Fusion Energy Development Applications **Utilizing the Spherical Tokamak** and Associated Research Needs and Tools

27th IAEA Fusion Energy Conference - IAEA CN-258

Paper Number OV/P-6

J.E. Menard, et al.

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

Collaborative and international effort including 23 co-authors

J.E. MENARD, R. MAJESKI, M. ONO Princeton Plasma Physics Laboratory Princeton, NJ USA	Y. NAGAYAMA Nihon University Tokyo, Japan
N.N. BAKHAREV, V.K. GUSEV Ioffe Institute Saint Petersburg, Russia	Y. ONO, Y. TAKASE The University of Tokyo Tokyo, Japan
M. GRYAZNEVICH, D. KINGHAM, S. MCNAMARA, P. THOMAS Tokamak Energy Ltd Oxfordshire, United Kingdom	M. REINKE Oak Ridge National Laboratory Oak Ridge, TN, USA
K. HANADA Kyushu University Fukuoka, Japan	K. TOBITA National Inst. for Quantum & Radiological Science & Technology Aomori, Japan
J. HARRISON, B. LLOYD Culham Centre for Fusion Energy (CCFE) Oxfordshire, United Kingdom	Z. GAO Tsinghua University Beijing, China
Y.S. HWANG Seoul National University Seoul, South Korea	F. ALLADIO ENEA Rome, Italy
B. LIPSCHULTZ, H. WILSON (also CCFE) University of York York, United Kingdom	R.J. FONCK University of Wisconsin-Madison Madison, WI, USA

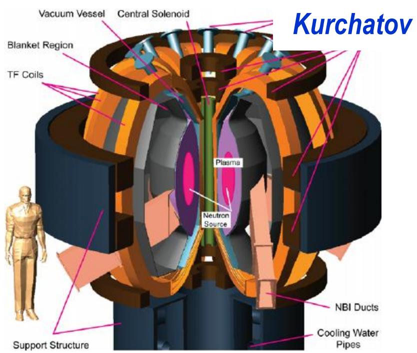
Abstract / Overview

The fusion community is assessing the suitability of the ST for applications to advance fusion energy including the development of:

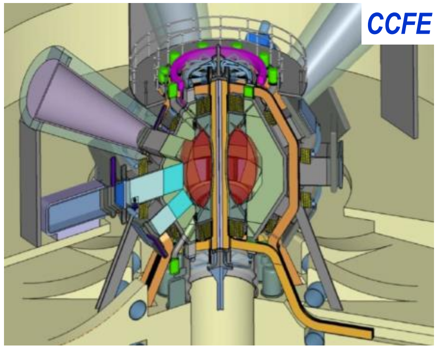
1. Solutions for the plasma-material-interface (PMI) challenge
2. Fusion neutron source / Fusion-fission hybrid systems
3. Fusion components capable of withstanding high fusion neutron flux/fluence including breeding blankets (Component Test / Fusion Nuclear Science Facility)
4. Demonstrating electricity break-even from a pure fusion system (Pilot Plant)
5. Electricity production at industrial levels in modular fusion power plants
6. Electricity production at industrial levels in larger-scale fusion power plants

This range of fusion energy development applications utilizing the ST is described, common application-driven research needs discussed, upcoming and recently achieved ST facility capabilities and relevant highlights described, and near-term prioritized ST research directions supporting longer-term fusion energy development applications presented.

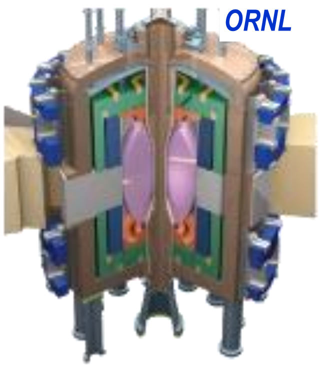
Possible next-step ST facilities

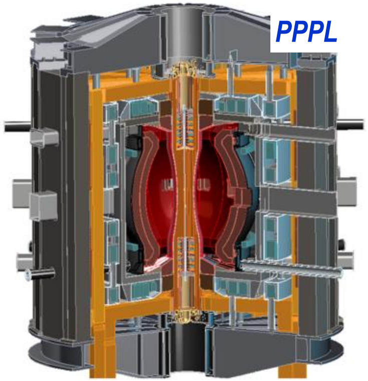


Fusion neutron source (FNS-ST)

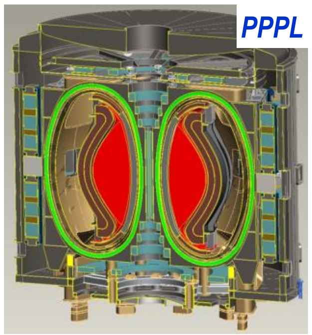


Component Test Facility (ST-CTF)



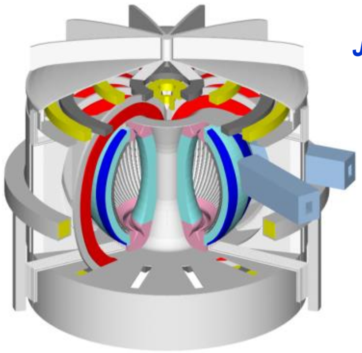


Fusion Nuclear Science Facility (ST-FNSF)

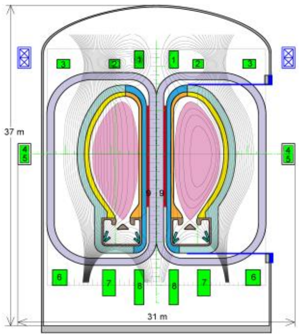


Low-A (A=2) HTS Pilot Plant

Japan



A=2.3 VECTOR

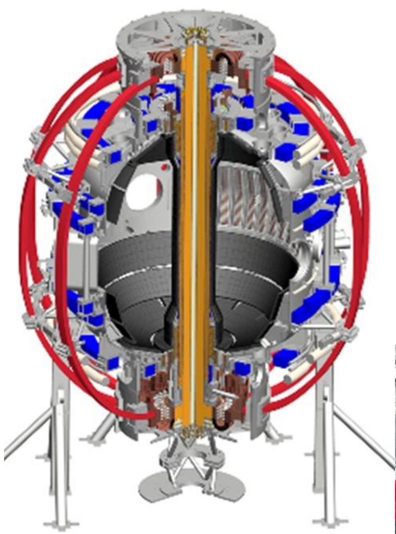


A=1.8 JUST

SC low-A reactors

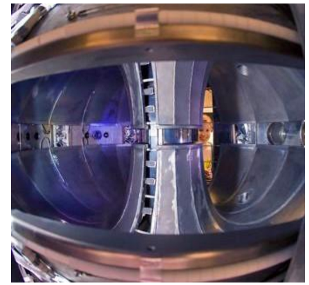
17 existing/near-term international ST facilities

NSTX-U, USA

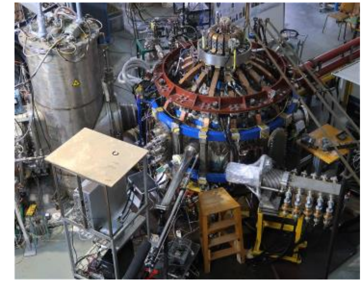


PEGASUS, USA

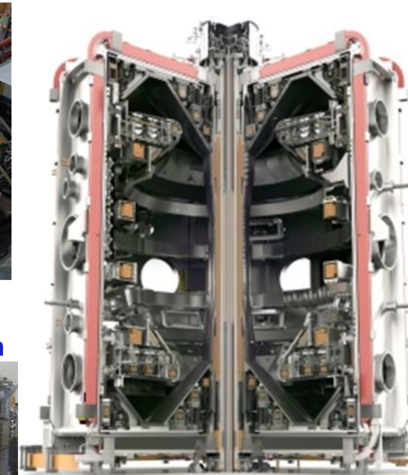
LTX-β / CDX-U, USA



GLOBUS-M2, Russia

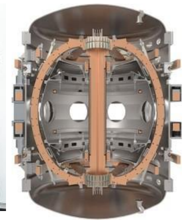


MAST-U, UK



PI3, Canada

ST40, UK

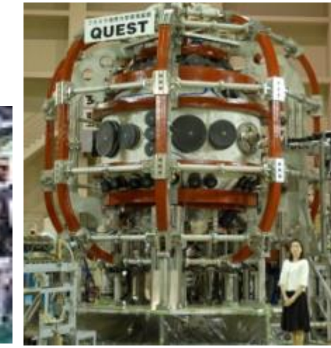


Proto Sphera, Italy

SUNIST, China

KTM, Kazakhstan

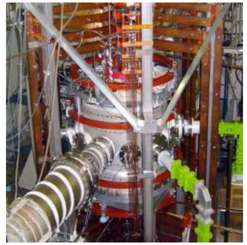
QUEST/CPD, Japan



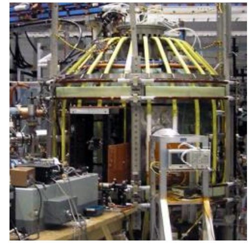
VEST, Korea

HIST, Japan

LATE, Japan



TST-2, Japan

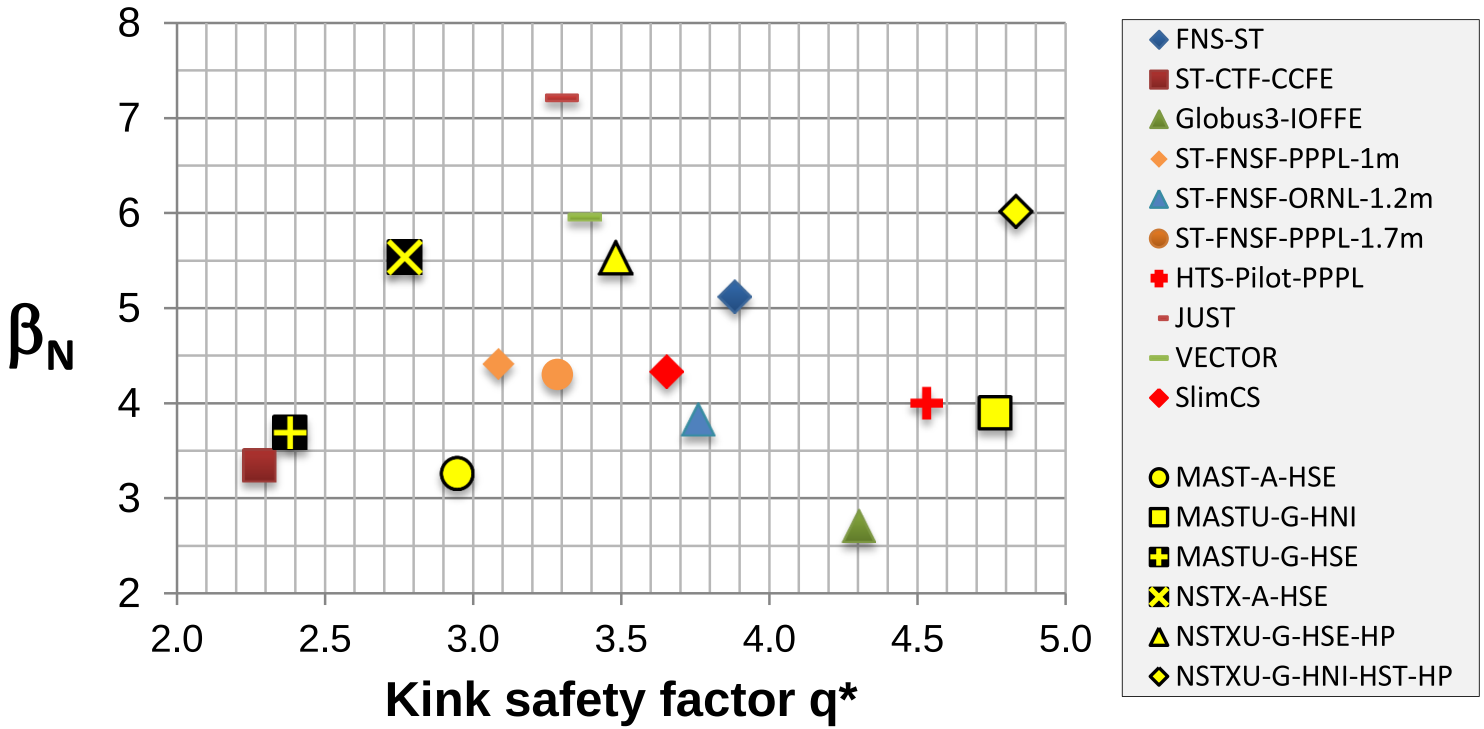


UTST, Japan

TS3/4, Japan

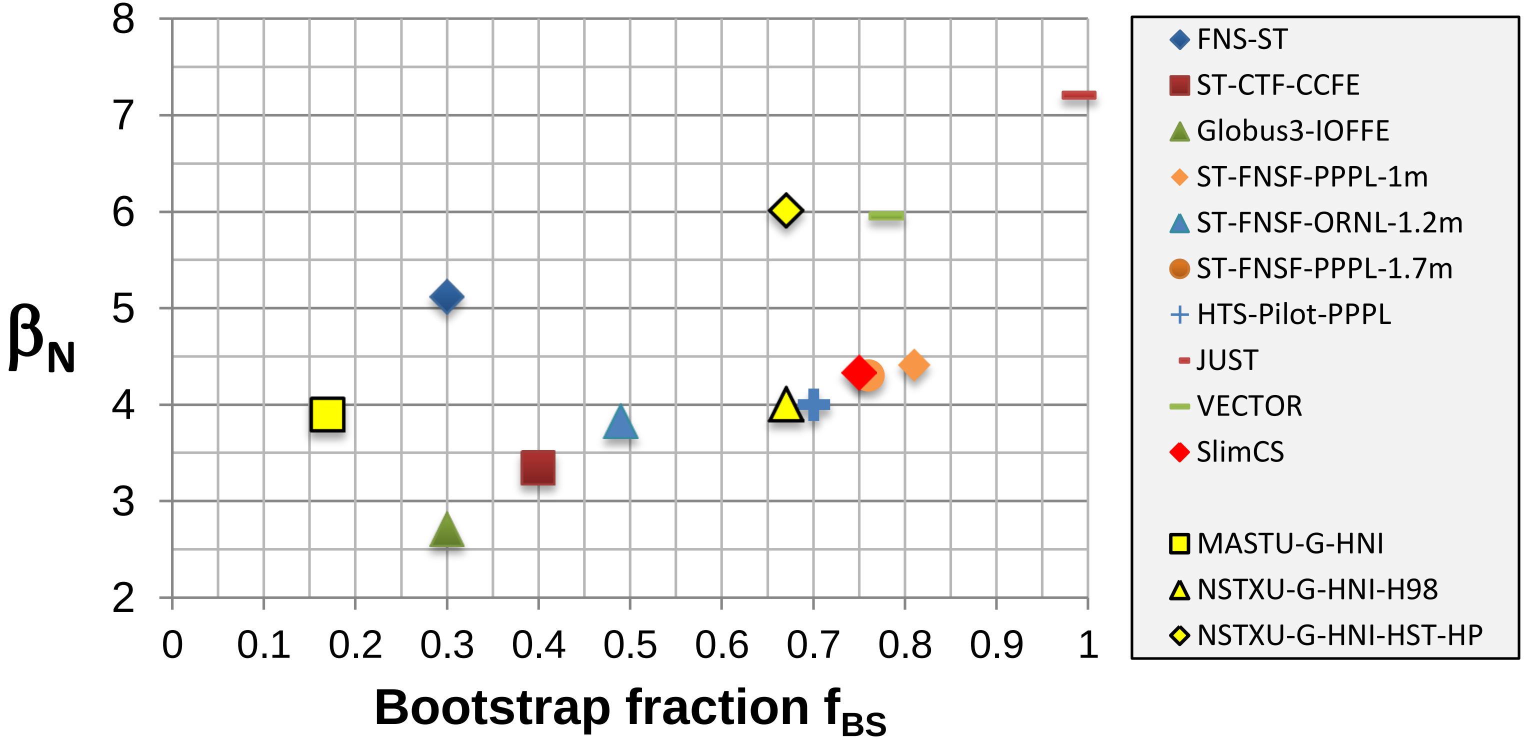
Near-term STTs support wide MHD stability space spanning nearly all proposed next-step ST configurations

- Exception: β_N = 7 of JUST exceeds expected near-term capabilities
  - Additional studies needed to assess MHD stability of JUST scenarios



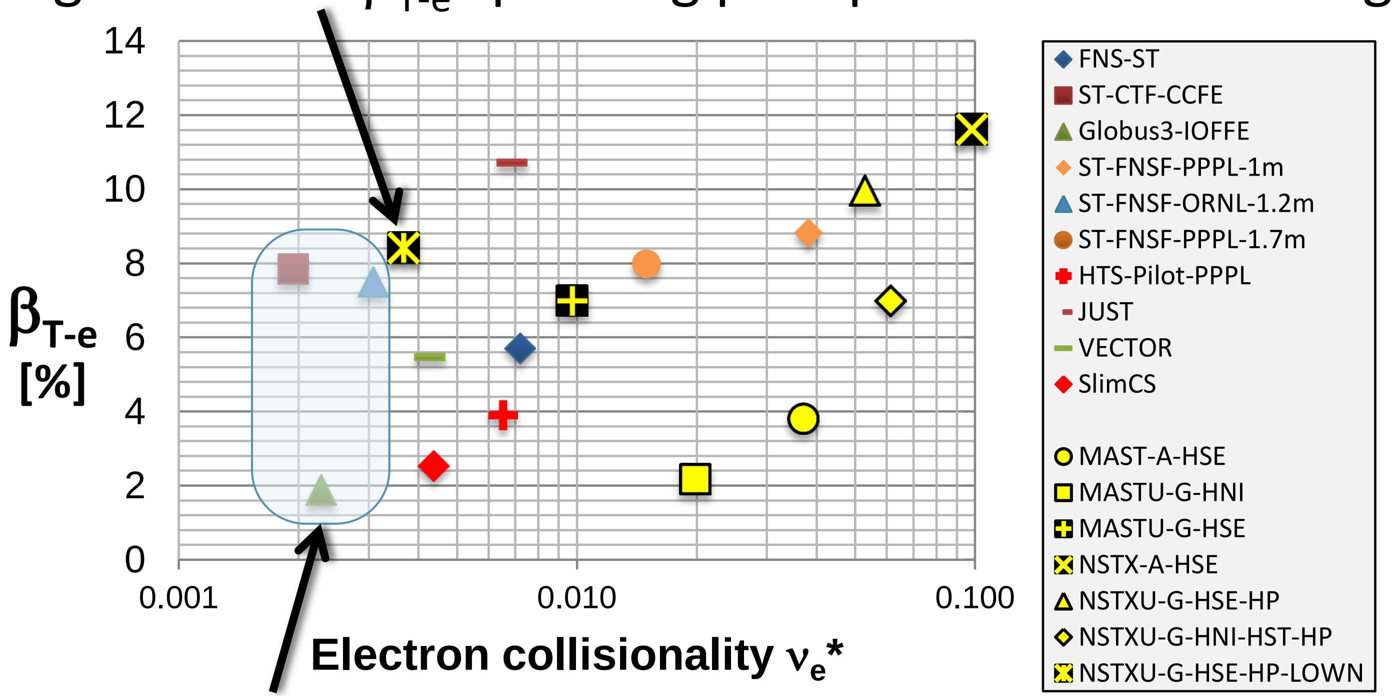
Near-term STs will need to access higher f_{BS} to study scenarios anticipated for steady-state ST reactors

- MAST-U / NSTX-U baseline non-inductive scenarios: $f_{BS} \approx$ 15-70%
- PPPL FNSF/Pilot and Japanese reactors: f_{BS} = 70-95% → research gap



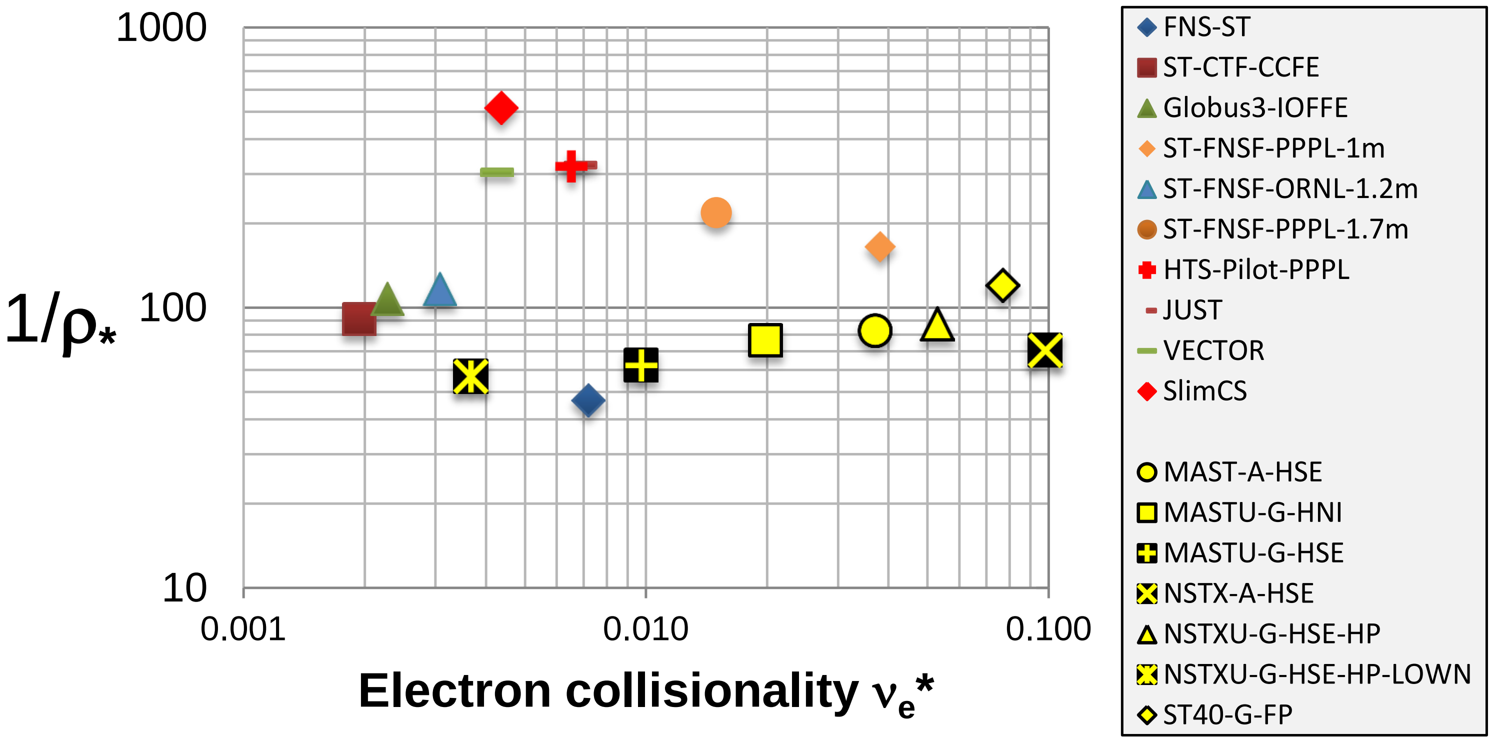
Near-term STs greatly expand access to high β at low ν*

- NSTX-U at full field, power and low density (f_{GW}=0.25) accesses low ν_e* at high electron $\beta_{T\text{-}e}$ spanning pilot plant and reactor regimes



- Low f_{GW}=0.25 CTF/FNSF projected to access ~2x lower ν_e*

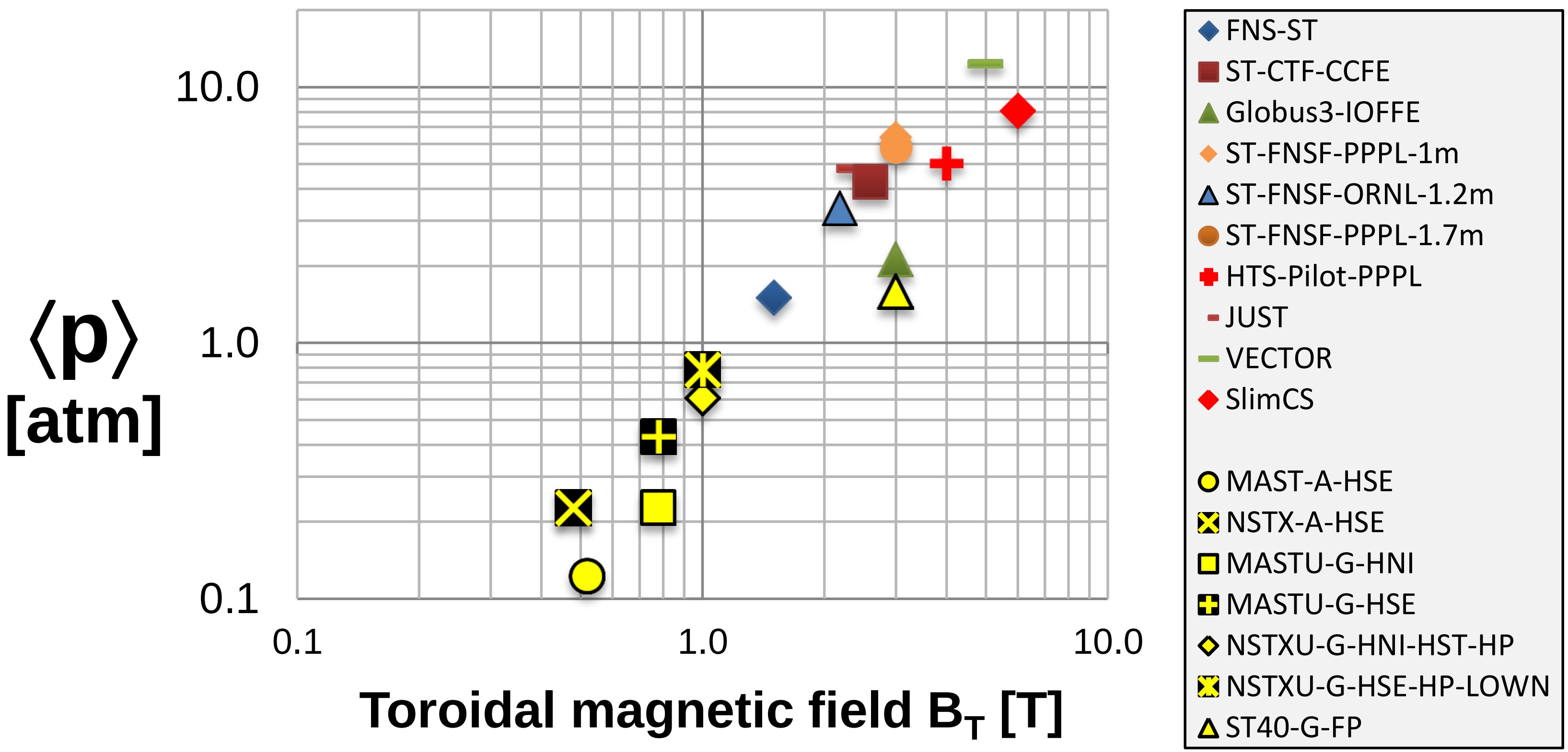
Near-term STs cannot access low ρ_* of larger next-steps



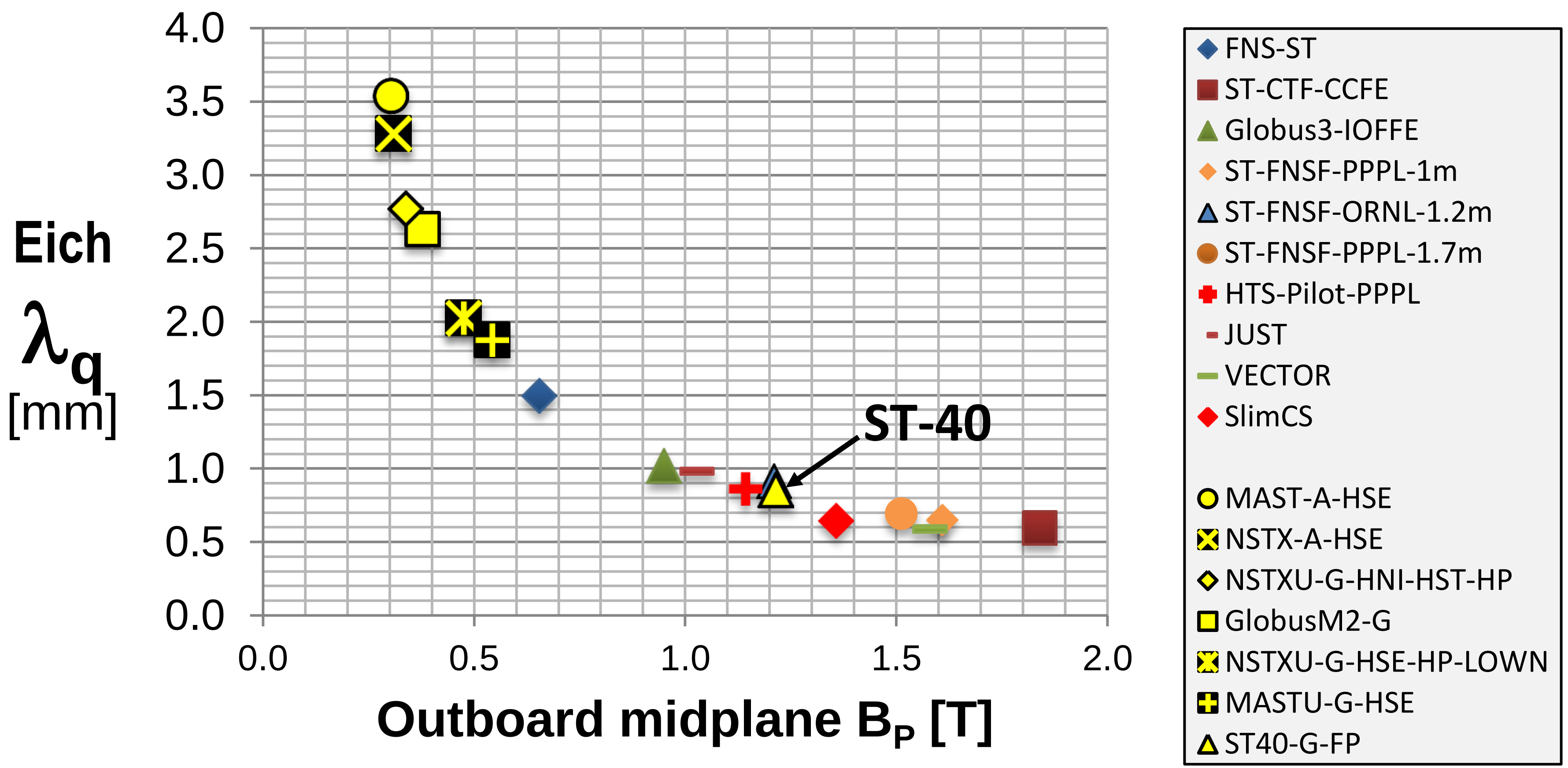
- Larger and/or higher field needed for more reactor-relevant ρ_*, ν^*

Near-term ST facilities targeting ⟨p⟩ ≈ 1 atm

- NSTX-U ≤ 0.8 atm, ST-40 ≤ 1.6 atm, next-steps: 1.5 to 12 atm

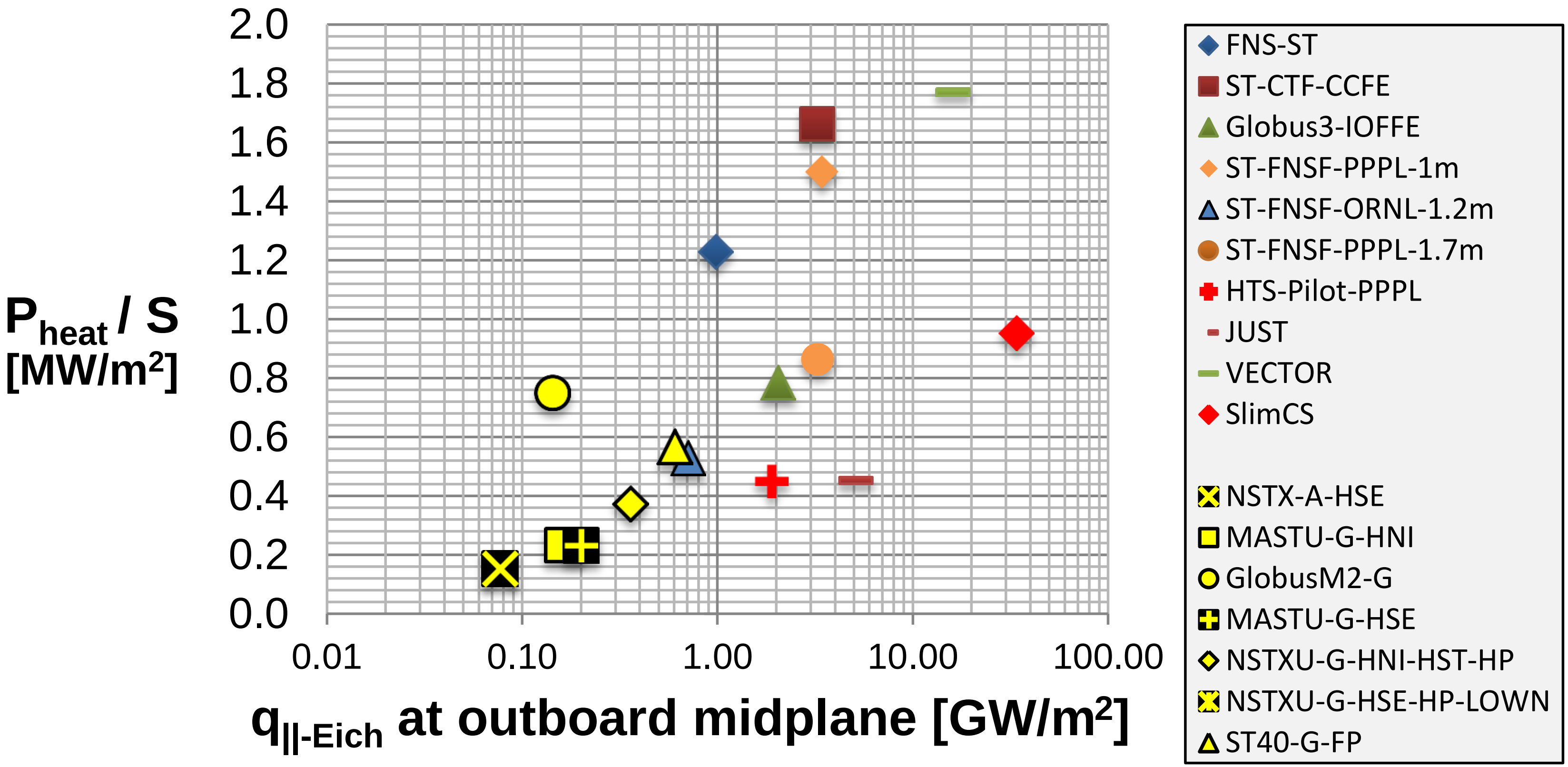


ST-40 could provide important tests of SOL-width scaling



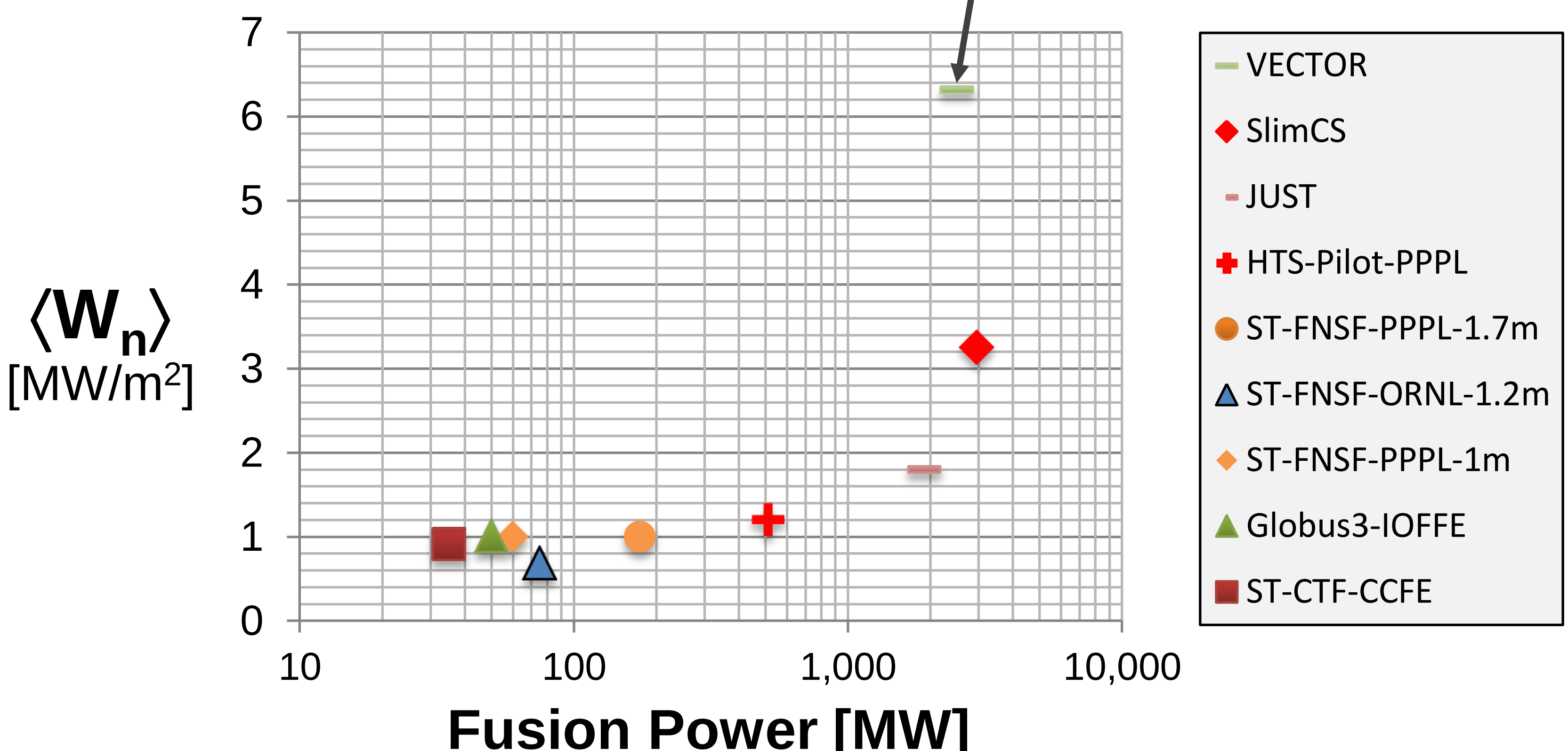
Next-steps extrapolate to higher P/S, very high $q_{||}$

- Advanced/new divertor concepts needed to mitigate $q_{||}$ = 1-30GW/m²



Most next-steps have neutron wall loading ≈ 1-3 MW/m^2

- **Exception**: (very) compact ST reactor VECTOR with $\langle W_n \rangle \approx 6$ MW/m^2



Summary of research needs to support next-steps

- MHD stability, access to low ν^* covered by near-term STs
- NSTX-U plans access to high f_{BS} and full non-inductive
  - Need to extend to 70-95% bootstrap fraction for reactor-relevant scenarios
- Near-term STs limited to $1/\rho_{i*} \leq \approx 50\text{-}120$
  - Need to extend to 200-300 with new facility (?) and/or leverage tokamak results
- Full performance ST-40 could test ST λ_q scaling to high B_P
- Very high $q_{||}$ in next-steps requires divertor innovation
  - MAST-U Super-X capability and/or liquid metals (LTX-β, long-term NSTX-U)
- Very compact ST reactors (R=3-4m) generate high neutron wall loading and require innovations in blankets and first-wall

Sign-up
