Experimental analysis of density peaking in KSTAR plasma

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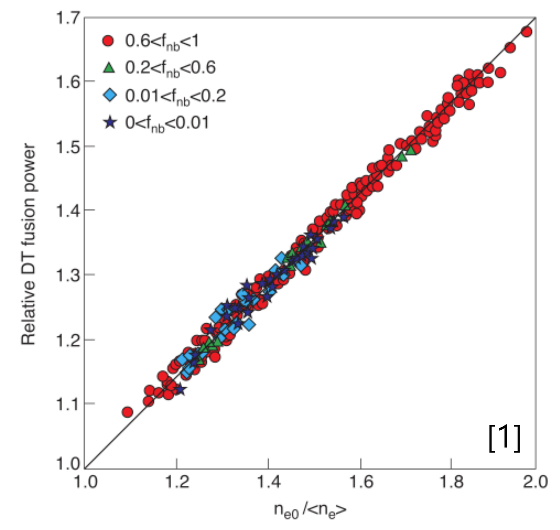
Introduction

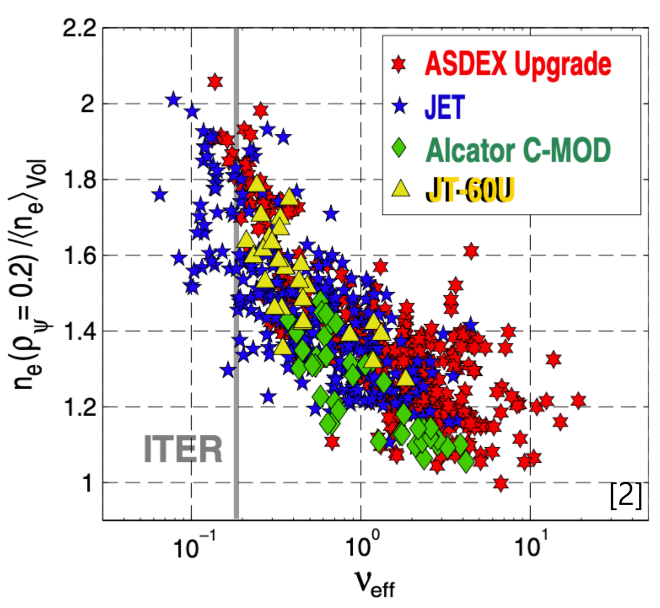
Significance of the study



- Predictions of density peaking are essential due to the strong dependency of fusion power and bootstrap current on the density profile.

✓ *Relative fusion power increase as a function of density peaking, together with the whole range of density profiles observed in JET H-modes [1].*

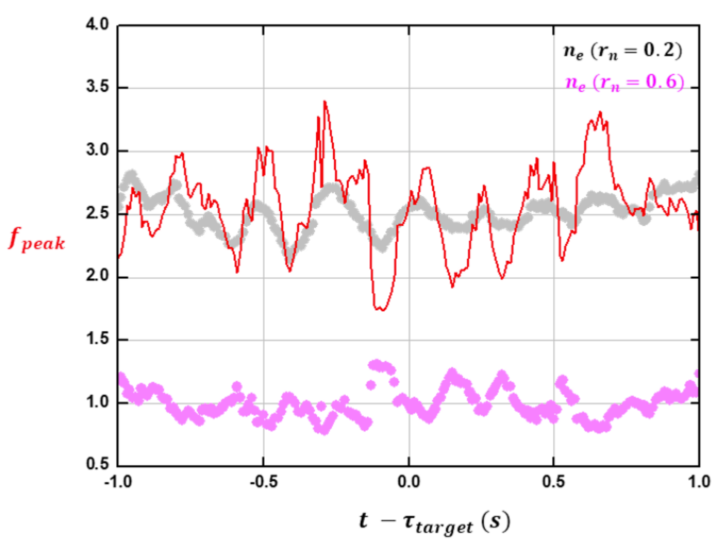
Previous studies found the trend of density peaking



- Previous studies found the inverse proportional trend of density peaking in terms of the effective collision frequency, through experimental observations in ASDEX Upgrade [3, 4], JET [5, 6], Alcator C-MOD [7] and JT-60U [8].
- From this studies, ITER plasmas are expected to have peaked density profiles.
- In this study, we attempted to reproduce the inverse-proportional trend of the multi-devices in KSTAR experiments with interpretative simulations for more rigorous understanding.

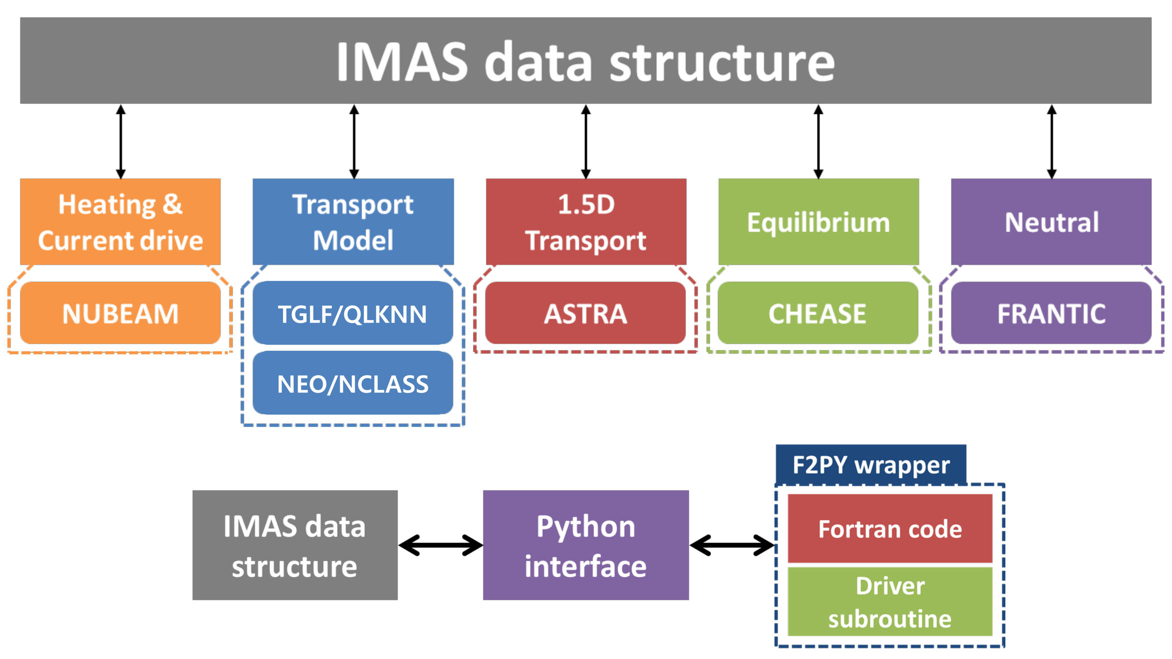
Methods

KSTAR database for analysis of density peaking



- Various parameters are needed :
  - n_e and T_e from Thomson
  - T_i and V_{tor} from CES
  - engineering parameters from PCS-KSTAR
- For selecting the representative value of peaking factor, averaged Thomson data is used and the target time is chosen without MHD instabilities.

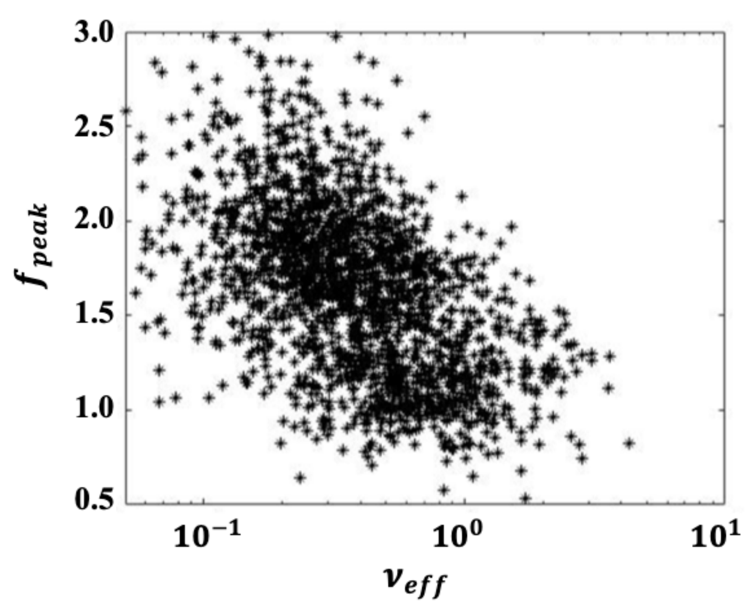
Integrated simulator, TRIASSIC



- Physics values were calculated from experimental engineering parameters through integrated simulator, TRIASSIC [9].
- This suite has various modules of core transport solver such as ASTRA and C2, equilibrium solver such as CHEASE, transport model such as TGLF, NEO, NCLASS and H&CD model such as NUBEAM, TORAY and CURRAY.
- Source distribution of NBI could be obtained from TRIASSIC in this study

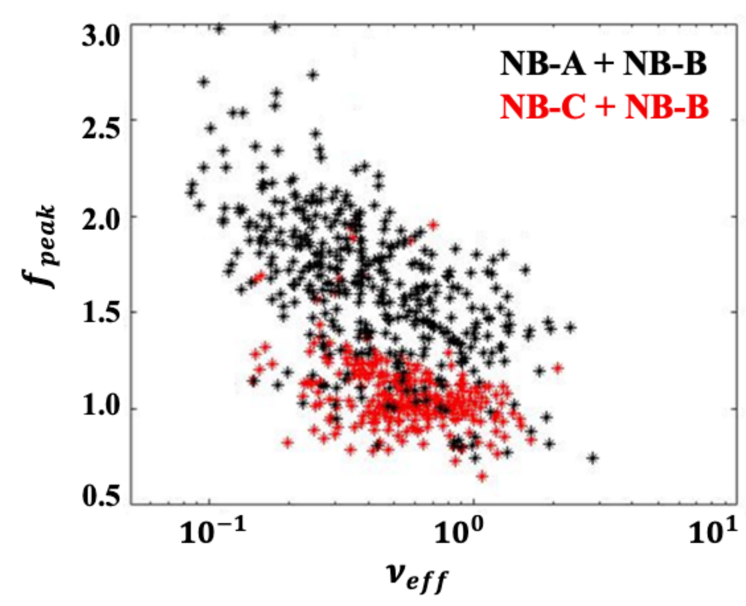
Results

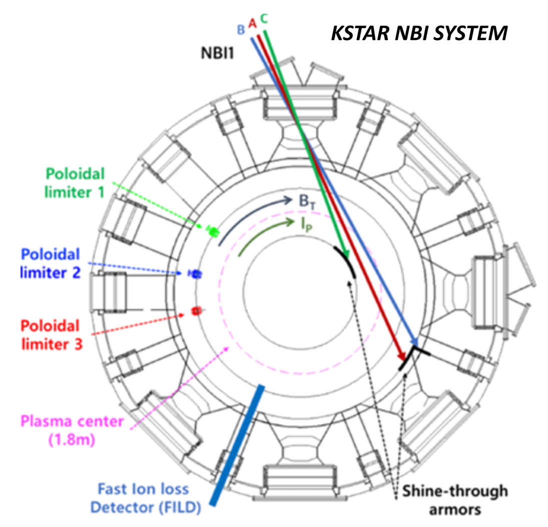
Reproducing of the previous results



- Previous study [2] showed that density peaking is inverse proportional to the effective collision frequency, where $\nu_{eff} \equiv \nu_{ei}/\omega_{DE} \sim 2Z_{eff} < n_e > / < T_e >^2$
- From KSTAR experiments database, this previous observation was successfully reproduced.
- Comparing with the results of other devices, it has broader scatter. All kinds of KSTAR discharges are plotted, while typical H-modes are plotted in the previous studies

Distinct deviation of the trend





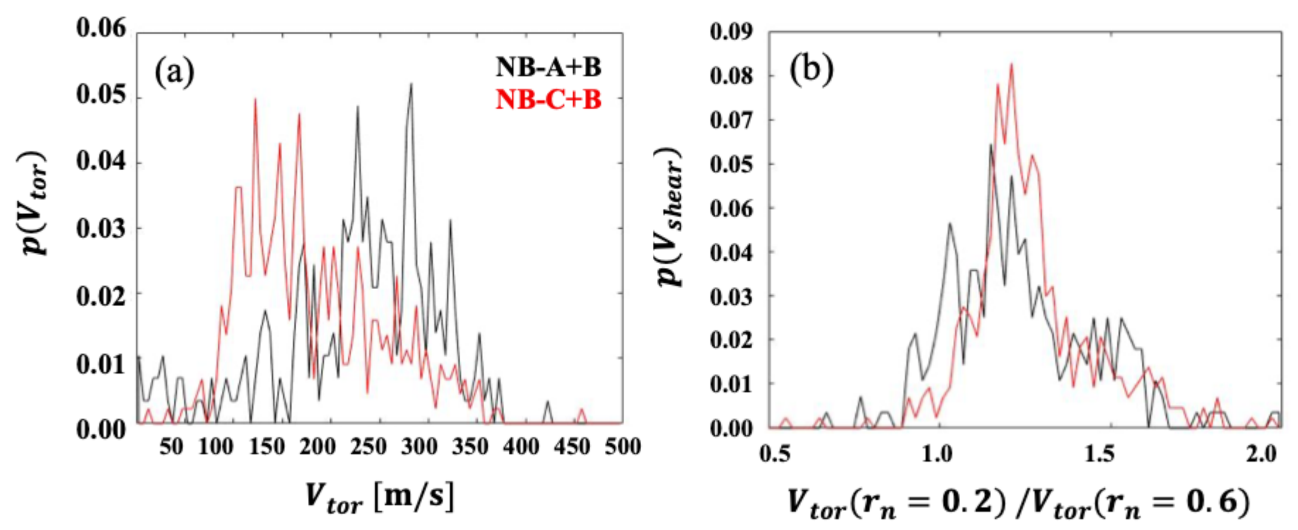
- A distinct deviation of the inverse proportional trend has been identified for discharges with *NB-C* and *NB-B* in 2018 year
- KSTAR has three beam *A*, *B*, and *C*. Among three beams, *NB-C* is the most perpendicular and absorption length is the shortest
- Comparing with discharges with *NB-A/B*, density profile of discharge with *NB-C/B* is less peaked in the same effective collision frequency.
- However, the inverse proportional trend between density peaking and effective collision frequency is kept though the degree of inverse proportion is decreased.

Discussion

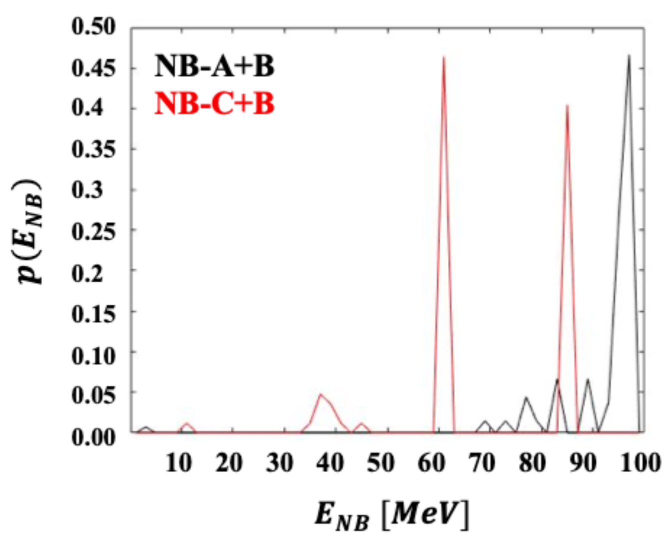
- Density peaking factor is decided by the balance of diffusion, particle pinch, source, and loss in the particle transport. The candidate reasons of the trend deviation are particle pinch and source as there's no significant difference in loss mechanism.
  - particle pinch : As neoclassical pinch is negligible in low collisionality plasma, anomalous pinch is main effect in particle pinch section.
  - source : As the difference of NB combination make the trend deviation, different NB source distribution could be a good ostensible reason.

Anomalous pinch effect

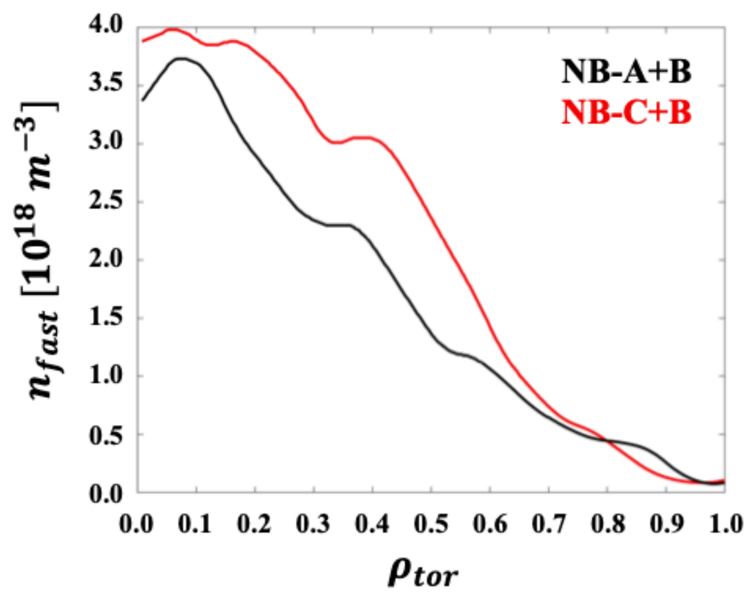
- Inward pinch driven by ITG turbulence can be decreased by stabilizing through $E \times B$ shearing [11] and fast ions [12]



- As *NB-C* is the most perpendicular beam, it can be expected that discharges with *NB-C/B* have lower toroidal velocity.
- However, the important thing to stabilize turbulence is not the value of velocity but shear of velocity. As the shear is similar, it would be hard to say the rotation shear is main cause of deviation.
- In low density condition, lower beam energy could increase the cross-section and absorption rate, which make n_{fast} increase.
- However, the simulation of fast particle is essential to confirm this hypothesis.



Source effect



- For source modeling, the reference discharges are chosen with same condition such as $\nu_{eff}\sim0.46, q_{95}\sim5.0$, $\overline{n_e}\sim5.25\times10^{19}\ [m^{-3}]$ and $P_{NB}\sim2.9\ [MW]$.
  - #21571 : ref. discharge with *NB-A/B*
  - #20949 : ref. discharge with *NB-C/B*
- Density peaking factor is 1.469 of #21571 and 1.217 of #20949
- The density profile of fast particle was calculated by using NUBEAM in TRIASSIC.
- The contribution of NB fueling on the density peaking is obvious.
- ITER could be flatter than expected by empirical scaling in the previous studies, because ITER will have low NB fueling.

Conclusion

- The inverse proportional trends of the density peaking in terms of effective collision frequency is reproduced in KSTAR plasma.
- The distinct deviation of the trend has been identified for 2018 KSTAR discharges with *NB-B/C*.
- We supposed the causes of this finding are the stabilizing turbulence effect and source effect.
  - As the rotation shear is similar, it may not be the main cause.
  - We could check recent study about effect of fast ions on density peaking based on KSTAR experiment.
  - NB fueling is identified obviously as cause of the trend deviation by source modeling.
- To classify the exact portion of contribution for each effect, non-linear transport simulation including fast ion is planned as future works.

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