CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Aix*Marseille université

IMAGEUR À RAYON-X POUR L'ÉTUDE DU PLASMA DE ITER

Patrick Pangaud – CPPM
pangaud@cppm.in2p3.fr

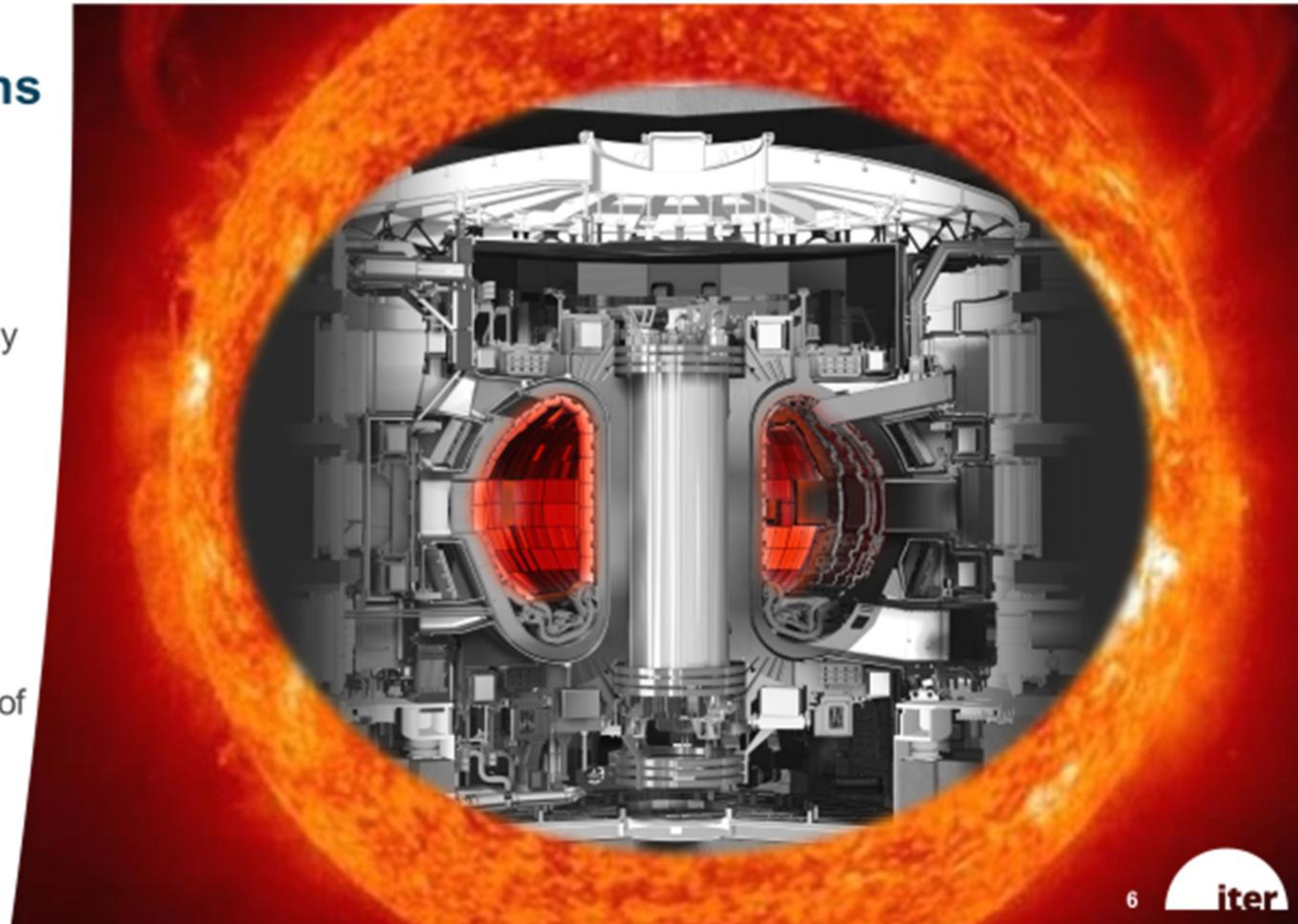
ITER Projet

ITER's missions

To demonstrate the scientific and technological feasibility of fusion power at industrial scale

To create a controlled "burning" plasma

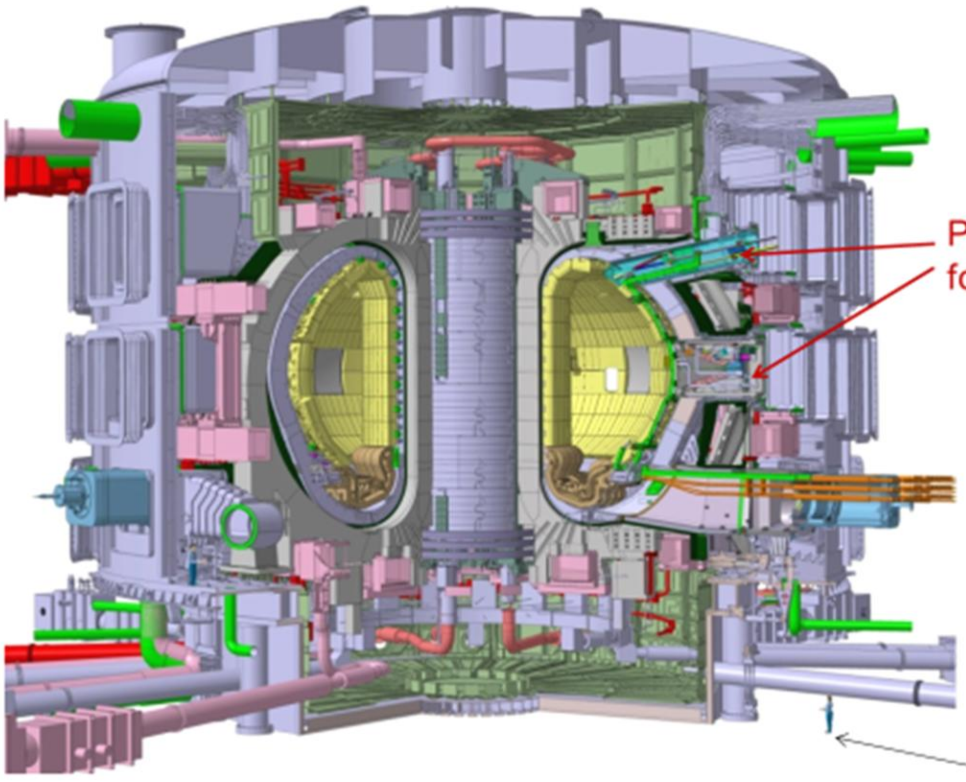
To generate 500 MW of fusion power in its plasma



ITER Projet

DIAGNOSTICS

- The eyes and ears of ITER
- About 50 systems
- Installed in view Ports all around the tokamak



17

ITER : Overall diagnostics situation

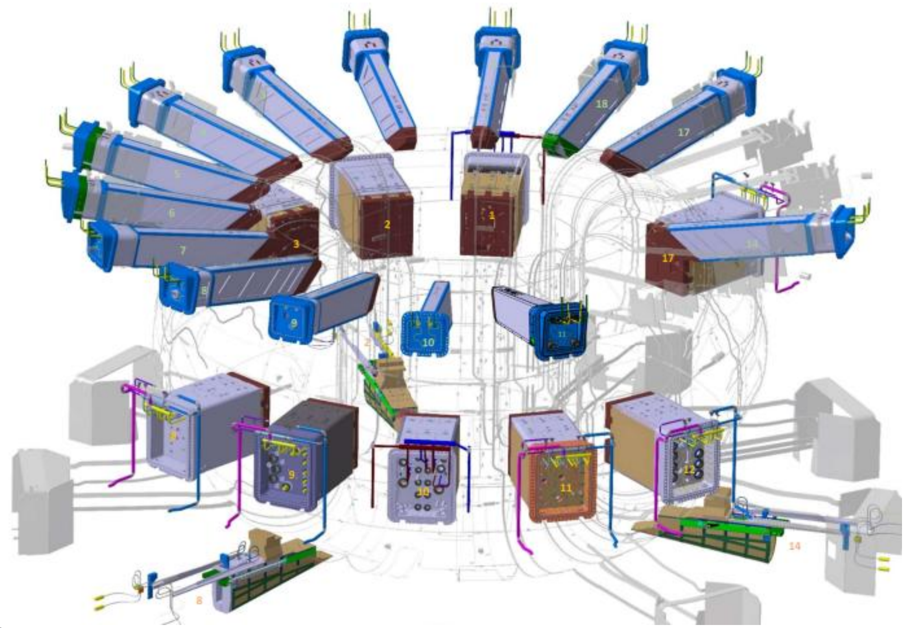
ITER has **26 diagnostic ports** which house about **50 diagnostic systems**.

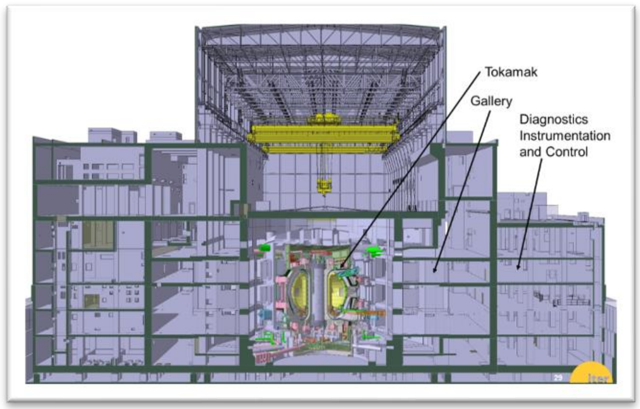
They are procured through **7 different DAs** (CN, EU, IN, JA, KO, RF and US) and by the **ITER Organization**.

Most diagnostics and ports **are in PDR and FDR phase.**

Manufacturing has started for many of these systems.

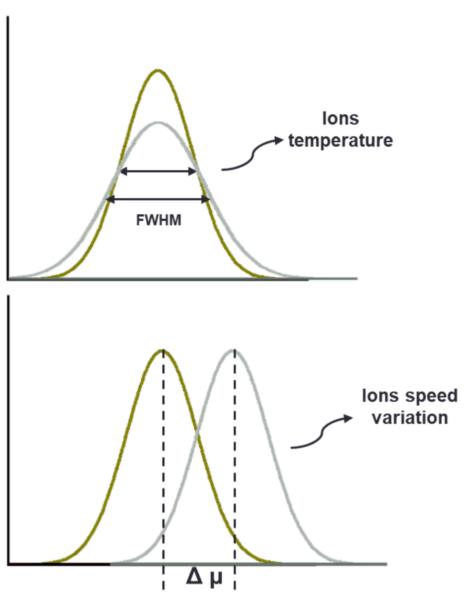
For some of the in-vessel diagnostics or diagnostics in the buildings, **the first parts have already been installed**.

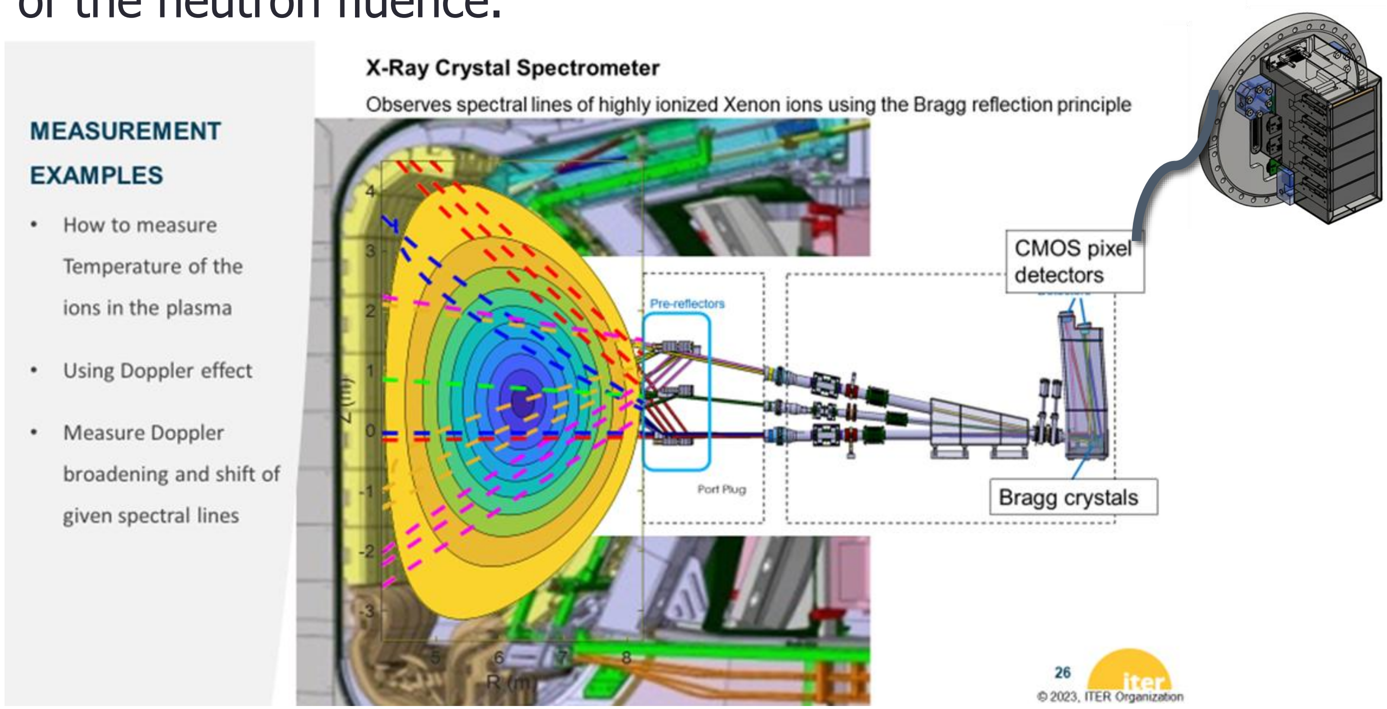




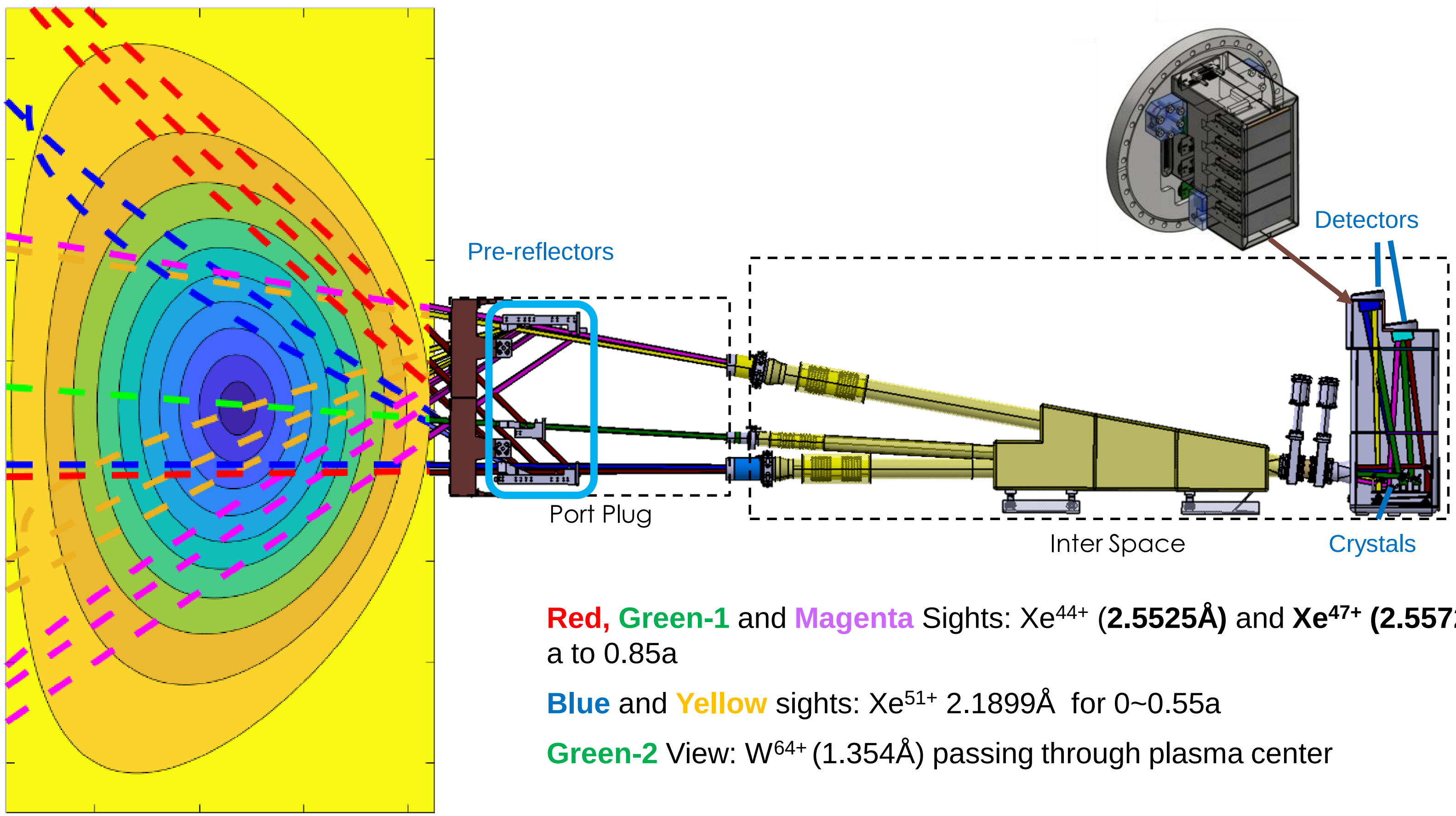
XRCS (X-Ray Crystal Spectrometer) diagnostic system

- Real time observation of spectral lines of highly ionized Xenon isotope inside the plasma.
  - Measurement of the temperature variation and speed stability of the plasma by spectrometry
- Real time observation of spectral lines of the Tungsten ions inside the plasma.
  - Measurement of the W dust pollution which might collapse the plasma stability.
- Real time observation of the neutron fluence.





XRCS - Core design



Red, **Green-1** and Magenta Sights: Xe^{44+} **(2.5525Å)** and **Xe^{47+} (2.5572Å)** from 0 a to 0.85a

Blue and **Yellow** sights: Xe^{51+} 2.1899Å for 0~0.55a

Green-2 View: W^{64+} (1.354Å) passing through plasma center

ITER schedule

- Phase SRO 2033-2035 (no neutron flux).
  COTS X-ray camera. No need for a radiation-hardness solution, and no low-energy detection.
- Phase DT1 2037 -> (high neutronic fluence)
  need a new X-Ray camera

ITER - CNRS (Agreement on Academic, Scientific and Technical Cooperation)

XRCS - X-ray photon counting detector

Needs of ITER X-ray detector

Active area:	Approximately 180 mm * 85 mm (for 55.E5 and 55.EI), and 100 mm * 85 mm (for 55.ED)
Pixel Size:	100 µm (preferable) to 200 µm
Vacuum grade:	UHV (for Sensor head)
Lower Energy threshold:	< 1.6 keV ➔ workable for ~2keV X-ray
Electronics configuration:	Separate Sensor (in vacuum) and detector electronics (DEU);
Communication constraint:	Cable length between DEU and Sensor head > 3 meters; Direct optical communication between DEU and Control
Material composition:	To be verified considering nuclear safety concerns
Frame rate:	>200 Hz
Latency for real-time:	<<10 ms
ICR/OCR:	Pixel linearity up to 10^6
Vacuum interface:	DN250CF/DN200CF
Magnetic Field Tolerance	200 mT
Neutron Flux Tolerance	>10^6 n/s.cm^2

Full Detector size :
180mm x 85 mm

In vaccum pressure :
UHV

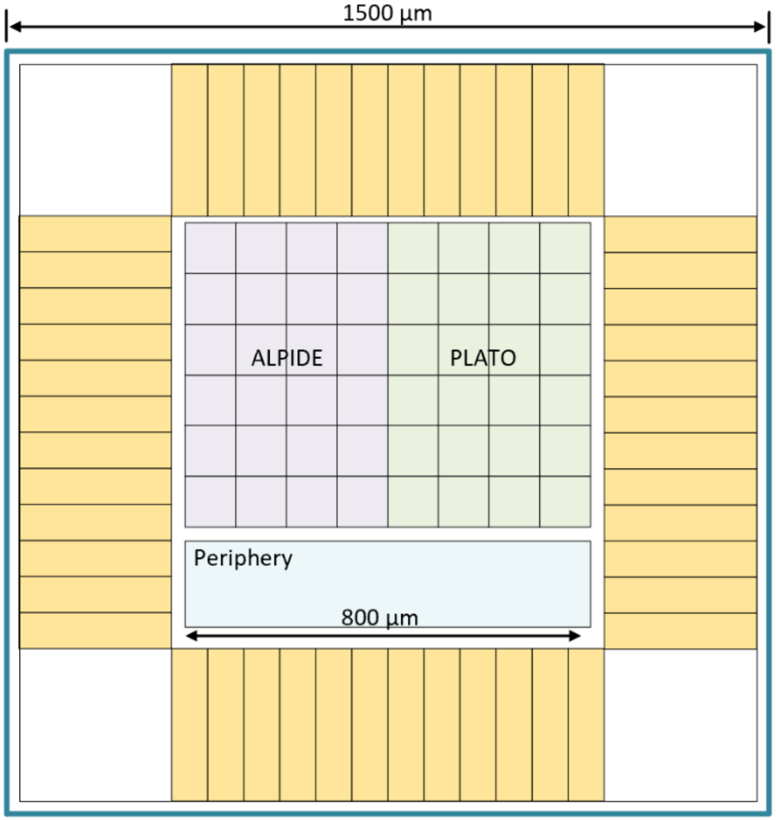
Expected low E Threshold :
<1.6 keV

Real-time latency (W detection) :
<< 10ms

Neutron fluence :
10^6 n/sec. cm²

Long distance communication to control room :
Optical fiber

XRCS Prototype chip (proof of concept)



Why TPSCo 65nm process

- Need a CMOS MAP rad-hard stitching technology with high sensitivity detection node
- But low epi depth will penalize the X-ray absorption efficiency

TPSCo 65nm chiplet (1.5mm x 1.5mm)

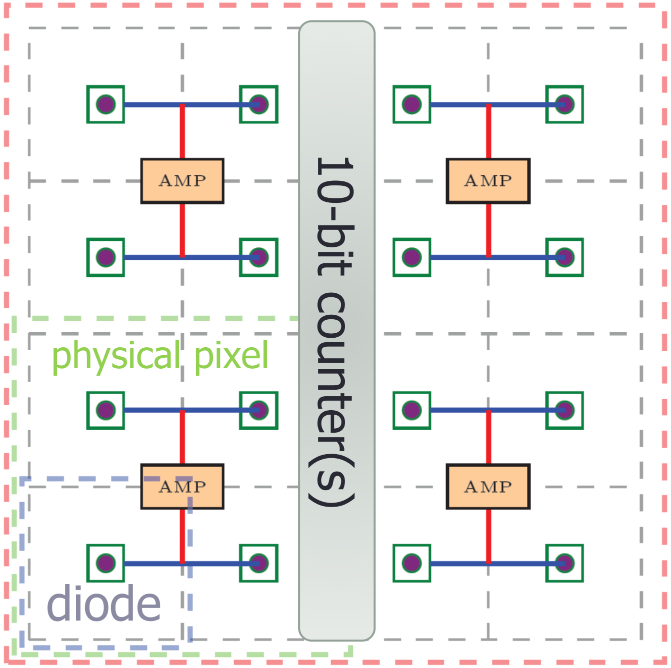
- Two double matrix (6x4 Super Pixels)
- 25µm diode collection size (to improve detection efficiency
- 100µm pixel size
- Minimum threshold 400 e-
- Maximum noise 40 e-
- Double thresholds (Photon + neutron detection)
- Output frame-rate >200 Hz
- Input Counting rate per diode : 6.25.10^3 hit/sec
- Neutron radiation hardness

Plato (DOI 10.1088/1748-0221/12/01/C01036)
Alpide (CERN-THESIS-2021-146)

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

Aix*Marseille université

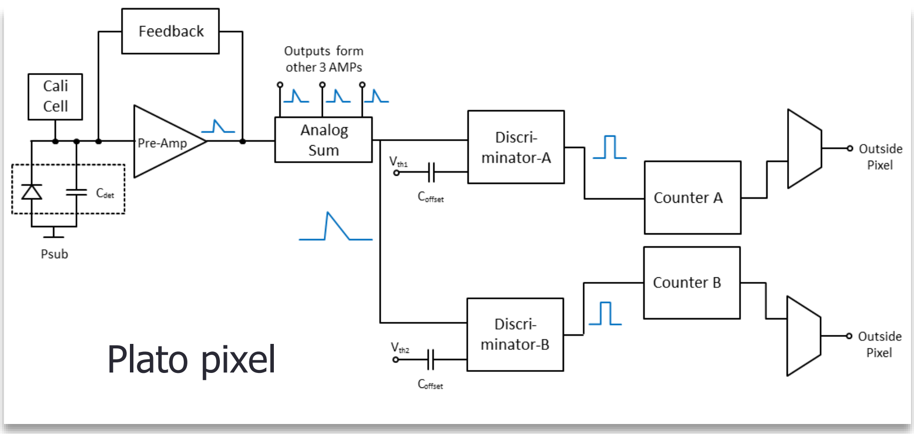
XRCS Prototype chip : Pixel architecture



25μm² pixel unit as "diode".

The "physical pixel" contains 4 "diode" and only 1 pre-amplifier for 50μm².

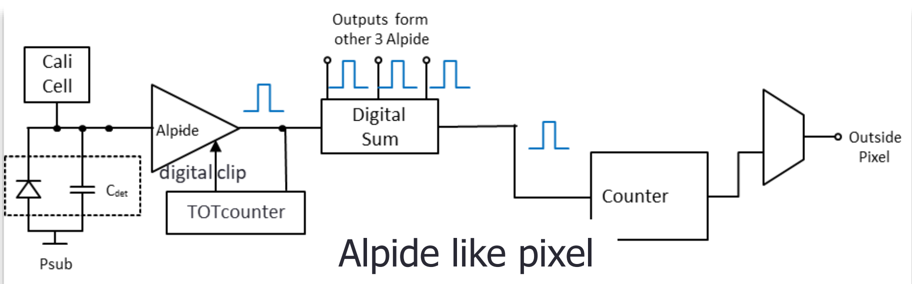
100μm² pixel as "super pixel".



Why two architectures ?

Plato was realized in an other technology and had very good results.

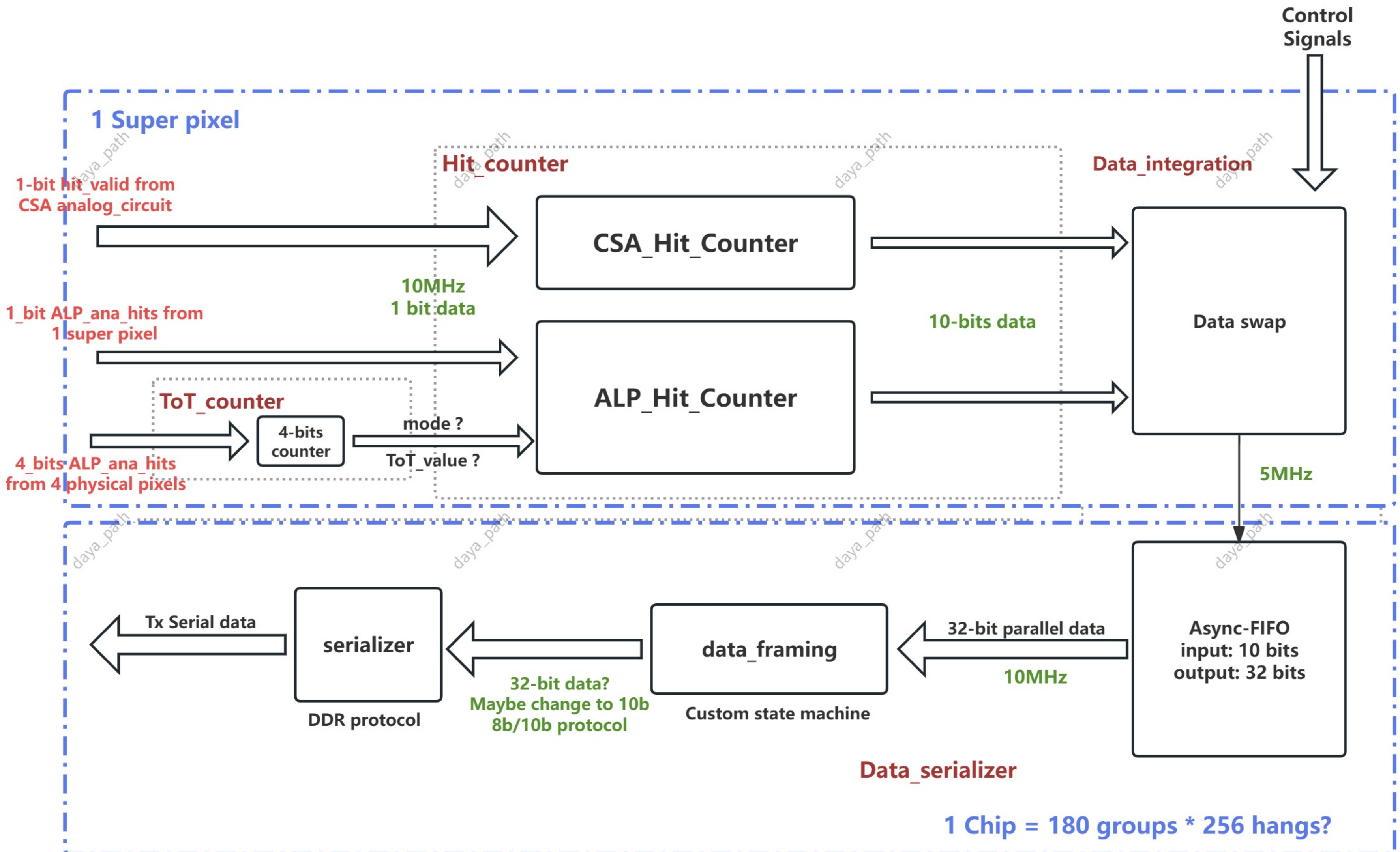
Alpide like is the known-well good candidate for a low capacitance diode value.



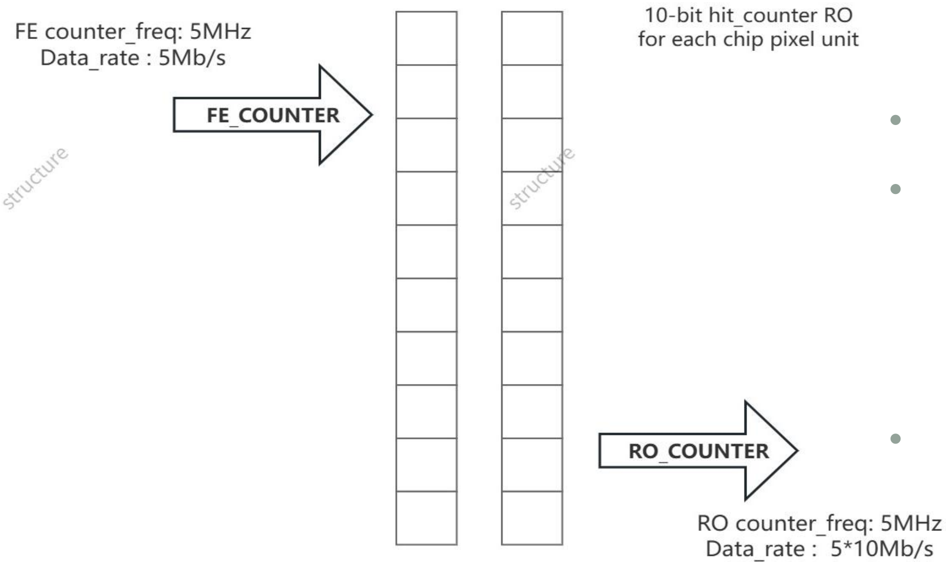
Mujin Li IHEP/CPPM (China)

Nour Mhanna CPPM (France)

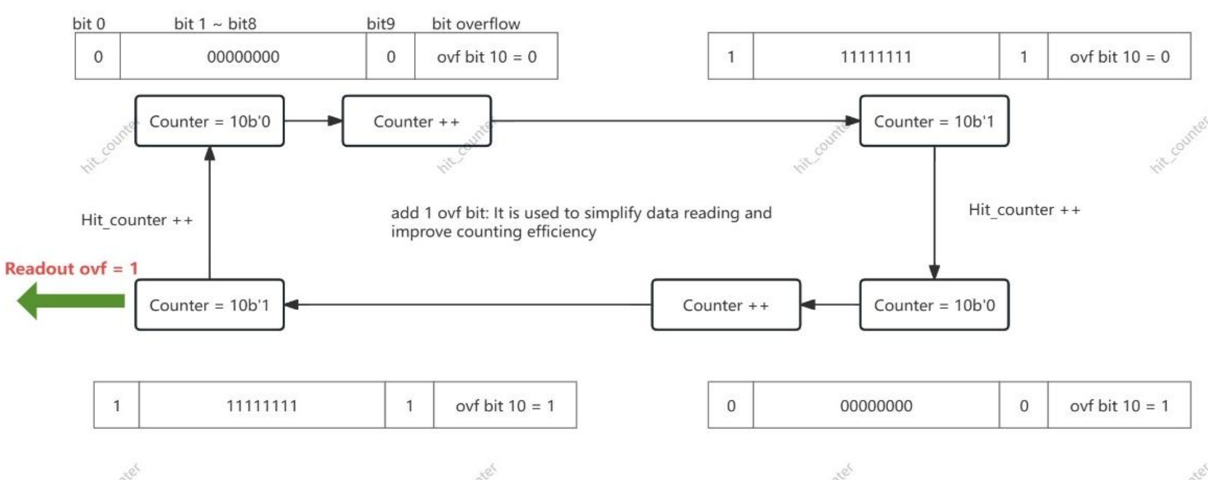
XRCS Prototype chip : Path of Data



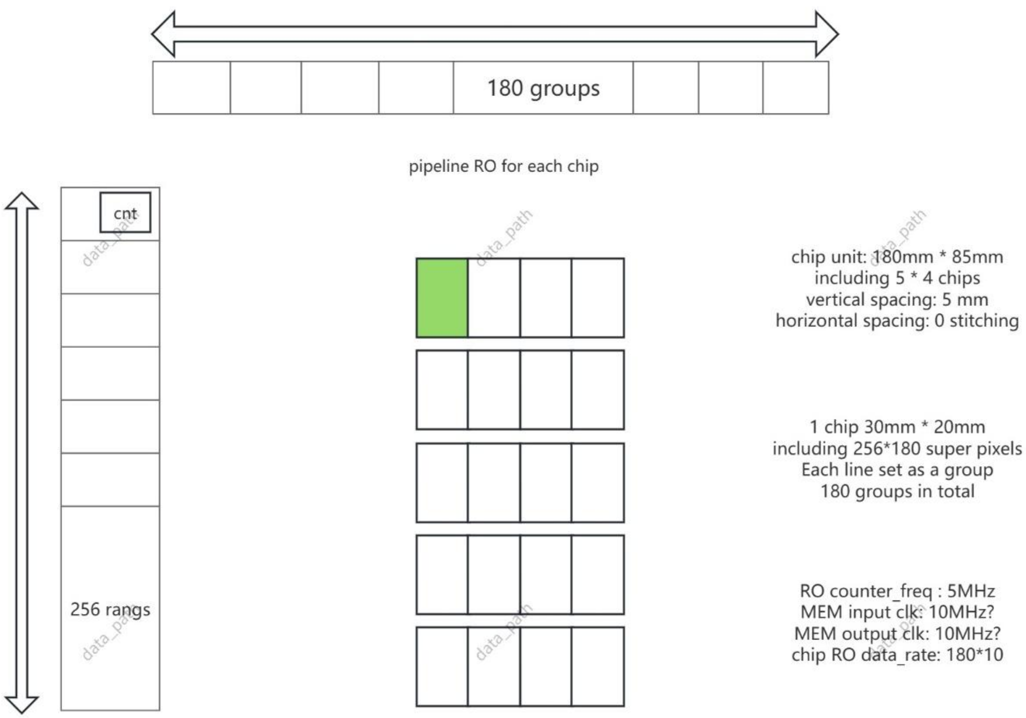
Full Project : EOC Digital Blocks Design



- 10-bit Pixel counter (~50Mb/s)
- Shift Register delivers hit_counter results to EOC (End-of-Column)
  - 'Freeze' and 'Read' signals
- Overflow bit can be added if needed



Full Project : Digital Blocks Design



Full Detector size : 180mm x 85 mm
5 modules of 4 chips
Space max between module : 5mm
Space between chip on module : 0

Chip size (reticle) ~ 30 mm x 20 mm
Super Pixel matrix size : 256 x 180

Frame Rate > 200Hz

- Input Count Rate : 10^5 cps (for 1 super pixel)
- Read-Out Data
  - Main clock : 160 MHz (maybe)
  - Full Output data rate is 5~10 Gb/s
  - DDR protocol

Summary

The aim is to design a X-Ray Crystal Spectrometer detector for the plasma diagnostic.

The TPSCo 65nm is a good candidate : rad-hard, well-used, stitching process.

LF110 technology could be an other good candidate

The project needs FIFO + serialiser + GigaBit Transceiver

And some analog blocks (BandGap, Analog biasing, buffer etc)

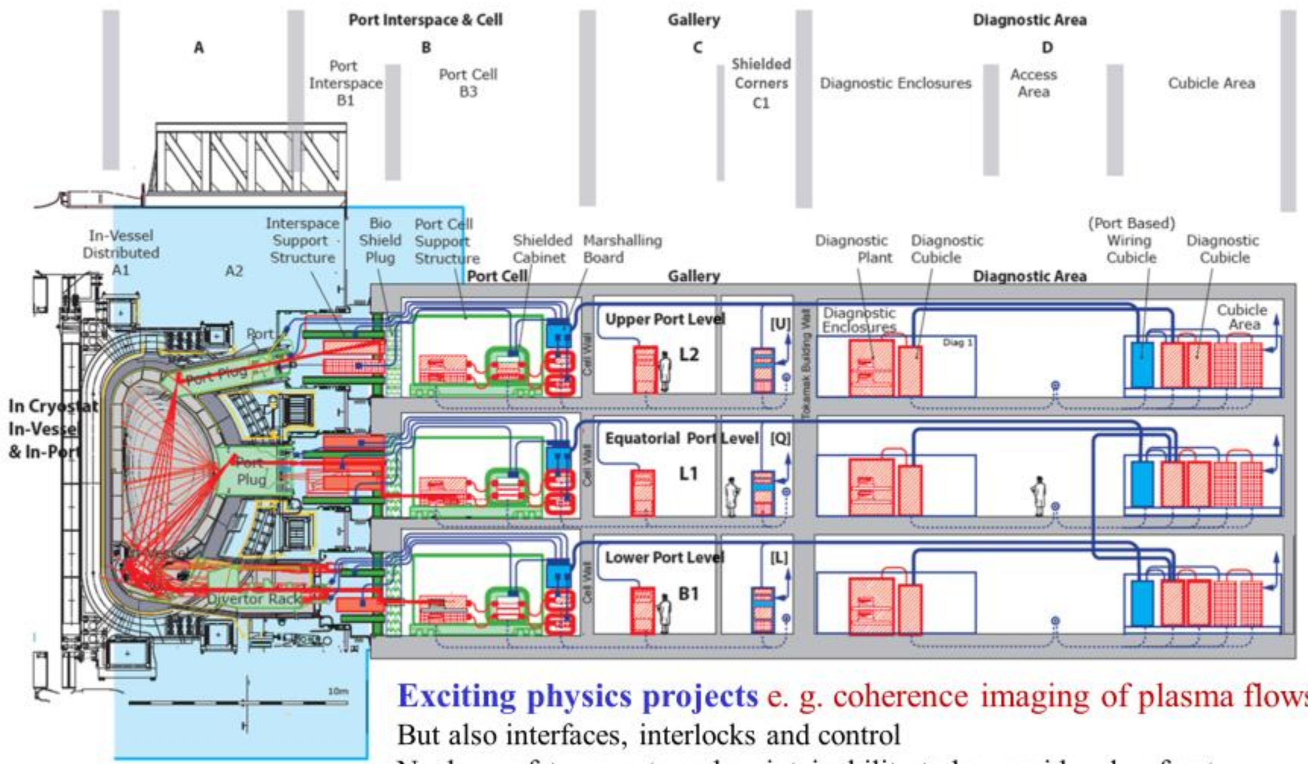
- Need discussion in the community for reusing IP blocks ?

Interest of this development for other spectrometry low energy application.

Collaboration welcomed

BACKUP

Diagnostics: the wider view



Exciting physics projects e. g. coherence imaging of plasma flows
But also interfaces, interlocks and control
Nuclear safety aspects and maintainability to be considered upfront
System to withstand some neutrons, gammas and residual magnetic fields

➔ **Integrated teams**

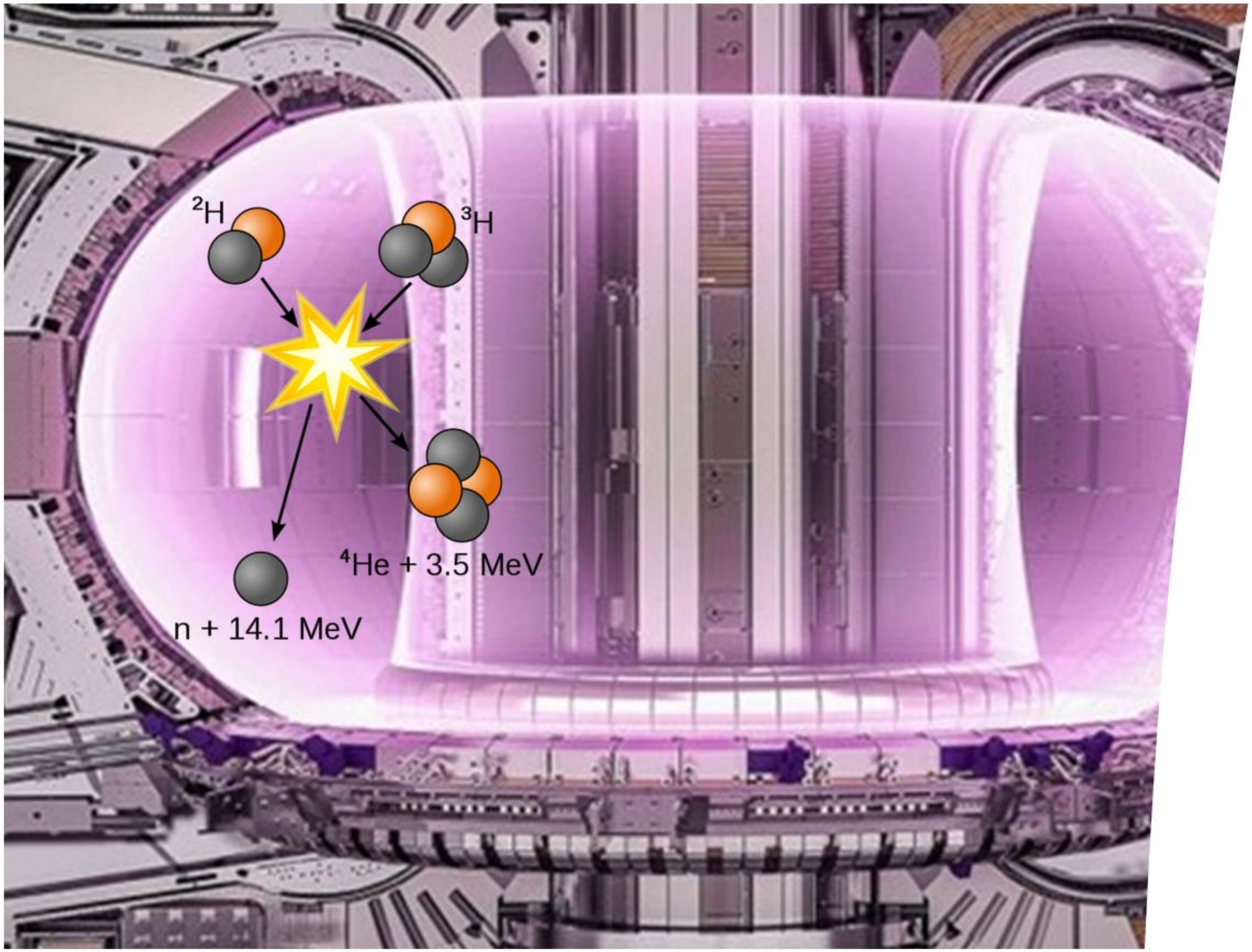
From M. Walsh

Premier sous-ensemble terminé en mars 2022

Un « sous-assemblage » est constitué d'un secteur de chambre à vide, deux bobines de champ toroïdal et une section de bouclier thermique.

Poids: 1,250 tonnes.

Neuf sous-ensembles composent le tore.



NUCLEAR FUSION

Using the Deuterium-Tritium reaction within a magnetically confined plasma heated at 150 million°C

1g of D-T fuel ≈ 8T of oil

Reaction products

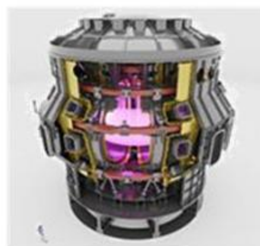
- ^{4}He contributes to plasma self-heating
- Neutron escapes with most of the energy (collected fusion power)

Experimental tokamaks

Fusion reactors

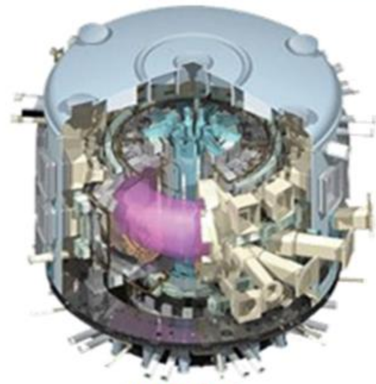
JET

80 m³



JT-60SA

135 m³



ITER

800 m³

(one-third the size of an Olympic swimming pool)

~ 500 MW_{th}

DEMO

~ 1000 – 3500 m³

(half to one and a half times the size of an Olympic swimming pool)

~ 2000-4000 MW_{th}

ITER Inherits a long history of tokamaks research

ITER will bridge the gap between today's smaller-scale experimental fusion devices and the demonstration fusion power plants of the future

ITER is the first fusion machine licensed as a Nuclear Facility