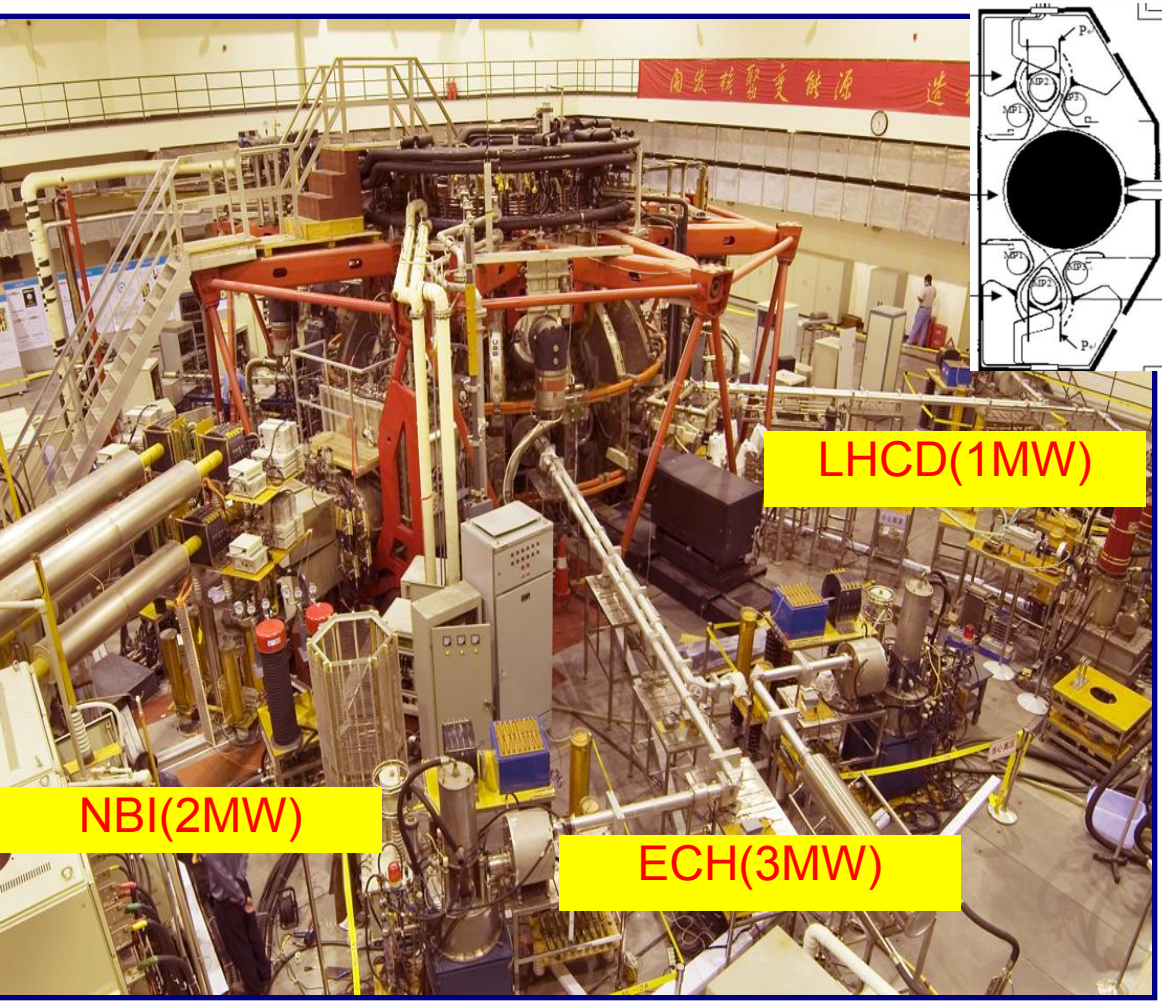
Present status of HL-2A tokamak (2017)



- 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

Diagnostics for energetic particle physics study

HL-2A

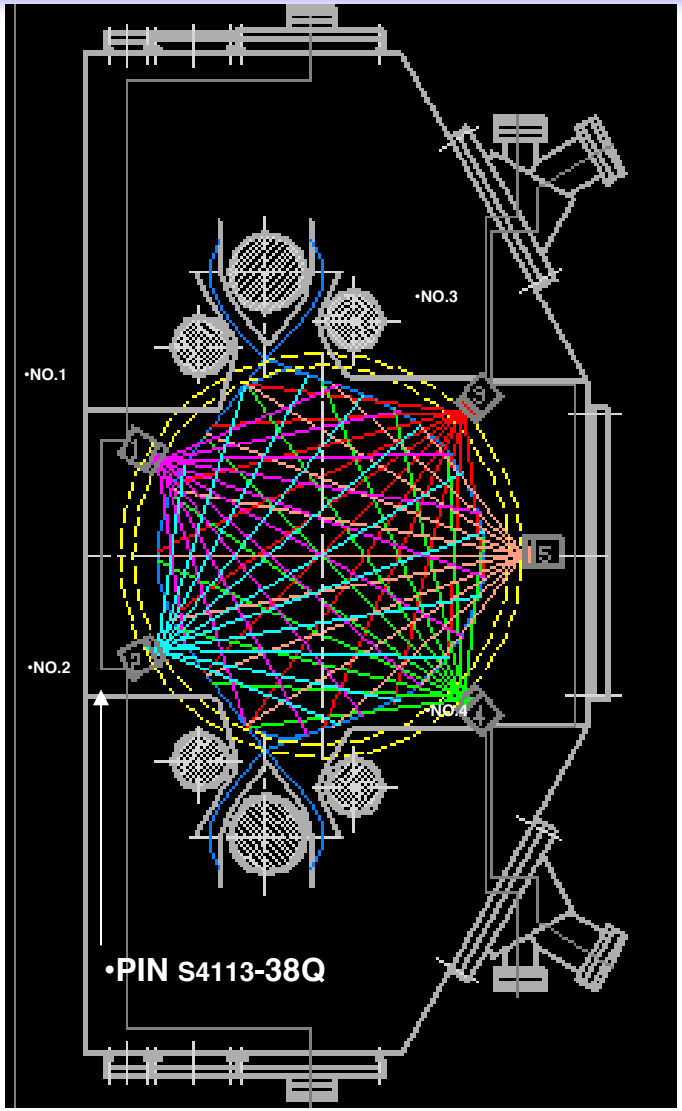
- **Heating: ECRH (3MW/1s), NBI(2MW/1s), LHCD(1MW)**
- **ECRH modulation: 500Hz**

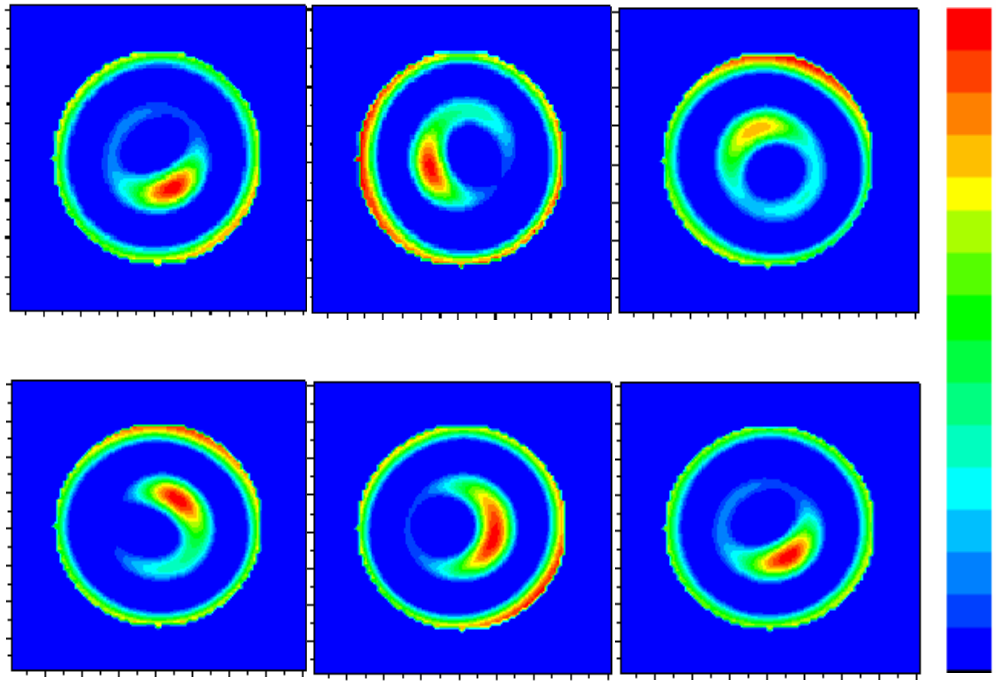
- **Fast ion spectrum and distribution**
  - CXRS (32ch)
  - Imaging-FIDA (2017)
- **Fast electron spectrum and distribution**
  - Multi-channel CdTe array (9-ch)
  - Soft-X-ray spectrum (SDD)
  - ECE (50-110G,110-170G, 2ms)
- **Fast particle loss**
  - gama-ray spectrum(NaI, HPGe)
  - Fission chamber (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%	

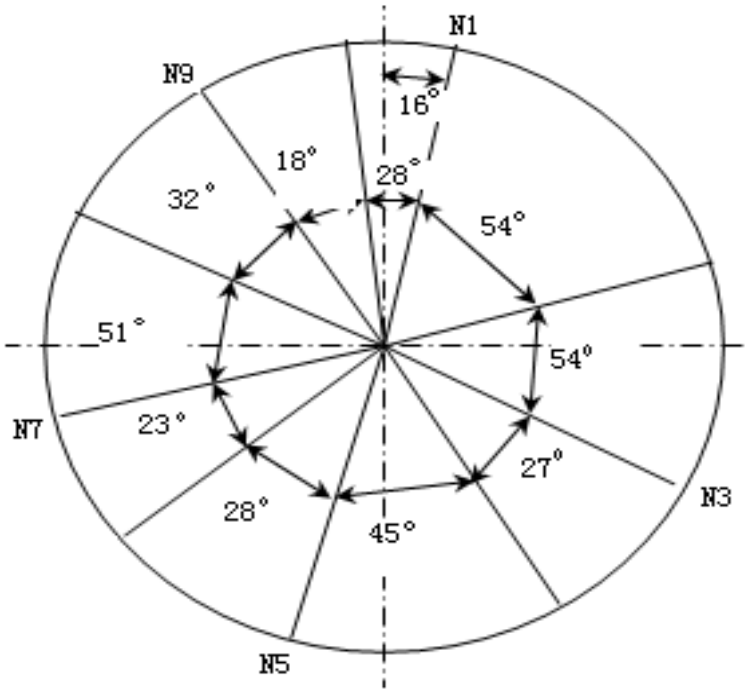
Soft X-ray array

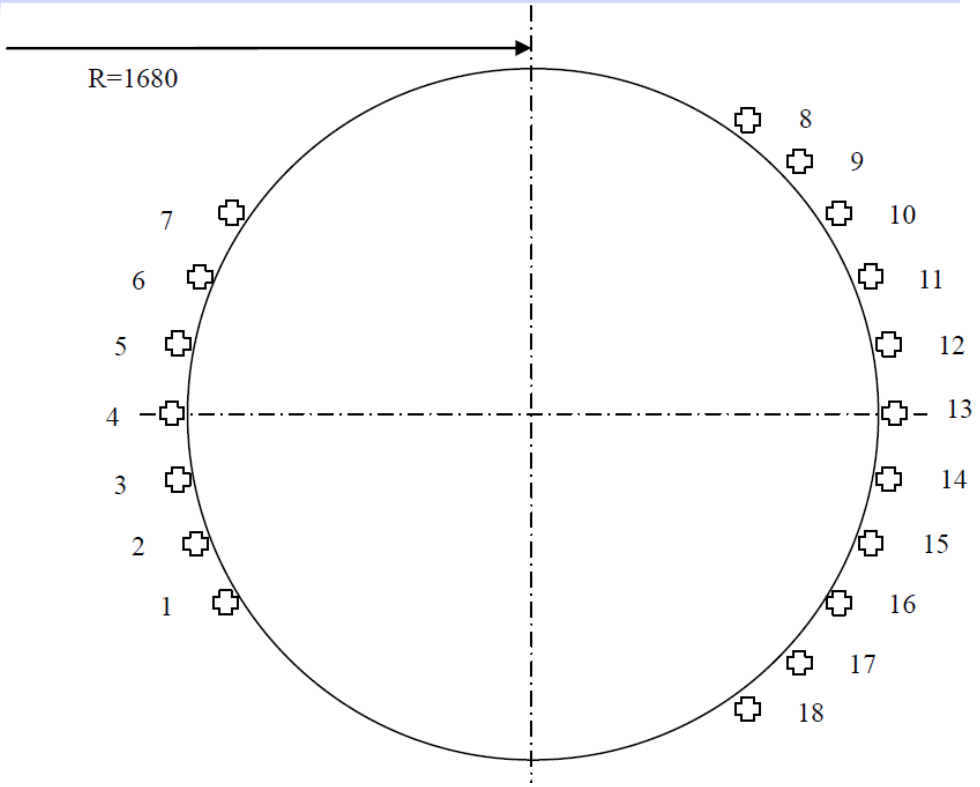




- Five arrays
- Lines of sight: 100
- spatial resolution: 2.5cm
- temporal resolution: 10us

Mirnov coils





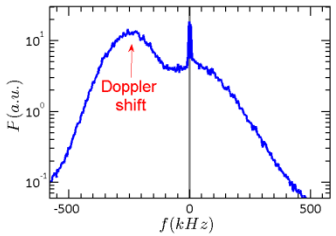
Parameters:

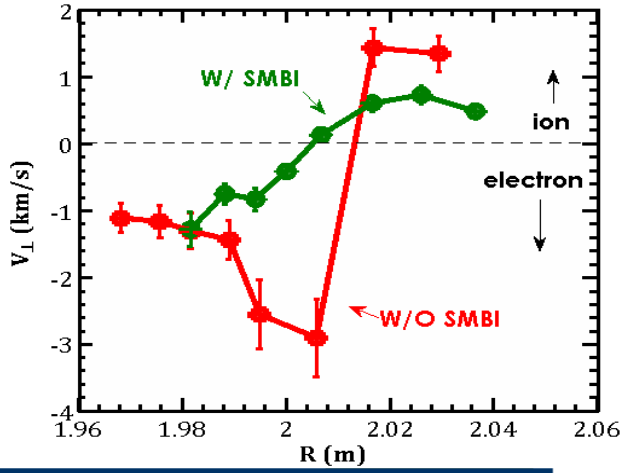
- **Poloidal: 18channels**
- **Toroidal: 10channels**
- **Sampling: 1MHz**

•m<17, n<4

DBS systems for poloidal rotation and turbulence measurements

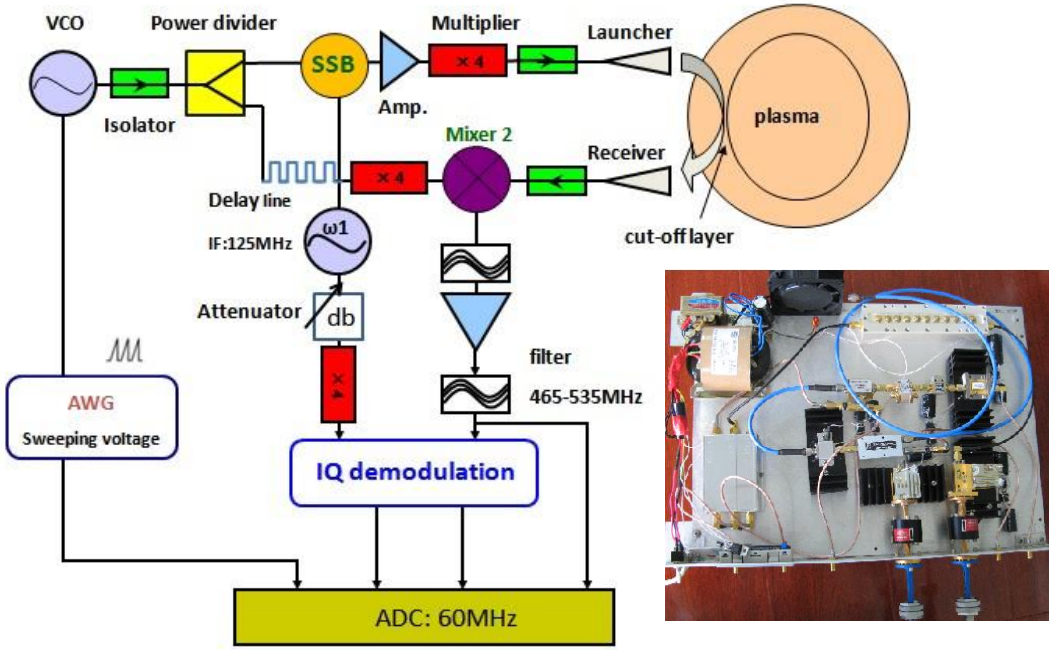
- **Multi-channel Doppler backscattering (DBS) /Reflectometry systems built by SWIP for HL-2A**
  - 8-channel K-band system: 17,18,19,20,21,22,23,24 GHz, O-mode
  - 8-channel Ka-band system: 31,32,33,34,35,36,37,38GHz , O/X-mode
  - 8-channel Q-band system : 34,36,38,40,42,44,46,48GHz , O/X-mode
  - 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)
    - …

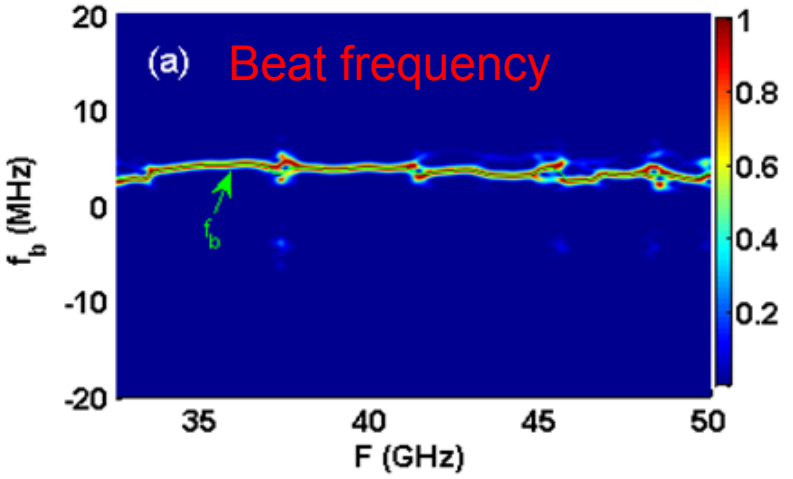


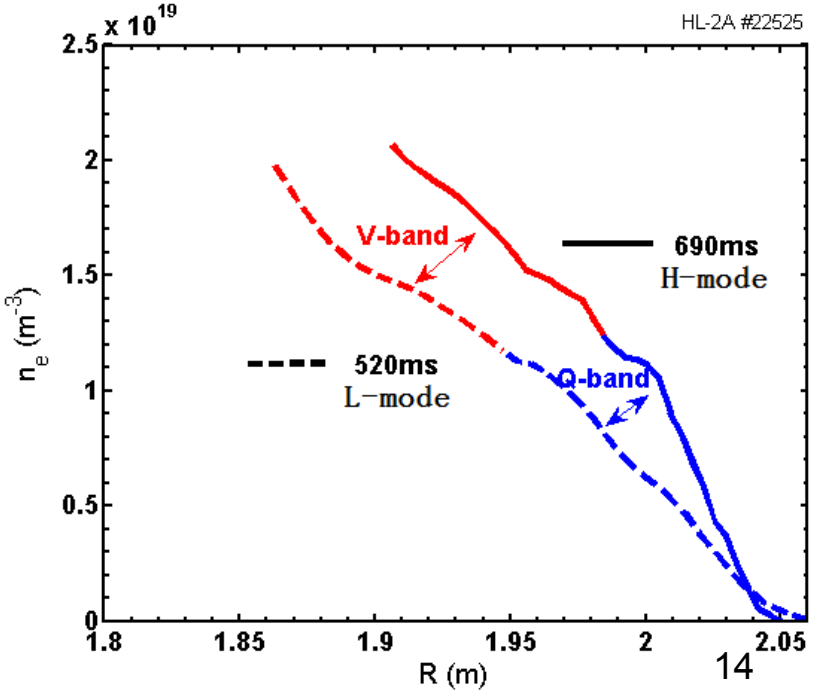


X-mode FMCW reflectometer for density profile measurement

HL-2A



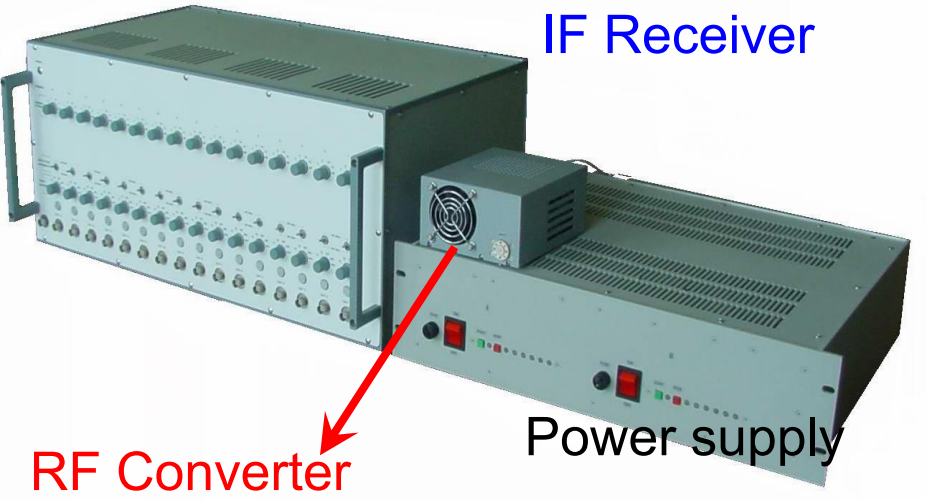




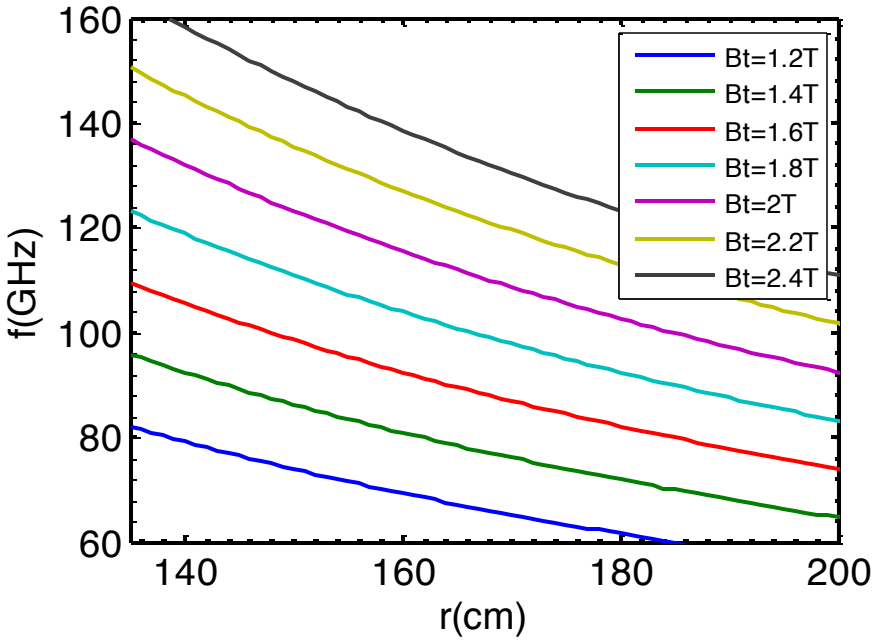
- Q,V,W bands: 33-110GHz
- Bt=1.3-2.4Tesla
- n_e=(0-4)X$10^{19}m^{-3}$
- Temporal resolution: 20us→10us
- Spatial resolution: 0.5cm

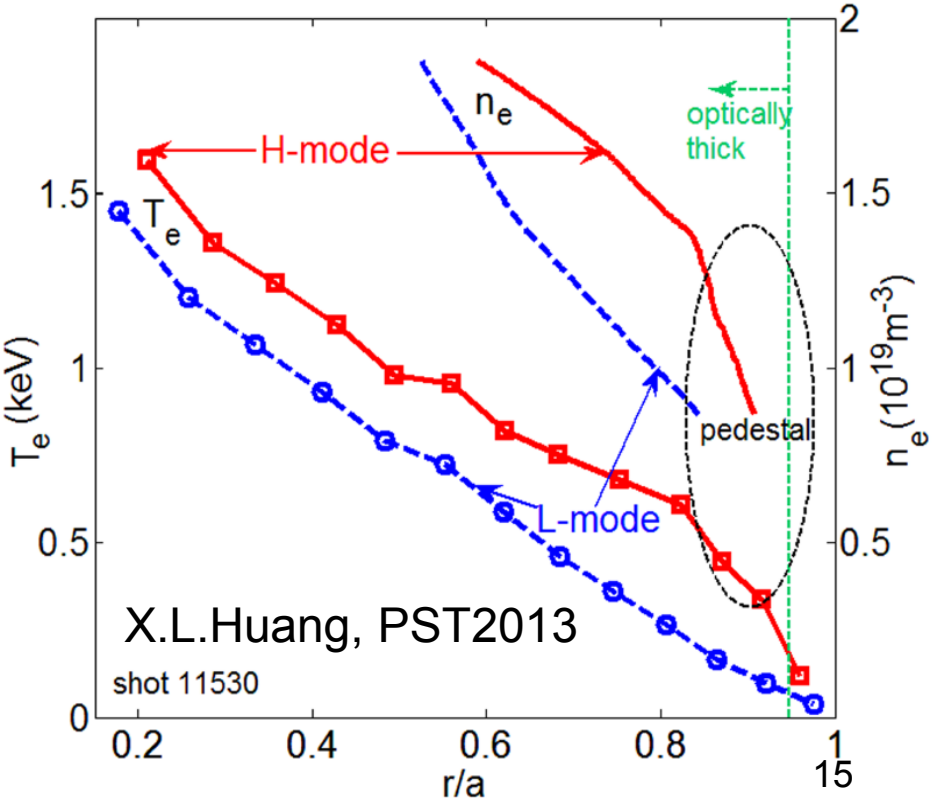
32-channel superheterodyne ECE system

HL-2A



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

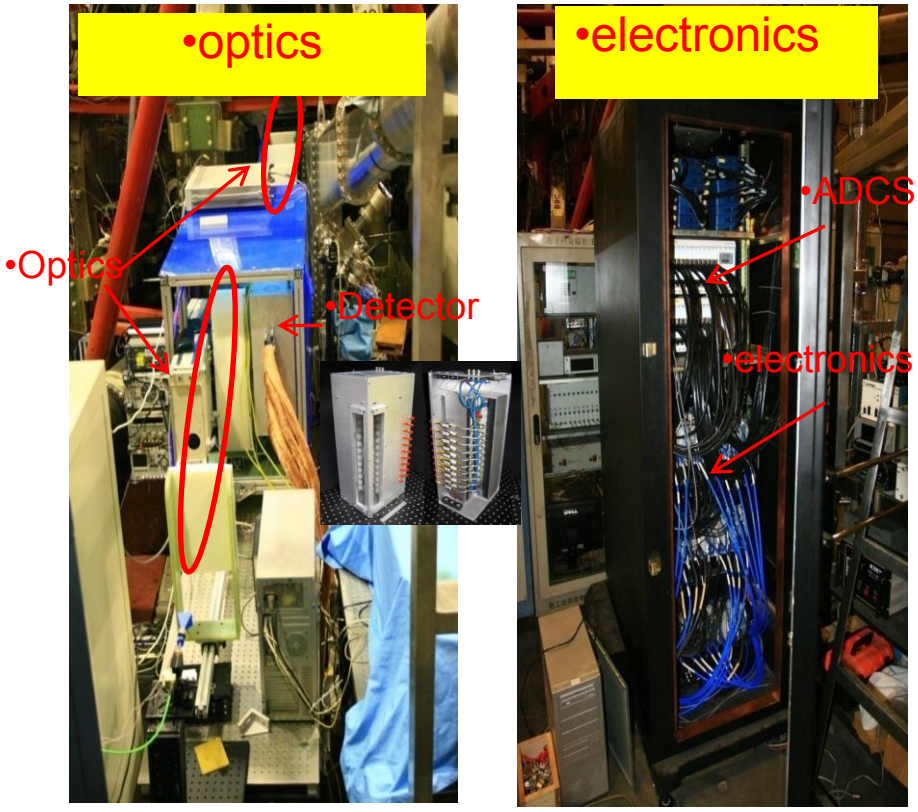




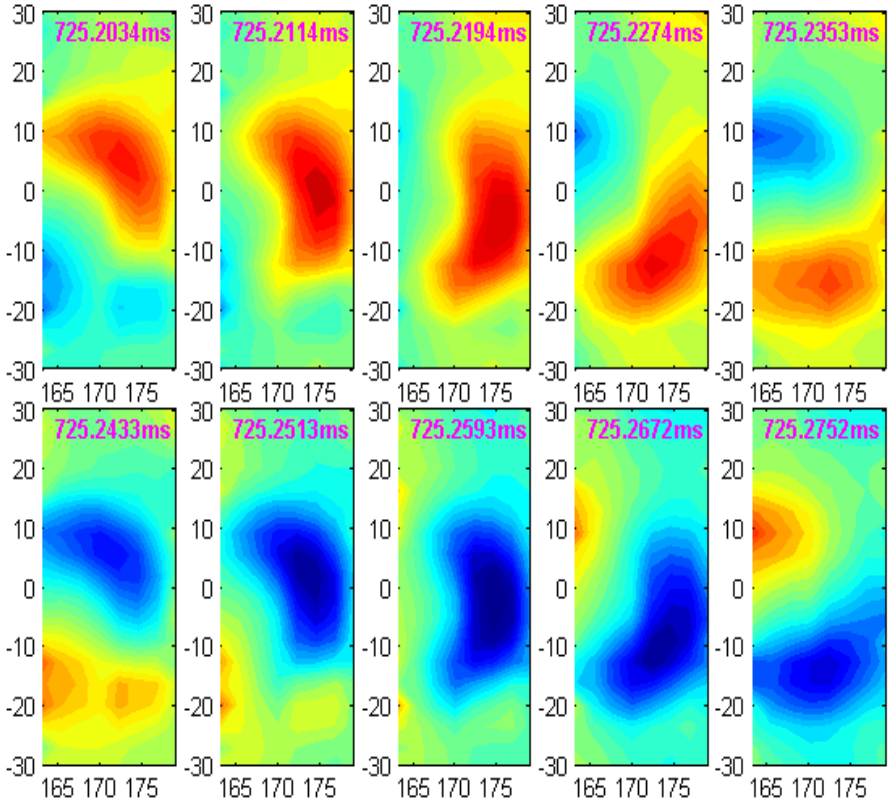
Visualization of 2D Te fluctuation with ECEI

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

8-channel ^{3}He Neutron spectrum

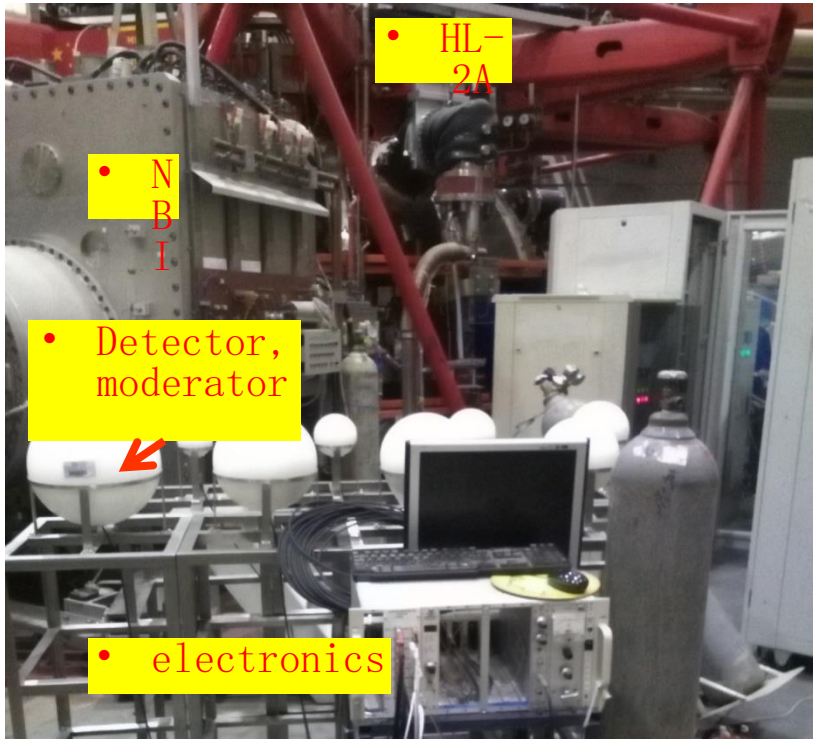
HL-2A

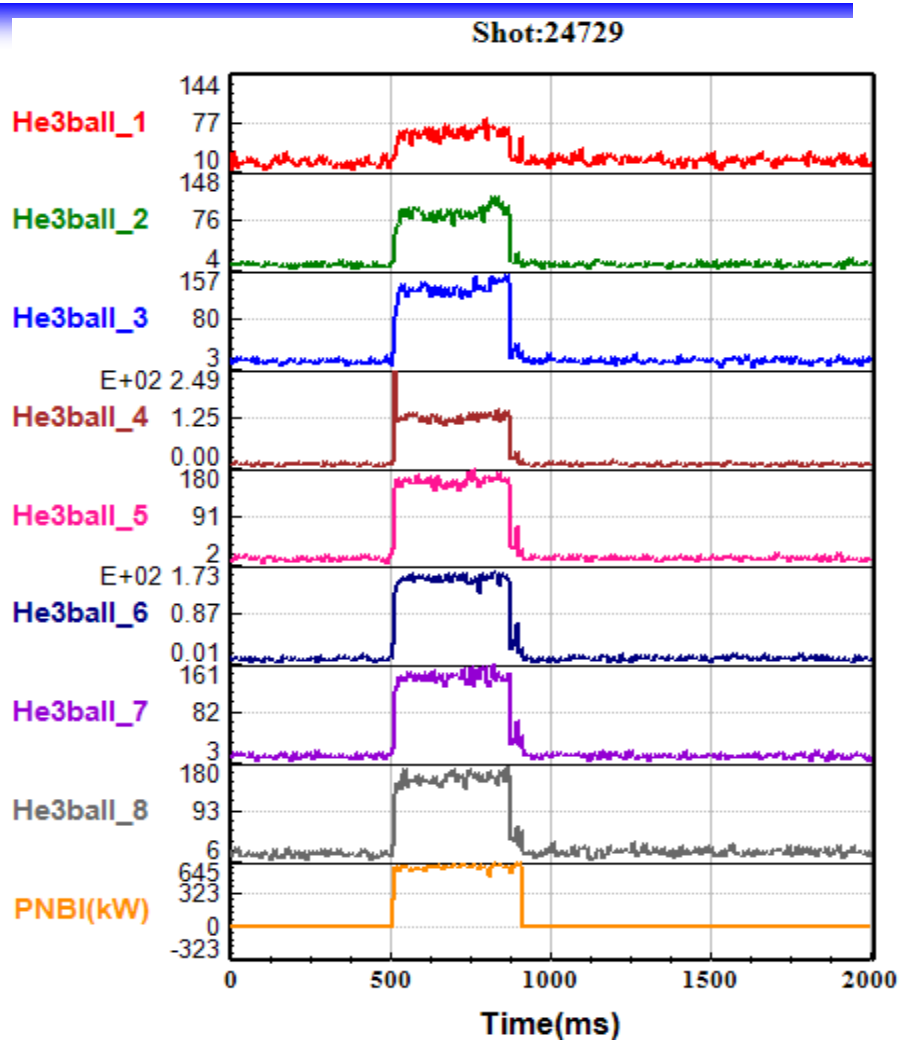
- For fusion neutron spectrum measurement:

➢8 moderator balls: from 12 to 4 inches。

➢Temporal resolution: 1ms。

➢Energy spectrum range:0～5MeV。

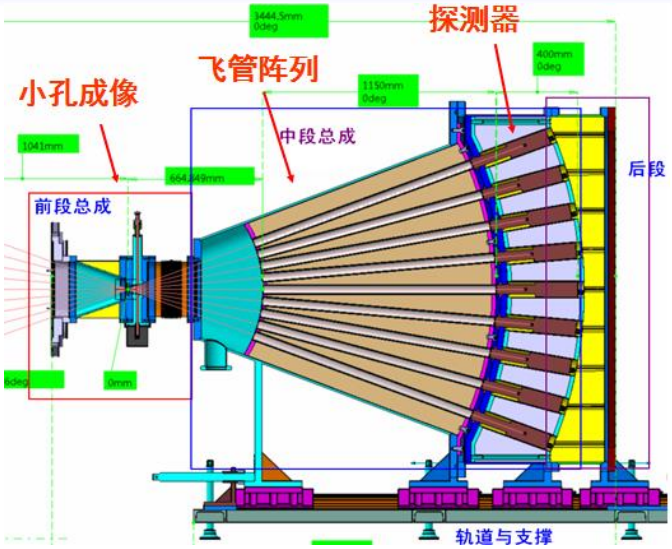


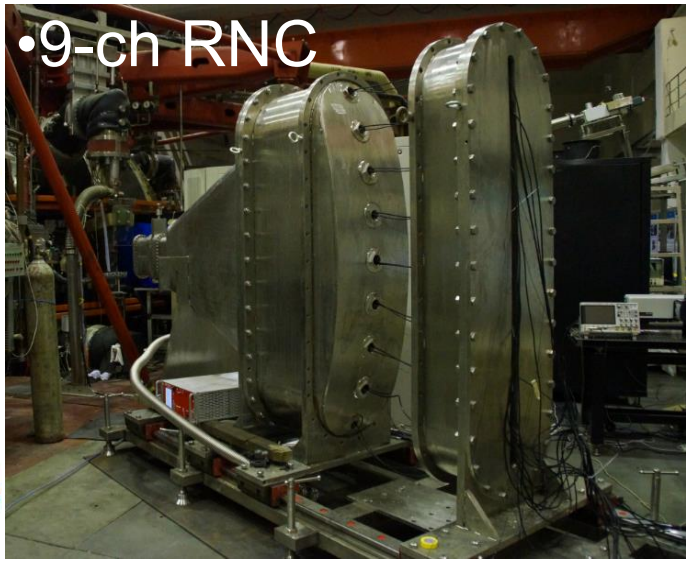


•Neutron spectrum during NBI

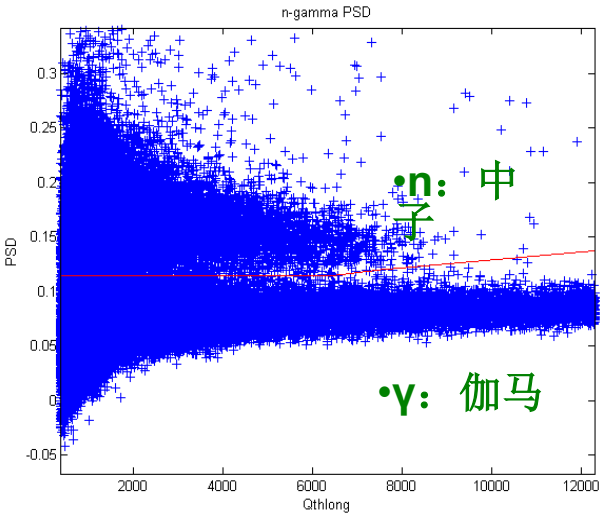
9-channel radial neutron camera (RNC)

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

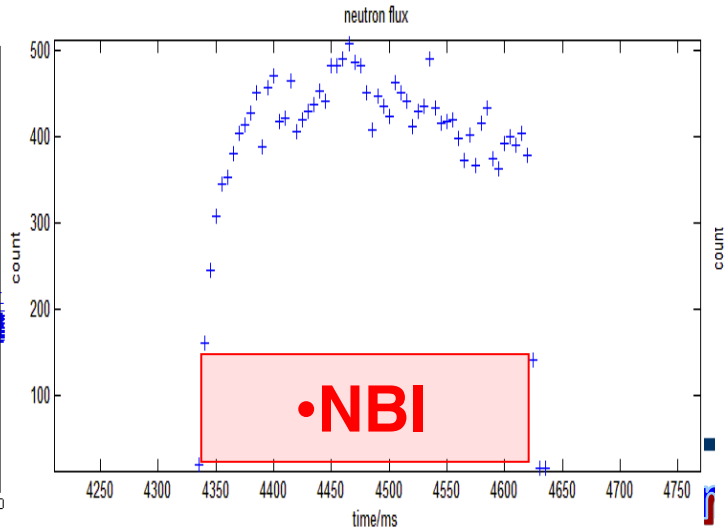




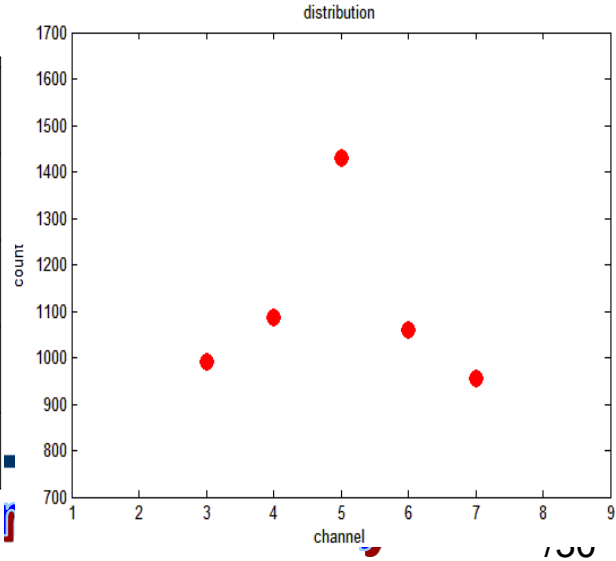
•n/γ spectrum



•Evolution of neutron flux during NBI



•Neutron flux profile



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