Bayesian probabilistic data analysis platform

R&D on HL-2A

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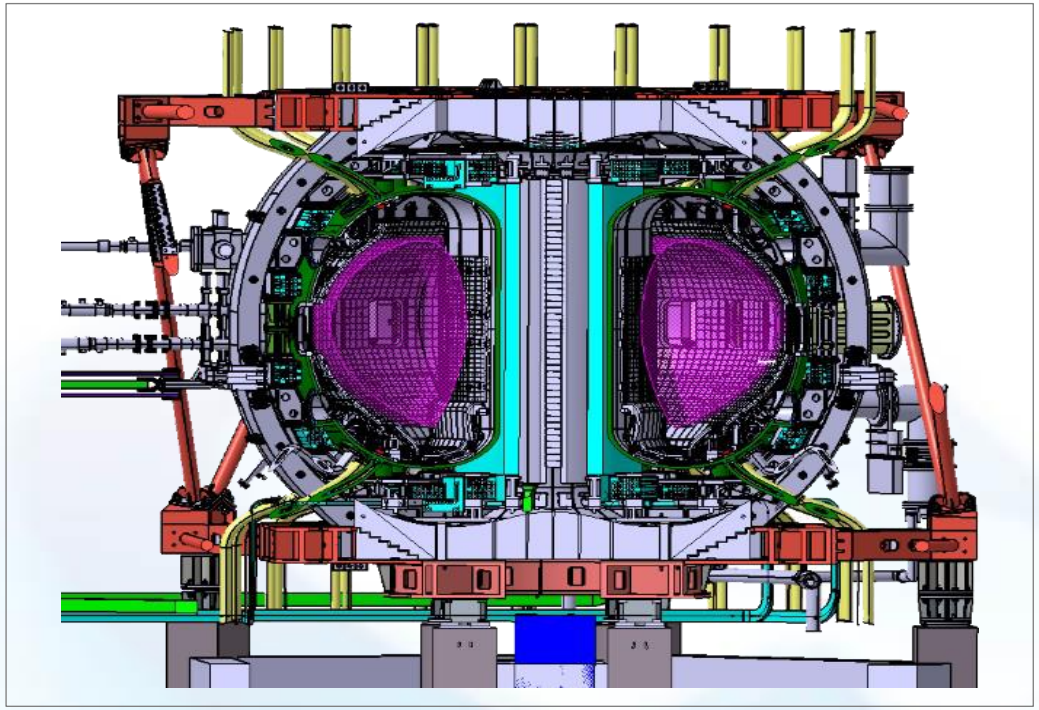
Motivation

HL-2A/2M experimental data analysis requirement

MOTIVATION

HL-2A/2M TOKAMAKS



Ion temperature
>150M Degree

Plasma current
6 times to HL-2A

Plasma volume
3 times to HL-2A

H&D power
2.5 times to HL-2A

Parameters	HL-2A	HL-2M
Major Radius, R	1.65m	1.78m
Minor Radius, a	0.4m	0.65m
Aspect ratio	4.1	2.8
Plasma current, I_p	**0.45MA**	**2.5~3MA**
Toroidal magnetic field, Bt	2.8T	2.2~3T
Triangularity, δ	<0.5 (DN)	>0.5 (DN)
Elongation, κ	<1.3 (DN)	2 (DN)
Auxiliary heating power	**>10MW**	**>25MW**

MOTIVATION

HL-2A/2M EXPERIMENTAL DATA ANALYSIS REQUIREMENT

HL-2A has more than 30 physics diagnostics with different spatial-temporal resolution.

Conventional (individual)

Disadvantages:

× (self-) consistent results?

× error propagation

× loss of information about the physics interdependency

× often backward inversion techniques

IDA (probabilistic combination)

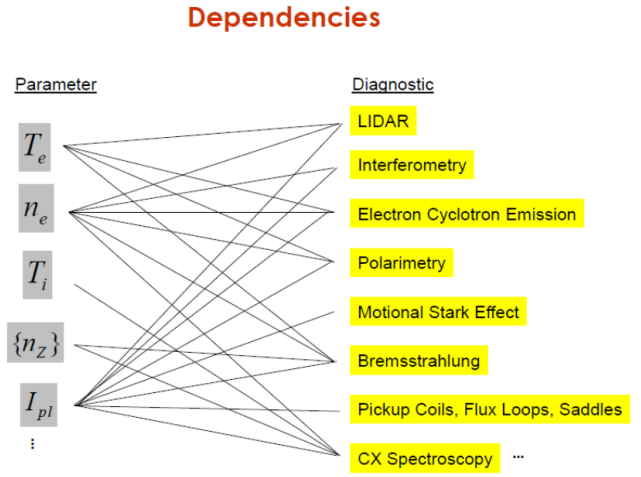
Advantages:

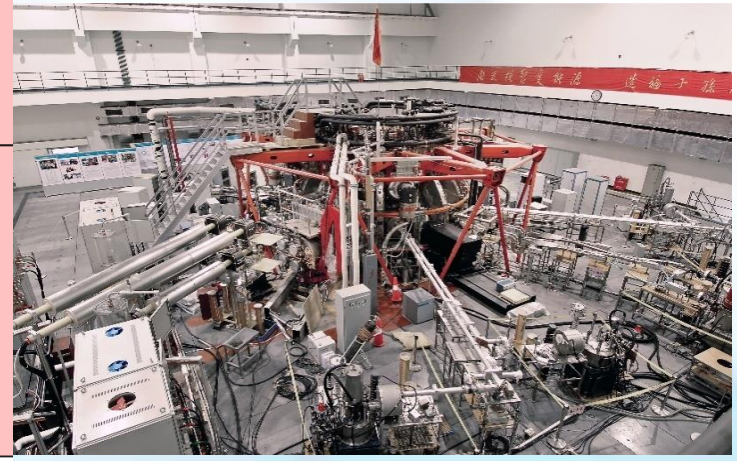
✓avoids error propagation

✓uses only forward modeling

✓can easily integrate additional physical information and improve results

✓result: probability distribution of parameters of interest





The Goal of IDA:

• replace combination of results from individual analysis

• with combination of measured data from heterogeneous diagnostics (one-step analysis of pooled data) to improve results.

Recent progress

of HL-2A Bayesian probabilistic data analysis

HL-2A BAYESIAN DATA ANALYSIS

INTEGRATED DATA ANALYSIS (**IDA**) LOGIC

$$p(profiles|diagnostics) \sim p(diagnostic|profiles) \cdot p(profiles)$$

posterior **likelihood** **prior**

$$p(profiles|diagnostics) \sim p(diagnostic\ No.1|profile\ corresponding\ to\ diagnstic\ No.1) \cdot p(diagnostic\ No.2|profile\ corresponding\ to\ diagnstic\ No.1) \cdot p(diagnostic\ No.3|profile\ corresponding\ to\ diagnstic\ No.3) \cdot p(diagnostic\ No.4|profile\ corresponding\ to\ diagnstic\ No.4)\ldots \cdot p(profiles)$$

Individual diagnostic Forward models

$$p(\bar{n}_e, \bar{T}_e, \bar{T}_i, \bar{\omega} \ldots | \bar{d}_{ECE}, \bar{d}_{TS}, \bar{d}_{CXRS} \ldots) \sim p(\bar{d}_{ECE}, \bar{d}_{TS}, \bar{d}_{CXRS} \ldots | \bar{n}_e, \bar{T}_e, \bar{T}_i, \bar{\omega} \ldots) \cdot p(\bar{n}_e, \bar{T}_e, \bar{T}_i, \bar{\omega} \ldots)$$

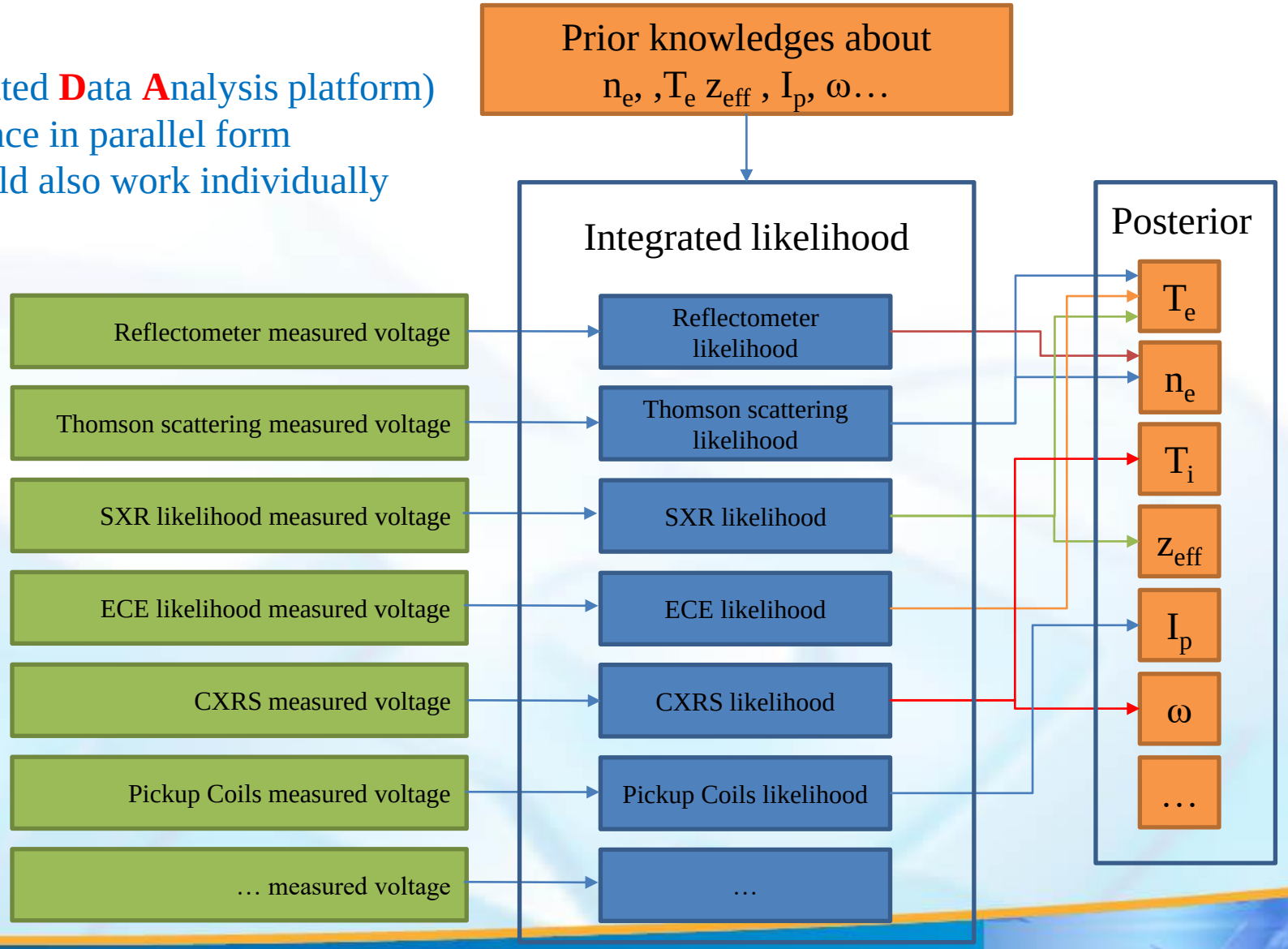
$$\sim p(\bar{d}_{ECE} | \bar{T}_e) \cdot p(\bar{d}_{TS} | \bar{T}_e, \bar{n}_e) \cdot p(\bar{d}_{CXRS} | \bar{T}_i, \bar{\omega}) \cdot \ldots \cdot p(\bar{n}_e) \cdot p(\bar{T}_e) \cdot p(\bar{T}_i) \cdot p(\bar{\omega}) \ldots$$

HL-2A BAYESIAN DATA ANALYSIS

RETINA: RECOGNITIVE INTEGRATED DATA ANALYSIS PLATFORM

RETINA for HL-2A
(Recognitive **I**ntegrated **D**ata **A**nalysis platform)

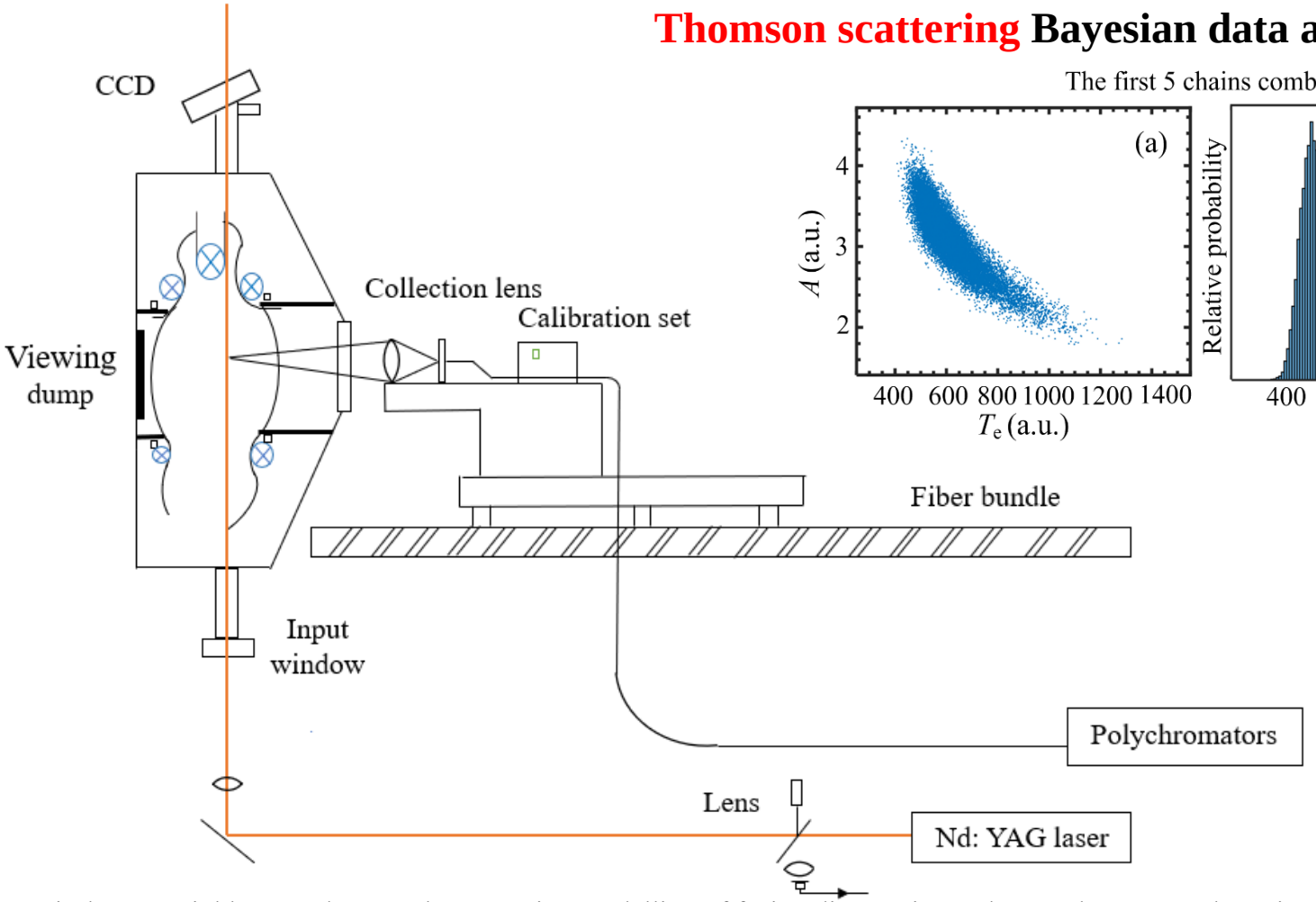
- Integrated inference in parallel form
- Sub-modules could also work individually

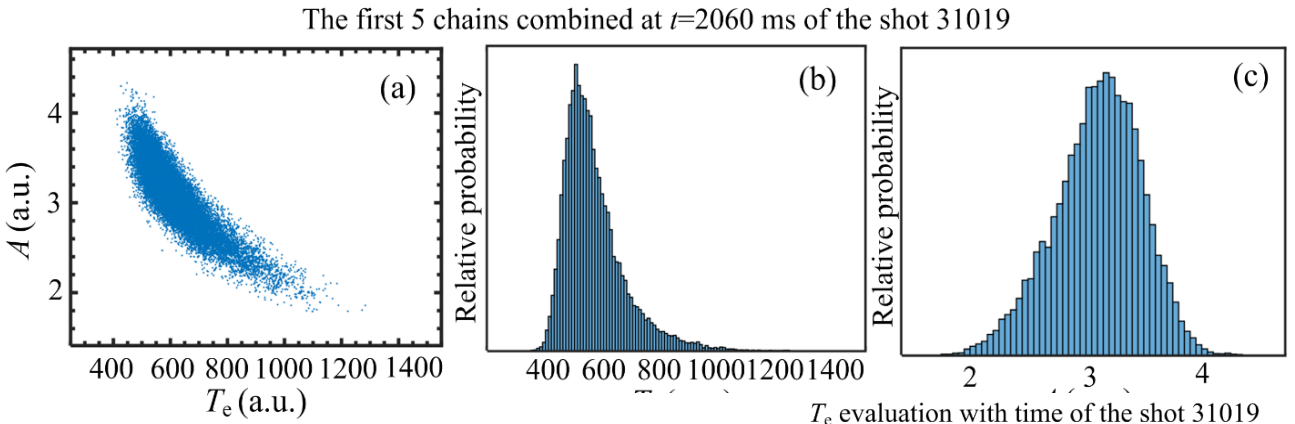


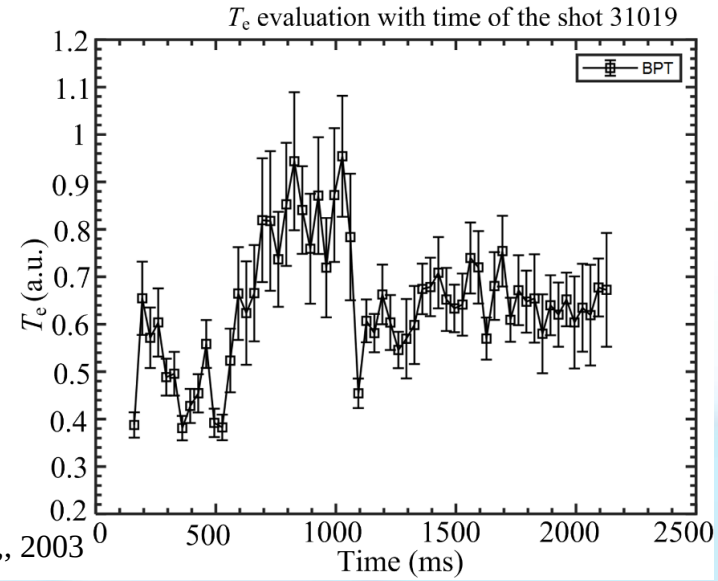
HL-2A BAYESIAN DATA ANALYSIS

EXAMPLE OF THOMSON SCATTERING INFERENCE

Thomson scattering Bayesian data analysis by using Hamiltonian sampling







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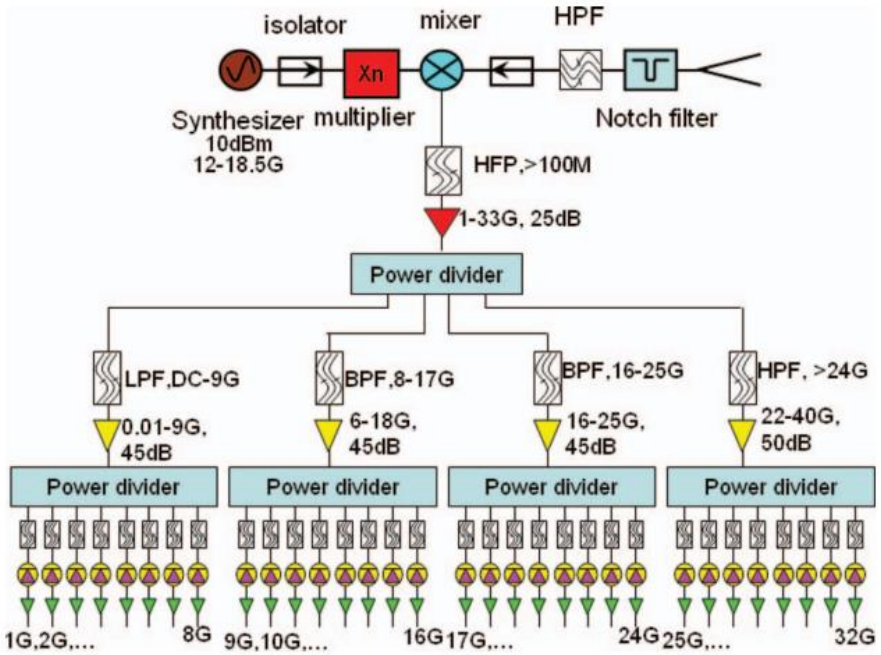
Wenan Pan, Tianbo Wang*, Zhibin Wang , Yonghao Yang, Hao Wu, Zengchen Yang, Chunhua Liu, Bingli Li, Zijie Liu, Wenbin Wu, Min Xu, Integrated Data Analysis on the Electron Temperature profile of HL-2A with Machine Learning Method, submitted to Plasma Science and Technology.

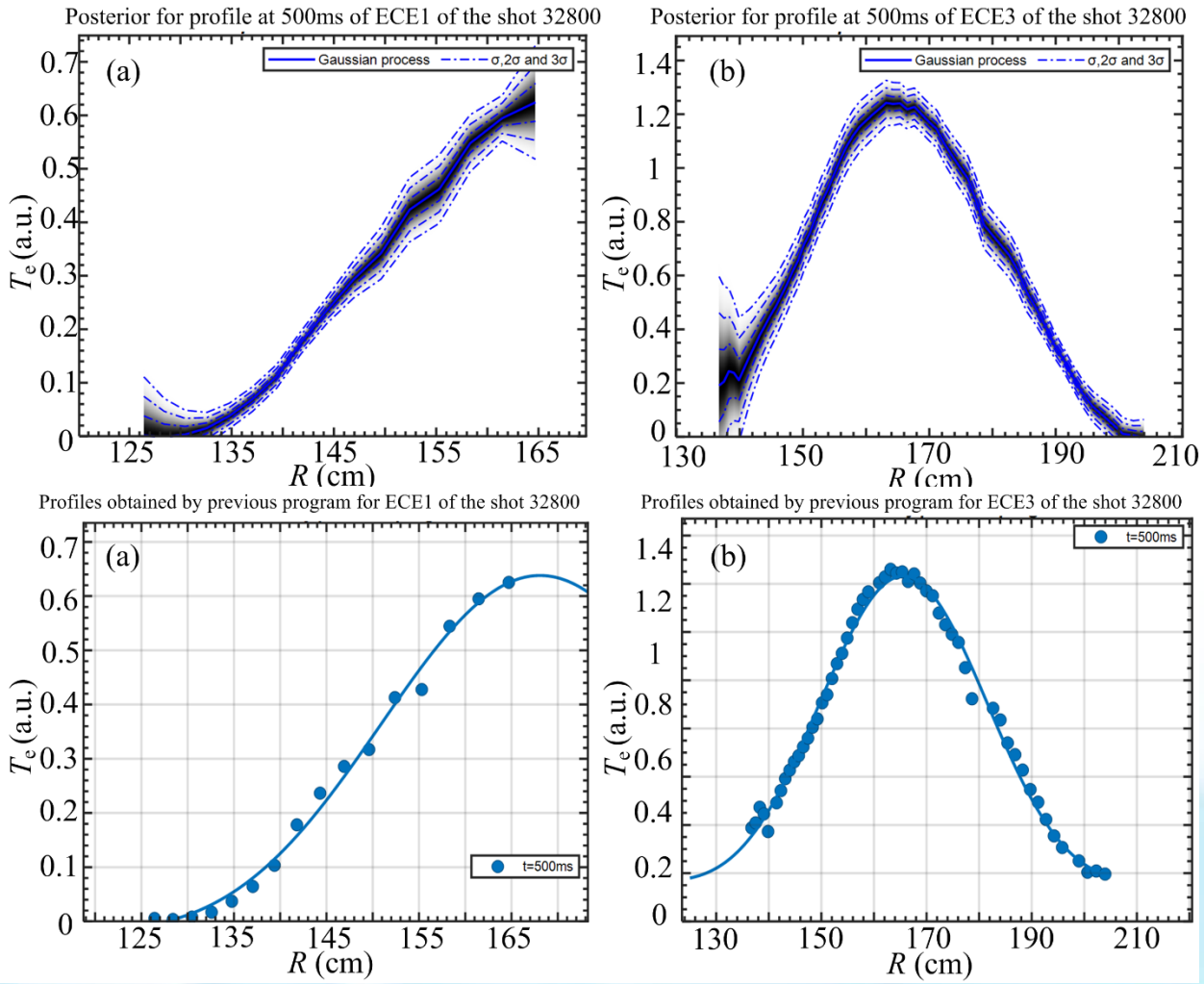
HL-2A BAYESIAN DATA ANALYSIS

EXAMPLE OF ELECTRON CYCLOTRON EMISSION INFERENCE

Electron Cyclotron Emission

Bayesian data analysis on HL-2A





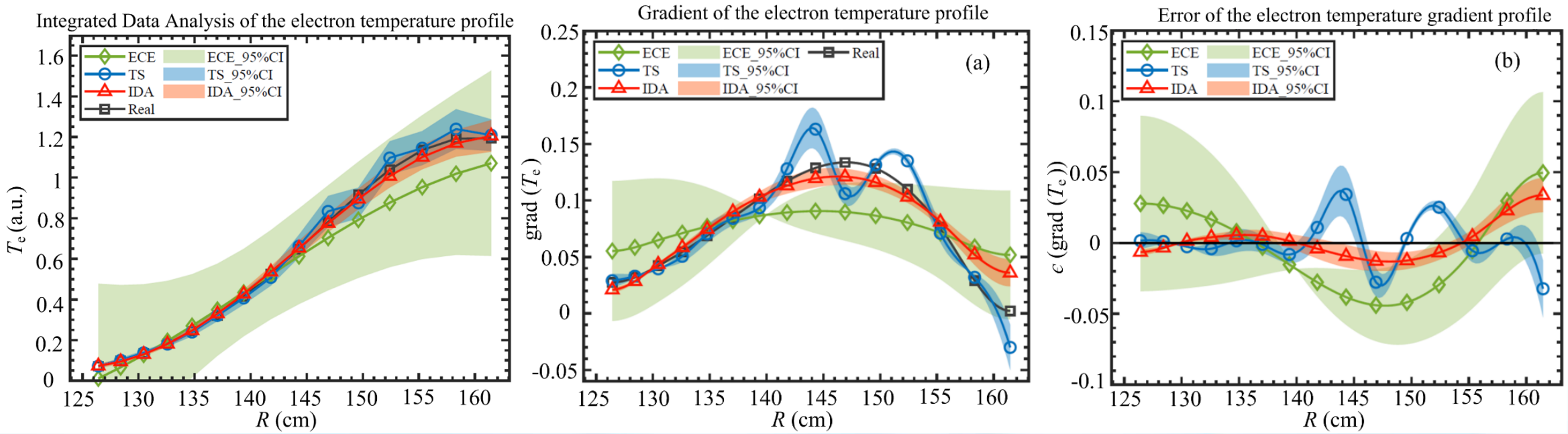
Bayesian

Conventional

HL-2A BAYESIAN DATA ANALYSIS

EXAMPLE OF PHANTOM TEST FOR ELECTRON TEMPERATURE PROFILE

Electron temperature profile integrated data analysis by using ECE & TS



Wenan Pan, Tianbo Wang*, Zhibin Wang , Yonghao Yang, Hao Wu, Zengchen Yang, Chunhua Liu, Bingli Li, Zijie Liu, Wenbin Wu, Min Xu, Integrated Data Analysis on the Electron Temperature profile of HL-2A with Machine Learning Method, submitted to Plasma Science and Technology.

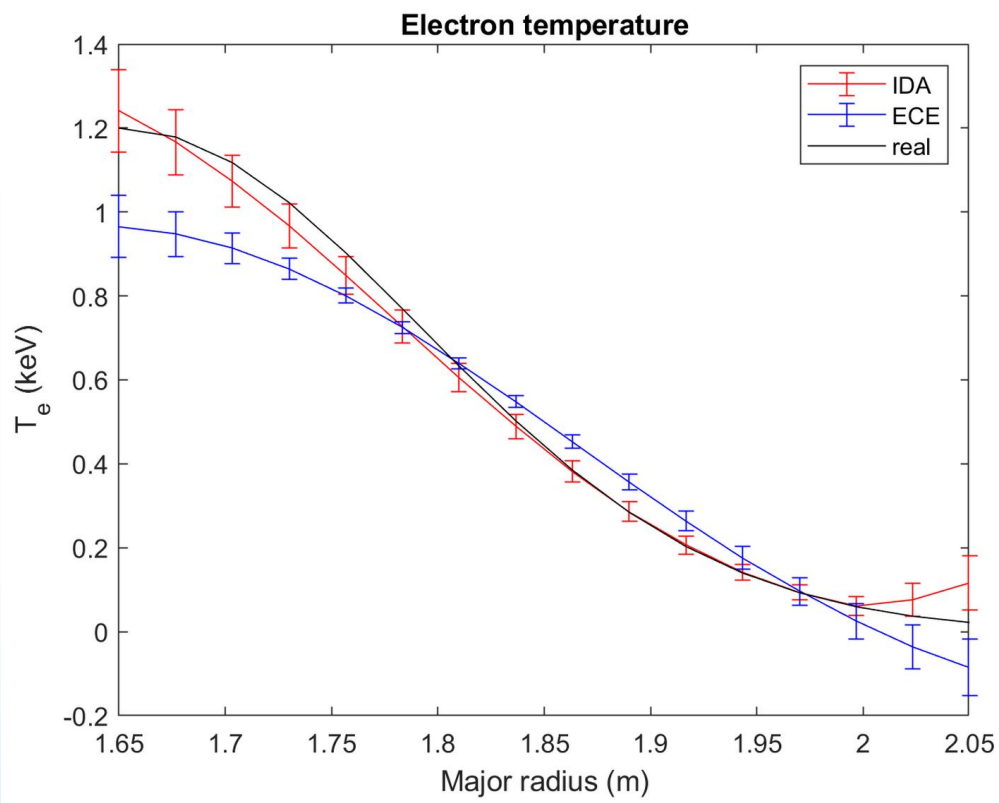
HL-2A BAYESIAN DATA ANALYSIS

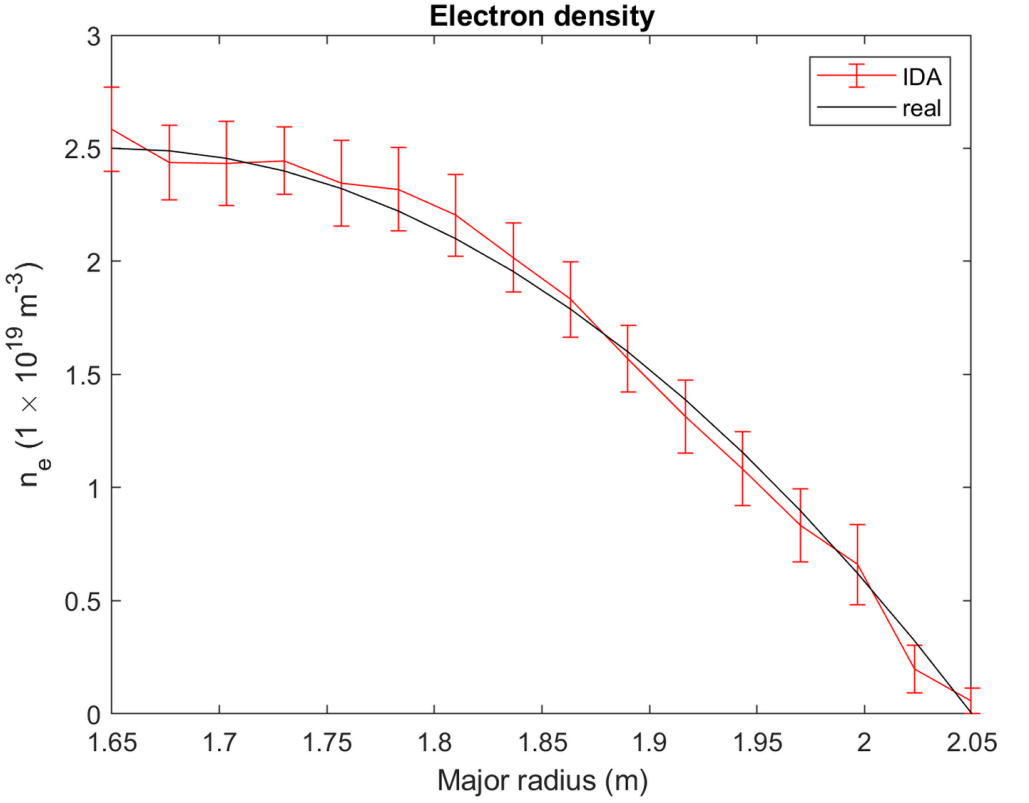
PHANTOM TEST FOR ELECTRON TEMPERATURE & DENSITY PROFILE IDA

Electron temperature & density profiles integrated data analysis by using ECE & TS & Reflectometry

More difficult than single profile inference, and the prior selection plays an important role.

The work is still on going with optimization.

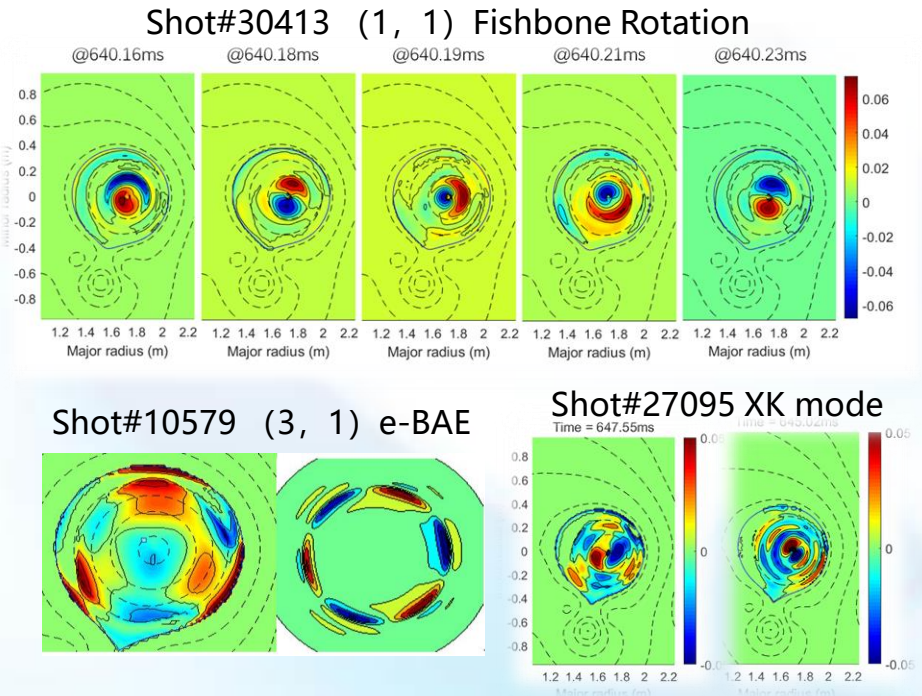




HL-2A BAYESIAN DATA ANALYSIS

BAYESIAN TOMOGRAPHY

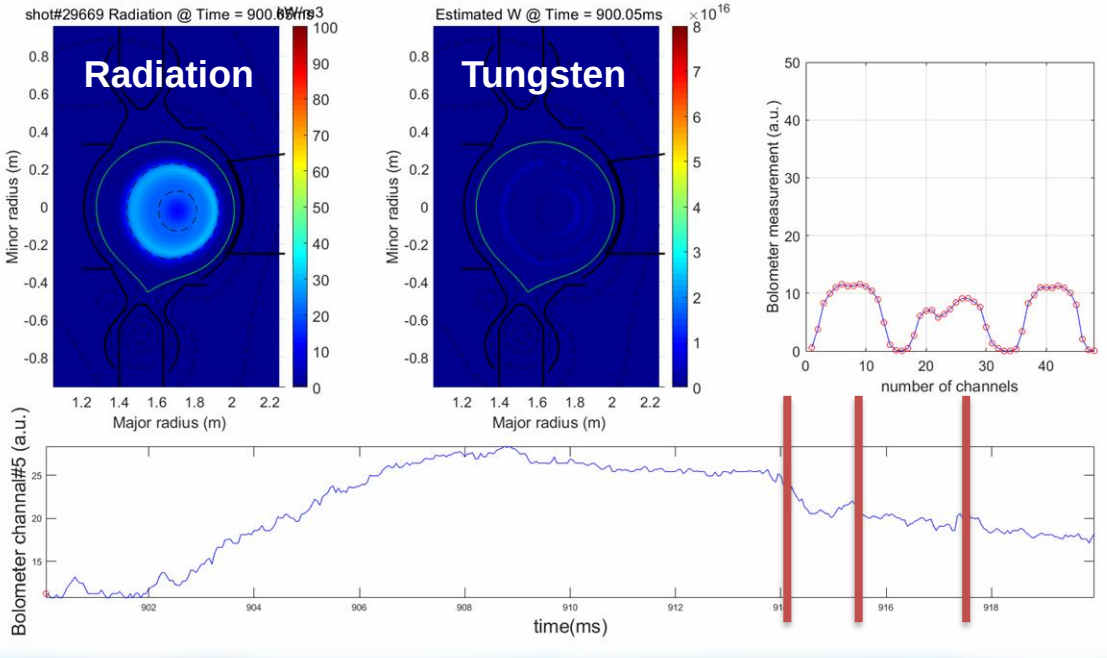
SXR tomography for MHD structure analysis



Yu Liming, Chen Wei, Shi Zhongbing, Wang Tianbo et al., Experimental observation of low-frequency magnetohydrodynamic instabilities driven by energetic electrons in low hybrid current drive plasmas, Nucl. Fusion, 2021, 61

X X He et al., The ITB dynamics controlled by internal kink modes on HL-2A tokamak, Plasma Phys. Control. Fusion 64 (2022) 015007 (11pp)

Bolometer tomography for tungsten monitoring with cooling factor

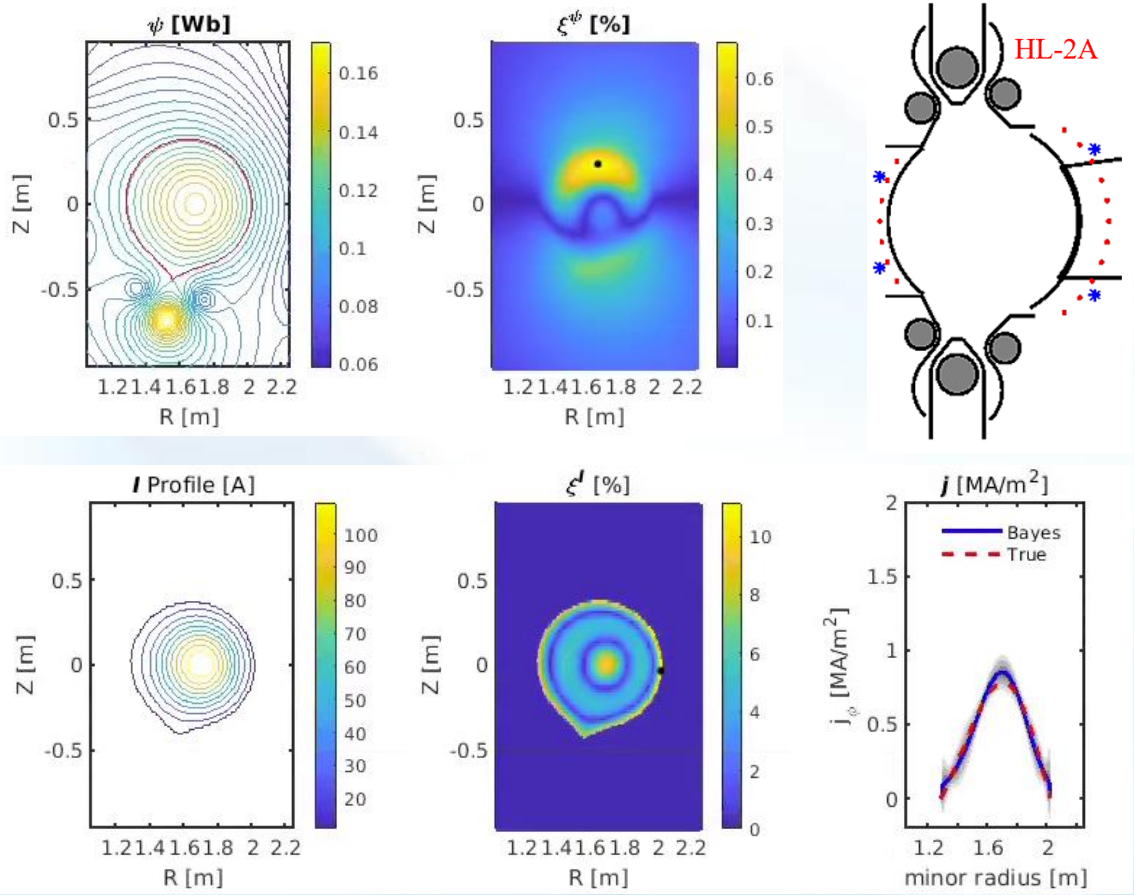


Tianbo Wang et al., Monitoring of two-dimensional tungsten concentration profiles on the HL-2A tokamak, under revision.

HL-2A BAYESIAN DATA ANALYSIS

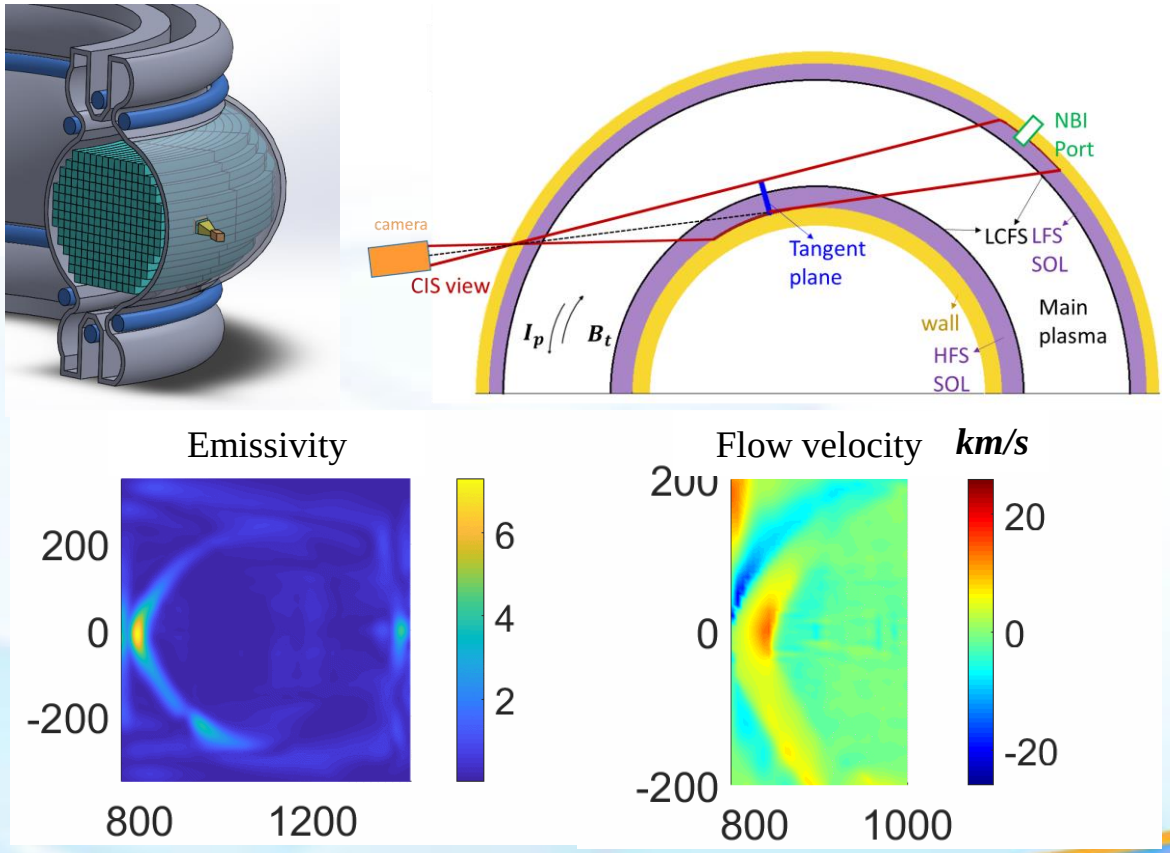
BAYESIAN TOMOGRAPHY

Magnetic flux & plasma current reconstruction by using pick-ups, flux & Rogowski loops on HL-2A



Zijie Liu, Zhengping Luo*, Tianbo Wang* et al., Plasma current profile reconstruction for EAST based on Bayesian inference, Fusion Engineering and Design,2021,172

Magnetic flux & plasma current reconstruction by using Doppler coherence imaging spectroscopy (CIS) on HL-2A



Li Bingli, Wang Tianbo* et al., Tomography of emissivity for Doppler coherence imaging spectroscopy diagnostic on HL-2A, Fusion Science and Technology 2021.

HL-2A BAYESIAN DATA ANALYSIS

RETINA CURRENT R&D SITUATION

RETINA **available** modules on HL-2A:	RETINA **available** functions:
Thomson scattering	T_e profile
ECE	n_e profile
Reflectometry	z_{eff} profile
SXR	SXR tomography
Bolometer	Bolometer tomography
Passive visible spectroscopy	Plasma current & magnetic flux reconstruction
Magnetic diagnostics	

RETINA **ongoing** modules on HL-2A:	RETINA **ongoing** functions:
Laser interferometry	T_i profile
CXRS	ω profile
VUV	Multi-species/impurity profile by using cooling factors

Current technical challenge:

- The current sampling method (Hamiltonian Monte Carlo) is **computational expensive** and have to frequently deal with **convergence issue**.
- Since the RETINA is working on IDA in parallel structure, the parameter scale is very large. IDA in series structure or hybrid structure might be a potential option?

Summary

SUMMARY

- The **Bayesian data analysis** has been applied on considerable number of diagnostics on HL-2A, and has doubtless delivered its value on experimental data analysis, especially on tomography applications.
- A set of individual Bayesian modules are being put together as a integrated data analysis platform, namely **RETINA**. This project is still ongoing in SWIP, aiming on inferences of basic experimental profiles of HL-2A, both for fresh experimental data and historical data base.
- A standardized data analysis platform could naturally deliver the desirable **data standard** on accuracy & consistency & uncertainty, which is extremely important for physics study.
- Giving a good data analysis standard is much more easier and cost-effective than historical data repairment.

Thank you!