Neutron diagnostics for EAST deuterium operation

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ISINN-26， May 28 – June 1, 2018, Xi’ an, China

Outline

- ◆ **Neutron emission rate measurements**
  - ➢ **Neutron flux monitors (NFM)**
  - ➢ **Radial Neutron camera (RNC)**
  - ➢ **Neutron fluctuation diagnostic**
- ◆ **Neutron Emission Spectroscopy(NES) diagnostics**
  - ➢ **Compact NES systems**
  - ➢ **2.5 MeV neutron time-of-flight spectrometer (TOFED)**
- ◆ **Concluding marks**

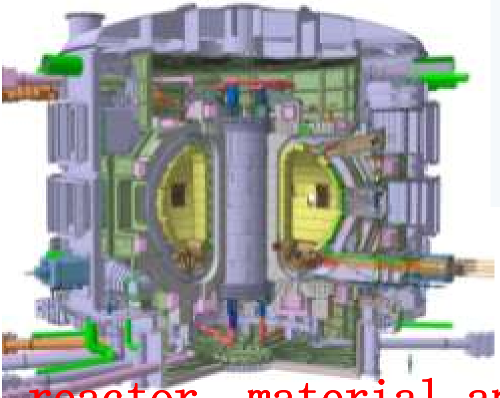
Fusion neutron diagnostics of increasing importance

Neutrons, fusion energy carriers, deposit their energy in the blanket, where it would be extracted by the primary fluid to drive the turbines in the fusion reactor

JET

10^4 times higher

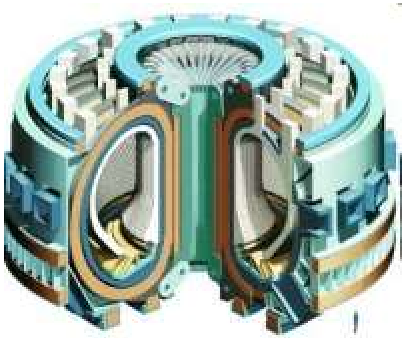
（neutron fluence）



ITER ~ 2025

100 times higher

（neutron fluence）



DEMO ~ 2045 (?)

- Neutron data for Fusion reactor material and engineering developing
- Tritium breeding: **$n + {}^6Li \rightarrow \alpha + t$**
- Neutron spectrum and flux distribution data for radiation protection

The neutron emission is an immediate measure of the progress towards the achievement of thermonuclear reactor conditions.

Neutron diagnostics for fusion reactors

Neutron flux monito

- Reconstruct Ion temperature profiles
- Inv plasmas

Both have become routine diagnostics

-- L Giacomell NF(2005)

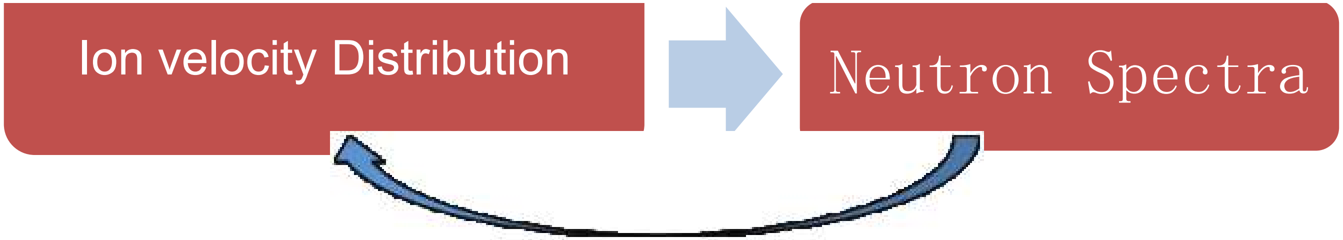
2-D neutro camera

- Diag
- Study fuel fast particle slowing-down

Neutron emission Spectrometer

- Measure ion temepratre and n_d/n_e ratio
- Analyse components of fuel fast ions
- Diagnose velocity distributions of fuel fast ions
- Study the poloidal rotation process
- Investigate MHD activities

Neutron Emission Spectroscopy (NES) at tokamak devices



Ion velocity Distribution

Neutron Spectra

$$F_n = \frac{dN}{dE} = \frac{n_A n_B}{1+\delta_{AB}} \iint \delta(E - En) f_A(\vec{v}_A) f_B(\vec{v}_B) v_{rel} \sigma(v_{rel}, \theta_c) d\vec{v}_A d\vec{v}_B d\Omega_{lab}$$

MPR for DT neutron @ JET

Plasma Physics Information from NES:

Ti

Fuel ion kinetic information

Plasma rotation

Knock-on tail effect

Auxiliary heating effect

Impurity level

……

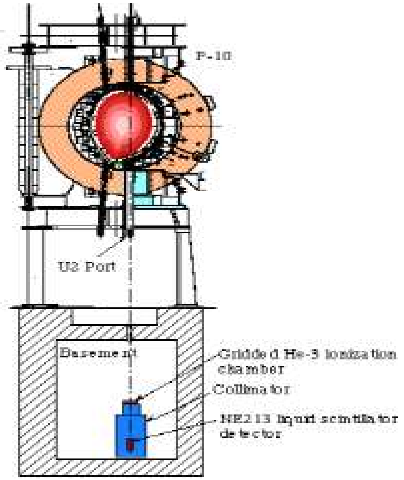
Ohmic Discharges:

D-D plasmas

$$\mathrm{FWHM(keV)} = 82.6\sqrt{\mathrm{T(keV)}}$$

D-T plasmas

$$\mathrm{FWHM(keV)} = 177.2\sqrt{\mathrm{T(keV)}}$$



Liquid Scintilaion detectors @ JT60U

TOFOR for 2.5 MeV neutron @ JET

B Wolle Physics Reports 312 (1999)
O N Jarvis Plasma Phvs Control Fusion 36 (1994)
J Kallne PRL 85(2000)
H.Henriksson Plasma Phys. Control. Fusion 47(2005)
L Giacomelli Nucl. Fusion 45(2005)
B. Esposito Rev. Sci. Instr. 75 (2004)

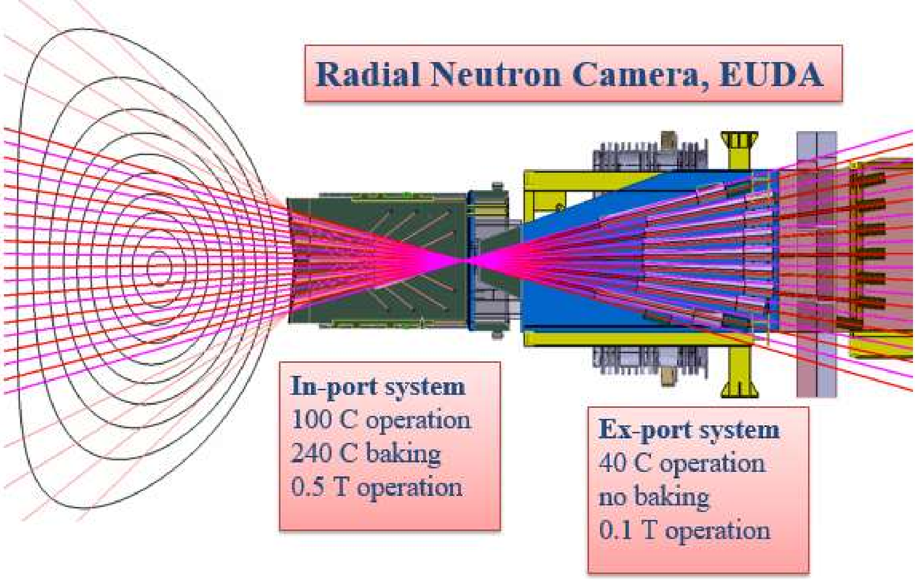
Neutron diagnostic systems for fusion reactors

Fusion facilities	Time-resolved neutron monitors (no-energy-resolved)	Time-resolved neutron monitors (14 MeV)	Activation system	Profile measurements	spectrometers (DD or DT)
JET	3	2	8	10H，9V	D-D，D-T
JT-60U	3	1	1	6H，1V	D-D
TFTR（closed)	4	1	4	10V	D-D，D-T
DIII-D	2	1	no	no	no
ASDEX-U	1	1	3	No	D-D，D-T
Tore-Supra	y	no	no	No	D-D
FTU	3	1	2	6H	D-D
KSTAR	3	no	no	no	D-D
EAST	5	1	1	6H	D-D，TOFED
HLD (Stellarator)	2	no	2	11H	TOFED (plan)

^{235}U fission chamber is a standard detector of NFM in fusion

Device	Type	Countries	Organizations	NFM detectors	Remarks
JT-60U	**tokamak**	**JA**	**JAEA**	**^{235}U FC / ^{238}U FC /^{3}He gas counter**	**Wide dynamic range** **Max. $S_n > 10^{16}$ (n/s)**
JET	**tokamak**	**UK**	**Culham Centre**	**^{235}U FC/ ^{238}U FC**	**Wide dynamic range** **Max. $S_n > 10^{16}$ (n/s)**
TFTR	**tokamak**	**US**	**PPPL**	**^{235}U FC / ^{238}U FC**	**Wide dynamic range** **Max. $S_n > 10^{16}$ (n/s)**
DIII-D	**tokamak**	**US**	**GA**	**^{235}U FC / BF_3 & ^{3}He gas counter**	**Max. $S_n \sim 10^{16}$ (n/s)** Only pulse counting
ASDEX-Upgrade	tokamak	Germany	IPP	^{235}U FC/ ^{238}U FC/ BF_3 & ^{3}He gas counter	Only pulse counting
Alcator C-Mod	tokamak	US	MIT	^{235}U FC / BF_3 gas counter	Only pulse counting
NSTX	**tokamak**	**US**	**PPPL**	**^{235}U FC**	**Wide dynamic range**
MAST	tokamak	UK	Culham Centre	^{235}U FC	Only pulse counting
EAST	tokamak	CN	ASIPP	^{235}U FC / ^{3}He gas counter	Only pulse counting
HL-2A	tokamak	CN	SWIP	^{235}U FC	Only pulse counting
KSTAR	tokamak	KO	NFRI	^{235}U FC / ^{3}He gas counter	Only pulse counting
ATF	helical	US	ORNL	^{235}U FC / ^{3}He gas counter	?
Wendelstein 7-X	helical	Germany	IPP	^{235}U FC/ BF_3 & ^{3}He	Plan

Only large tokamaks and NSTX have been equipped with wide dynamic range NFM.

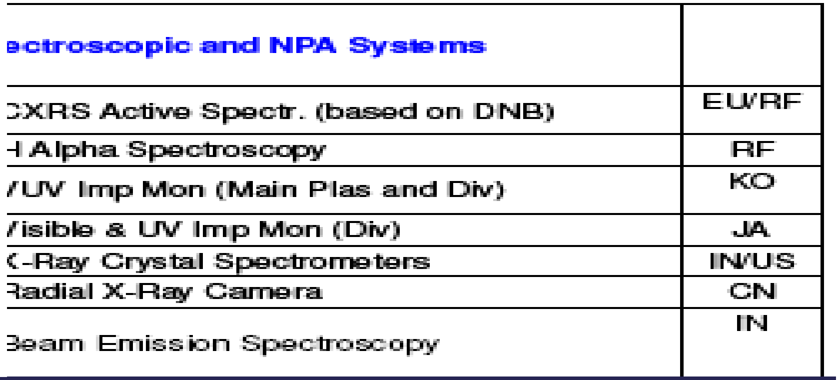

Radial Neutron Camera, EUDA

In-port system
100 C operation
240 C baking
0.5 T operation

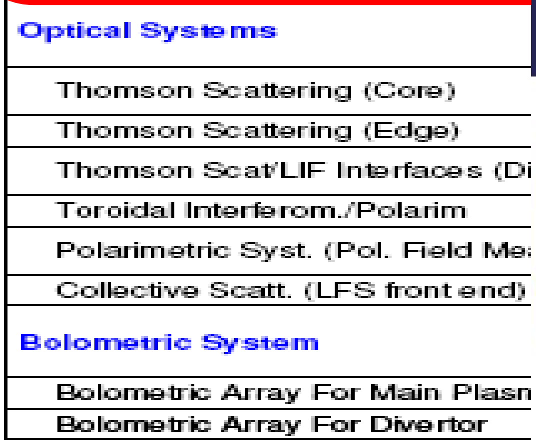
Ex-port system
40 C operation
no baking
0.1 T operation

Baseline on ITER

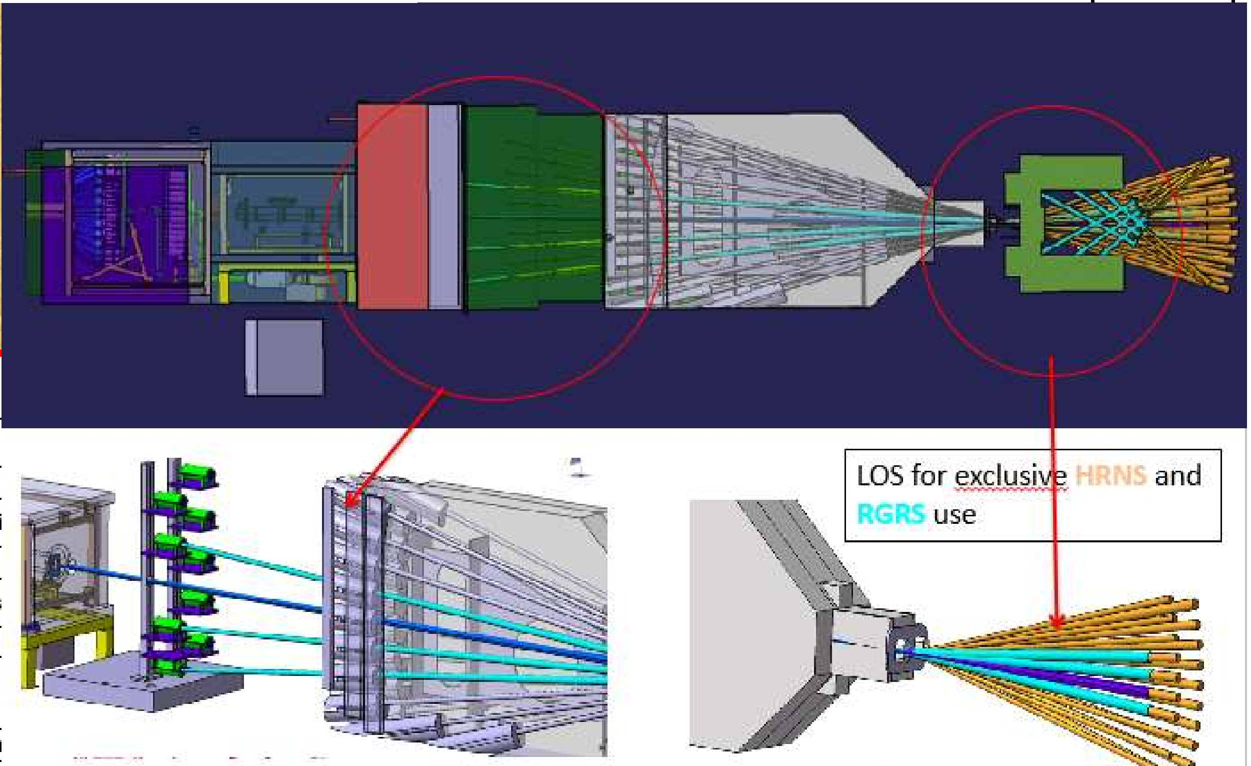
/ et al. 22th IAEA FEC,Geneva,2008



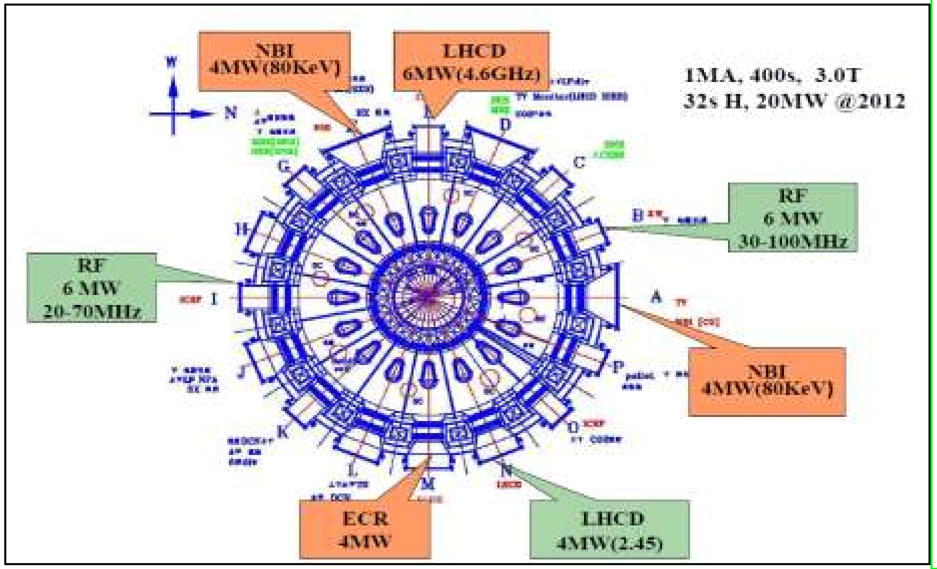
ectroscopic and NPA Systems	
:XRS Active Spectr. (based on DNB)	EU/RF
I Alpha Spectroscopy	RF
/UV Imp Mon (Main Plas and Div)	KO
/isible & UV Imp Mon (Div)	JA
(-Ray Crystal Spectrometers	IN/US
Radial X-Ray Camera	CN
3eam Emission Spectroscopy	IN



Optical Systems
Thomson Scattering (Core)
Thomson Scattering (Edge)
Thomson Scat/LIF Interfaces (Di
Toroidal Interferom./Polarim
Polarimetric Syst. (Pol. Field Me
Collective Scatt. (LFS front end)
Bolometric System
Bolometric Array For Main Plasn
Bolometric Array For Divertor


LOS for exclusive HRNS and RGRS use

EAST Tokamak @ CASIPP, Hefei,China



EAST Auxiliary heating Capacity

- 4 MW LHW @ 2.45 GHz (E-port)
- 6 MW LHW @ 4.6 GHz (N-port)
- 6 MW ICRF @ 20-70 MHz (B-port)
- 6 MW ICRF @ 30-100 MHz (I-port)
- 2-4 MW ECRF @140 GHz (M-port)
- *4-8 MW NBI @ 50-80 keV (N-, K –port)*

Main Parameters

B_T	3.5 T
R_0	1.85 m
a	0.45 m
κ_{max}	~ 1.8
I_P	1 .0 MA
H&CD	~25 MW
Diverter	Double & single Null

Expected $n \tau_E T \sim 10^{18\sim19}$ m^{-3} s kev

Long pulse or steady-state operation

First fully superconducting tokamak with ITER-like magnetic field configurations and heating schemes to demonstrate high-power, long pulse plasma operations

Neutron yields:

$10^9 \sim 10^{11}$n/s (OH, RF)

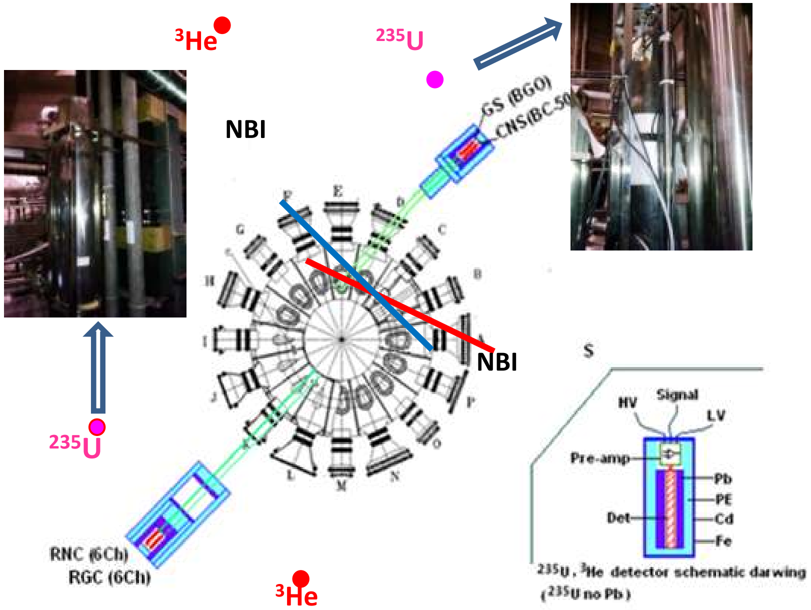
$10^{11} \sim 10^{15}$n/s (NBI)

Key neutron diagnostics available for EAST D-D plasmas

Detector system	Function	status
Neutron flux monitor	Total neutron emission	Working
Neutron fluctuation detector	Fast temporal response measurement	Working
Neutron activation system	Neutron yield calibration	Working
Radical Neutron Camera	Neutron emission profile	Working
Compact neutron spectrometers	Neutron energy spectrum measurement	Working
2.5 MeV neutron time-of-flight spectrometer (TOFED)	Advanced NES diagnosis of D plasmas	Working

- **Neutron emission rate measurements**
  - **Neutron flux monitors (NFM)**
  - **Radial Neutron camera (RNC)**
  - **Neutron fluctuation diagnostic**

Neutron flux monitor (NFM)



^{235}U, ^{3}He detector schematic darwing (^{235}U no Pb)

Bird's View of neutron diagnosis on EAST

- ☐ Views: Integral measurement
- ☐ Dynamic range: 10^8~10^{14} n/s
- ☐ ^{3}He detectors (ZZ1/ZZ2)
- ☐ ^{235}U detectors (ZZ7/ZZ8)
- ☐ Upgrade data acquisition system
- ☐ Neutron in-situ calibration

^{235}U FC Digital Data Acquisition (Count + Campbelling Modes)

PXI BUS

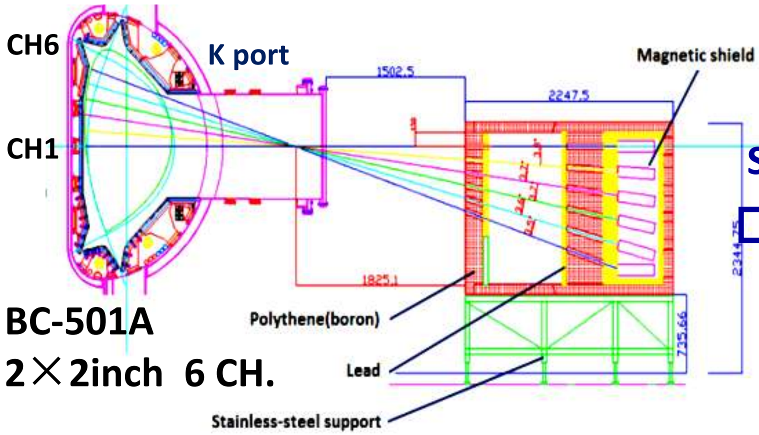
Pre-Amplifier

Data Acquisition Card 3U (FPGA Flash ADC 250MS/s 10bit)

G.Q. Zhong et al., Rev. Scient. Instrum. 87, 11D820(2016)

Radical neutron camera (RNC)

Sight line distribution of the RNC and collimator framework



BC-501A
2×2inch 6 CH.

Signal Processing

Traditional electronics module

Upgraded in 2015

Total 5 tons and 6 CH (PE+B & Lead)

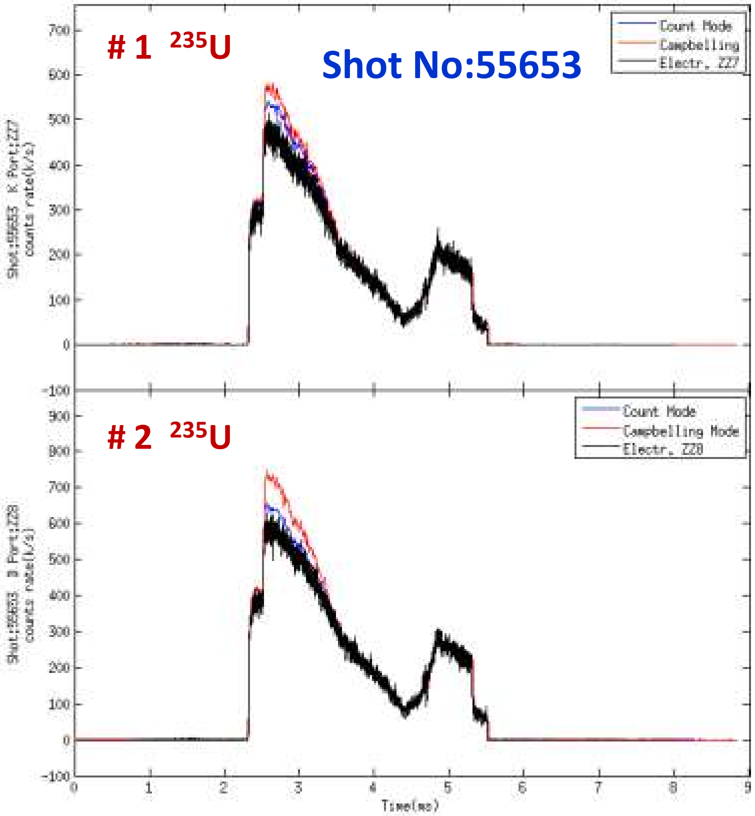
- ☐ **Neutron intensity distribution measurement**
- ☐ **Spatial resolution: 15 cm**
  Time resolution: 10 ms
- ☐ **Count rate > 1MHz**
- ☐ Routine monitor

Digitizer CAEN VX1730:
8 CH. 500 MS/s 14 bit

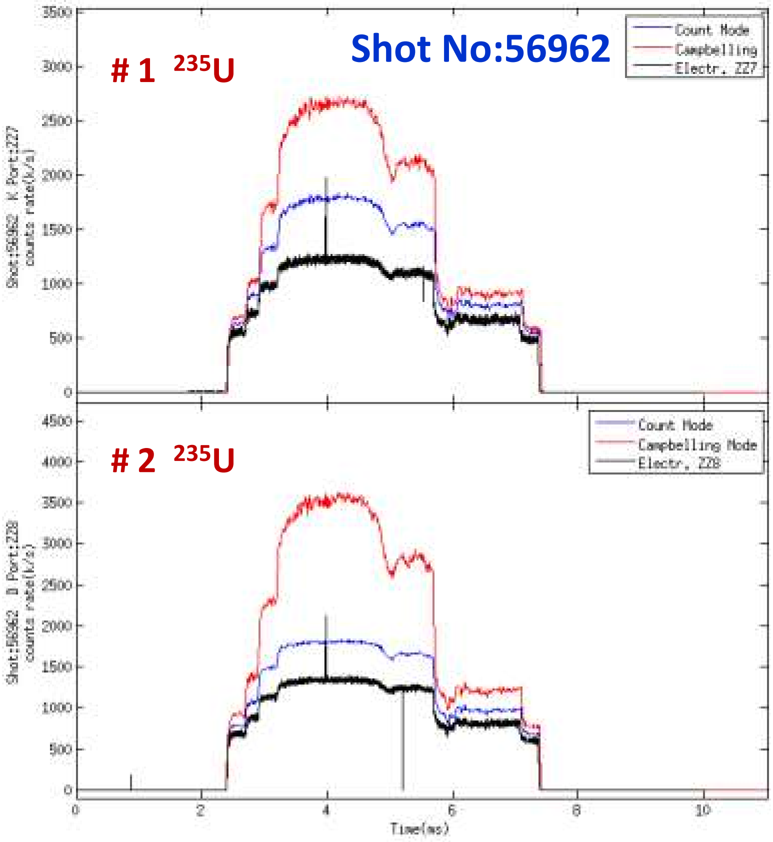
G. Q. Zhong et al **.,Review of Scientific Instruments, 2016, 87(11):11D820.**

NFM experimental results

NBI Source Power ~ 2.8 MW



NBI Source Power ～5.5 MW



Traditional electronics count mode: black line

Digital count mode: blue line

Digital campbelling mode: red line

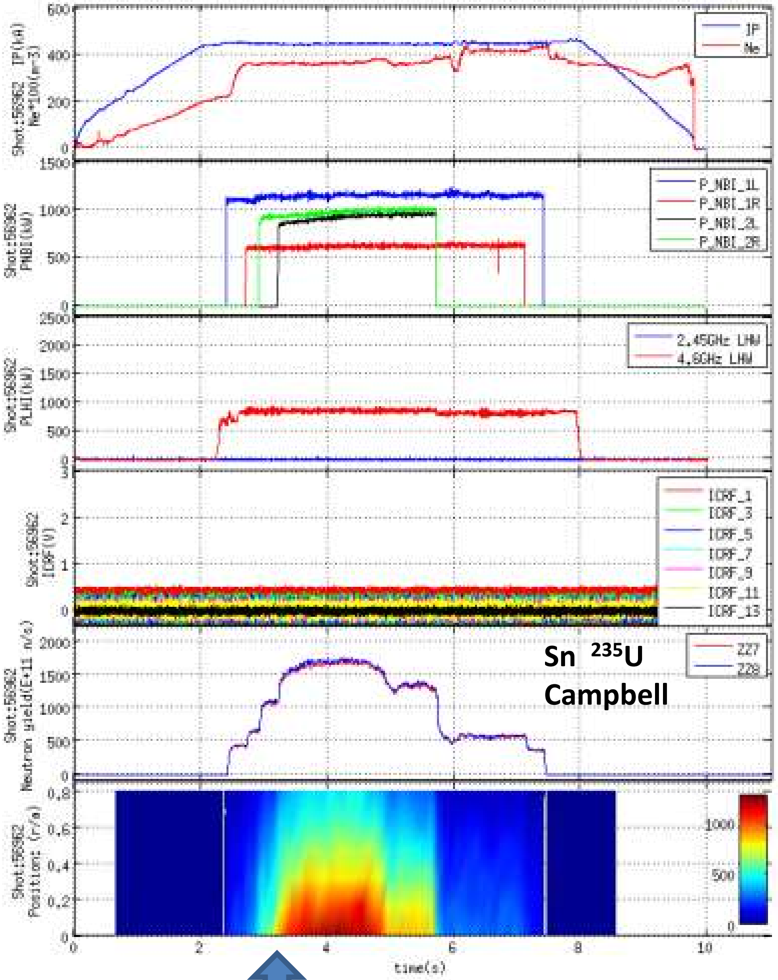
Count mode < 500kcps √

Campbelling mode >100kcps √

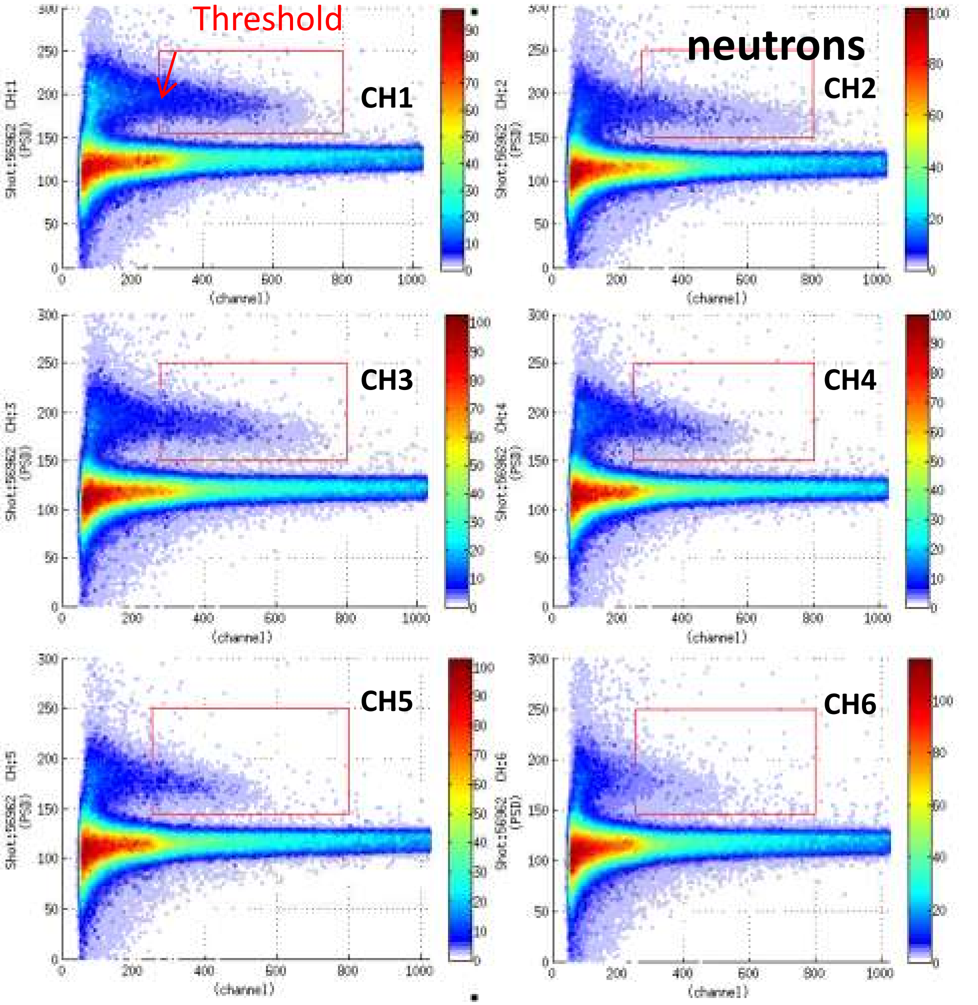
北京大学
PEKING UNIVERSITY

RNC plasma experimental results

Shot No: 56962



Time evolution of neutron intensity spatial distribution

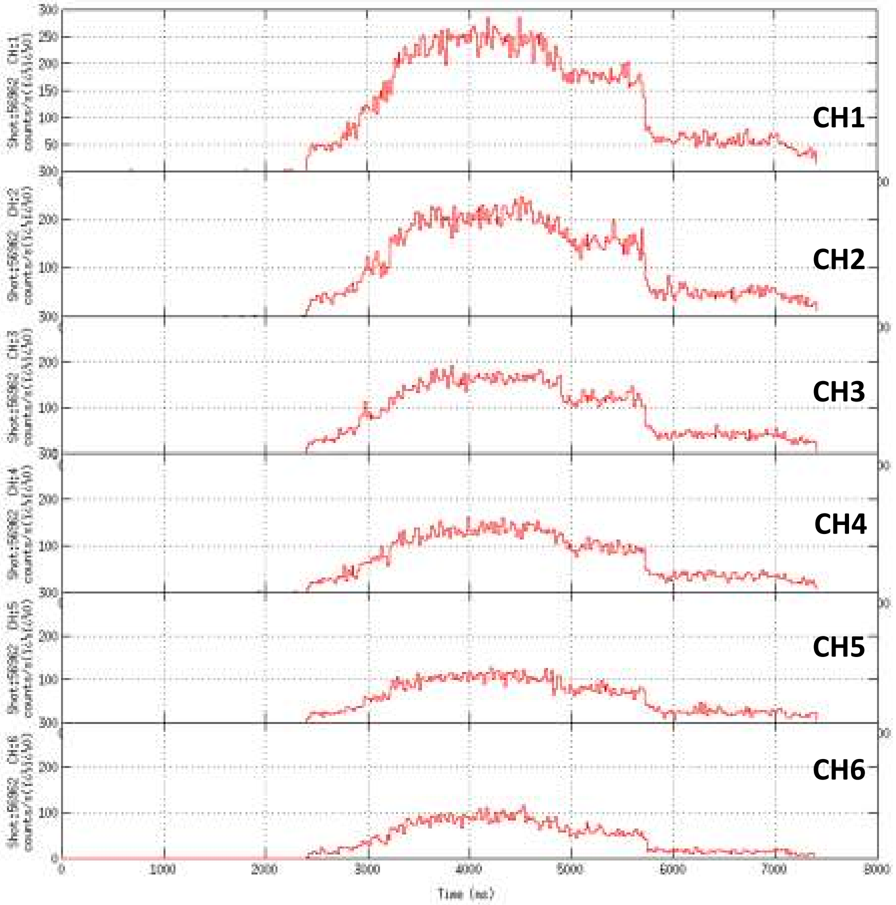


2-D spectra of neutron and γ-rays signals acquired from shot # 56962

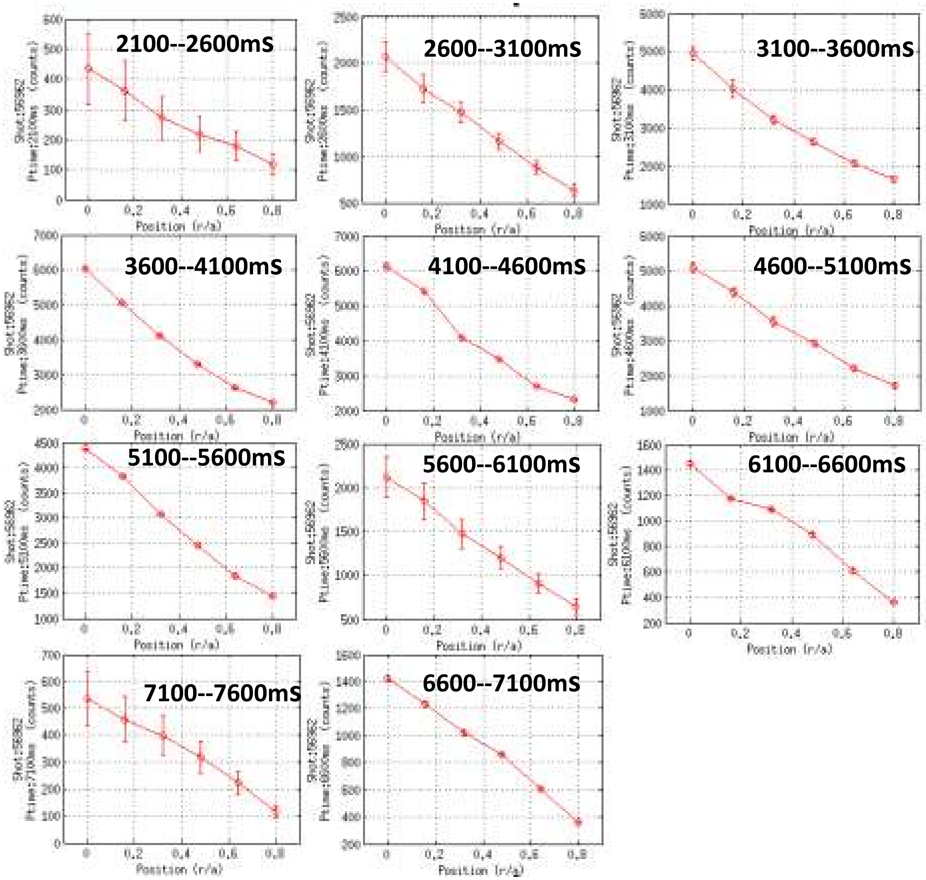
G. Q. Zhong et al., Plasma Phys. Control. Fusion 58, 075013 (2016)

RNC plasma experimental results

Shot No:56962



Time evolution of neutron flux measured by BC-501A (E_n>1MeV, Temporal rep. 10ms)



Neutron emission profile (not in-situ precise calibration)

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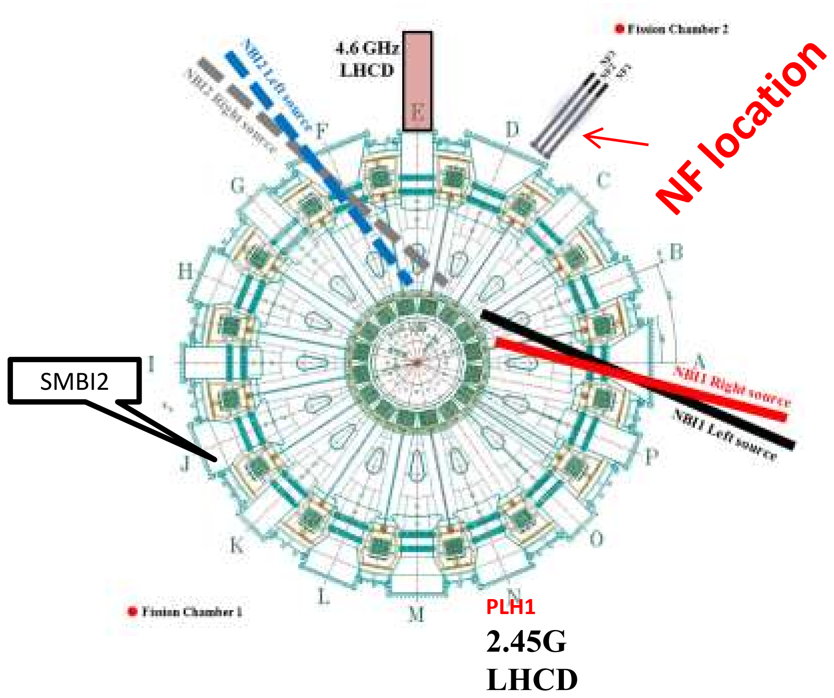
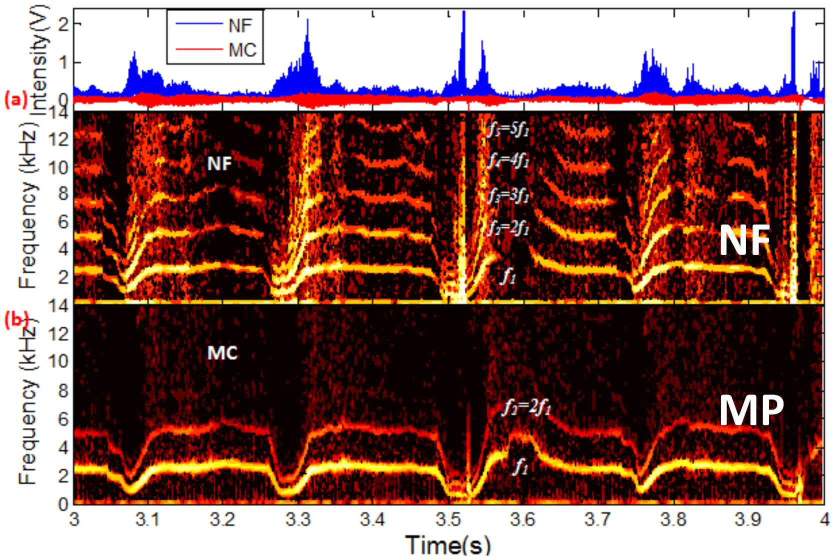
G. Q. Zhong et al .,Review of Scientific Instruments, 2016, 87(11):11D820.

Neutron fluctuation diagnostic



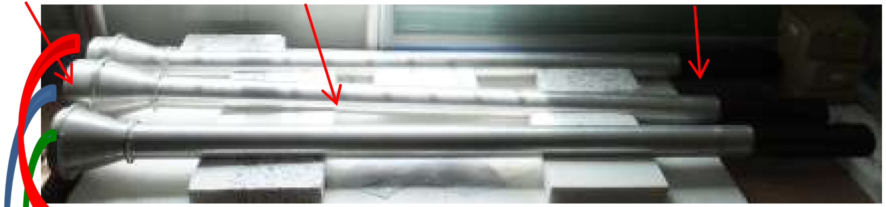
NF location



Fast response capability validation (1MS/s, NF3 measurement)

MP= Magnetic Probe

Scin. Light guide(1.5m) PMT(Current Mode)



NF1: Thermal and fast neutrons (ZnS+Li)

NF2: Fast neutrons(ZnS)

NF3: Fast neutrons and γ-rays (Plastic Scint.)

- Fast ion loss measurements
- Fast temporal response
- Time resolution: ~ 5 μs
- Compact & Not occupy flange
- Need n/γ response calibration

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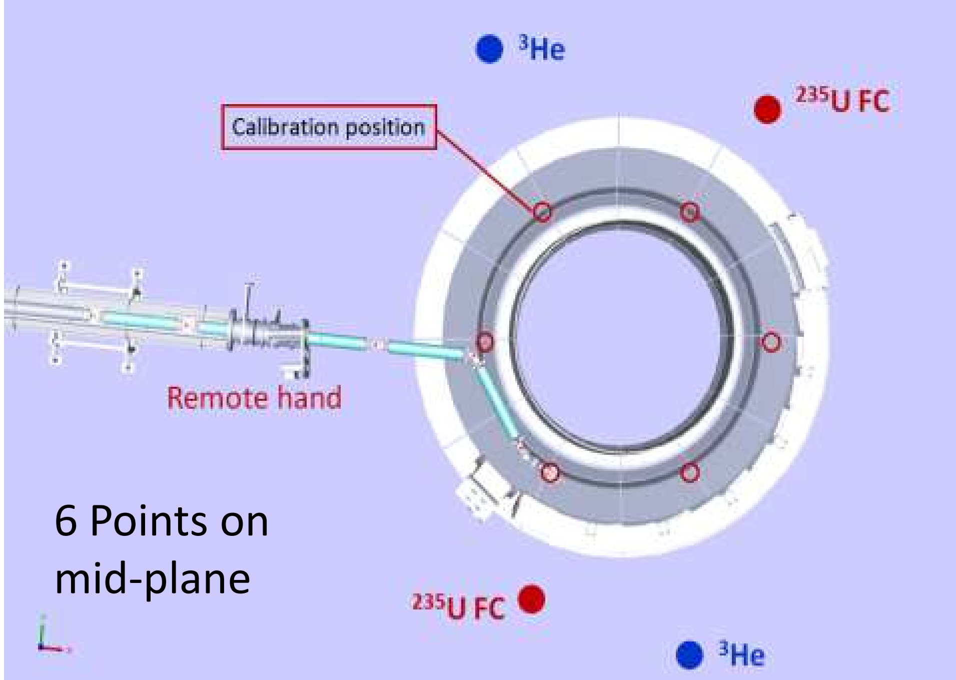
Pu N, et al. Journal of Instrumentation, 2015, 10(12): P12013.

NFM calibration test

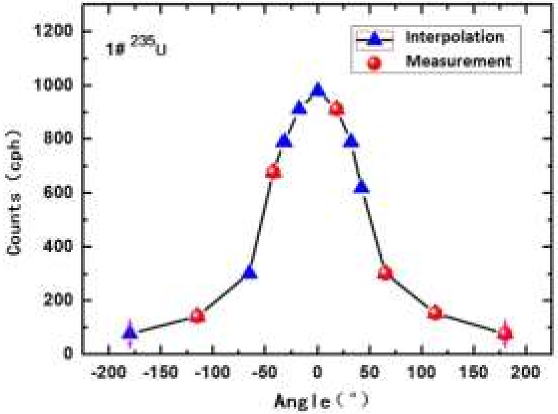
On 19, Jan. , 2017



6 Points on mid-plane

- **source ^{252}Cf source factory activity: 60MBq.** During in-situ calibration test , neutron emission rate: ~1.764×10^6 n/s
- **Source transferred by Remote hands**
- **Measuring time for each position: 1 hour**

Photograph of remote hands in EAST



1# FC detector calibration data

◆ Neutron Emission Spectroscopy (NES) Diagnostics

- Compact NES Systems
- 2.5 MeV neutron time-of-flight spectrometer (TOFED)

Neutron yield in D plasmas

facilities	Year	Neutron Yield (n/s)
PLT with NB heating	In 1980’	≤10^{14}
JET with ohmic heating	From 1983	>10^{13}
JET with auxiliary heating	From 1983 on	>10^{14} -- 10^{16} Aiming for 10^{17}
LHD with auxiliary heating	March， 2017	$3.3*10^{15}$ Aiming for 10^{16}
EAST with auxiliary heating	From 2008 on	>10^{9} -- 10^{14} Aiming for > 10^{15}
HL-2A with auxiliary heating	From 2007 on	10^{9} -- 10^{13}

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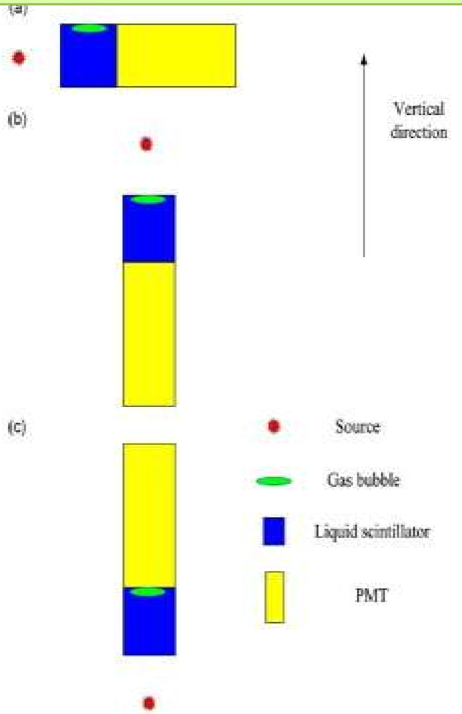
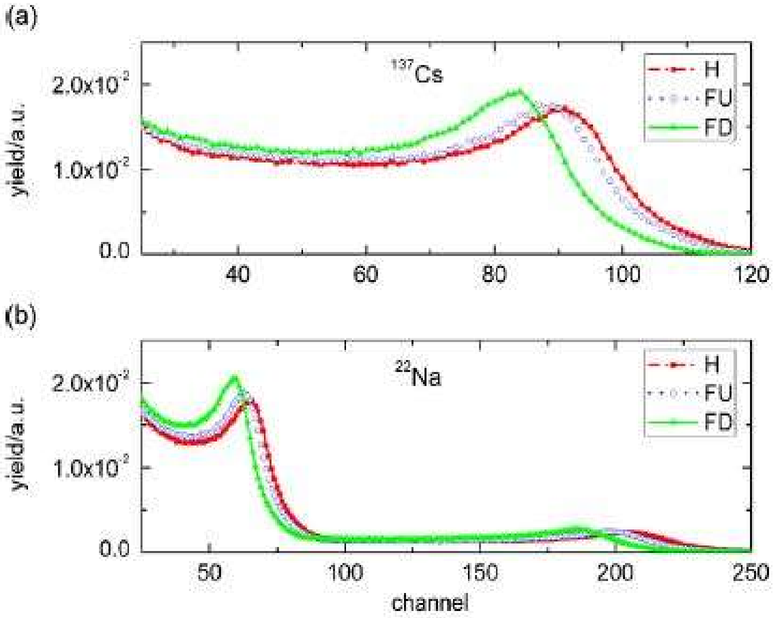
Compact liquid scintillator spectrometer

The influence of the gas bubble inside the EJ301 detector on the response of the detector has been investigated and the best detector placement was recommended for the neutron energy measurement for the first time.

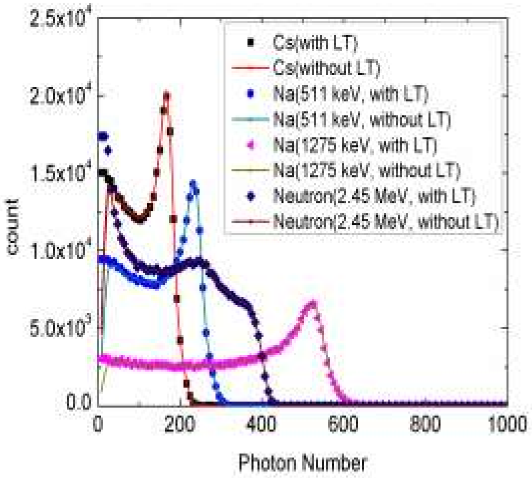


Sketch diagram of the three detector placing styles



Responses of EJ301 detector to gamma-rays from 137Cs and 22Na at three different placement styles.

Xufei Xie NIM A 721(2013)

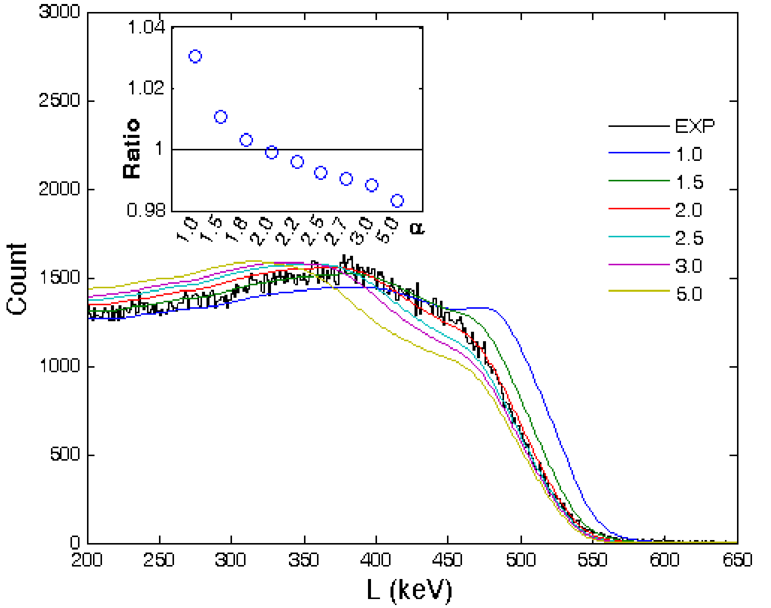


Comparison of the theoretical and experimental pulse height spectra of gamma-rays and neutrons.

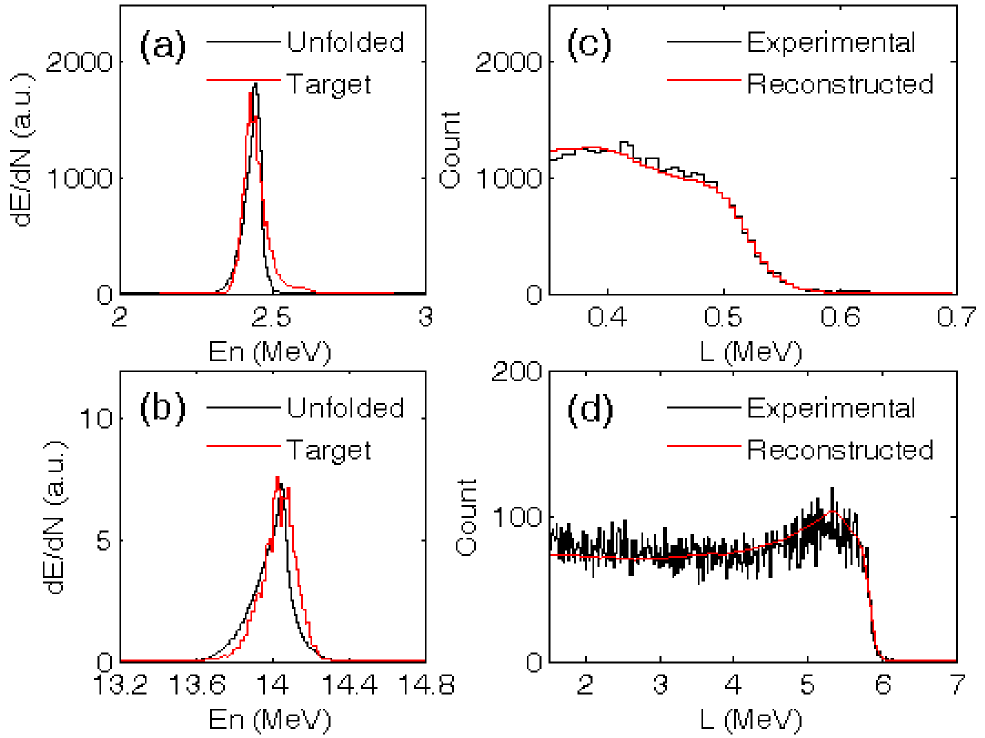
Stilbene crystal detector

A new method for determining the anisotropic light output in the stilbene crystal is presented, and a new compact stilbene crystal neutron spectrometer is investigated and applied for NES on EAST.

$$L\left(E_p,\theta\right)=\left(1+f(E_p)\sin^{\alpha}(\theta)\right)L_0\left(E_p\right)$$



Comparisons of the simulated spectra with different alpha value to the experimental spectra induced by 2.4 MeV neutrons. The inset figure shows the ratios of the centroids in the simulated spectra to the measured with lower hybrid wave injection and ion cyclotron resonance heating on the EAST tokamak

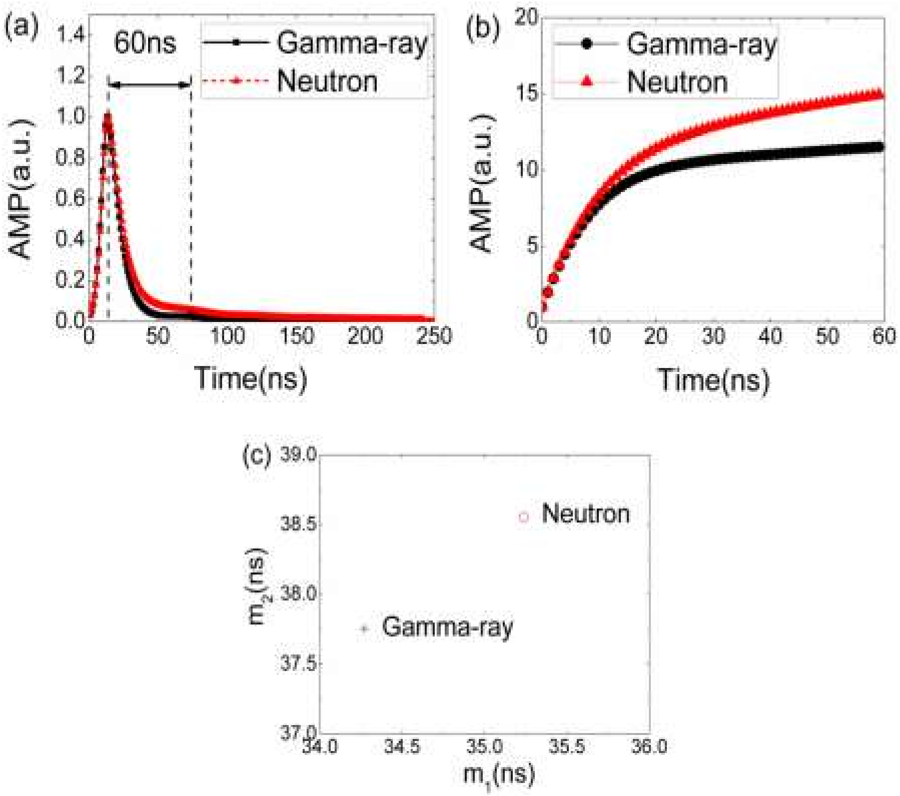


Unfolded neutron spectra and TARGET calculated spectra of 2.5 MeV neutrons (a) and 14 MeV neutrons (b). (c) and (d) are the comparisons of the reconstructed pulse height spectra with measured ones.

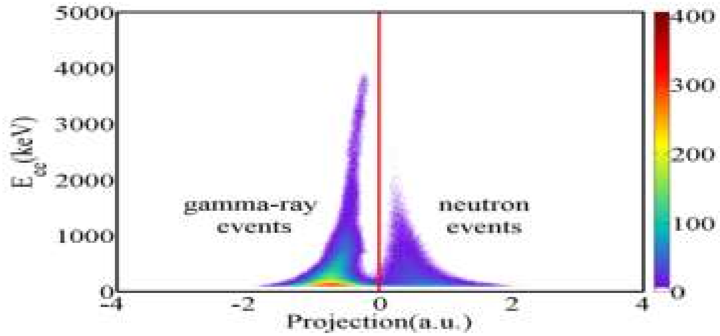
Xing Zhang REV SCI INSTRUM 84(2013)

Digital data processing techniques

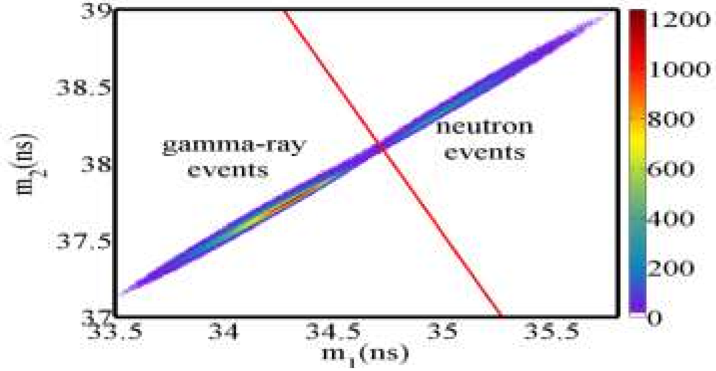
The original moment analysis technique has been modified for digital PSD in the organic scintillation detectors. The good discrimination results are achieved in different neutron/gamma-ray mixed fields.



Principle of Moment Analysis of averaged neutron and gamma signals from an Am-Be neutron source



Plot of projection vs Eee for Neutron and gamma-ray signals acquired from Am/Be neutron source

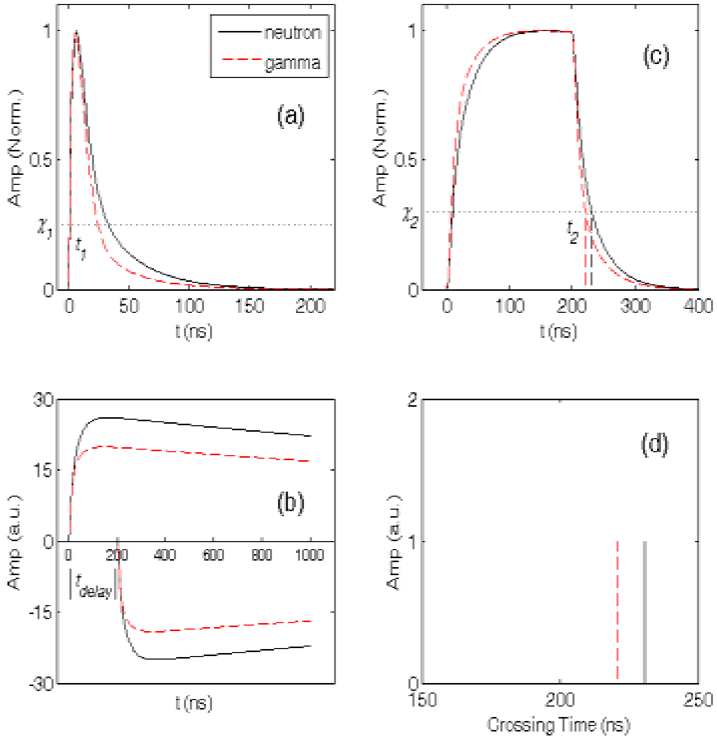


Plot of m2 vs m2 for neutron and gamma-ray signals acquired from Am/Be neutron source

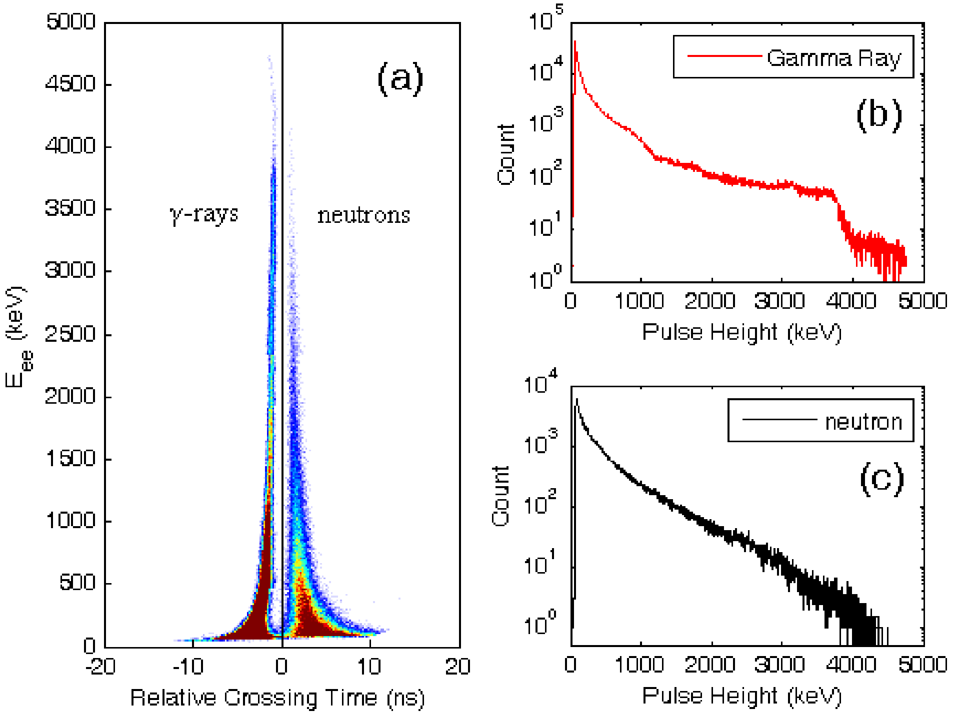
Xufei Xie et al. Rev. Sci. Instrum. 83(2012)093507

Digital data processing techniques

Digital Delay-Line-Shaping (DLS) method has been presented to do neutron/gamma-rays discrimination in stilbene neutron detector. The method performs well for a wide energy range, the energy threshold can be as low as 500 keV for neutrons and180 keV for g-rays.



Principle of digital Delay-Line-Shaping algorithm (constant fraction timing tech)



Validation of an Am-Be Neutron Source

(a) 2D plot of relative crossing time vs Eee in the whole range

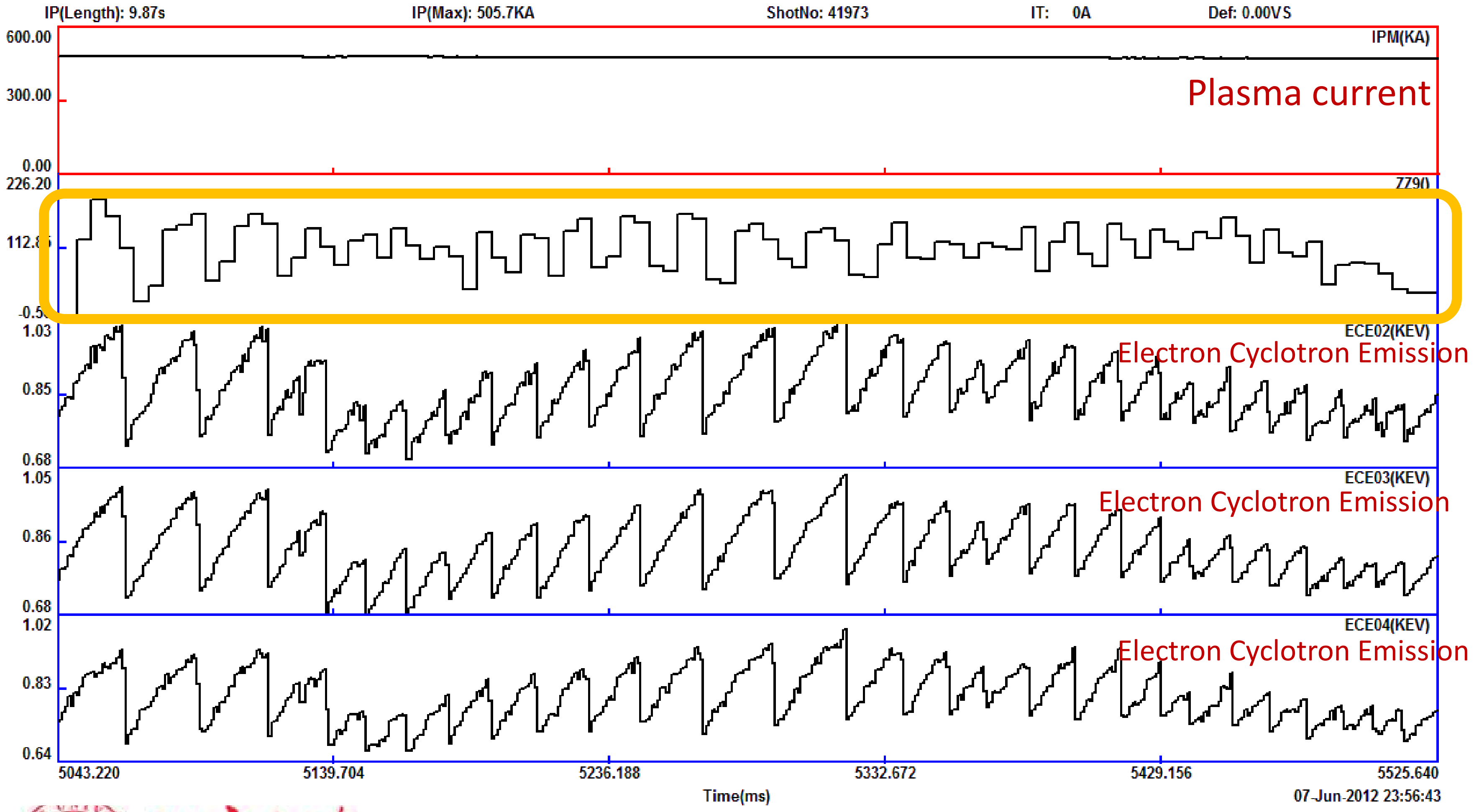
(b) PH spectrum of gamma-rays (c) PH spectrum of neutrons

Xing Zhang NIM A 687(2012)

Compact liquid scintillator spectrometer

- Time trace of neutron signals with Sawtooth @ EAST

Shot 41973 IP= 500 kA P_{LHI}= 1.4 MW



Plasma current

Electron Cyclotron Emission

Electron Cyclotron Emission

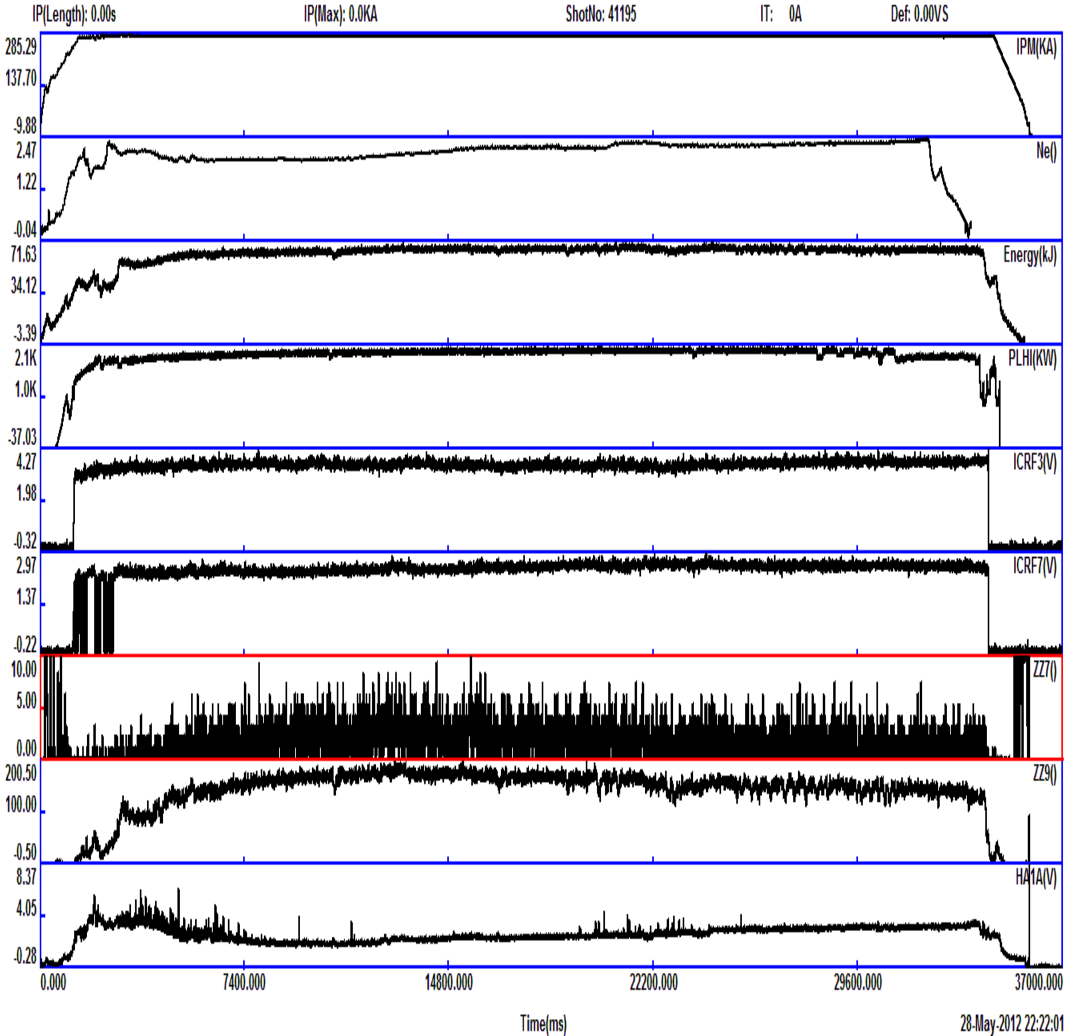
Electron Cyclotron Emission

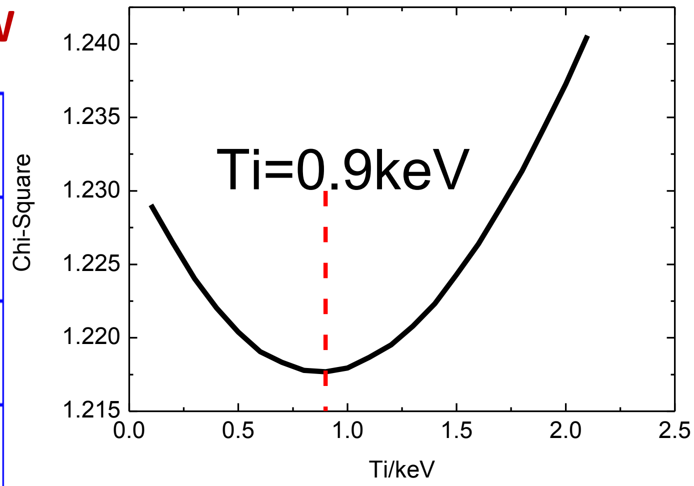
Compact NES system @ EAST

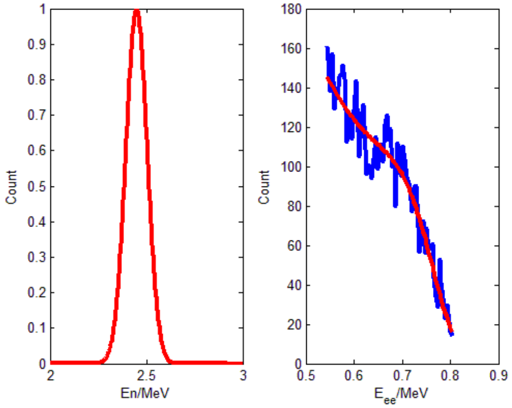
High confinement H-mode discharge over 30s driven by ICRH & LHCD

Ti= 0.9 keV (shots： 41194-41196) @ EAST

Shot 41195, n_e=2.2*10^{19}/m^3, P_{LHI}=2 MW, P_{ICRF}=800 kW

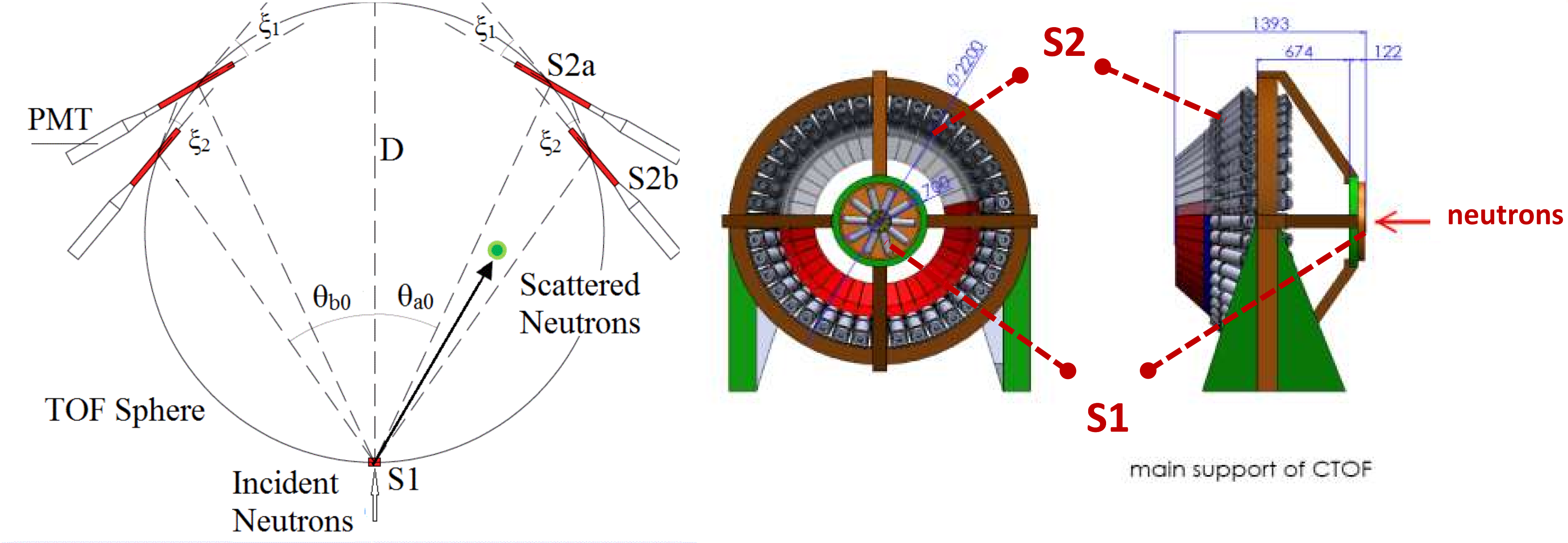






Li J G Nature Phys 9(2013)

TOFED： design



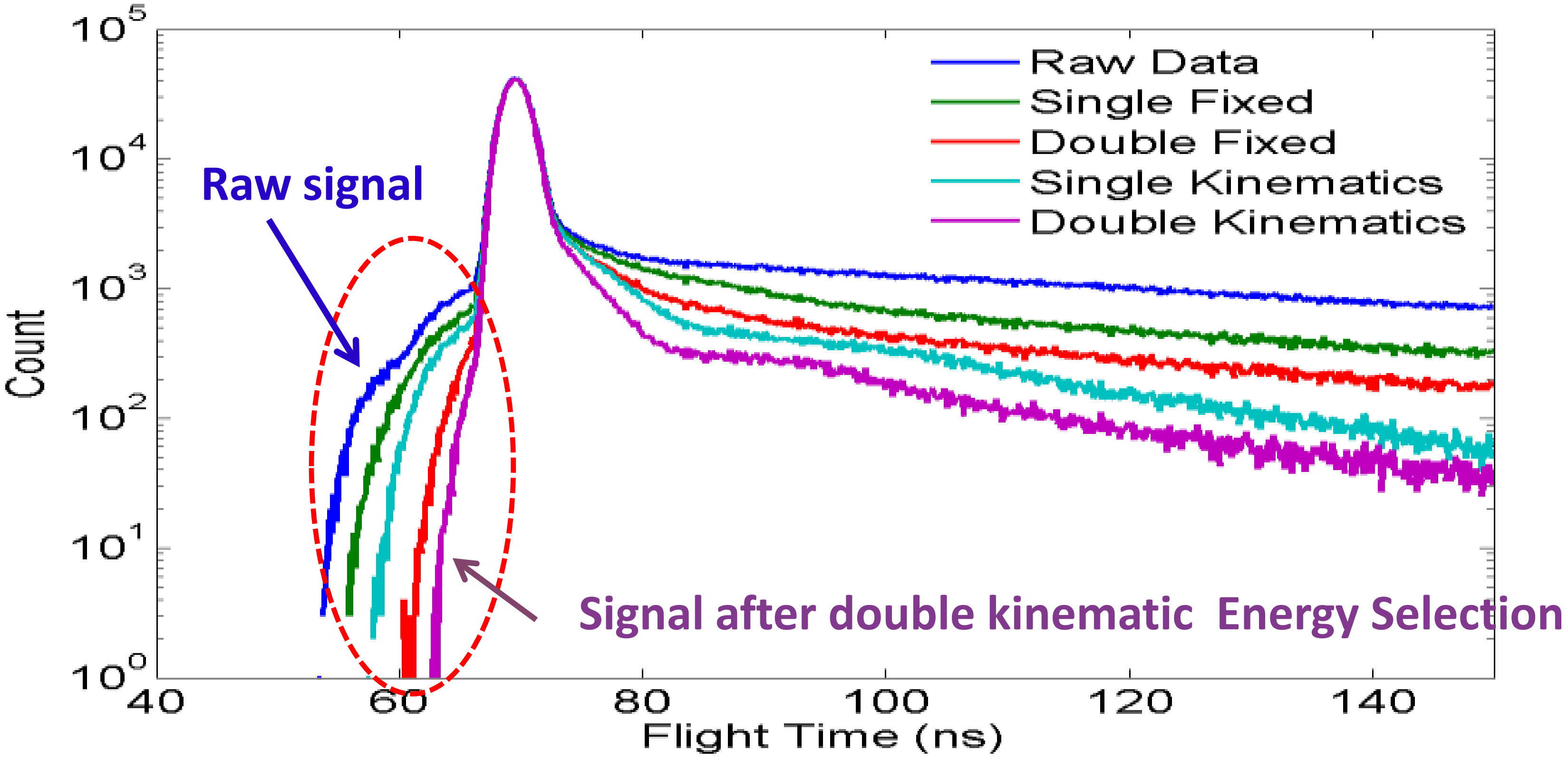
TOFED (80 S2 channels) @ EAST

- **TOFED = Time Of Flight Enhanced Diagnostics**
- **Increasing the covered solid angle of the scattered neutrons to increase the detection efficiency (1.6% for 80 S2 dectectors)**
- **Decreasing the geometric indetermination to improve the energy resolution (designed 6%)**

Z.J. Chen, et al., ***REV. SCI. INSTRUM., 85****, 11D830(2014)*
X. Zhang, et al., ***NUCL. FUSION, 54****, 104008(2014)*

TOFED： design

A double-ring structure and a fully digital data acquisition system allows for a Double dynamic Energy selection in the time-of-flight/recoil proton energy space

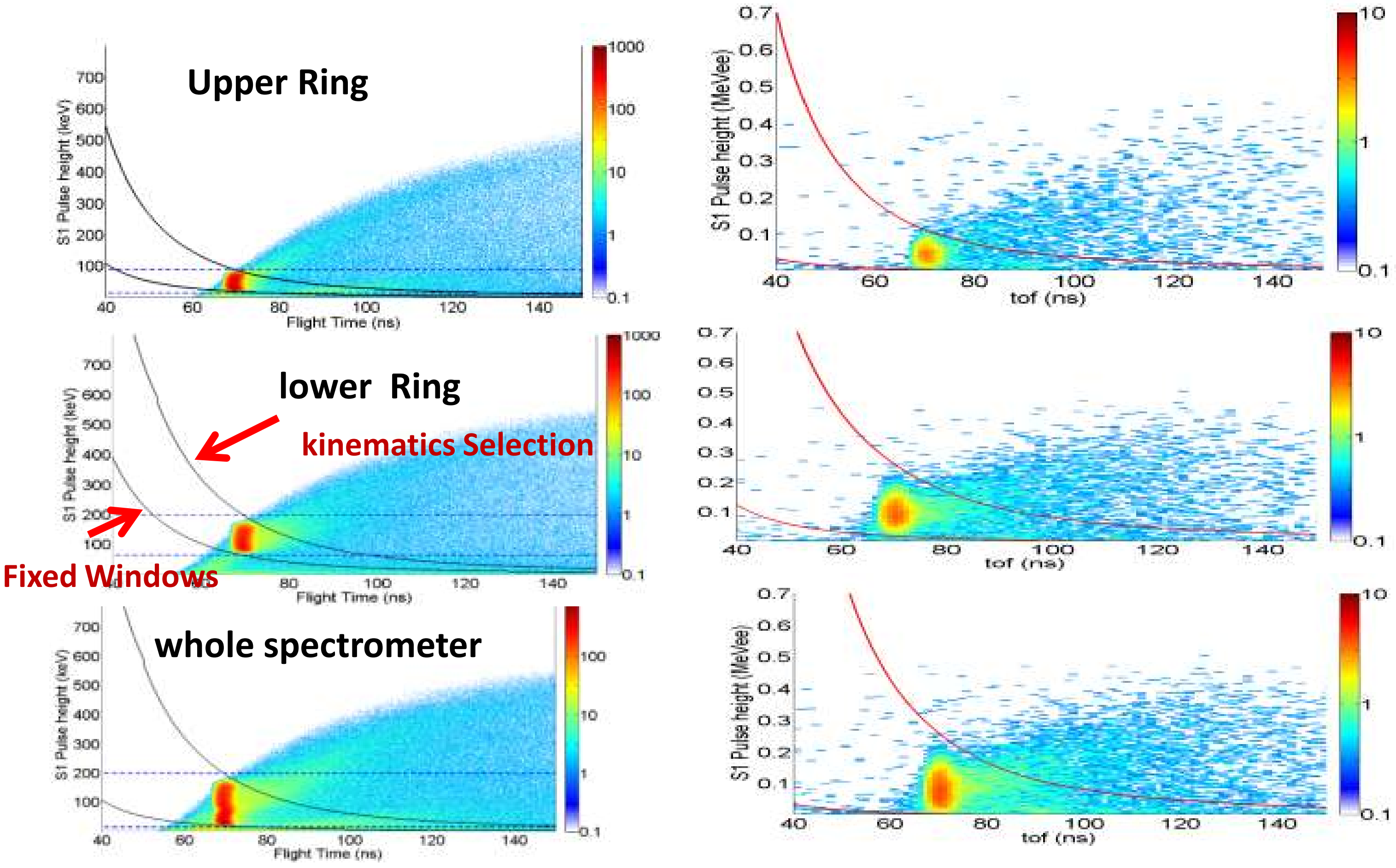


Improving the spectrometer capability to resolve fast ion signatures in the time-of-flight spectrum up to a factor ~ 100 for the first time

X. Peng, et al. **REV. SCI. INSTRUM., 85**, 11E112(2014）

TOFED： design

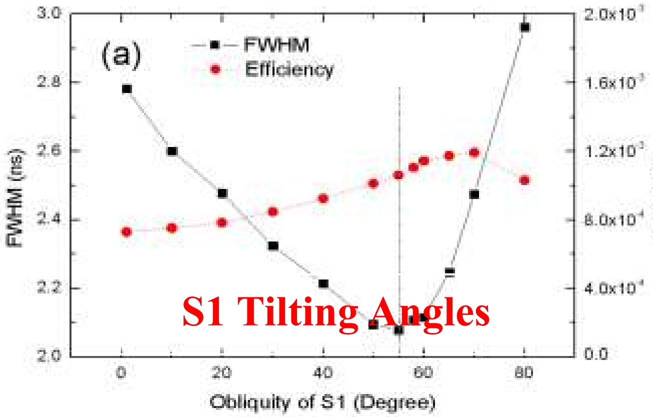
Double kinematic Energy Selection Windows: GEANT4 cal. & experimental results

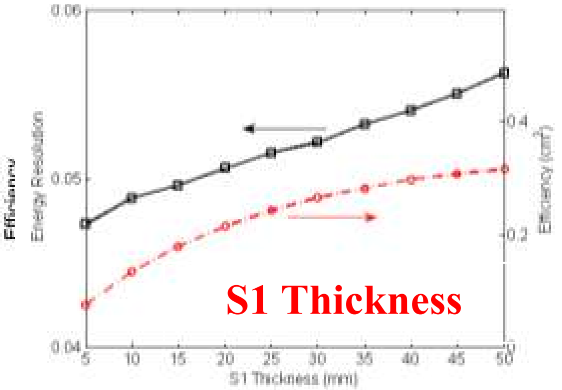


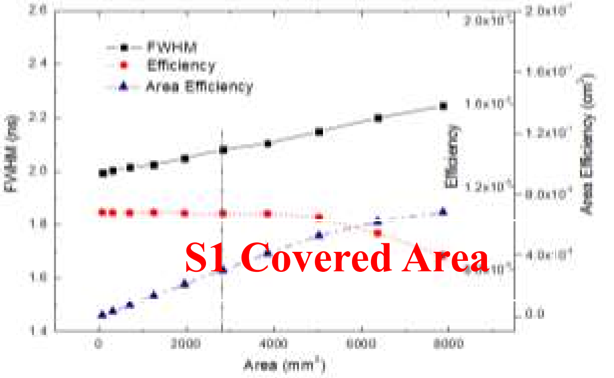
2.45 MeV neutron Flight time vs. the recoil proton Pulse Height in S1 for TOFED

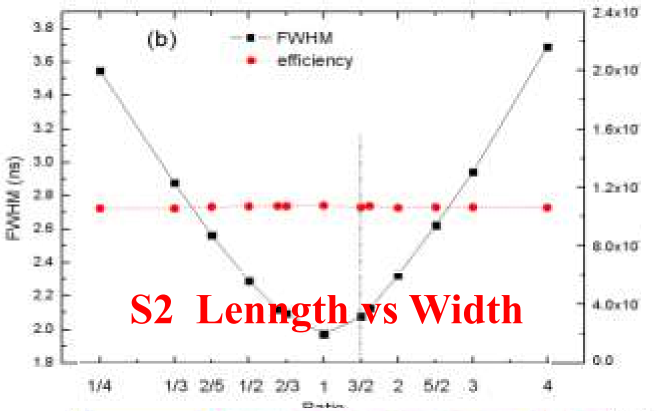
X. Peng, et al. ***REV. SCI. INSTRUM., 85***, *11E112(2014）*

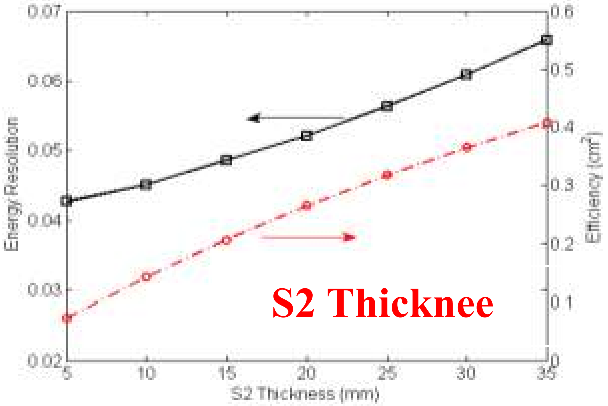
Design & simulations using Geant 4.9 & ROOT5.2 6

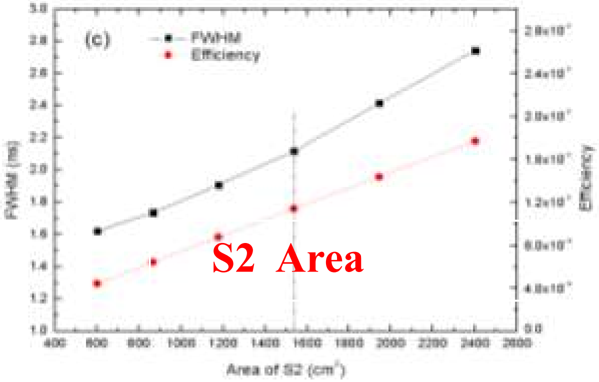

S1 Tilting Angles

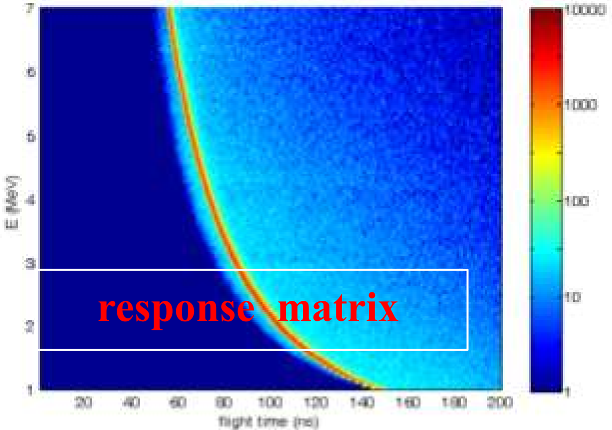

S1 Thickness

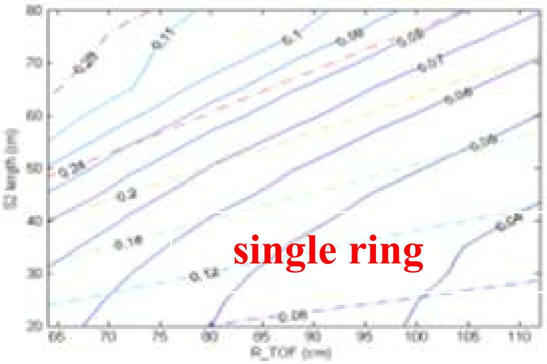

S1 Covered Area

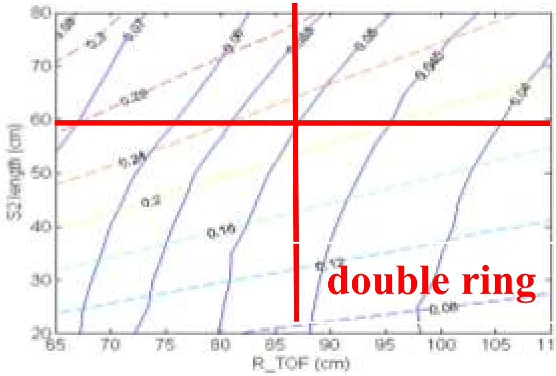

S2 Lenngth vs Width


S2 Thicknee


S2 Area


response matrix

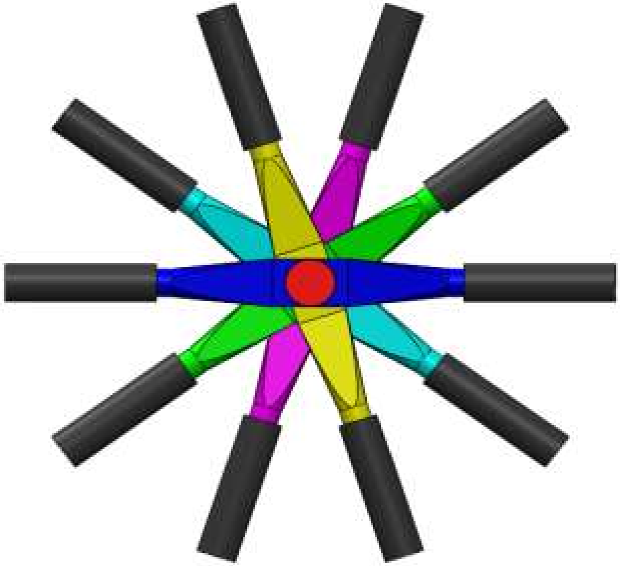

single ring


double ring

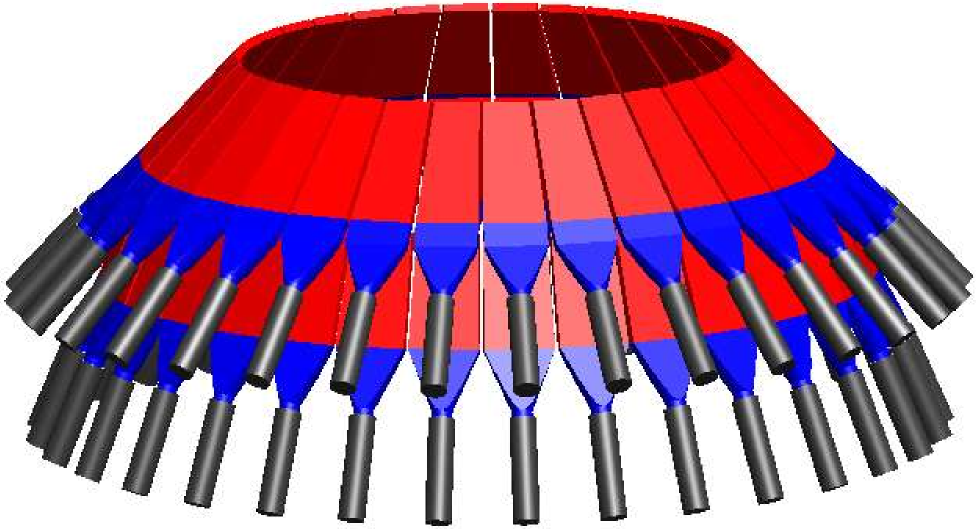
Zhang Xing *et al.*, Plasma Sci. & Tech, 14(2012)674

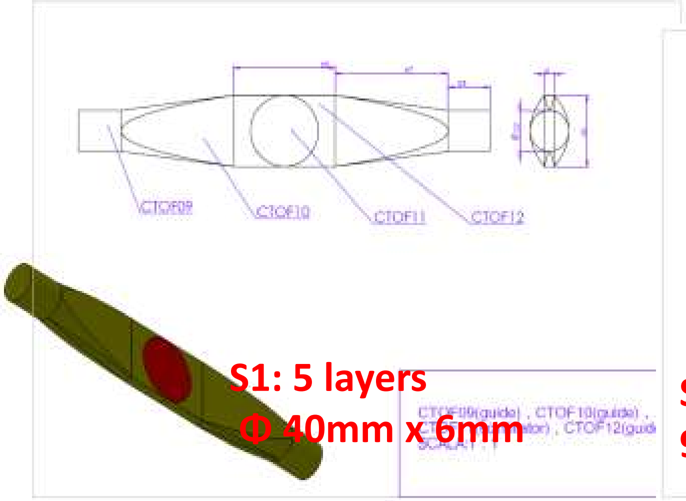
Double ring structure of TOFED

S1: 5 layers
Φ 40mm x 6mm

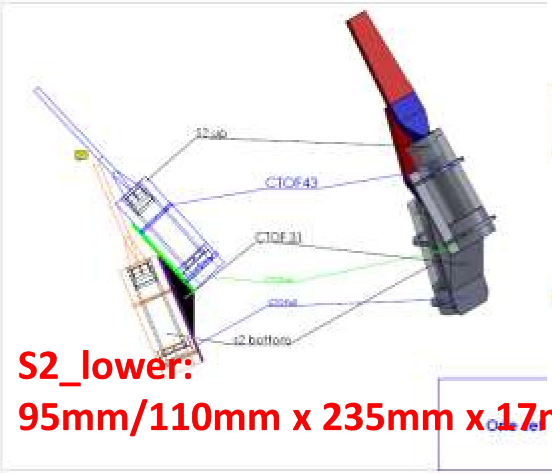


S2: Double Ring Array
40 scintillators on each ring

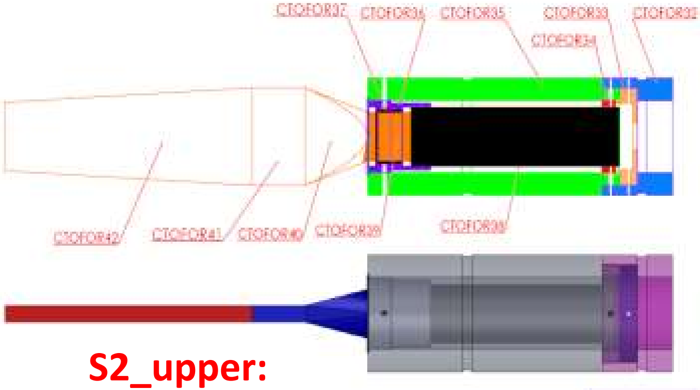




S1: 5 layers
Φ 40mm x 6mm



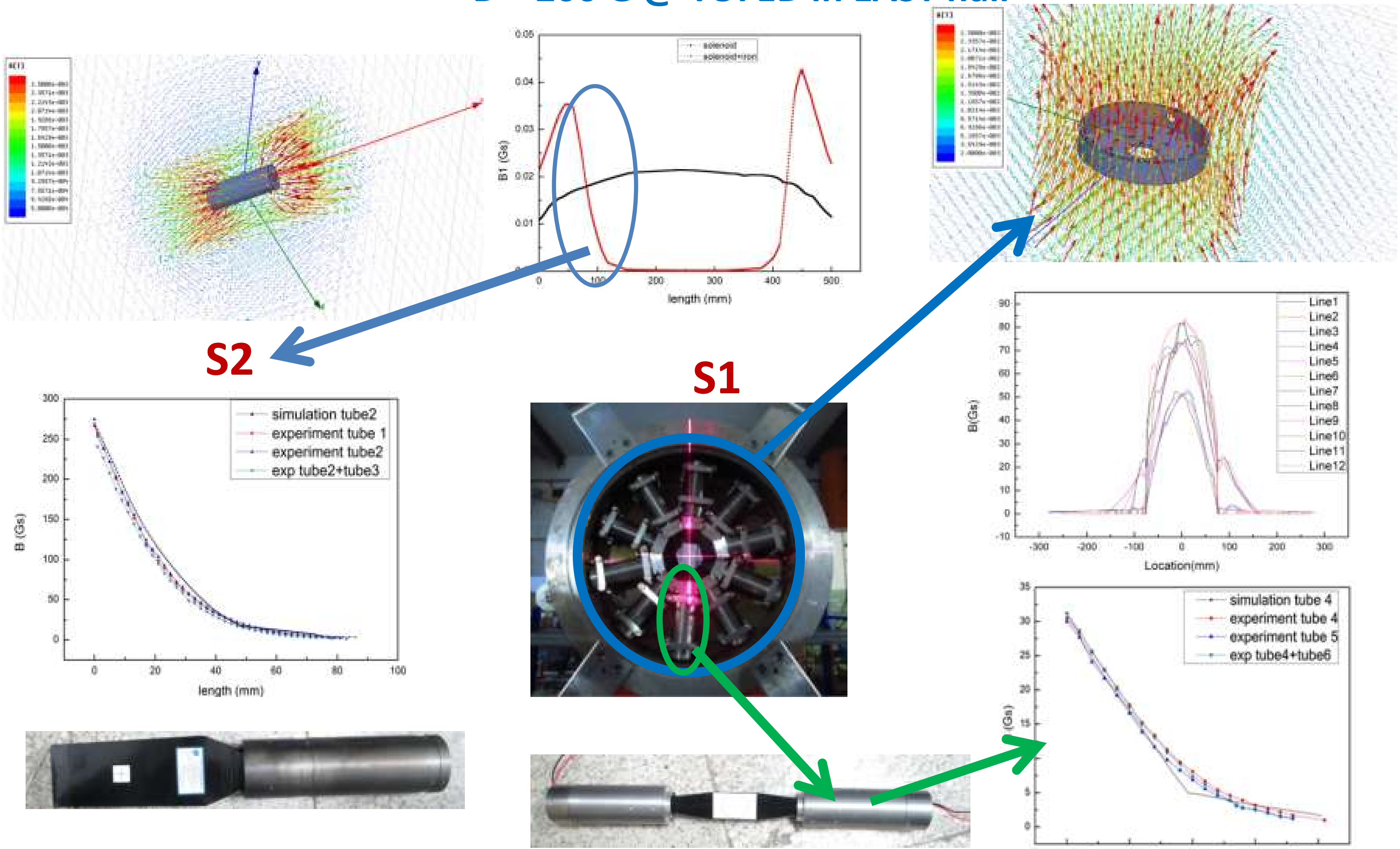
S2_lower:
95mm/110mm x 235mm x 17mm



S2_upper:
70mm/100mmx280mmx17mm

Design and test of magnetic shield of PM tubes

B < 200 G @ TOFED in EAST hall

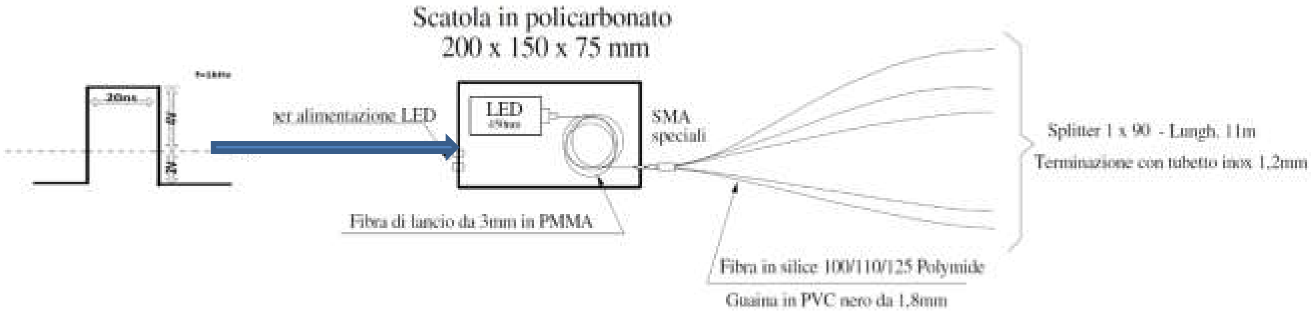


Simulations with Ansoft Maxwell code

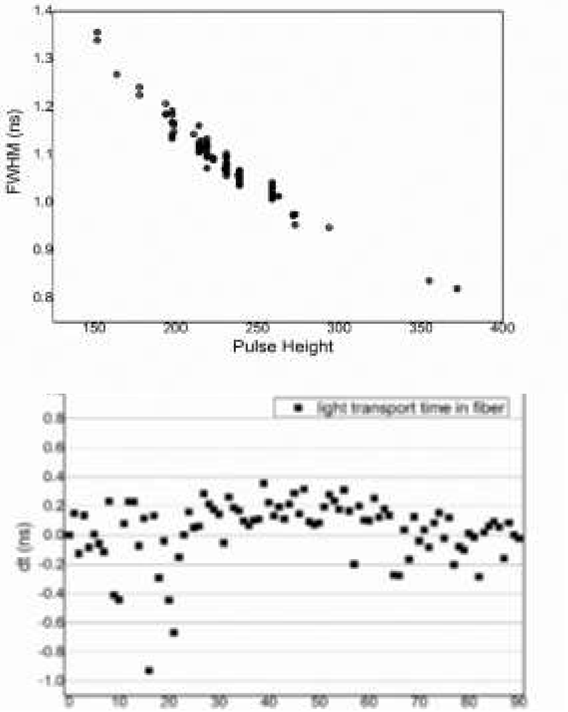
PEKING UNIVERSITY

Z.Q. Cui, et al., REV. SCI. INSTRUM., 85, 11D829(2014)

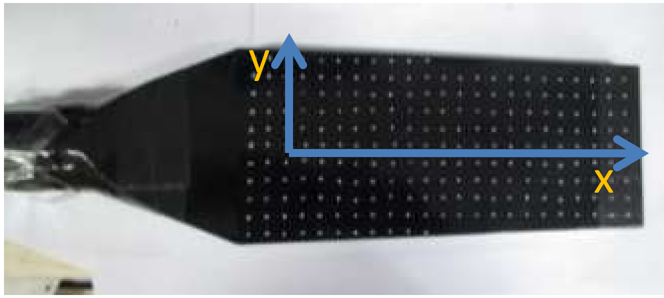
LED timing monitoring system



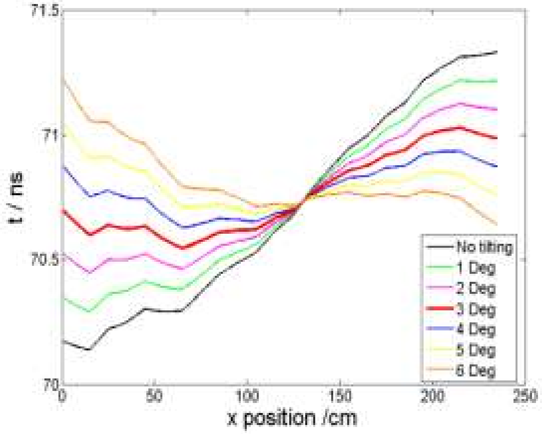
The LED with 1*90 splitters used to determine the time alignment among TOFED detectors

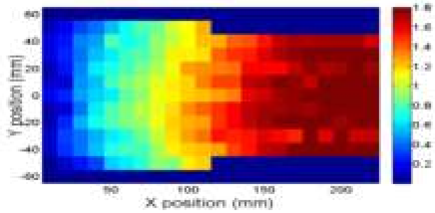


Deviation of the light transport time: ~ ±0.2 ns

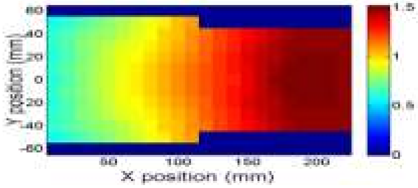


Photon transport time test in S2





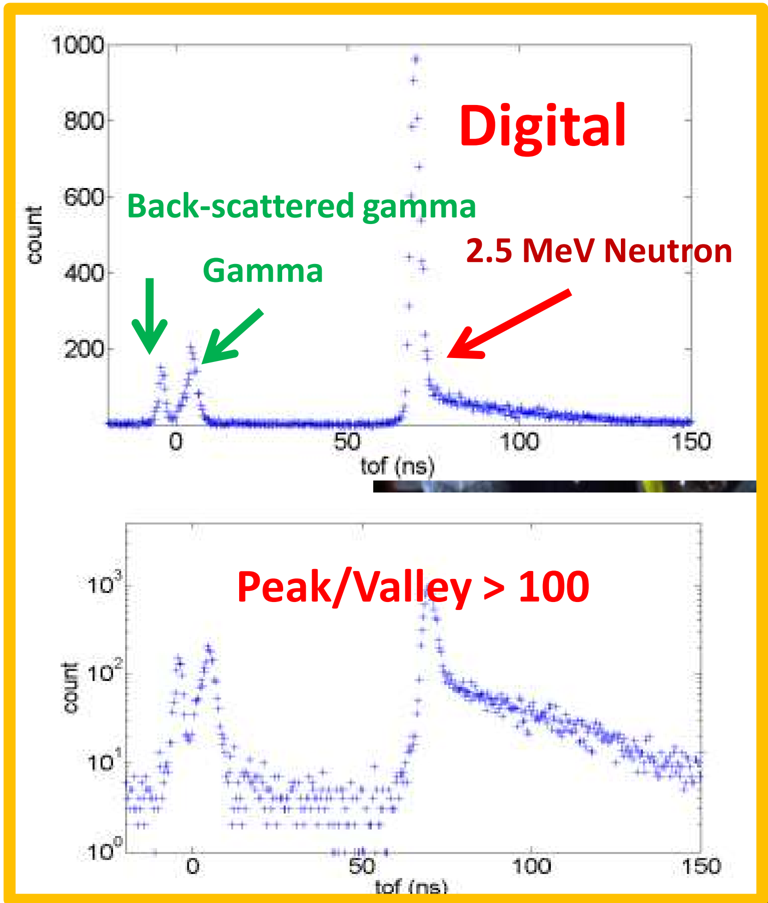
Experimental

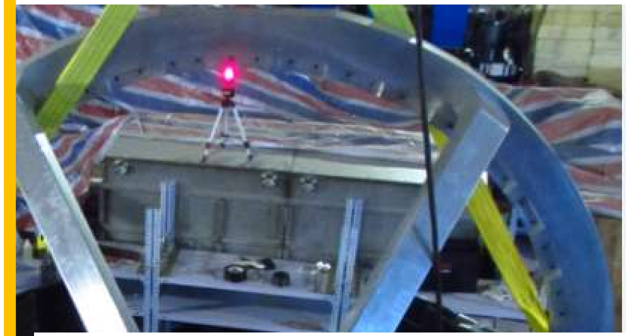


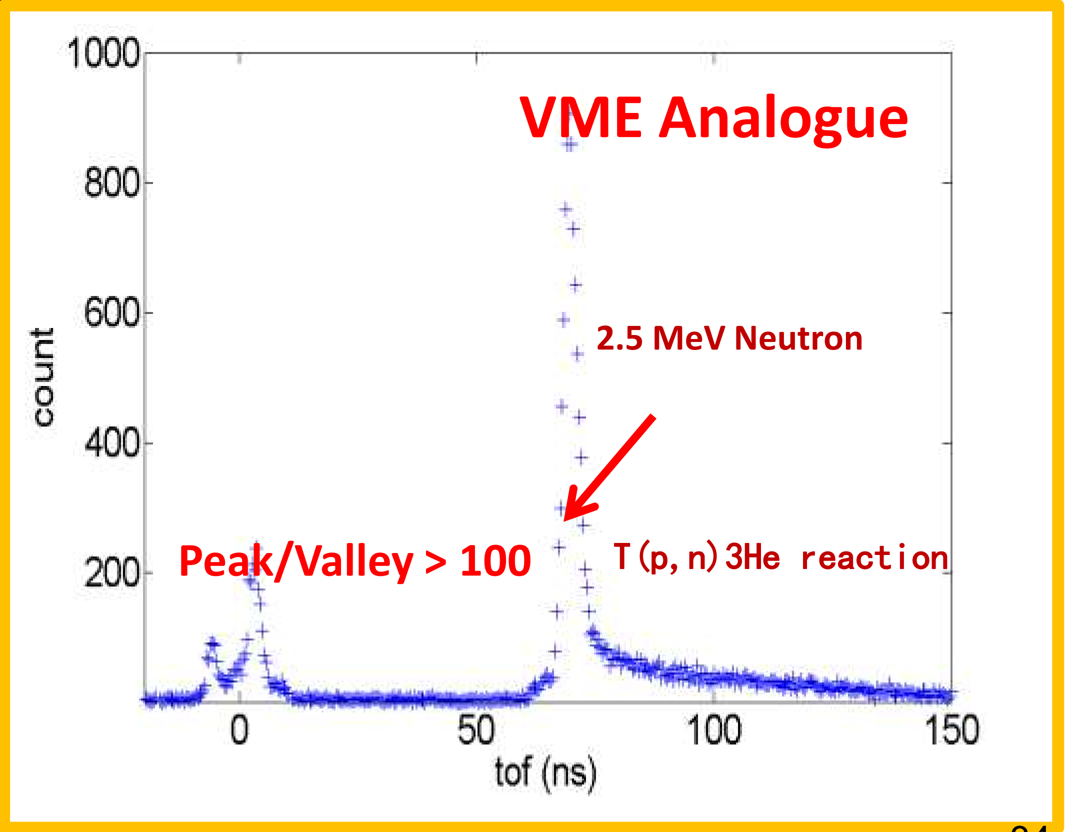
GEANT4 Simulated

An tilting angle of 3 degree to middle points of two S2 rings decreases the timing variation from 1.5 ns to 0.6 ns.

TOF spectra of 2.5 MeV neutron beams produced by a 4.5 MV Van de Graaff accelerator at Peking University







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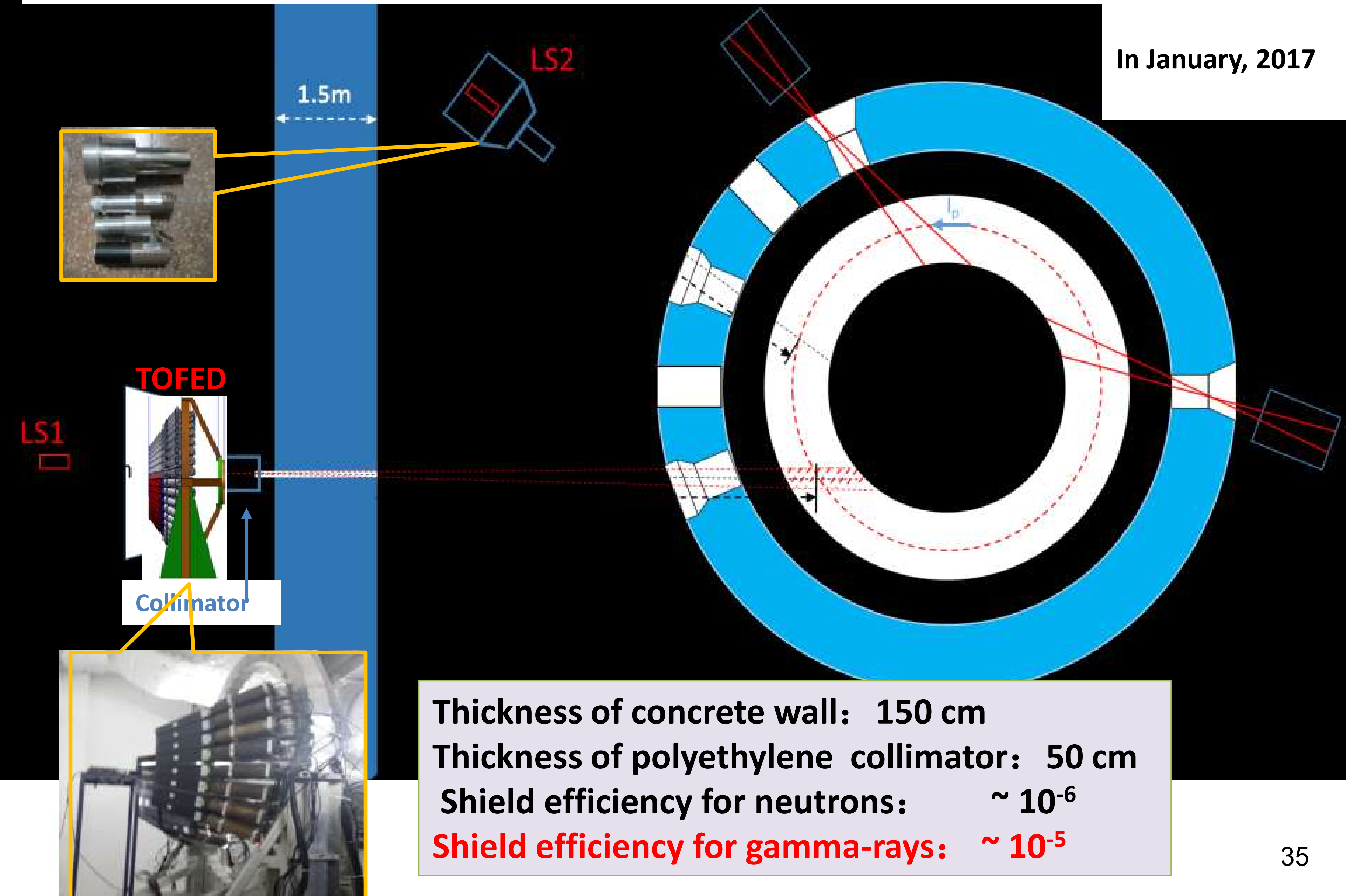
PEKING UNIVERSITY

X.Y. Peng, et al., REV. SCI. INSTRUM., 85, 11E112(2014)

Synergized diagnostics from TOFED & SL Spectrometers



In January, 2017

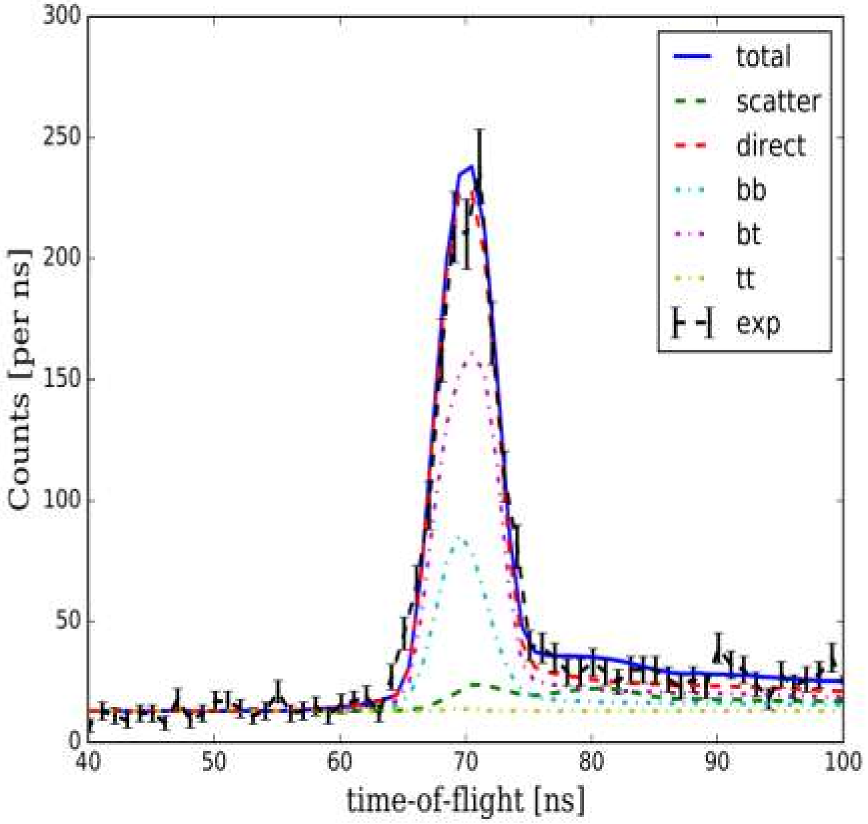
Thickness of concrete wall： 150 cm

Thickness of polyethylene collimator： 50 cm

Shield efficiency for neutrons： ~ 10^{-6}

Shield efficiency for gamma-rays： ~ 10^{-5}

Preliminary Results in 2017 summer campaign



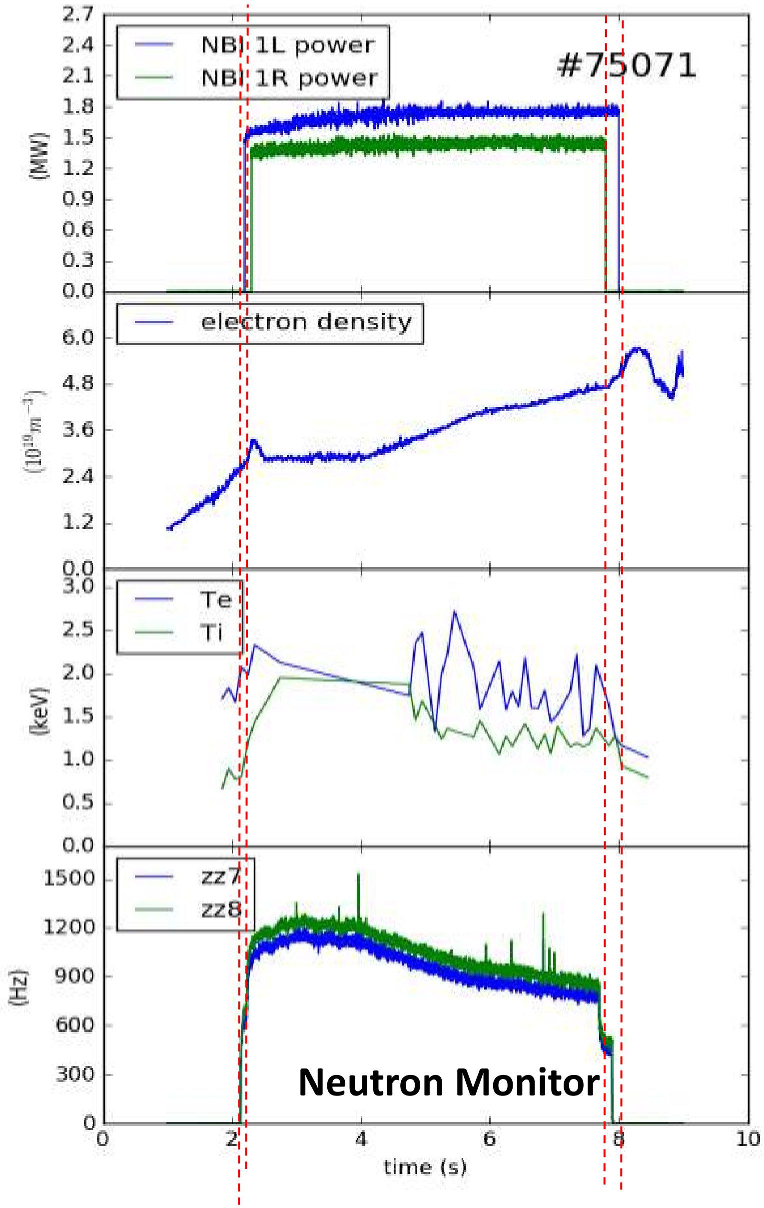
Measured TOF Spectra by TOFED

SHOT #75051~75061 & #75067~75071

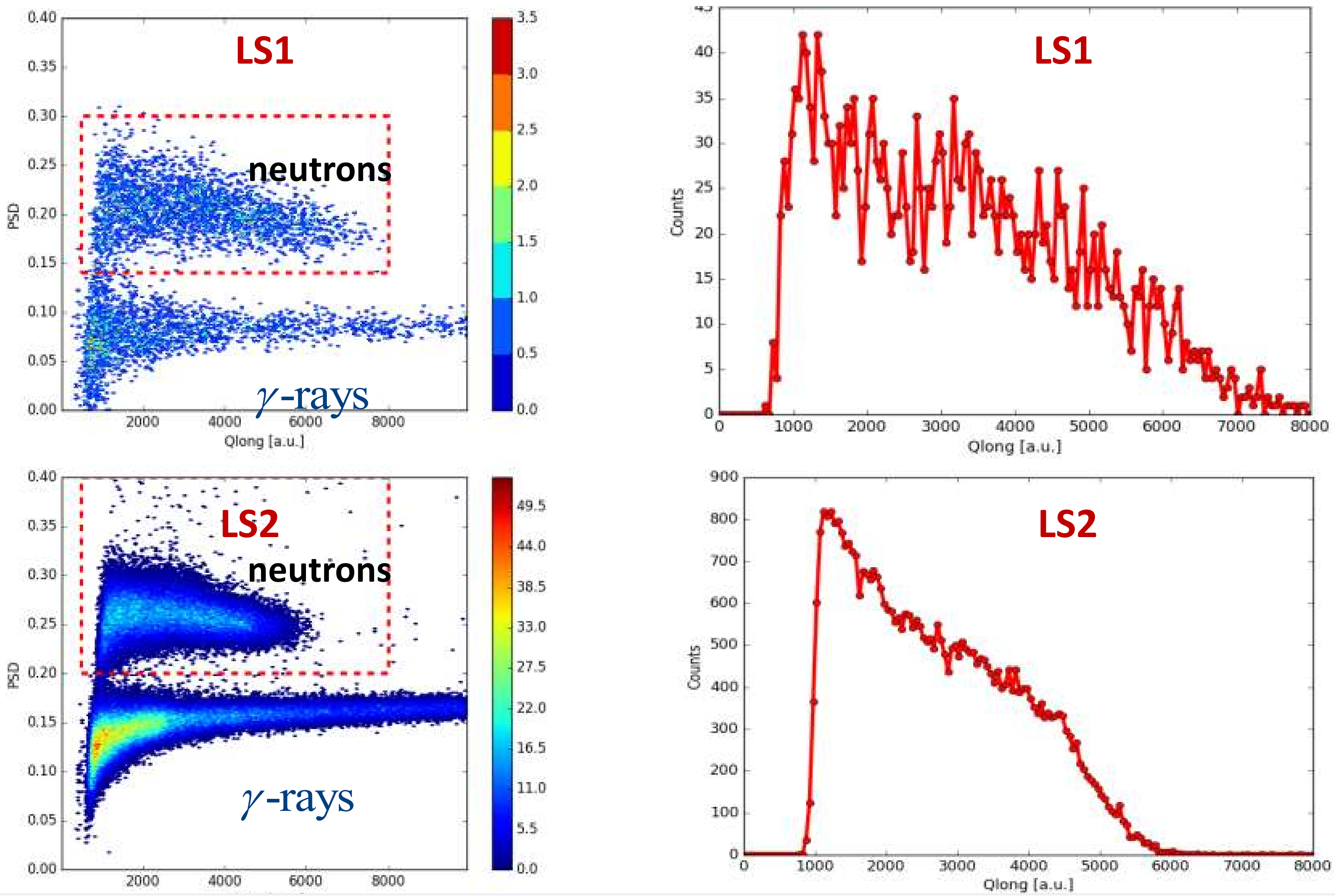
（2017.07.21）

NBI-I: Beam Energy = 56/53 keV,

Power = 1.7/1.4 MW



Preliminary Results in 2017 summer campaign



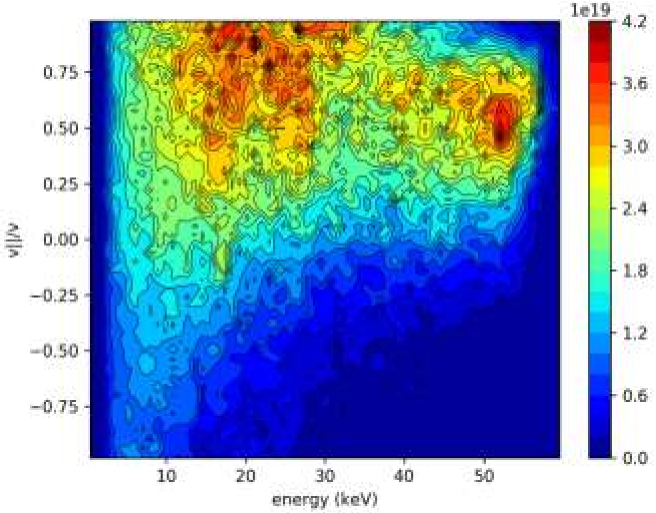
Shot #75071（2017.07.21）with 5.5s D co-NBI heating

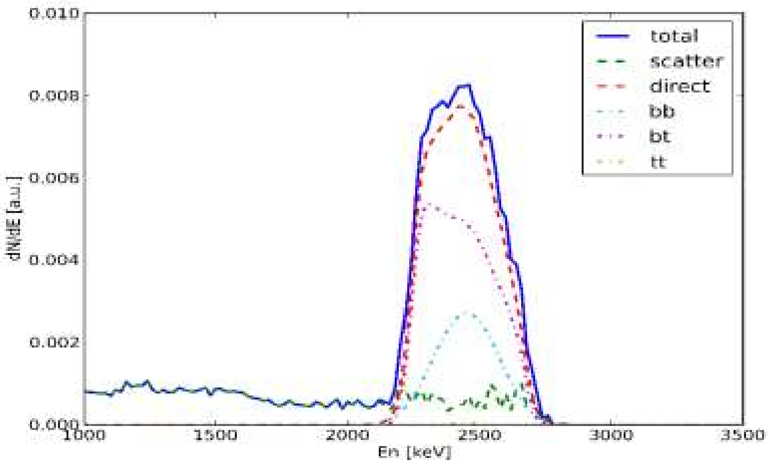
T_e : 1.5~2.5 keV, T_i : 1.0~2.0 keV, n_e : $3.3\sim4.8\times10^{19}\ m^{-3}$

Synergic diagnostics by TOFED & compact SL spectrometers

Velocity distributions of fast ions simulated by NUBEAM code

The neutron spectra have been analyzed from dynamics of fusion reactions and fast ion distributions by GENESIS & MCNP codes





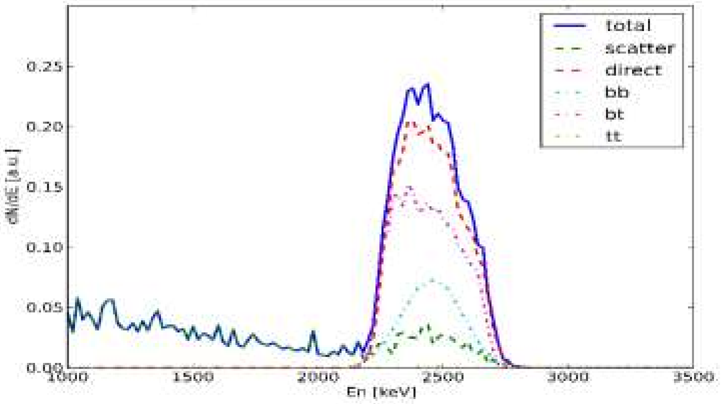
Neutron spectra @ S1 detector of TOFED

SHOT # 75071

$(T_e = 2.0\ keV,$

$T_i = 1.2\ keV,$

$n_e = 3.3 \times 10^{19}\ m^{-3})$



Neutron spectra @ LS2 spectrometer

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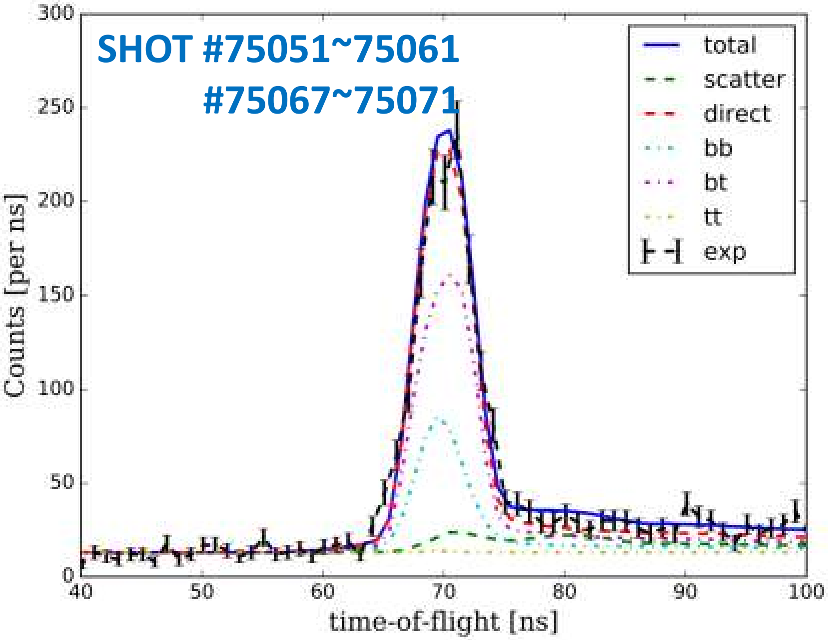
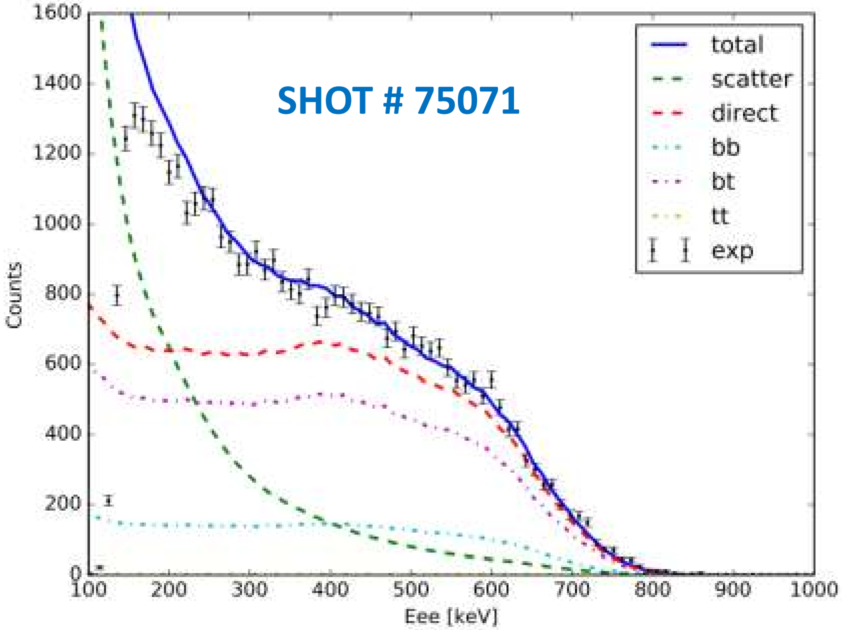
TOFED & compact SL spectrometers

Synergized diagnostics from TOFED and LS spectral measurements



Comparison between calculated and measured TOF spectra by TOFED



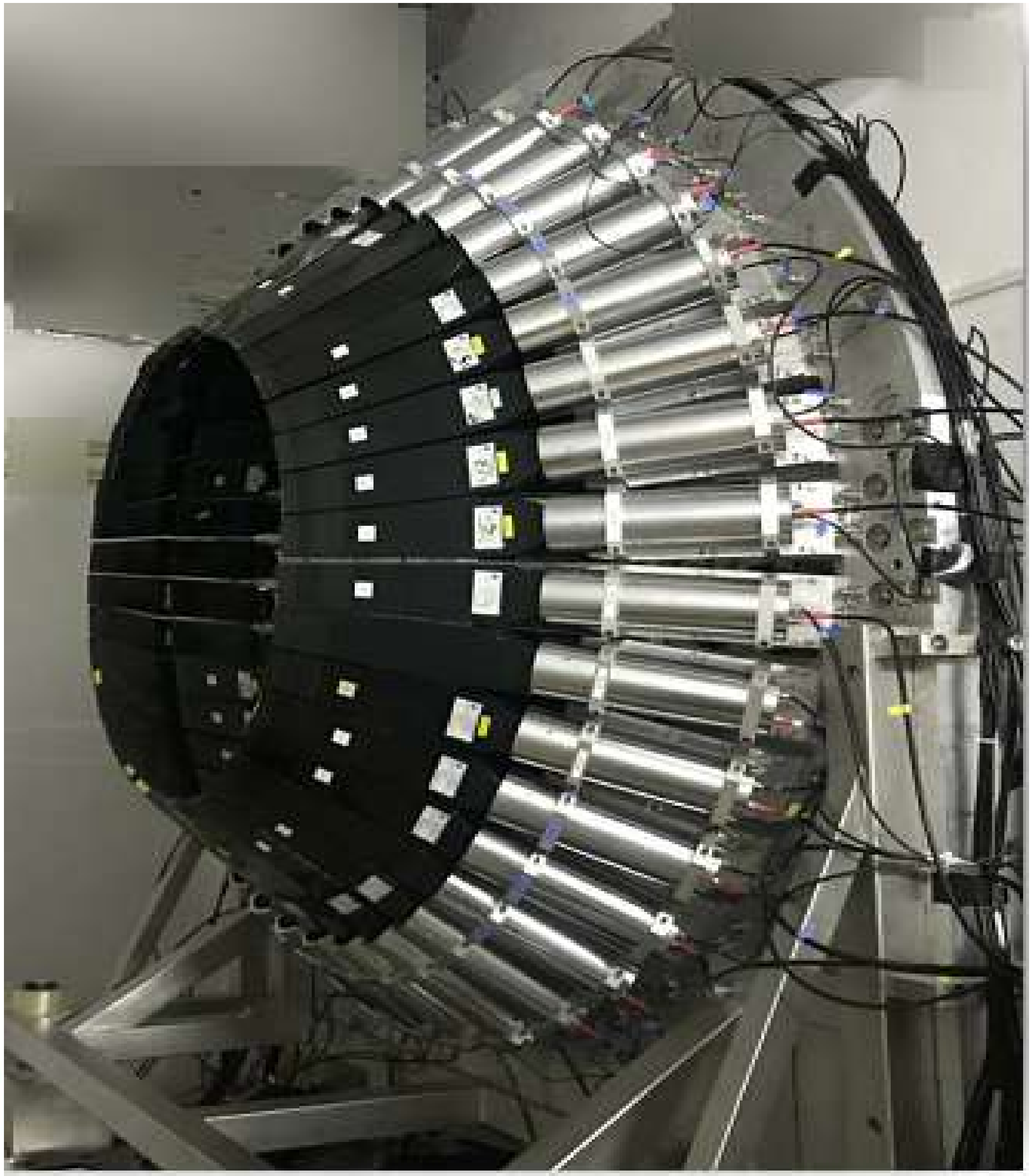
Pulse Height spectra measured by the Liquid Scintillation spectrometer LS2

- The measured data are in reasonable agreement with the simulated data, specially for broadening width
- The different components of neutron spectra are successfully separated at EAST plasmas with NBI heating
- Fusion neutrons mainly come from beam-target reactions for these NBI heating discharges

Concluding marks & future work

- A whole set of diagnostic systems for EAST deuterium operation has been developed including
  - ☐ Neutron Flux Monitors for neutron yield and fusion output
  - ☐ Radial Neutron Camera (6 ch) for neutron emission profiles
  - ☐ Neutron activation and fluctuation diagnostics for fast time response and calibration
  - ☐ Compact neutron emission spectrometers for neutron emission spectrum measurements
  - ☐ TOFED neutron time-of-flight spectrometer for fast ion physics
- The synergized diagnostics from TOFED & compact liquid scintillator spectrometers show that fusion neutrons sill mainly come from beam-target reactions during for D plasma operation with NBI heating

Concluding marks & future work

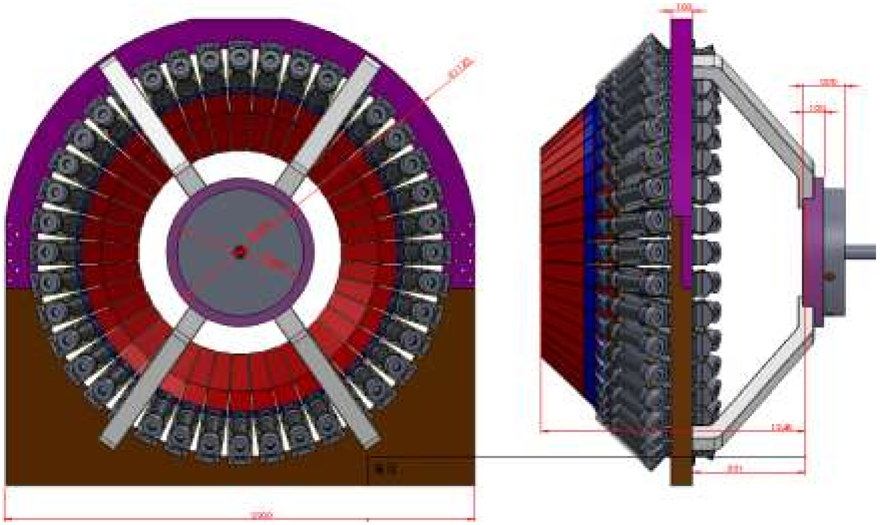


- **TOFED at EAST is the first high performance neutron spectrometer on a long pulse tokamak and it is of relevance as a step in the development of NES diagnostics after JET.** ***[Nucl. Fusion, 54, (2014)]***

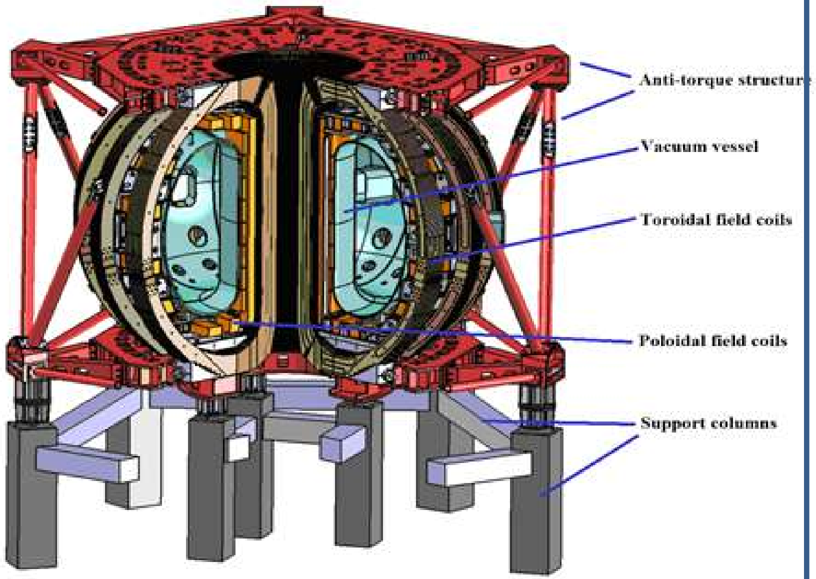
Concluding marks & future work

HL-2M: an advanced tokamak for fusion science studies relevant to ITER physics: High beta plasma, new configurations, higher auxiliary power heating (20MW)

TOFED @ HL-2M is under construction



HL-2M



- **Heating, current drive and fuelling:**
  - NBI: 55(80)keV, 9(15)MW
  - ECRH: 105GHz, 3MW, 500Hz modulation
  - LHCD: 3.7GHz, 2MW
  - Pellet: repetitive
  - SMBI: 0.2-3MPa, 100Hz modulation

Concluding marks & future work

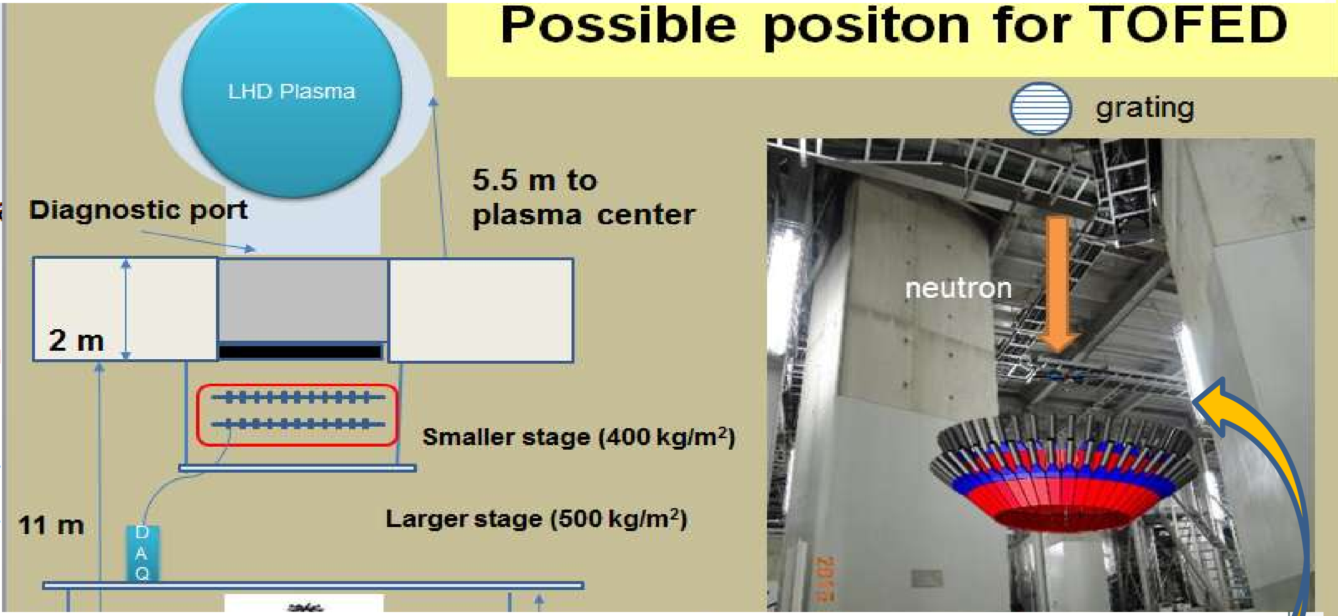
发件人：M@nifs.ac.jp>
主题：fr
收件人：ts
抄送：o kunihiro@nifs.
回复：：is

Prof. M. Isobe, NIFS, Japan

Dear Prof. Fan of Peking Un

I hope that you are doing f

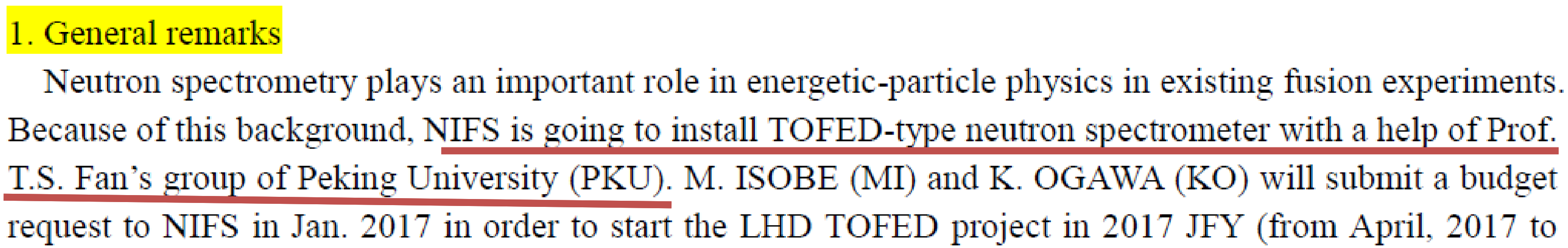
By the way, I am now at ASI



Possible positon for TOFED

To do list (draft) toward implementation of TOFED on LHD
based on discussion between NIFS and Peking University in Dec.19th-21st, 2016

TOFED @ LHD, NIFS, presented by Prof. M. Isobe on 2016.12.20



1. General remarks

Neutron spectrometry plays an important role in energetic-particle physics in existing fusion experiments. Because of this background, NIFS is going to install TOFED-type neutron spectrometer with a help of Prof. T.S. Fan's group of Peking University (PKU). M. ISOBE (MI) and K. OGAWA (KO) will submit a budget request to NIFS in Jan. 2017 in order to start the LHD TOFED project in 2017 JFY (from April, 2017 to

Concluding marks & future work

- TOFED at EAST is the first high performance neutron spectrometer on a long pulse tokamak and it is of relevance as a step in the development of NES diagnostics after JET. *[Nucl. Fusion, 54, (2014)]*

Thank you for your attention!