

# The Compelling Need for a Mid-Scale Stellarator Facility

National Stellarator Coordinating Committee

N.A. Pablant<sup>1,a</sup>, D. Anderson<sup>2,21</sup>, J.K. Anderson<sup>2</sup>, S. Anderson<sup>2</sup>, D. Andruczyk<sup>5</sup>, A. Bader<sup>2</sup>, S-G. Baek<sup>10</sup>, B. Ballinger<sup>10</sup>, L.B. Baylor<sup>3</sup>, N. Bertelli<sup>1</sup>, A. Bhattacharjee<sup>17,24</sup>, A.H. Boozer<sup>7</sup>, J. Canik<sup>3,21</sup>, A. Cerfon<sup>4</sup>, C.S. Chang<sup>1</sup>, R.M. Churchill<sup>1</sup>, D. Curreli<sup>5</sup>, S. De Pascuale<sup>3</sup>, L. Delgado-Aparicio<sup>1</sup>, D.R. Demers<sup>11</sup>, D.J. Den Hartog<sup>2</sup>, C. Deng<sup>2</sup>, A. Dominguez<sup>1</sup>, W. Dorland<sup>1</sup>, B.D.udson<sup>14</sup>, E. Edlund<sup>16</sup>, D. Ennis<sup>6</sup>, B.J. Faber<sup>2</sup>, R. Fonck<sup>2</sup>, J.P. Freidberg<sup>10</sup>, D.A. Gates<sup>18</sup>, B. Geiger<sup>2</sup>, A.H. Glasser<sup>15</sup>, R. Granetz<sup>10</sup>, W. Guttenfelder<sup>21</sup>, R. Hager<sup>1</sup>, K. C. Hammond<sup>1</sup>, J.D. Hanson<sup>6</sup>, J.H. Harris<sup>3</sup>, A. Hassam<sup>9</sup>, C.C. Hegna<sup>2,21</sup>, W. Heidbrink<sup>23</sup>, E.H. Hinson<sup>3</sup>, S.R. Hudson<sup>1</sup>, R. Jorge<sup>2</sup>, I. Joseph<sup>14</sup>, C.C.K. Klepper<sup>3</sup>, S. Knowlton<sup>6</sup>, E. Kolemen<sup>17</sup>, M.D. Kriete<sup>6</sup>, T. Kruger<sup>18</sup>, S. Kumar<sup>18</sup>, M. Landreman<sup>9</sup>, K.M. Likin<sup>2</sup>, Z. Lin<sup>23</sup>, J.D. Lore<sup>3</sup>, C. Lowe<sup>22</sup>, R. Lunsford<sup>1</sup>, N. Mandell<sup>1</sup>, D. Maurer<sup>6</sup>, C. Michoski<sup>19</sup>, A. Mollen<sup>1</sup>, H. Mynick<sup>1</sup>, S. Naik<sup>22</sup>, G.H. Neilson<sup>1</sup>, F. Nespoli<sup>1</sup>, F. Parra<sup>1</sup>, E. Paul<sup>7</sup>, M. Porkolab<sup>10</sup>, S. Prager<sup>1</sup>, M.J. Poeschel<sup>2</sup>, A. Punjabi<sup>22</sup>, A. Ram<sup>10</sup>, A. Reiman<sup>1</sup>, D. Ruzic<sup>5</sup>, J.S. Sarff<sup>2</sup>, J. Schmitt<sup>21</sup>, O. Schmitz<sup>2</sup>, J. Schwartz<sup>1</sup>, W. Sengupta<sup>17</sup>, S. Shiraiwa<sup>1</sup>, D.R. Smith<sup>2</sup>, D.A. Spong<sup>3</sup>, C.P.S. Swanson<sup>18</sup>, J.N. Talmadge<sup>2</sup>, J. Terry<sup>10</sup>, E.U. Unterberg<sup>3</sup>, A. Ware<sup>12</sup>, H. Weitzner<sup>4</sup>, A.M. Wright<sup>2</sup>, G. A. Wurden<sup>8</sup>, M. Zarnstorff<sup>1,24</sup>, B. Zhu<sup>14</sup>

\* Author affiliations at end of document

## 1. Introduction

In the pursuit of the goal of commercial fusion as an abundant and safe source of energy, the stellarator is a leading concept with compelling attractiveness and demonstrated performance. In this white paper we, as a community of US researchers from Universities, National Laboratories, and Private Industry, involved in studying the stellarator concept, lay out the programmatic and technical motivation for a new mid-size stellarator research facility in the US.

This contribution is complementary to several other whitepapers authored by members of our community which address different mid-scale stellarator aspects. A community based technical facility proposal has been prepared by F. Parra, *et al.*: [Flexible Stellarator Physics Facility](#). Two private stellarator companies have submitted proposals supporting the development of a mid-scale stellarator: Thea Energy (C.P.S. Swanson, *et al.*), Type One Energy (W. Guttenfelder, *et al.*).

## 2. Context

The motivation and vision for a mid-scale stellarator has been previously described in a series of publications and whitepapers surrounding the APS-DPP community planning process (CPP) in 2018-2020 which culminated in the documents: [A Community Plan for Fusion Energy](#) [1], and the [FESAC Long Range Plan](#) [2], both of which recommend the construction of a mid-scale stellarator facility. A few of the most relevant contributions are:

- [A U.S. Intermediate Scale Stellarator Experiment](#) [3]
- [Overview of and Reasoning for a Stellarator Strategic Block in the U.S. Fusion Program](#) [4]
- [Advancing the physics basis for quasi-helically symmetric stellarators](#) [5]
- [Stellarator Research Opportunities](#) [6]

While the motivations for such a mid-scale stellarator facility remain essentially unchanged (see Section 3), the many advancements in our understanding of stellarator physics since the

---

<sup>a</sup> Corresponding Author: N. Pablant, [npablant@pppl.gov](mailto:npablant@pppl.gov)

APS-DPP CPP have made such a facility ever more compelling. Key findings and developments in theory and modeling have enabled the design of experiments with superior optimization compared to existing devices, including: **(a)** the identification of quasi-symmetric configurations with excellent neoclassical and fast-ion confinement [7][8], **(b)** the introduction of new gyrokinetic codes capable of incorporating turbulent transport as an optimization objective (GX, [9]), **(c)** enhanced stellarator MHD modeling capabilities (M3D-C1 [10]), **(d)** validated understanding and modeling of neoclassical transport (SFINCS [11]), **(e)** tools for simplifying coils and reducing engineering tolerances, **(f)** further development of US stellarator optimization tools such as SIMSOPT [12], STELLOPT, and DESC [13], **(g)** improved equilibrium codes like DESC and SPEC, and **(h)** the utilization of dipole coils and permanent magnetics.

Moreover, there is growing fusion community interest and support for the stellarator, as demonstrated by the crowd that gathered to attend the 2024 APS-DPP mini-conference *The Stellarator Path to an FPP – a Public & Private Endeavor*.

### 3. Motivation and Outstanding Gaps

The U.S. program needs a mid-scale stellarator to realize the potential predicted by a solid body of theory and simulation. Notably, it is possible to combine the advantages of the stellarator (steady state, no current drive, no disruptions) with the good confinement regularly achieved in tokamaks. The top priorities for experimental work, and the motivation for a mid-scale stellarator experiment are:

- **Turbulence control.** A particular aspect of interest for stellarators is the exploitation of 3D magnetic fields to reduce and control turbulence, demonstrated theoretically through optimized configurations that have reduced simulated turbulent transport [14][15][16]. In addition, quasisymmetric configurations, with their associated low flow damping in the symmetry direction, provide another important mechanism for turbulent suppression through sheared flows [17].
- **Non-resonant divertor.** The non-resonant divertor [18] promises a robust exhaust solution for 3D configurations. Unlike other types of stellarator divertors, the non-resonant divertor should be resilient to equilibrium changes such as those introduced by finite bootstrap currents [19]. To fully take advantage of this US invention, one of the priorities of the US program must be the experimental demonstration and optimization of this exhaust solution.
- **MHD stability at large beta.** LHD and W7-AS have reported that the linear MHD beta limits can be crossed experimentally without catastrophic effects on the plasma [20][21]. If demonstrated in reactor-relevant plasmas, this resilience of the stellarator to theoretical MHD limits would be advantageous for an FPP. A combined program of theory, simulation and experiment is needed to elucidate the effect of MHD stability in different stellarator configurations.
- **Confinement of fast particles.** Confinement of fast particles has been considered a problem in some stellarator designs, but modern optimization techniques produce confinement similar to that in tokamaks [3][7][22][39]. Fast particle-driven instabilities can also enhance fast particle losses above neoclassical levels [23][40][41]. A US experiment is needed to demonstrate experimentally that configurations with the desired energetic particle confinement can be built and to assess the role of energetic particle instabilities.

- **Coil Simplification.** Many new theoretical techniques and computational tools now allow optimized stellarator magnetic fields to be generated through a variety of techniques in addition to the traditional modular coil design. Alongside these new developments, there are great advancements of modular coil designs that are robust against manufacturing tolerances and deformations. Moreover, coil designs which offer ample space between coils for attractive maintenance schemes and space for a breeding blanket have become attainable [24].

#### 4. Facility Description and Technical Proposal

Numerous concepts for stellarator designs exist which range from large helical coils, to modular 3D shaped coils, to a combination of saddle coils and planar coils. Moreover, the coil geometries can be used to form optimized magnetic field configurations that follow either a quasi-isodynamic magnetic field structure (W7-X) or use quasi-symmetry as underlying principle for improved confinement (HSX, MUSE).

The US has historically taken leadership of the quasisymmetric approach which provides excellent fast-ion confinement and facilitates flows in the direction of symmetry which may reduce anomalous transport due to flow shear similar to tokamaks. Therefore, it is proposed to continue this path and further augment US leadership in the field of quasi-symmetric stellarators with a new mid-scale device.

Within the provided budget range (\$180M - \$720M) different mission scopes and device sizes can be proposed. At the higher end of this range a device could simultaneously demonstrate ion and electron turbulence optimization, non-resonant divertor performance, fast-ion confinement, and core-edge integration at reactor relevant collisionalities. Such a stellarator could feature a major of  $R=3$  m, a minor radius  $a=0.6$  m, and a medium magnetic field strength of 2.5 T. At the lower end of the budget range a mission to study turbulence and non-resonant divertor strike-line physics is possible utilizing an experiment with a major radius of 2 m, and a magnetic field strength of 1.7 T.

A technical description of these options for a proposed mid-scale stellarator facility can be found in the whitepaper: [Flexible Stellarator Physics Facility](#), by F. Parra, *et al*, which has been co-authored by many members of the NSCC with affiliations ranging across universities, national laboratories and private industry.

#### 5. Synergy with Privately Funded Companies

There has been strong growth in private investment into fusion companies. As of writing, there are at least eight private companies that aim to develop fusion power plants based on the stellarator concept: **Type One Energy** (USA)[26], **Thea Energy** (USA)[27], **Stellarex** (USA)[28], **Proxima Fusion** (Germany)[29], **Gauss energy** (Germany)[30], **Helical Fusion** (Japan)[31], **Renaissance Fusion** (France)[32], and **nT-Tao** (Israel)[33]. Two of these companies have been awarded DoE grants that promote private-public partnerships through the highly competitive Fusion Milestone Program: Thea Energy and Type One Energy.

The private companies all aim to develop their intermediate and next-step devices on aggressive schedules aimed at the fastest possible path to a fusion power plant. Such aggressive commercially focused goals may in some cases limit the ability for these companies to pursue exploratory science and deep theoretical understanding and, depending on the

strategy employed by a given company, motivate the use of demonstrated designs and technologies relative to innovative, but unproven, concepts.

Several key ways in which a mid-scale user facility would complement and augment goals of the private fusion industry include:

- **Scientific innovation.** Experimental demonstration of innovative theoretical advancements and proposed novel concepts will lead to better designs that can be incorporated into future higher performing commercial designs. Examples are the development of new quasi-symmetric magnetic field configurations with unprecedented fast-ion confinement or the new turbulence metrics and codes which have allowed for the identification of turbulence optimized configurations. Another excellent example is the non-resonant divertor which is currently unproven but has the potential to drastically improve the stellarator concept.
- **Physics Studies and Theoretical Validation.** A research program that focuses both on basic science, in addition to applied physics and engineering aspects, is critical for validation of sophisticated theoretical models and the development of robust predictive capability. Such predictive model validation is a pressing need for the private companies. A national research program based on open science is enhanced by extensive participation and collaboration between universities, national labs and private industry.
- **Comprehensive Diagnostics.** A comprehensive suite of diagnostics are a strength of user-facilities and are needed for detailed validation of theoretical models.
- **Flexibility.** A stellarator built specifically for scientific innovation and a research mission can have a large amount of flexibility in terms of achievable magnetic configurations and divertor designs. For instance, a publicly funded stellarator does not exclusively need to demonstrate strongly improved confinement. Additional coil sets can be installed that allow for the comparison of optimized and degraded magnetic field structures.
- **Experimental Access.** The ability to conduct research in an experiment with low neutron activation is key to supporting the previous points.
- **Workforce Development.** The field of fusion science, and stellarator physics in particular, is complex and development requires a highly trained and experienced workforce. These workforce demands will only grow with the success of the private companies endeavors. A stellarator user-facility would provide ideal opportunities for education and training across a wide range of disciplines and with research timelines compatible with graduate education through the Ph.D. level.

The development of a mid-size stellarator user-facility presents many opportunities for extensive private-public partnerships including participation in design, construction, experimental operation, and coordinated development of open-source theoretical and engineering codes. Such a facility would also be highly beneficial towards the development of any other fusion configurations that utilize 3D shaping, and the computational tool development and validation will be broadly applicable to the fusion community.

Further discussion on benefits to the private industry and opportunities for partnerships can be found in the white papers submissions by the private companies Thea Energy (C.P.S. Swanson, *et al*) and Type One Energy (W. Guttenfelder, *et al*).

## 6. International Landscape and Opportunity for US Leadership

There are currently two major operating stellarator facilities in the world: W7-X in Germany, and the Large Helical Device (LHD) in Japan (LHD is scheduled to be shut down in 2025). Now, is a prime opportunity for the US to become a global leader with a new mid-size facility; such a US experiment would immediately become the most advanced stellarator in the world and would take a leading global role in stellarator research alongside W7-X.

Both W7-X and LHD have provided technical demonstration of high-power long-pulse operation and W7-X has experimentally confirmed successful neo-classical optimization for energy confinement [34][35] along with absence of impurity accumulation (largely due to turbulent transport) [36]. However, it has found its performance significantly hampered by turbulent ion heat transport [37]. W7-X has utilized profile shaping techniques with transient success [38], but further experimental work is needed. W7-X has also demonstrated energy handling with its island-divertor, including the ability to achieve robust heat detachment and impurity retention; however, particle exhaust remains a challenge.

The most promising solutions to these challenges, which are the motivation for the US mid-scale stellarator proposed herein, cannot be addressed on W7-X due to its specific design choices. Additional context on research activities and limitations at W7-X and the role of a new US stellarator facility in the global context are provided in the whitepaper by F. Parra, *et al.*

## 7. Synergy with Existing US Stellarator Experiments

A new mid-scale stellarator experiment would be embedded in the suite of existing US small stellarators primarily operated by universities. These stellarators have historically not only contributed to workforce development but have also laid the groundwork for the US leadership in quasi-symmetric stellarator research. The HSX stellarator at UW Madison, for instance, is the world's first quasi-symmetric stellarator experiment and has received significant attention as it successfully demonstrated the benefits of quasi-symmetry with respect to neoclassical transport. Moreover, the CTH stellarator in Auburn has pioneered research in terms of disruptive MHD events and is currently moving towards studies of non-resonant divertors, MUSE at PPPL is exploring the use of permanent magnets and quasi-axisymmetry, and HIDRA at U. Illinois is performing ground-breaking research with respect to liquid metal PFCs. New small experiments are being built such as the STAR\_Lite stellarator at Hampton university and the CXS experiment at Columbia university.

Moving forward, the existing small-scale stellarators will be used as test-beds for targeted theory studies and diagnostic development which can then be applied to the more reactor-relevant conditions of the proposed medium-scale experiment. Moreover, US students will gain hands-on working experience at the university scale experiments and can simultaneously perform high visibility through collaborations on the new user facility.

## 8. Conclusion

A new mid-size stellarator is needed to retire risks and innovate towards a high performance, economically attractive, stellarator Fusion Pilot Plant. Such a stellarator, built as a user facility, would make the US a global leader in stellarator understanding and strongly augment private industry, providing a program of innovative research, concept validation, theoretical advancement, and workforce development. Growing support and interest for stellarators by the fusion community and private industry affirms this rationale.

## Author Affiliations

- <sup>1</sup> Princeton Plasma Physics Laboratory, Princeton, NJ, USA
- <sup>2</sup> University of Wisconsin-Madison, Madison, WI, USA
- <sup>3</sup> Oak Ridge National Laboratory, Oak Ridge, TN, USA
- <sup>4</sup> New York University, New York, NY, USA
- <sup>5</sup> University of Illinois Champaign-Urbana, Urbana, IL, USA
- <sup>6</sup> Auburn University, Auburn, AL, USA
- <sup>7</sup> Columbia University, New York, NY, USA
- <sup>8</sup> Los Alamos National Laboratory, Los Alamos, NM, USA
- <sup>9</sup> University of Maryland, College Park, MD, USA
- <sup>10</sup> Massachusetts Institute of Technology, Cambridge, MA, USA
- <sup>11</sup> Xantho Technologies, Madison, WI, USA
- <sup>12</sup> University of Montana, Missoula, MT, USA
- <sup>14</sup> Lawrence Livermore National Laboratory, Livermore, CA, USA
- <sup>15</sup> Fusion Theory & Computation, Inc., Kingston, WA, USA
- <sup>16</sup> SUNY Cortland, Cortland, NY, USA
- <sup>17</sup> Princeton University, Princeton, NJ, USA
- <sup>18</sup> Thea Energy, Princeton, NJ, USA
- <sup>19</sup> University of Texas at Austin, Austin, TX, USA
- <sup>20</sup> Pennsylvania State University, University Park, PA, USA
- <sup>21</sup> Type One Energy, Madison, WI, USA
- <sup>22</sup> Hampton University, Hampton, VA, USA
- <sup>23</sup> University of California Irvine, Irvine, CA, USA
- <sup>24</sup> Stellarex Inc., Princeton, NJ, USA

## References

- [1] S. Baalrud et al. A Community Plan for Fusion Energy and Discovery Plasma Sciences, Tech. rep. American Physical Society (2020), <https://doi.org/10.48550/arXiv.2011.04806>
- [2] T. Carter et al. Powering the future: Fusion & plasmas, Tech. rep. US Department of Energy (2020), <https://doi.org/10.2172/1995209>
- [3] A. Bader et al. A U.S. Intermediate Scale Stellarator Experiment, *whitepaper* American Physical Society (2019), [https://drive.google.com/file/d/1WDf4Te7rb9hjqDDMQloKu\\_vvBPPxZlvJ](https://drive.google.com/file/d/1WDf4Te7rb9hjqDDMQloKu_vvBPPxZlvJ)
- [4] O. Schmitz et al. Overview of and Reasoning for a Stellarator Strategic Block in the U.S. Fusion Program, *whitepaper* American Physical Society (2019) [https://drive.google.com/file/d/14mUnyQx7U\\_N4cDn7nCdiJJFN1ouhgiO](https://drive.google.com/file/d/14mUnyQx7U_N4cDn7nCdiJJFN1ouhgiO)
- [5] A. Bader et al. Advancing the physics basis for quasi-helically symmetric stellarators, *Journal of Plasma Physics* 86.5 (2020), <https://doi.org/10.1017/S0022377820000963>

- [6] D.A. Gates et al. Stellarator Research Opportunities: A Report of the National Stellarator Coordinating Committee, Journal of Fusion Energy (2018), <https://doi.org/10.1007/s10894-018-0152-7>
- [7] M. Landreman et al. Optimization of quasi-symmetric stellarators with self-consistent bootstrap current and energetic particle confinement, Physics of Plasmas (2022), <https://doi.org/10.1063/5.0098166>
- [8] M. Landreman and E. Paul, Magnetic fields with precise quasisymmetry for plasma confinement, Physical Review Letters (2022), <https://doi.org/10.1103/PhysRevLett.128.035001>
- [9] N.R. Mandell et al. Laguerre–Hermite pseudo-spectral velocity formulation of gyrokinetics, Journal of Plasma Physics (2018), <https://doi.org/10.1017/S0022377818000041>
- [10] Y. Zhou et al. Approach to nonlinear magnetohydrodynamic simulations in stellarator geometry, Nuclear Fusion (2021), <https://doi.org/10.1088/1741-4326/ac0b35>
- [11] M. Landreman et al. Comparison of particle trajectories and collision operators for collisional transport in nonaxisymmetric plasmas, Physics of Plasmas (2014), <https://doi.org/10.1063/1.4870077>
- [12] M. Landreman et al. SIMSOPT: A flexible framework for stellarator optimization, Journal of Open Source Software (2021), <https://doi.org/10.21105/joss.03525>
- [13] D.W. Dudt and E. Kolemen, DESC: A stellarator equilibrium solver, Physics of Plasmas (2020), <https://doi.org/10.1063/5.0020743>
- [14] H. E. Mynick, N. Pomphrey, and P. Xanthopoulos Optimizing stellarators for turbulent transport, Physical Review Letters (2010), <https://doi.org/10.1103/PhysRevLett.105.095004>
- [15] R. Jorge et al. Direct Microstability Optimization of Stellarator Devices, *preprint* (2023), <https://arxiv.org/abs/2301.09356>
- [16] P. Kim et al. Optimization of Nonlinear Turbulence in Stellarators, *preprint* (2023), <https://arxiv.org/abs/2310.18842>
- [17] T. Estrada and C. Hidalgo, H-mode transition in the TJ-II stellarator plasmas, Phil. Trans. R. Soc. (2023) A.3812021022920210229 <http://doi.org/10.1098/rsta.2021.0229>
- [18] A. Punjabi and A.H. Boozer Simulation of non-resonant stellarator divertor, Physics of Plasmas (2020), <https://doi.org/10.1063/1.5113907>

- [19] A. Bader et al. HSX as an example of a resilient non-resonant divertor, Physics of Plasmas (2017), <https://doi.org/10.1063/1.4978494>
- [20] M. Fujiwara et al. Overview of LHD experiments, Nuclear Fusion (2001), <https://doi.org/10.1088/0029-5515/41/10/305>
- [21] A. Weller et al. Experiments close to the beta-limit in W7-AS, Plasma Physics and Controlled Fusion (2003), <https://doi.org/10.1088/0741-3335/45/12A/019>
- [22] E Sánchez et al. A quasi-isodynamic configuration with good confinement of fast ions at low plasma  $\beta$ , Nuclear Fusion (2023), <https://doi.org/10.1088/1741-4326/accd82>
- [23] E.J. Paul et al. Fast ion transport in quasisymmetric equilibria in the presence of a resonant Alfvénic perturbation, *preprint* (2023), <https://doi.org/10.48550/arXiv.2306.12531>
- [24] R. Jorge et al. Single-stage stellarator optimization: combining coils with fixed boundary equilibria, Plasma Physics and Controlled Fusion (2023), <https://doi.org/10.1088/1361-6587/acd957>
- [25] J.A. Alonso et al. Physics design point of high-field stellarator reactors, Nuclear Fusion (2022), <https://doi.org/10.1088/1741-4326/ac49ac>
- [26] Type One Energy, *company website* (2024), <https://typeoneenergy.com>
- [27] Thea Energy, *company website* (2024), <https://thea.energy>
- [28] Stellarex, *company website* (2024), <https://stellarex.energy>
- [29] Proxima Fusion, *company website* (2024), <https://www.proximafusion.com>
- [30] Gauss energy, *company website* (2024), <https://www.gauss-fusion.com>
- [31] Helical Fusion, *company website* (2024), <https://www.helicalfusion.com/en>
- [32] Renaissance Fusion, *company website* (2024), <https://renfusion.eu>
- [33] nT-Tao, *company website* (2024), <https://www.nt-tao.com>
- [34] CD Beidler et al. Demonstration of reduced neoclassical energy transport in Wendelstein 7-X, Nature 596.7871 (2021), <https://doi.org/10.1038/s41586-021-03687-w>
- [35] N. Pablant et al. Investigation of the neoclassical ambipolar electric field in ion-root plasmas on W7-X, Nuclear Fusion (2020), <https://doi.org/10.1088/1741-4326/ab6ea8>

- [36] A. Langenberg et al. Impurity transport in ion- and electron-root confinement scenarios at Wendelstein 7-X, Nuclear Fusion (2021), <https://doi.org/10.1088/1741-4326/ac24d4>
- [37] M.N.A. Beurskens et al. Ion temperature clamping in Wendelstein 7-X electron cyclotron heated plasmas, Nuclear Fusion (2021), <https://doi.org/10.1088/1741-4326/ac1653>
- [38] S.A. Bozhentkov et al. High-performance plasmas after pellet injections in Wendelstein 7-X, Nuclear Fusion (2020), <https://doi.org/10.1088/1741-4326/ab7867>
- [39] A. Bader et al. Stellarator equilibria with reactor relevant energetic particle losses, Journal of Plasma Physics (2019), <https://doi.org/10.1017/S0022377819000680>
- [40] D.A. Spong et al. Global linear gyrokinetic simulation of energetic particle-driven instabilities in the LHD stellarator, Nuclear Fusion (2017), <https://doi.org/10.1088/1741-4326/aa7601>
- [41] J. Varela, et al. Analysis of Alfvén eigenmode destabilization by energetic particles in Large Helical Device using a Landau-closure model, Nuclear Fusion (2017), <https://doi.org/10.1088/1741-4326/aa5d04>