Compact Stellarator Approach to DEMO

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Compact stellarators address DEMO issues

- Compact stellarators $\Rightarrow$ confinement physics as in tokamaks
- Crucial advantages for steady-state reactors
  - quiescent, steady-state, high-β, disruption-free
  - no power input to sustain current or rotation $\Rightarrow$ true ignition
  - no profile control or close fitting walls
  - high density limited only by power density
    - * reduced α slowing-down time $\Rightarrow$ reduced α instability drive
    - * less energetic particle fluxes to wall
  - 3-D shaping of plasma edge
  - optimal control of distribution of particle fluxes, radiation losses
- Features shown in high-R/a, non-symmetric stellarators
- Develops important tools for 3-D control of tokamaks
  - ELMs, RWMs, disruptions, plasma-wall interactions

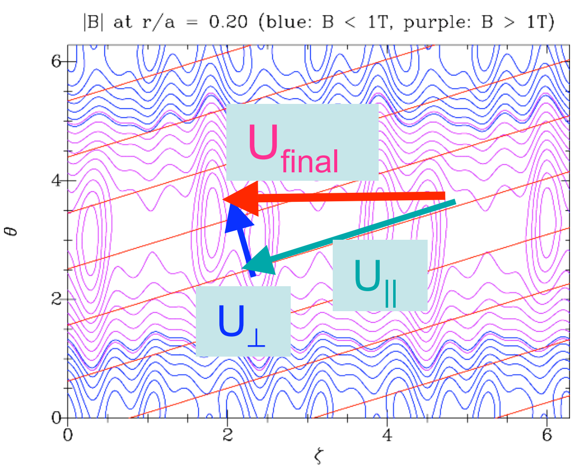
Quasi-symmetry ⇒ key to compact stellarator

- Quasi-symmetry ⇒ minimize variation of |***B***| in symmetry direction in straight field line coordinates
  - toroidal, poloidal or helical quasi-symmetry
  - conserved canonical momentum as in axisymmetric system
    ⇒ good orbit confinement
  - reduced effective field ripple along ***B***
    ⇒ reduced neoclassical transport (depends only on |***B***|)
    ⇒ allows strong rotational transform at lower R/a
  - reduced viscous damping in the symmetry direction
    ⇒ promotes large ***E*** x ***B*** flow shear ⇒ reduced anom. xport
- Exploits physics commonality with tokamaks
- Reduced viscosity, neoclass. xport demonstrated in HSX

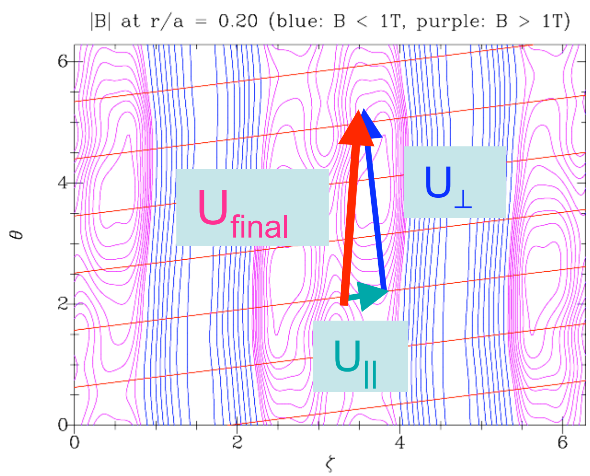
Quasi-symmetry ⇒ confinement improvement

Quasi-symmetry: small $|\boldsymbol{B}|$ variation in a symmetry direction

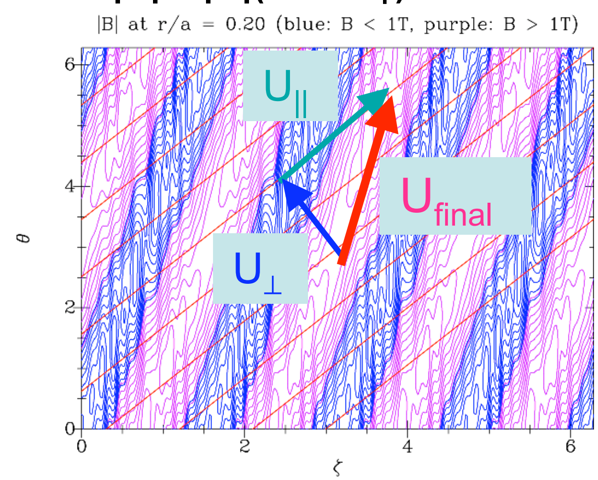
Quasi-toroidal symmetry
$|B| \sim |B|(\theta)$ NCSX



Quasi-poloidal symmetry
$|B| \sim |B|(\phi)$ QPS



Quasi-helical symmetry
$|B| \sim |B|(m\theta - n\phi)$ HSX

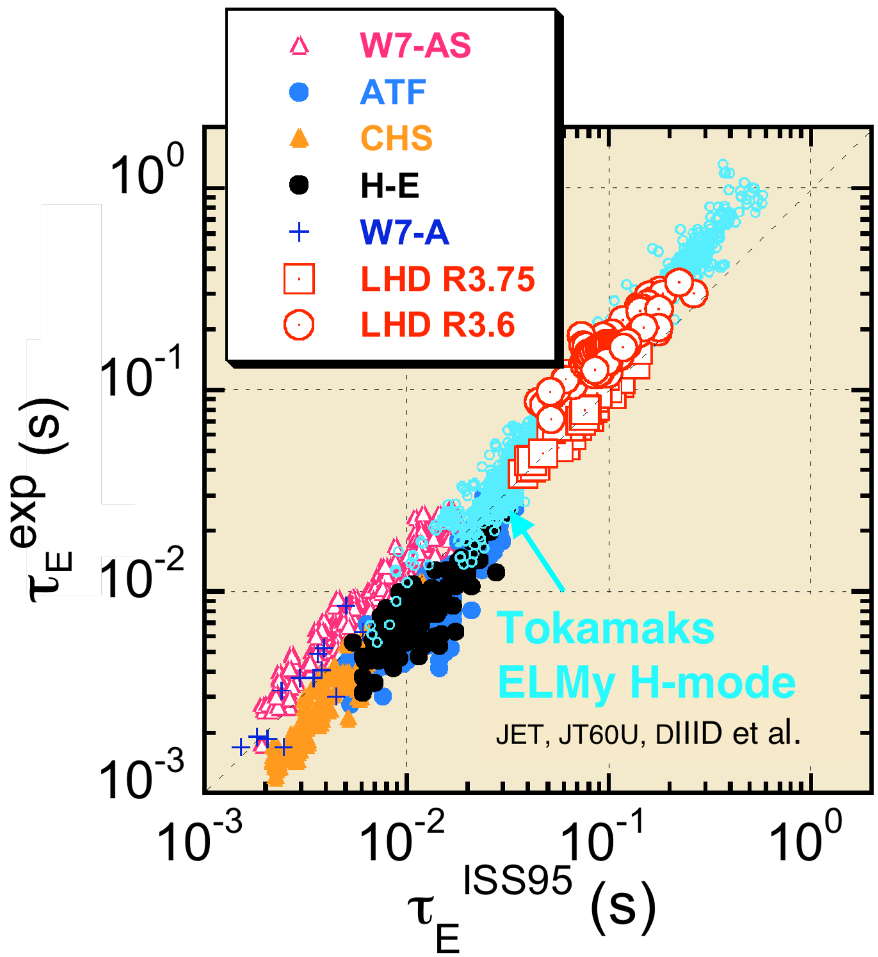


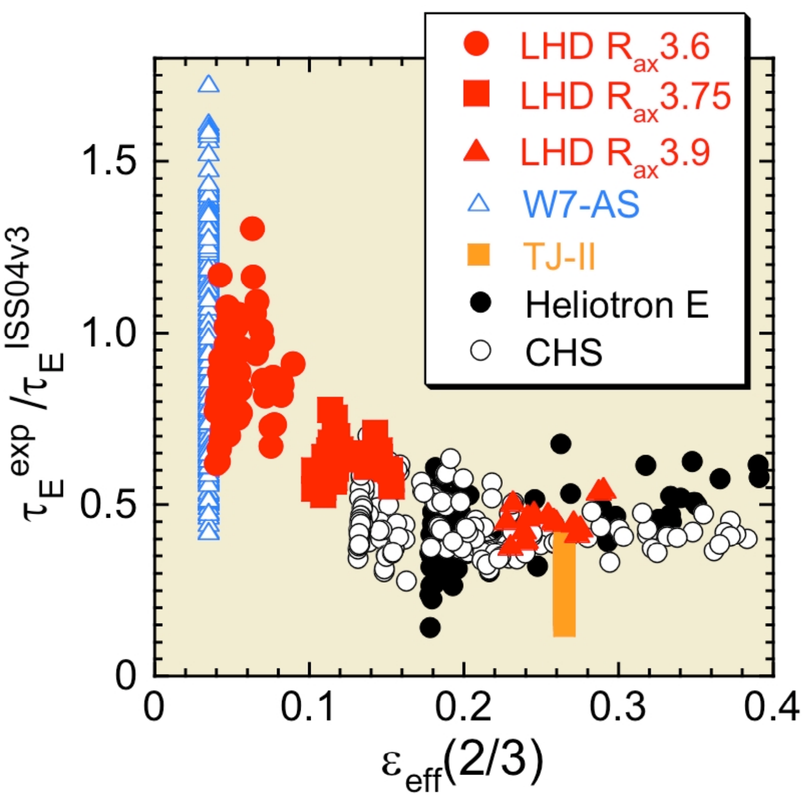
⇒ lower viscosity ⇒ lower flow damping in sym. direction

⇒ large flow shear and breakup of turbulent eddies

Stellarator confinement similar to tokamak

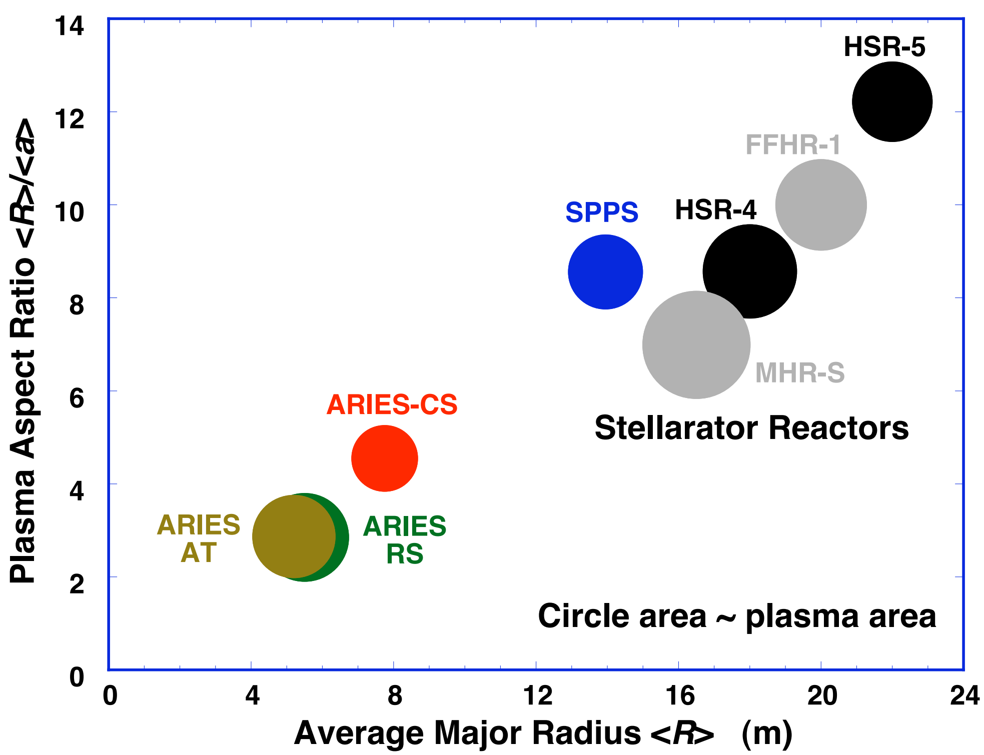
- Comparable plasma for same volume, field & power
- Very low effective ripple (ε_{eff}) in compact stellarator $\Rightarrow$ enhance confinement ?

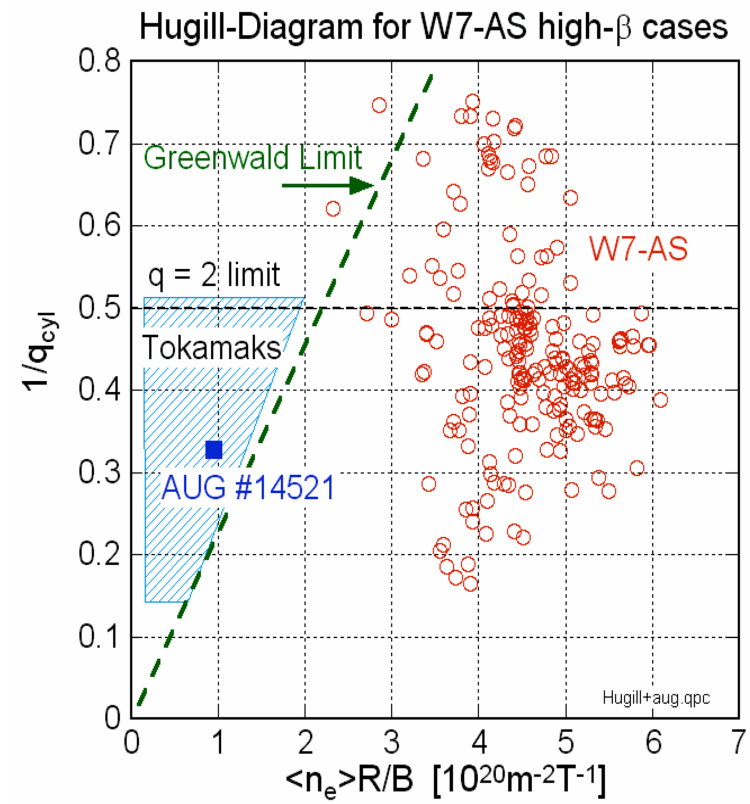




ARIES-CS reactors ⇒ competitive with tokamak

- Costing approach, algorithms as in other ARIES; updated mat'l costs
- CoE similar to that for ARIES-AT & ARIES-RS
- Main issues: coil complexity & optimizing divertor geometry
- High density operation reduces α losses, reduces divertor load





Issues to be addressed before CS DEMO

- **Physics issues include**
  - size scaling at a/ρ_i relevant to DEMO
    - $\Rightarrow$ adequate thermal confinement and α confinement
  - workable steady-state divertor
  - simpler coil design, cheaper construction
- **How can issues be addressed?**
  - build on results from ITER, other tokamaks: overseas stellarators; and materials & component development programs
  - results of US compact stellarator program: NCSX, QPS, HSX, CTH
  - results from large, next-generation compact stellarator
    - * extend parameters to fill gaps
    - * D-T operation needed . . . or simulate α's with tail ion heating ?
    - * superconducting vs extrapolation from LHD and W 7-X?
    - * experience constructing superconducting stellarators & ITER sufficient to develop reliable cost estimates for a CS DEMO?

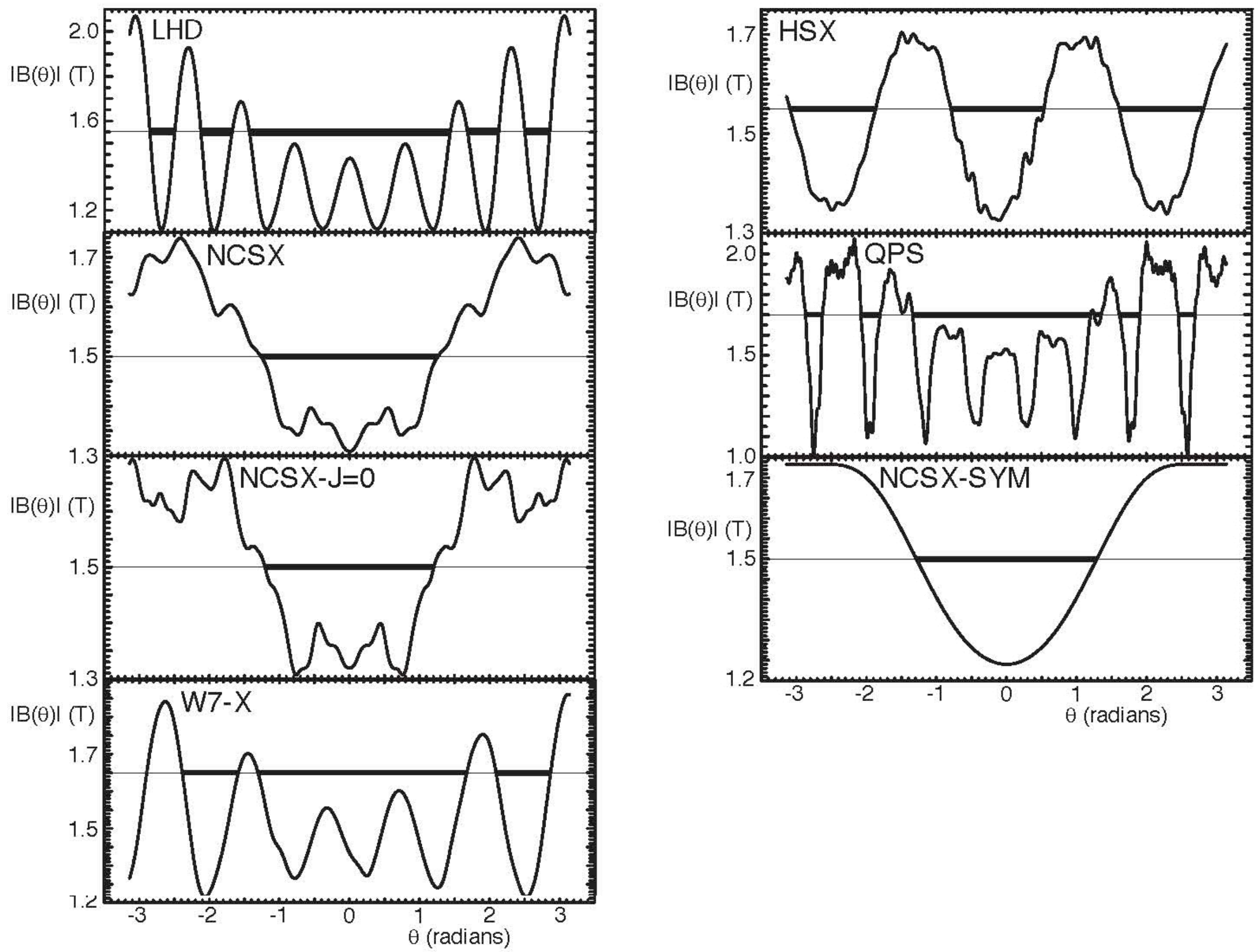
Start now on definition of Next Generation Compact Stellarator (NGCS)

- US compact stellarators + foreign stellarators (LHD, W 7-X) $\Rightarrow$ development of NGCS to overlap with ITER
  - integrate burning plasma experience into a compact stellarator configuration better suited for a DEMO
- Study can begin now to
  - assess options for NGCS based on
    - NCSX and QPS physics principles
    - 3-D plasma theory & simulation
  - explore tradeoffs, sensitivity; costing models
  - optimized configurations with simpler coils, enhanced flows, improved confinement, robust flux surfaces & high β limits
  - integrate full 3-D plasma, RF heating, divertor & boundary physics in assessing NGCS performance

Conclusions

- Compact stellarators offer:
  - tokamak-like confinement physics
  - ignited, sustained plasma operation without external power input
  - passive safety to MHD instabilities, including disruptions
  - reduced energy and controlled distribution of particle flux to walls
  - reactor size & CoE comparable to advanced tokamak
  - 3-D coils vs 50-200 MW of CW current drive + feedback systems
- DEMO concept evolution ⇒ clear opportunity for US leadership
  - compact stellarator = US innovation
  - aimed at convergence with tokamak/ITER program
  - well differentiated from overseas stellarator & tokamak programs
  - coordinated multi-inst. program: exp’ts, theory/comp., engineering
  - explore elements of improved toroidal reactor
  - define performance extension device to overlap with ITER

|B| variation for various stellarators



Rewoldt, Ku, & Tang, PPPL-4082 (2005)