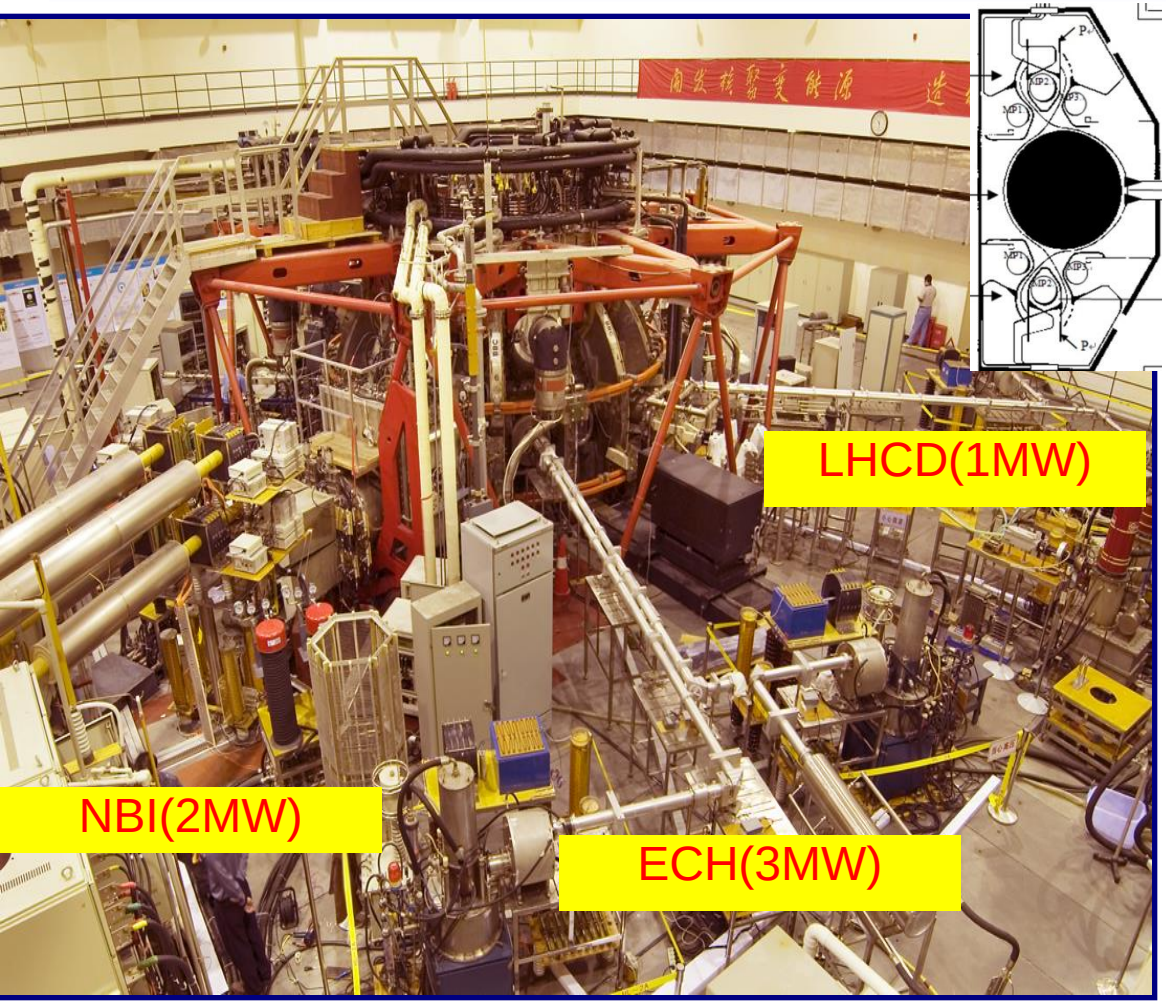
HL-2A 2017 experimental campaign opportunities and HL-2A capabilities

Southwestern Institute of Physics

PPPL, Princeton, NJ, 12/12/2016

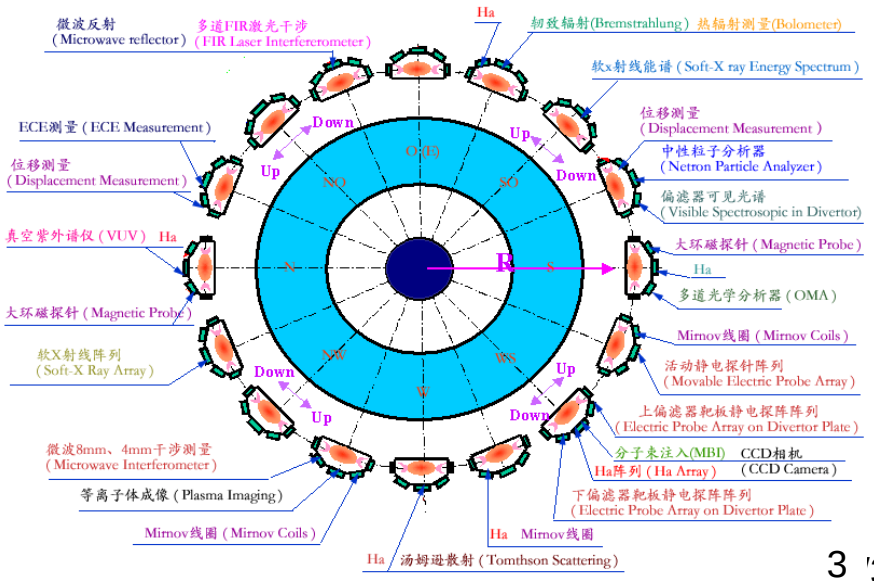
Present status of HL-2A tokamak (2017)



- HL-2A tokamak:
  - R/a=1.65m/0.4m
  - Ip=150-300kA, B_T=1.3-2T
  - ne=1-4e19 m^{-3},T_e=1-3 keV
- Heating and fuelling
  - ECRH: 2-3MW (coupled power), 500Hz modulation,68GHz
  - NBI: 1-2MW, 40keV
  - LHCD: 1MW, 3.7GHz
  - Pellet: repetitive
  - SMBI: 0.2-3MPa, 100Hz modulation
- RMP (n=1)
- More than 30 diagnostics have been developed

Physics activities on HL-2A

- MHD instability
  - Edge stability
  - Neoclassical tearing mode
  - sawteeth
- Transport and confinement
  - Turbulence characterization
  - Heat transport
  - Particle transport
  - Momentum transport,
  - Transport barriers: ETB,ITB
  - Nonlocal transport
  - Impurity transport
- Energetic particle physics
  - Wave properties: BAE, TAE, EPM
  - nonlinear EP
  - Fast particle transport
- Boundary physics
  - Divertor physics
  - SOL flows
  - Fuelling: SMBI
  - RMP(2014)
- Heating and current drive
  - ECRH/ECCD
  - Neutral beam
  - Low hybrid wave(2014)



HL-2A 2017 campaign: taskforce group

Taskforce group	Leaders	Subjects and roles
Pedestal physics and ELM control	L.W.Yan, W.L.Zhong	LH transition, pedestal width, ELM mitigation,…
Edge transport	Y.H.Xu, M.Xu	Filament, zonal flow, GAM,…
Core transport	Z.B.Shi, D.L.Yu	ITB, momentum transport, heating/particle transport…
MHD	Y.Liu, X.Q.Ji	NTM control, disruption mitigation, …
Energetic particles	W. Chen, Y.P. Zhang	AEs and EPM control Fast ion loss…
Heating and current drive	S.D.Song, X.Y. Bai	Noninductive CD, PAM antenna coupling, RF startup, H-mode with ECRH …

HL-2A 2017 campaign schedule and special considerations for NSTX-U team

- Rough plan is to start operation in March 2017 and to finish the run in June 2017
- Internal experimental proposal review is going now
  - NSTX-U team is exempted from this review
  - Still need to work with task force leaders in proposal preparation process
- Run time is guaranteed for NSTX-U team (with reasonable XPs) and no preset runtime allocation limit

Diagnostics for transport study

HL-2A

•The transport study, i.e. electron heat transport, particle transport, impurity transport, and momentum transport, have been carried out on HL-2A.

•Perturbative techniques: gaspuffing, SMBI(H,D2,He,…), pellet, LBO(Al,Fe,W,Ti,30Hz), M-ECRH/ECCD (500Hz), NBI(4 pulse), …

•Te profile Measurement

- 32 Channel ECE (32ch/3cm/10us)

•Ne profile measurement

- 4 Channel HCN laser Interferometer
- Reflectometer,33-110G($6\times10^{19}m^{-3}$,20us）

•Ti profile Measurement

- CXRS（for Ti(r) 1.5cm,10ms,32ch）

•Multi-Channel Detector arrays

- Soft X-Ray System: 5arrays 100chs
- Bolometer system：4arrays 48chs
- Ha measurement： 2arrays 92chs

•Plasma rotation

- CXRS （for Vt(r), .5cm,10ms, 32ch）
- Doppler （for Vp(r), >20 ch, 2 ms）
- Probe array (edge velocity)

•Impurity

- EUVSpectroscopy(3nm-40nm,6ms/2mm)

Diagnostics for energetic particle physics study

HL-2A

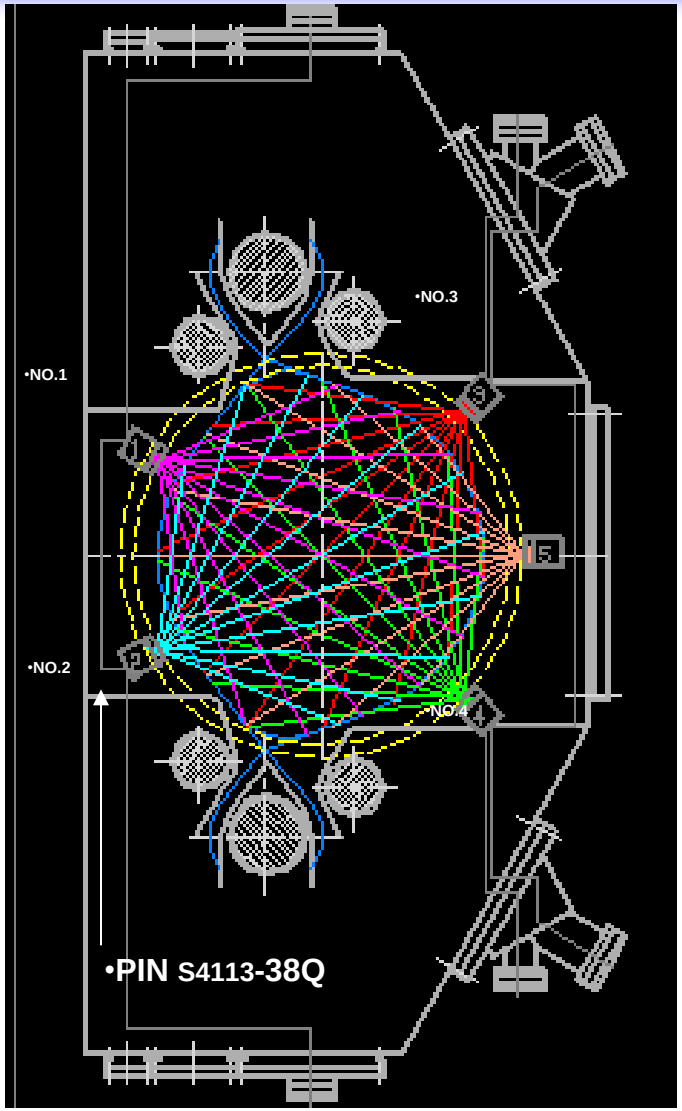
- **Heating: ECRH (3MW/1s), NBI(2MW/1s), LHCD(1MW)**
- **ECRH modulation: 500Hz**

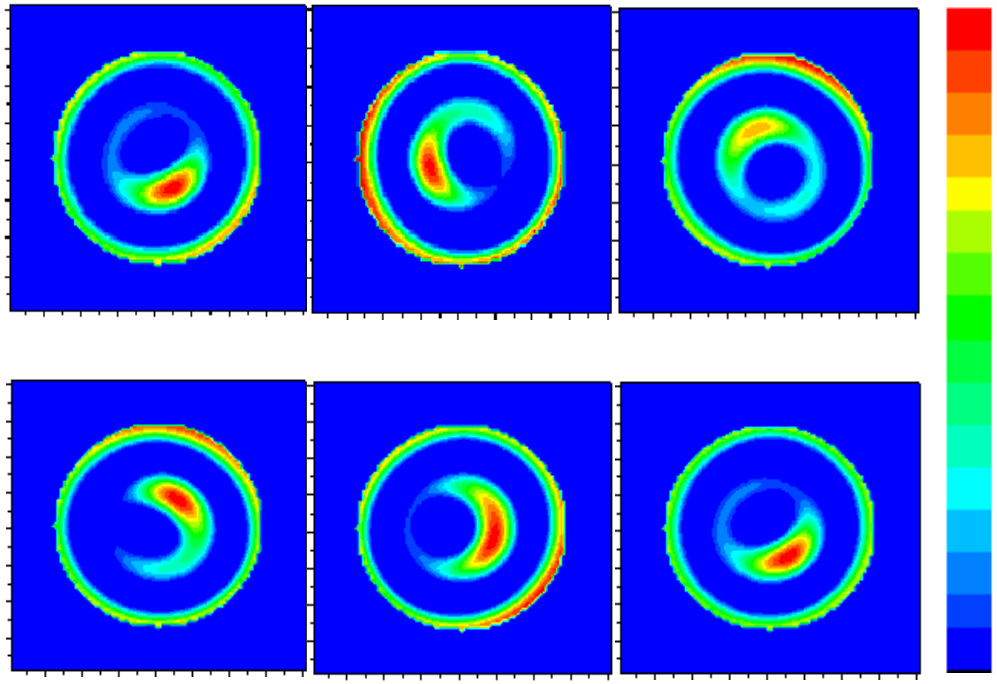
- **Fast ion spectrum and distribution**
  - CXRS (32ch)
  - Imaging-FIDA (2017)
- **Fast electron spectrum and distribution**
  - Multi-channel CdTe array (9-ch)
  - Soft-X-ray spectrum (SDD)
  - ECE (50-110G,110-170G, 2ms)
- **Fast particle loss**
  - gama-ray spectrum(NaI, HPGe)
  - Fission chamber (2-ch)
  - ^{3}He Neutron spectrum
  - Neutron camera (9-ch, 2015)
- **Wave-particle interaction**
  - Mirnov probe (18ch+10ch)
  - Reflectometer (2ch)
  - Interferometer (4ch)
  - Doppler (>20ch)
  - ECE/ECEI (32ch, 384ch)
  - Soft-X-ray array (100ch)
  - BES (2017)

Diagnostic systems for fluctuation measurements on HL-2A

Parameters	Diagnostics	channel	Spatial	Temporal	Reliability	error	
Plasma image	Visible CCD camera	1	Entire	9 ms	>90%	--	
	Fast visible CCD camera	1	-	100 ns		--	
Te	Multi-channel ECE/ECEI	16/384	2.5/1 cm	1/10 μs	>70%	a.u.	73-97G
ne	MW interferometers	4		1 μs			
	Doppler reflectometers	24	1cm	1-5ms			17-60GHz
MHD	Mirnov coils	2 sets	m<17, n<4	50 kHz	100%	2 %	
	Soft-x-array	20*5	3 cm	10 μs	>90%	5%	
Edge parameters (ne,Te, EXB,…)	Movable electrostatic probe	2	1 mm	1 μs	~50%	30%	
	Fast reciprocating probe	1	1 mm	1 μs	~70%	30%	
Divertor parameters	Movable electrostatic probe	2	1 mm	1 μs	>50%	30%	
	Target plate probe	7*4	1 cm	1 μs	100%	30%	
	Microwave interferometer	1	--	10 μs	<30%	5%	
Target plate temp.	IR camera	1	1 mm	1 μs	>70%	1%	
Edge turbulence	Electrostatic plate	3	1 mm	1 μs	>50%	30%	
Plasma rotation	doppler reflectometer	4	1 cm	1-20 ms	~50%	10%	

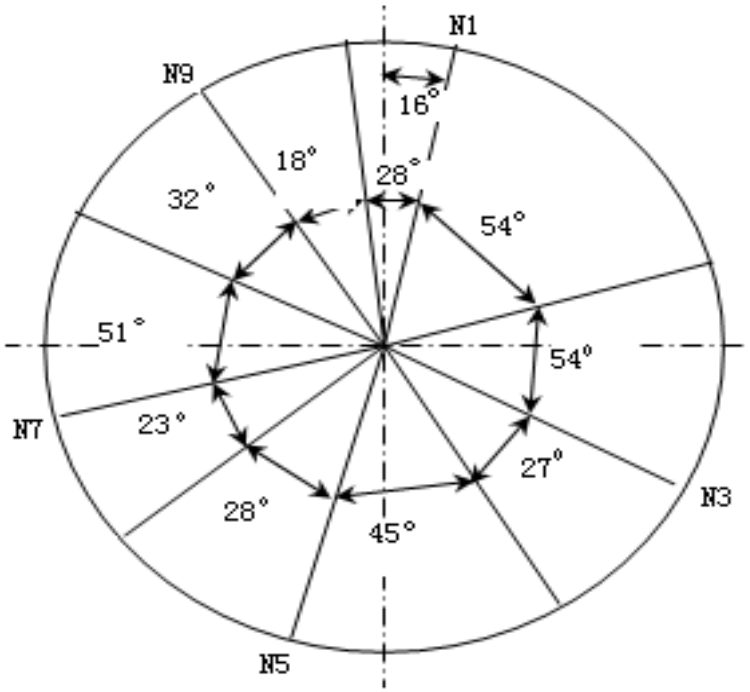
Soft X-ray array

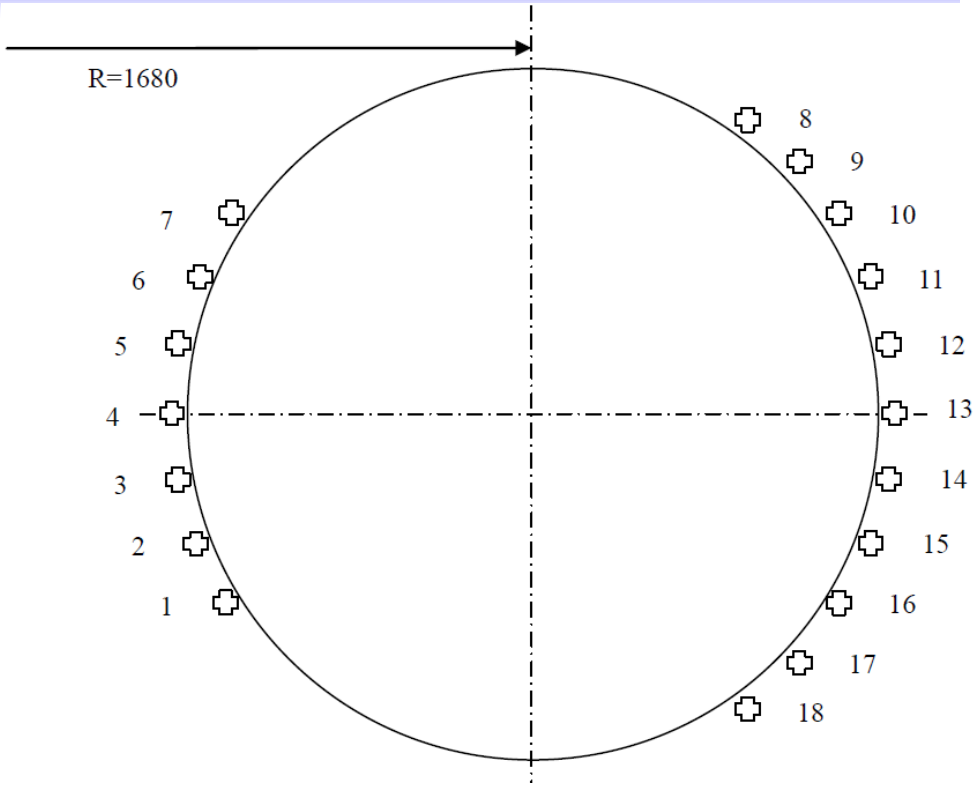




- Five arrays
- Lines of sight: 100
- spatial resolution: 2.5cm
- temporal resolution: 10us

Mirnov coils





Parameters:

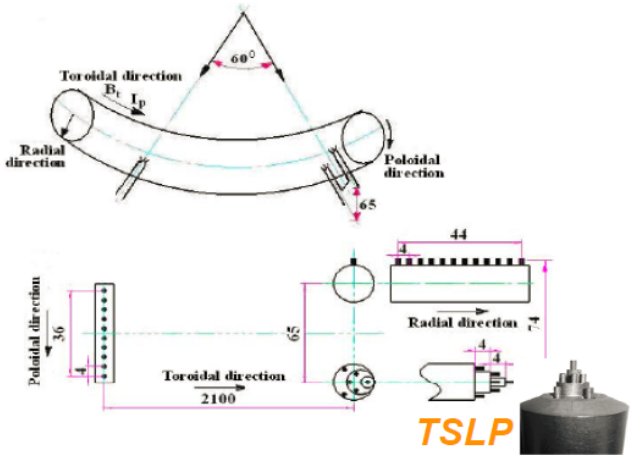
- **Poloidal: 18channels**
- **Toroidal: 10channels**
- **Sampling: 1MHz**

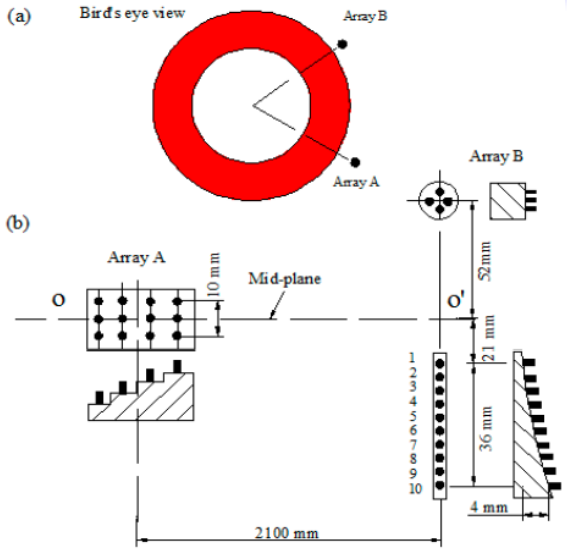
•m<17, n<4

Electrostatic probe system

HL-2A

3D Langmuir probe arrays





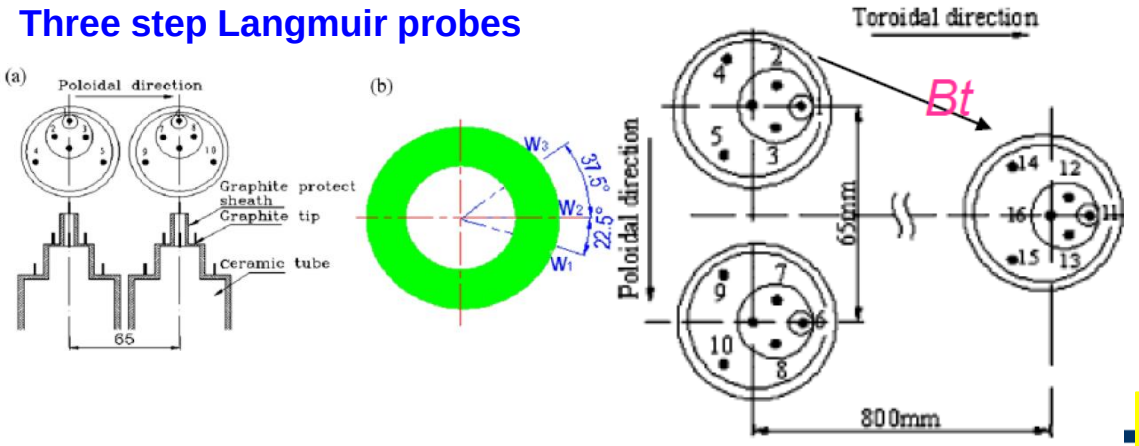
Parameters measured simultaneously:

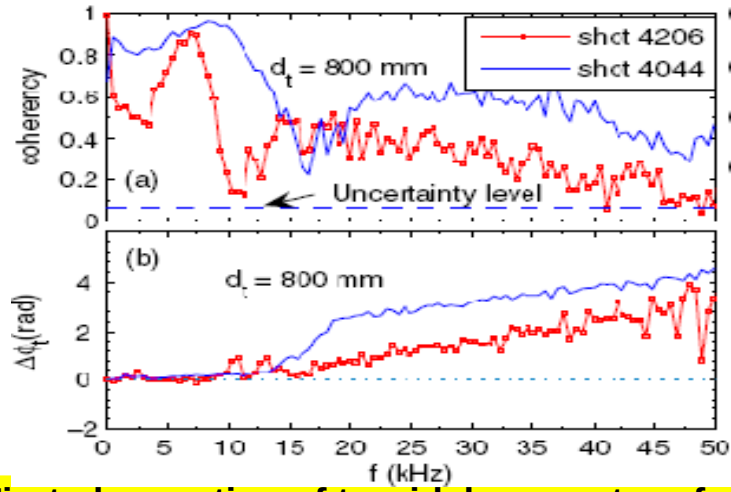
$T_e, n_e, \phi_f, \tilde{n}_e, E_r, P_e, E'_r, P_e',$

etc. at a few radial and poloidal positions in two poloidal sections;

- **Sampling rate = 1 MHz**
- **Spatial resolution= 4 mm**
- **Diameter of tips is 1.5 mm.**
- **Height of tips is 3 mm.**

Three step Langmuir probes

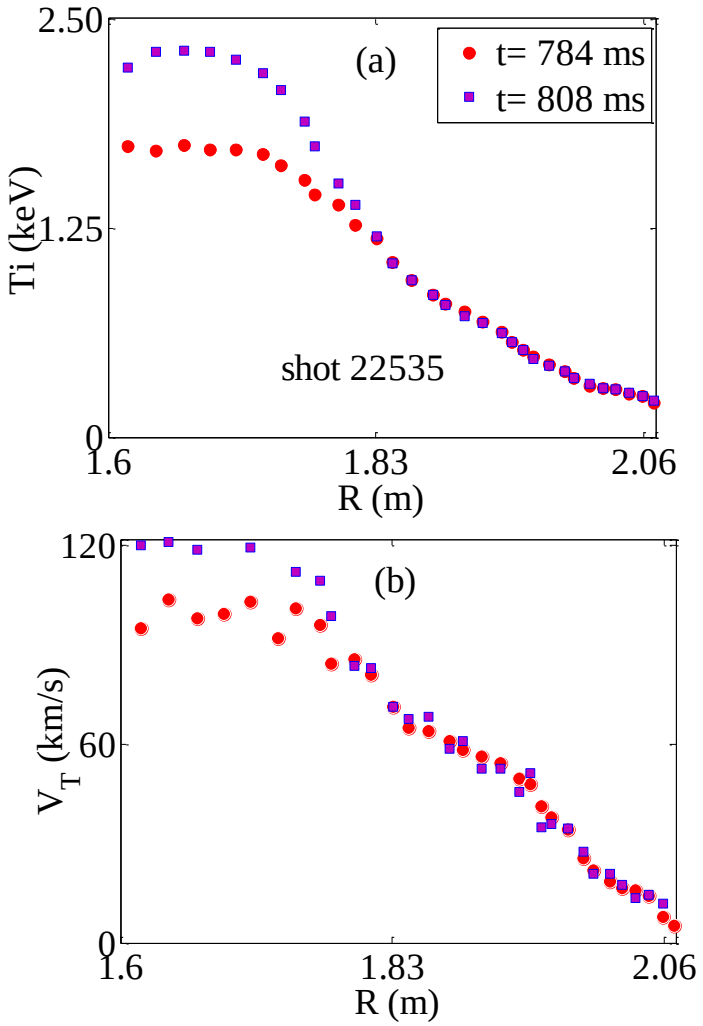




•First observation of toroidal symmetry of GAM (n~0,m~0,finite kr)

•K.J. Zhao, PRL96 (2006)255004.

CXRS

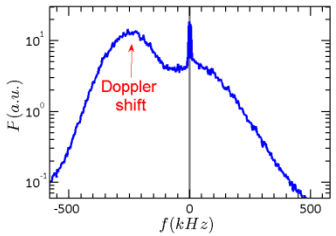


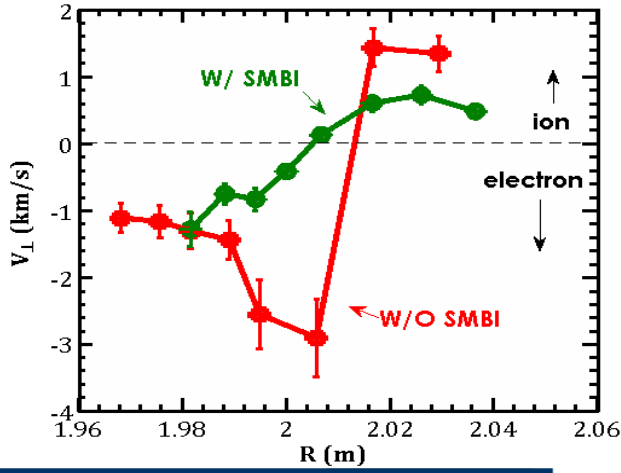
Parameters:

- **F/#=2.8**
- **32 spatial channels;**
- **Temporal and spatial resolutions of ~10 ms and 1.5 cm;**

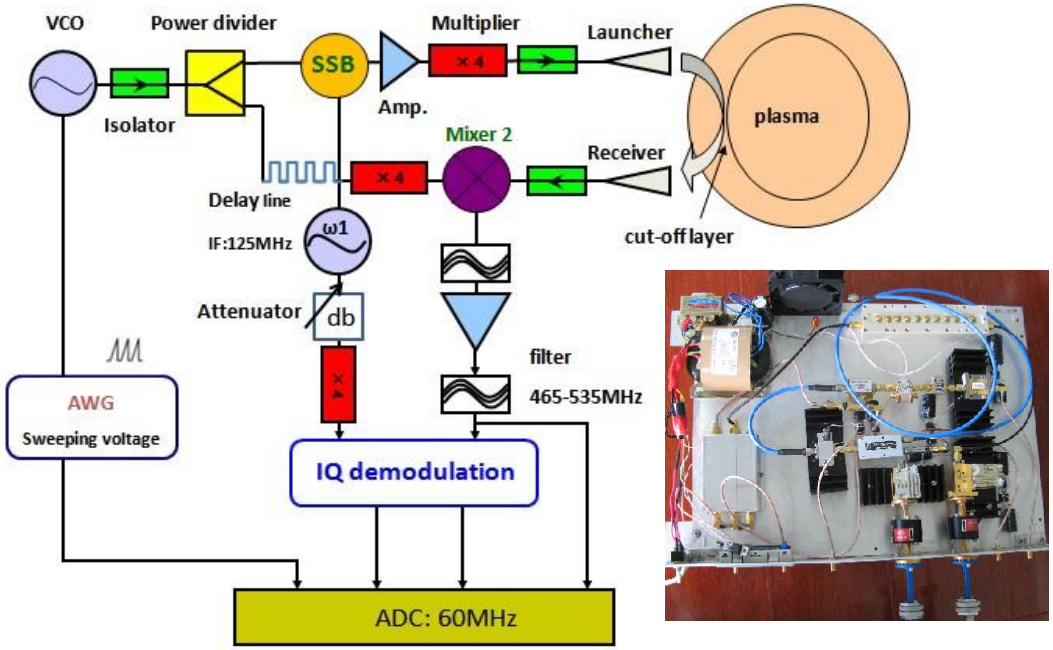
DBS systems for poloidal rotation and turbulence measurements

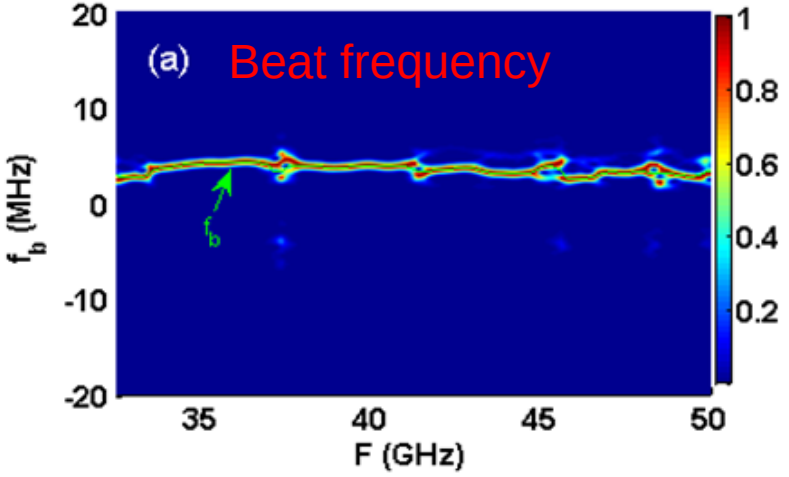
- **Multi-channel Doppler backscattering (DBS) /Reflectometry systems built by SWIP for HL-2A**
  - 8-channel K-band system: 17,18,19,20,21,22,23,24 GHz, O-mode
  - 8-channel Ka-band system: 31,32,33,34,35,36,37,38GHz ， O/X-mode
  - 8-channel Q-band system : 34,36,38,40,42,44,46,48GHz ， O/X-mode
  - 4 frequency correlation DBS system: one launcher, 2/16 receivers: 32,34,36,38GHz , O/X-mode (studying toroidal, poloidal correlation)
  - Tunable systems:26-40GHz (O/X-mode), 40-60GHz(X-mode)
  - Systems detailed in
    - Z.B.Shi et.al., ITPA diag.(2011),
    - Z.B.Shi et.al., IRW12(2015),
    - Z.B.Shi et.al., RSI 87(2016)113501,
    - W.L. Zhong, et.al., Nucl. Fusion **55** (2015) 113005,
    - W.L.Zhong et.al.,1st EPS diag. (2015)
    - …

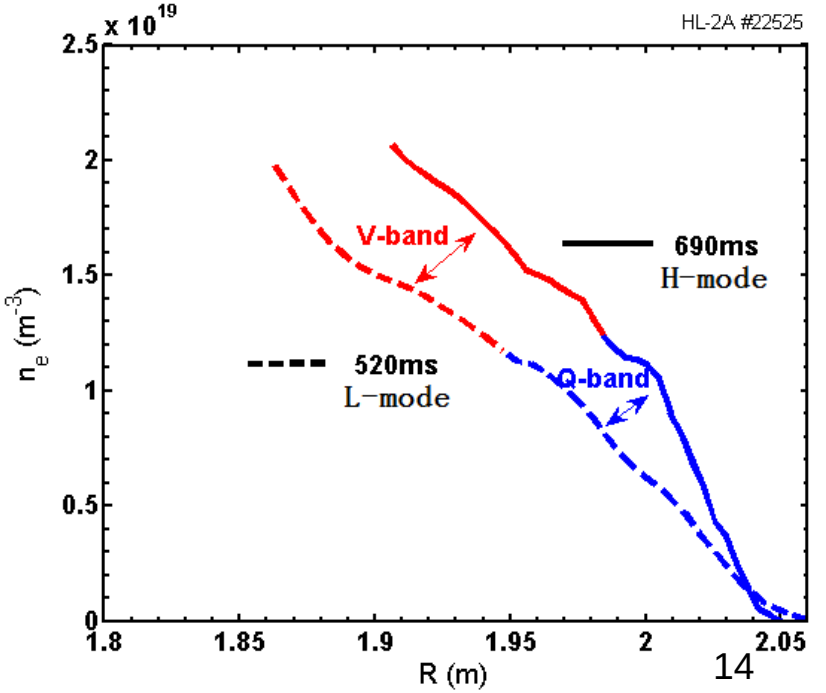




X-mode FMCW reflectometer for density profile measurement



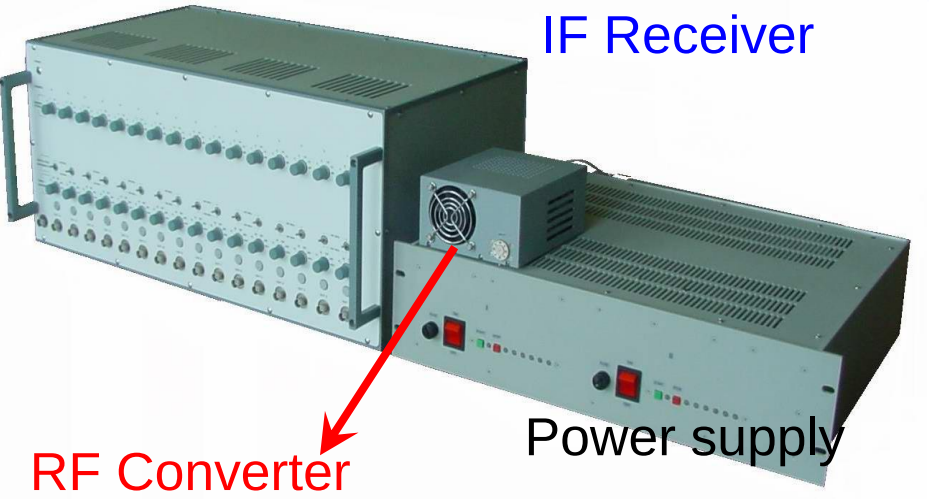




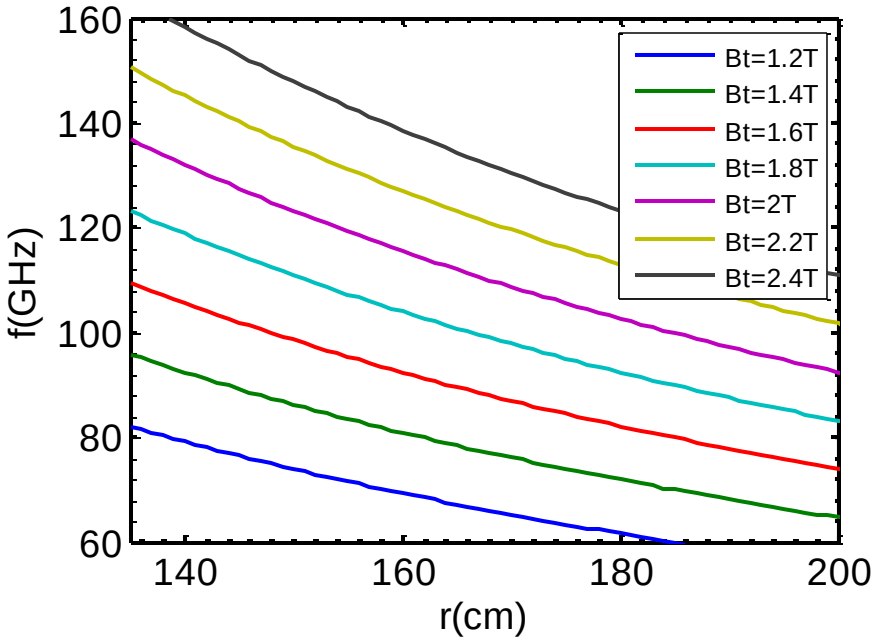
- Q,V,W bands: 33-110GHz
- Bt=1.3-2.4Tesla
- n_e=(0-4)X$10^{19}m^{-3}$
- Temporal resolution: 20us→10us
- Spatial resolution: 0.5cm

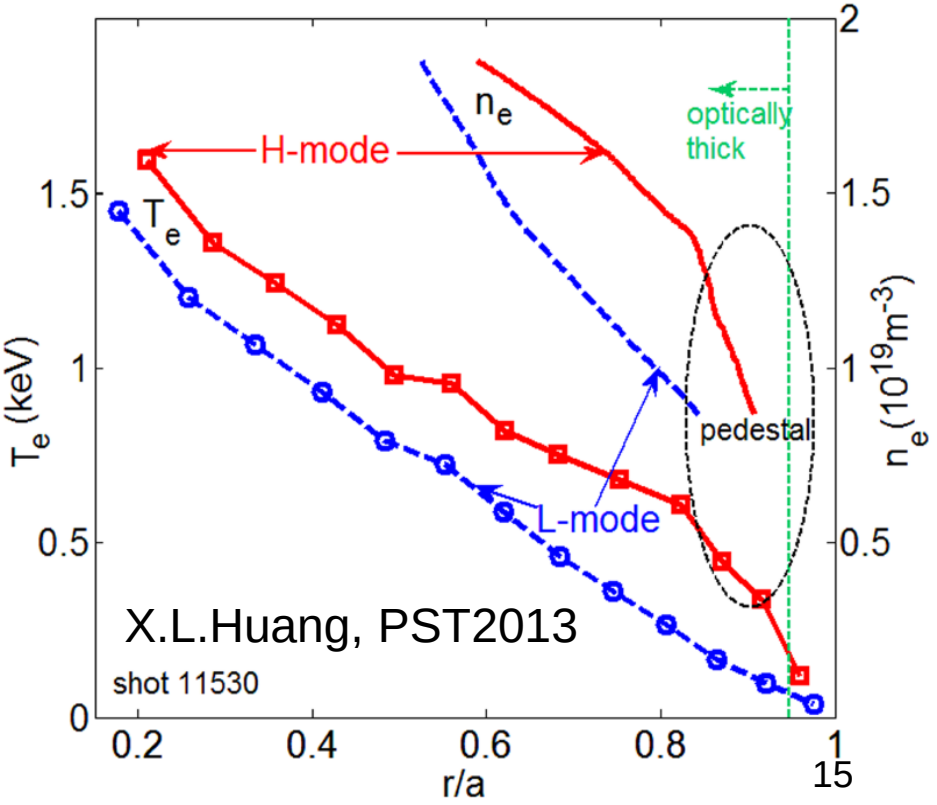
32-channel superheterodyne ECE system

HL-2A

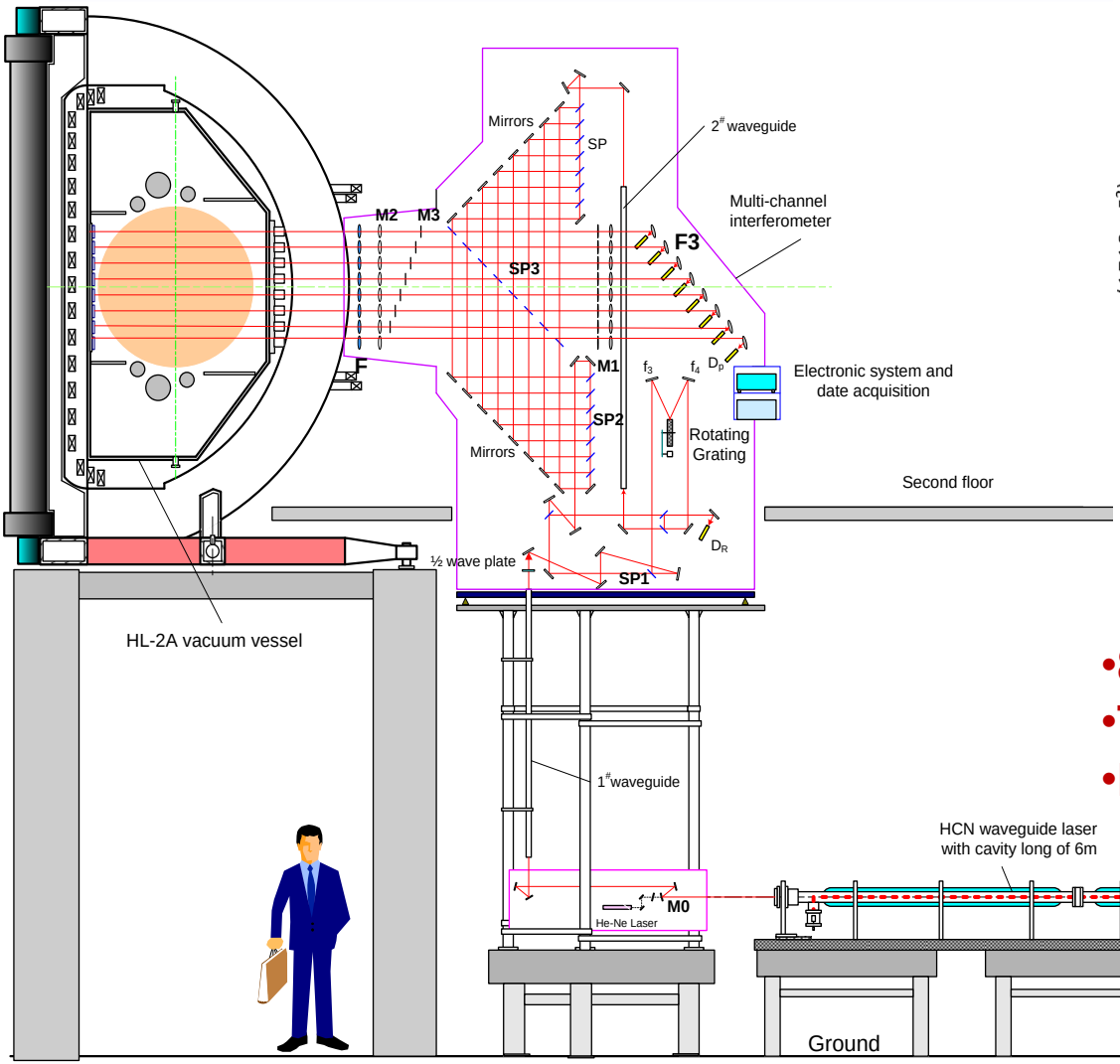


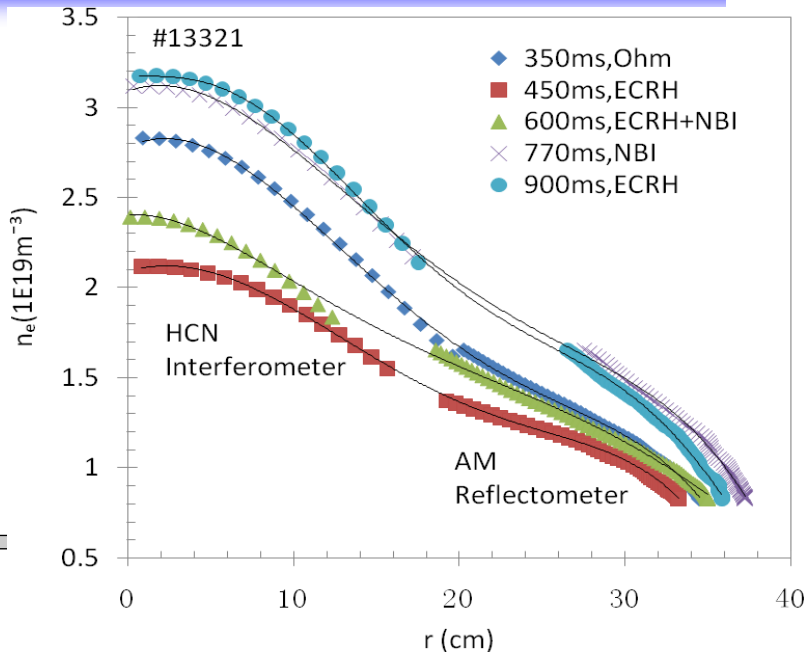
1. Working frequency: 60-160GHz
2. Bt=1.3-2.4T for whole Te profile
3. Temporal/spatial resolutions: 10us, 3cm





8-channel HCN interferometer

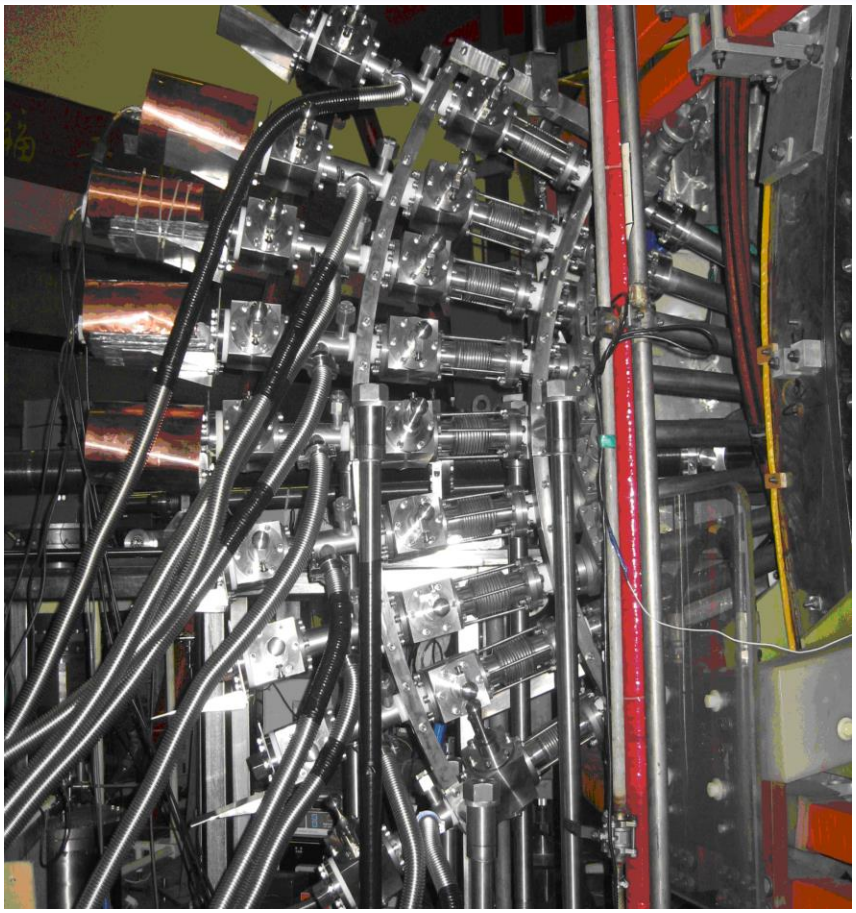


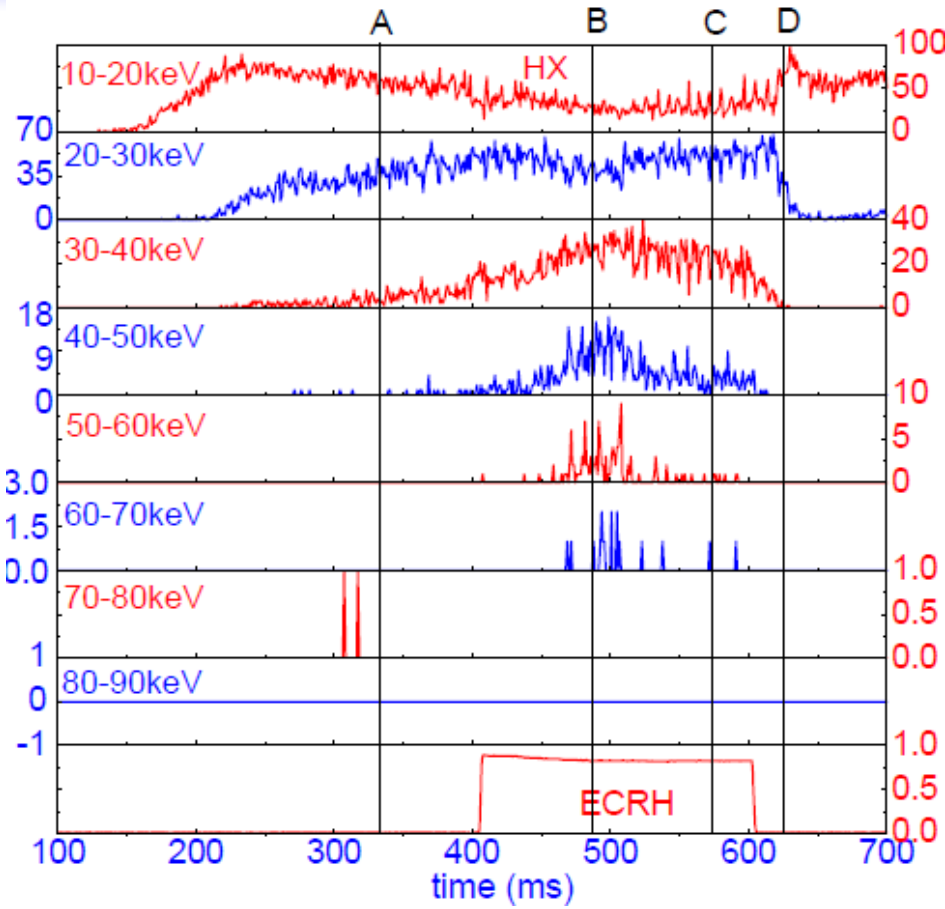


- 8 channels (4 channels in use)
- Temporal resolution: 0.1ms
- Density resolution: $1.7X10^{17}m^{-3}$

Fast electron bremsstrahlung CdTe array

HL-2A



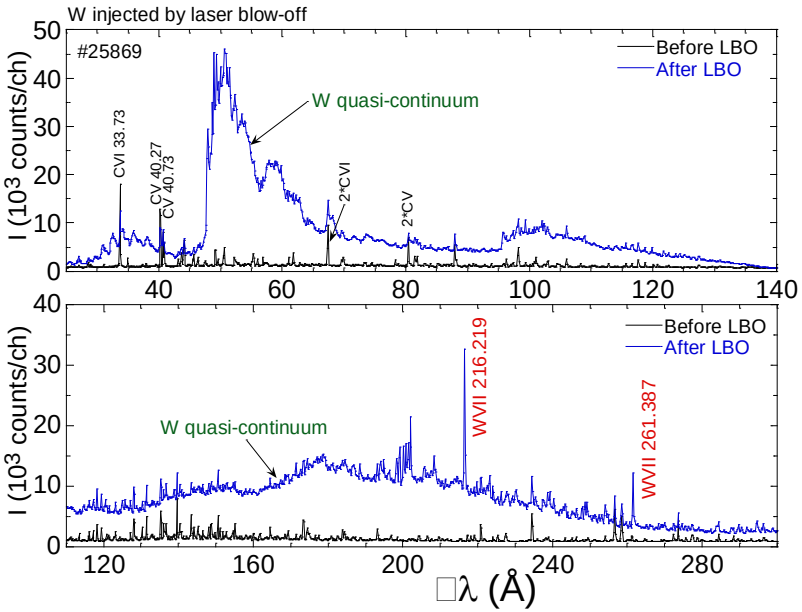


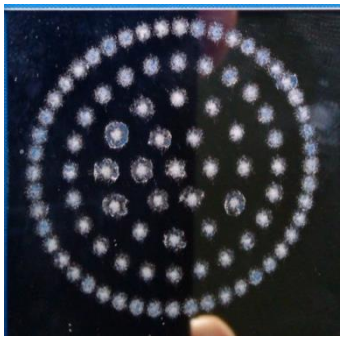
- 9 channels
- Energy range:10-200keV
- Resolutions:1ms/5cm

- The energetic electron energy spectra during ECRH

Multi-pulse Laser blow-off system

- 30Hz, multi-pulses
- Target: Al, Fe, Ti, W
- First observation of W spectrum on HL-2A
  - ➢WVII216.2 andWVII261.4。





•Target after LBO

•LBO system

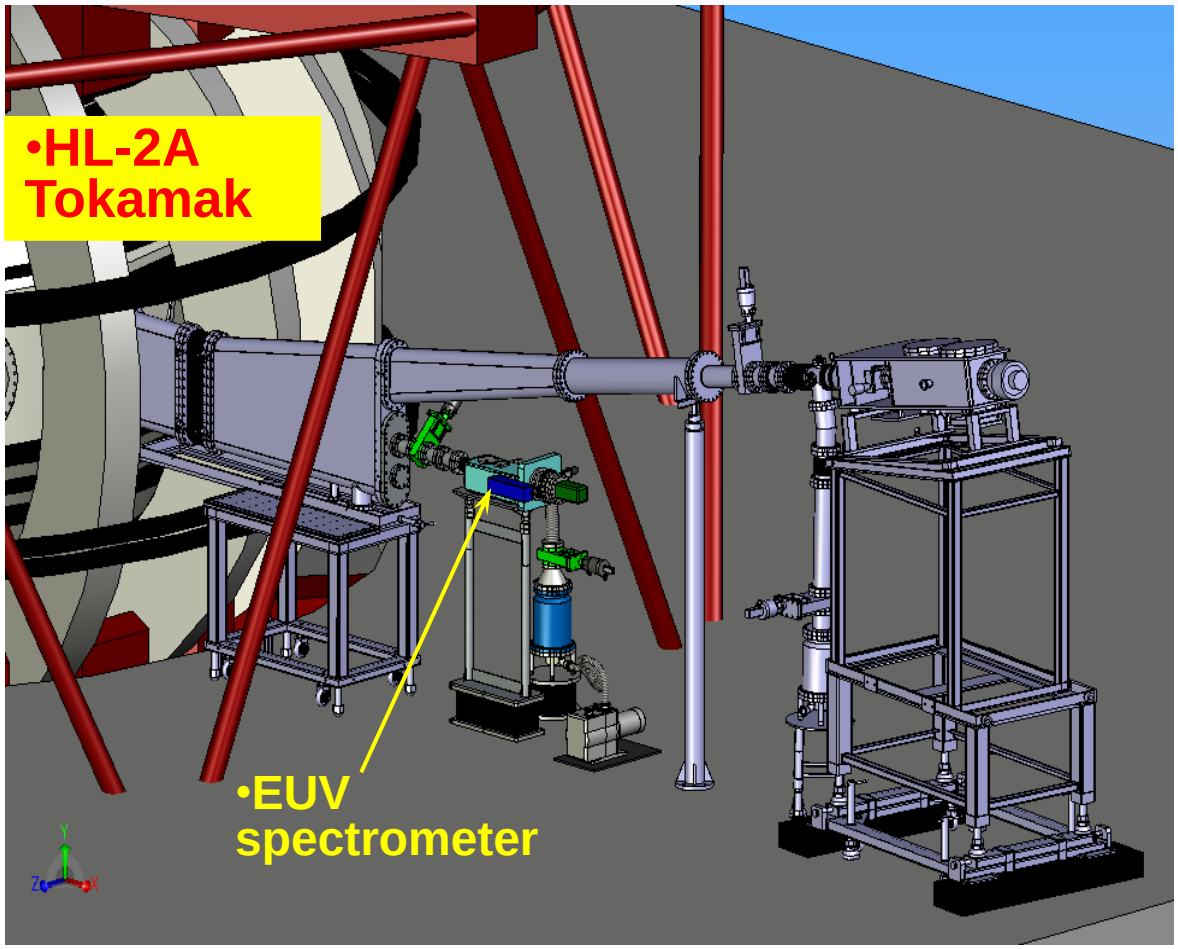
•Z.Y. Cui, et al., NF 55(2015)093034

•C. F. Dong, et al., 201505 A3 meeting

•Southwestern Institute of Physics

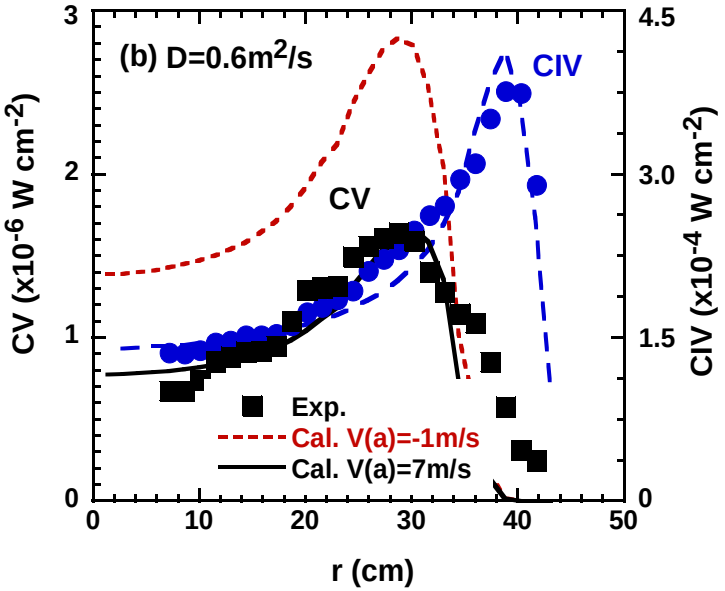
Space-resolved EUV spectrometers

HL-2A



➢Extreme Ultraviolet (EUV) Spectroscopy (3nm-40nm)

•The transport coefficient during ECH



•D=0.6 m²/s and V(a)=7m/s

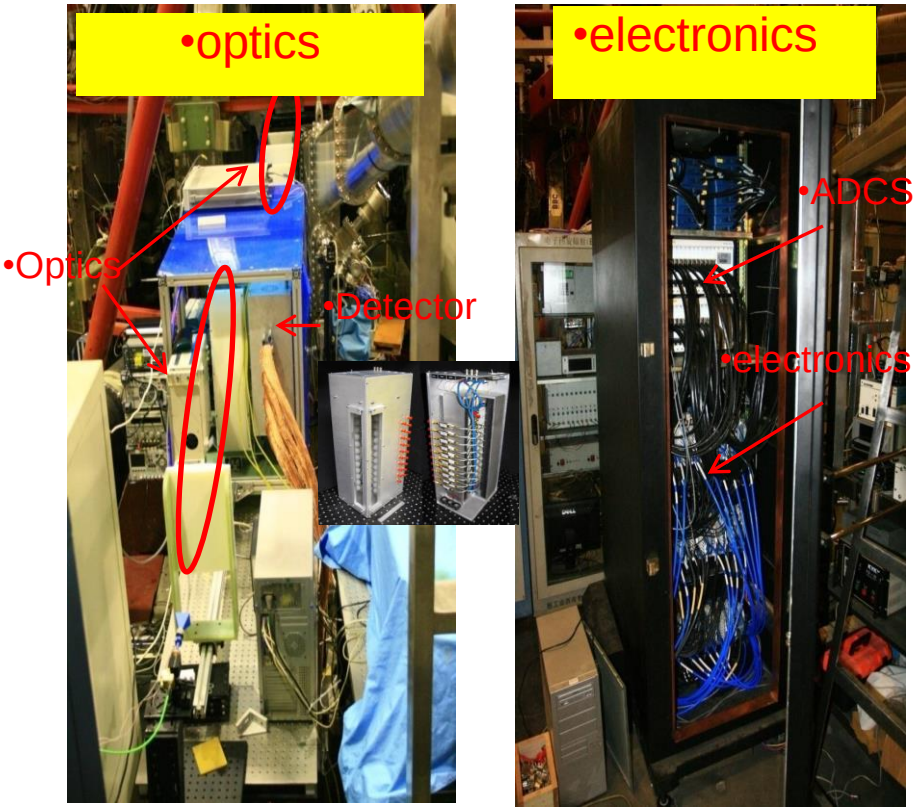
•Possible explanation for the reversal of V

•Transition of ITG/TEM turbulence after ECRH switch-on

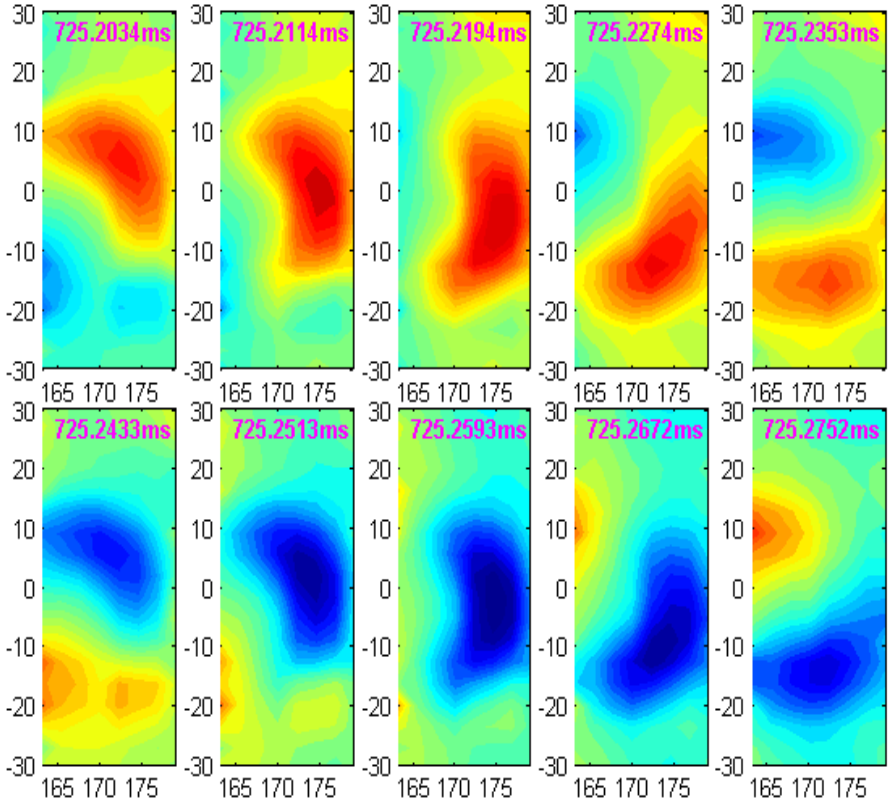
Visualization of 2D Te fluctuation with ECEI

HL-2A

- LFS image (X2),
- 384channels (polo. 24* radi. 8*2)
- resolutions: ~1cm/10us



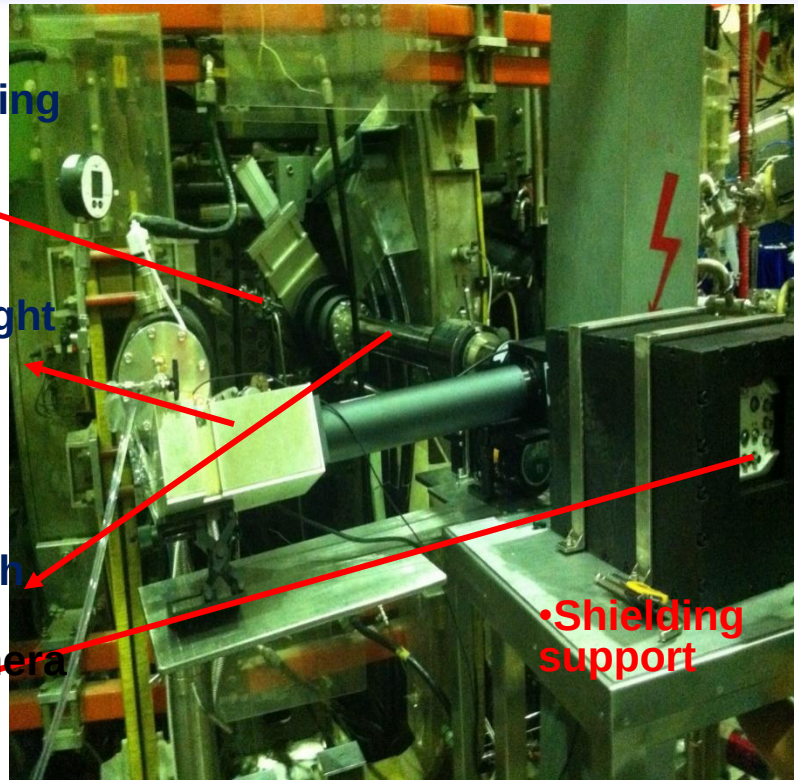
•Basic observations on HL-2A similar to those on other tokamaks



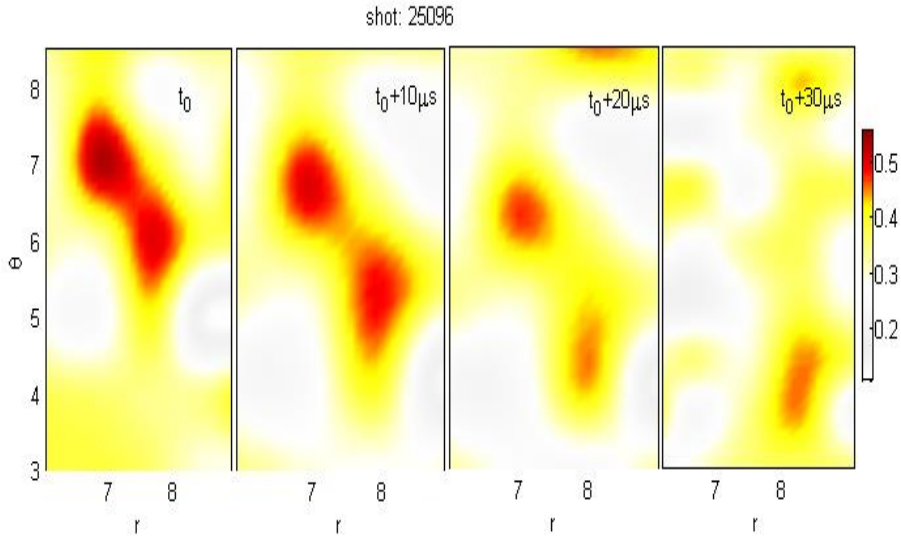
•Evolution of Sawtooth precursor

Visualization of blob generation and propagation with GPI system on HL-2A

HL-2A



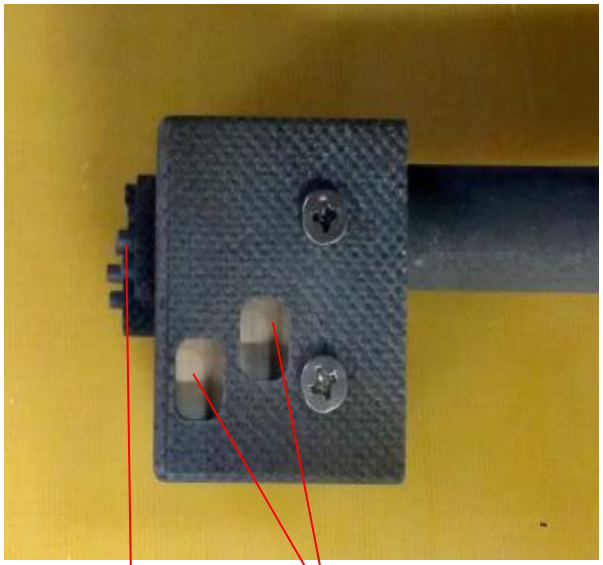
•2D imaging of density fluctuations by GPI



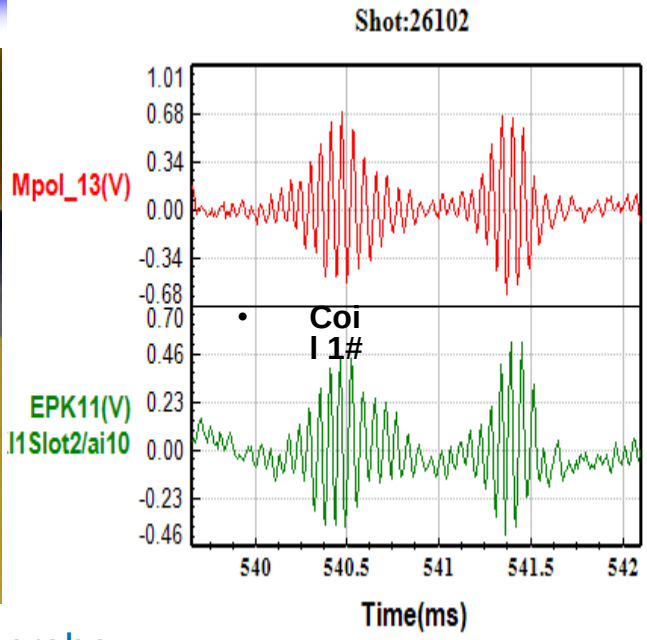
➢ The eddies tiled, deformed; eddies evolution into smaller-scale blobs in a few us

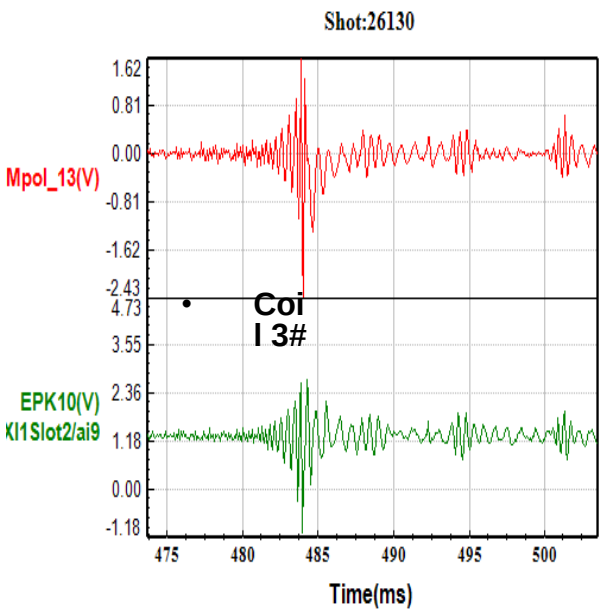
- Gas：He, Pressure：0.2-1.0 Mpa
- Fast camera: sampling : 200-400 kHz, spatial : 1-3 mm
- Visible light detector: the imaging area:20x20 mm^2

Two dimensional electromagnetic measuring system



• Langmuir probe • Magnetic probe





•A significant correlation of magnetic fluctuations measured by mirnov and electronmagnetic probe

- Electromagnetic probe applied to study edge turbulence, including coherent mode, pedestal instability, LCO, L-I-H transition, etc
- The effective area of one magnetic probe is about 3x5 mm^2, band width: 300 kHz
- The shielding cover is made by CFC material
- Many parameters simultaneously measured (Pe、Rs、Br, Bθ and its gradient)

8-channel ^{3}He Neutron spectrum

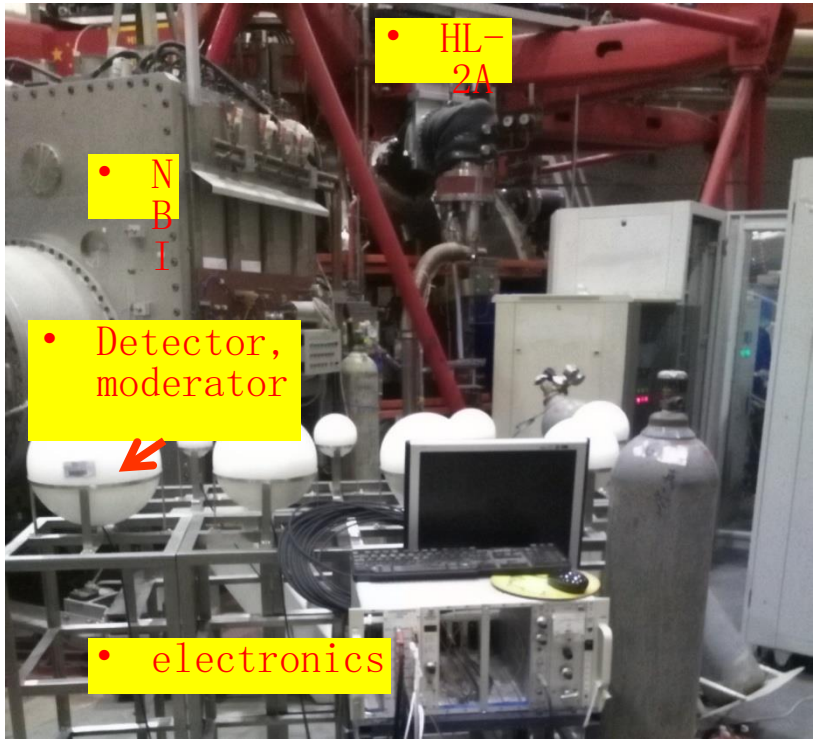
HL-2A

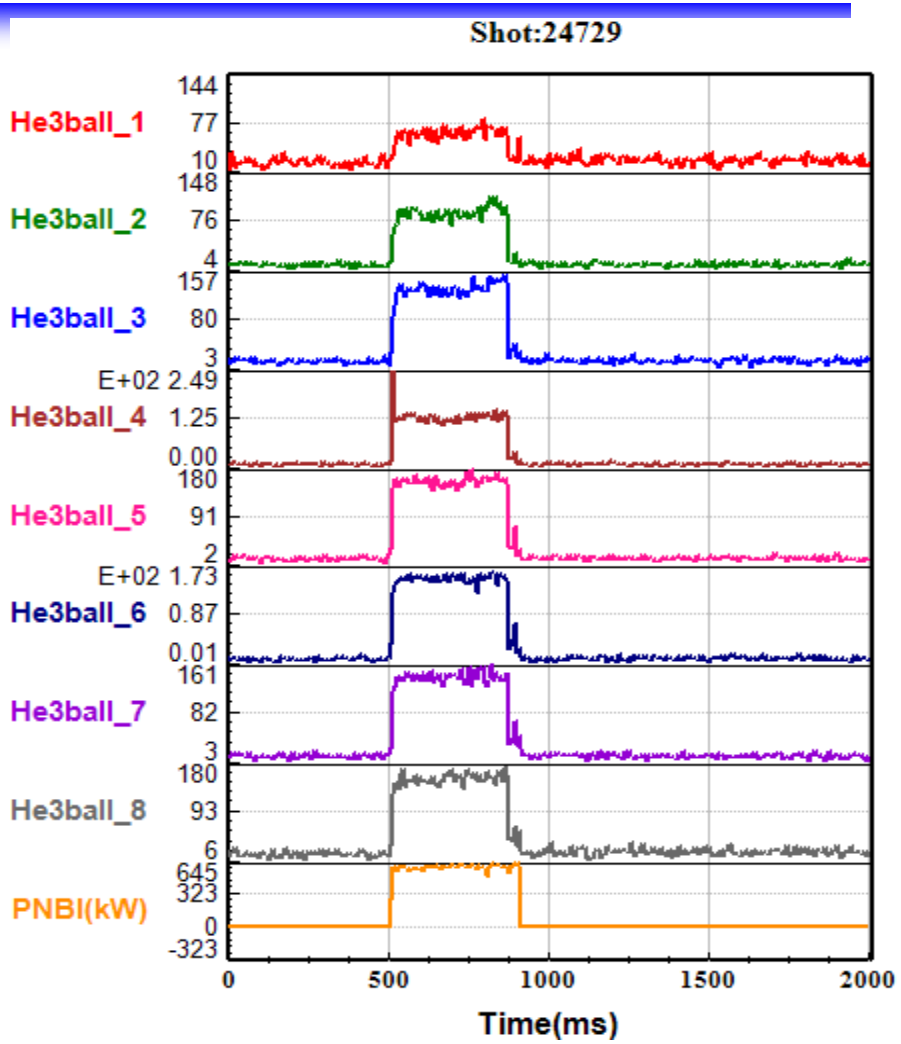
- For fusion neutron spectrum measurement:

➢8 moderator balls: from 12 to 4 inches。

➢Temporal resolution: 1ms。

➢Energy spectrum range:0～5MeV。

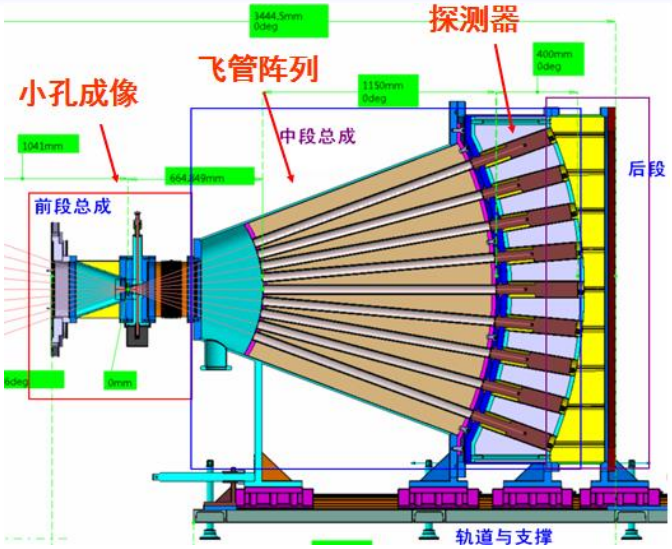


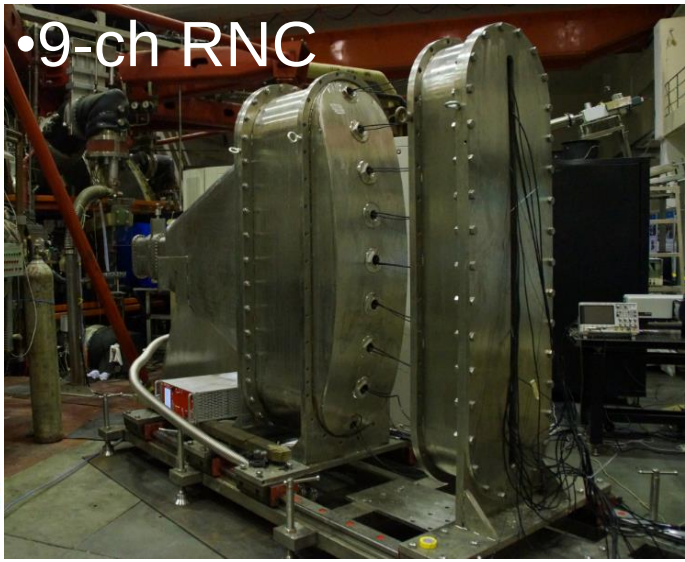


•Neutron spectrum during NBI

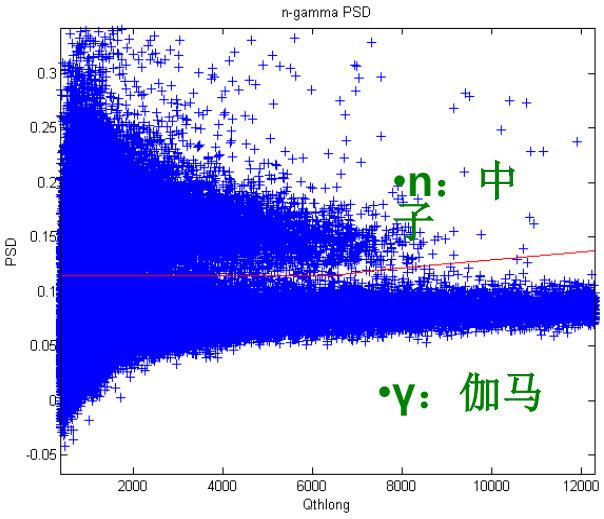
9-channel radial neutron camera (RNC)

- Neutron camera：
  - 9-ch for neutron flux profile
    - 5-ch available
  - Temp. resl.：1-10ms
  - Spatial cover：r/a≤0.7

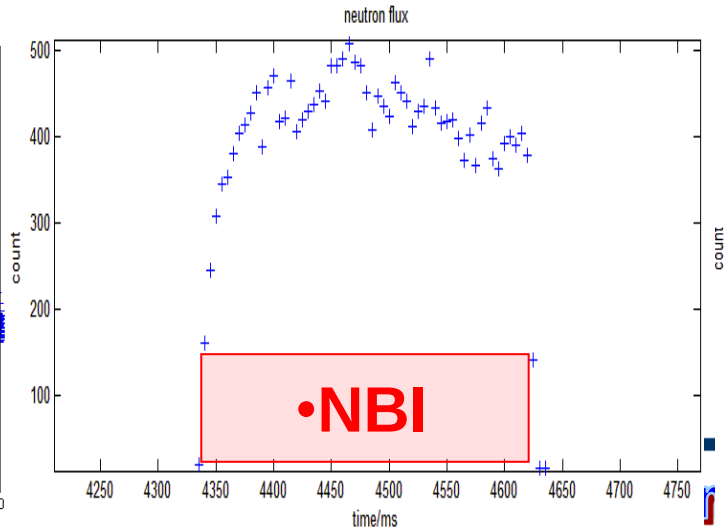




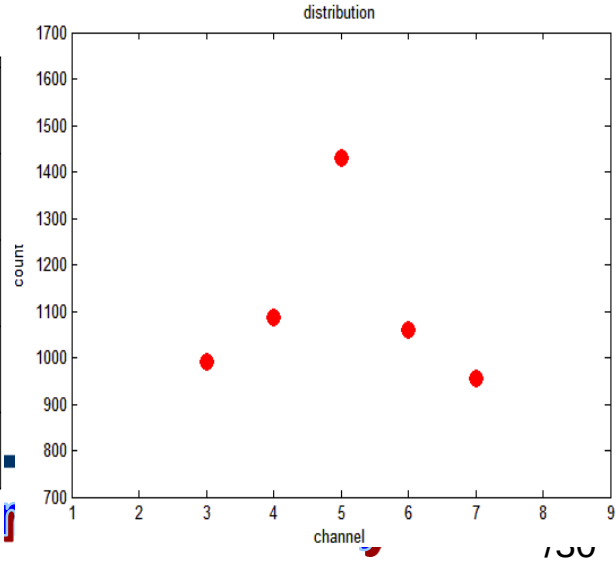
•n/γ spectrum



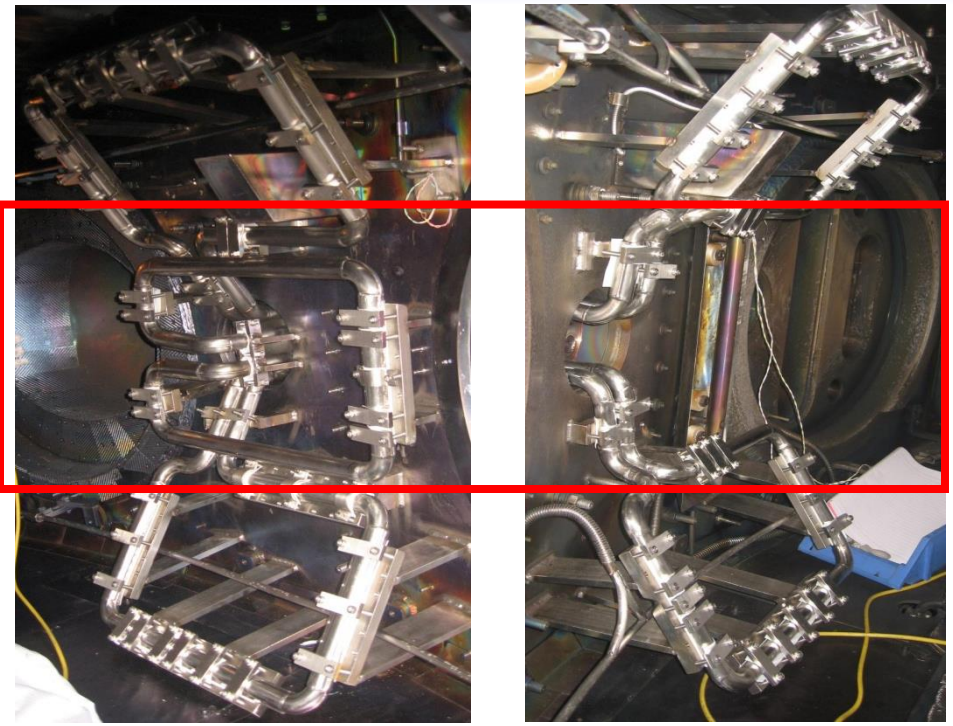
•Evolution of neutron flux during NBI

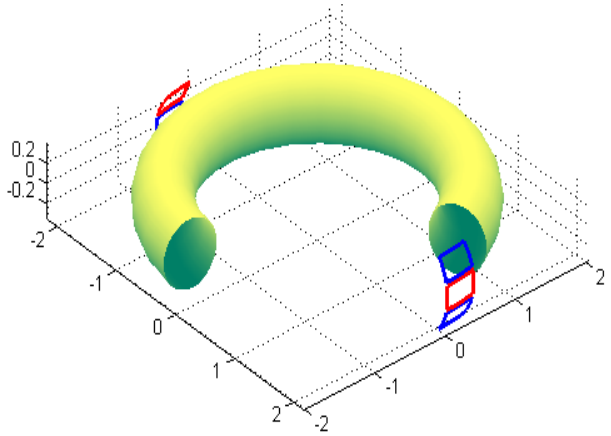


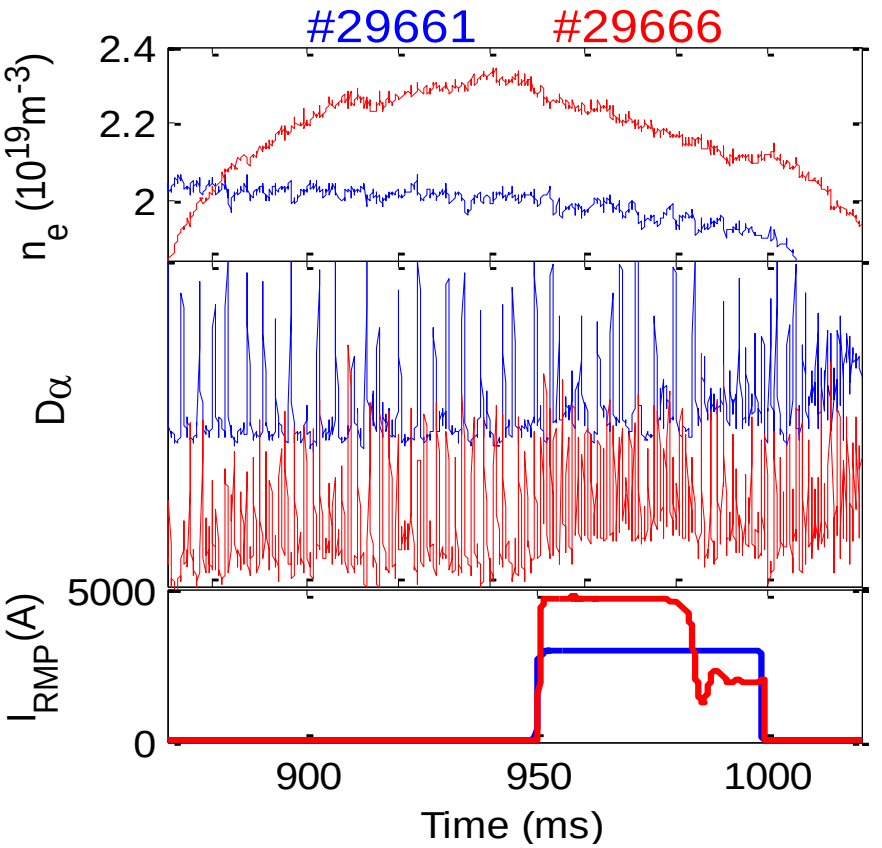
•Neutron flux profile



RMP coils on HL-2A





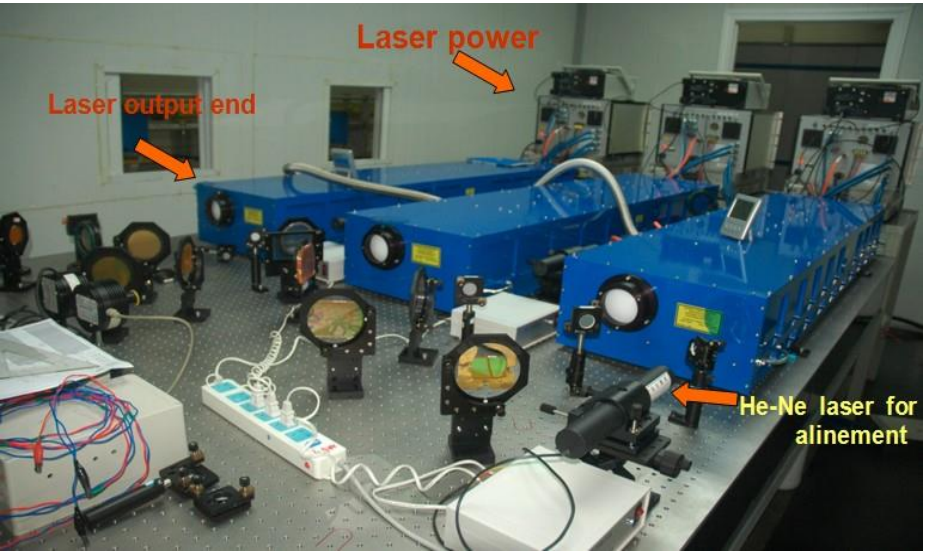


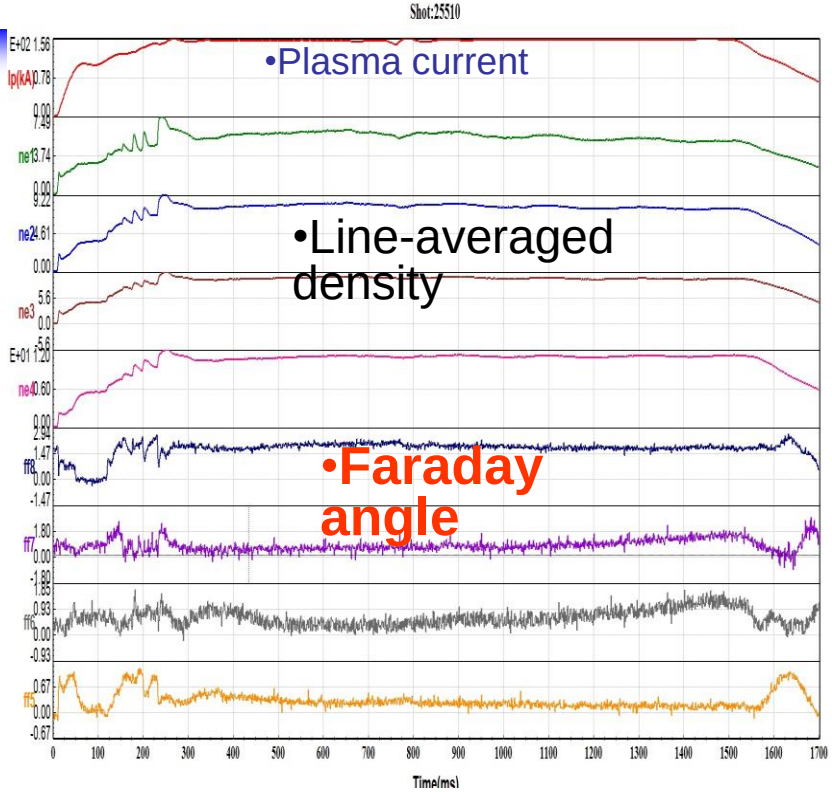
•A distinct increase of the ELM frequency is observed as the RMP coil current increases

Far-infrared laser polarimeter

HL-2A

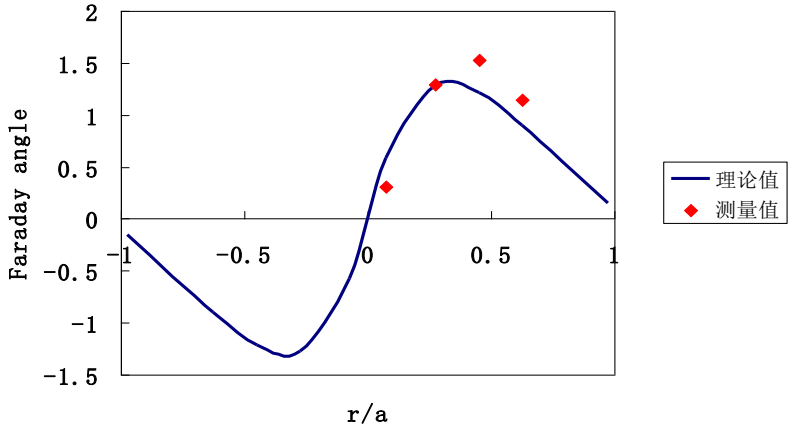
The FIR laser polarimeter has been developed to measure the density and Faraday rotation





4 chords for interferometer;

- **4 channels** *4 chords for polarimeter;*
- **Faraday rotation angel resolution: 0.2 °**
- **Time resolution: 0.1ms**



•Y Zhou, Z.C.Deng Y.G.Li, et al， “The development of multi-channel FIR interferometer/polarimeter on HL-2A” *Review of scientific Instruments,*78,11,3503(2012)

Newly developed diagnostics

Diagnostics	parameters	
CO2 interferometer	Line-averaged density, 1ch, 1us (for density feedback)	2016
BES	Density fluctuation, based on NBI	2017
CTS	High K turbulence, ETG	2017
Scintillator fiber array	Fast ion loss, 20keV-200keV, 12ch (working on calibration issue)	2016
imaging-FIDA	Fast ions, 10ms, (need to improve signal)	2016
PCI	Density fluctuation	2017
Wide zoom IR camera	Whole vacuum chamber	2016
He-GPI	2D density fluctuation	2017
CIS	Impurity(Carbon) rotation (CIII, SOL, divertor, high spatial resolution)	2017

Summary

•More than 30 diagnostic systems have been developed for the routine measurements: profiles, MHD, fluctuations, transport, impurity,…

•HL-2A team is inviting NSTX-U team to propose experiments and run time is guaranteed