激光聚变研究中心
LASER FUSION RESEARCH CENTER

Design of diagnosis integrated management and control system and application of AI technology in laser experiment

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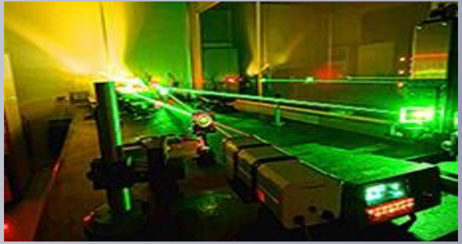
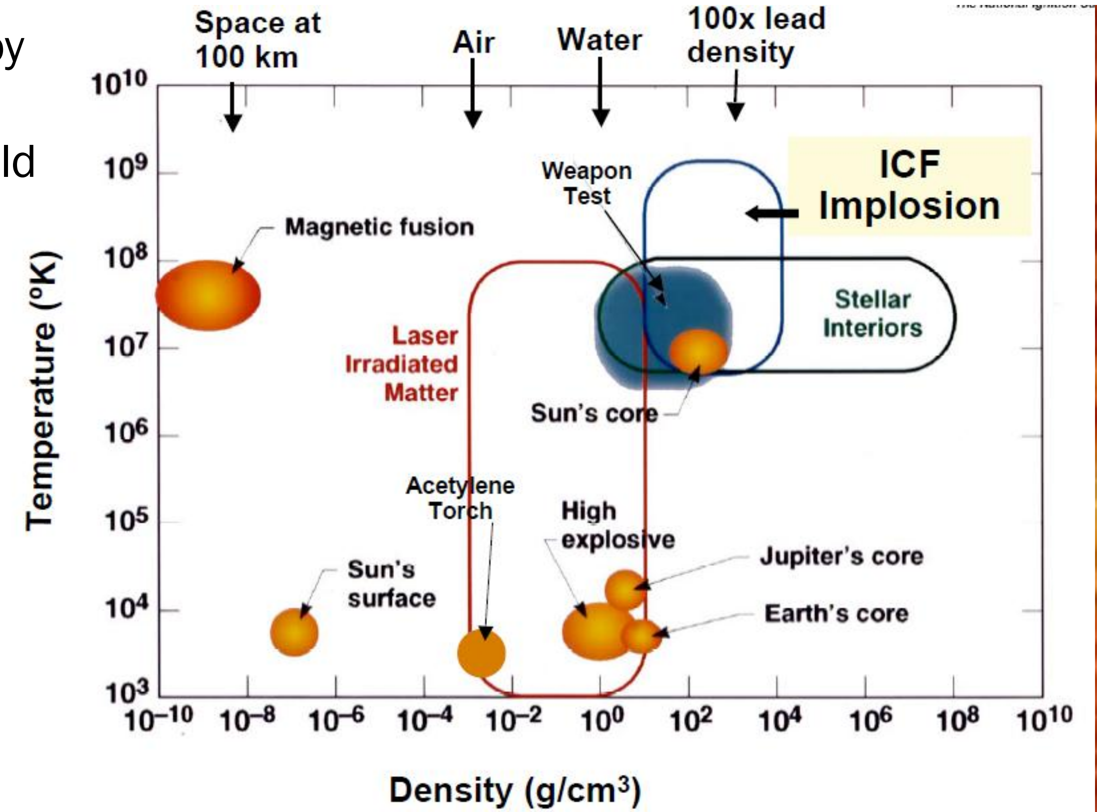


Items

- Target diagnostics of ICF
- Framework of the ICCS
- Applications of AI
- Conclusion

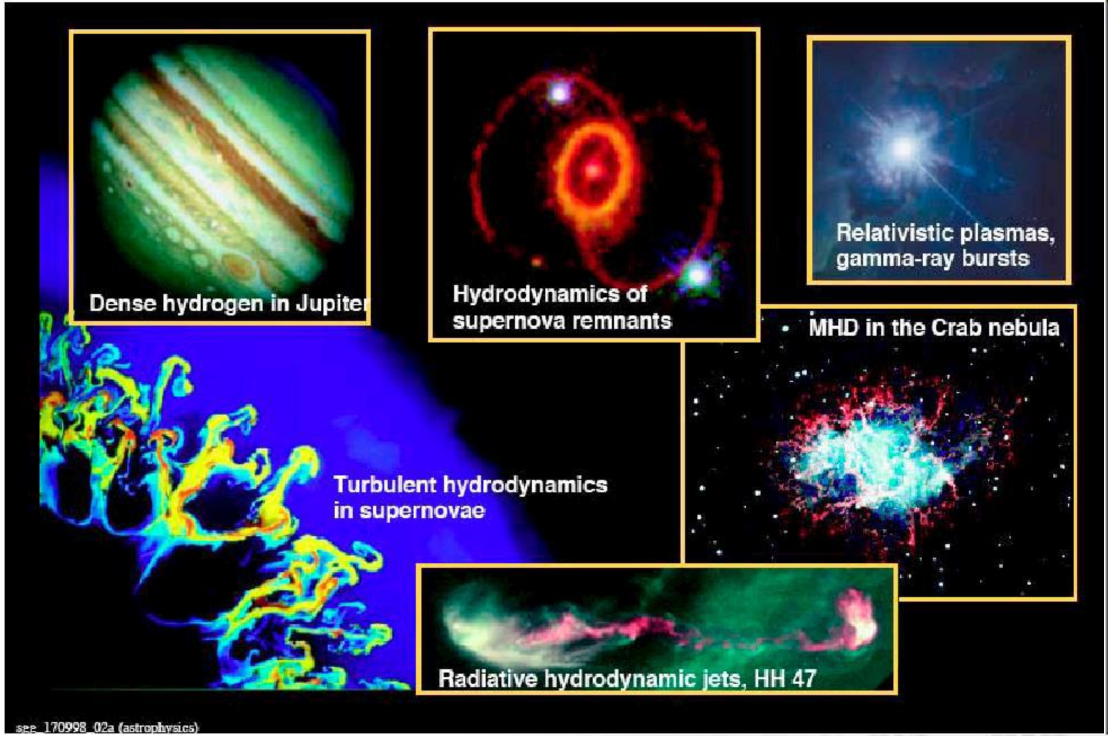
Varied ways to the controlled fusion

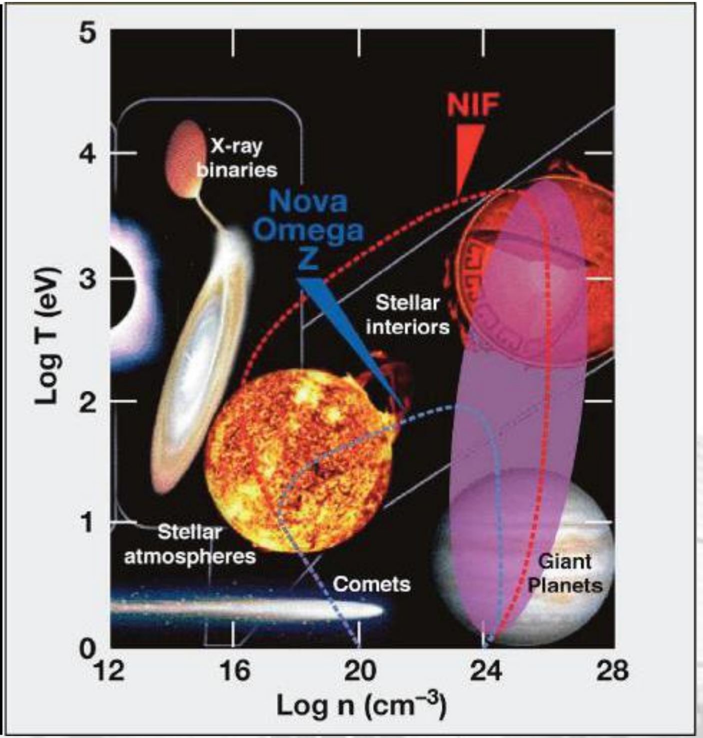
Enhance t by the strong magnetic field
t~s
R~m
MCF



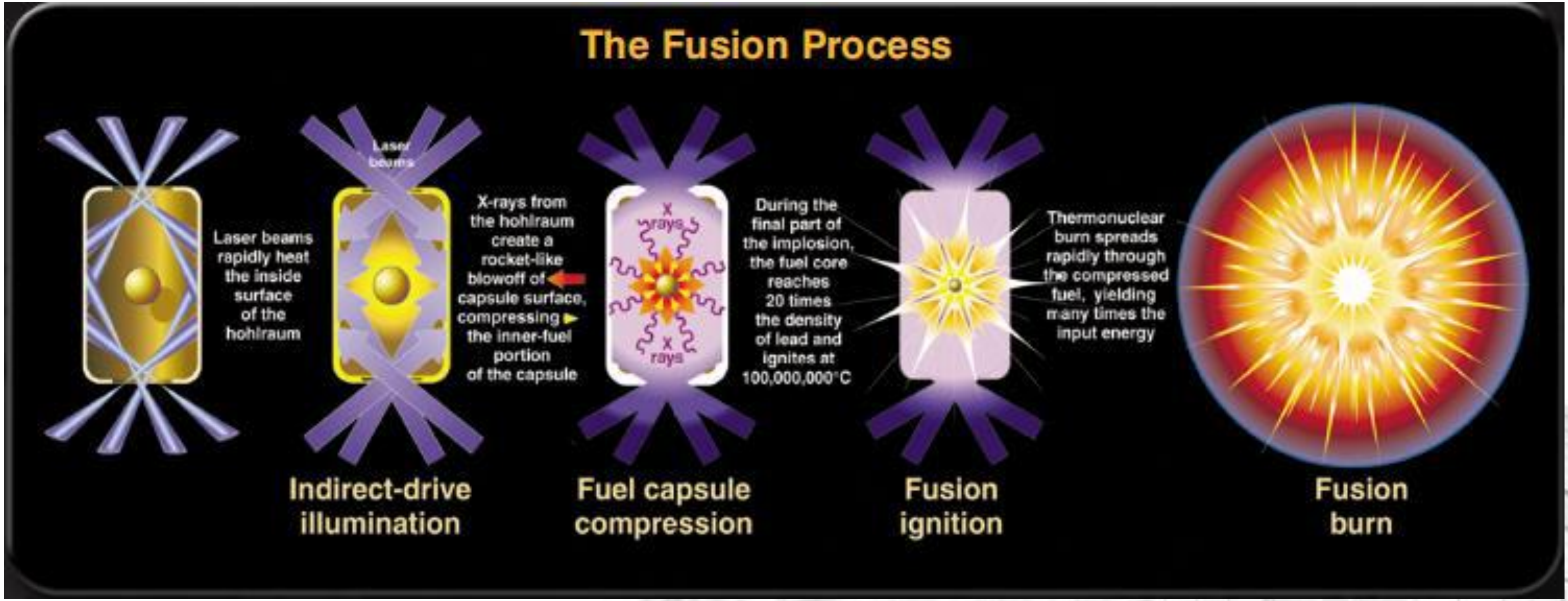
ICF
Enhance ρR by ablated mass
t~ns
R~μm

High Pressure and Astrophysics researches on laser facilities





Inertial Confinement Fusion（ICF）



- 1960s, the idea was given by three scientists individually
- 1980s, a professional team in ICF research was founded in China

ICF observations

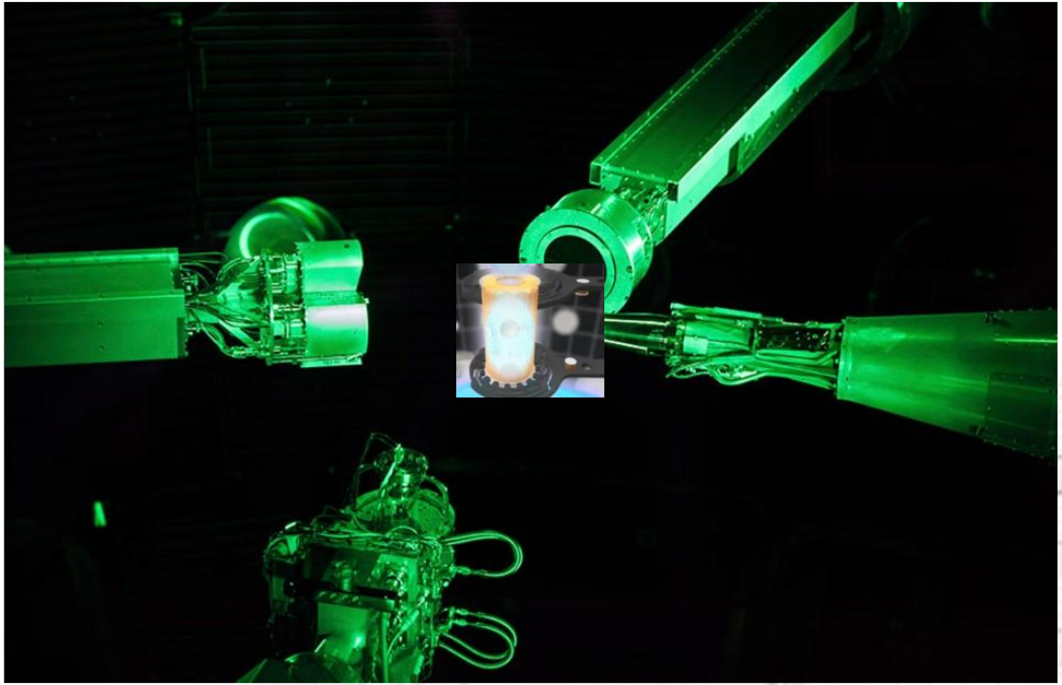
Spatial distribution ~μm

Temporal scale ~ps-ns

flux

spectrum

dimensions



species

optics

UV

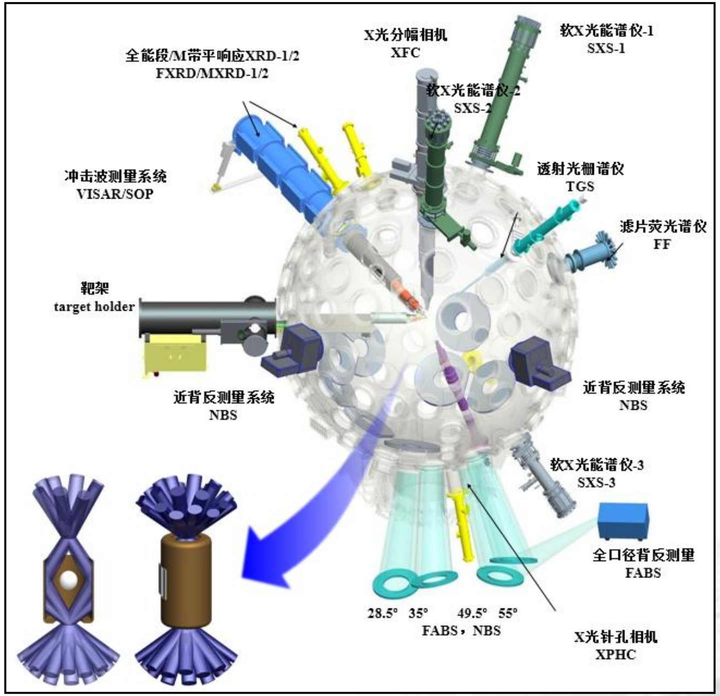
X-ray

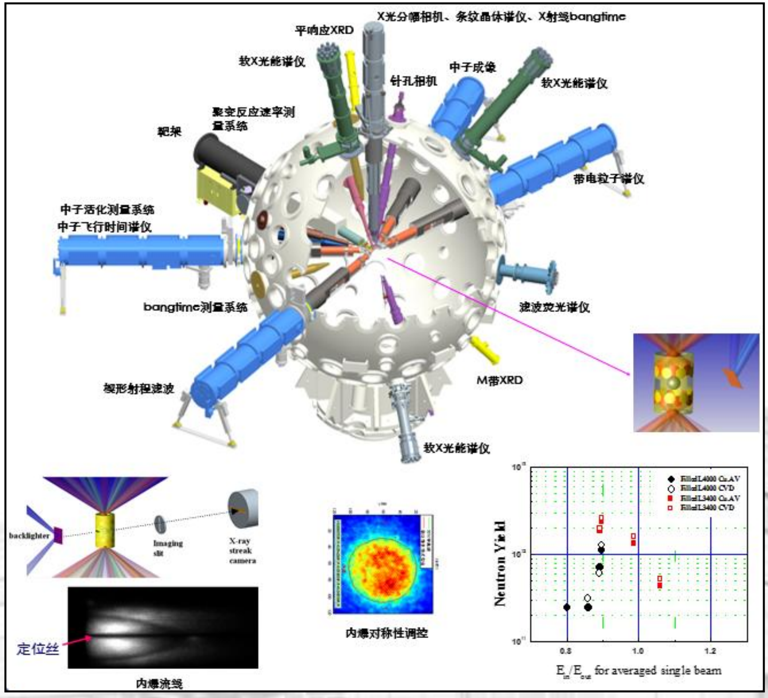
proton

neutron

gamma

ICF diagnostics



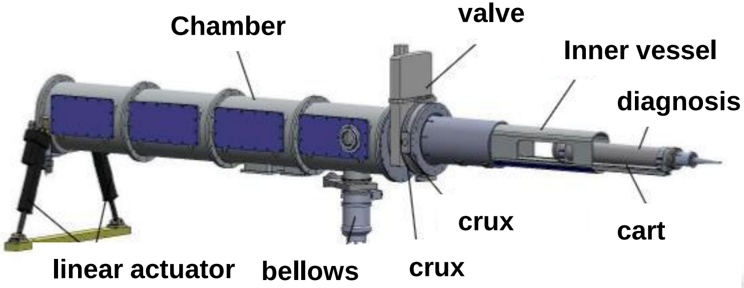


- ❖ Different design, different setup
- ❖ Shift frequently experiment by experiment

Diagnostic instrument manipulator

- Installed and aligned through the DIM
- Face the risk of interference near the center part

NIF Target Chamber

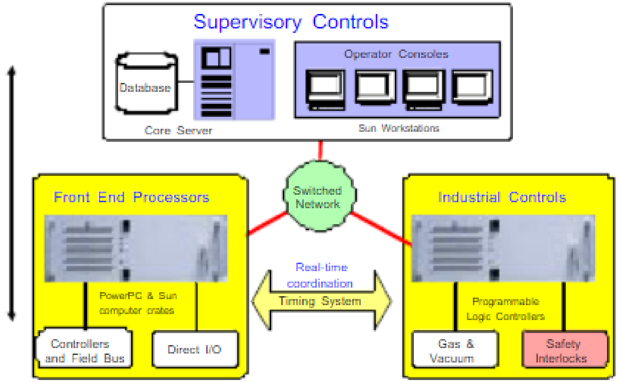


Integrated Computer Control System(ICCS)

❖ ICCS on NIF

NIF control room

Framework of ICCS system

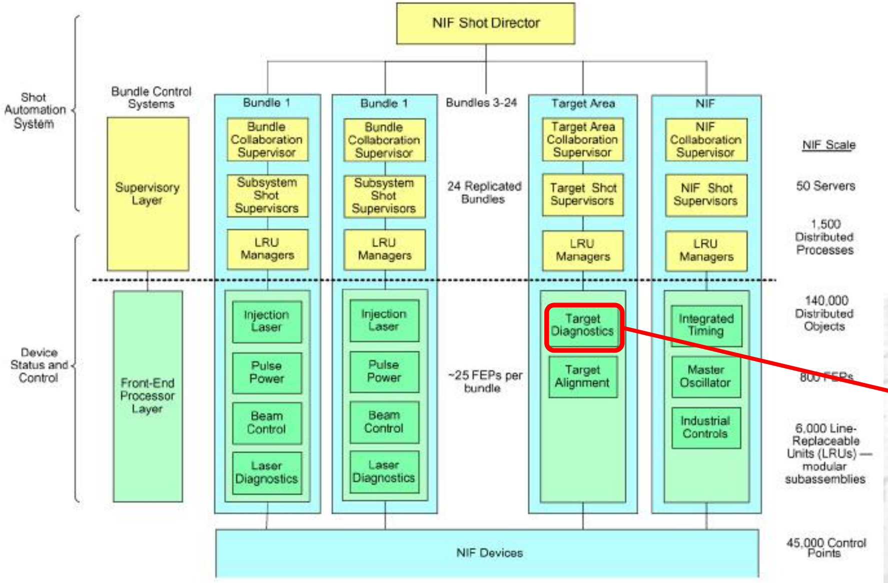


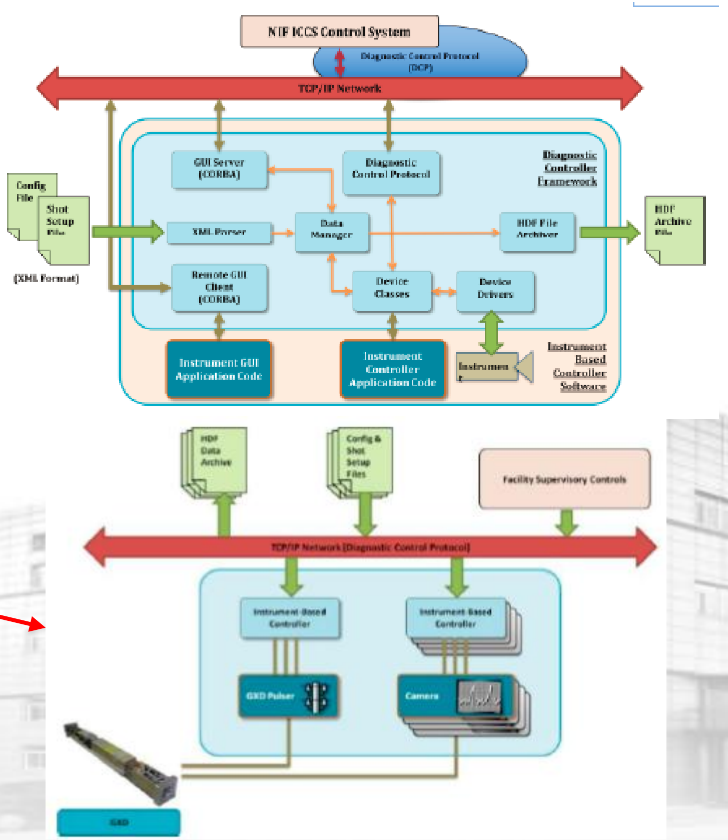
❖ The main part of ICCS is the facility control subsystem

❖ The control system is comprised of two principle layers—supervisory controls and FEP

Target Diagnostic Control System Implementation

- DCS is the subsystem of ICCS
- minimal application code, easy testing, and high reliability





Framework of diagnostic control system(DCS)

❖ The micro-Services framework

- ➢ Disperse the apps. in different micro-services, decouple the complicated system

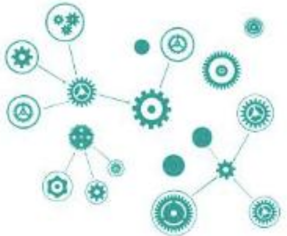
1st generation: Monolith

- Tight coupled
- Complicated, Intricate
- Repeat : OS，DB, Middleware
- Completely enclosed

2nd generation: SOA

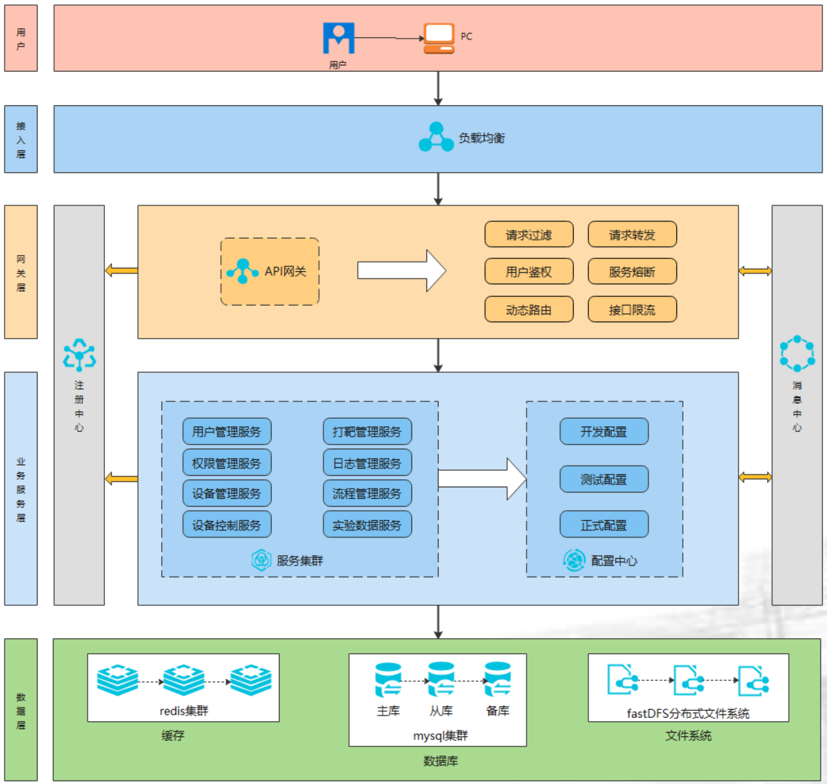
- loose coupled
- System integration by ESB
- Stated
- Big Team: 100-200
- TTM: 1year, half year, months
- Centralized, planned downtime maintenance

3rd generation: Microservices



- decoupled
- Small Team: 2 Pizza Team
- TTM: Days, weeks
- DevOps: CI, CD, Automatic
- High available: update, extension without shutdown

DCS Architecture



individual
- Each service is developed by different team
- Efficiency is ensured by target decomposition

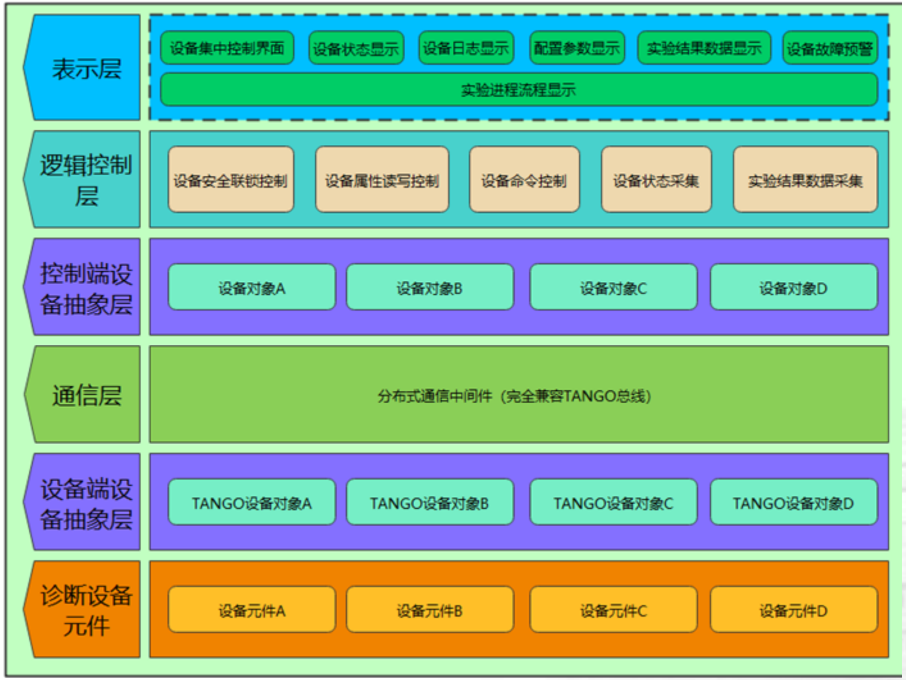
reliable
- The app. and unit element are decoupled
- Would not collapse due to single failure service

repairable
- Every service is deployed dispersedly
- Every services is maintenanced dispersedly

extensible
- Arranged in different servers and frameworks
- No limitation in language & technology

The layers of DCS

❖ DCS has six basic-layers



- GUI for the integrated control and experimental data display;
- DCS controls the instruments through the distributed communication middleware
- The TANGO agreement is employed
- To lower the difficulties of joining up, both the controller and instruments are implemented an object oriented design, and packaged the communication protocol of infrastructure

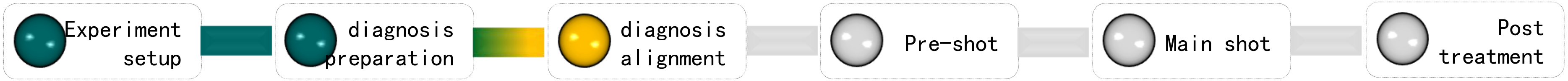
Functions of the DCS

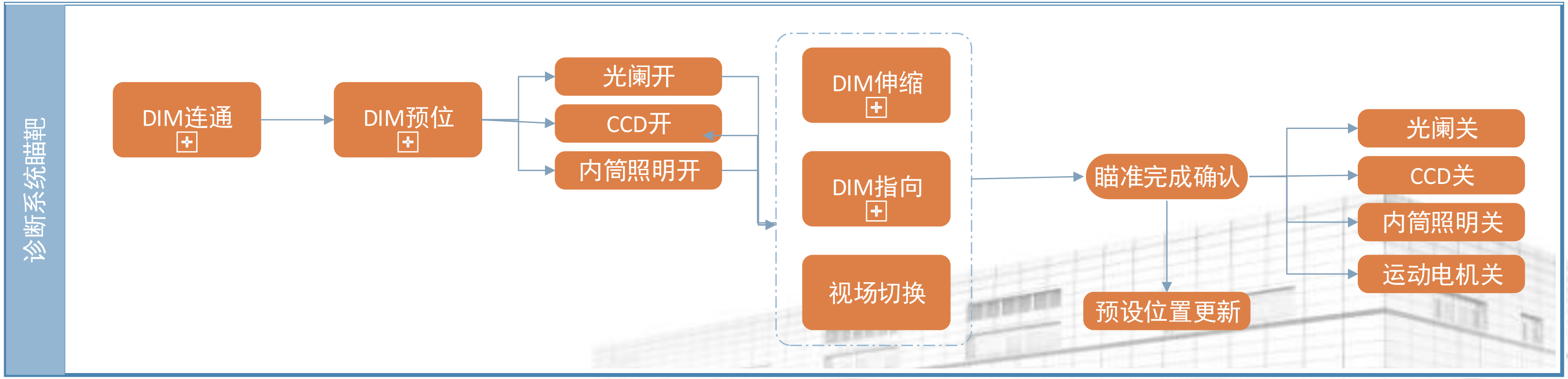
❖ DCS consists of five individual functions

- Target diagnostics control system
  - System manager
    - 组织机构管理
    - 用户管理
    - 角色管理
    - 授权管理
  - Instruments manager
    - 设备厂商管理
    - 设备型号管理
    - 设备类型管理
    - 设备信息管理
  - Procedure manager
    - 标准流程管理
    - 自定义流程管理
    - 流程验证
  - Experiment manager
    - 打靶任务管理
    - 流程控制管理
    - 实验数据查询
    - 实验数据显示
    - 实验数据统计
  - Journalizing
    - 系统日志记录
    - 系统日志查询

Designed by Procedure driven

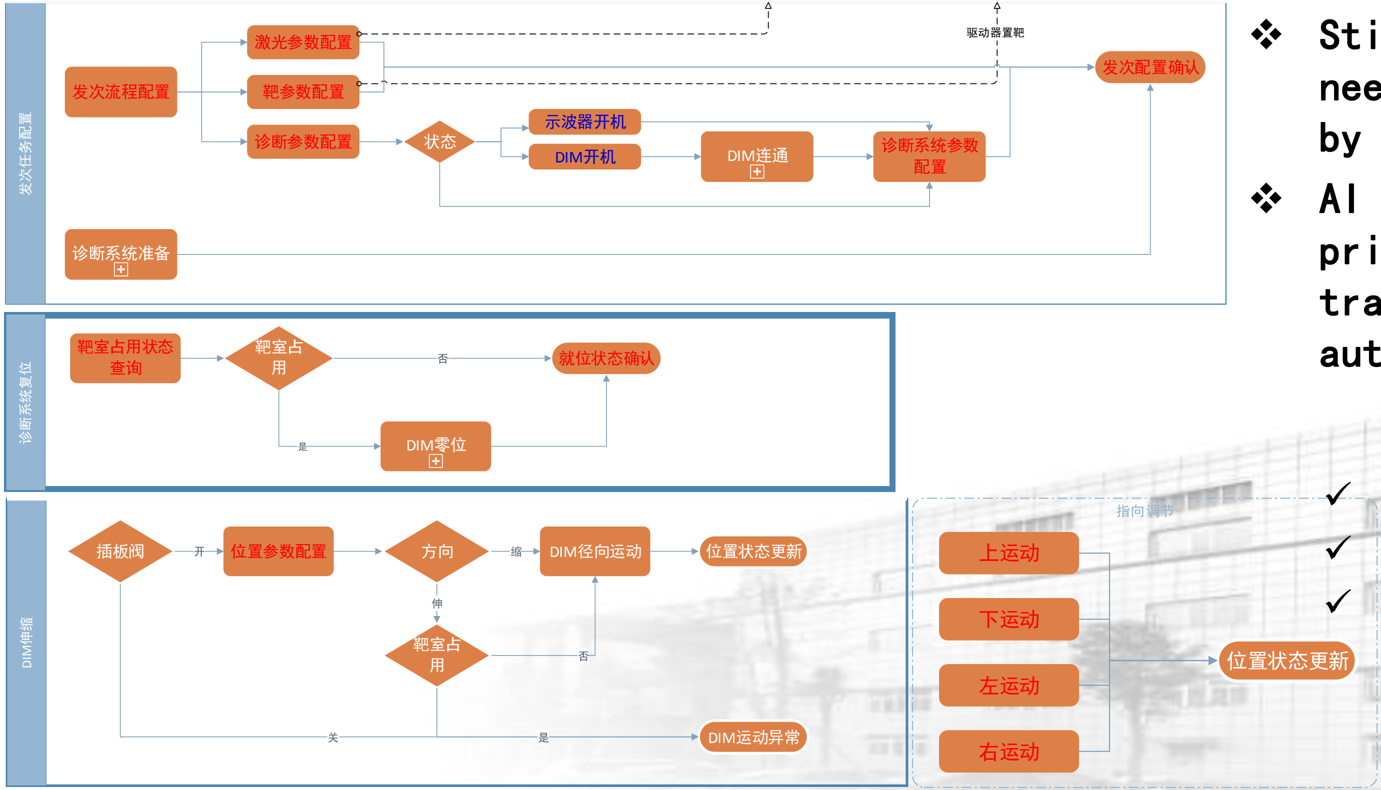
Integrated control realized by procedure driven





- The controller unit is formed from the basic functions of the instrument, and programming by the operation procedures
- To implement the sub-procedures following the experiment control point

Manual operation still needed in the DCS



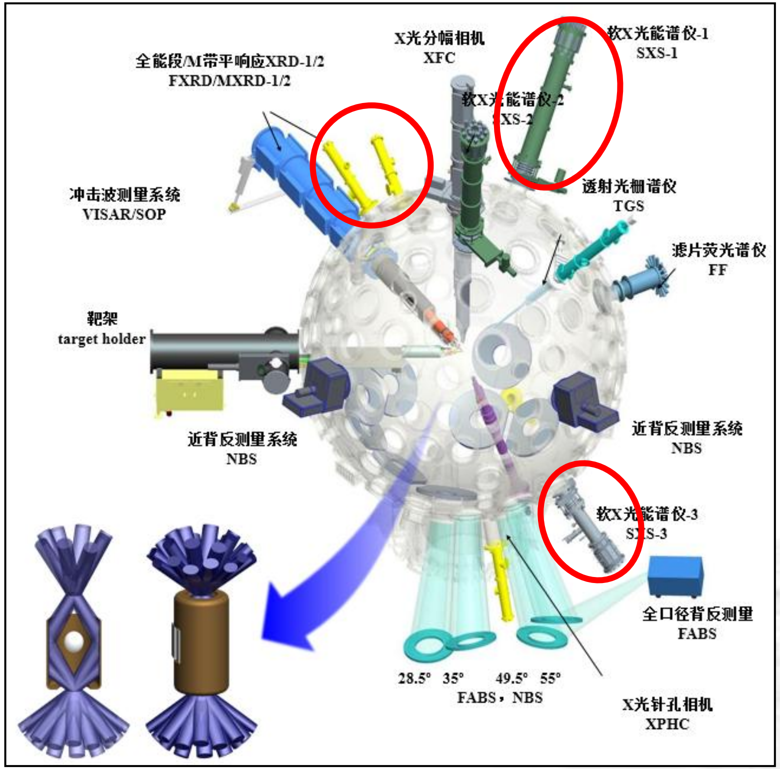
- Still many processes need be participated by experimenters
- AI technique is the primary candidate transforming to automatic control

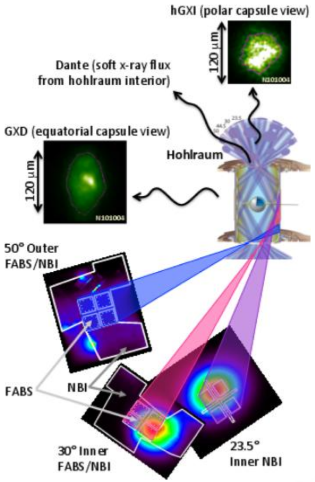
✓ Instrument setup

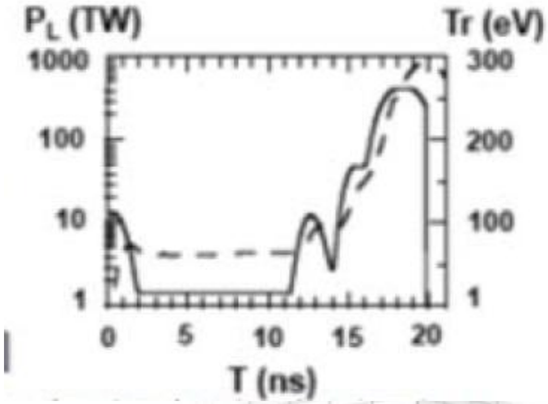
✓ Instrument aligning

✓ Warning for instrument collision

Holhraum temperature measurement

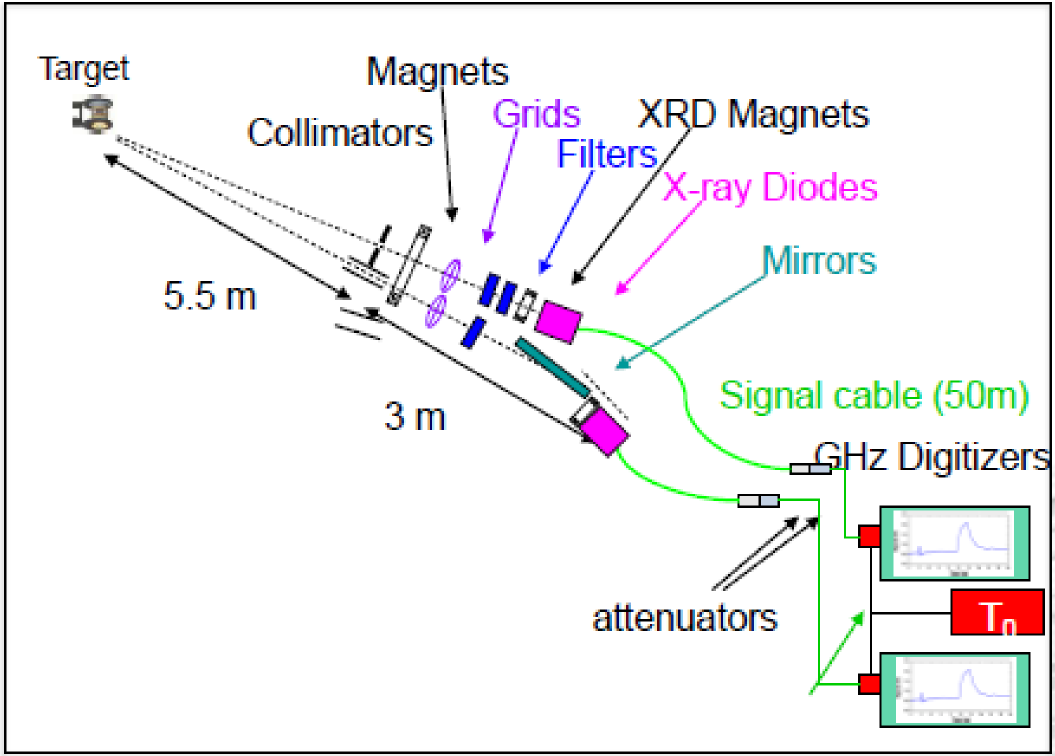




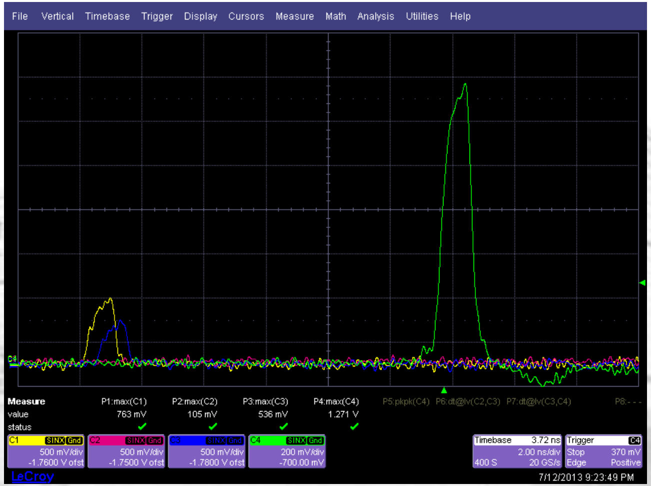


- Tr is the basic metric of the holhraum energetics physics
- Tr is related to the albedo, asymmetry, etc., which will affect the convert efficiency

The setup of the oscilloscope



- ❖ Based on the simulation or the historical set
- ❖ Affect the measurements precision, even damage the OSC



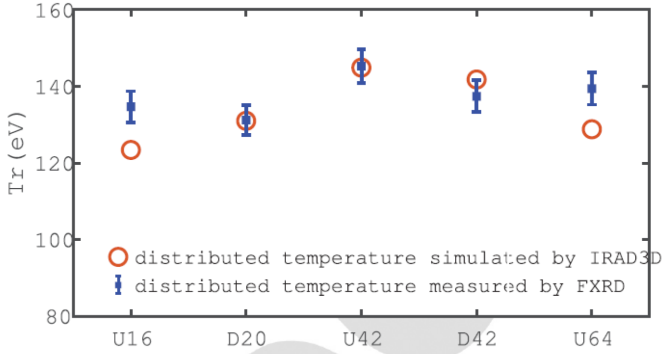
Estimation of the Tr

- Calculation based on the power balance(0D)

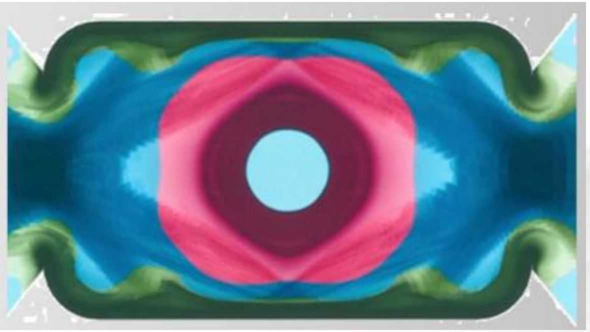
$$\eta_e E_L = E_{wa} + E_h = A_{wa}\int_0^t S_{wa}dt + A_h\int_0^t S_h dt$$

View factor

- Based on the historical measurements



- Simulation with the radiation-hydrodynamics codes(2D)



- 0D:has approximated, un-precise
- 2D:depend on parameters, large amount of calculation
- Measurements: with uncertainties, many influencing factors

Estimation of the peak Tr

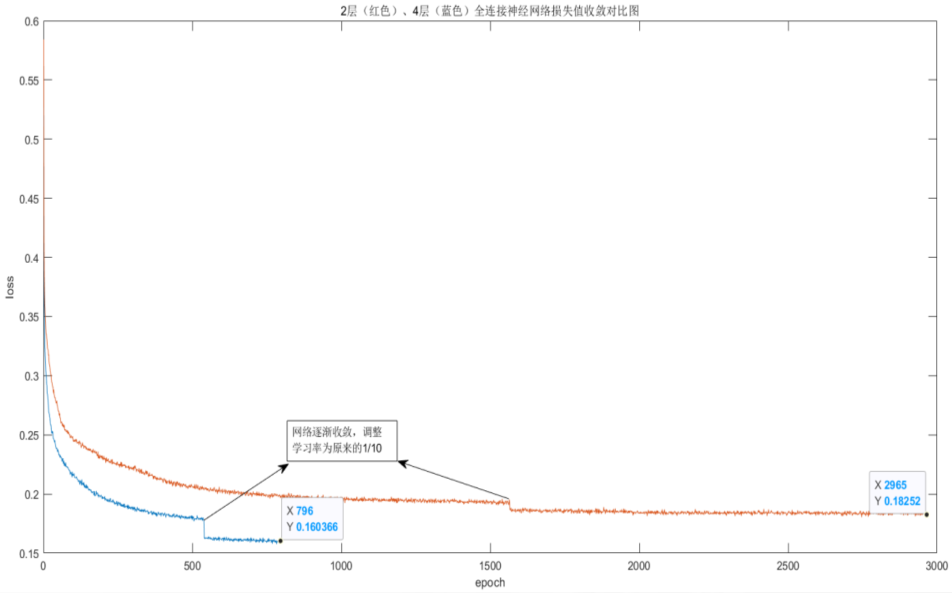
- Based on the PyTorch framework
- Training data produced by 0D calculation
  - Varies the laser power, holhraum dimension, LEH diameter etc.
  - Full connect CNN

✓ Training database-1million

✓ Adjust the parameters based on the CNN performances

✓ After 965 epochs with 2 layers CNN, lose is convergent to 0.183

✓ After 965 epochs with 4 layers CNN, lose is convergent to 0.160



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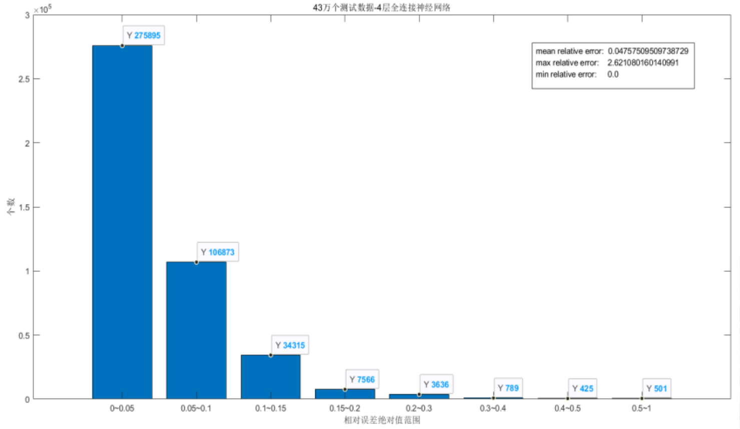
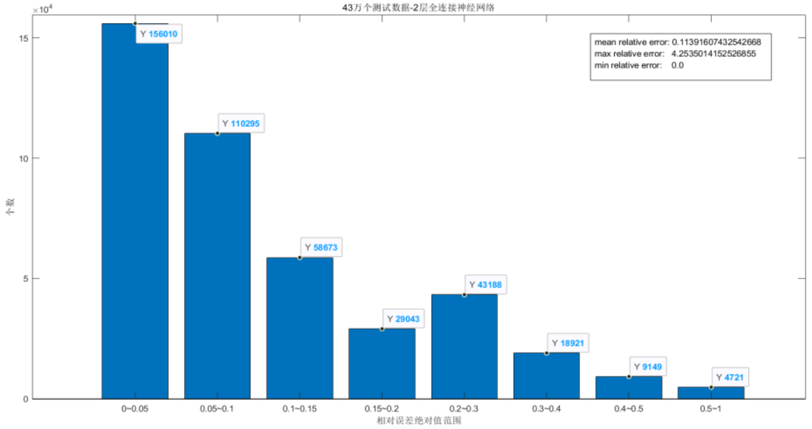
Testing of the CNN model

- The relative error is about 4.76% for 4 layers, only 1.24% testing data bias larger than 20%
- The relative error is about 11.39 % for 2 layers, 17.67% testing data will bias larger than 20%



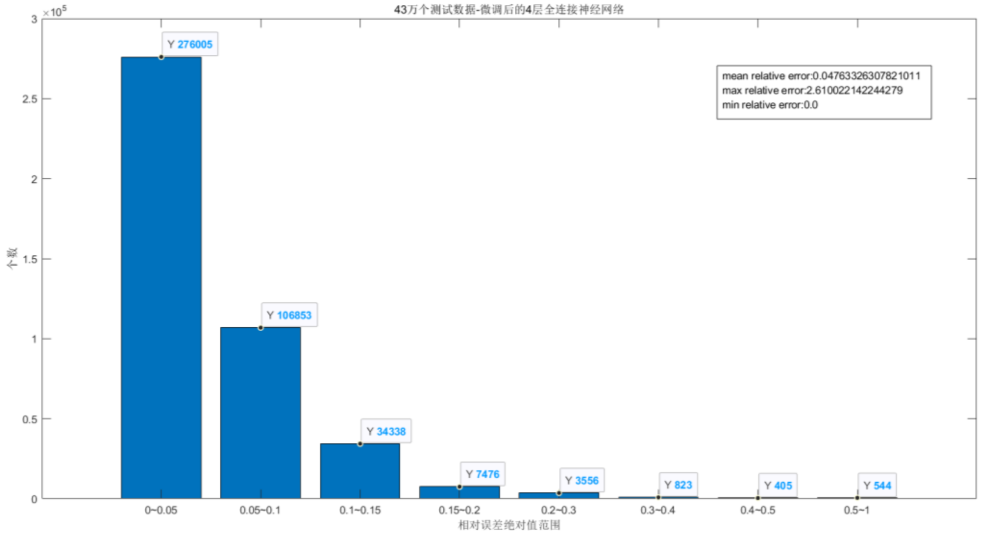
Bias statics of 430 thousand testing data for 4 layers



Bias statics of 430 thousand testing data for 2 layers

Generalization and Robustness of the model

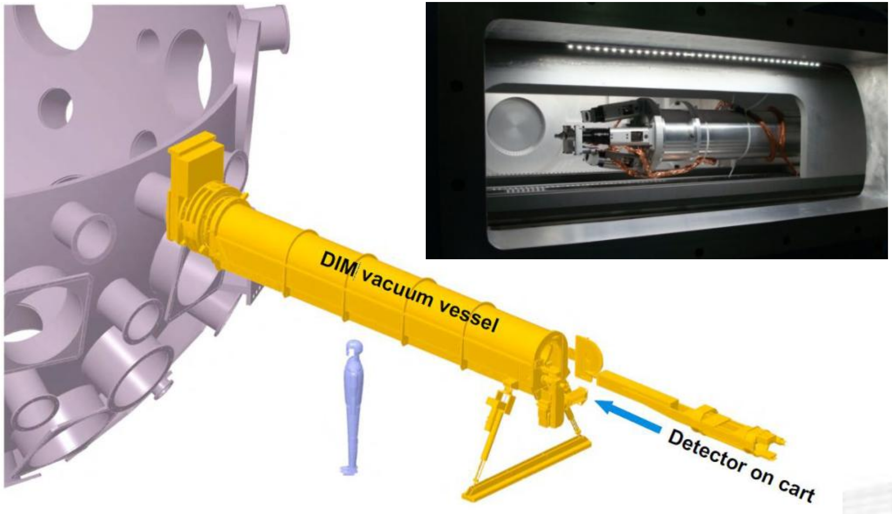
❖ Add 0-5% rand noise to the training data



- ✓ Robustness to the statics noise
- ✓ An enhance learning were performed by adding the experimental data and 2D simulation data
- ✓ Begin to test the RNN model to estimate the temporal profile

- ➢ The precise has satisfied the requirement of control system by a simple 4-layers model
- ➢ More computing resource, more data and RNN model will use for scaling research

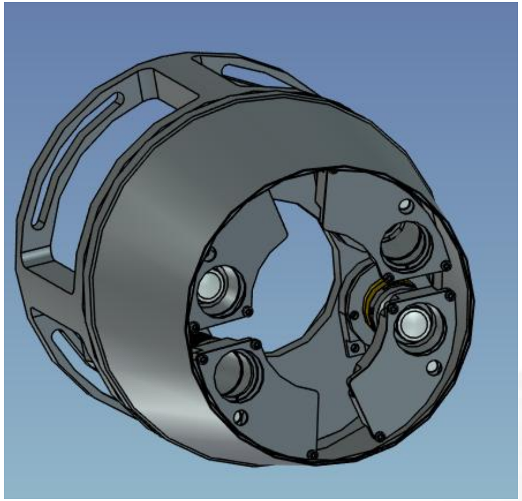
Alignment of the DIM based instrument

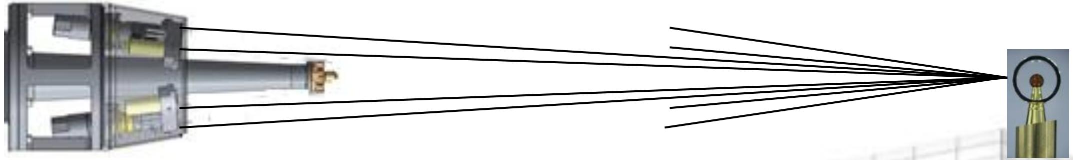


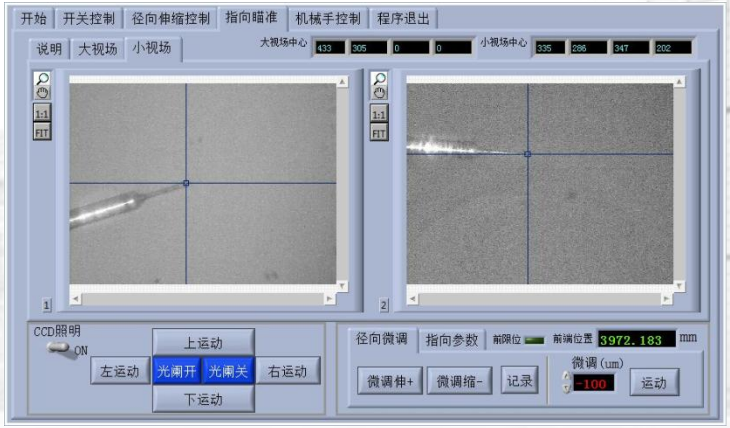
- Diagnostics inserted into the cart of DIM to keep the chamber vacuum
- Aligned to the target with the binocular visual system

Alignment procedures

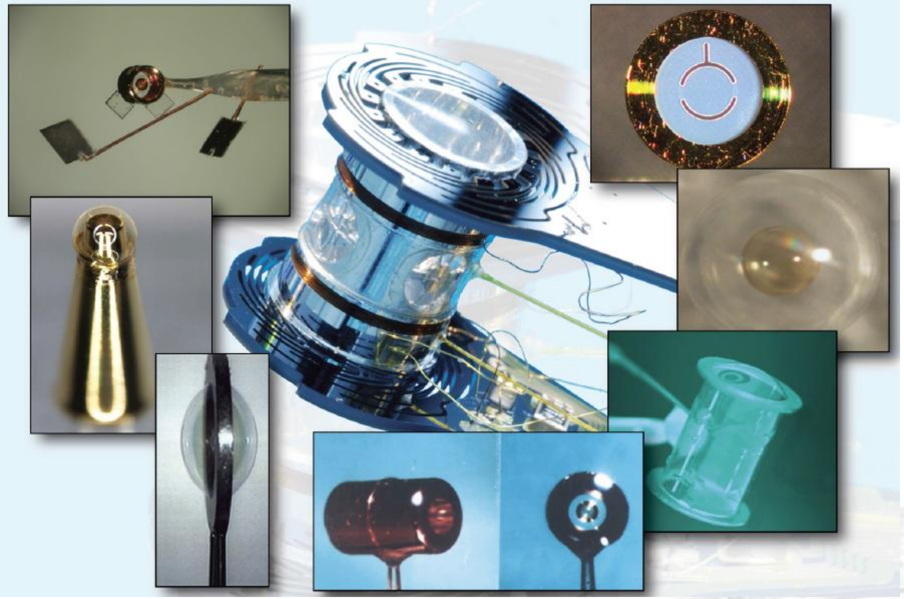
- ❖ **Two sets of binocular lens**
  - ➢ Binocular set with large VOF， to find the target
  - ➢ Binocular set with high resolution， to aim the target

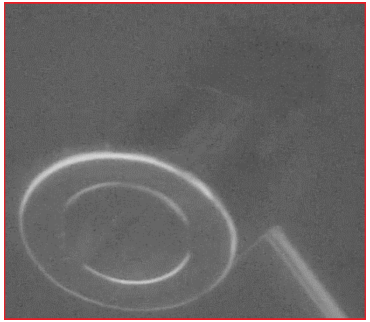


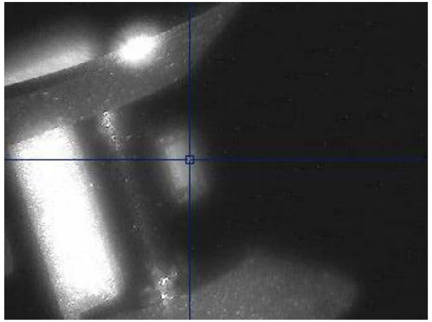




Autonomous target detection with machine vision





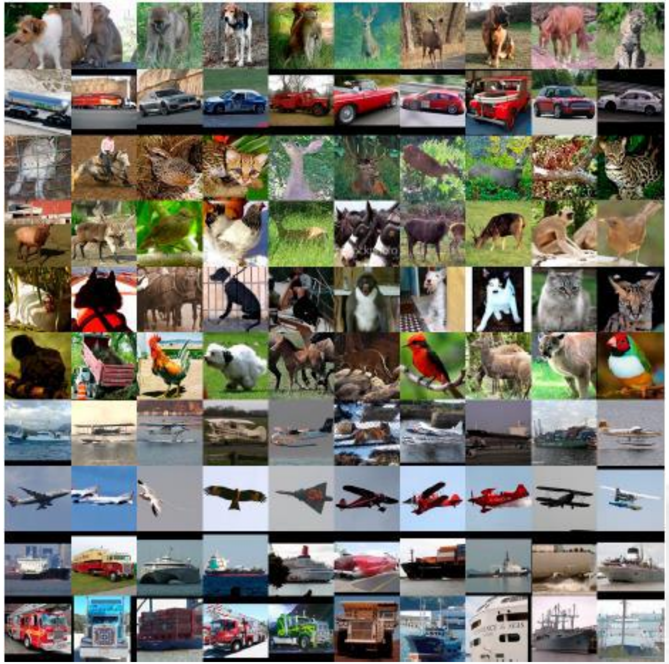


- Traditional machine vision
  - Less robustness
  - Easy affected by quality of the images
  - Need calibration

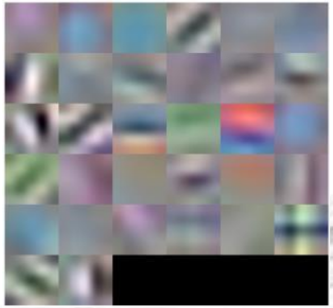
- Different platform, different design and dimension of the targets
- Poor lighting, large chamber, low quality of images

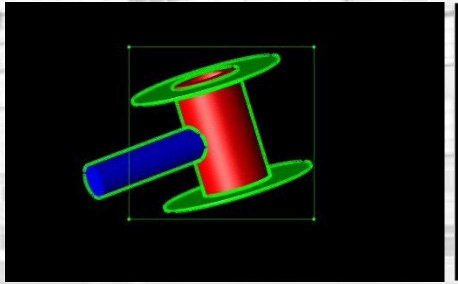
Target detection with deep learning

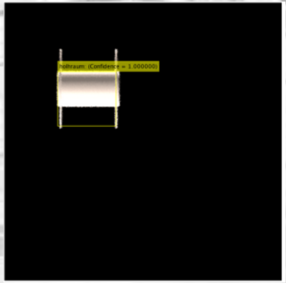
❖ Autonomous target detection with large FOV images by ROI label



ImageNet for transfer learning



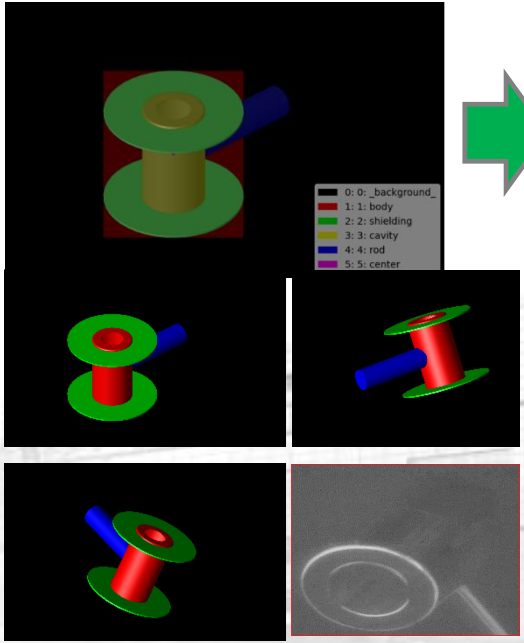


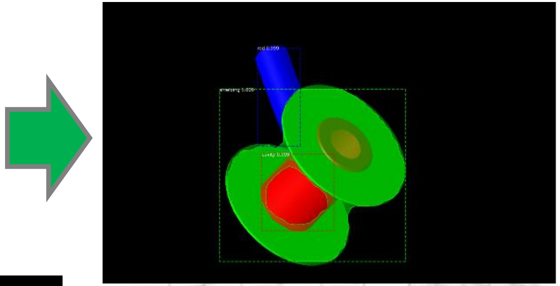


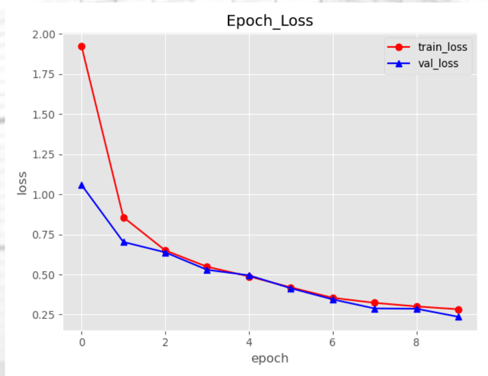
Target recognition

❖ Based on the Mask-CNN, aiming the target precisely by semantic segmentation

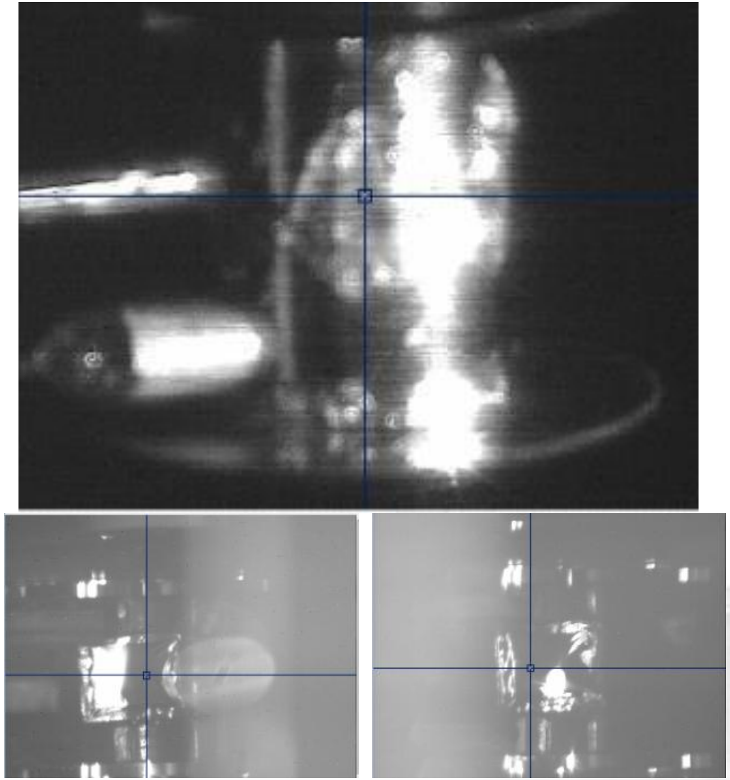
- Produce the training data with 3D target model and labelled automatically
- Enhanced training with real images







Characters of the auto-alignment



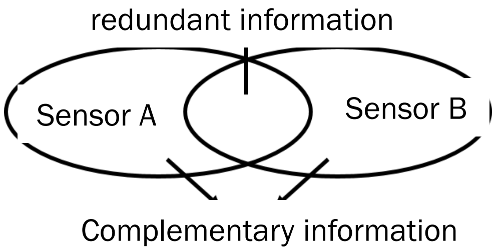
- **Usability**
  - Simple background
  - Easy detected
  - Accuracy 3D model

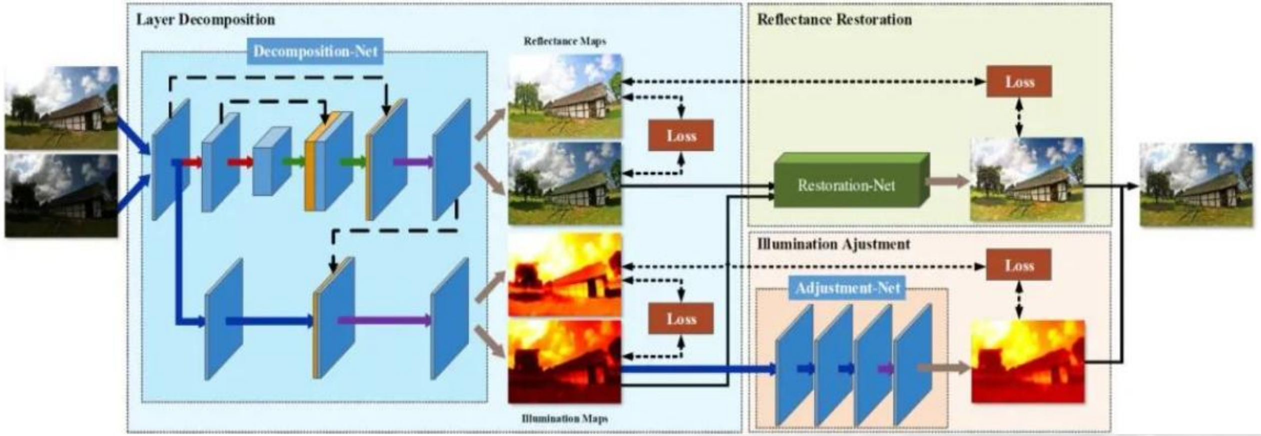
- **Difficulties**
  - Low light level
  - Part of the target due to the FOV
  - High precision requirement

Improved the image quality through image fusion

Image Fusion by deep learning

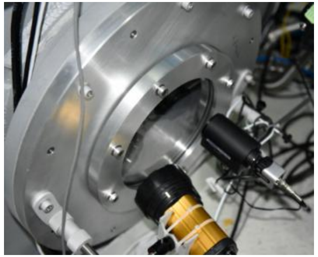
- Primary problems of the auto-aiming
  - Low quality images due to low light level
  - Image distortion due to the depth of focus
- To improve the aiming precision by improving the image quality with image fusion

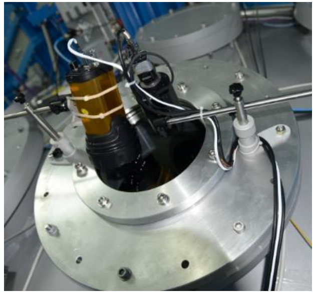


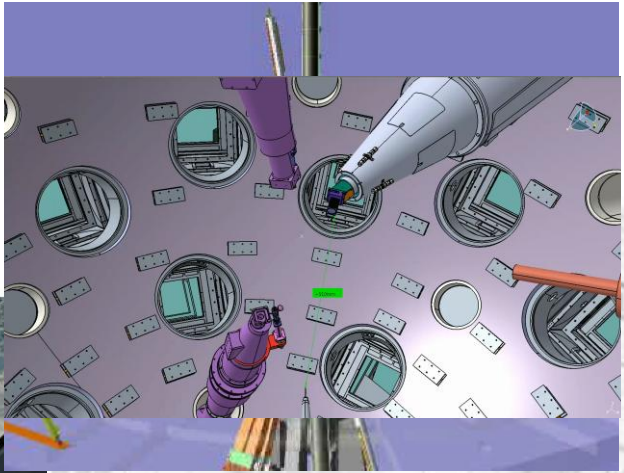


Warning of the instrument interference

- Convert 2D images to 3D models through images fusion and joint
- The instrument location real-time display can displayed through the 3D model and video monitors images arranged in different ports

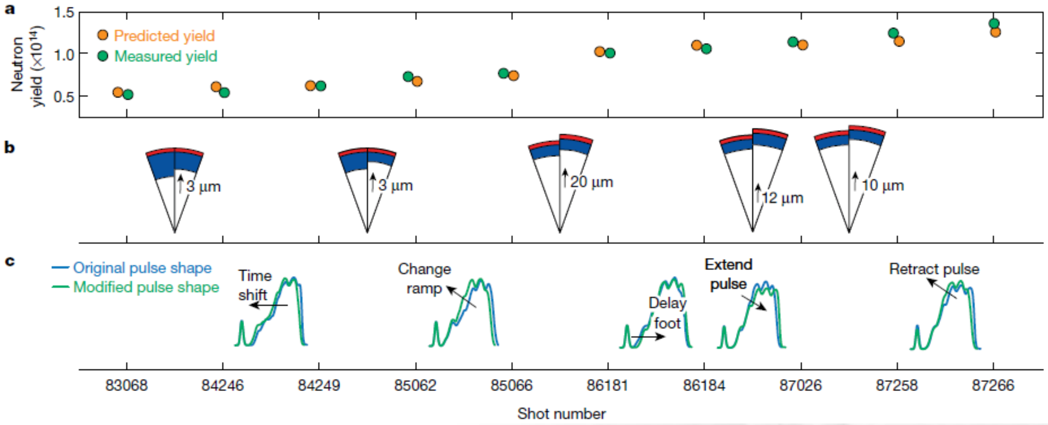


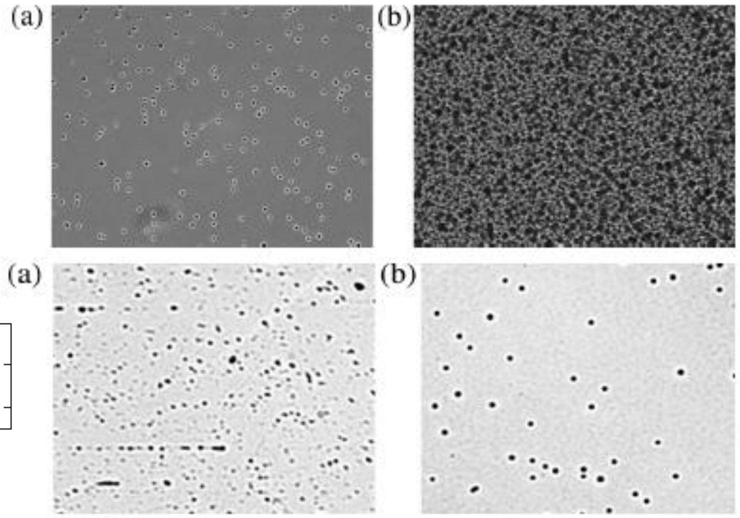


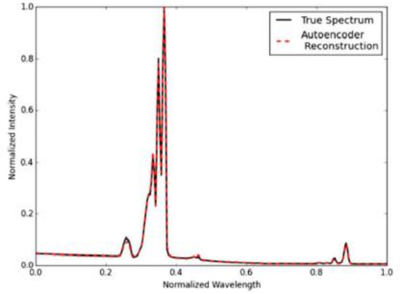


Applications of AI in data analysis

- CR39 data recognized
- X-ray spectrum fitting
- Scaling law of the implosion performance







Conclusion

- Diagnostics play an great role in ICF experiment researches
- The DCS framework based on the micro-services and procedure driven design has the advantages in easy coding, extension, and reliable operation etc.
- AI is significant for the autonomous control of the DCS, and will be used in system setup, operation control and data regression
- The applications in signal analysis, super-resolution imaging, instrument health control are under developing by CNN, GAN, RL

Thanks