

Magnetic Confinement Fusion

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Outline

- Magnetic Confinement scheme
- Progress in the world
- Tokamak Research at the University of Saskatchewan

Magnetic Confinement Scheme

Charged particle motion in straight magnetic field

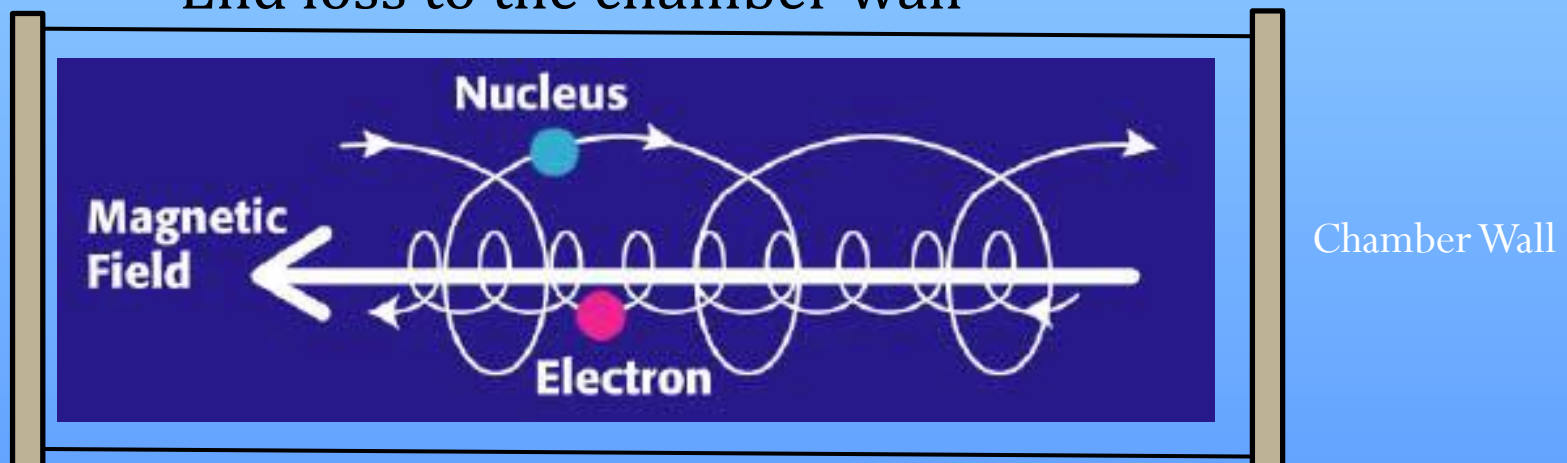
- A charged particle circulates around the magnetic field lines (e.g., produced in a solenoid)

→ Cross-field motion is restricted within Larmor radius

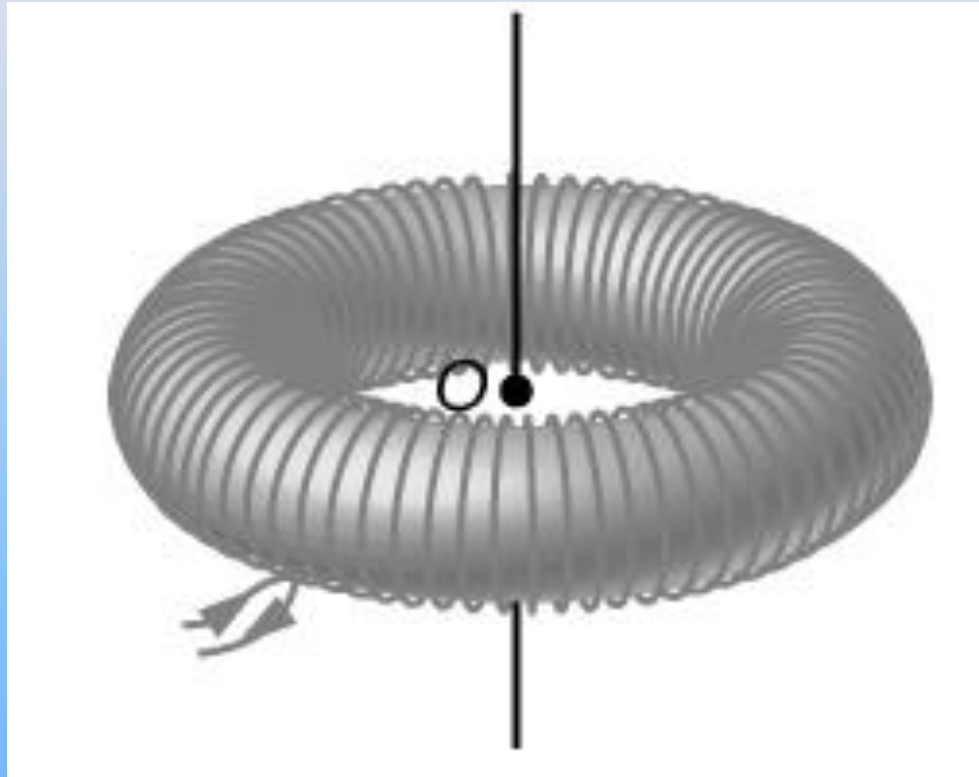
$$r_L = \frac{mv}{qB}$$

→ Motion along the field lines is still free

End loss to the chamber wall



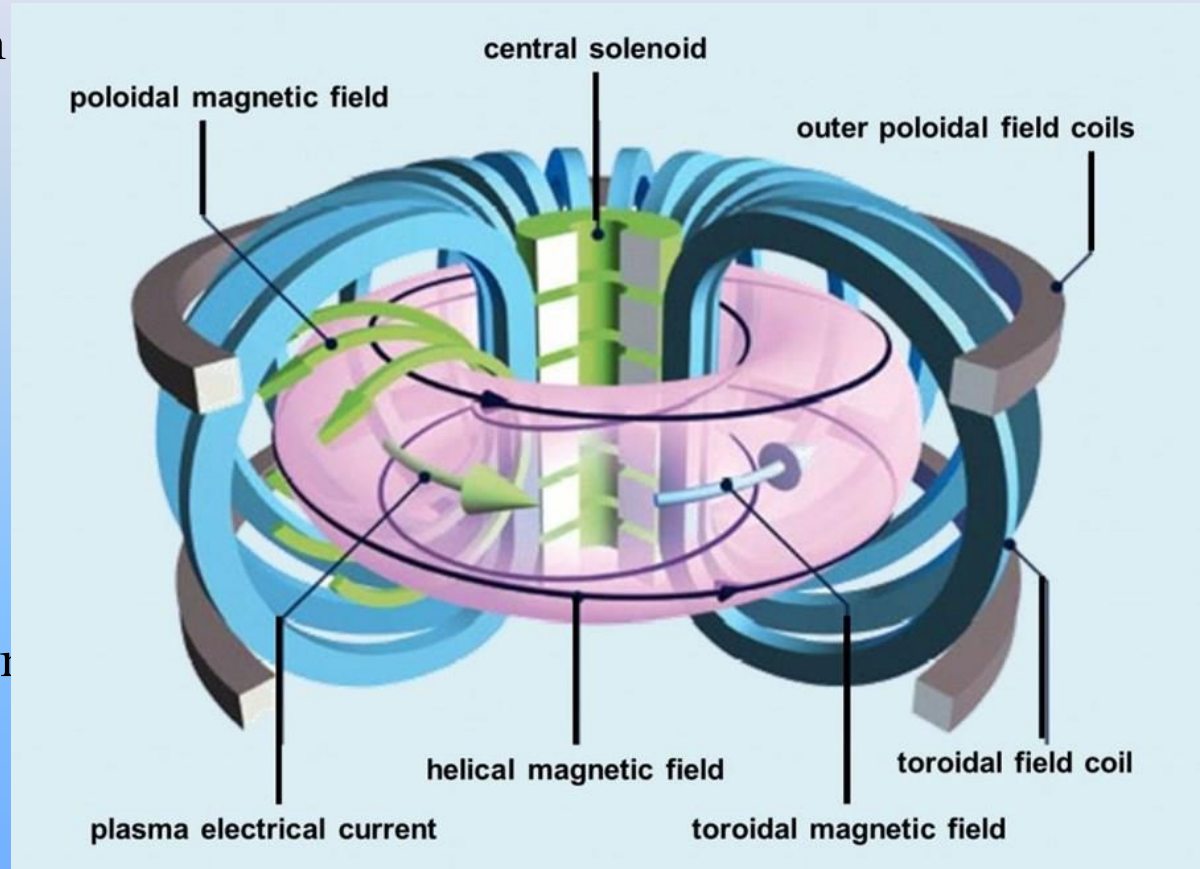
Toriodal geometry is the solution



However, plasma in simple toroidal field drifts to outboard on the wall

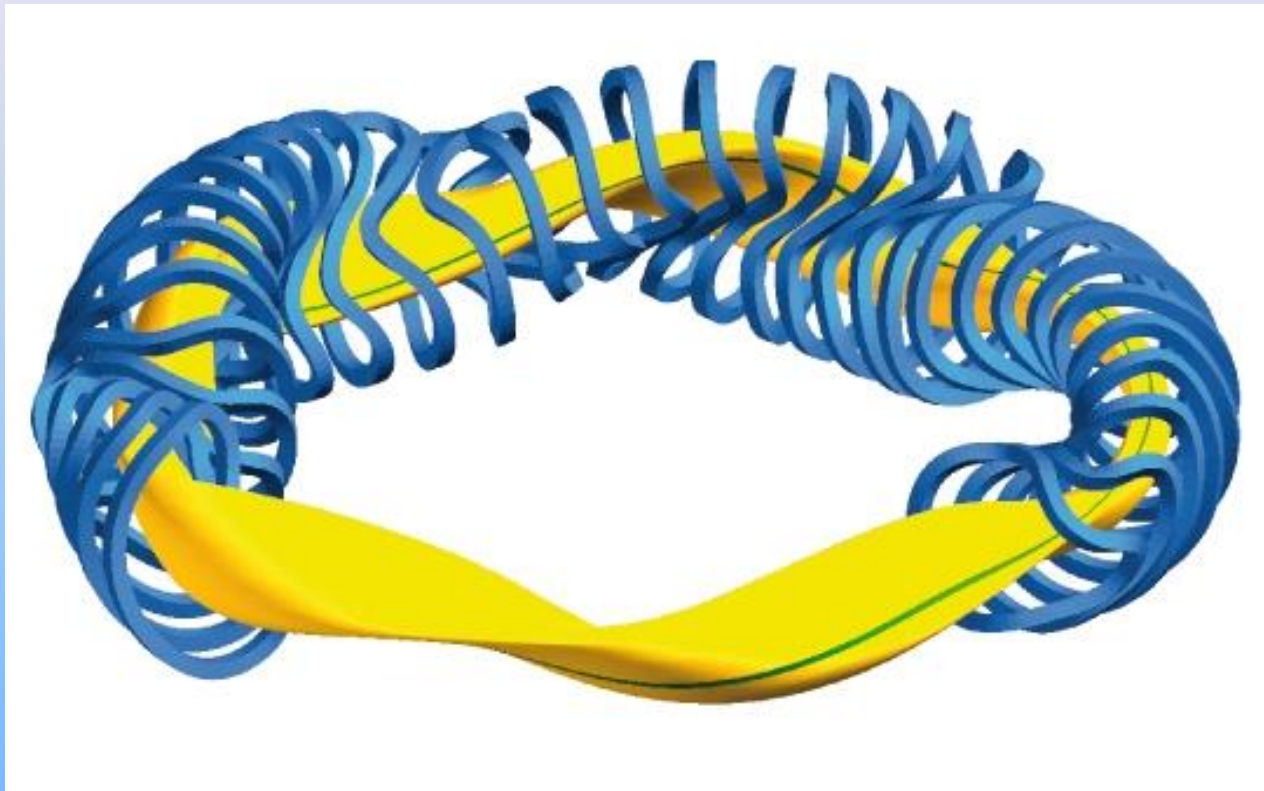
Tokamak

- Bend solenoid to form closed magnetic field lines
 - circular field line without ends
 - no end-loss.
- Transformer action produces a huge current in the chamber
 - Generate poloidal field
 - Heats the plasma



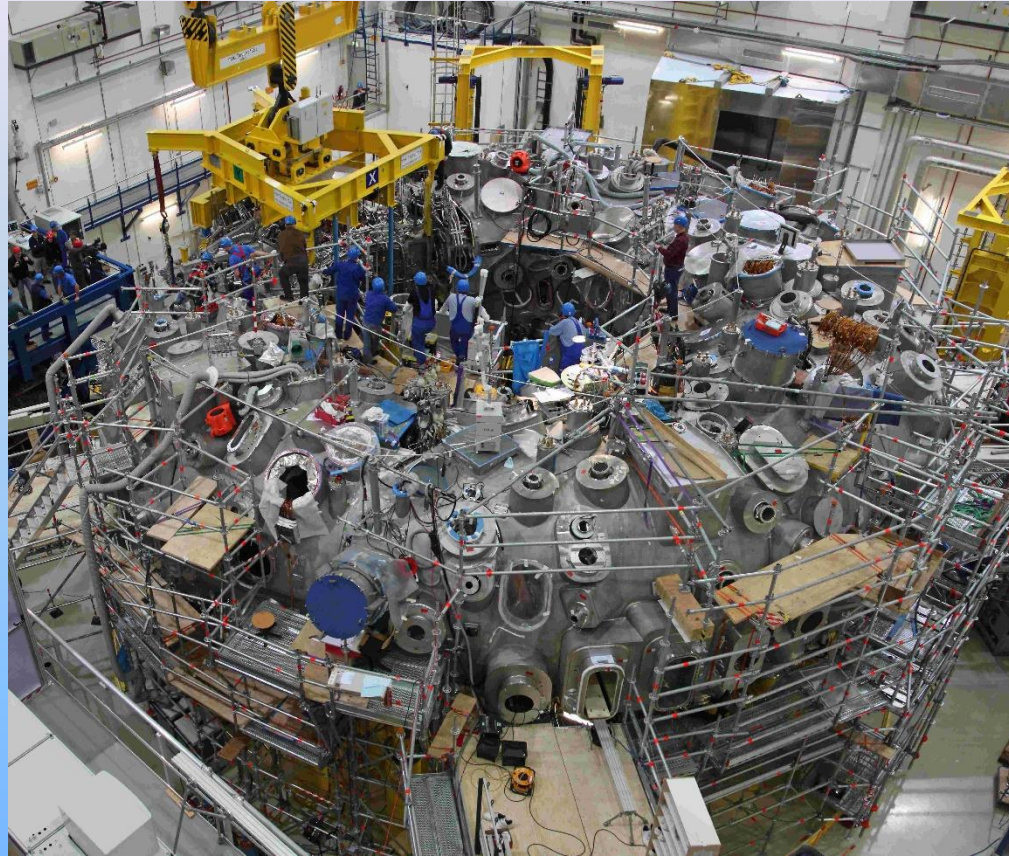
Tokamak: abbreviation of Russian words for toroidal magnetic chamber

Stellarator



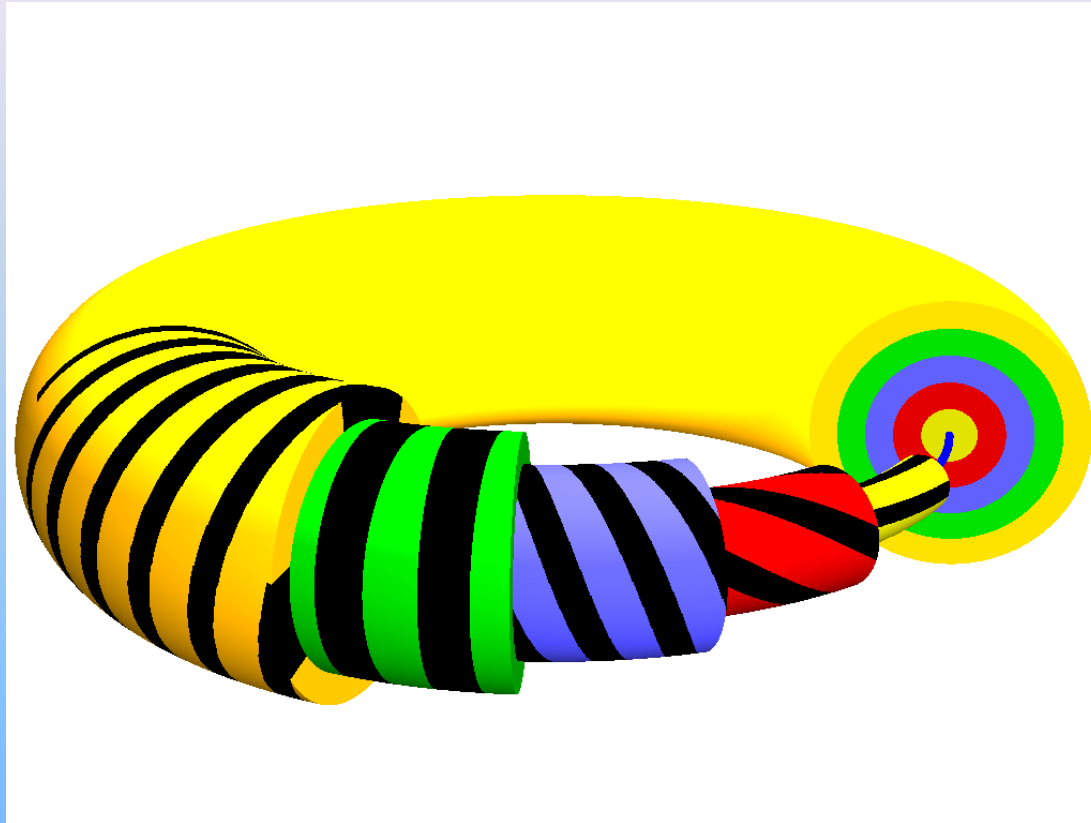
- The magnetic field are generated by complicated external coils
- No plasma current, no disruptions
- Engineering is challenge

Wendelstein 7-X, Greifswald, Germany



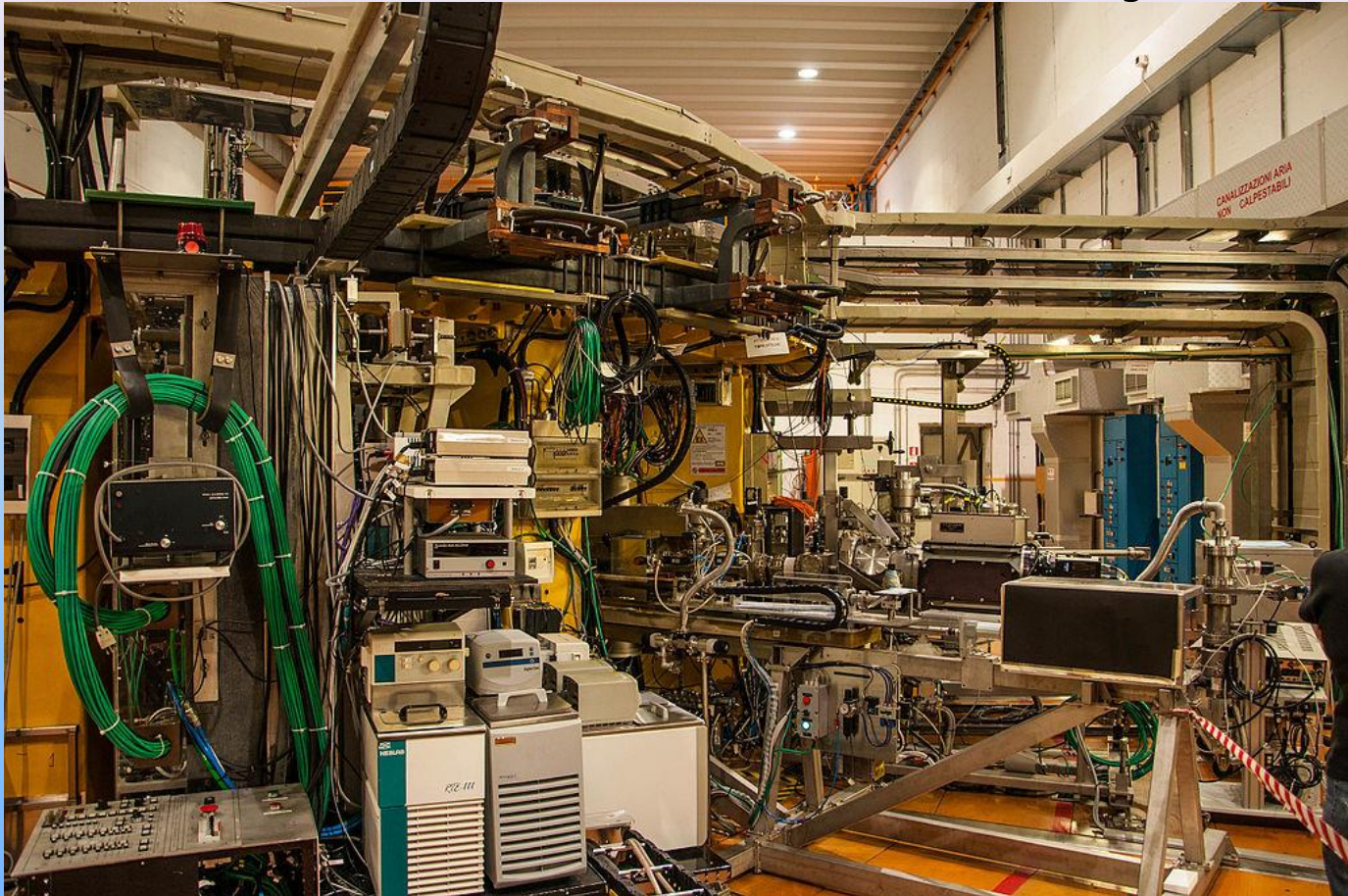
- Completed in October 2015
- Superconducting coils
- High density and high temperature have been achieved

Reversed Field Pinch



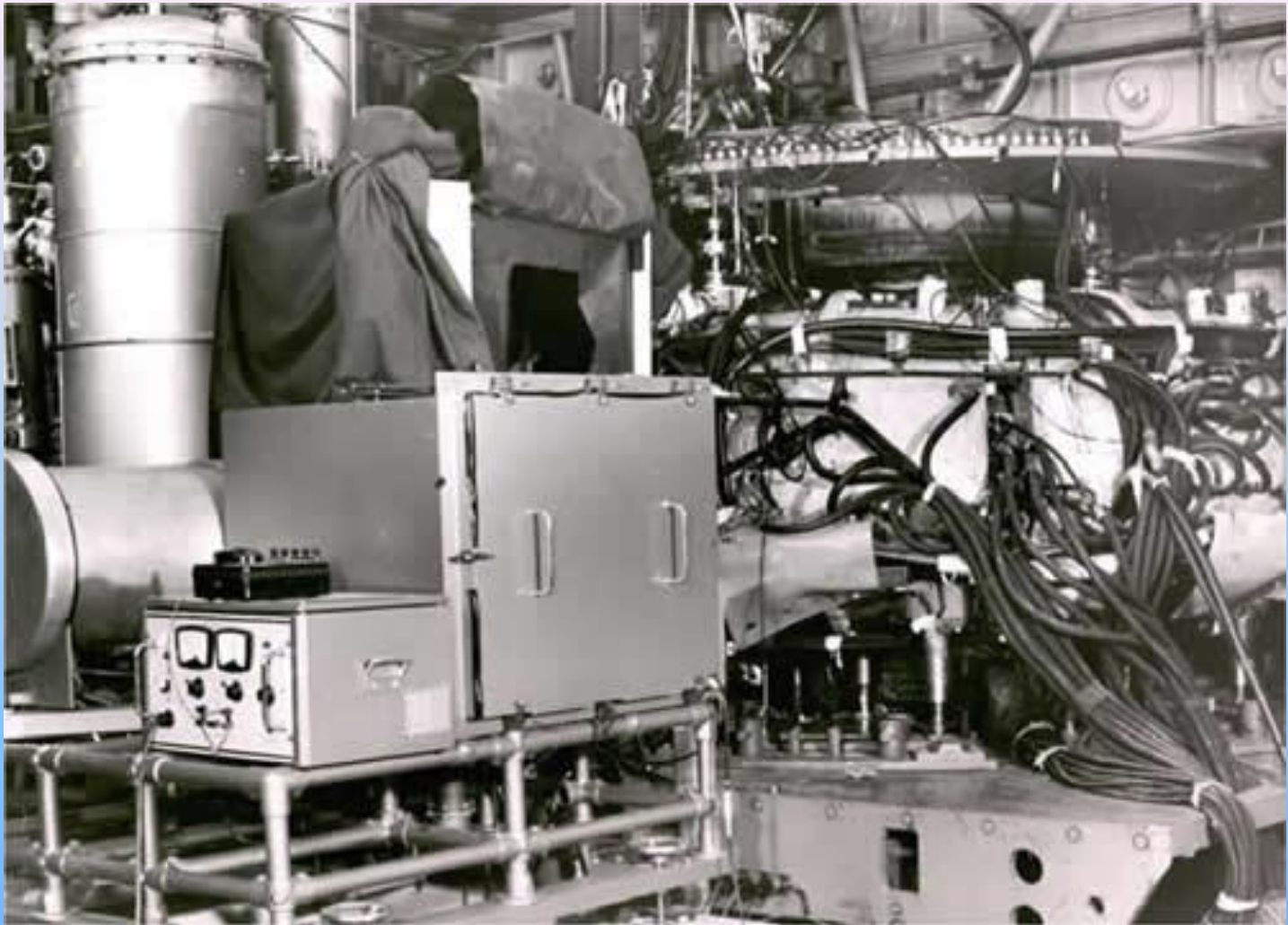
- Toroidal field reverses direction at the edge
- The magnetic field are generated by current in plasma
- Toroidal field and poloidal field are of similar strength.

RFX-Mod, Padua, Italy



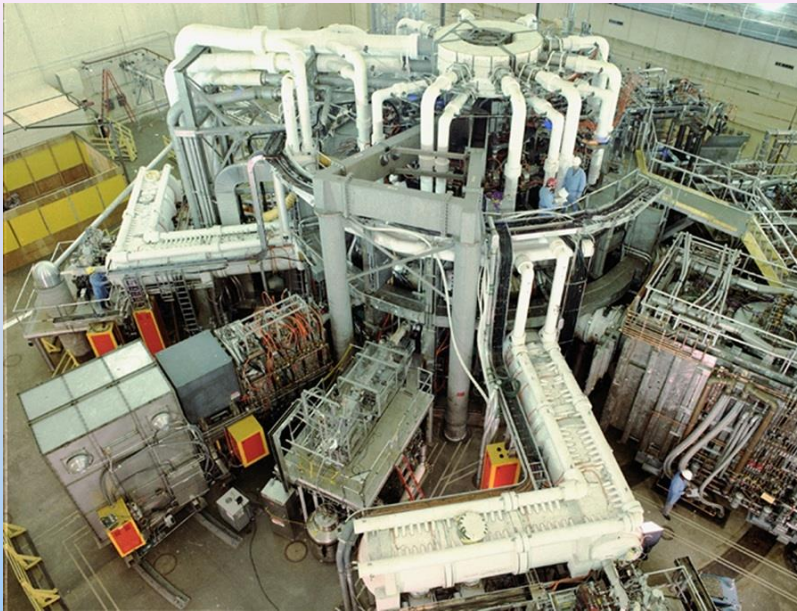
- Toroidal field reverses direction at the edge
- The magnetic field are generated by current in plasma
- Other devices: MST, KTX, ...

Progress



1969: T3 tokamak achieved 1 keV (10 million °C)

Picture credit: <https://www.euro-fusion.org/wpcms/wp-content/uploads/2005/11/nov05t3-m.jpg>



1994:
TFTR in USA used D-T fuel
to produce 10 MW fusion

Picture credit:

https://en.wikipedia.org/wiki/Tokamak_Fusion_Test_Reactor#/media/File:TFTR_1989.jpg



1997:
JET (UK) produced 16 MW
Fusion Power for 22 MW
input power

Picture credit:

https://en.wikipedia.org/wiki/Joint_European_Torus#/media/File:JointEuropeanTorus_external.jpg

$a = 2.0 \text{ m}$

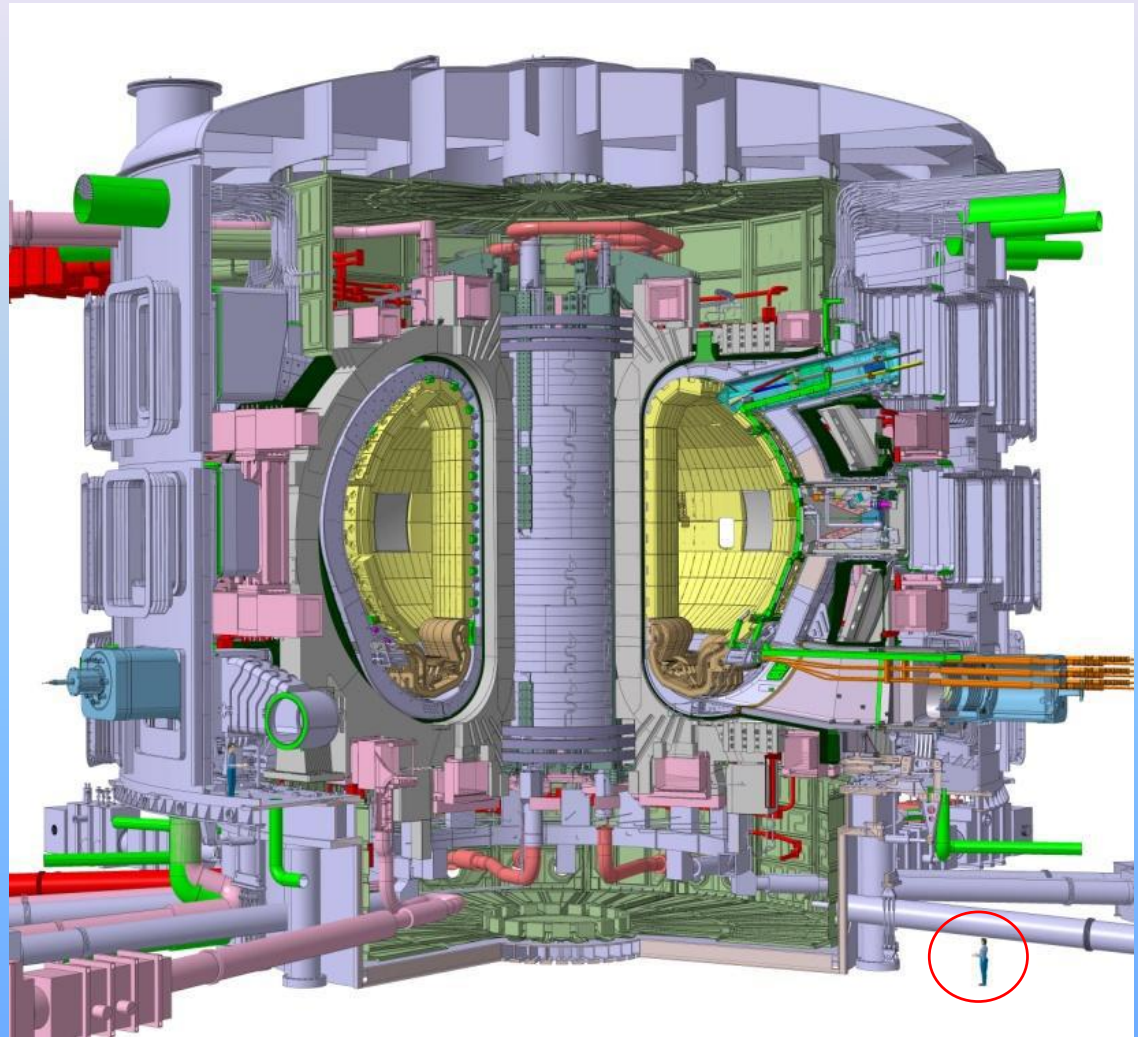
$R = 6.2 \text{ m}$

Power:

500 MW fusion

73 MW heating

Weight $> 23,000$ Tonnes



Human size

<https://www.iter.org/>

CNS-2019 Fusion Session, June 24, 2019

ITER is making concrete
and solid progresses



<https://www.iter.org/>



<https://www.iter.org/>



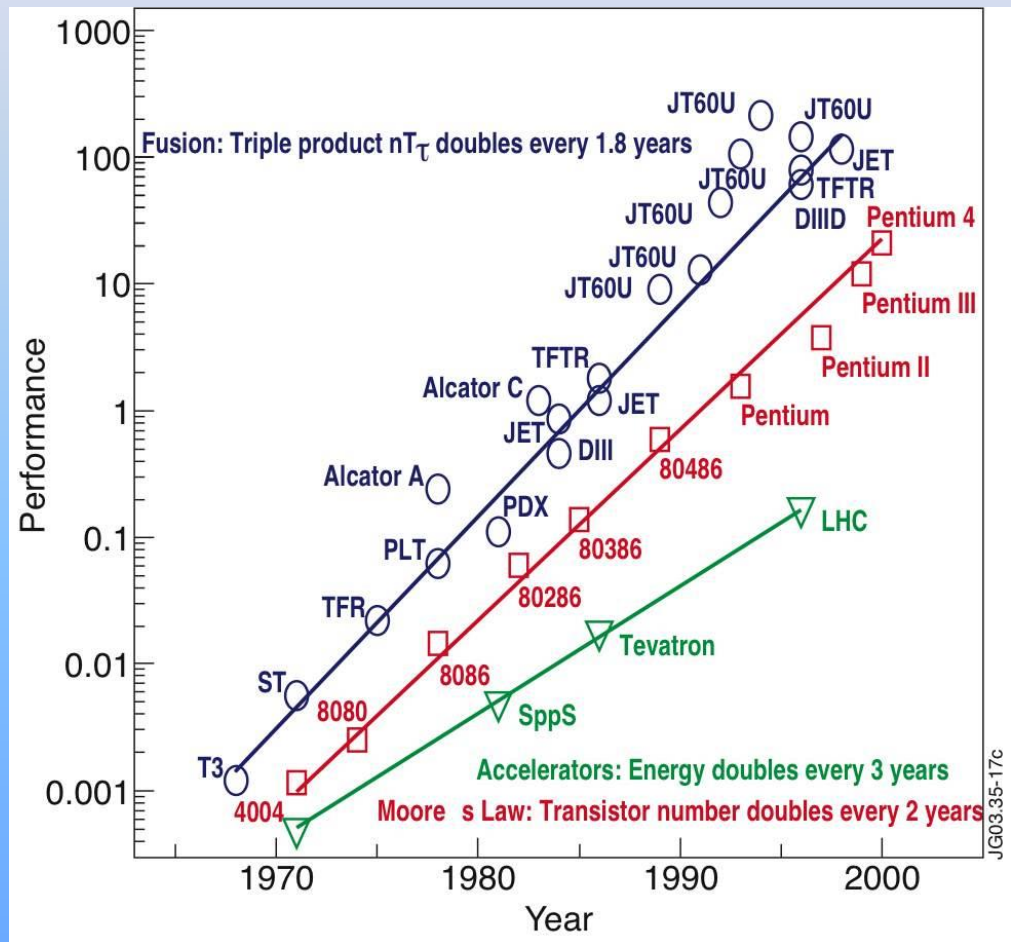
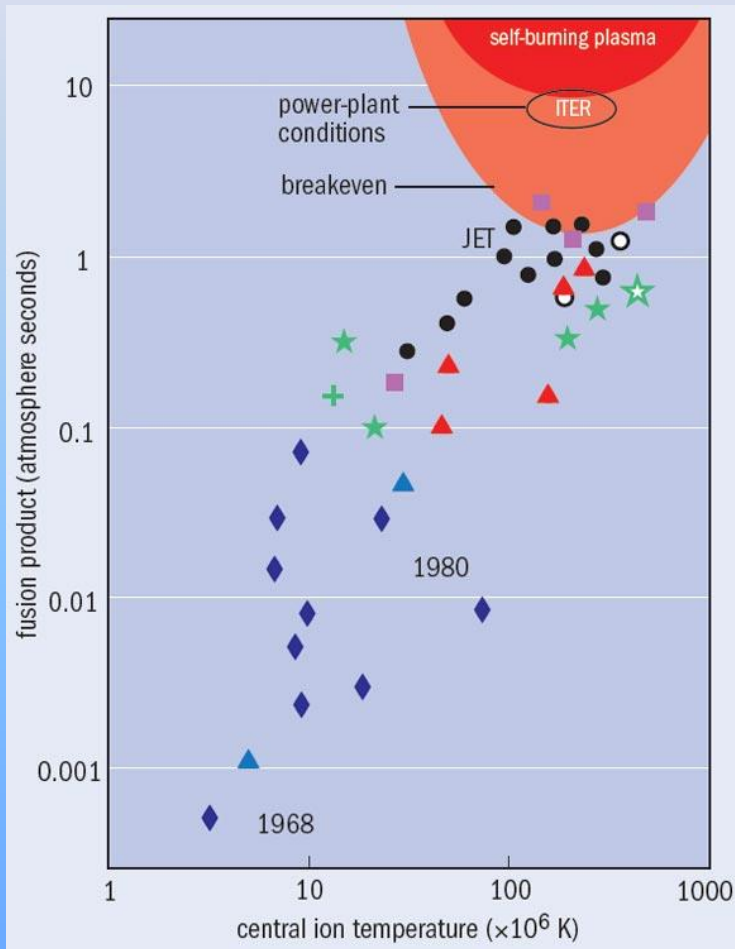
By Oak Ridge National Laboratory - ITER Site, CC BY 2.0,
<https://commons.wikimedia.org/w/index.php?curid=74249979>

PEP-Seminar Feb. 8, 2019

What is Exciting?

- Private investment
 - TAE, USA (FRC, aneutronic Fusion)
 - Tokamak Energy, UK (ST-40, High-T Superconductor)
 - General Fusion, Canada (MTF)
 - ENN Group, China (Compact reactor, ST)
 - Commonwealth Fusion Systems/MIT, USA
 -

Fast progress vs. Moore's Law



What is Exciting?

- News to come in the near future
 - JET, new D-T experiments (2019, 2020?)
 - JT-60SA (2020)
 - WEST (formerly Tore Supra)

Tokamak Research at the University of Saskatchewan

Tokamak at UofS

- Tokamak Research at the University of Saskatchewan
 - Lab established in 1958
 - First Canadian tokamak STOR-1M (early 80s)
 - STOR-M (built in 1987, still active), now only tokamak in Canada
 - Compact torus injector added (Mid 90s)

Professors with PPL



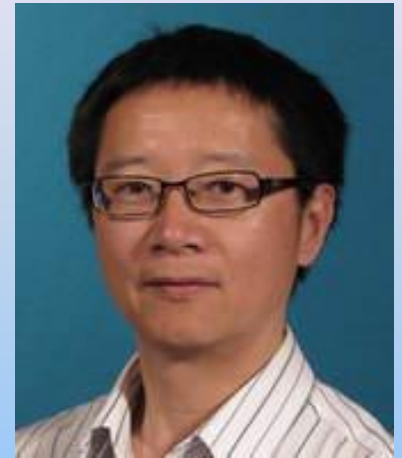
M. Bradley



L. Couedle



A. Smolyakov



C. Xiao

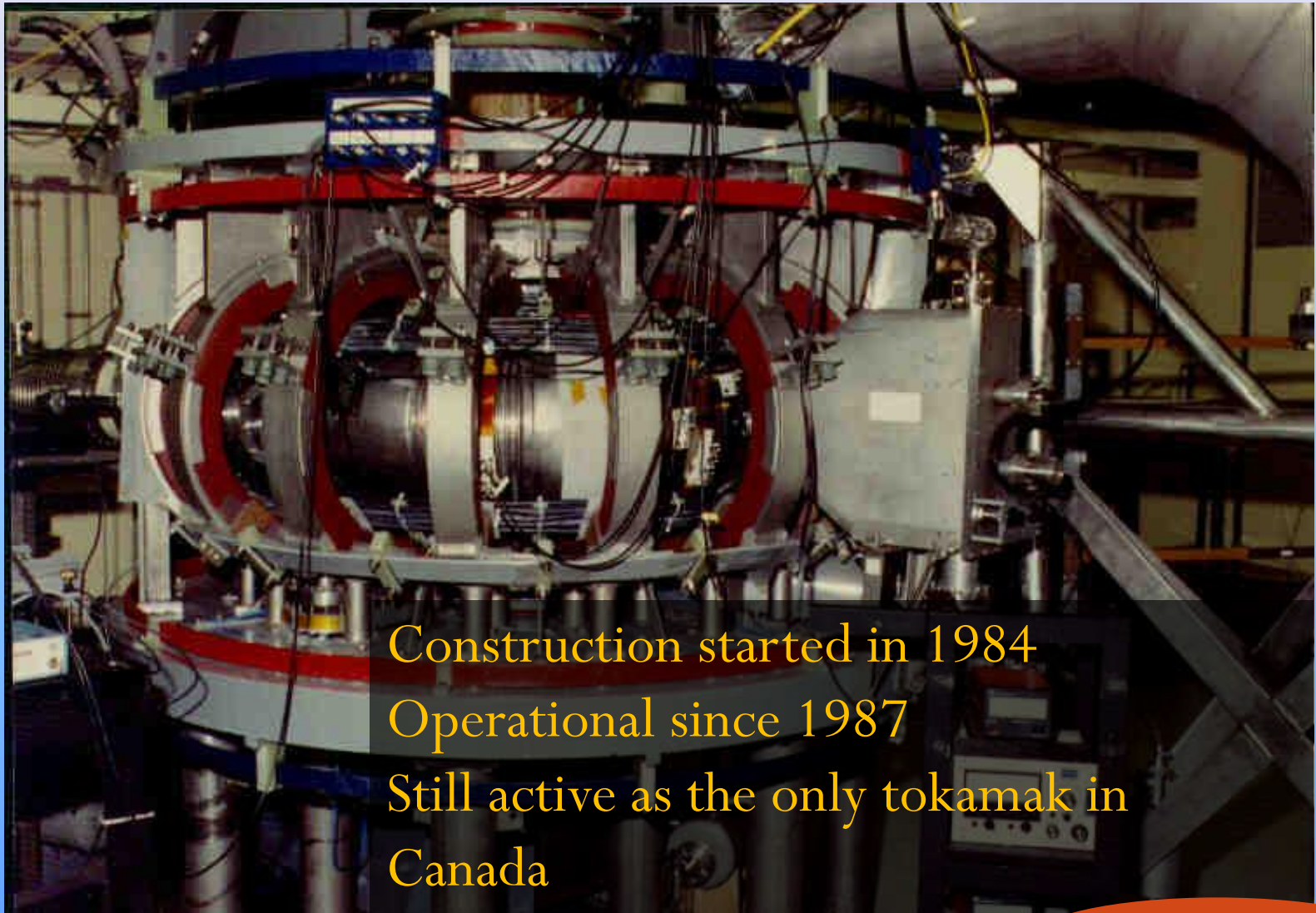


H. Skarsgard
(1929 – 2018)

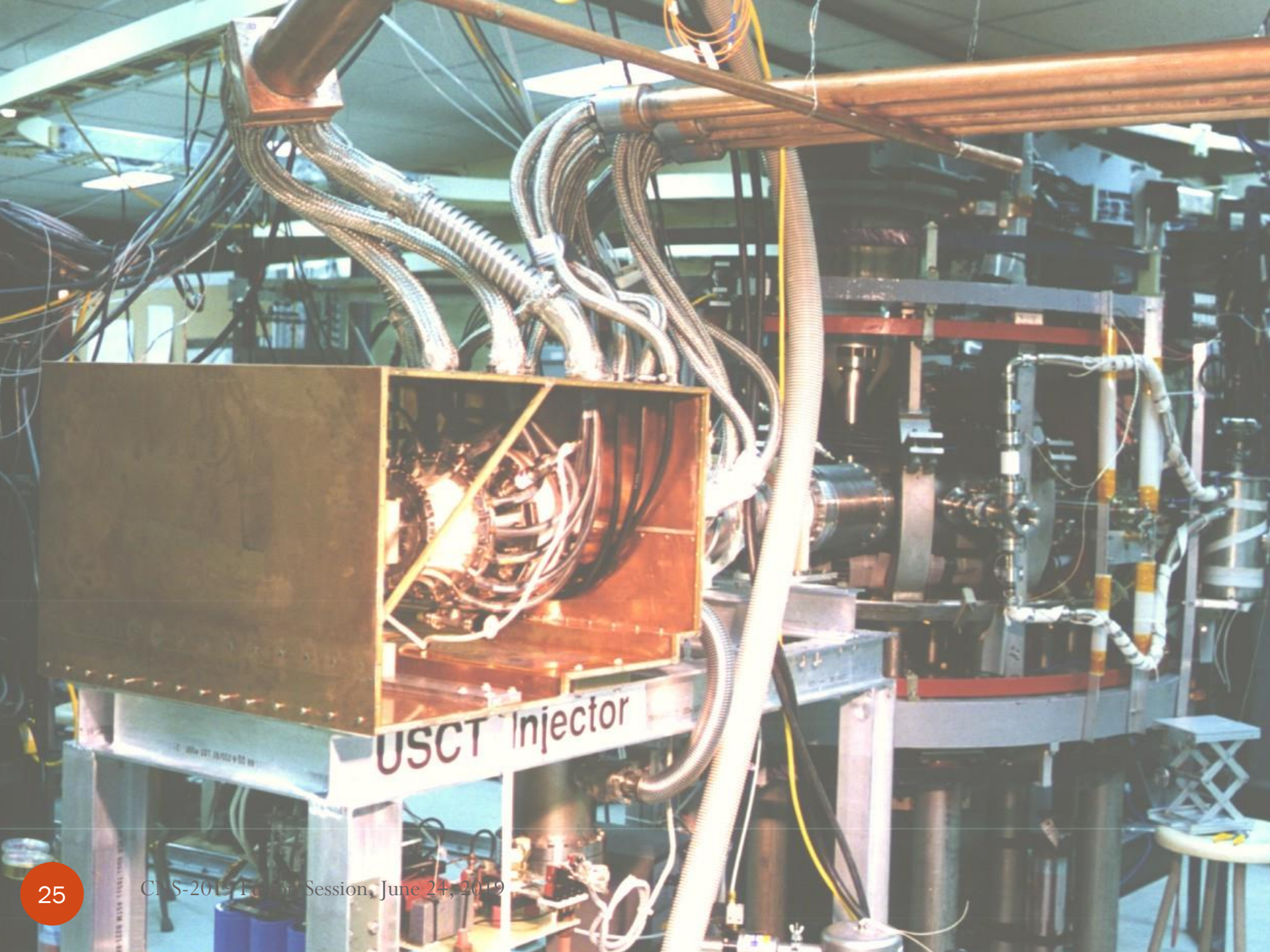


A. Hirose
(1941-2017)

STOR-M Tokamak



Construction started in 1984
Operational since 1987
Still active as the only tokamak in
Canada



USCT Injector

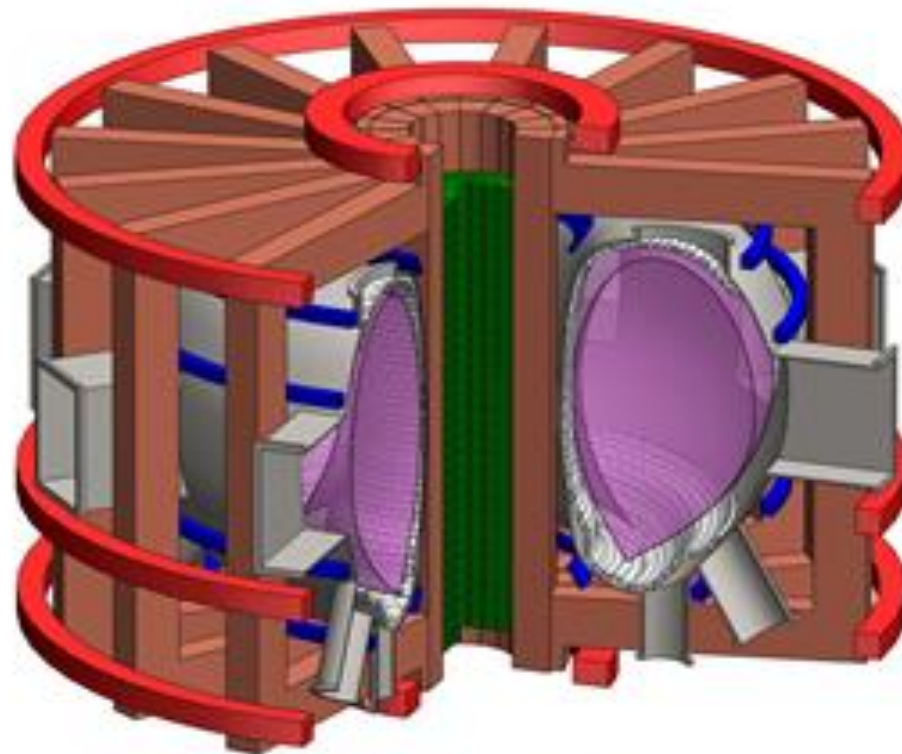
Innovative contributions

- AC operation
 - Followed by JET (1 MA), and HT-7 (continuous)
- CT injection
 - Fuelling technology development
 - 10 Hz repetitive operation
 - Working for 50 Hz (needed for ITER fueling)
 - Momentum injection

Design of STOR-U

- Designed at UofS PPL
 - simplified tokamak design: removal of central solenoid and replacement with coaxial helicity injection will be tested.
 - Quasi-steady state operation: AC operation will be considered
 - innovative technology development
- Larger and higher parameters than the previous Canadian TdeV tokamak

STOR-U Tokamak Conceptual Design



Scale

1m

$R = 80 \text{ cm}$ $a = 36 \text{ cm}$
Aspect ratio $= R/a = 2.2$
Elongation $k = 1.6 \sim 1.8$
Magnetic field $= 1.5 \text{ T}$
Plasma current $= 1 \text{ MA}$
3 MW NBI
 $n_e = (1 \sim 5) \times 10^{13} \text{ cm}^{-3}$
 $T_e = 700 \sim 1,700 \text{ eV}$
 $T_i = 600 \sim 3,500 \text{ eV}$
Discharge 300 ms long
Confinement time =
35~50 ms

Thank you!