Tracer-Encapsulated Solid Pellet (TESPEL) Injection for LHD plasmas

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for LHD team

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NINS
National Institutes of Natural Sciences
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Outline

I. Overview of LHD diagnostics

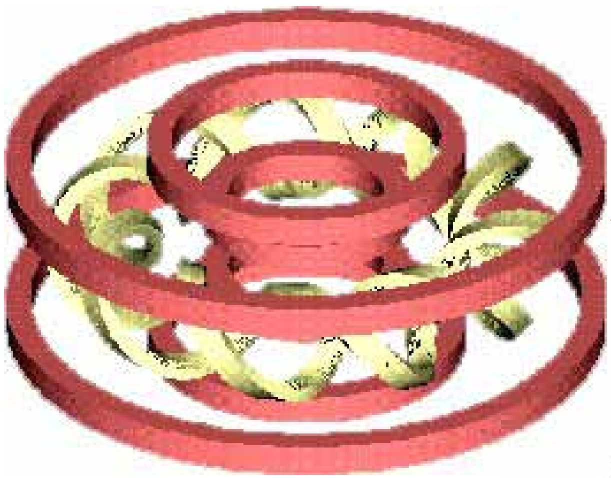
II. TESPEL

- A) Properties of TESPEL
- B) Its ablation study
- C) Impurity transport study
- D) Electron thermal transport study
- E) Others

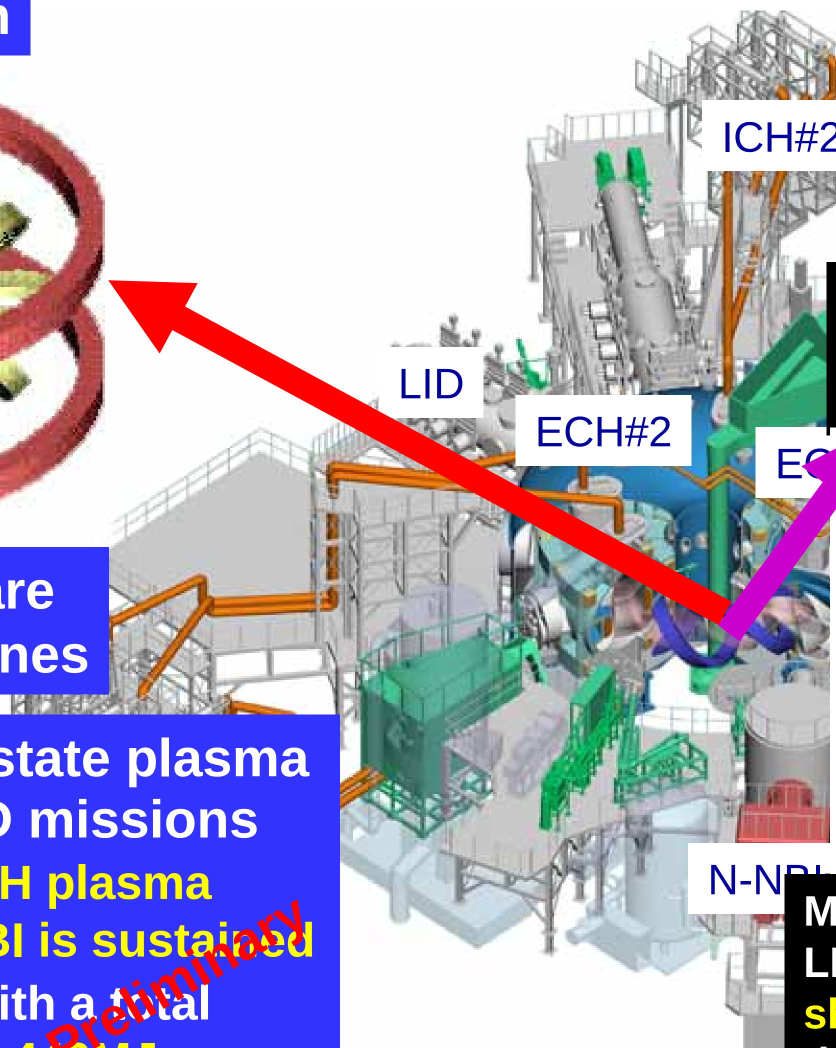
III. Summary

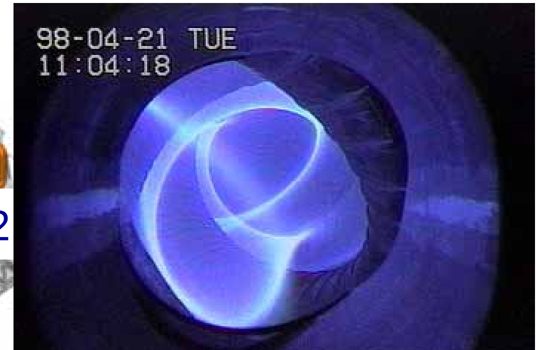
0. Large Helical Device (LHD)

LHD coil system

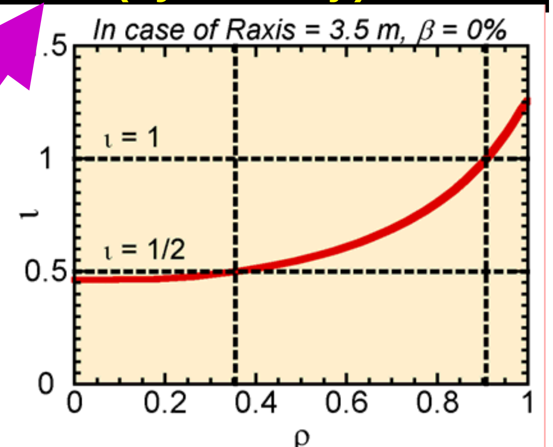


All magnet coils are superconducting ones





Observation with CCD camera with a tangential view (by M. Shoji)



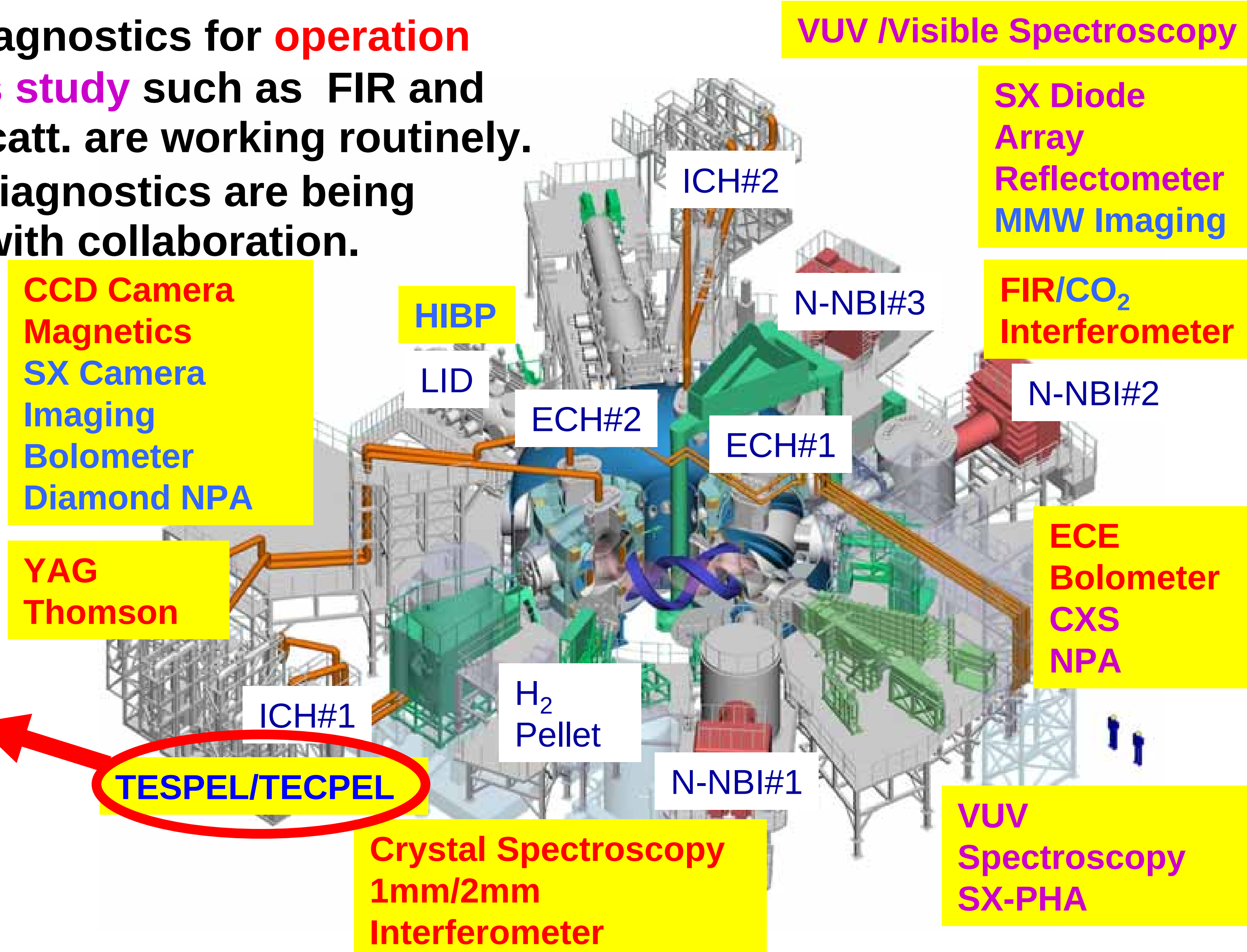
Magnetic configuration of the LHD has **negative magnetic shear over a whole plasma** in the low beta regime.

- ✓ Study of steady state plasma is one of the LHD missions
  - Last Friday, **ICH plasma assisted by NBI is sustained for 728 sec** with a total input power of **440MJ**

Preliminary

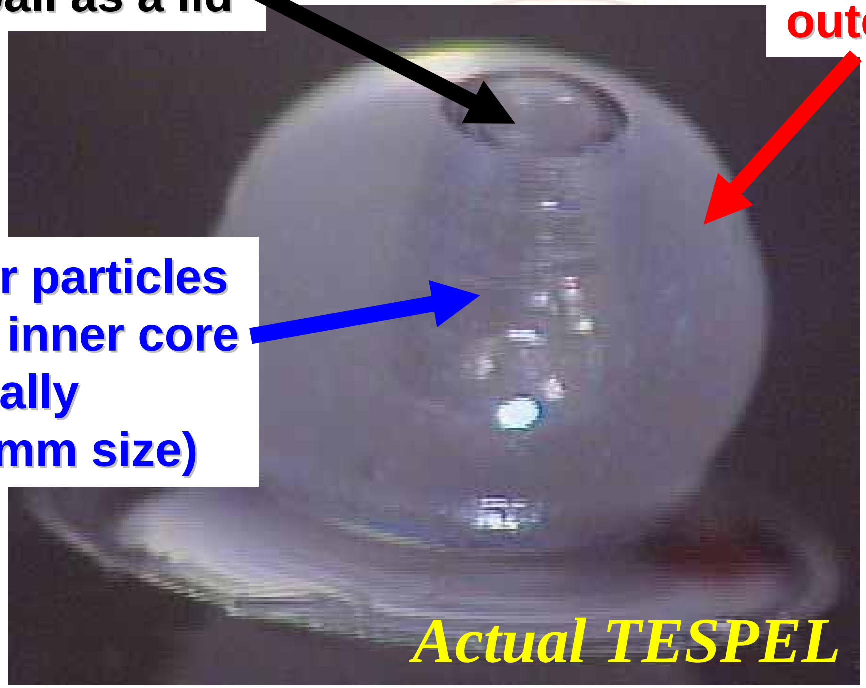
I. Overview of LHD diagnostics

- ✓ **Standard diagnostics for operation and physics study such as FIR and Thomson scatt. are working routinely.**
- ✓ **Advanced diagnostics are being developed with collaboration.**



Here is TESPEL!

II. Tracer-Encapsulated Solid PELlet (TESPEL)
A) Introduction

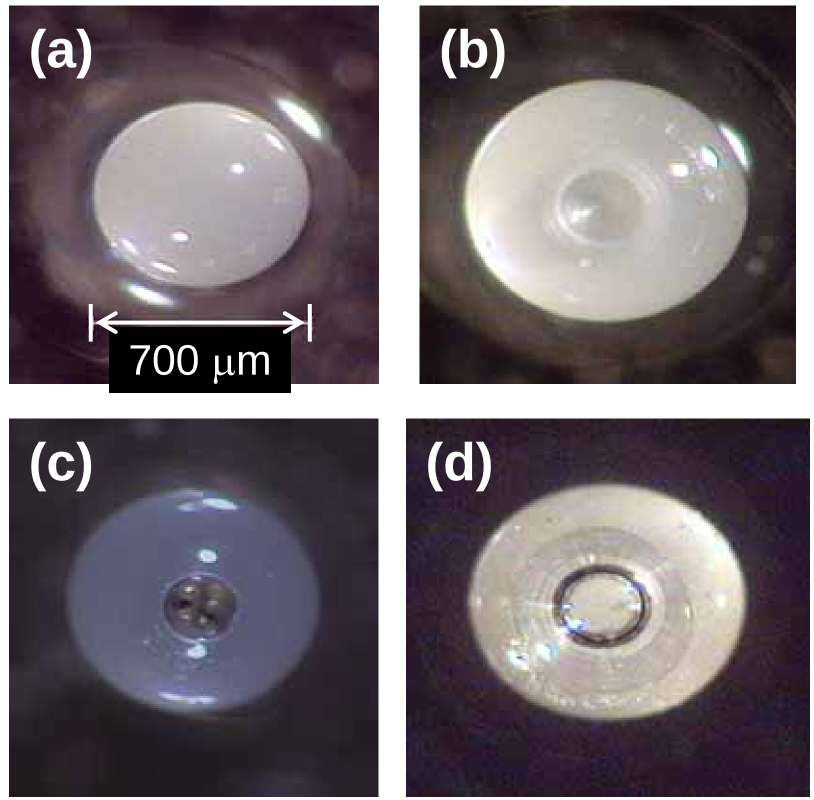


Special features of TESPEL

1. TESPEL can make a **both poloidally and toroidally isolated impurity particle source** as tracer.
2. **Total quantity** of the injected tracer particles **can be identified precisely**.
3. Relatively **wide selection of the tracer material** is possible.

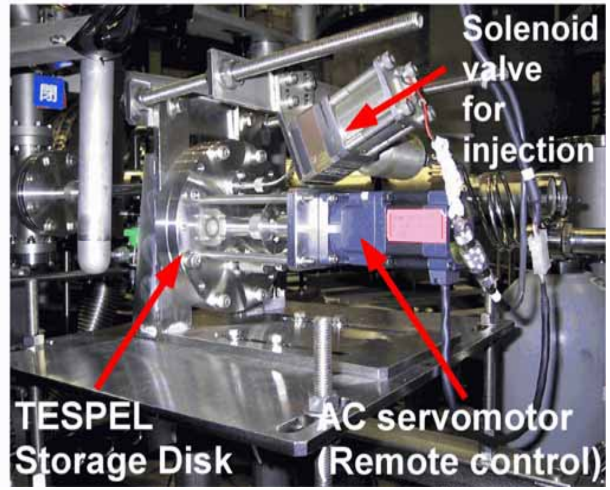
II. A) Recipe of TESPEL

1. **Polystyrene ball (ICF spin-off from Osaka Univ.) (a) was drilled with a micro-drill (b)**
2. **Tracer particles were stuffed into the hole (c)**
3. **Small polystyrene ball was stuffed into the hole as a lid (d)**

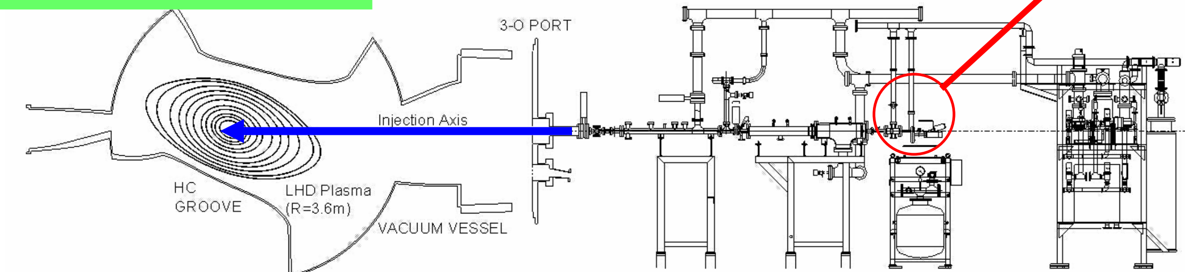


II. A) TESPEL injector on LHD

- ✓ **Pneumatic pipe gun method is used.**
  - **Barrel diameter : 1.0 mm**
  - **Acceleration gas pressure : 6 - 30 atm**
  - **TESPEL velocity : 200 - 500 m/s**
    - **Depend on the TESPEL diameter**
- ✓ **Up to 59 TESPELs can be loaded in the TESPEL magazine.**

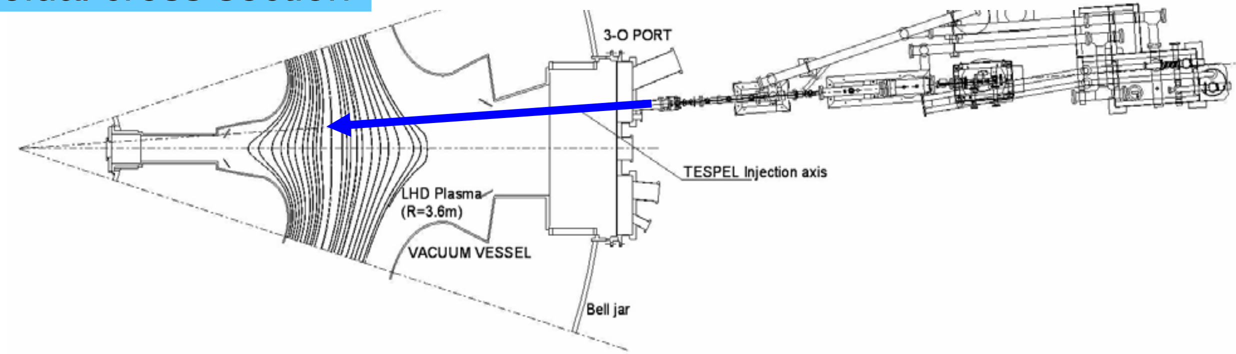


Poloidal cross section



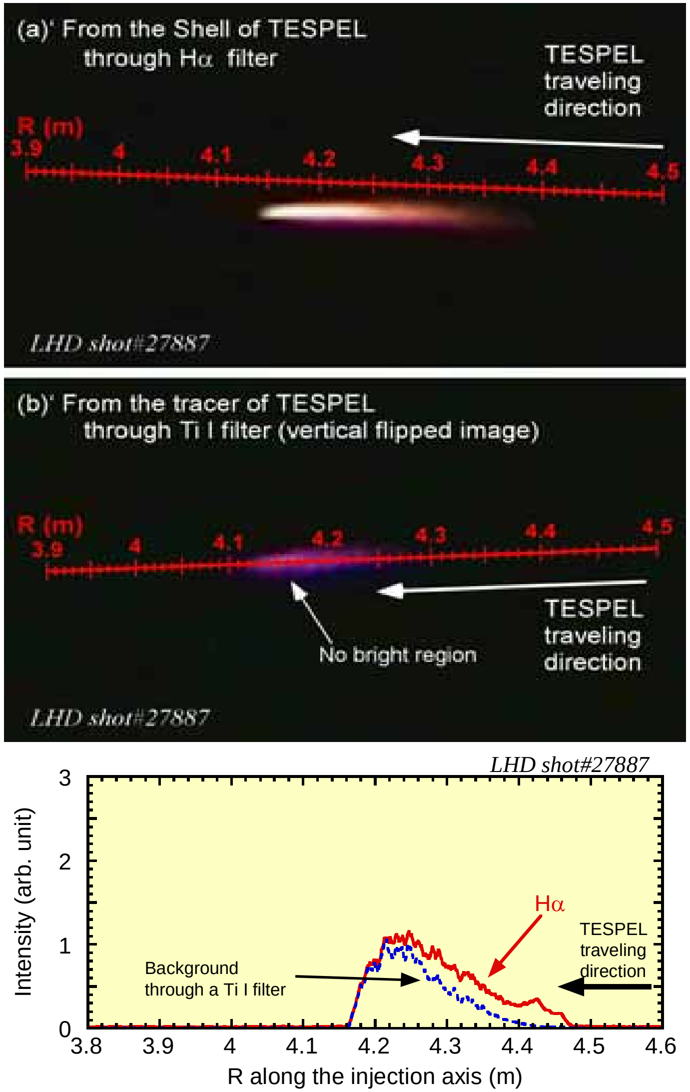
TESPEL injector with the differential pumping system

Toroidal cross section

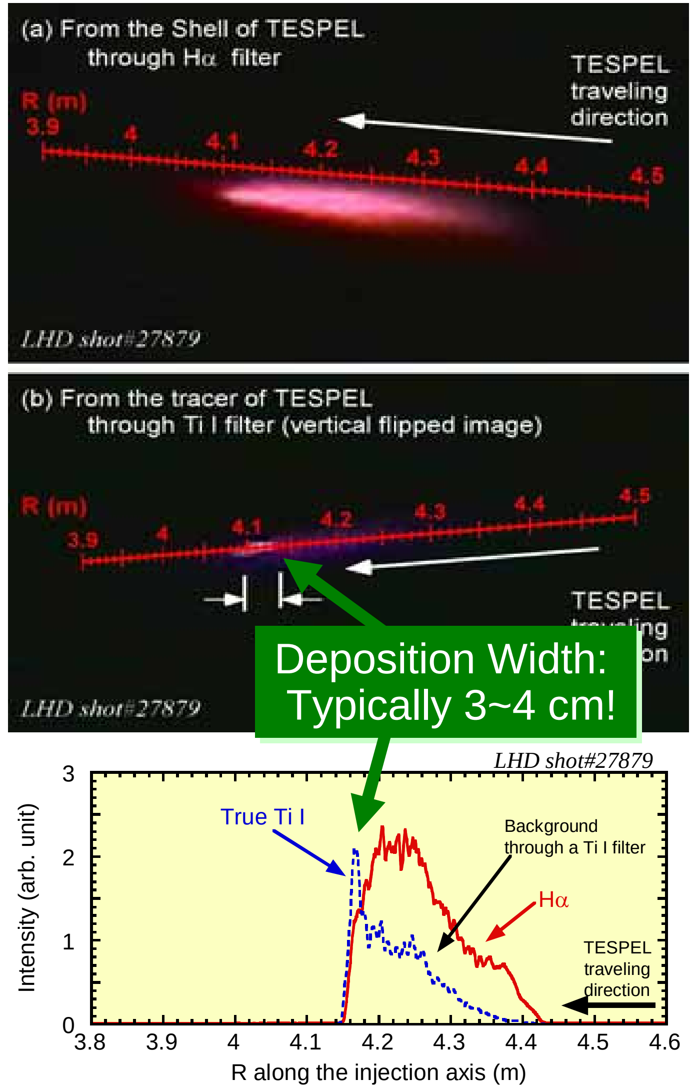


II. A) Local deposition of the tracer particles owing to the TESPEL method

TESPEL W/O Ti tracer



TESPEL WITH Ti tracer



II. B) Spectra of line emissions from the ablation cloud of TESPEL

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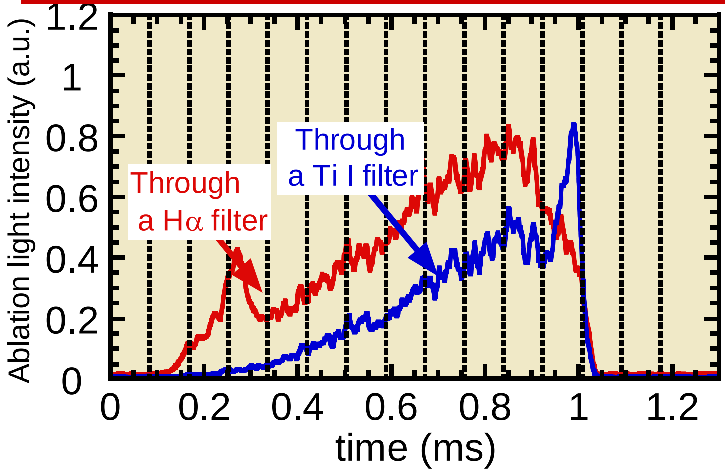
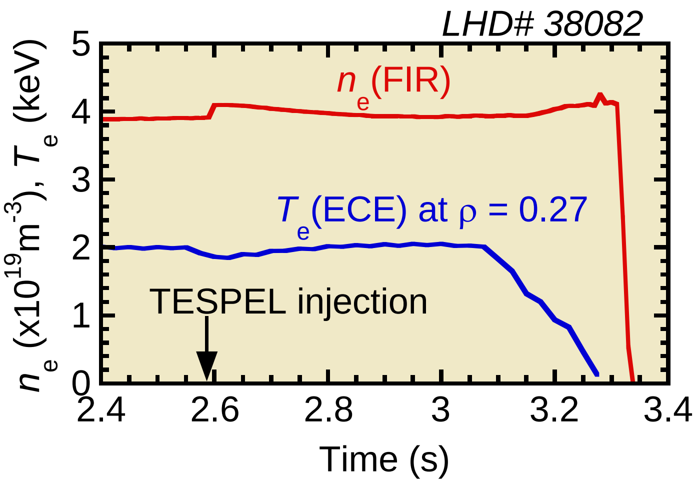
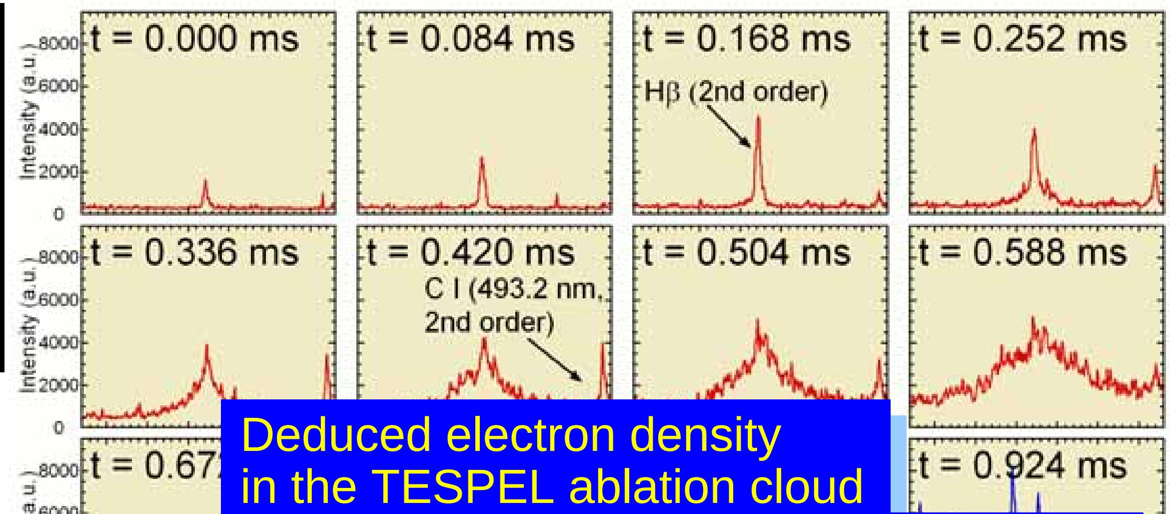
Photomultiplier + Interference filter



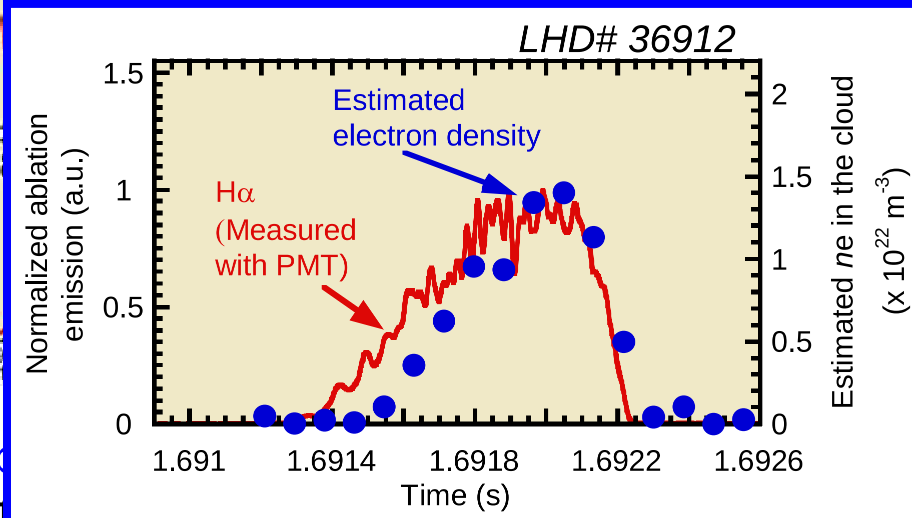
n_e, T_e response to the TESPEL injection



fast Intensified CCD Visible + spectrometer



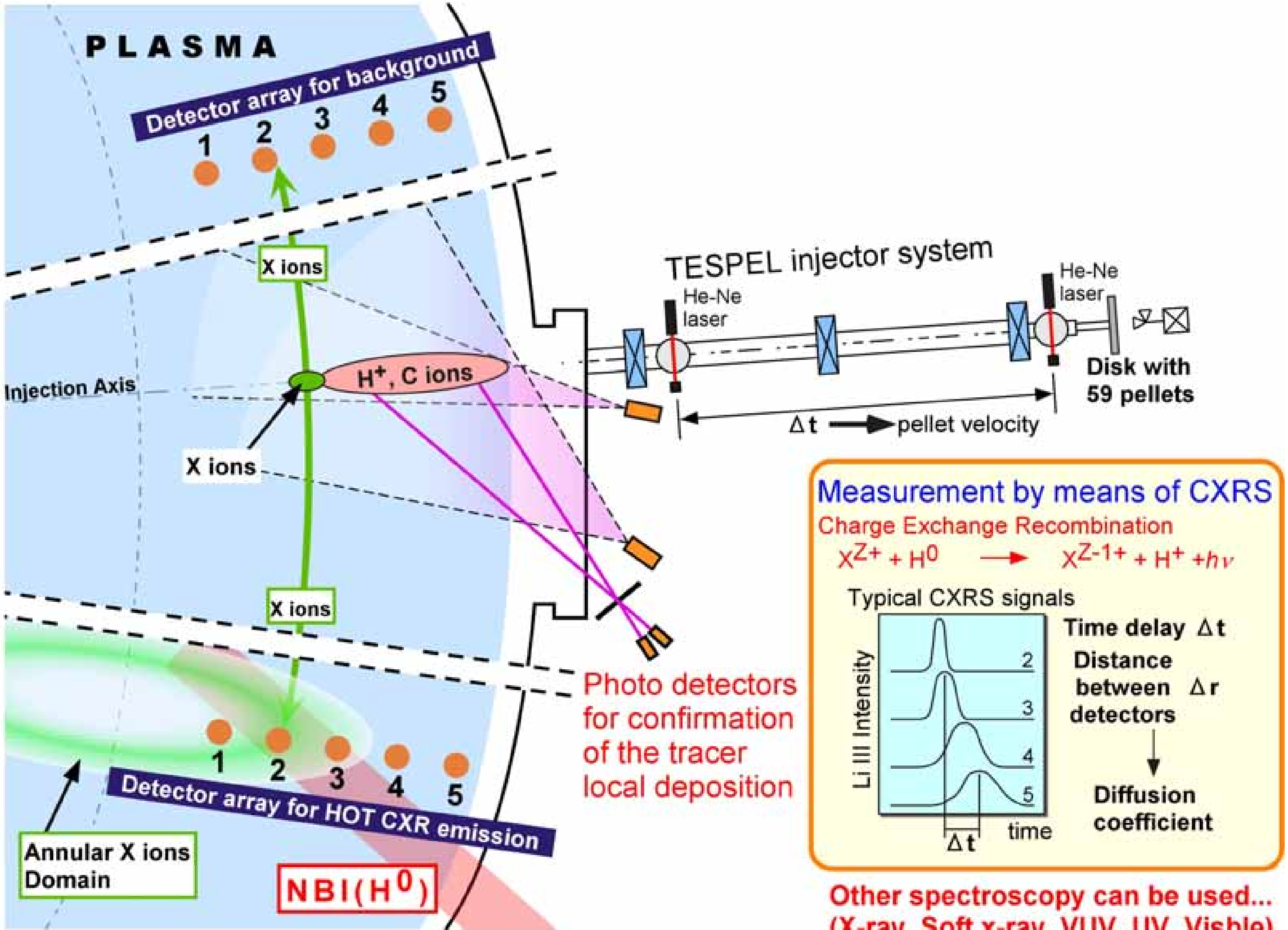
Deduced electron density in the TESPEL ablation cloud



Stark b

→ Elec

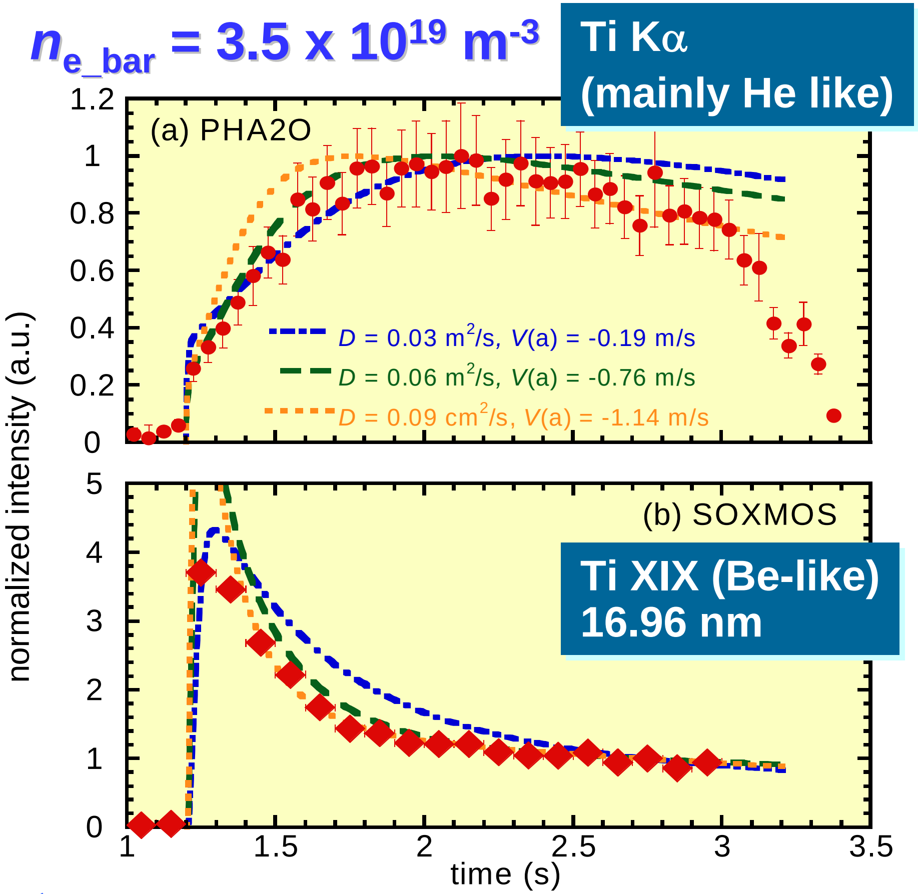
II. C) Schematic of diagnostic for impurity transport study by means of the TESPEL injection



Other spectroscopy can be used...
(X-ray, Soft x-ray, VUV, UV, Visble)

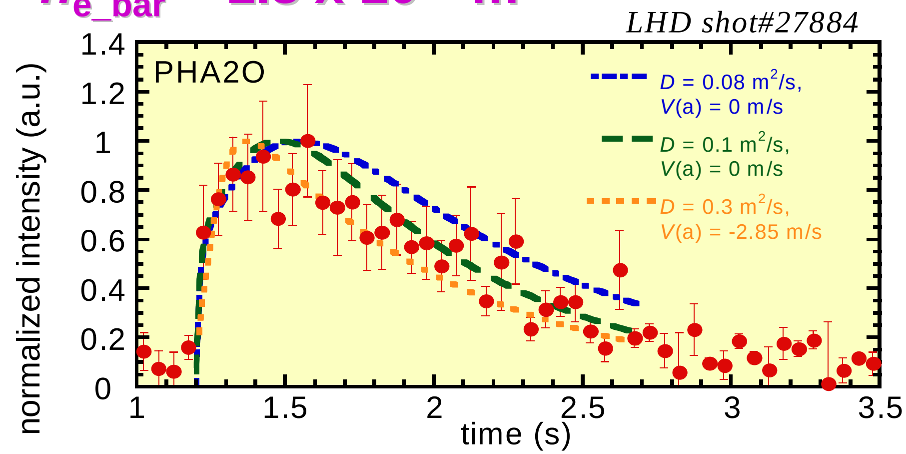
II. C) Impurity transport study with TESPEL injection
1. Basic transport properties in LHD plasmas

n_{e_bar} = 3.5 x 10^{19} m^{-3}



- ✓These temporal behaviors are analyzed with a time dependent MIST code.
- ✓***D* = 0.06 m²/s and inward convection velocity of *V*(a) = 0.8 m/s** fit well with the data of n_{e_bar} = 3.5 x 10^{19} m^{-3}.

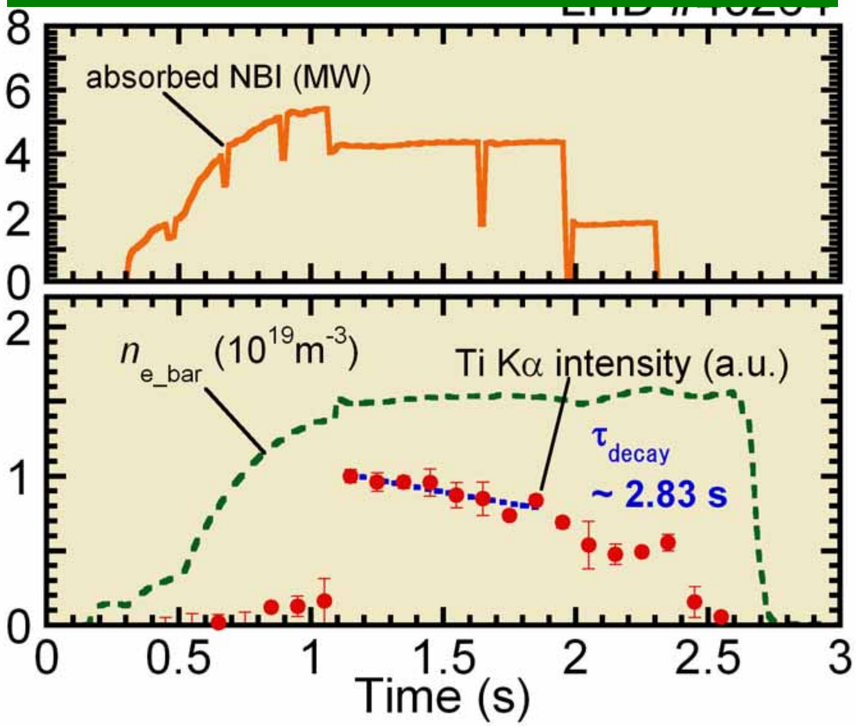
n_{e_bar} = 1.8 x 10^{19} m^{-3}



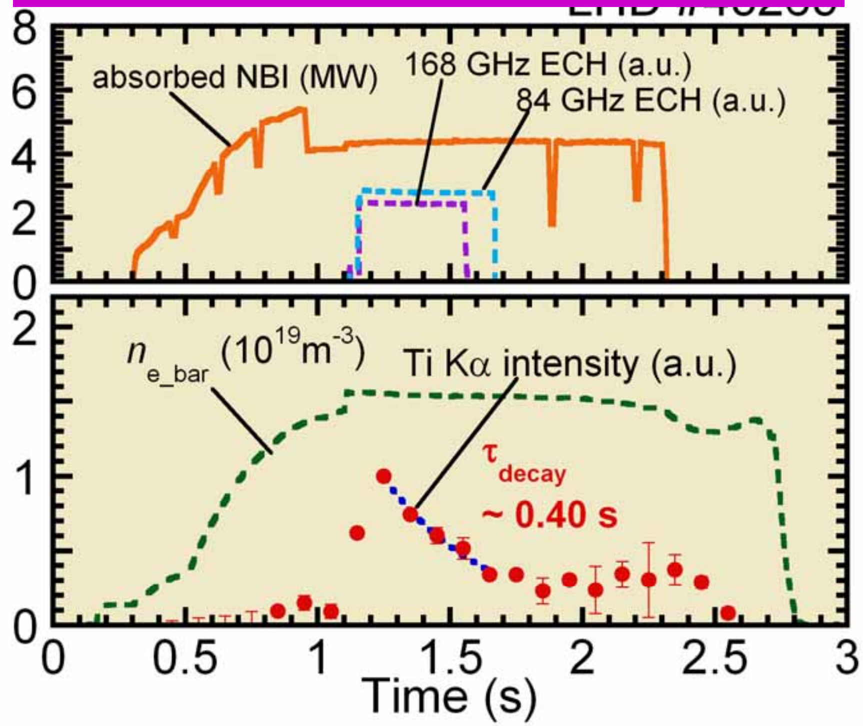
- ✓Decay of Ti Kα for the lower density is faster than that in the higher density case.
- ✓***D* = 0.1 m²/s, *V* = 0 m/s** agree well with the experimental results.
- ✓*D*s obtained experimentally are larger than the neoclassical ones. This discrepancy reduces in the higher density.

II. C) Impurity transport study with TESPEL injection
2. ECH effect on the temporal evolution of Ti Kα emission

w/o ECH



with ECH

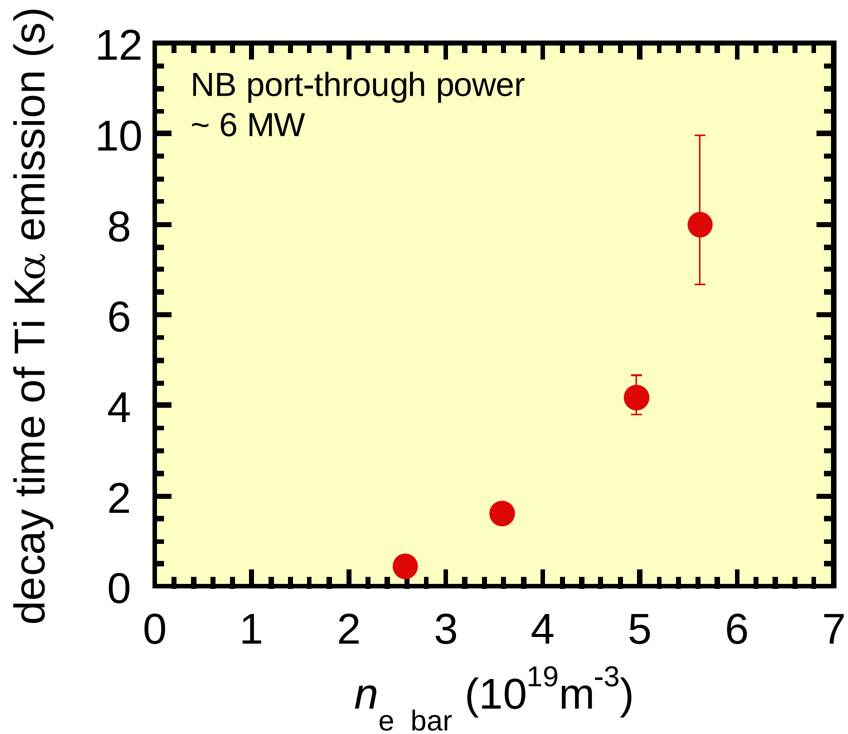


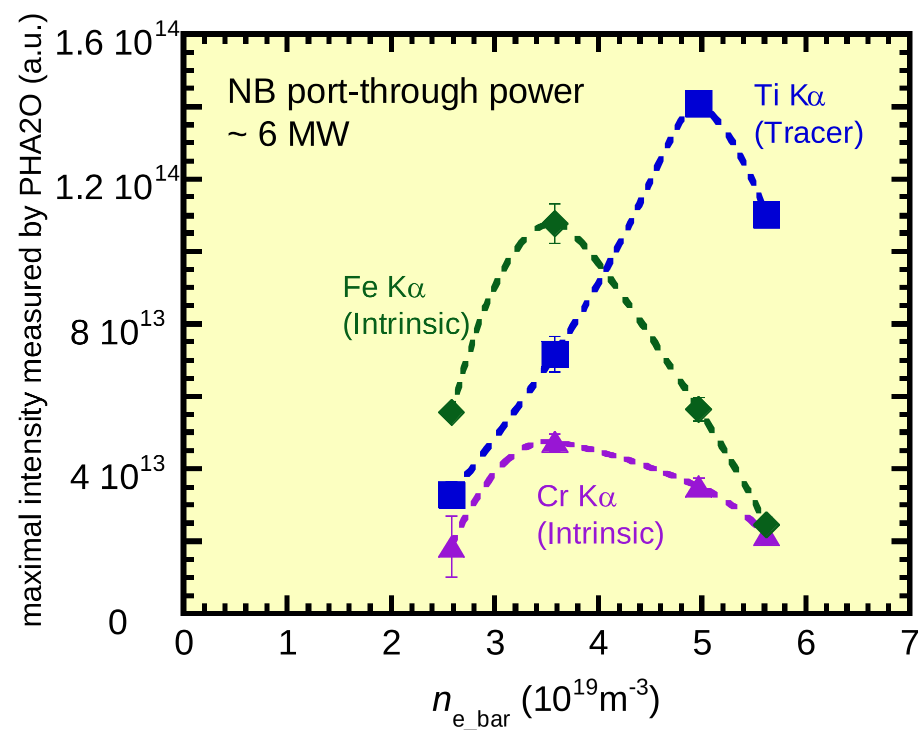
TESPEL injection time: ~ 1.1 s

- ✓ **A clear decrease of signal intensity for the Ti Kα emissions was observed for the case of the ECH pulse (~1.1 MW power).**
- ✓ **The decay time of the Ti Kα emissions decreases by a factor of 7 in the phase of the ECH pulse.**

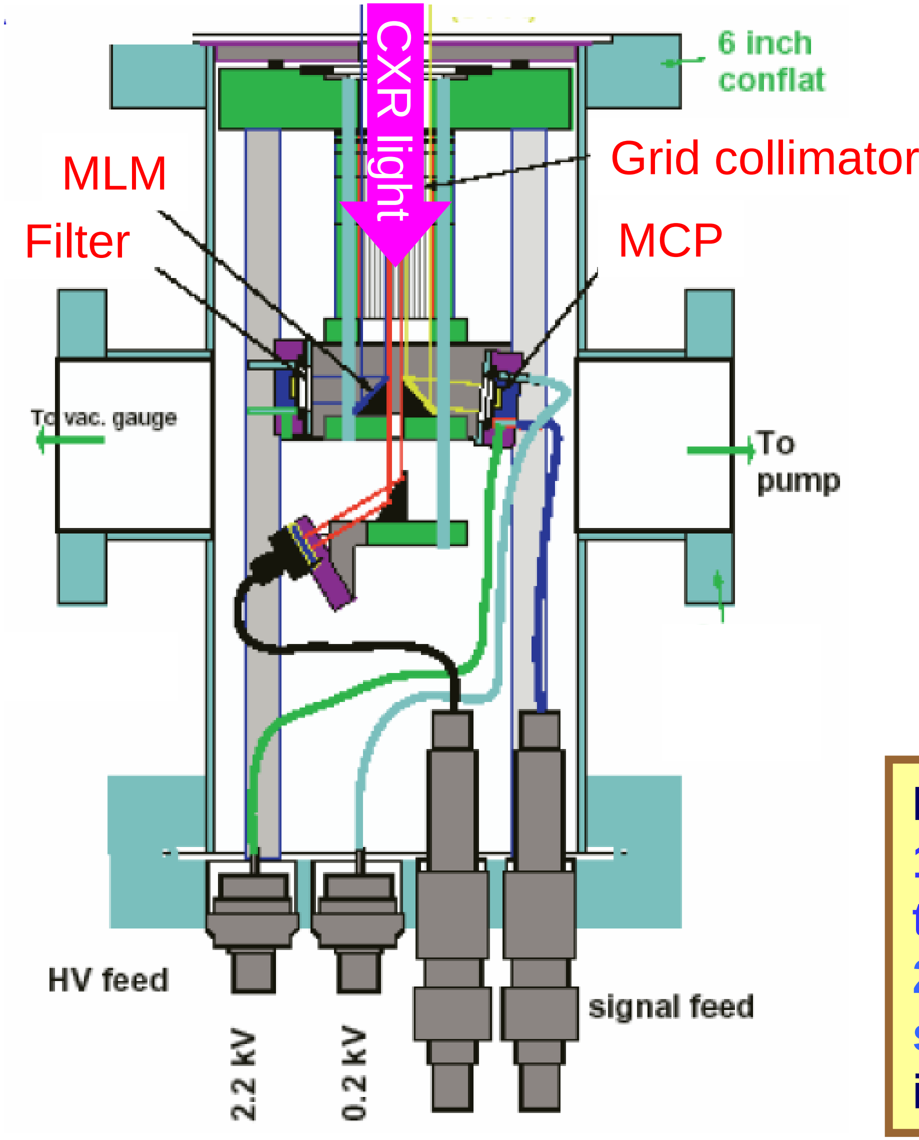
In the high-density case,

- ✓ Tracer impurity, Ti, deposited inside the plasma (r/a < 0.8) shows the accumulation.
- ✓ Intrinsic impurities (Fe, Cr) were diffused out from the plasma.
- ✓ Therefore this experimental result suggests that **the pumping out mechanism of the impurities exist on the periphery of the plasma (r/a > 0.8).**





4. Collaboration between NIFS and JHU



System features

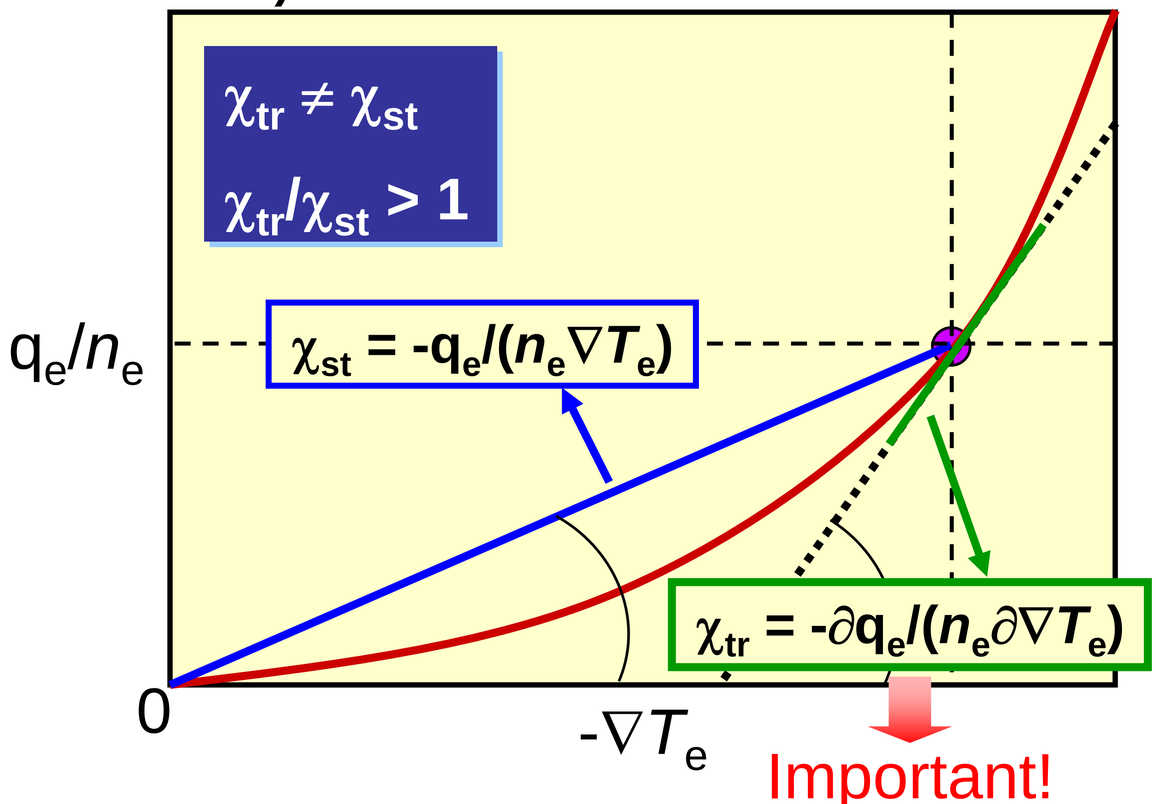
1. High throughput together with few cm radial resolution by **toroidally aligned grid collimator**
2. A few Å spectral bandpass together with strong background rejection by **planar multilayer mirrors (MLMs) and foil filters**

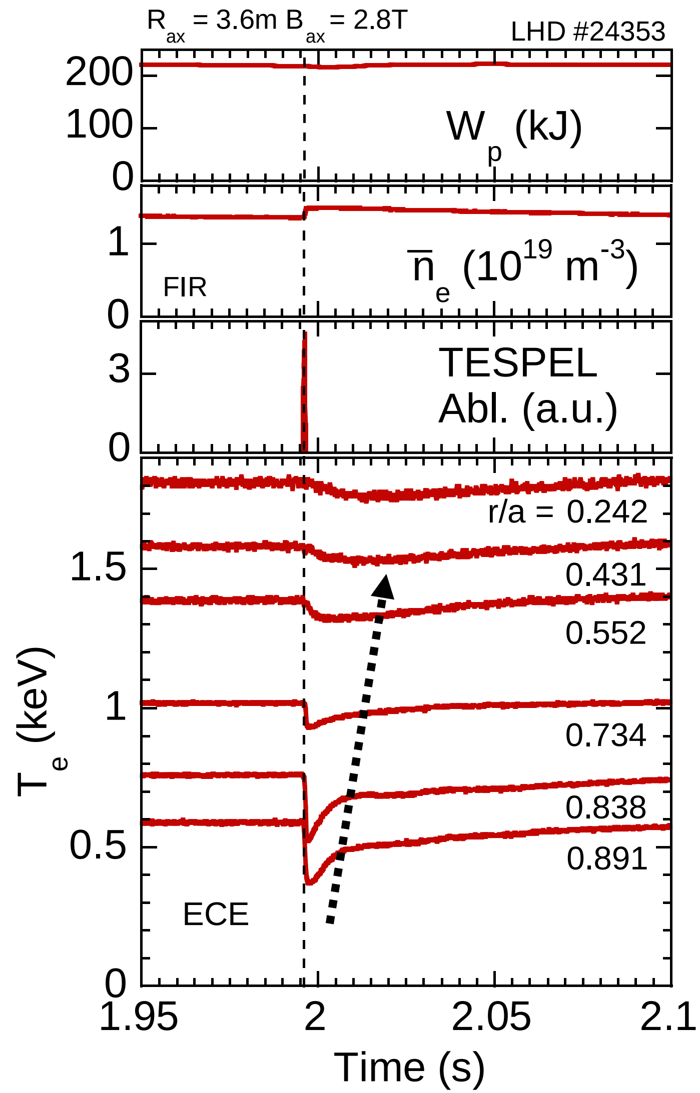
Experimental result for Mg XII at 4.5 nm

Background measurement
1) with a channel at a different toroidal location w/o NBI
2) with a shot w/o NBI at the same location w/o NBI
is highly required.

II. D) Electron heat transport study with cold pulse propagation induced by the TESPEL injection

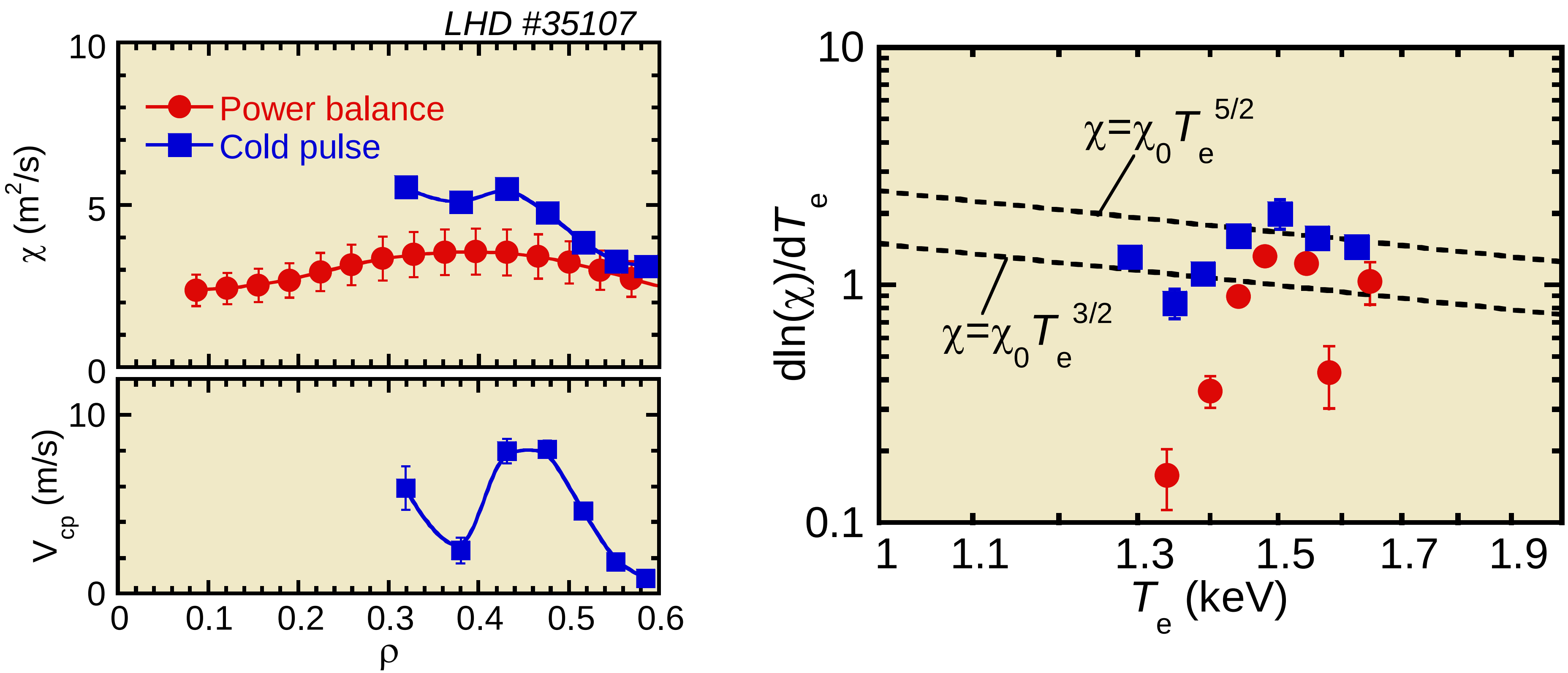
- ✓**Transient analysis technique is very powerful tool for the study of the non-linearity of the heat transport.**
- ✓**Owing to the flexibility of the size and tracer material, the TESPEL can make appropriately a negative *T*e perturbation in the plasma (r/a = 0.5 ~ 0.7).**





II. D) Cold pulse experiment in typical NBI plasma of the LHD

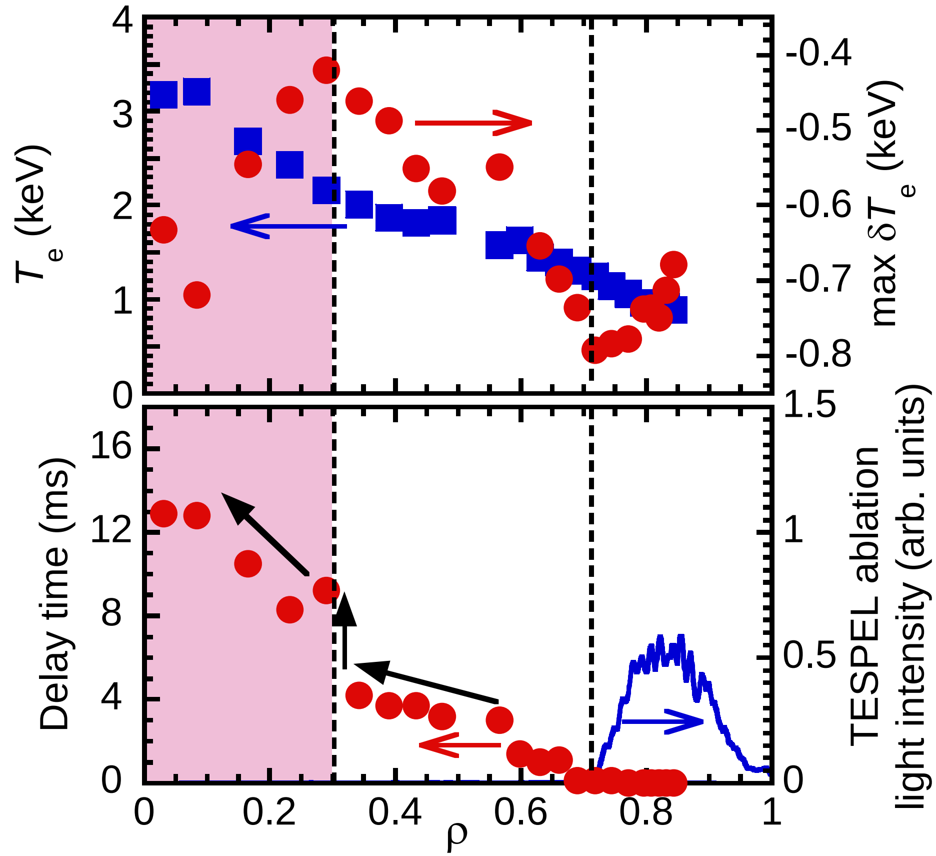
- ✓In typical NBI plasma (P_{NBI} = 2~3 MW), $\chi_{transient}/\chi_{power\ balance}$ = 1~2 is obtained. → **weak ∇T_e dependence**
- ✓**Outward flow is necessary** to explain the analysis result from the cold pulse propagation.
- ✓Gyro-Bohm like dependence doesn't conflict with the experimental results.

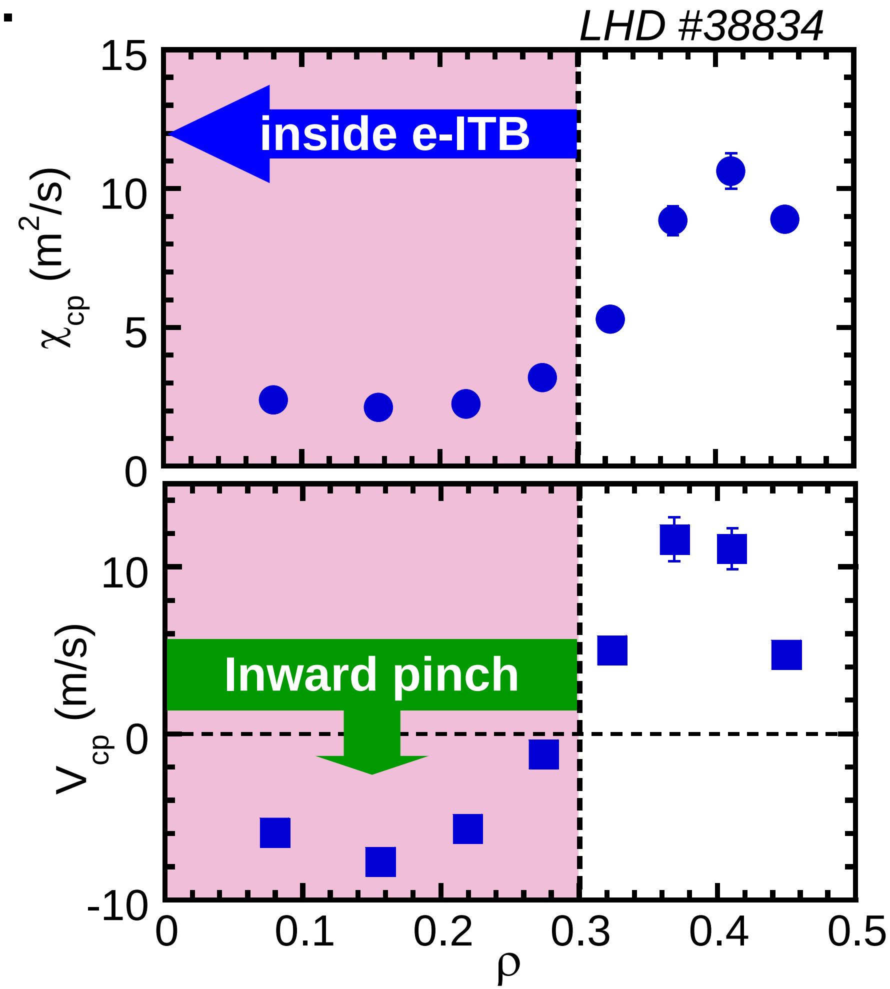


II. D) Cold pulse experiment in LHD plasma with an electron internal transport barrier (e-ITB)

✓Heat transport changes significantly at the barrier (r/a ~ 0.3).

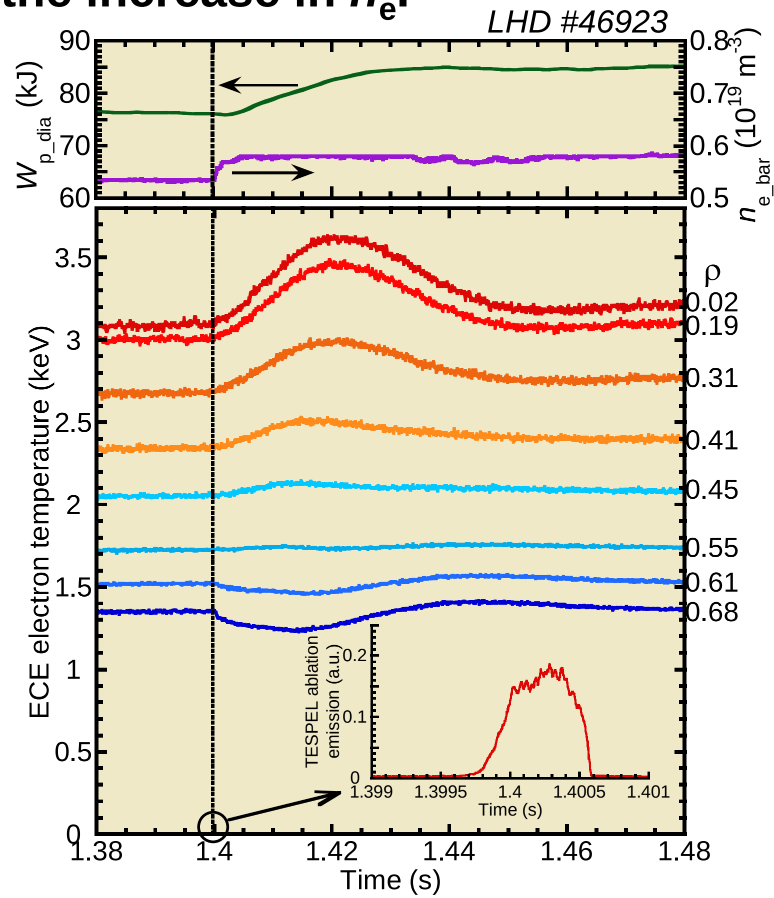
✓Reduced χ_e and heat pinch are observed.

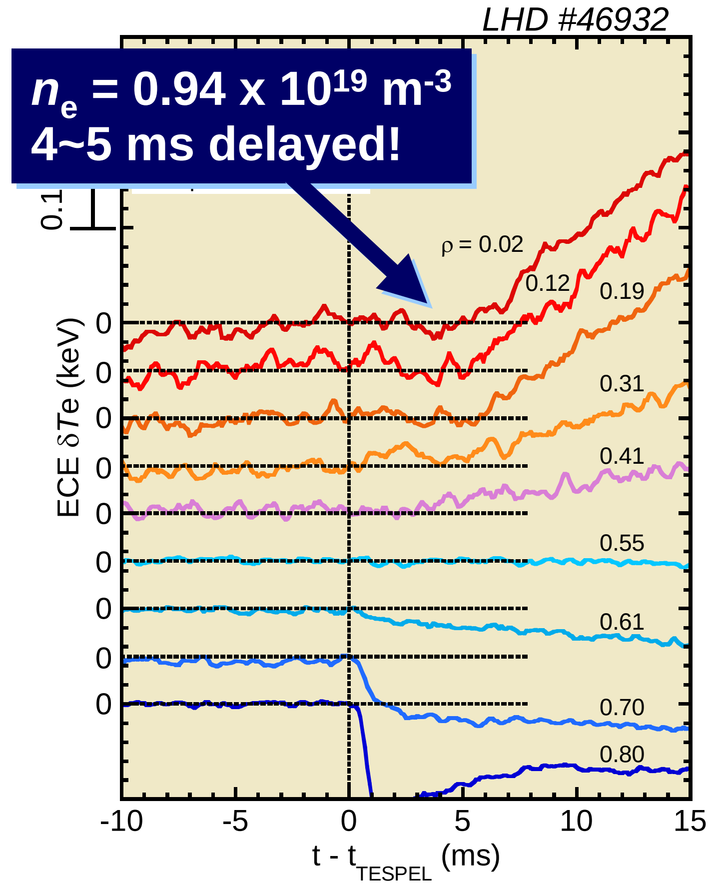




II. D) First observation of the inversion of the T_e perturbation polarity in toroidal helical plasma

- ✓Core T_e ($\rho < 0.45$) begins to rise almost at the time (less than 1 ms) of the TESPEL penetration into the LHD plasma.
- ✓No appreciable excitation of low-*m* MHD modes is observed.
- ✓Response time of core T_e to the edge cooling tends to be delayed with the increase in n_e.





II. D) Reduced heat transport inside magnetic island O point is observed

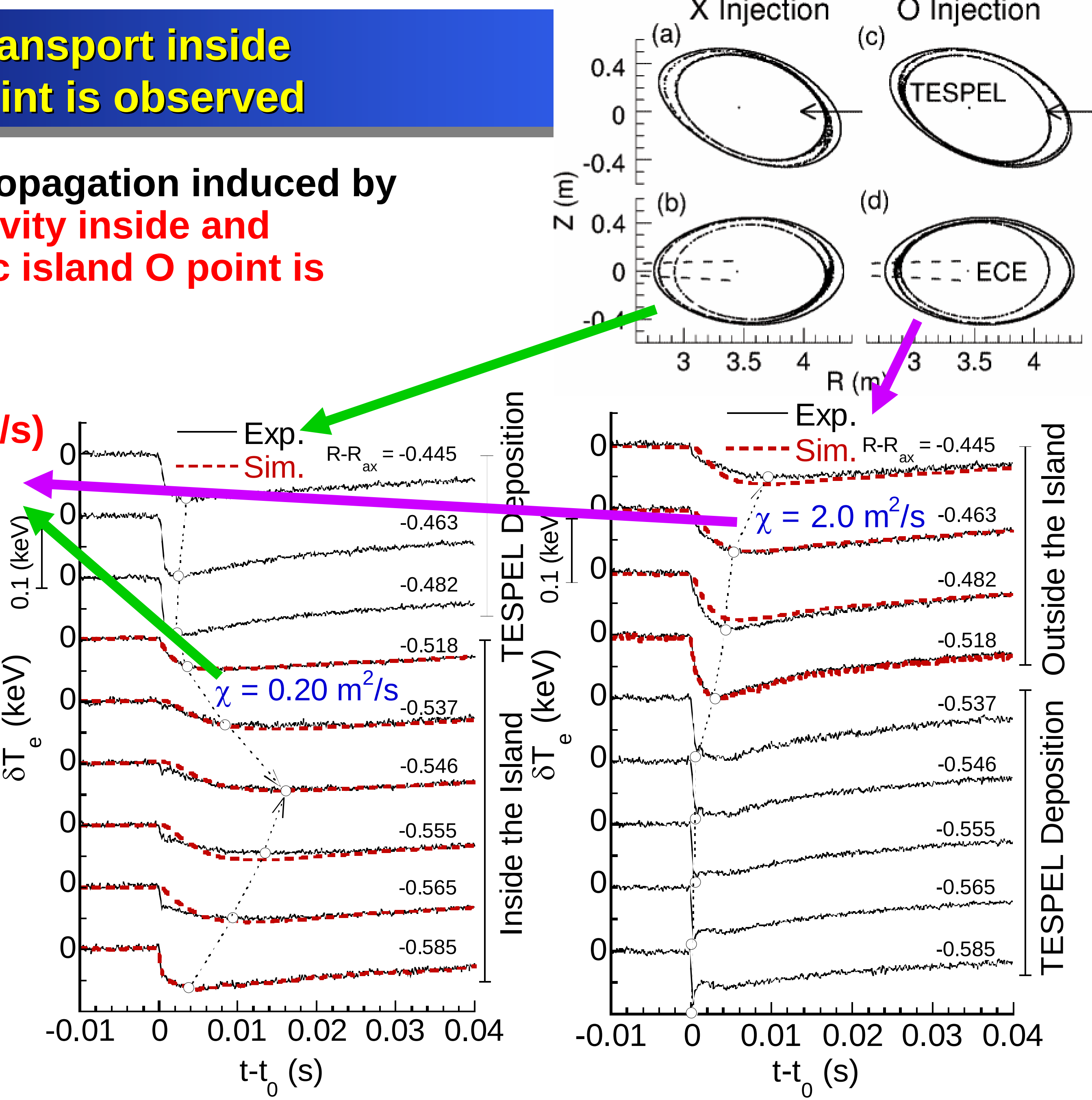
✓From the cold pulse propagation induced by TESPEL, **heat conductivity inside and outside of the magnetic island O point is measured.**

Heat diffusivity in the island O point (χ_e=0.2 m²/s) is lower than that in the main plasma (χ_e=2 m²/s)

✓***R* is the major radius.**

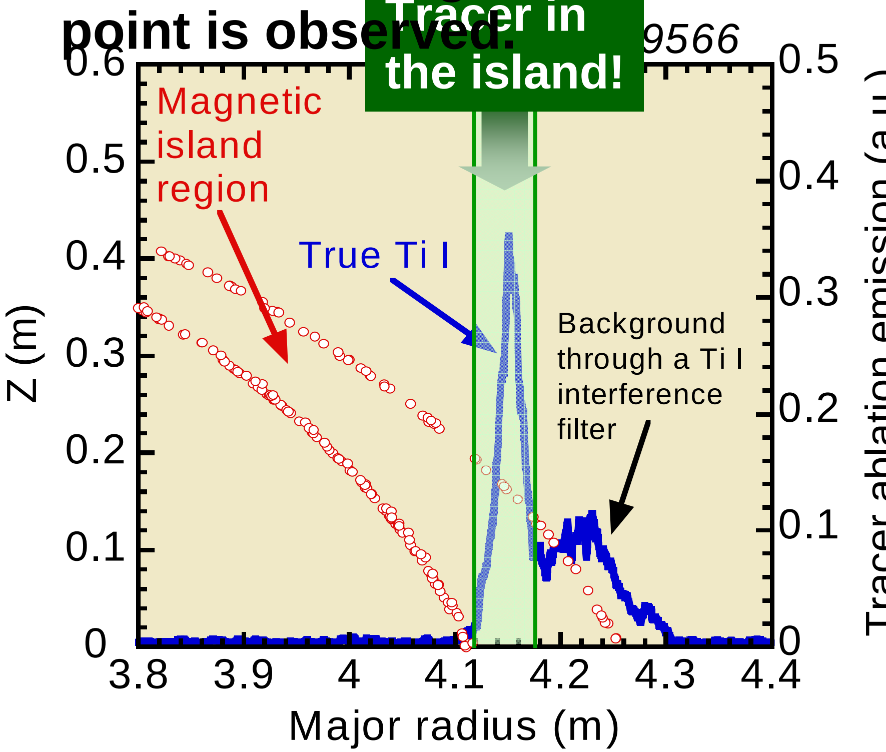
✓**Last closed magnetic surface is at *R* - R_{ax} = -0.7 m.**

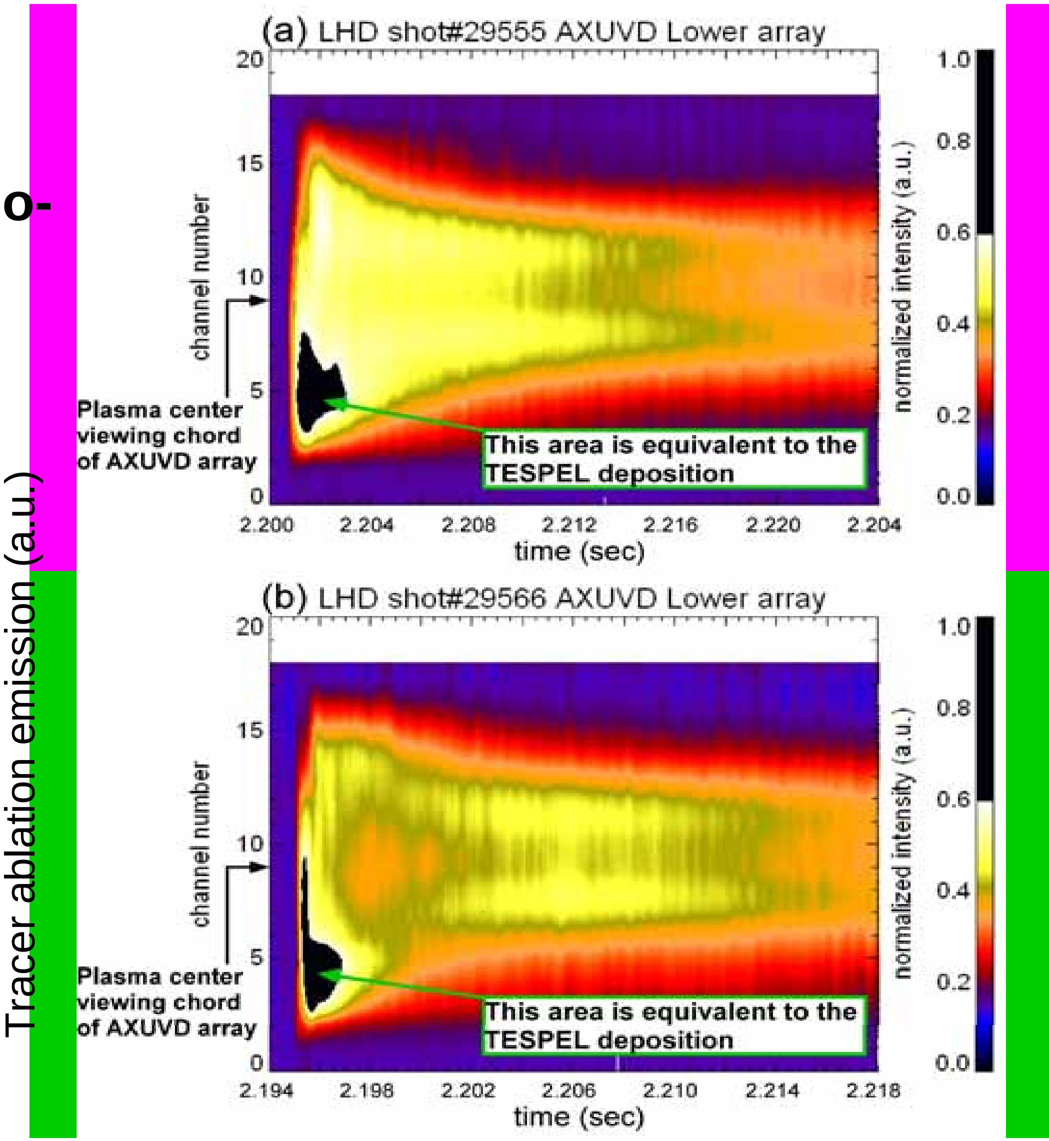
✓**ECE receiving antenna is mounted at the inboard side of LHD, meanwhile a TESPEL is injected from the outboard side of that.**



II. E) Feature of particle flow inside magnetic island is different from that outside the island

- ✓ **Tracer particle is deposited inside the magnetic island O point by TESPEL method.**
- ✓ **Apparent difference of the spatio-temporal behavior of the tracer deposited between inside and outside the magnetic island O point is observed.**





Summary

- ✓ **Diagnostics using a TESPEL technique can investigates many important issues in regard to impurity transport**
  - **Properties in the core and edge region**
  - **Properties inside the magnetic island**

- ✓ **From the tracking of the cold pulse propagation due to TESPEL injection, heat diffusivity was estimated. Moreover the remarkable difference of the heat diffusivity inside and outside the magnetic island was observed.**

- ✓ **Other important issues such as transport study of high energy particle (HEP) are also investigated with the TESPEL technique**
  - **Active HEP study with pellet charge exchange method**

TESPEL technique have unlimited potential to diagnose magnetically confined plasma properties