IEEE-CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), June 2023.
Presentation given at Coated Conductors for Applications Workshop, Houston, TX, USA, April 2023.

RENAISSANCE FUSION

HTS coils without HTS tapes: Direct deposition and patterning on wide surfaces

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CCA 2023 Workshop, Houston 04-04-2023

A fusion of talents!

10 nationalités

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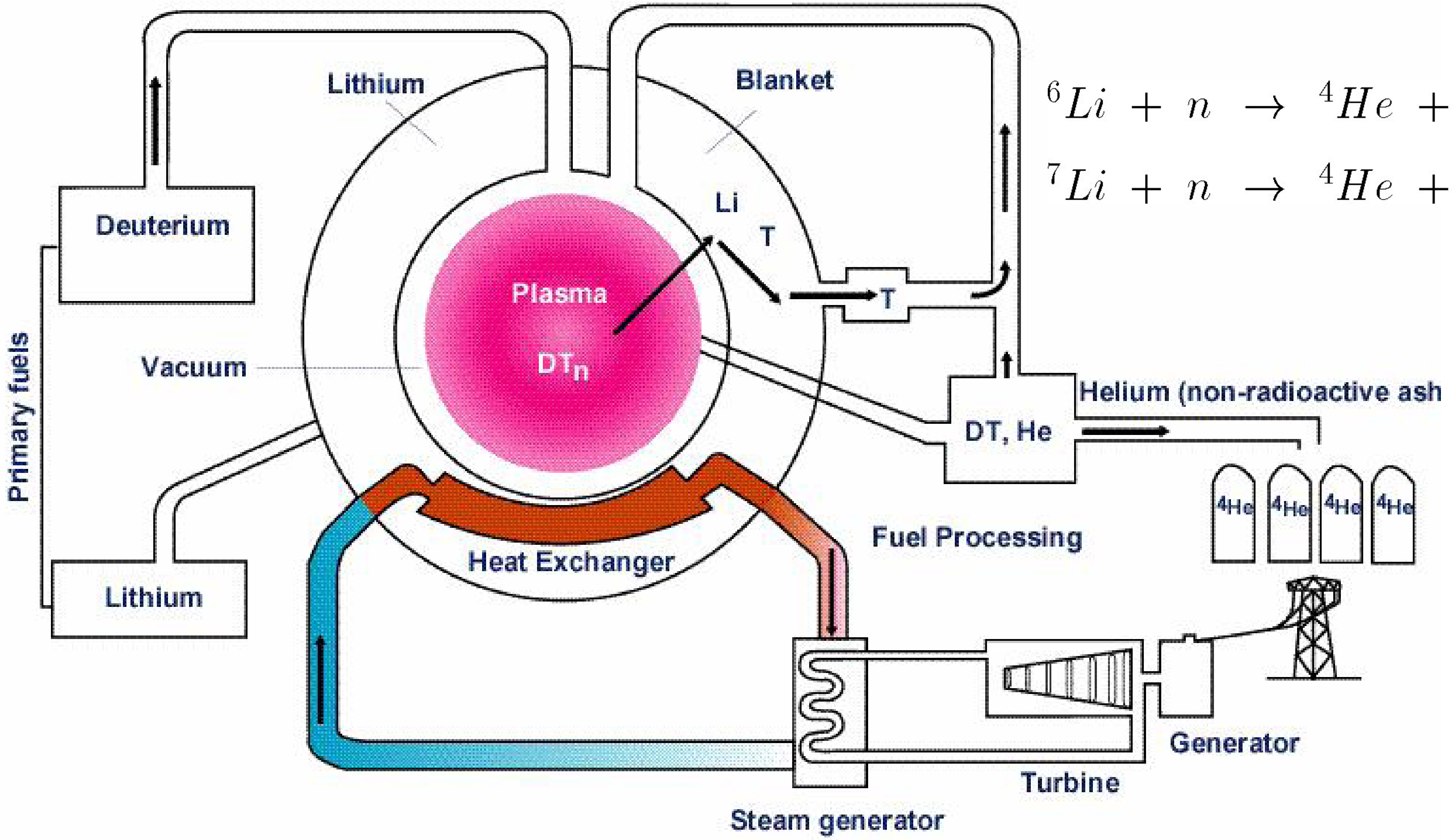

$$^{6}Li + n \rightarrow {}^{4}He + T$$

$$^{7}Li + n \rightarrow {}^{4}He + T + n'$$

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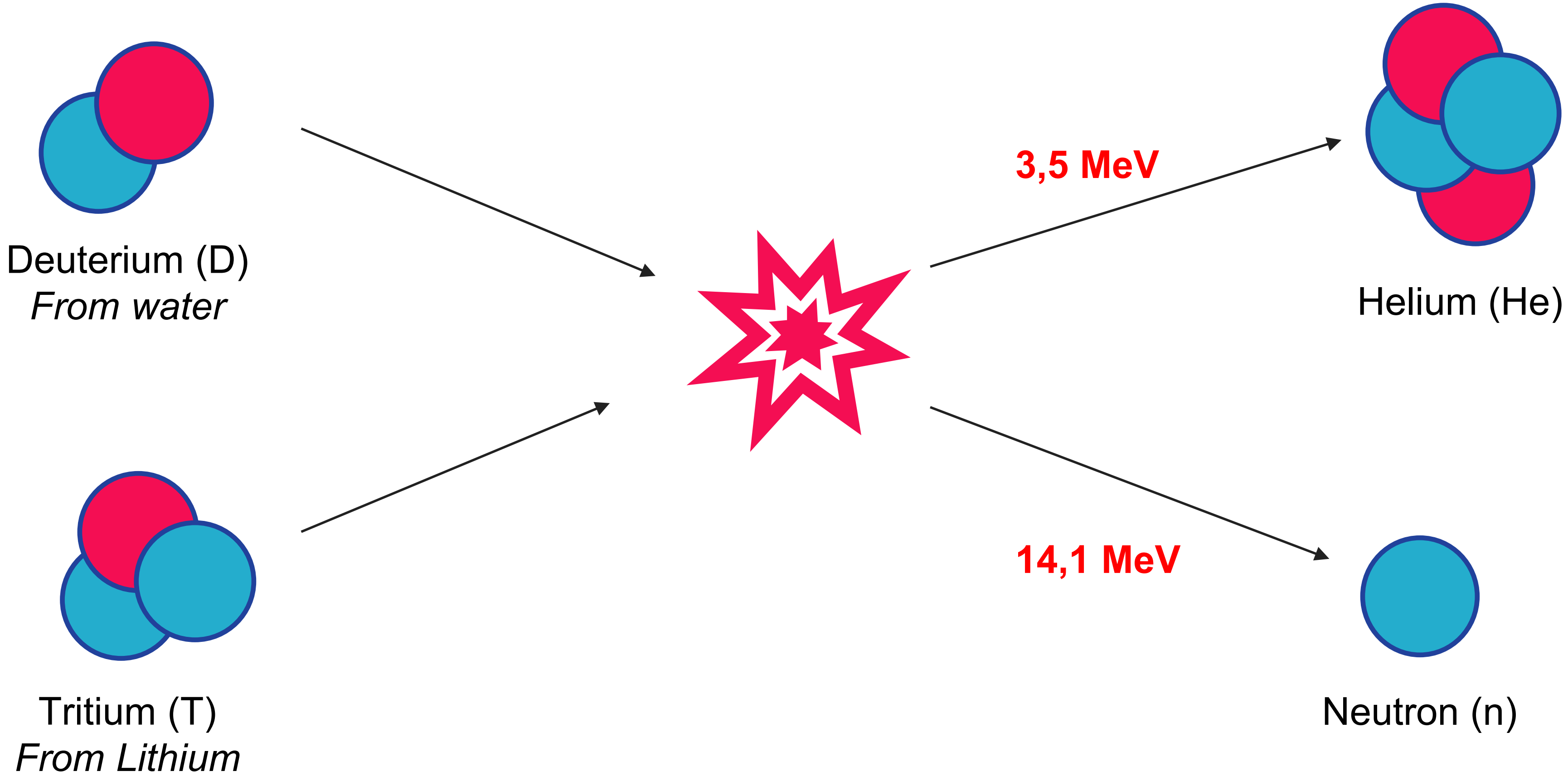
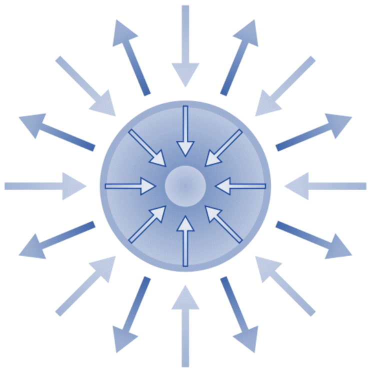
Deuterium-Tritium Fusion



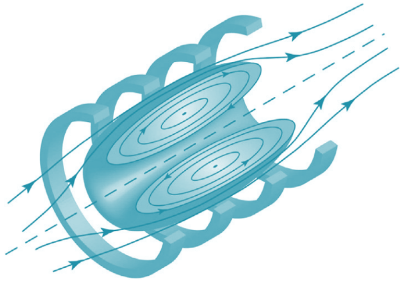
For D-T, **Triple product** $n\,T\,\tau_E > 3 \cdot 10^{21}\mathrm{m}^{-3}\mathrm{keV\ s}$

INERTIAL
Compression, e.g. by lasers



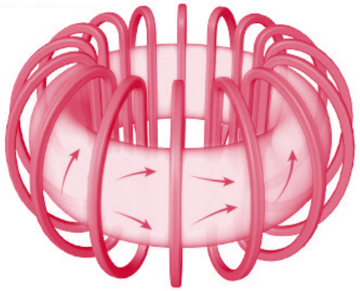
Improves with:
- **Laser power**
- **Target nanofabrication**
- **Uniformity of compression**
- **Repetition rate**

MAGNETO-INERTIAL
Magnets & Compression



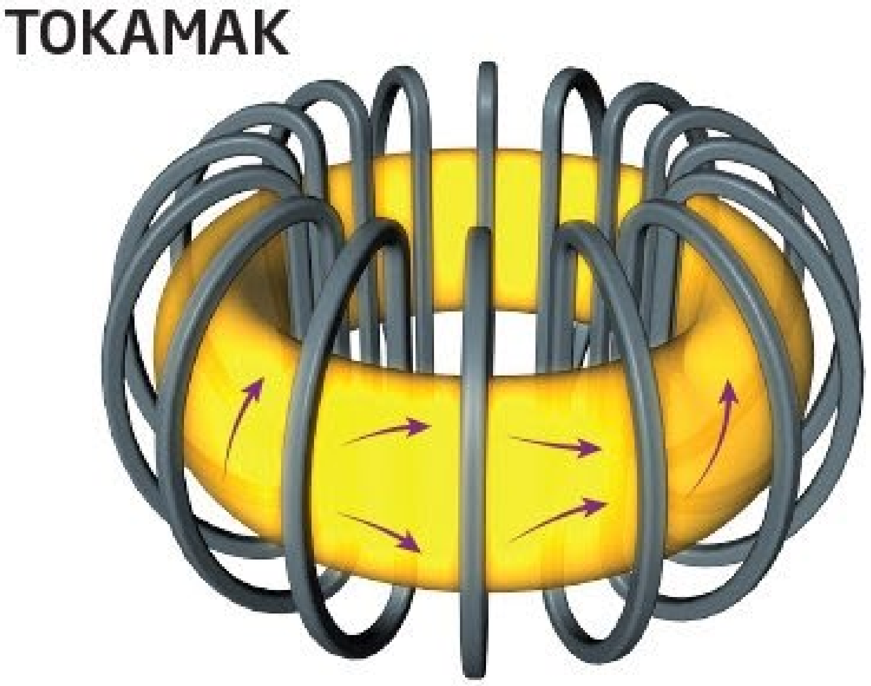
***Improves with*:**
- **Uniformity of compression**
- **Compression ratio**
- **Plasma purity**

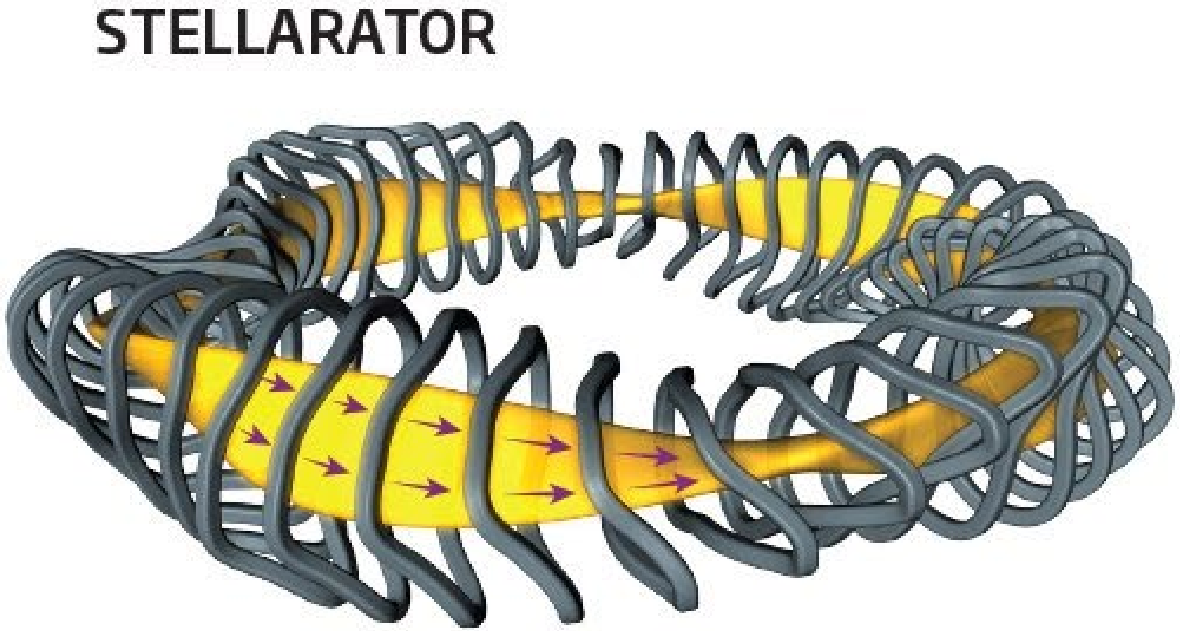
MAGNETIC
Confinement by strong magnets



***Improves with*:**
- **Size of device**
- **Magnetic field strength**

Tokamaks vs. stellarators





Simple to build

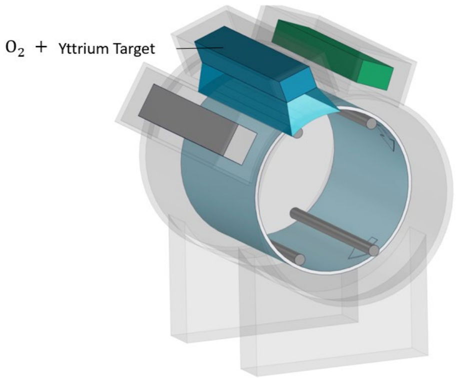
Difficult to operate (pulsed, unstable, subject to "disruptions", regulatory issues)

Difficult to build

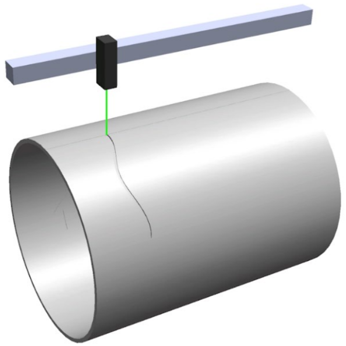
Simple to operate (steady-state, stable)

…and simplify HTS manufacturing

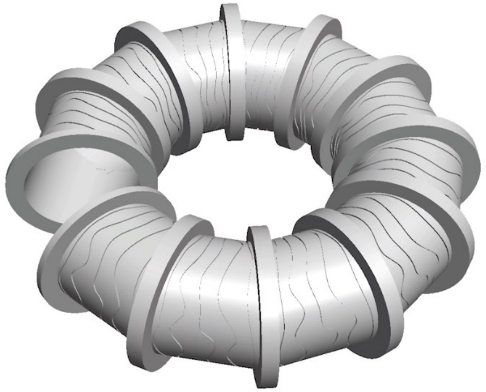
Deposition



Patterning



Assembly



2 machines instead of 7

7x faster process

Multi-layer

3D → two 1D movements

Portable sub-assemblies
(cryostat + vessel + coil-set)

Patents pending

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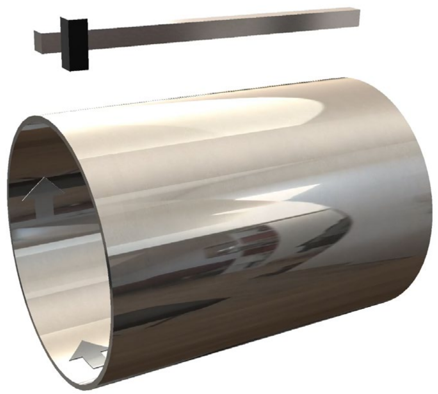
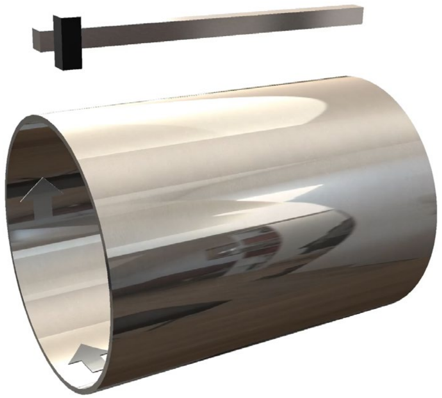
Many other applications

MRI

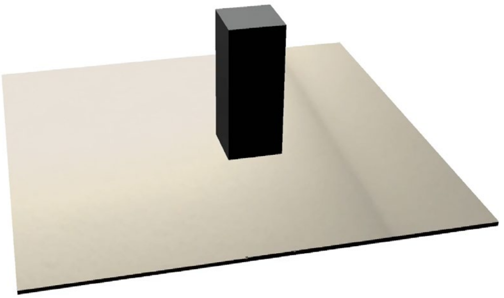


Energy Storage

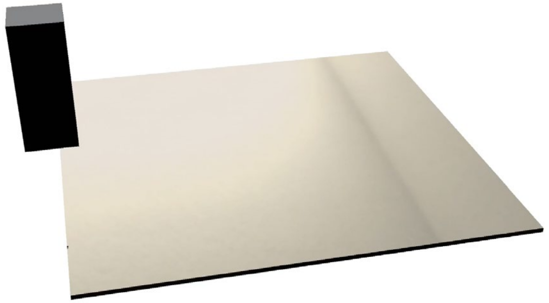


HTS tapes

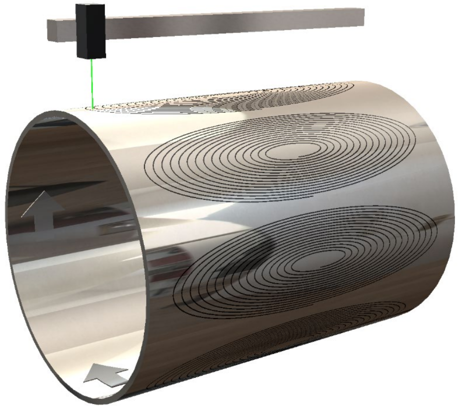
Quantum Computing



Energy Storage

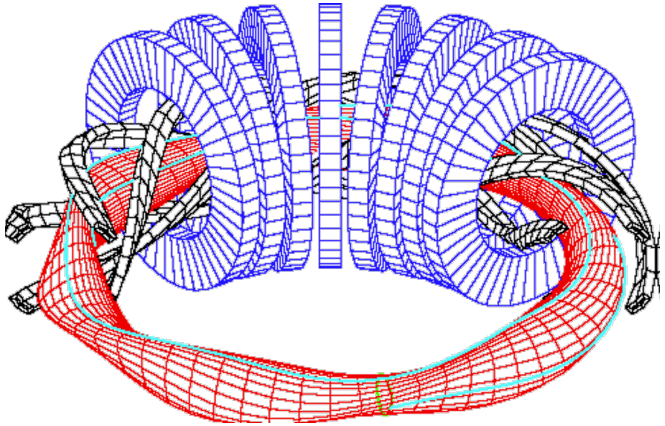


Electric Motors & Accelerator's Magnets

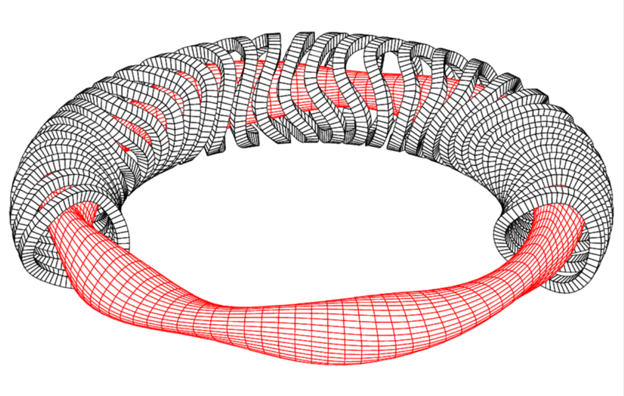


Coil Winding Surface (CWS)

Does it really have to be conformal to the plasma boundary?

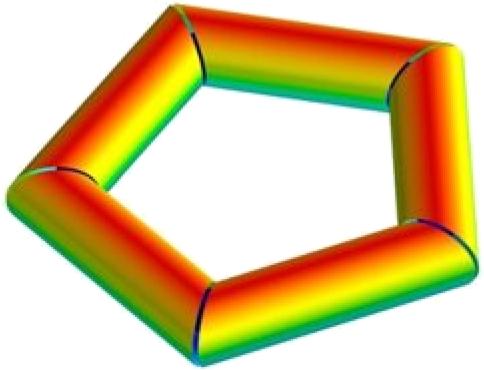


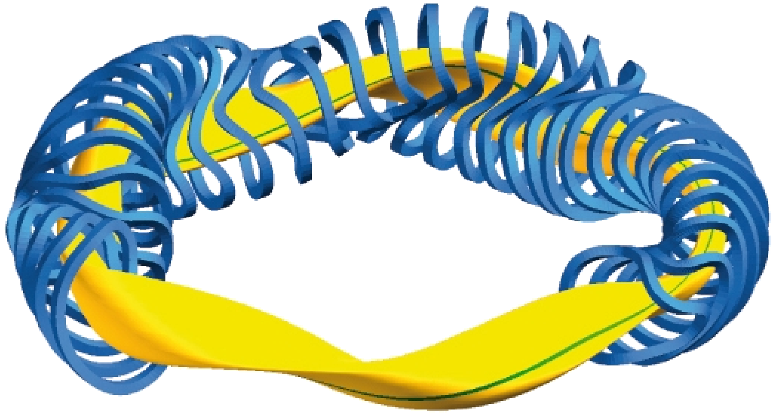
W7-A: axisymmetric



Early modular designs: **axisymmetric**

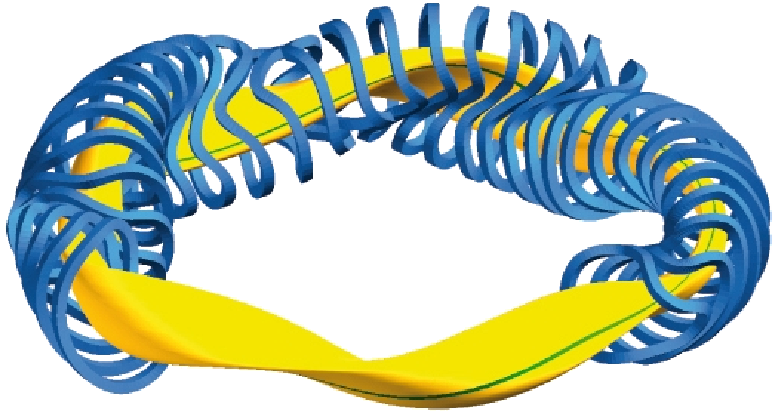
W7-AS: ~ piecewise **cylindrical**?

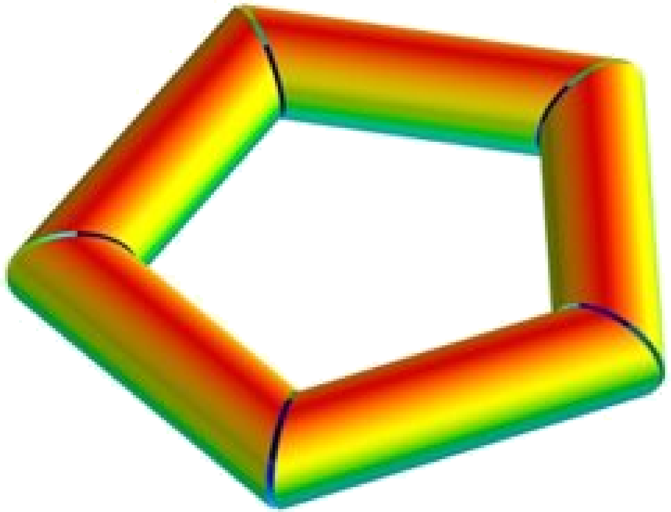




W7-X: ~ **conformal**

HTS cylinders simplify stellarators' Coil Winding Surface (CWS)





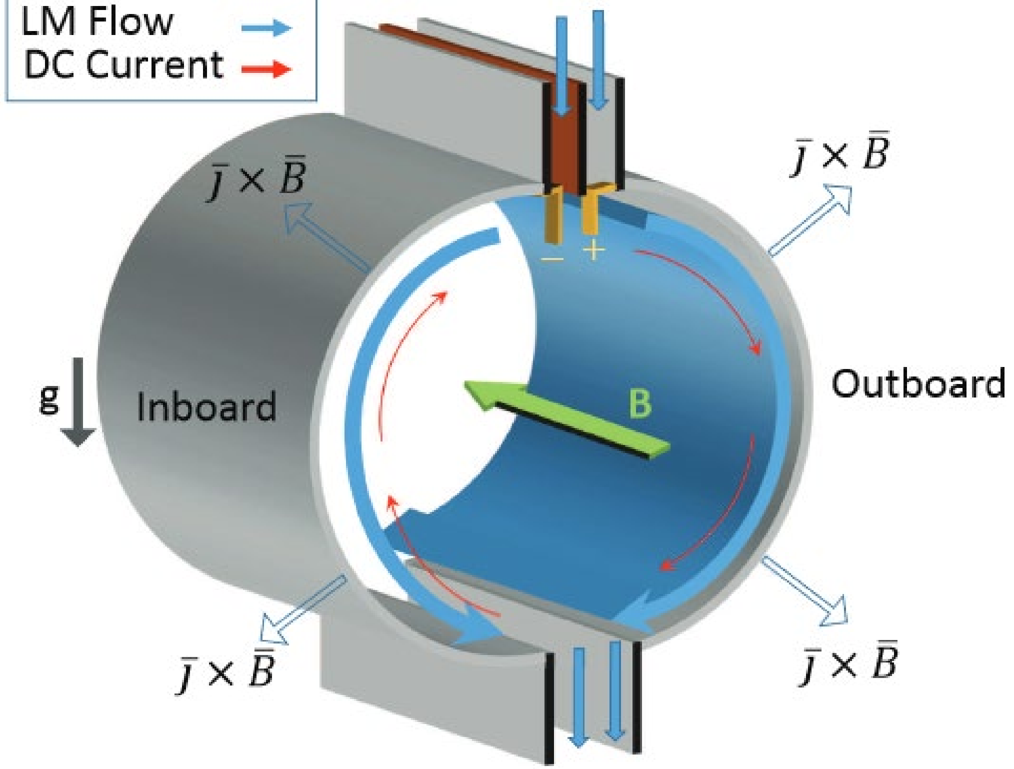
W7-X: ~ **conformal CWS**

Complex surface
Simple current-pattern

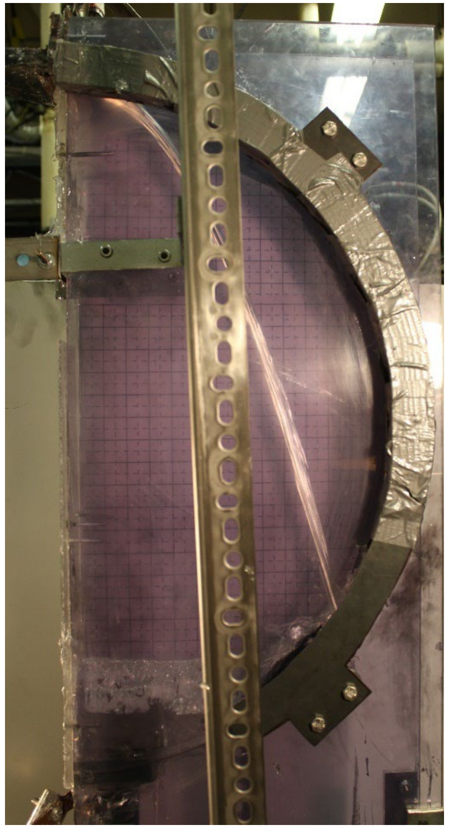
RF: piecewise **cylindrical**

Simple surface
Complex current-pattern
(but simple for the laser)

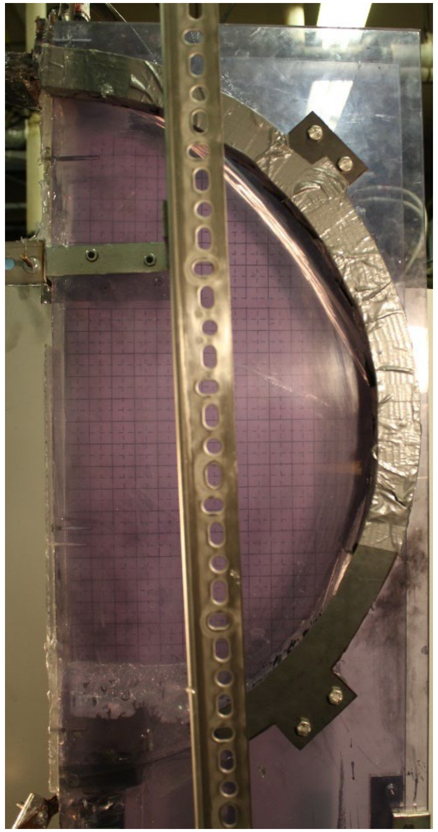
A **safer** reactor thanks to liquid metal walls



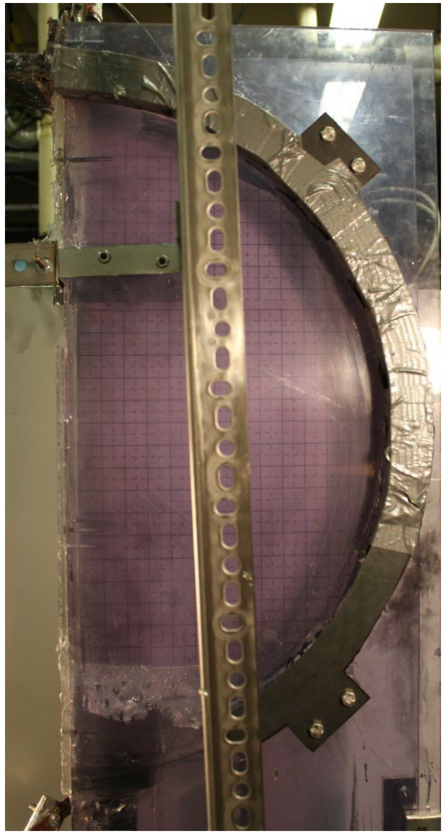
Increasing jxB and/or v



Parabolic



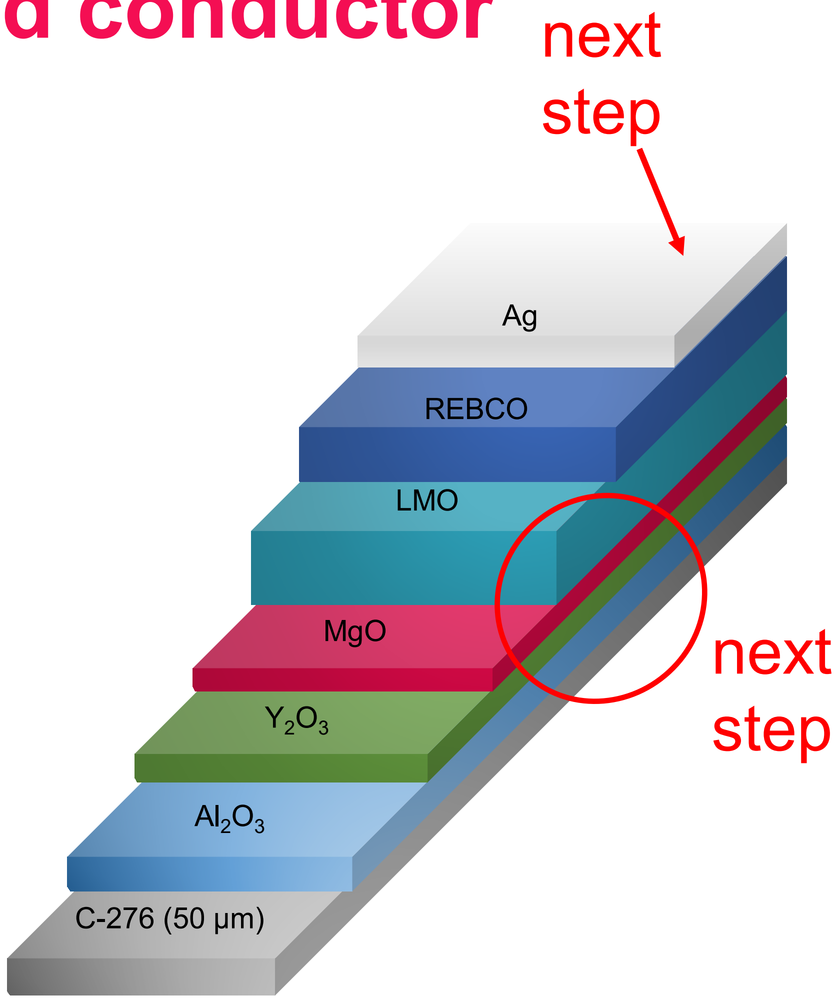
Near-circular



Circular
(full coverage)

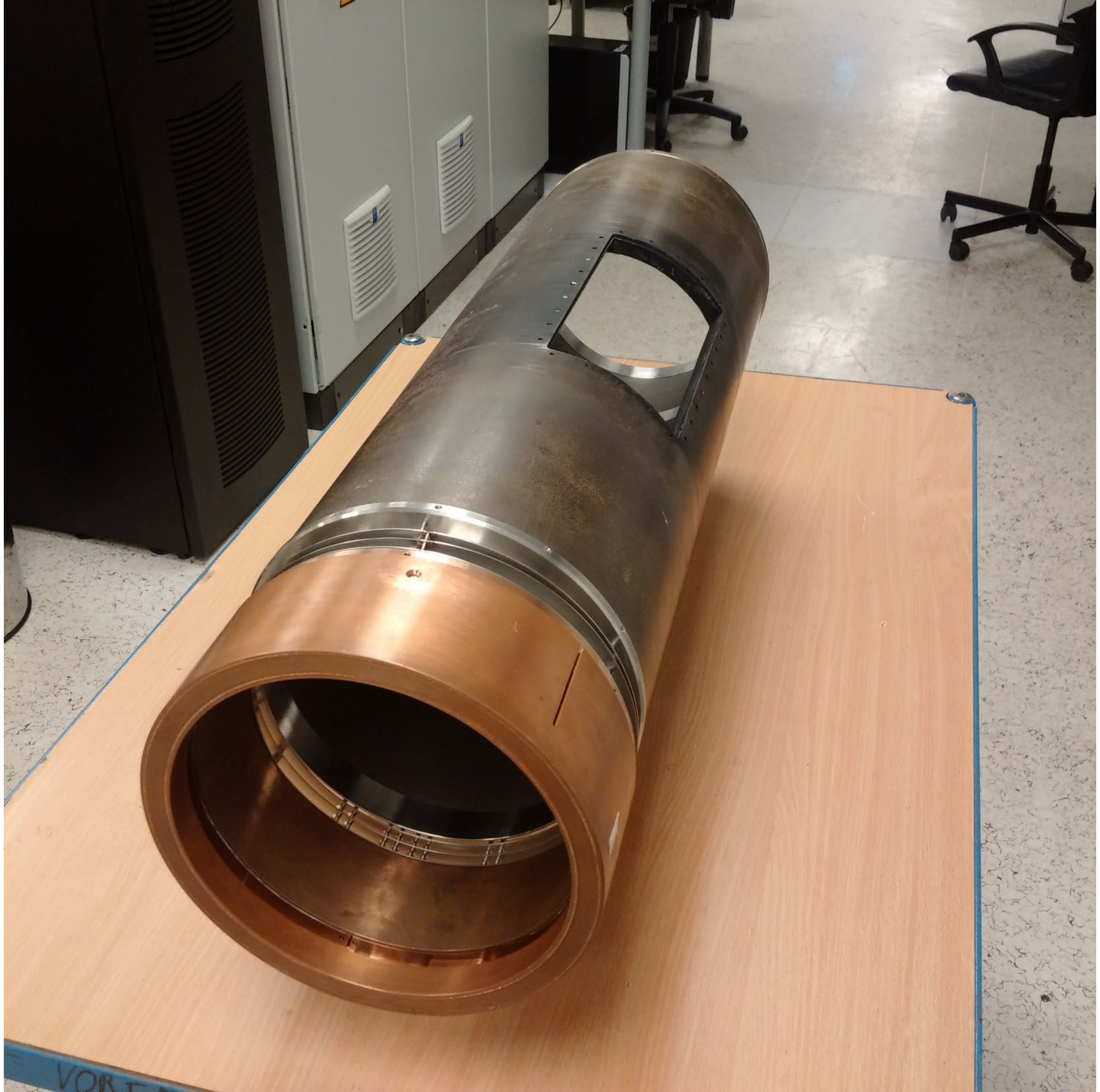
Architecture of REBCO coated conductor

Layer	Deposition technique	Thickness (±5%)	Max Deposition speed	Notes
Al_2O_3	Magnetron	80 nm	120 m.h^{-1}	Diffusion barrier to metal ions from C-276
Y_2O_3	Magnetron	7 nm	400 m.h^{-1}	Seed layer for MgO
MgO	IBAD	10 nm	~14 m.h^{-1}	Template for the epitaxial deposition of REBCO
MgO	MOCVD	20 nm	100 m.h^{-1}	Template for the epitaxial deposition of REBCO
LMO	MOCVD	30 nm	100 m.h^{-1}	Buffer layer (Lattice match)
REBCO	MOCVD	2 µm	7.5 m.h^{-1}	HTS layer
Ag	Magnetron	2 µm	70 m.h^{-1}	Protection layer



*Layers not up to scale

State of the art



State of the art

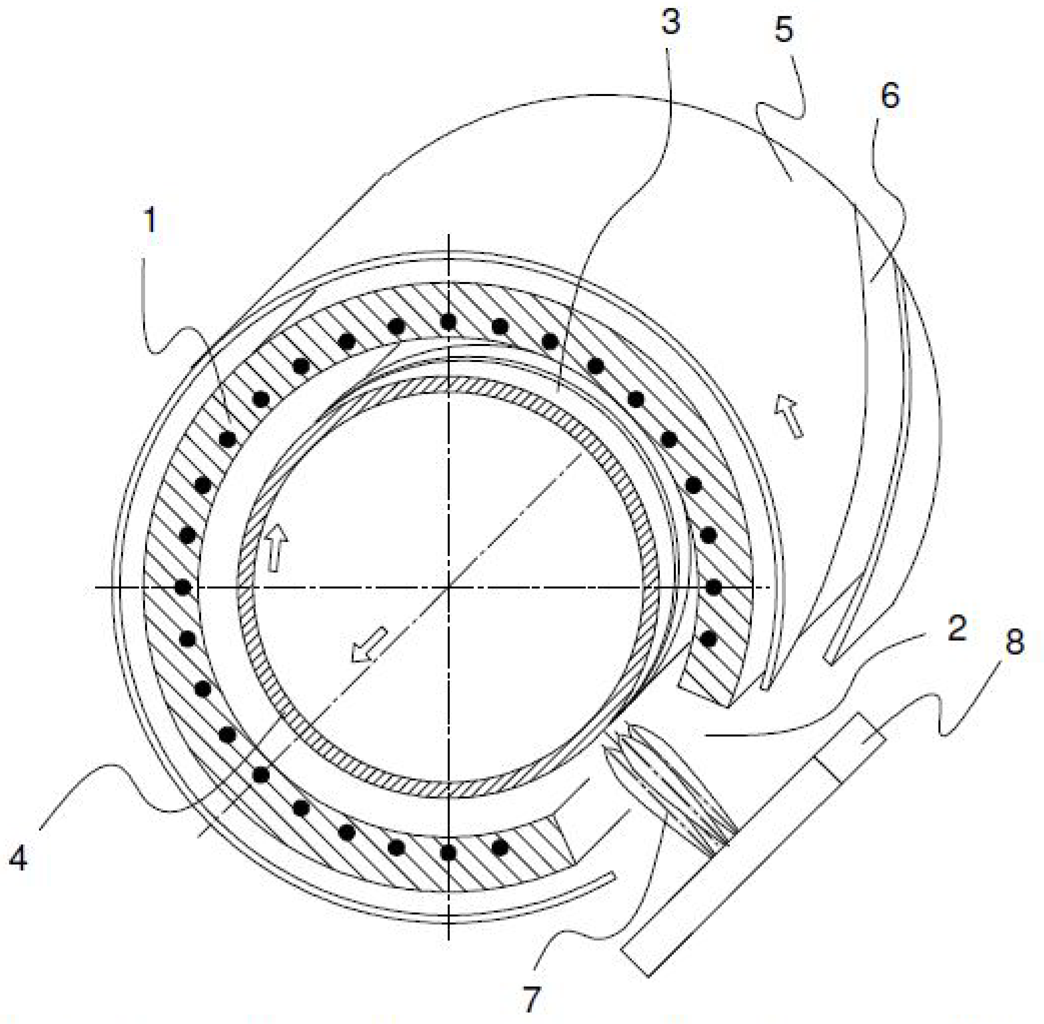
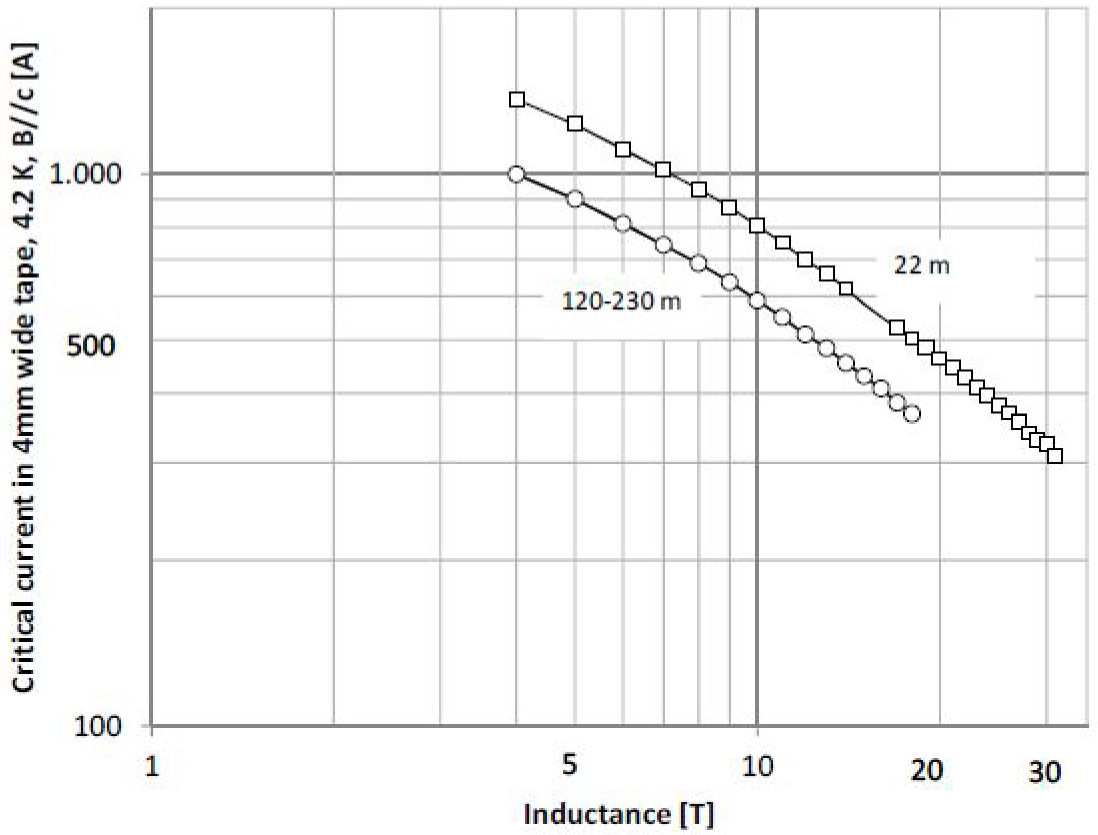
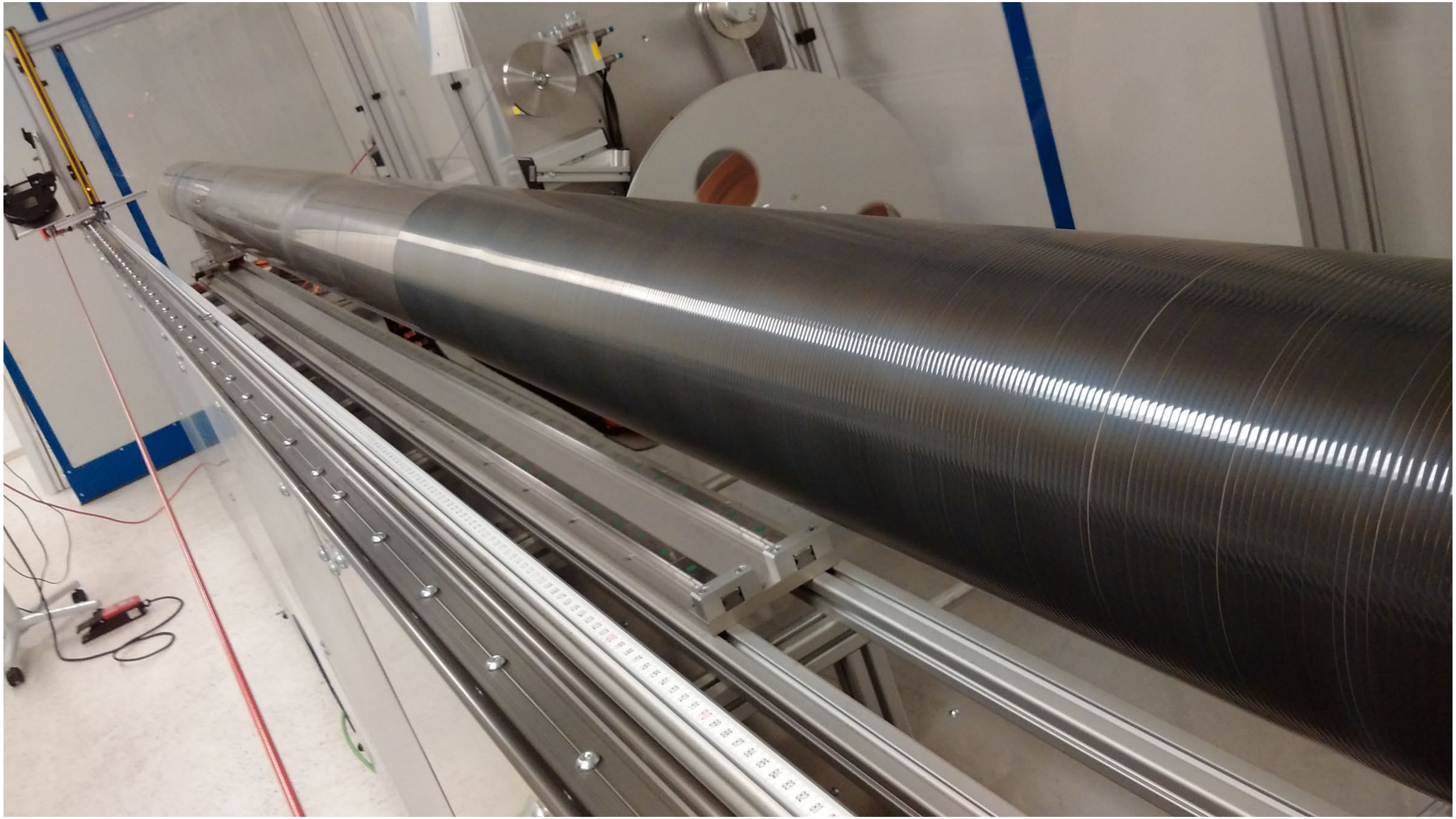


Fig. 1. Quasi-equilibrium heater 1, 2, 5, 6 with a substrate tape 3 helically wound on the cylindrical tape guide 4.

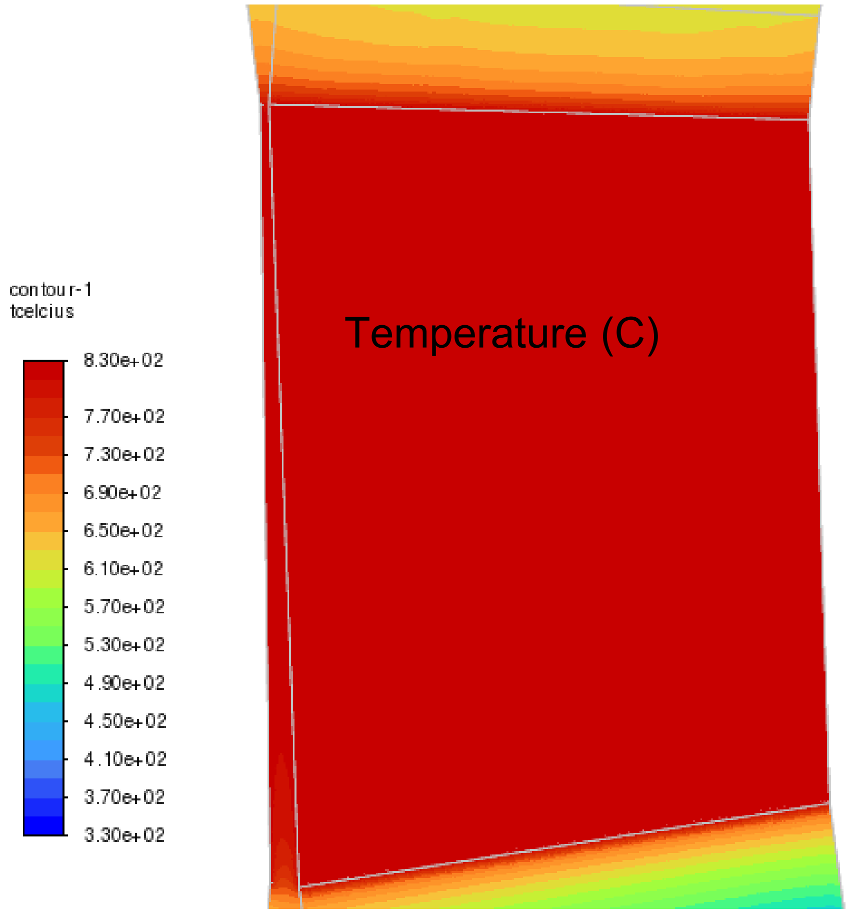


IEEE Trans. Appl. Superond. V.26, issue 3, April 2016, DOI: 10.1109/TASC.2016.2542253

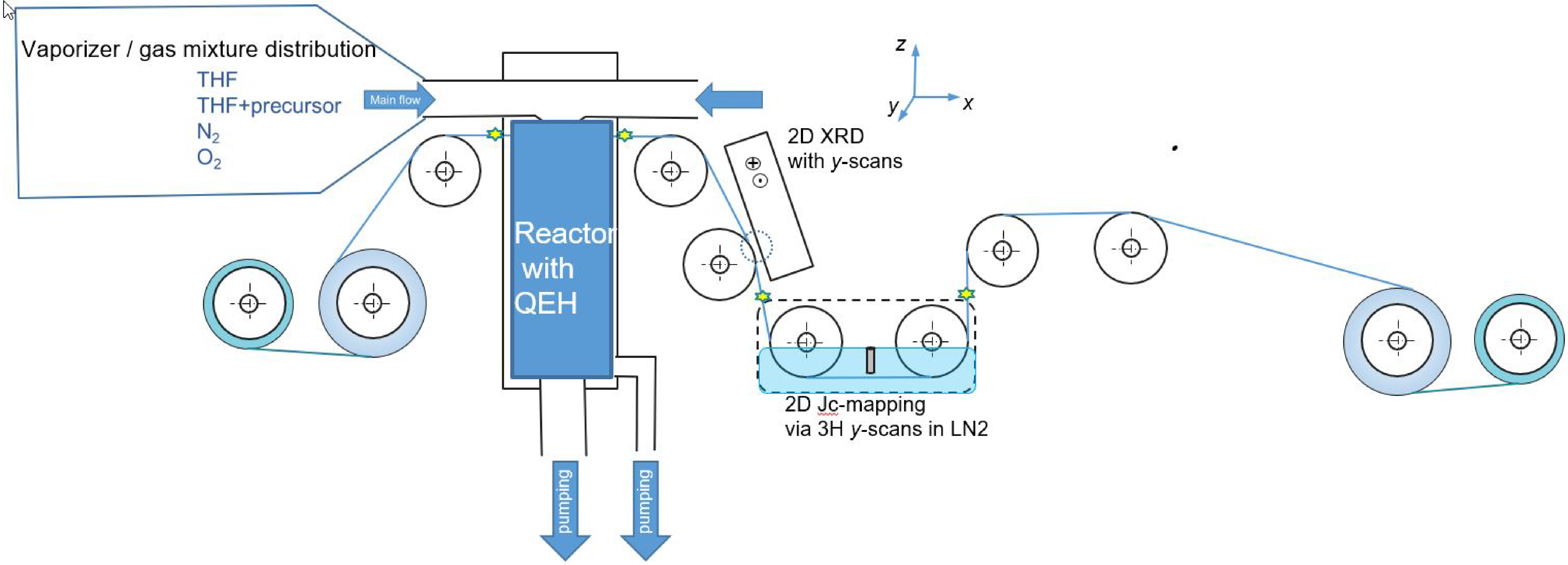
State of the art



MOCVD temperature distribution (FEA)



MOCVD machine with QEH reactor for 1 m wide tape



Instead of summary:

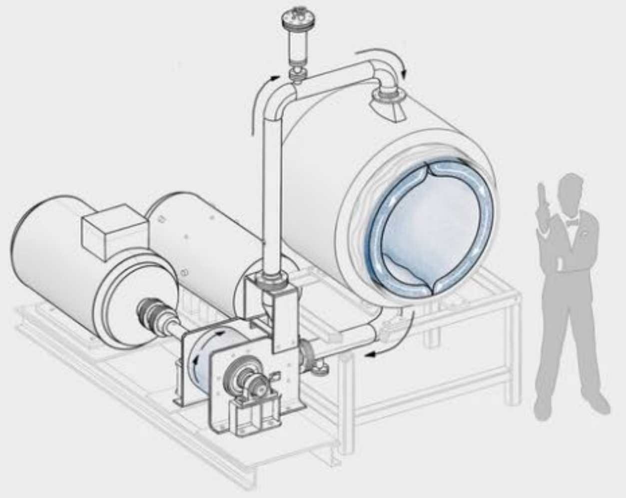
- MOCVD with QEH reactor should yield a sufficient surface homogeneity in wide tapes
- It should also exhibit a very high deposition efficiency suppressing material loss down to <20%
- Experimental confirmation of these features is expected in 2023

Backup foils

A clear roadmap to commercial fusion

+exit-point to early revenues

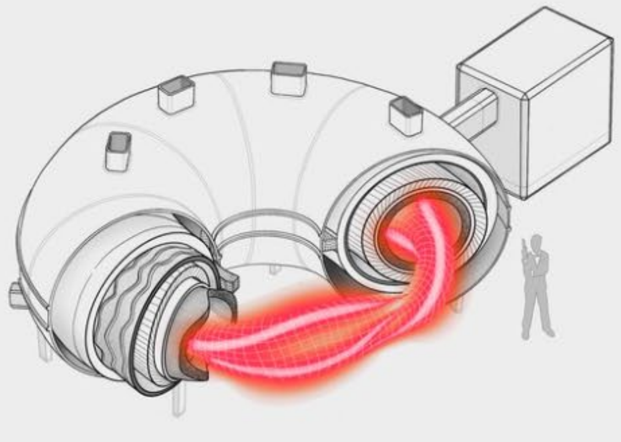
Skyfall III



Milestone 1 (late 2024)

Enable

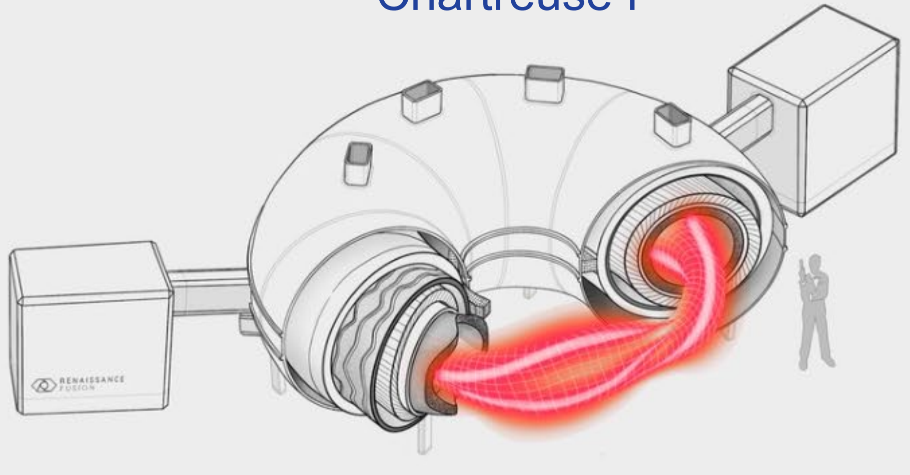
Chartreuse X



Milestone 2 (2025 onwards)

Integrate

Chartreuse P



Milestone 3 (early 2030's)

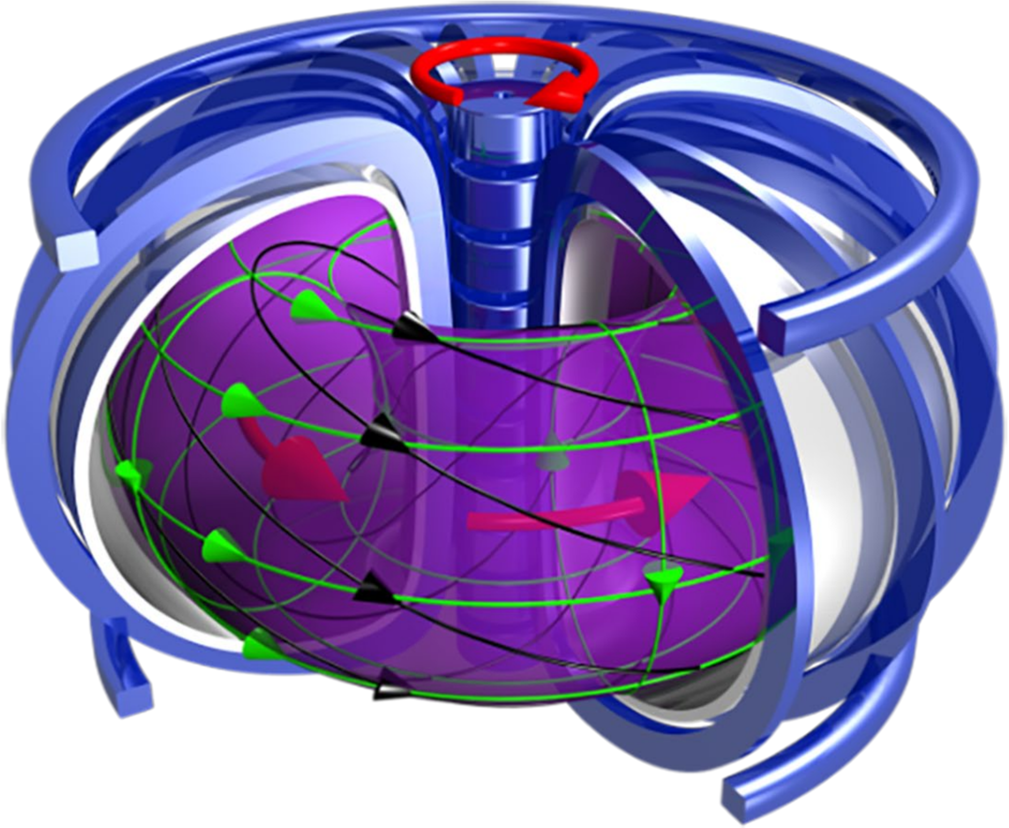
Electrify

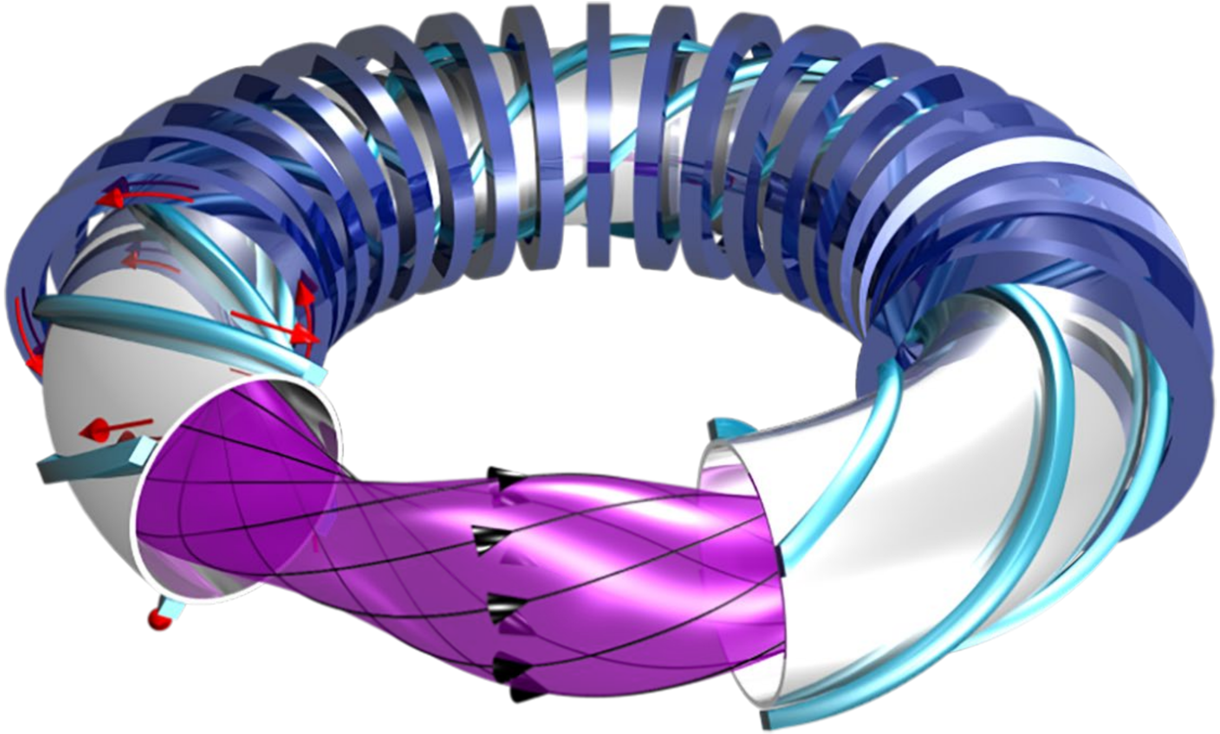
Business opportunities

Information for the session discussion: extra-wide tapes

- Gaps in technology: not found
- Conductor specifications – quantitative:
  w=1 m, L = 1000 m, Ic(SF, 77K) $\geq$ 250 A/cm-width (or 25 kA/m-width)
- Conductor volume needed – 3 years, 5 years: 10 km / 50 km
- What improvements are needed in conductor – prioritize:
  it will be needed: to provide high Jc homogeneity
- Supply Chain issues: not yet found
- Potential areas of collaboration with other applications, conductor manufacturers:
  possible applications: (see slide 8) energy storage, quantum computing,
  + electromagnetic shielding, levitation, high field magnets

Tokamaks vs. stellarators





Coils simpler to build

Difficult to operate (pulsed, unstable, subject to "disruptions", regulatory issues?)

Difficult to build

Simple to operate (steady-state, stable, no need for energy-intensive CD)