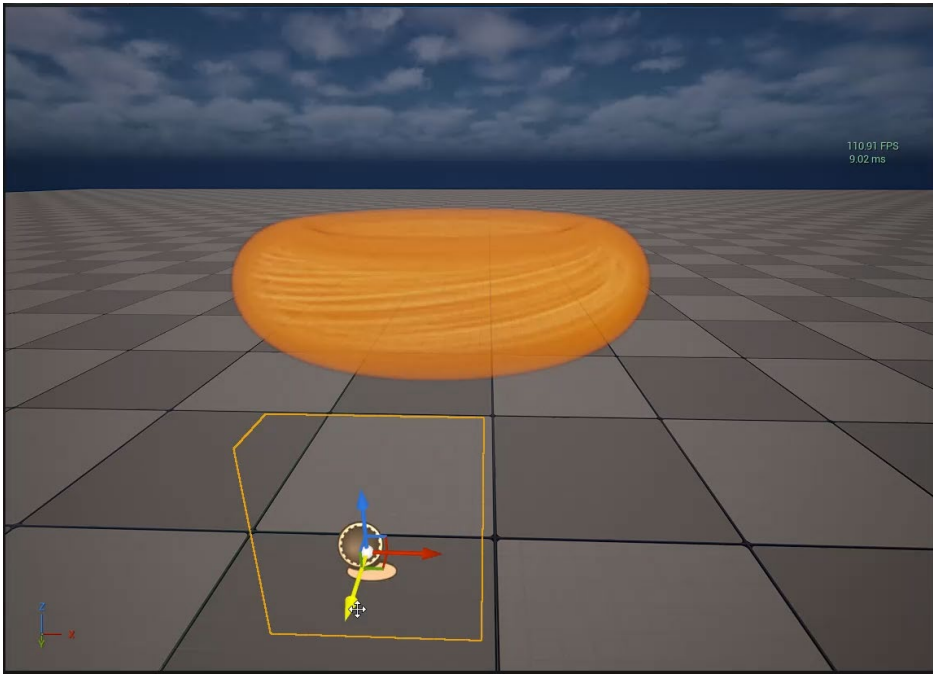
Loading PUMI mesh in Unreal
to visualize scientific results



Interactive 3D analysis with Unreal - 3D Volume Rendering



256x617x193
~ 30M
> 60~70 FPS

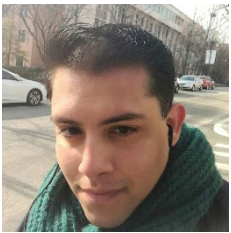
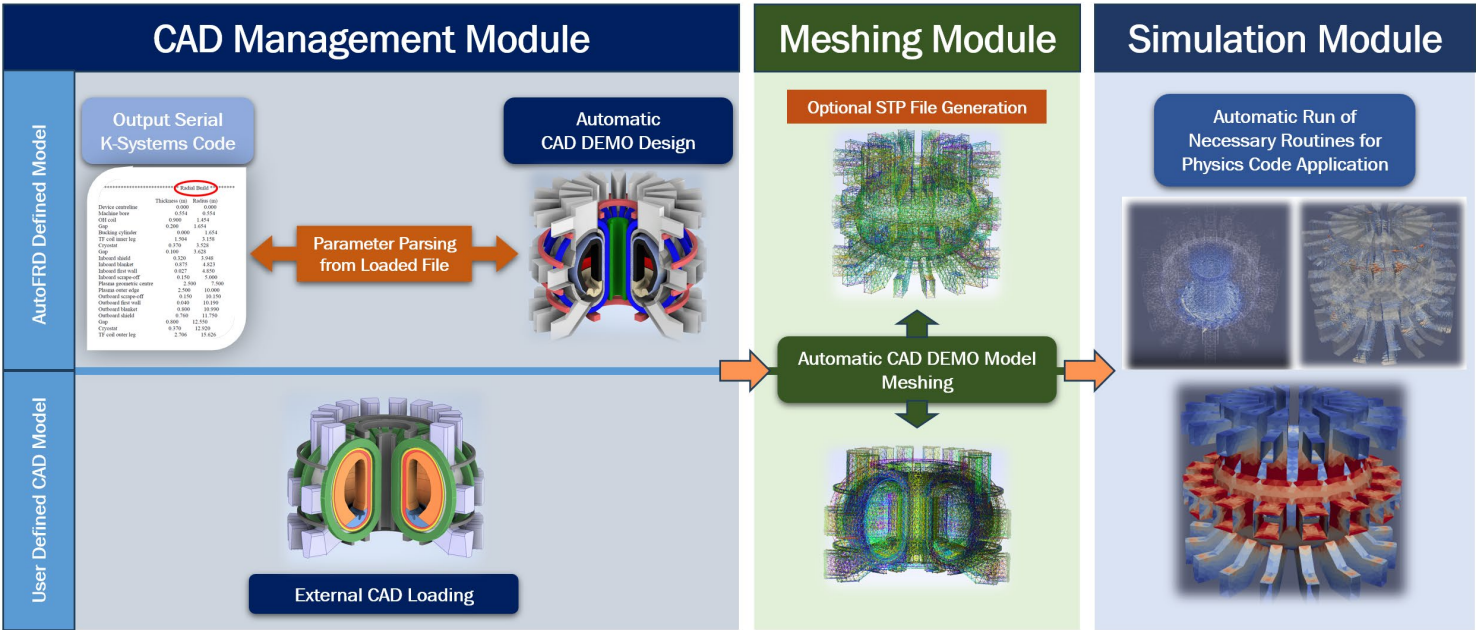


Visualization of electrostatic potentials from plasma turbulence simulation using gKPSP

Automated Fusion Reactor Designer (AutoFRD): CAD-Mesh-Sim.



- Targeting automatic 3D reactor design
- Python-based framework
- Input: K-Systems 1D radial build / STEP
- CAD: CadQuery & OCP (OpenCASCADE)
- Mesh: Gmsh
- Under development since 2024
- Supported by KFE

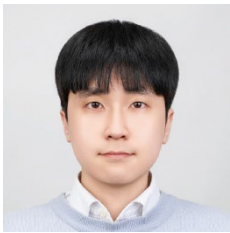


Darlan Figuera
(Grad.)

Overall framework/
CAD/Mesh/Interface
/Optimization

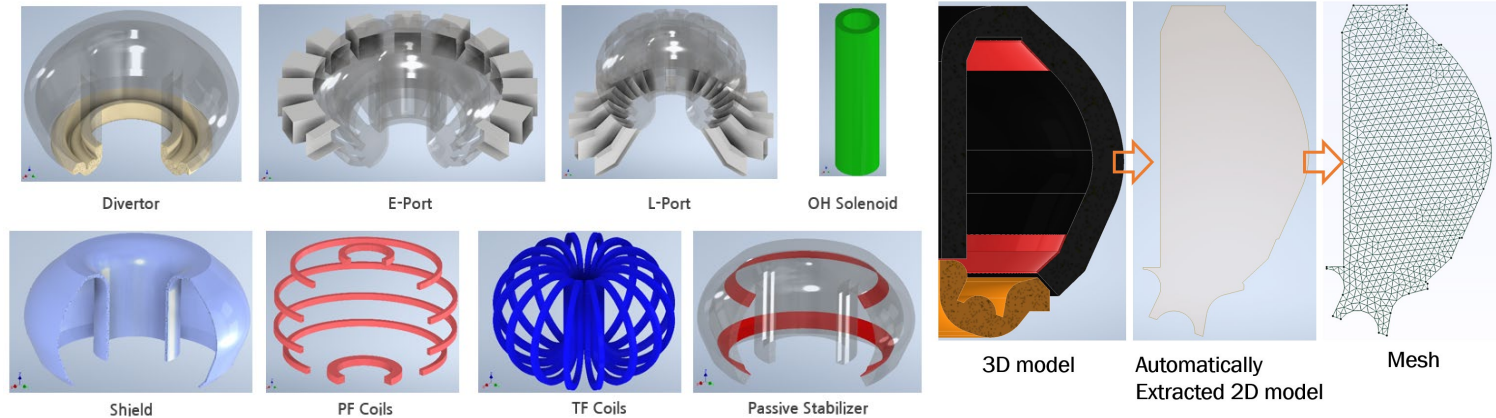


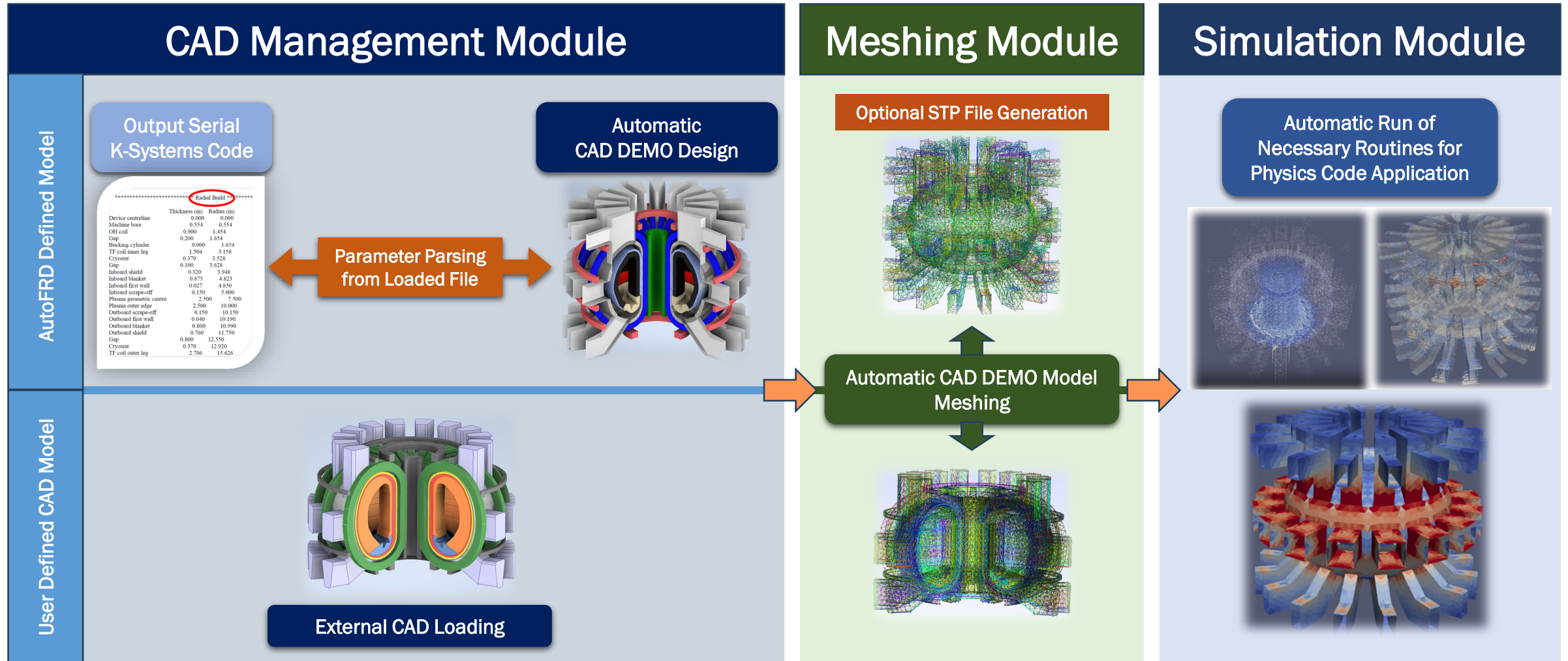
Wonjun Tae
(Post-Doc.)

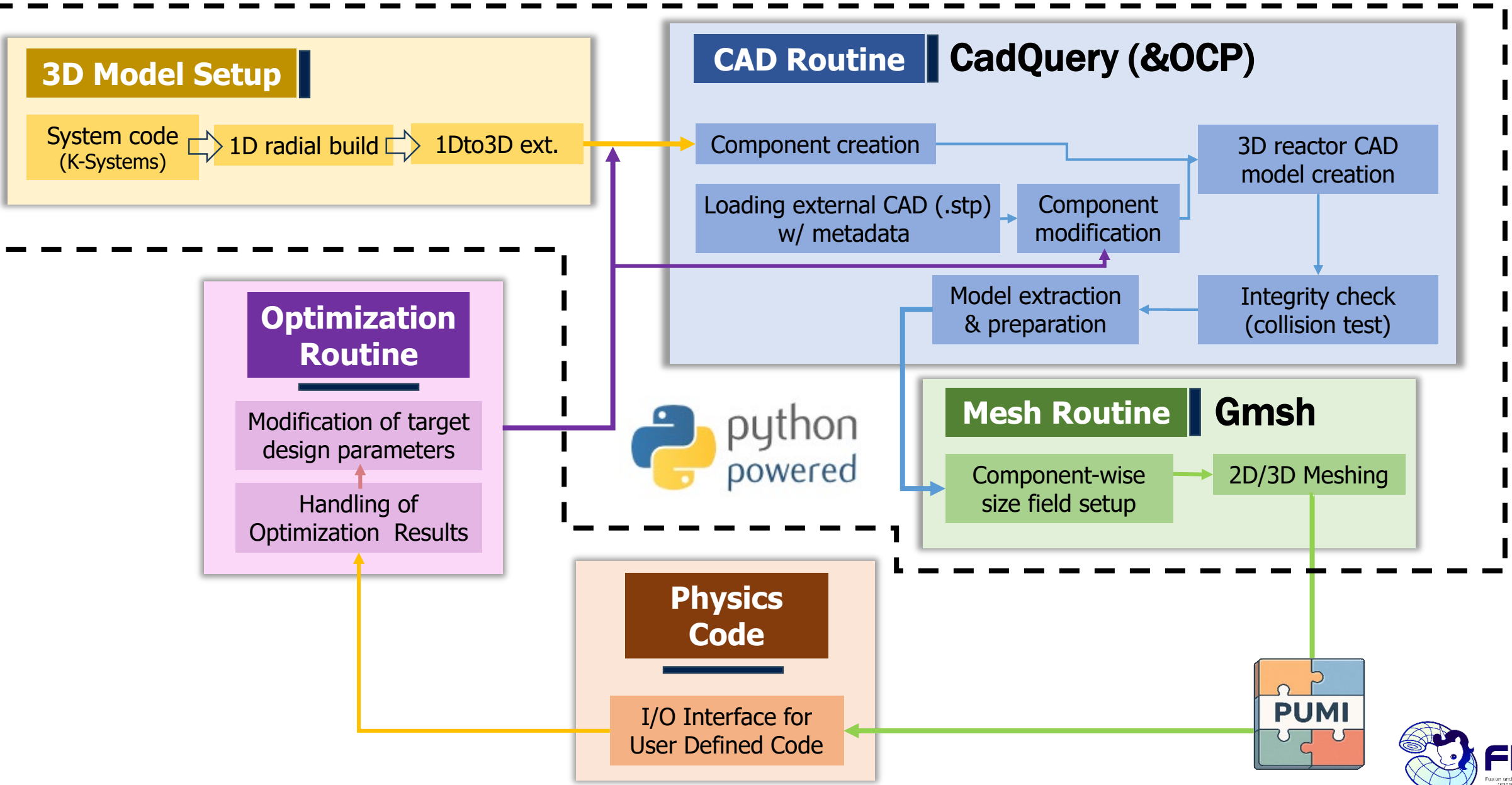


Boseong Kim
(KFE)

Optimization







- Korea has been developing a digital twin, WILL.
- Various applications of mesh technology for WILL are still ongoing.
- Mesh application on GPU needs to be explored.
- Data transfer through mesh between codes sharing same domain within error tolerance would be needed.
- Your interest and collaboration are highly appreciated. (E-mail to esyoon@unist.ac.kr)

Thank you.

See also ...

[Wed. 2:30 pm (Talk)] Prof. Jacob Merson

PCMS: A Geometry and Discretization Aware Multi-physics Coupling Tool for Fusion Devices

[Wed. 4:00 pm (Poster)] Dr. Jae-Min Kwon

Development of a data framework for conceptual design of fusion reactor

[Thu. 2:00 pm (Talk)] Dr. Chanyoung Lee (to be presented by Dr. Jae-Min Kwon)

Virtual Tokamak for Integrated Physics and Engineering Analysis

[Fri. 11:20 am (Talk)] Prof. Mark Shephard

Tools to Support Geometry and Meshing Needs for Fusion Energy System Simulation Codes