Plasma conditions for edge harmonic oscillation and QH-mode in DIII-D

C.J. Lasnier[†], J.S. deGrassie,[‡] K.H. Burrell,[‡] C.M Greenfield,[‡] E.J. Doyle,[Δ] and the DIII–D team

[†]Lawrence Livermore National Laboratory, Livermore, California

[‡]General Atomics, P.O. Box 85608, San Diego, California 92186-5608

[Δ]University of California, Los Angeles, California

Introduction to QH mode

Definitions

QH-mode: Quiescent H-mode

- **An ELM-free H-mode with density and radiated power control and extended duration**
- **Achieved with strong pumping, counter neutral beams, large outer gap (~10 cm)**

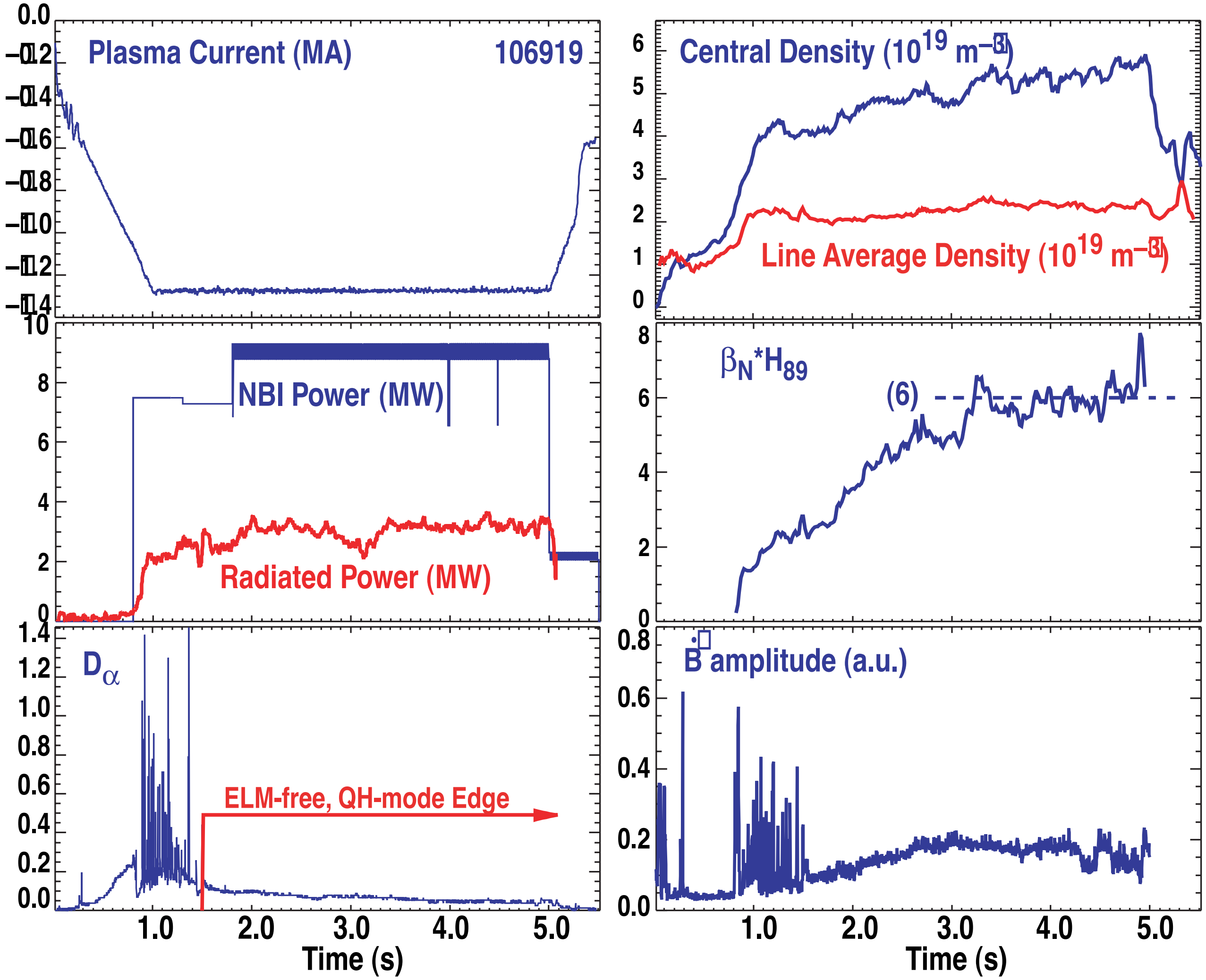
QDB: Quiescent Double Barrier

- **An internal transport barrier (ITB) and a QH-mode edge**

EHO: edge harmonic oscillation

- **A continuous MHD mode usually associated with QH-mode operation**

Sustained ELM-free H-mode operating regime obtained with density and radiated power control



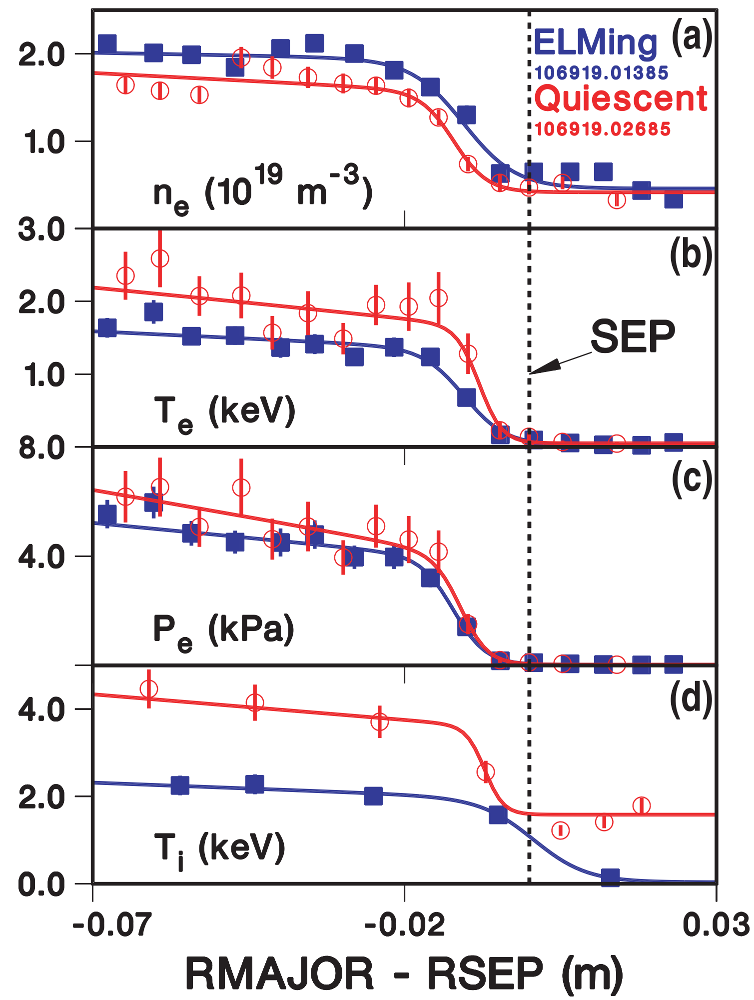
B_T = 2.0 T
q_{95} = 4.45

- Maintains quiescent ELM-free edge for >3.5 s, ~25 τ_E

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

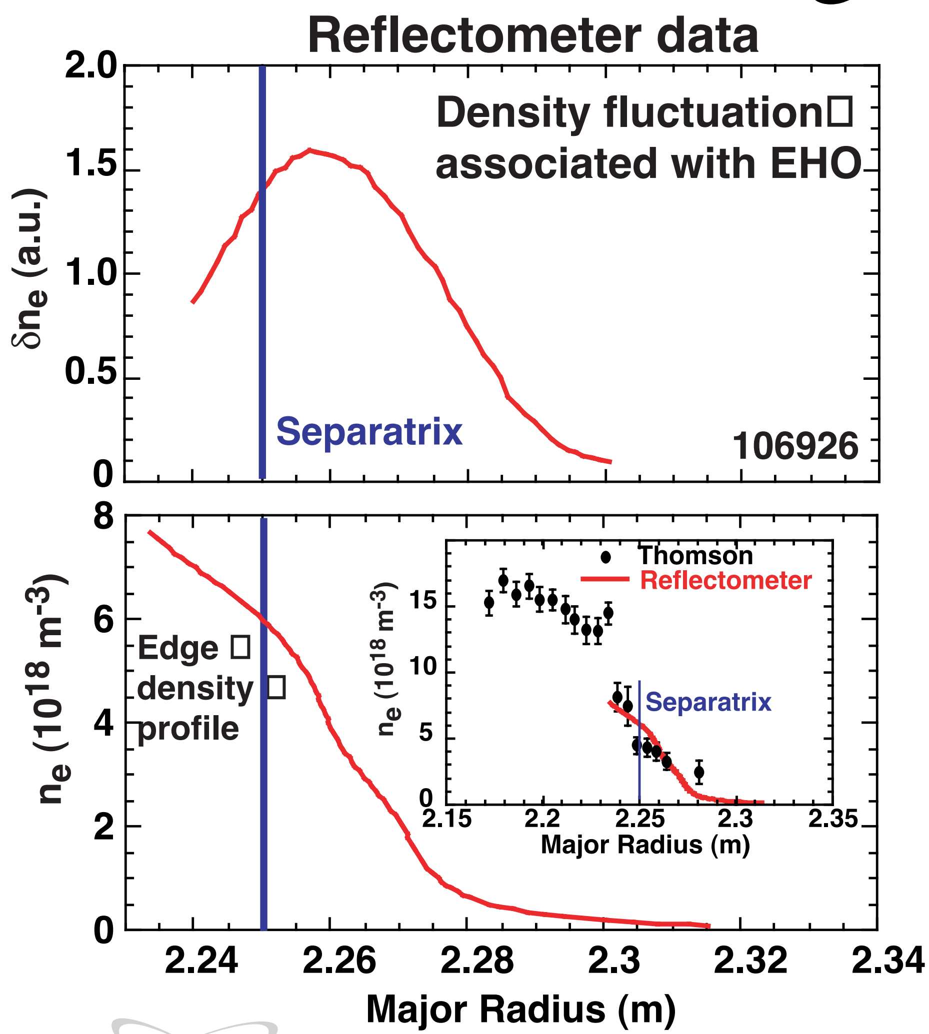
The plasma edge during the quiescent phase is an H-mode edge

- Edge gradients in quiescent phase are comparable to those in ELMing phase
  - Note high T_i pedestal
- QH-mode edge also has other standard H-mode signatures
  - Edge E_R well
  - Reduced turbulence



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

The EHO is located at the base of the edge pedestal

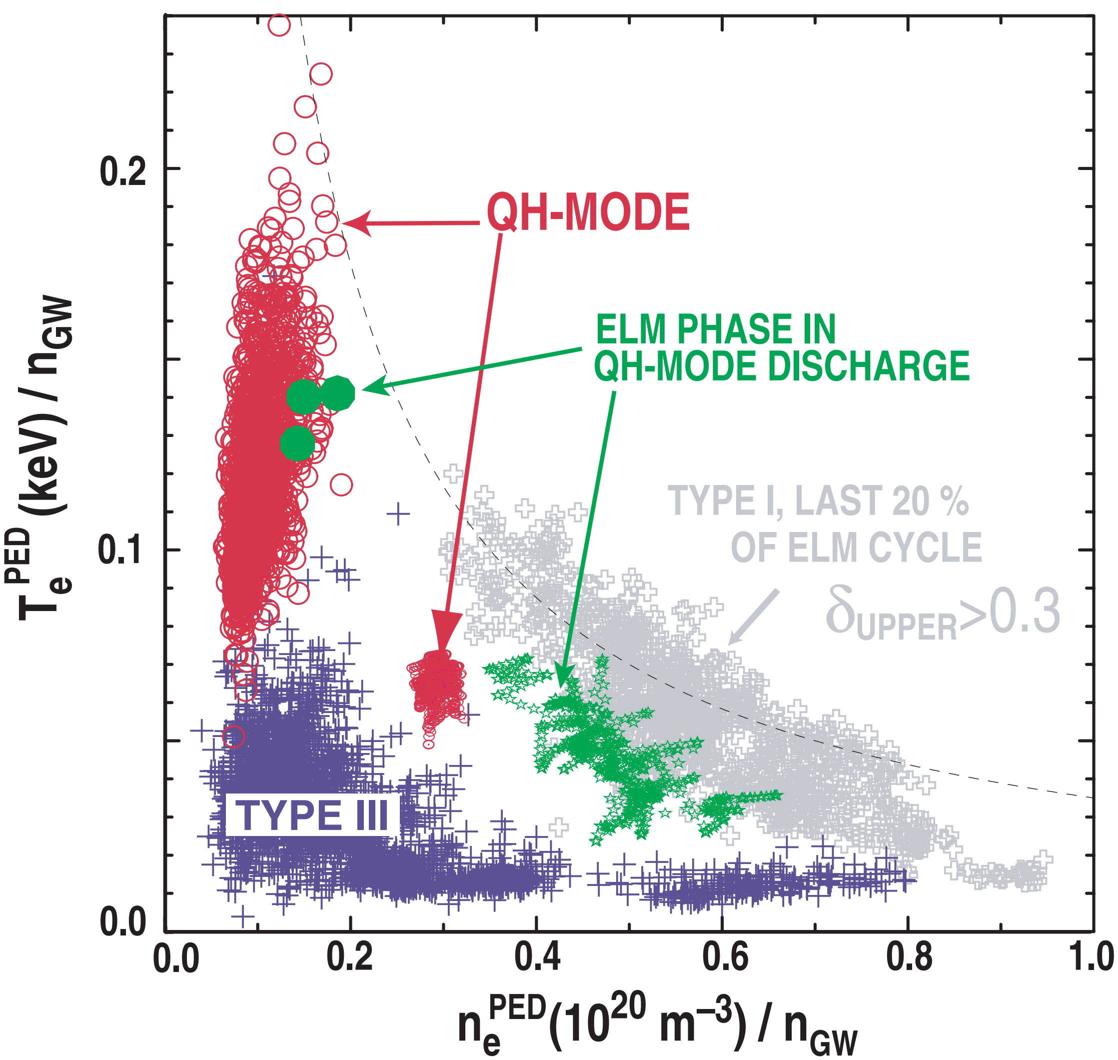


- High resolution measurements with profile reflectometer systems indicate that the EHO is located at the base of the edge profile pedestal, at or slightly outside the separatrix.

Lei Zeng, UCLA

QH-MODE OPERATING SPACE HAS BEEN EXPANDED

- Obtained with counter-NBI, i.e. injection anti-parallel to I_p, plus divertor cryopumping
- QH-mode seen to date for
  $3.4 \le q_{95} \le 5.8$
  $1.0 \le I_p\ (\mathrm{MA}) \le 2.0$
  $1.8 \le B_T\ (\mathrm{T}) \le 2.1$
  $1.0 \le n_e^{ped}\ (10^{19}\ \mathrm{m}^{-3}) \le 6.5$
  - Also low field example at 0.95 T, 0.67 MA
- QH-mode is not device specific
  - Recently obtained in ASDEX-U



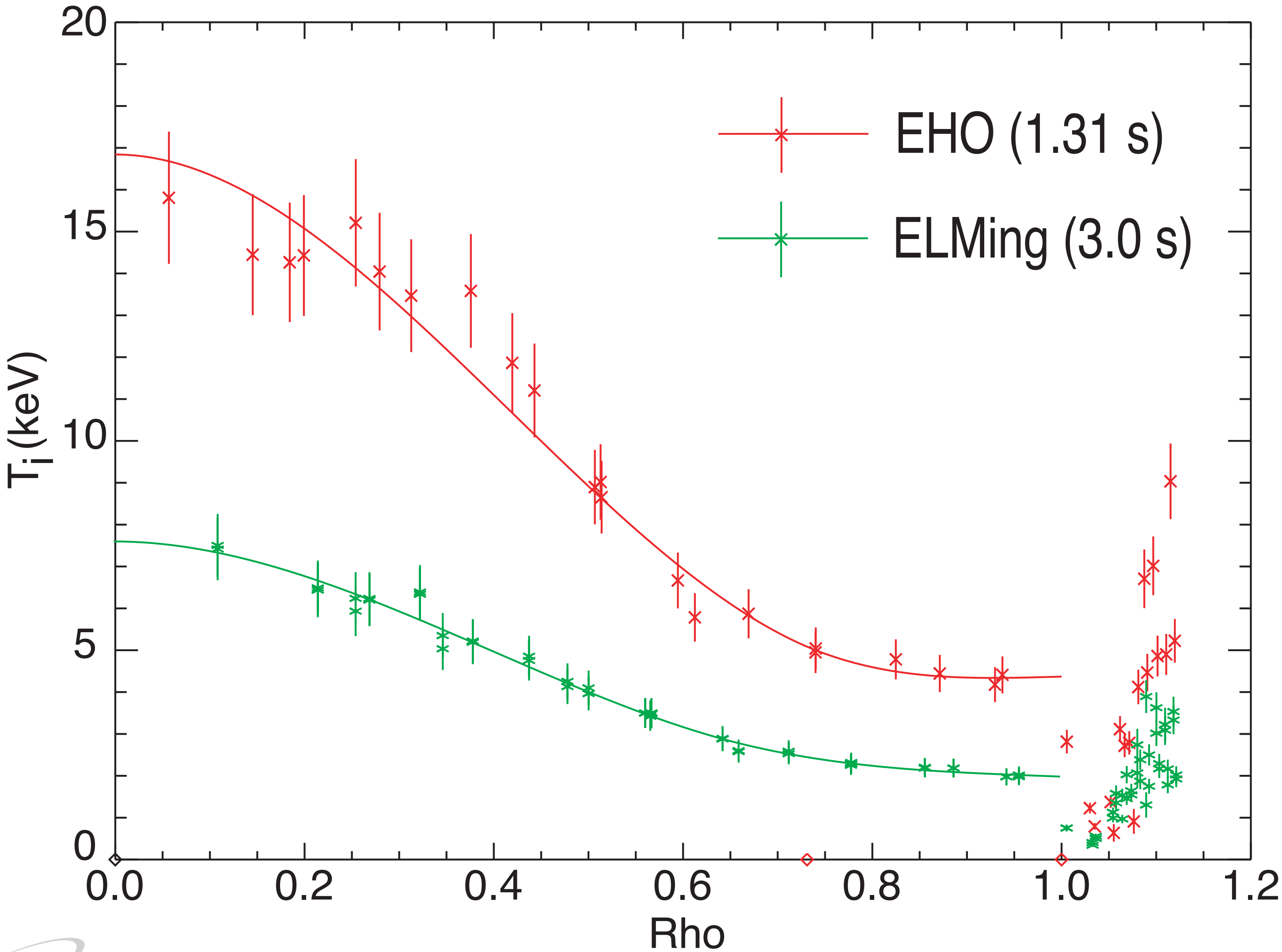
CJL APS 2002

EJD IAEA 2002

Previous results: elevated T_i and heat flux in SOL

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

CER shows high SOL ion temperature



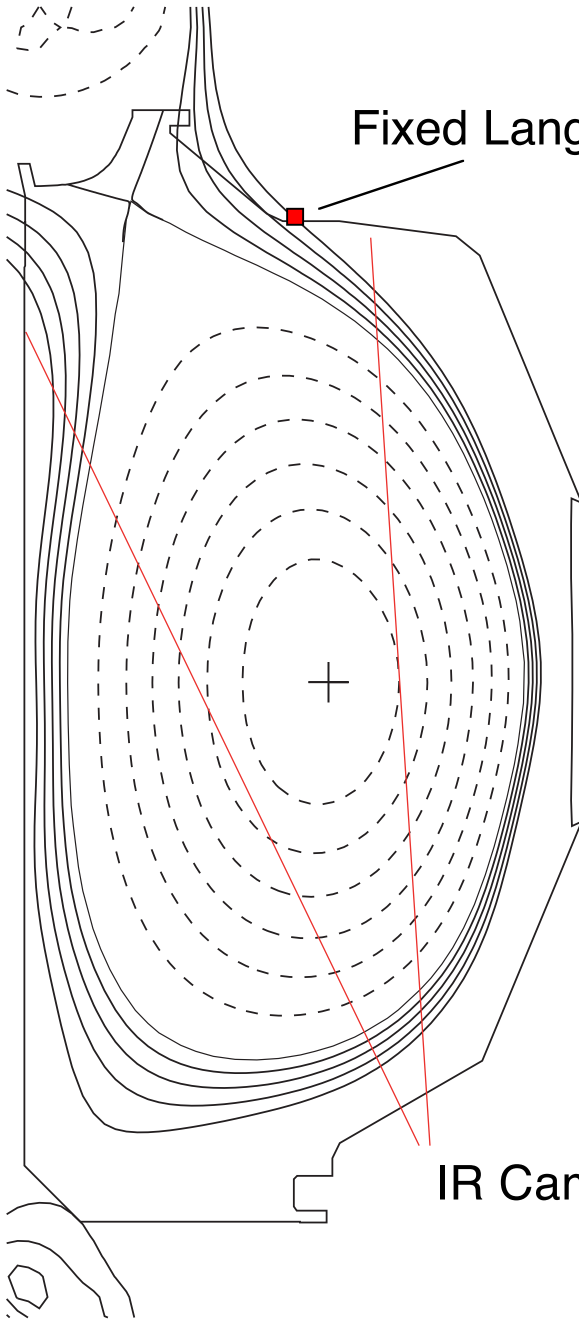
C^{6+}

CJL APS 2002

CerFit: 106919

- Some baffle heating may be due to hot particles on banana orbits perturbed by the EHO.
- Baffle heating could also be due to disturbances in field line geometry (see R.A. Moyer, this meeting).

The baffle area being
Heated by the SOL is
3-5 midplane cm from
the separatrix

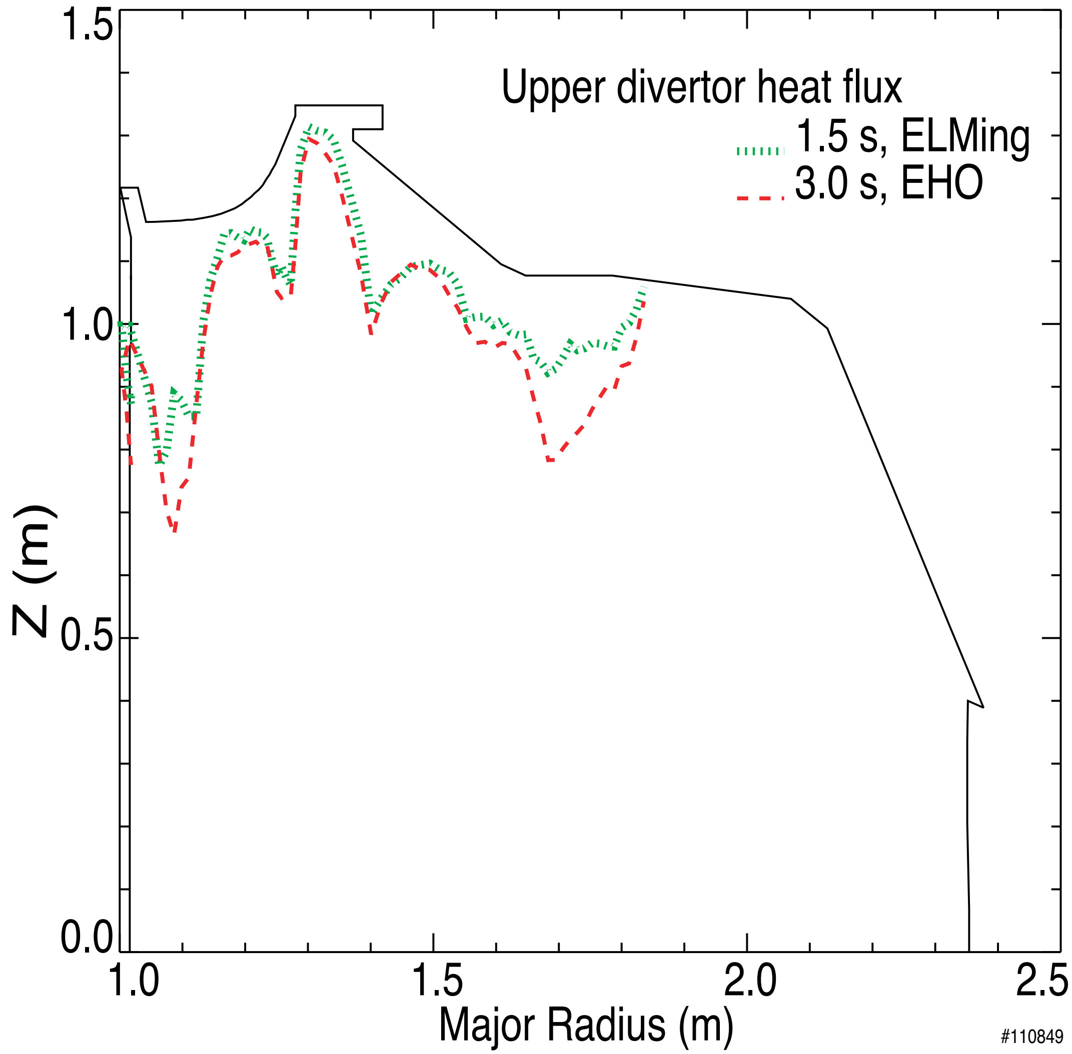


EFIT 106919
3710 ms

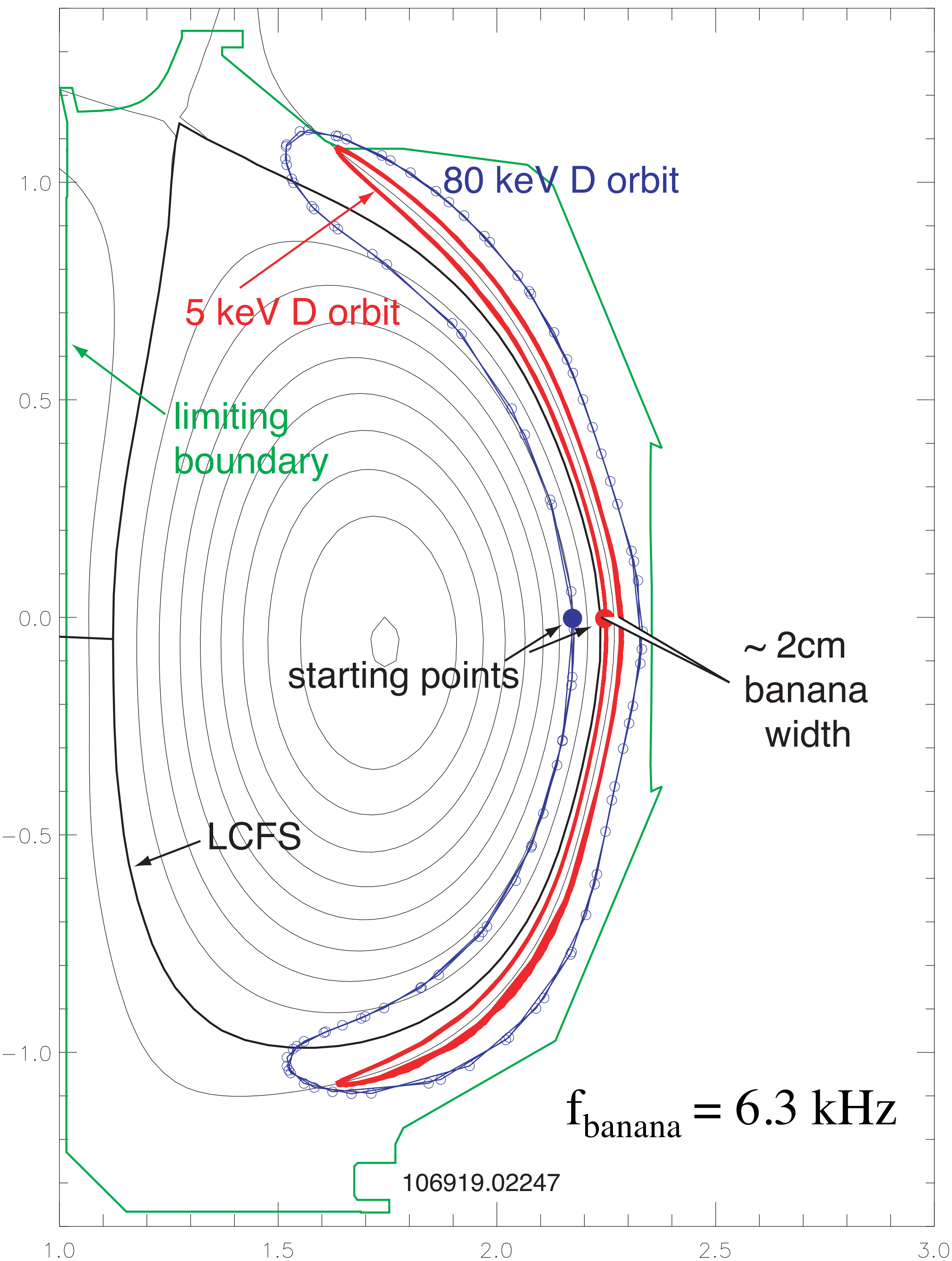
106919 3710.00

CJL APS 2002

Divertor heat flux on tile geometry



Banana orbits can intersect the baffle

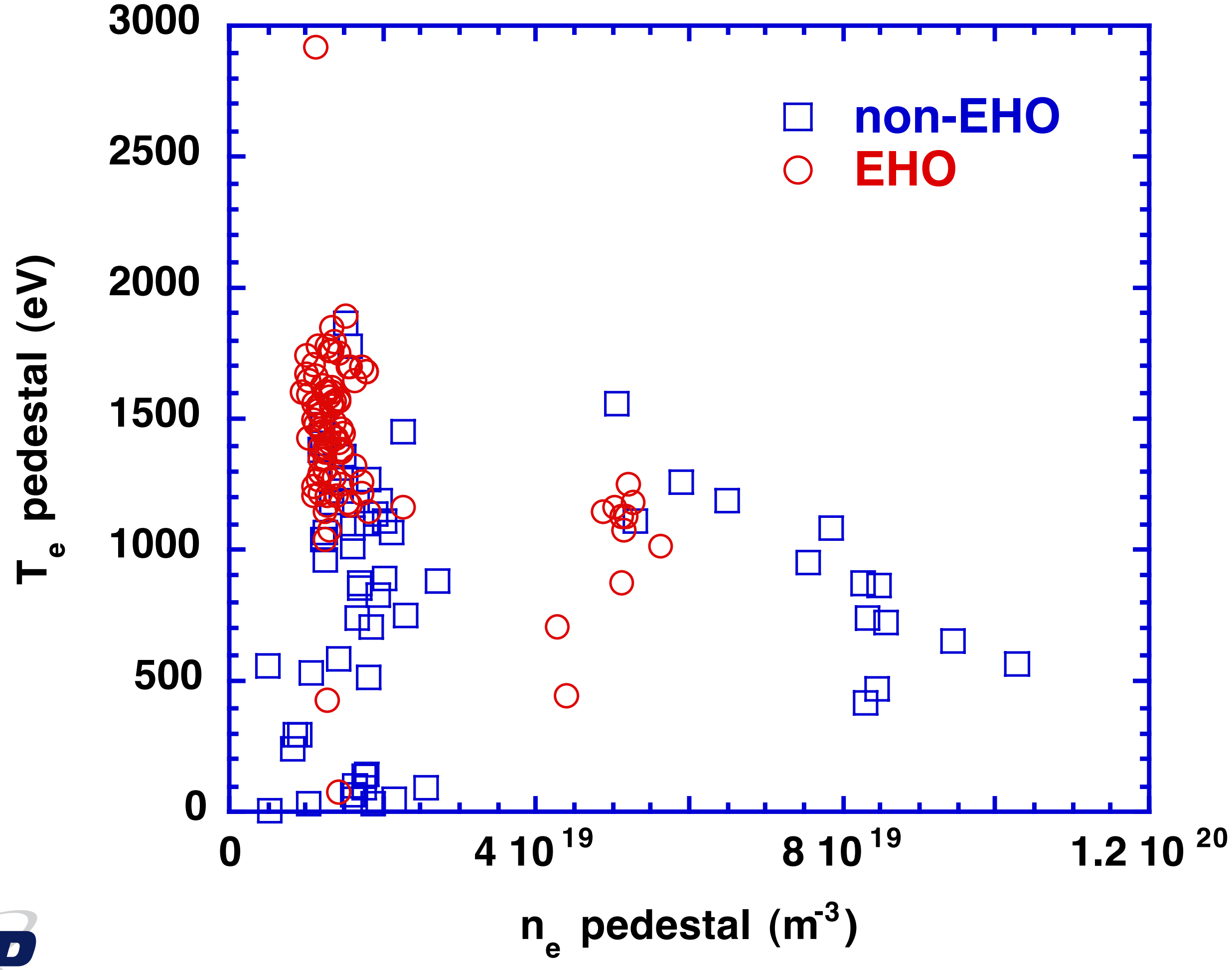


CJL PSI 2002

deGrassie orbit3.eps

The Question

Most EHO occurs at low pedestal density, high pedestal T_e



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Is the EHO dependent on:

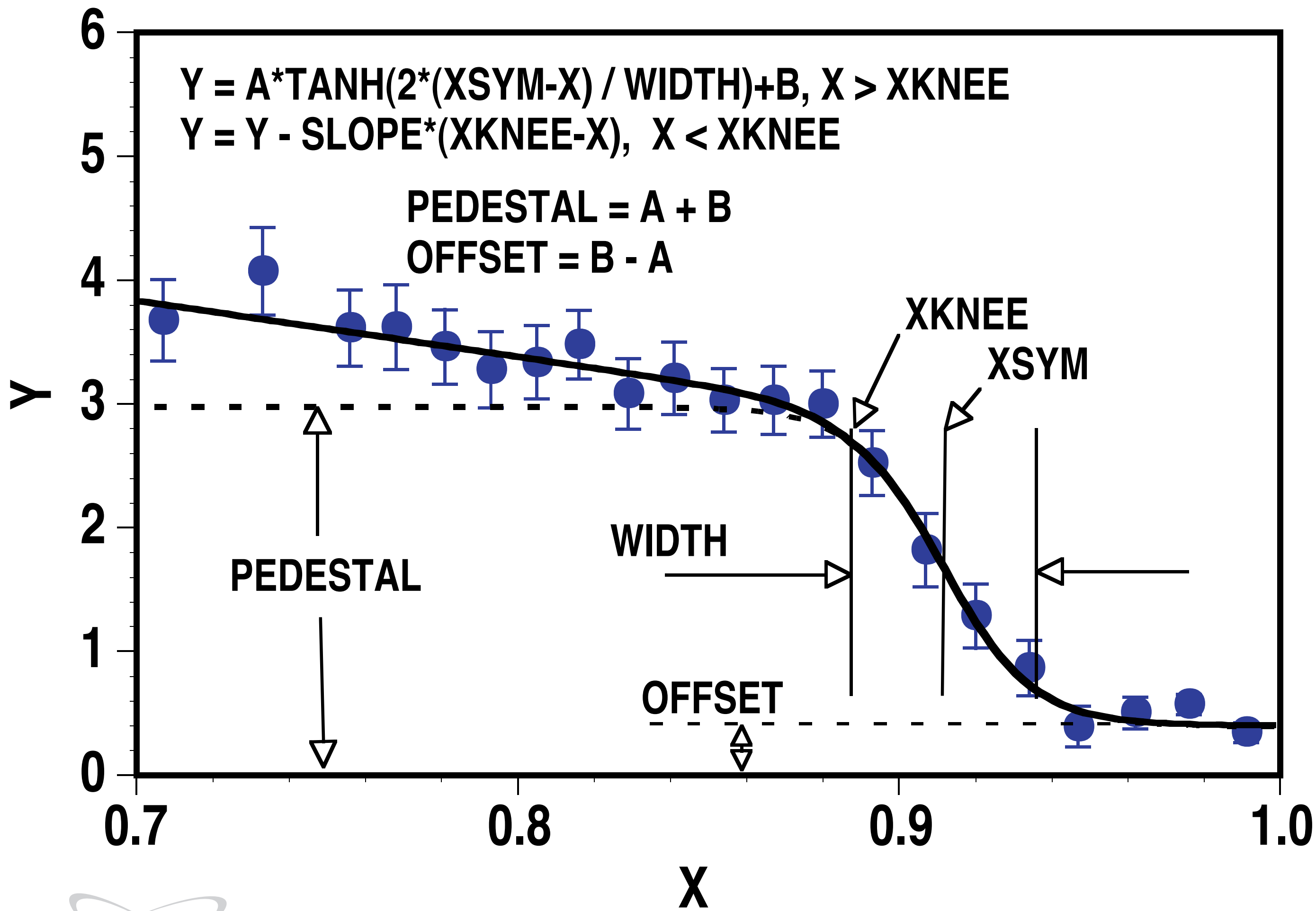
- Low density?
- High T_e in pedestal or SOL?
- High T_i in pedestal or SOL?
- Low collisionality in SOL to allow banana trapping of warm ions?

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Strategy

- Examine electron density and temperature in the pedestal and SOL, as determined from fitting tanh profiles to the pedestal and SOL Thomson temperature and density data.
- Calculate ion-electron collision frequencies in the pedestal and SOL assuming ion temperatures given by CER analysis.
- Compare these values for EHO and non-EHO times in discharges which had EHO for part of the shot. All these values are therefore "close" to the EHO condition.

Pedestal and SOL T_e, n_e taken from tanh fits to Thomson Scattering profiles

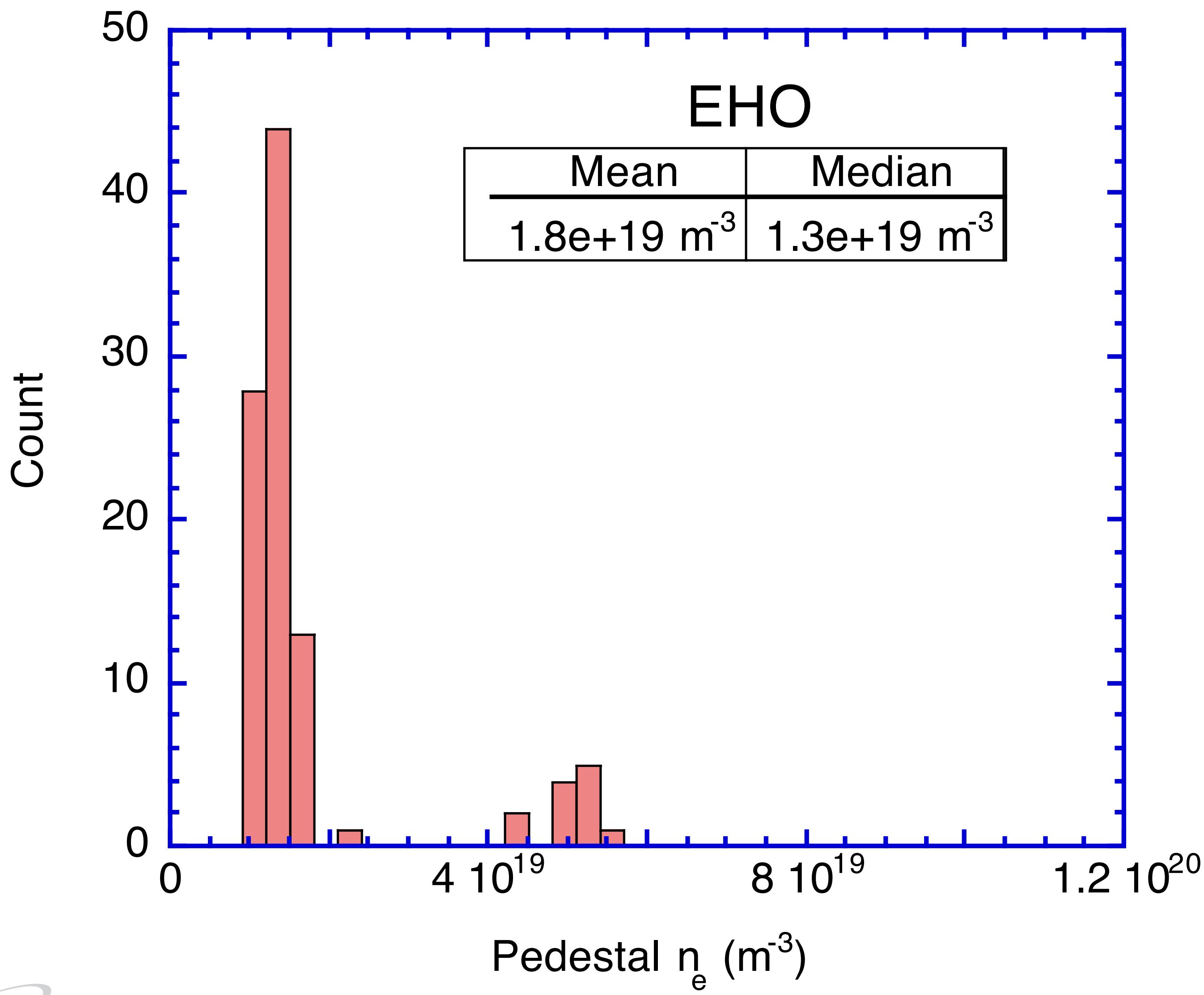


- Pedestal n_e,T_e
- SOL n_e,T_e = offset

Color Code: ○ EHO □ Non-EHO

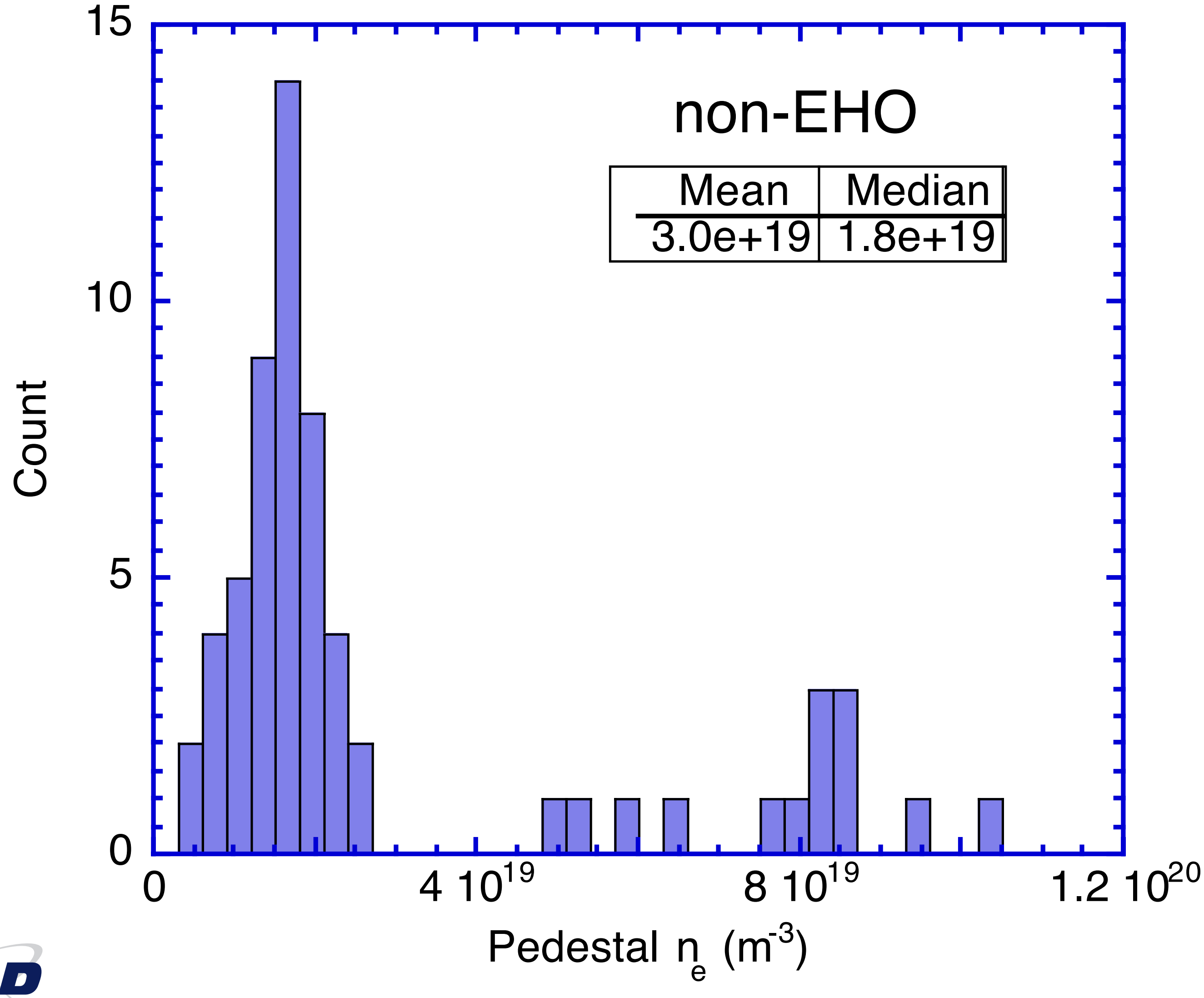
Density

Pedestal n_e similar in EHO and non-EHO phases

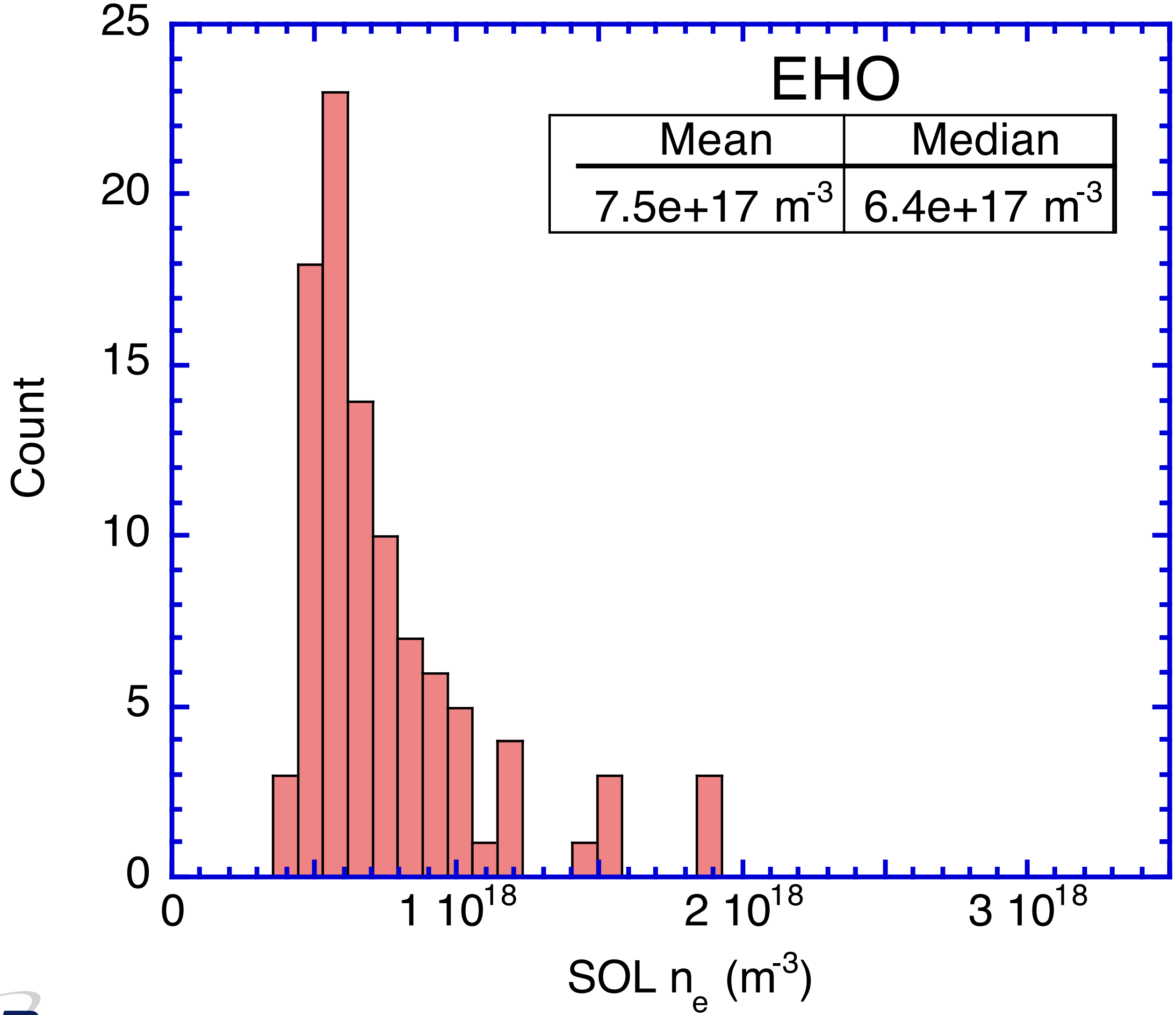


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Pedestal n_e without EHO

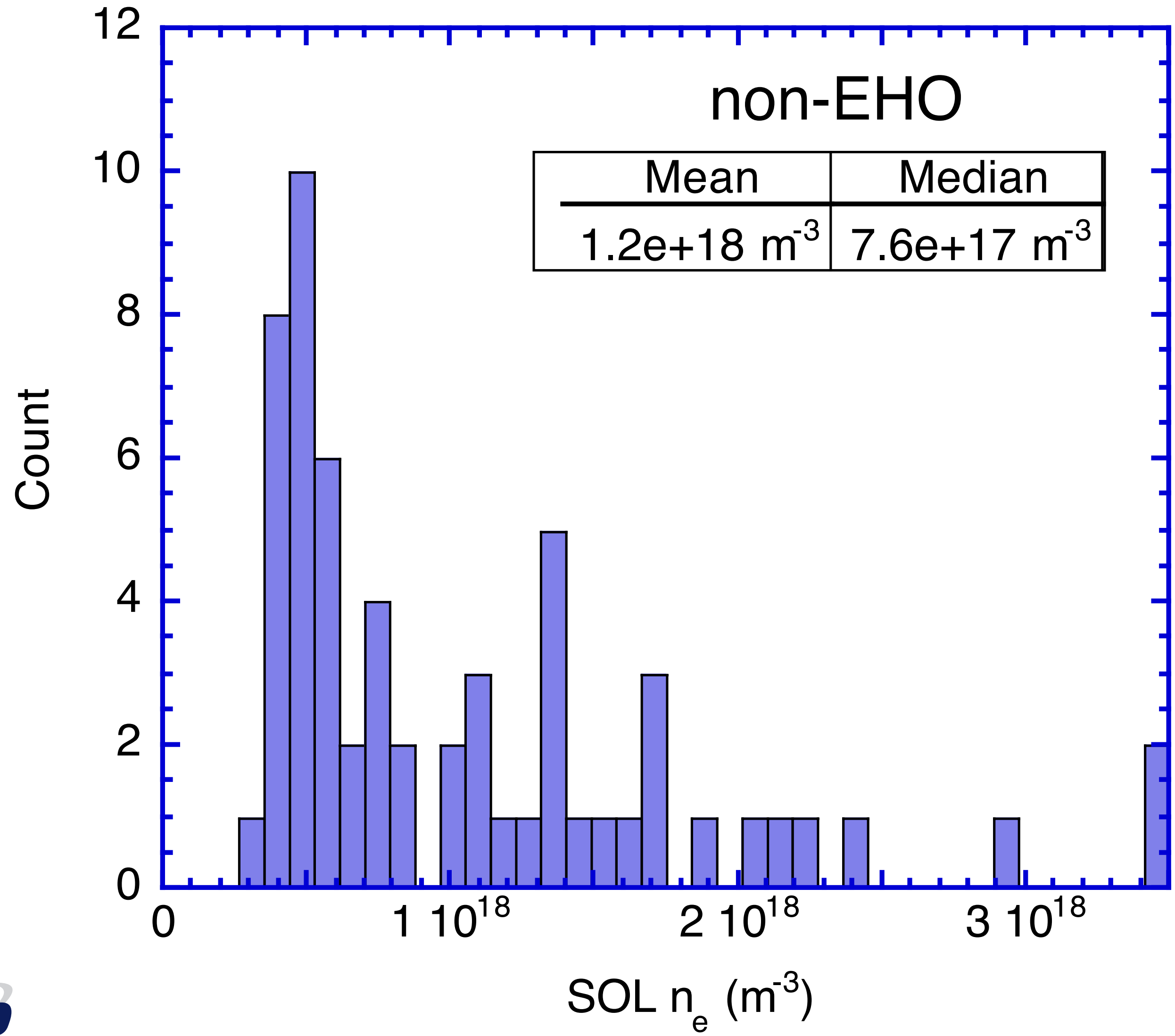


n_e in SOL similar for EHO and non-EHO



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

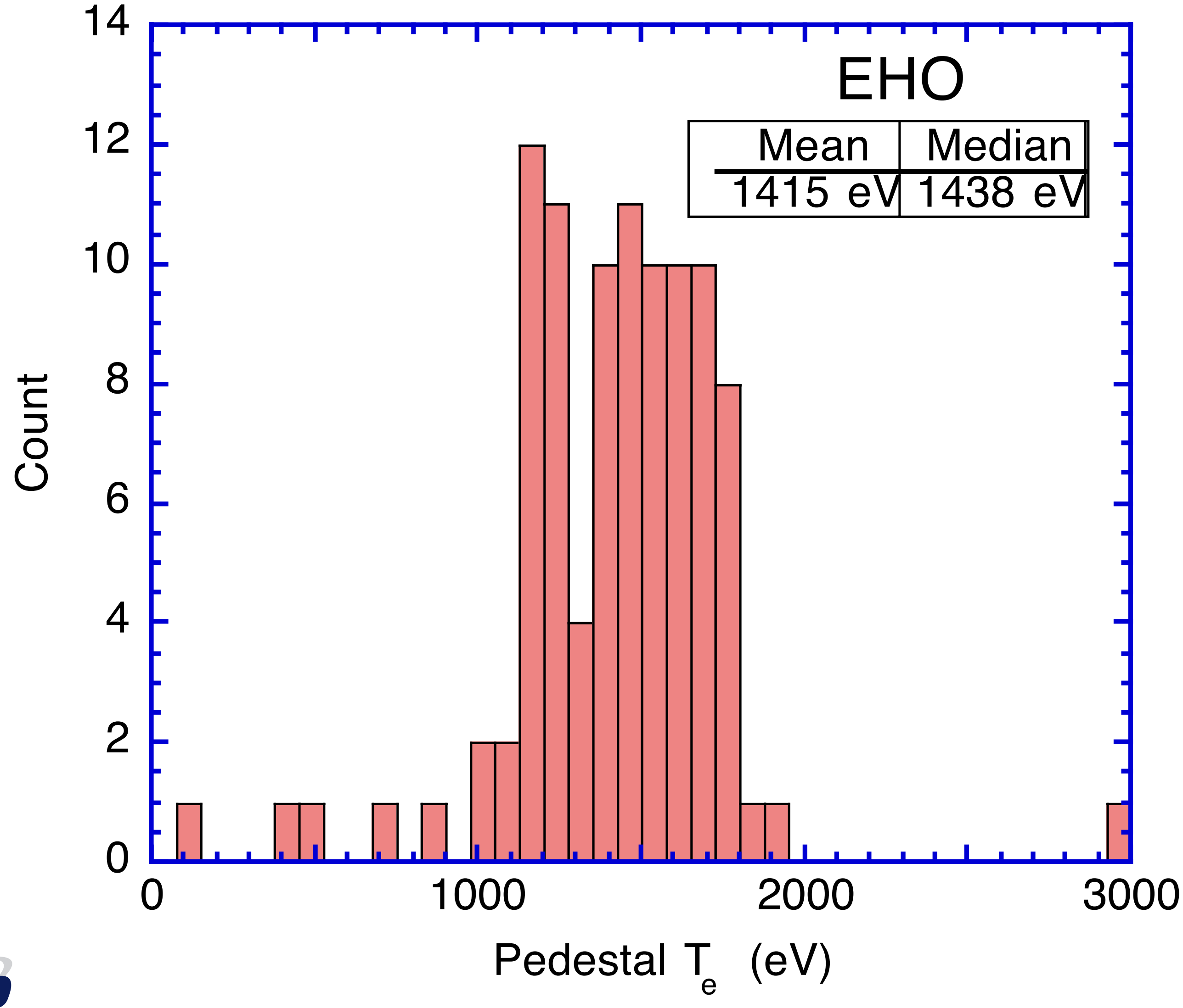
n_e in SOL



non-EHO
Mean
Median
1.2e+18 m-3
7.6e+17 m-3
Count
12
10
8
6
4
2
0
0
1 10^18
2 10^18
3 10^18
SOL n_e (m-3)

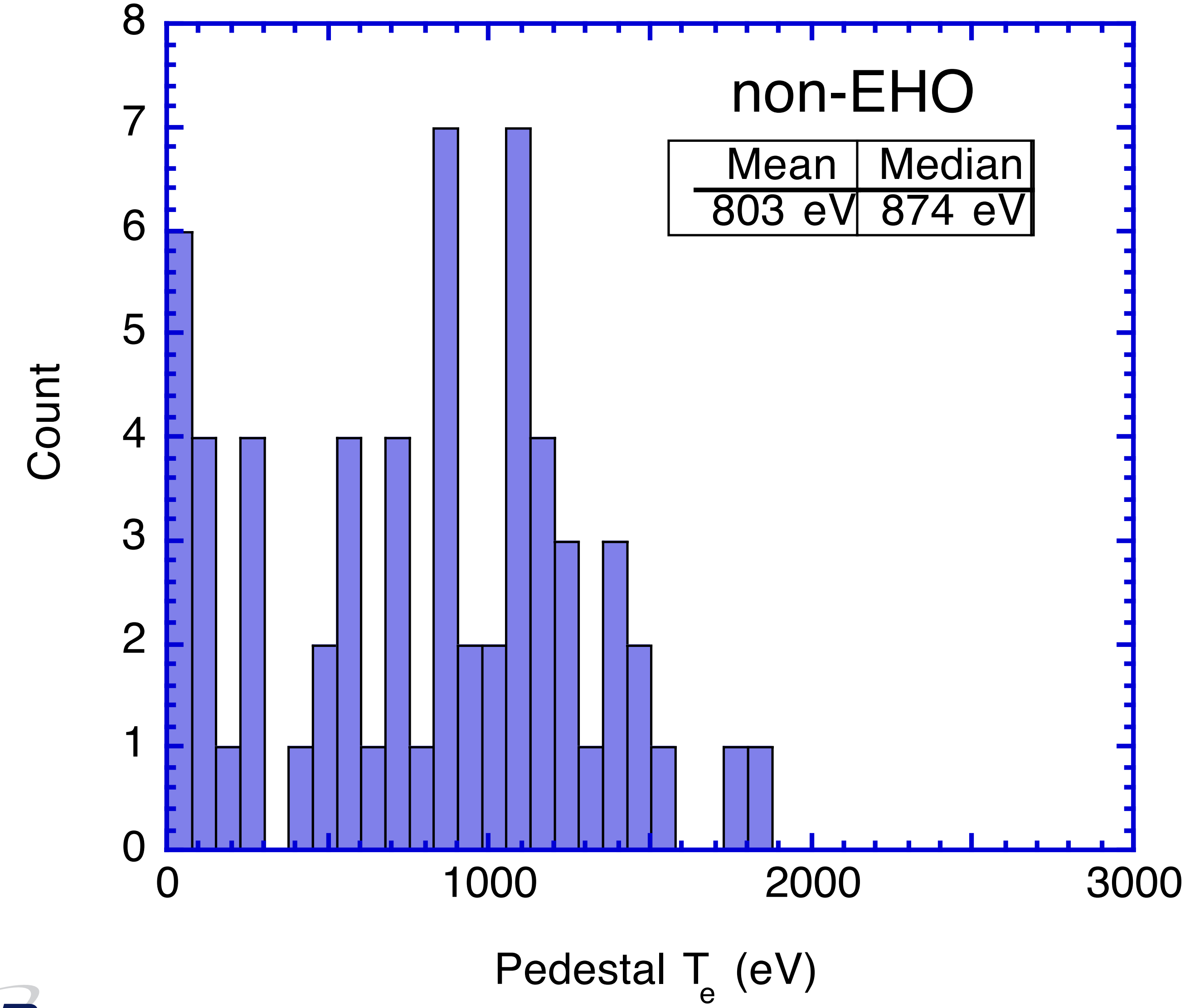
T_e

Pedestal T_e is higher during EHO

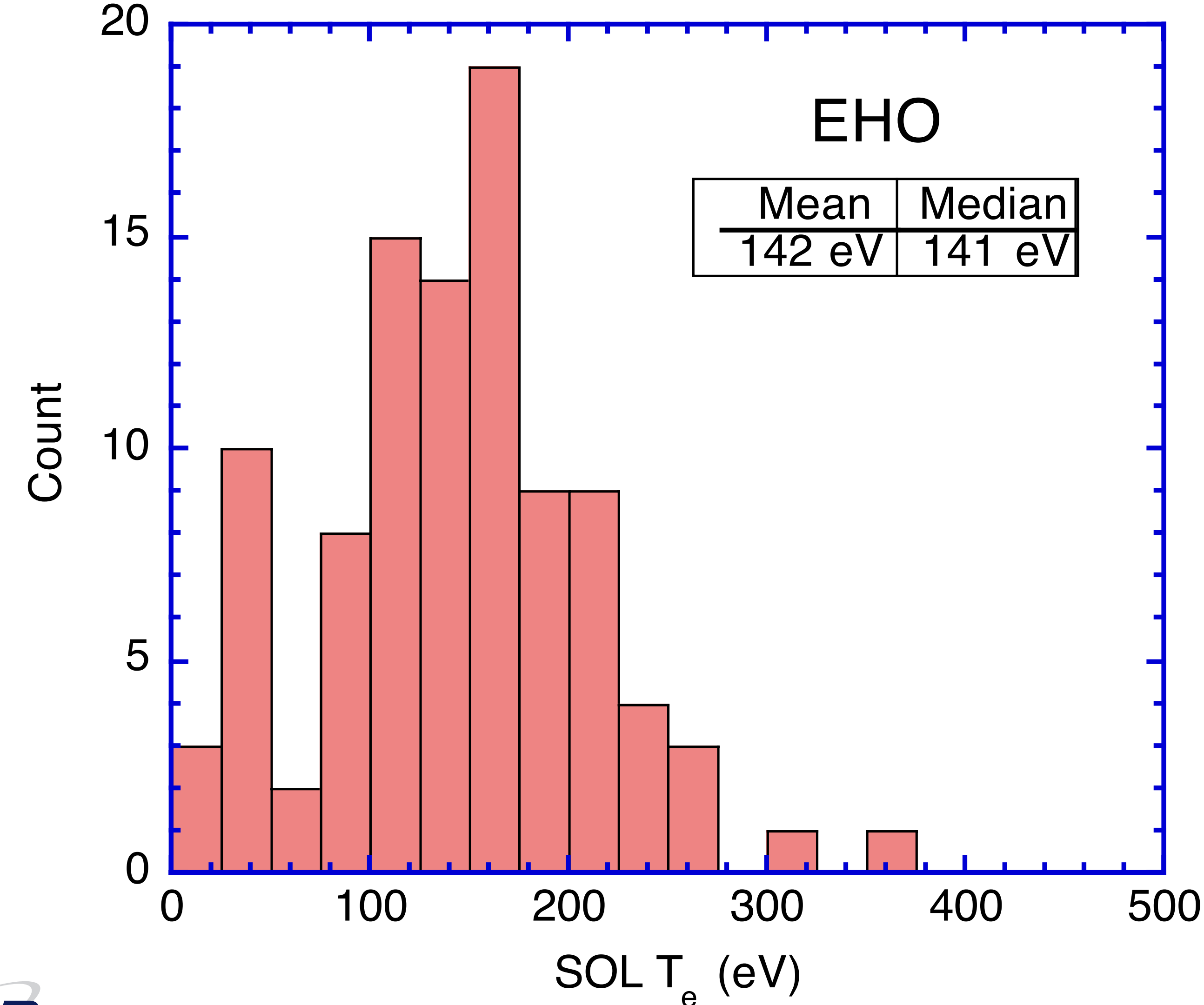


CJL APS 2002

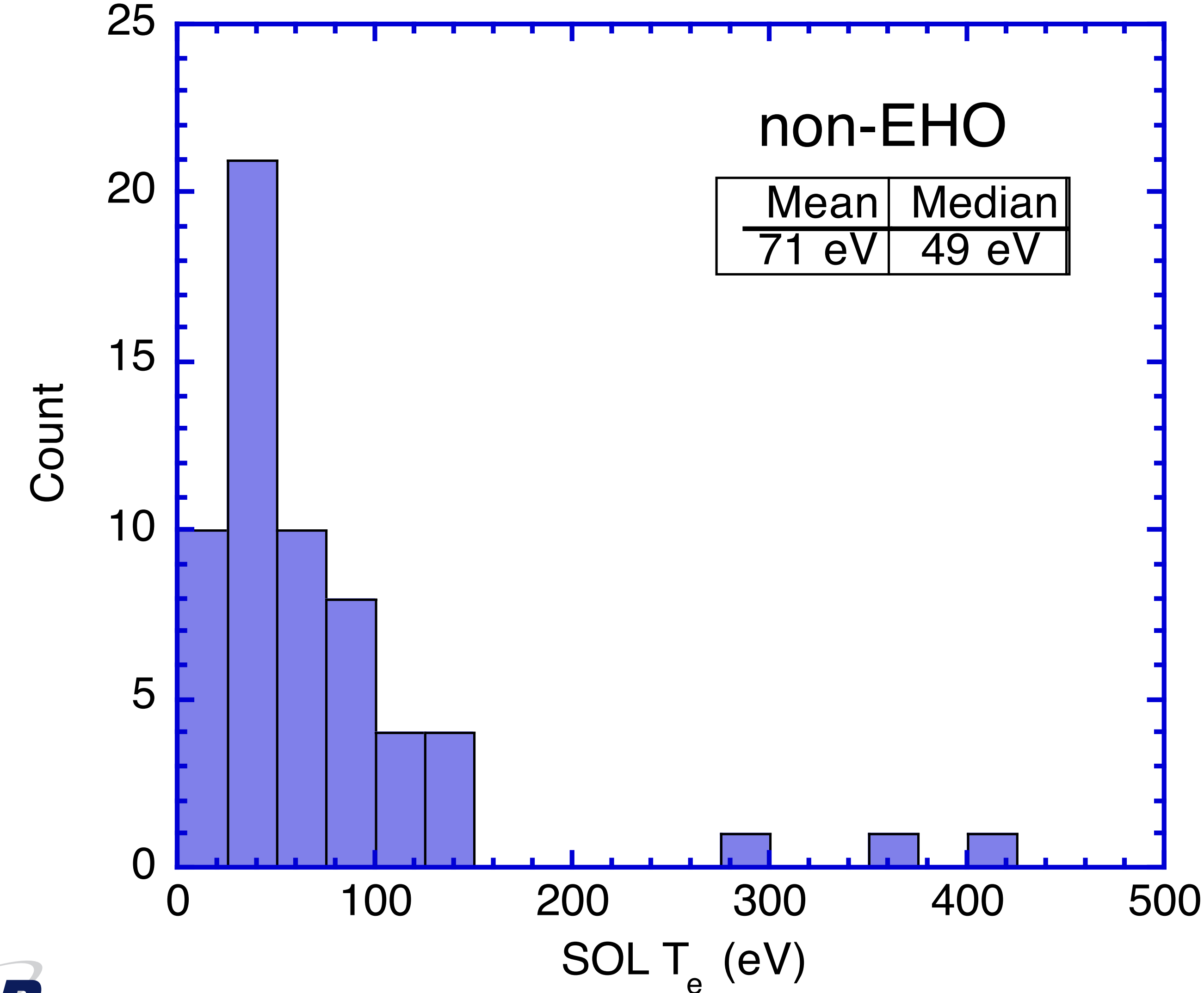
Pedestal T_e lower for non-EHO



Higher SOL T_e during EHO

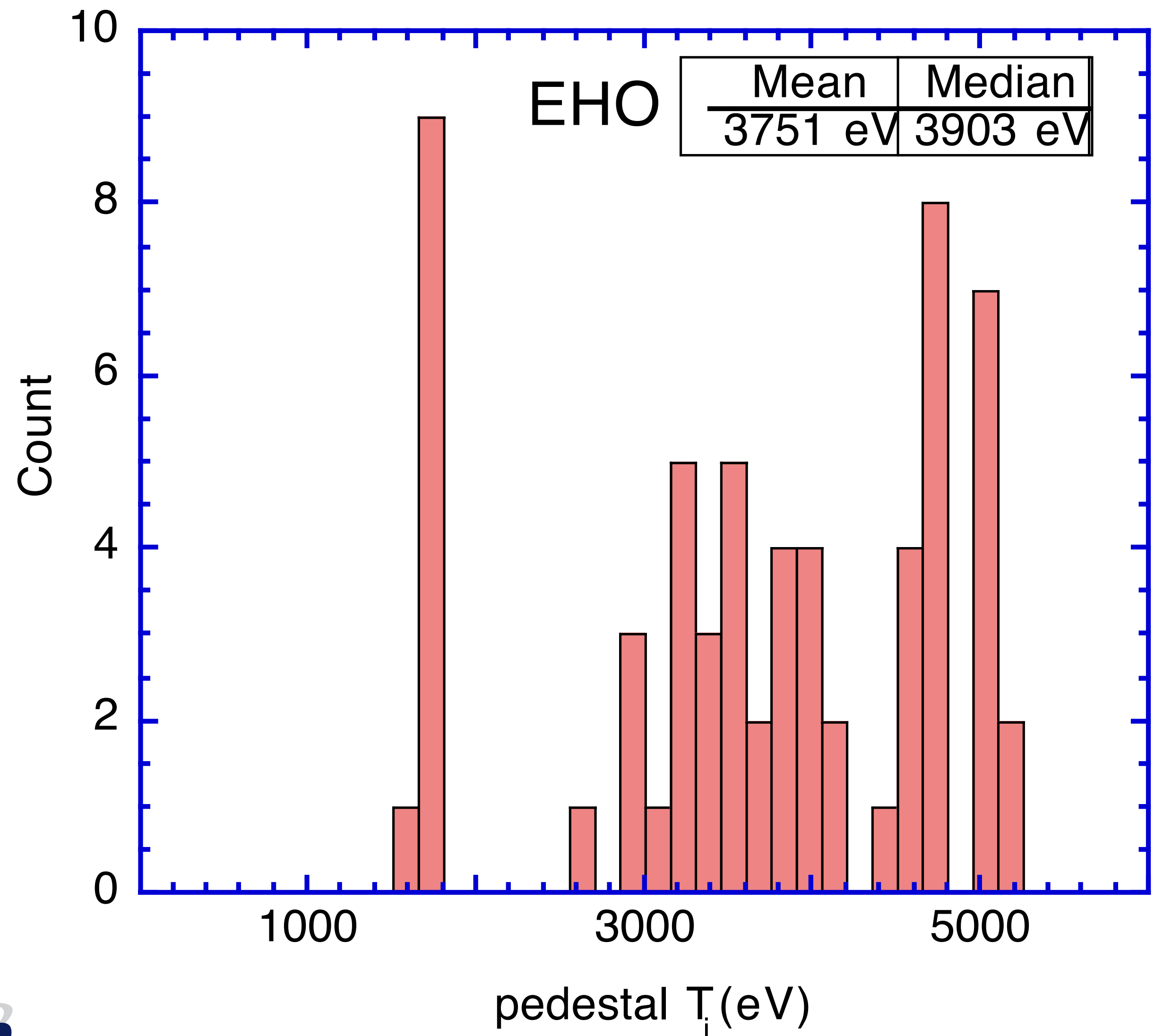


Low SOL T_e during most non-EHO phases



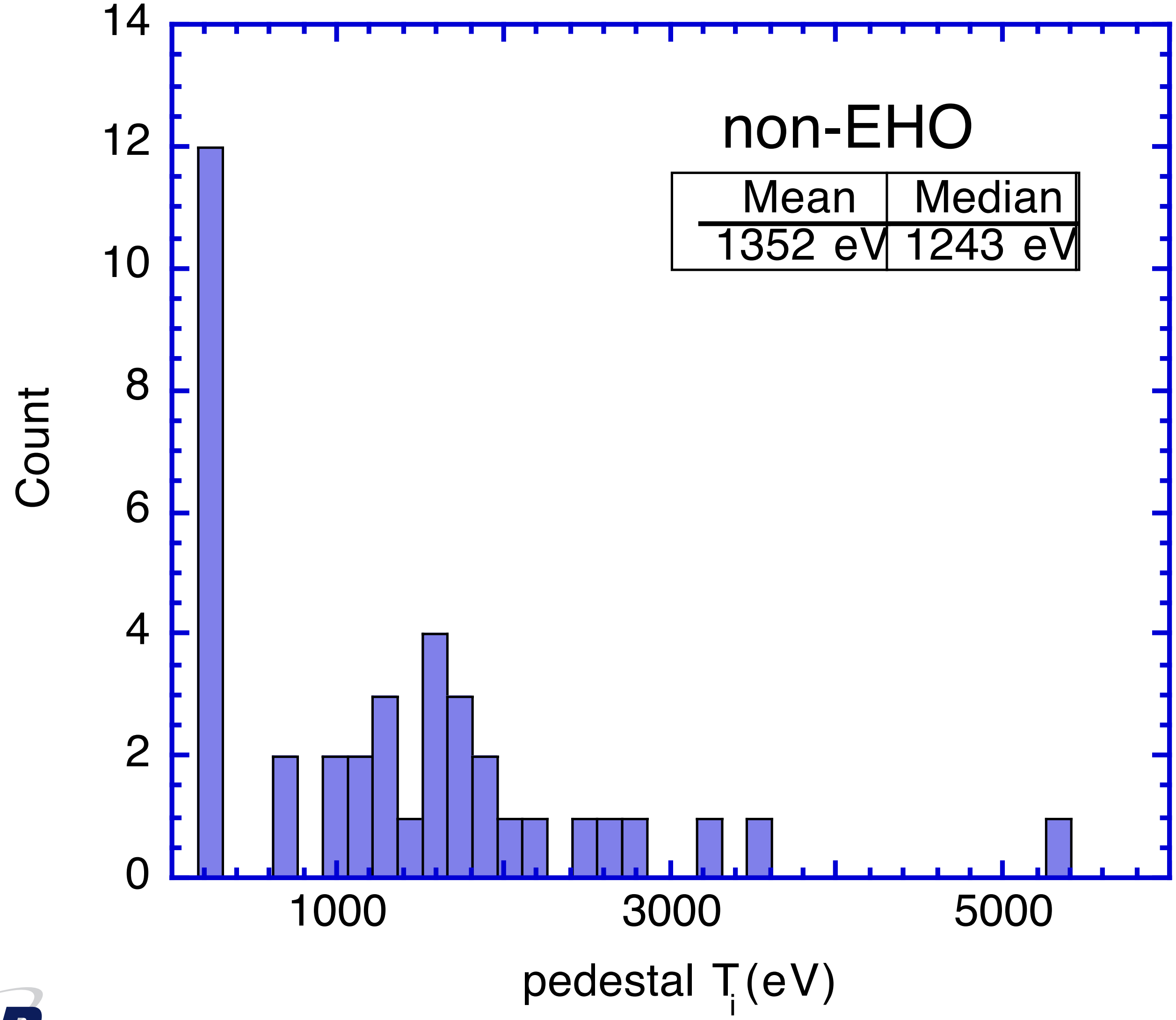
T_i

Pedestal T_i higher during EHO

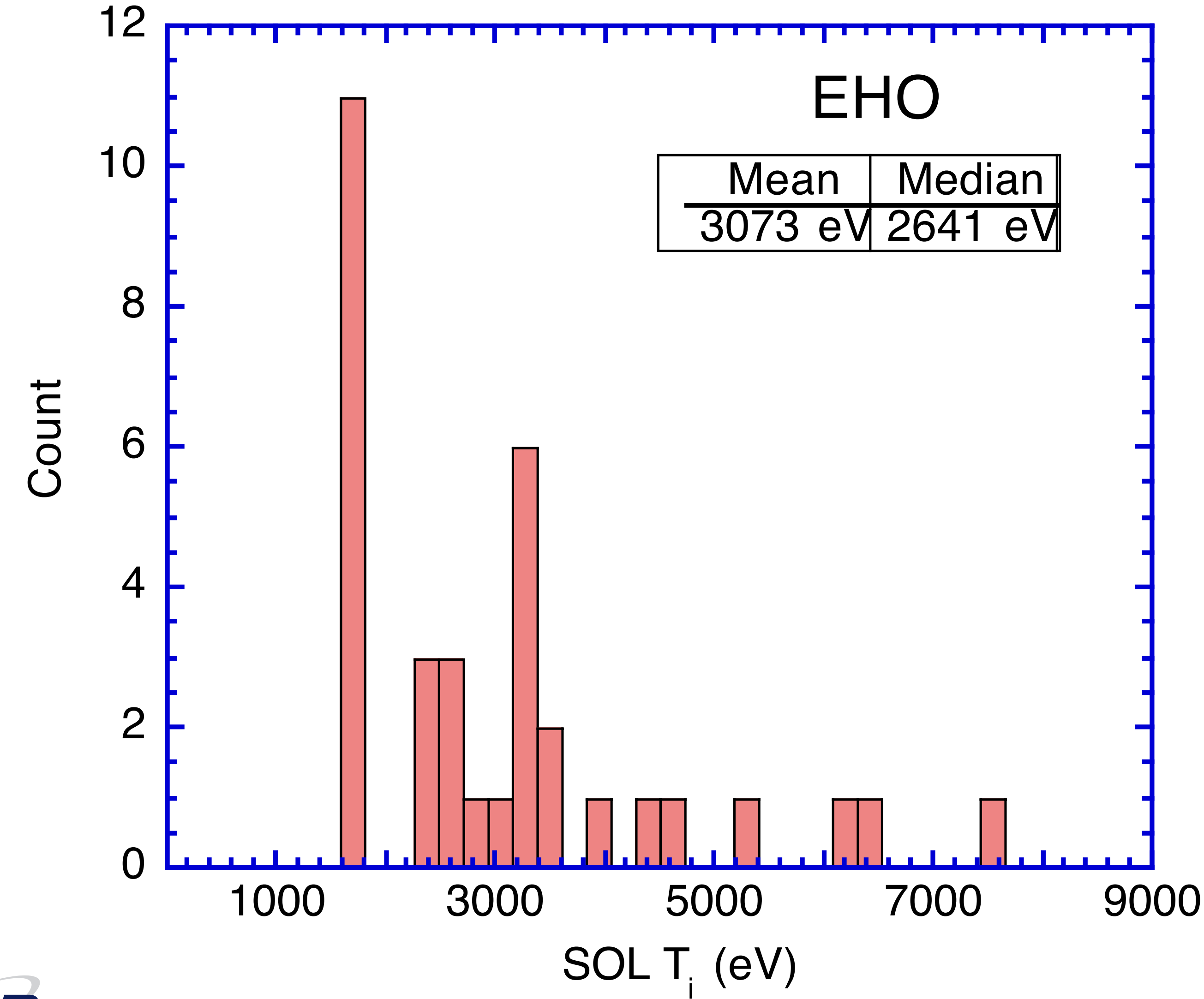


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Pedestal T_i is lower during non-EHO phase

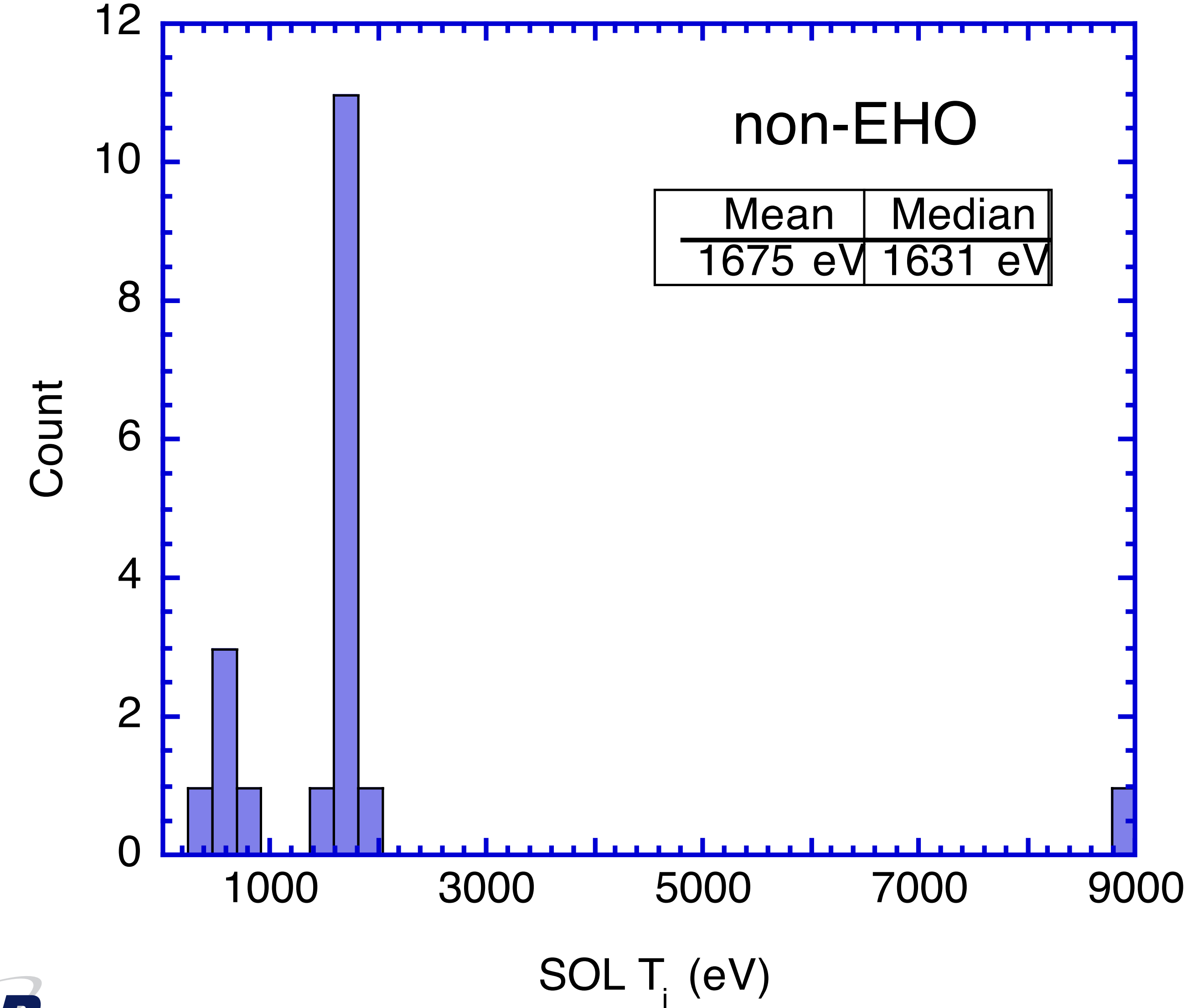


T_i in the SOL is higher during EHO



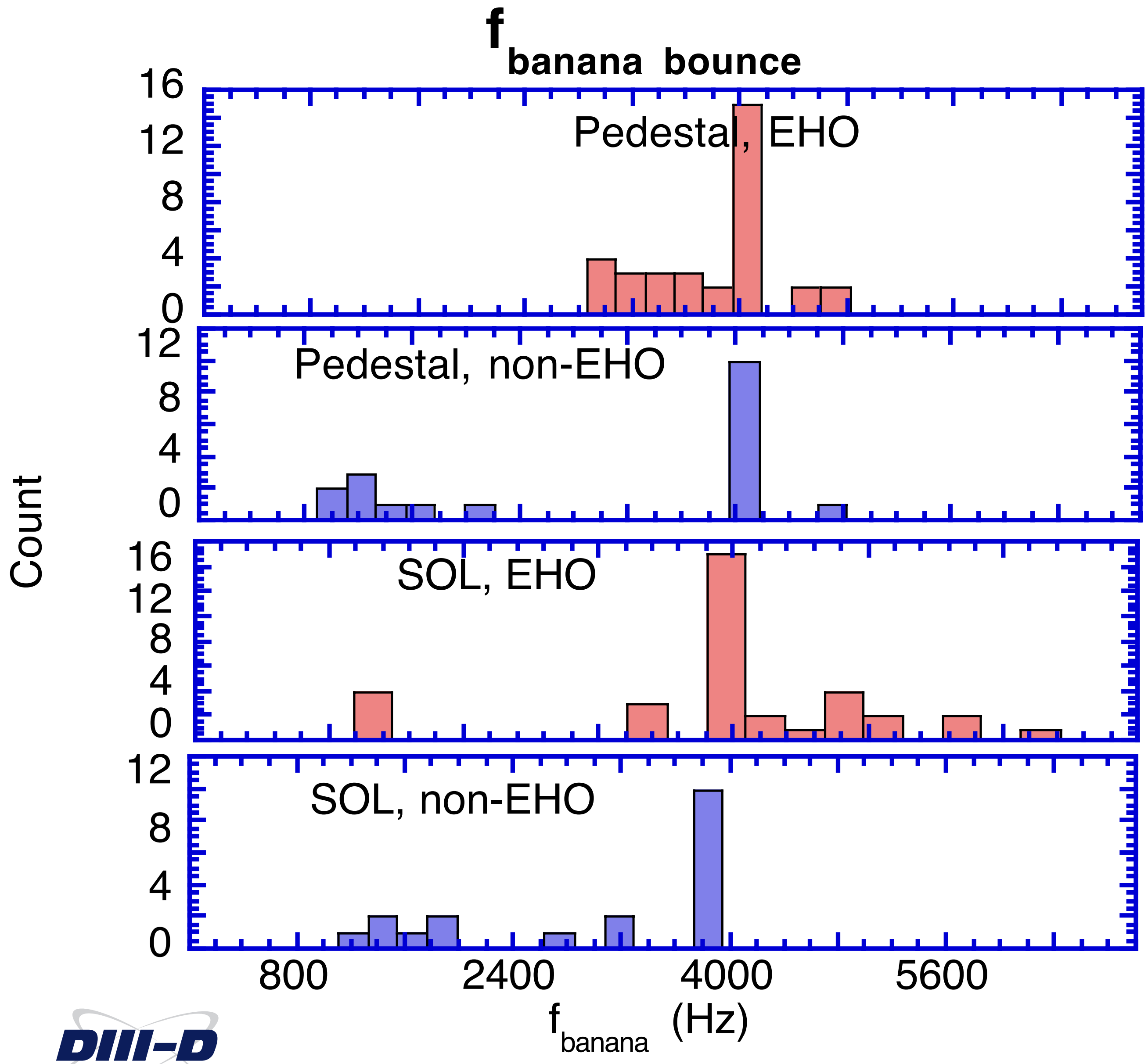
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

…and lower during non-EHO



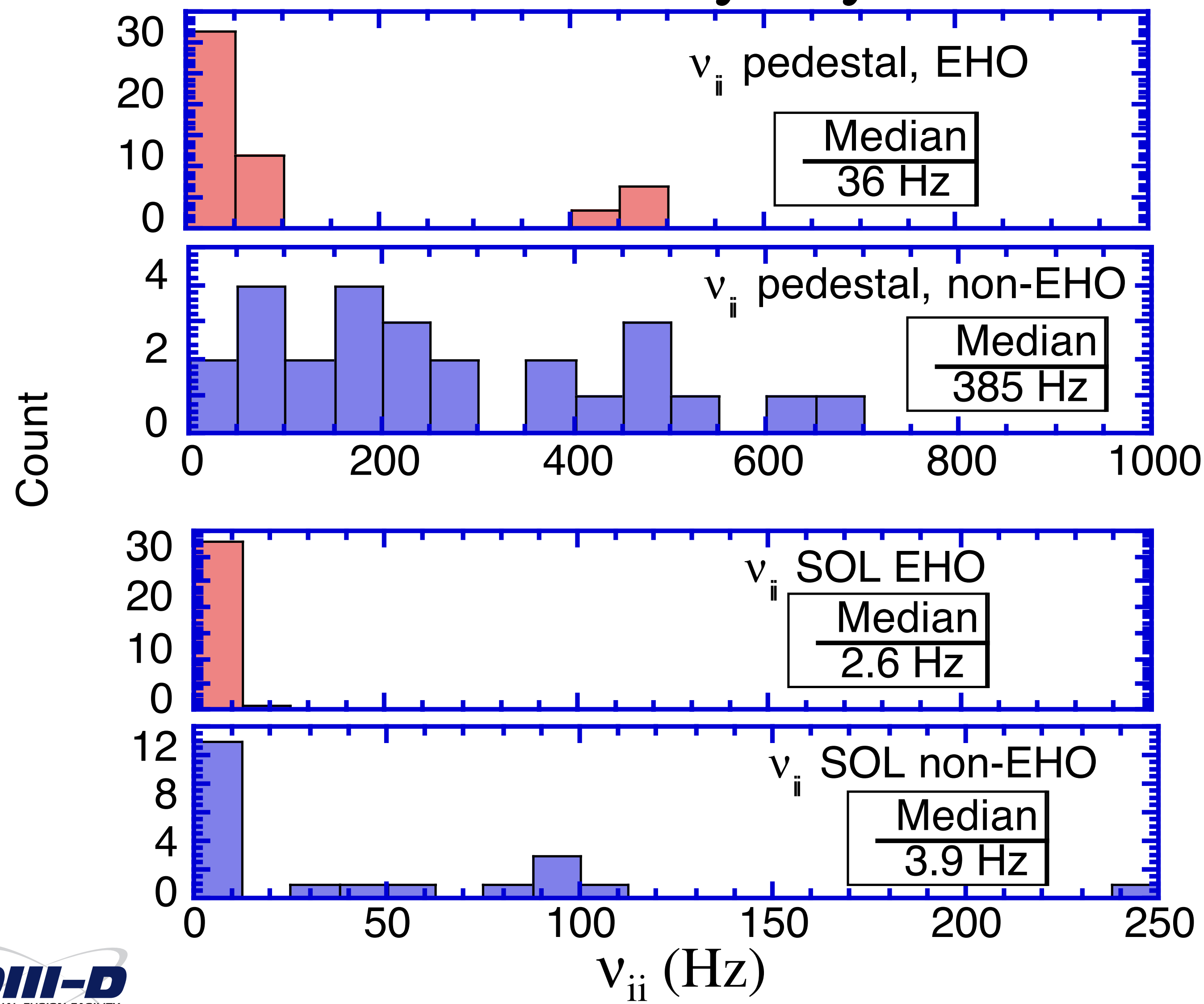
f_{banana} & ν_{ii}

f_{banana} ~4 kHz for orbits passing near upper baffle



Banana bounce frequency was calculated exactly in one case, and scaled by the ion velocity for other cases.

Collisionality is lower during EHO, but very low anyway



ν_{ii} calculated using Wesson, 2nd Ed. Eq. 2.15.3

Conclusions

- Electron density is similar in the pedestal and SOL, with or without EHO.
- Elevated T_e and T_i in the SOL and pedestal are observed with the EHO.
- High temperature is likely a controlling parameter for EHO, not density.
- Ions in SOL *and* pedestal are collisionless with or without EHO. ($\nu_{ii} << f_{banana}$)

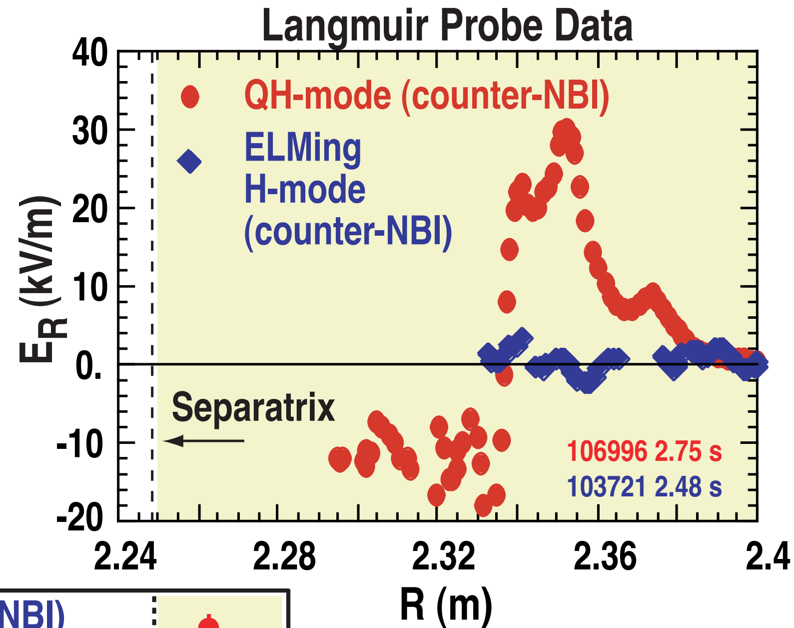
- EHO has been observed at higher density in a discharge with higher injected input power (12 MW) and plasma current (2 MA).
- Consistent with ASDEX-U, where RF helped induce a QH-mode.
- Prediction: QH mode can be obtained at higher density if more heating is applied.

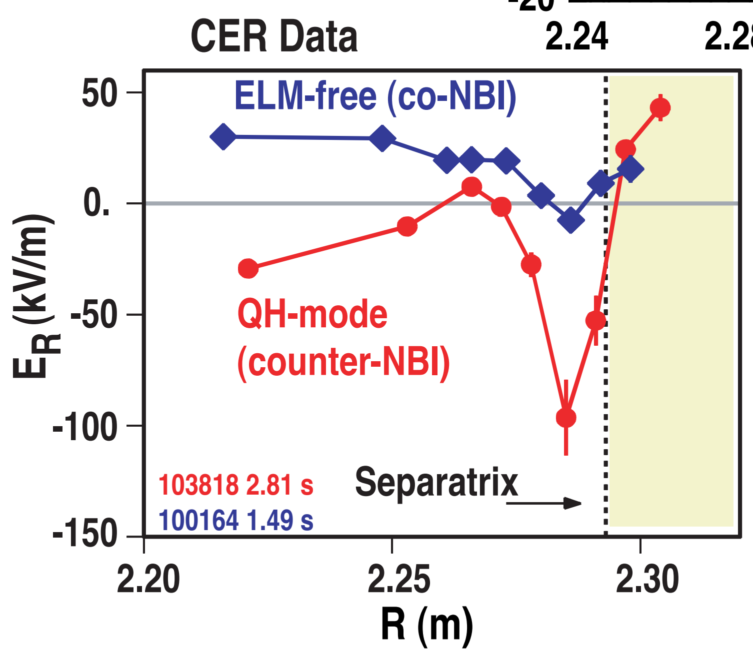
Overview: mid-SOL heat flux in QH discharges

- Significant heat flux appears 3-4 midplane cm from the separatrix
- Particle flux is also seen at this location
- Consistent with hot SOL ions seen in CER
- Present with EHO or tearing mode
- Not present or much smaller with ELMs
- Presence of core barrier has little direct effect on SOL
- The wall is a net sink for particles.

Large edge radial electric field E_R in QH-mode will strongly affect banana orbits

- Langmuir probe data show large E_R in SOL
  - SOL E_R is at normal levels in ELMing counter-NBI discharge
  - Change is associated with QH-mode, not counter-NBI per se





- CER data show large E_R in SOL and very deep E_R well inside the separatrix

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Ion-Ion collision frequencies calculated

Ion-Ion collision time (Wesson, 2nd Ed. 2.15.3)

$$\tau_{ii} = 6.6\times10^{17}\frac{(m_i/m_p)^{1/2}T_i^{3/2}}{n_i Z^4 Ln(\Lambda_{ii})}\ \mathrm{s}$$

where

$$Ln(\Lambda_{ii}) = 30 - Ln\left(\frac{Z^3\sqrt{n_i}}{T_i^{3/2}}\right)$$

(from Sauter, Angioni, Lin-Liu, Phys Plasmas **6**, 2834)

m_p is proton mass

m_i is ion mass

T_i is the electron temperature in eV

n_i is ion density in m^{-3}

Z is the ion charge in units of proton charge

DIII-D NATIONAL FUSION FACILITY SAN DIEGO