Recent Progress in the ITER EC H&CD System

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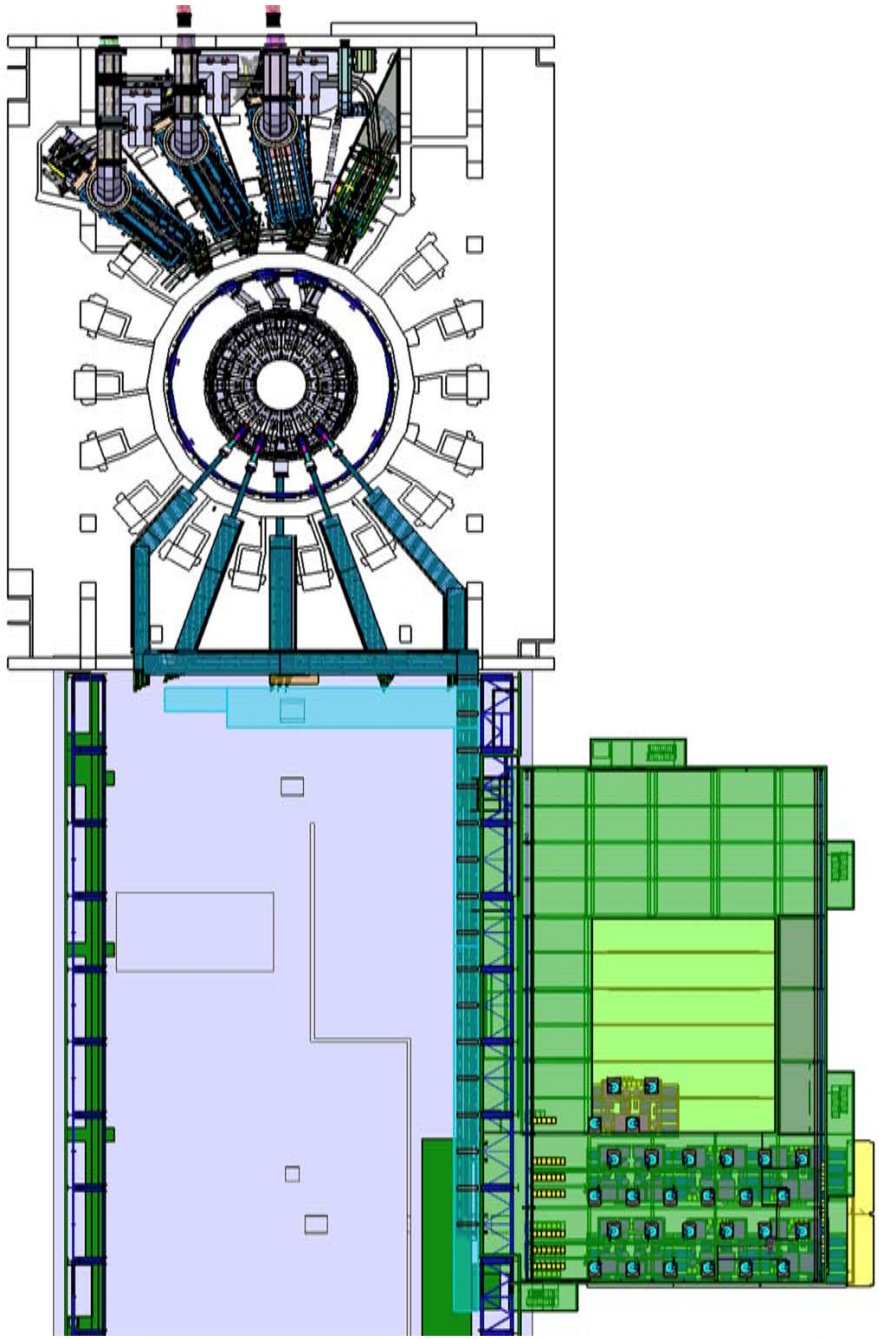
With the help of many, many other colleagues:

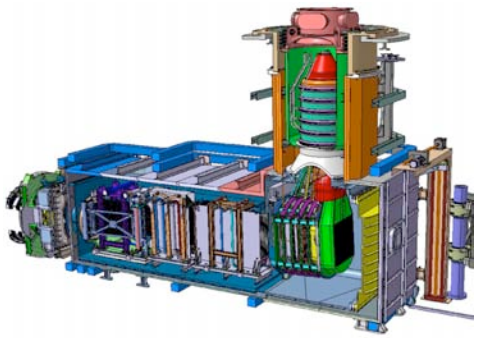
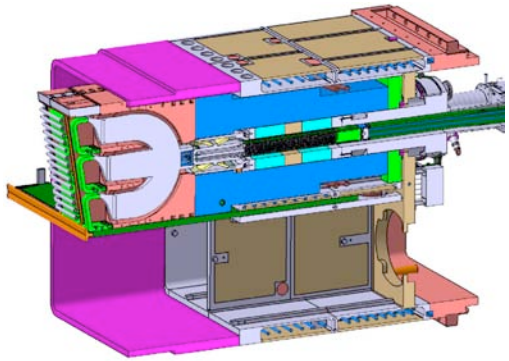
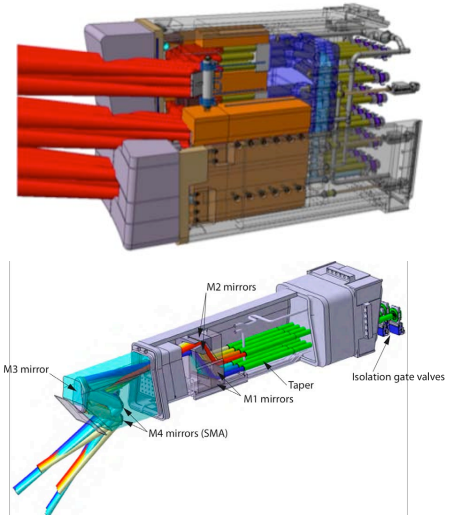
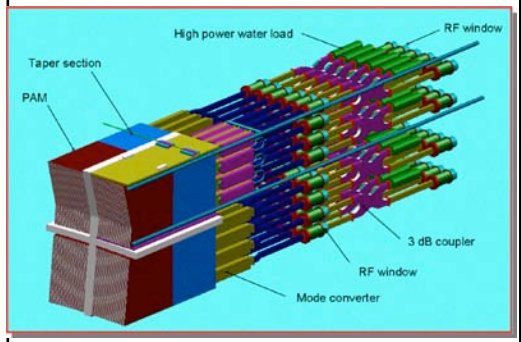
Outline

- General Overview of the EC system
- Progress in 2009
  - RF-building
  - Gyrotrons
  - Transmission Line
  - Launchers
  - Auxiliaries
- Scenario I Schedule
- Next Years (foreseen) Challenges



ITER H&CD Systems

All four heating systems envisioned for ITER in preparation for DEMO

NB	IC	EC	LH
			
33MW +17MW	20MW +20MW	20MW +20MW	0MW +40MW
Plasma Rotation for stabilizing RWM	Bulk ion heating	Localized H&CD for MHD control	off-axis Bulk current drive

Uniqueness of an EC System

ECH is ITERs only Heating and Current drive source
that is both **localized** and **steerable**

ECH is a **surgical tool** that can
"**pen point**" a spot in the plasma cross section
to **heat** and/or **drive current**

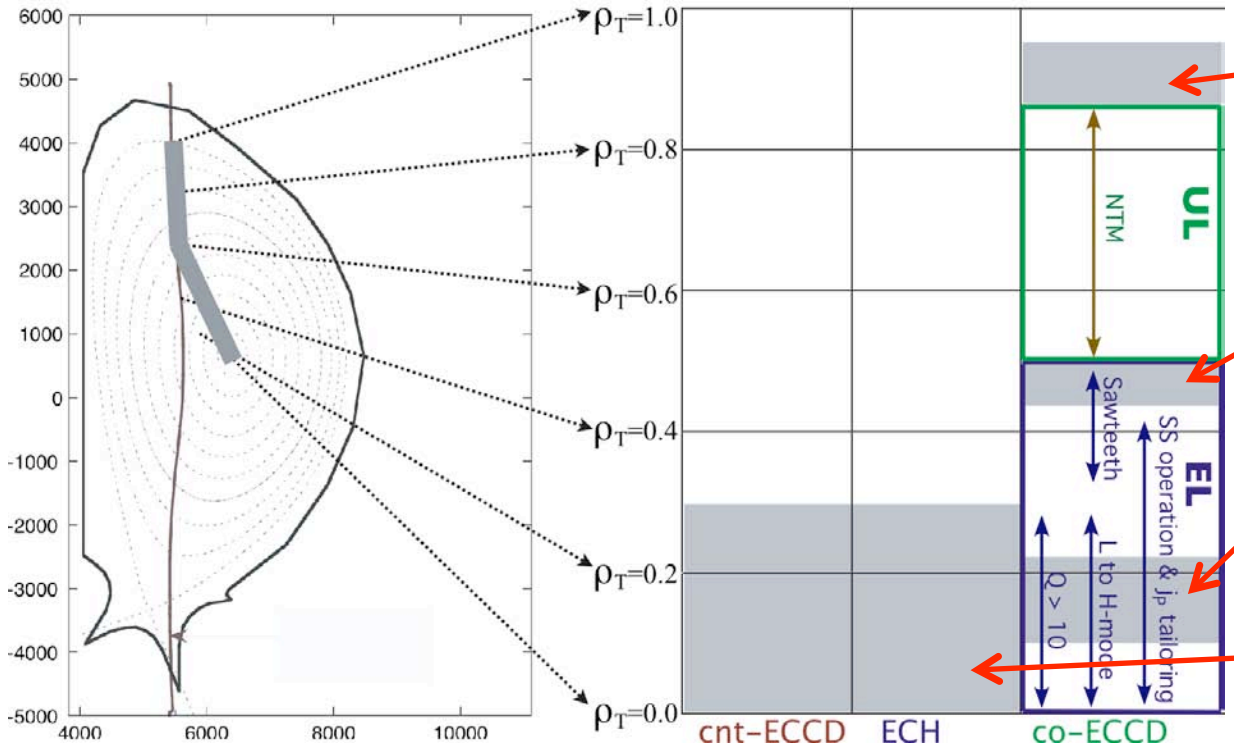
Localized:	power deposited in a small region ~0.04m (a=2.0m)
electron heating:	20MW
Driven current:	0.1 to 0.8 MA

Physics: Project Change Request PCR-098

The PCR optimizes the toroidal and poloidal steering angles of the EC launchers provide increased access from on-axis to near the plasma boundary

2008 baseline:

- **EL**
  - Access $0.0 \leq \rho_T < 0.5$ (Central heating and current drive applications)
- **UL**
  - Access $0.5 \leq \rho_T < 0.85$ (q=3/2 and 2 NTM locations)



No access for $\rho_{NTM} > 0.85$

EL can't access due to beam shine thru

EL limited access (geometrical limitation)

No pure heating (EL and UL in co-CD)

PCR-098 Accepted Changes

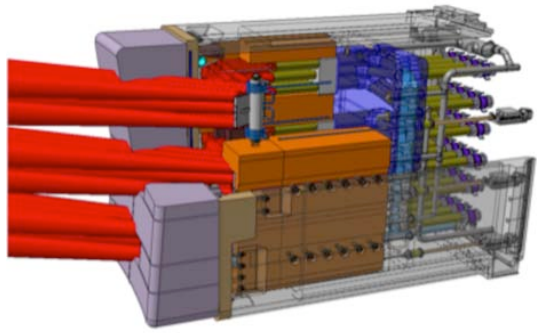
The **EL** modifications are:

- Introduce ±5˚ poloidal tilt in top and bottom steering mirror
- Limit toroidal steering angle to ≤40˚ (avoid beam shine thru)
- Flip middle steering row for counter ECCD.

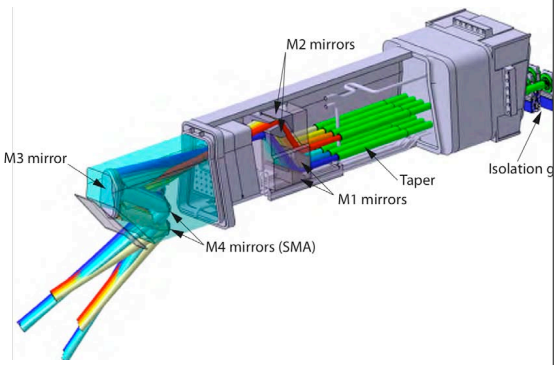
The **UL** modifications are:

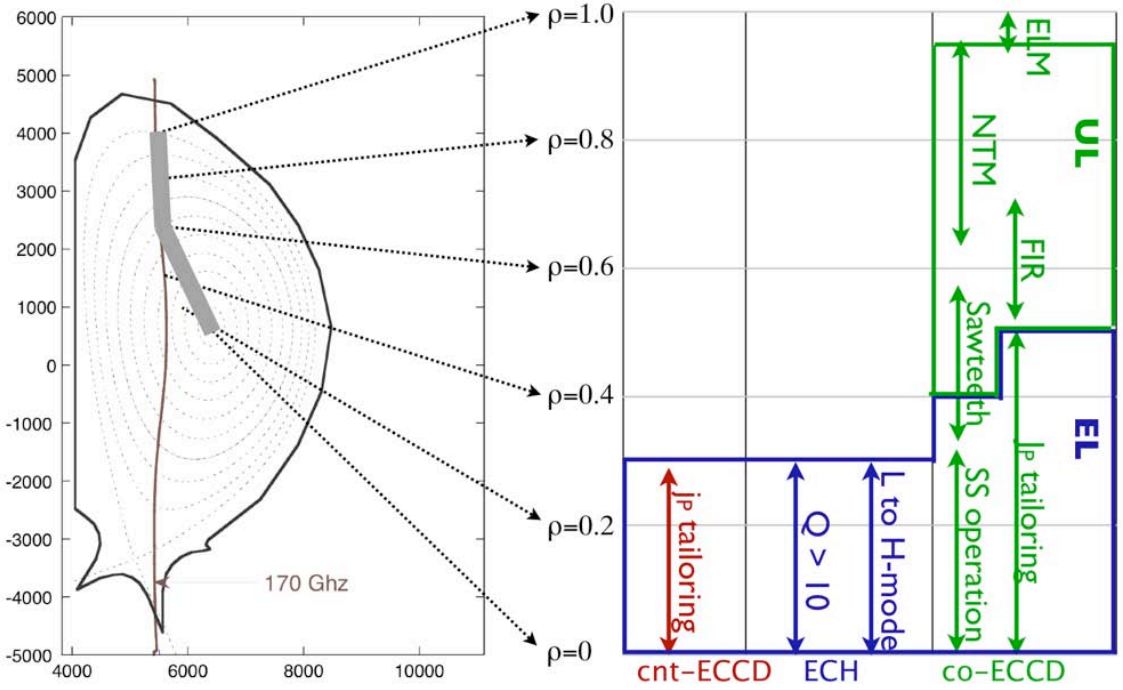
- Access $\rho_T \leq 0.3$ with upper steering mirror
- Access $\rho_T \geq 0.95$ with two lower steering mirrors.
- Access $\rho_T > 0.88$ with two lower steering mirrors.

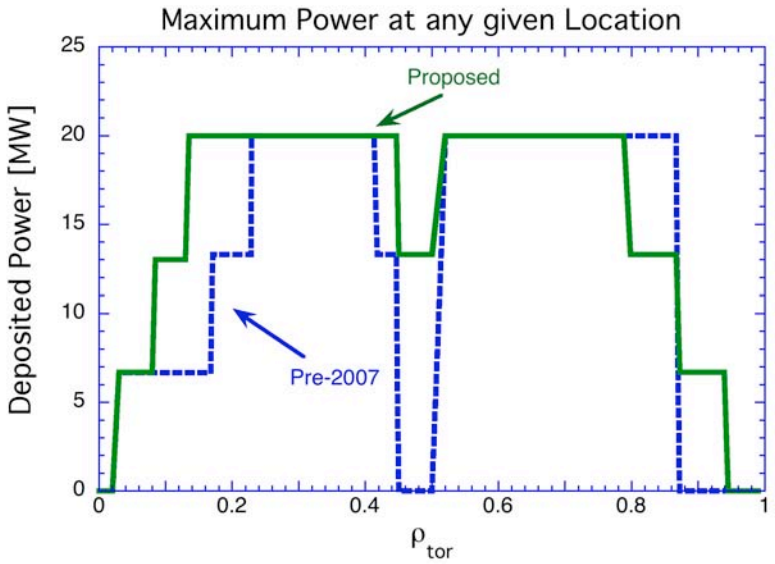
EL



UL

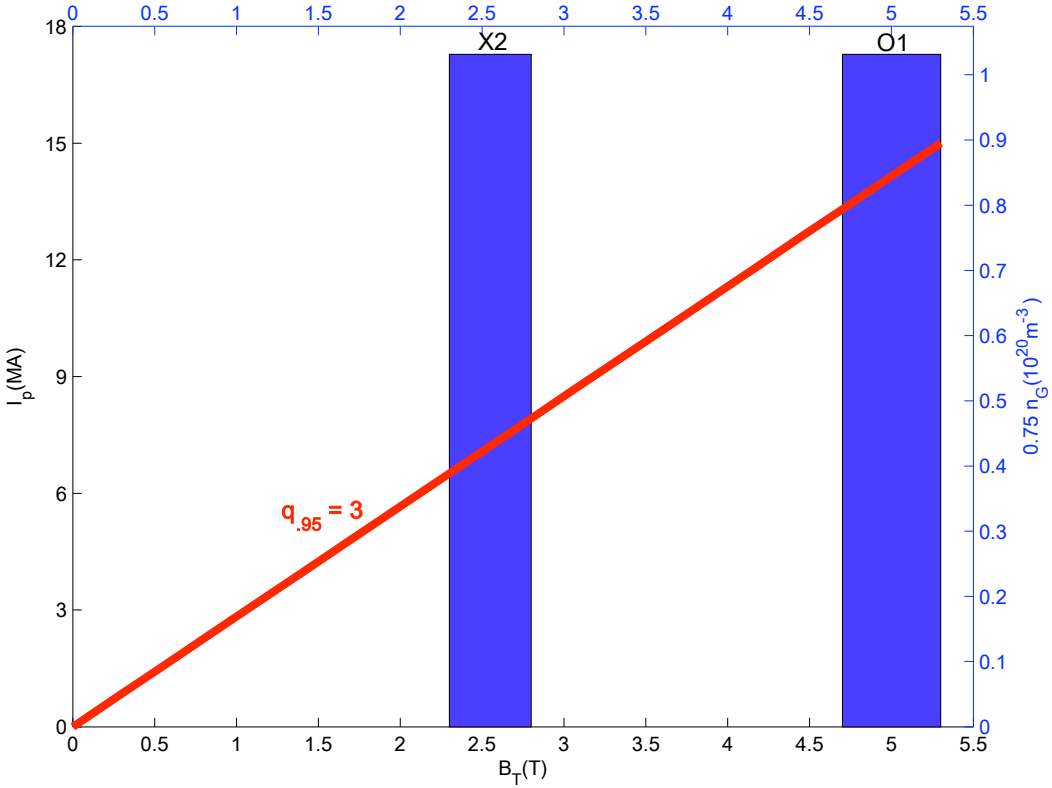






B_{TOR} EC system Operating Window

EC System achieves full functionality around two operating windows (X2 and O1)



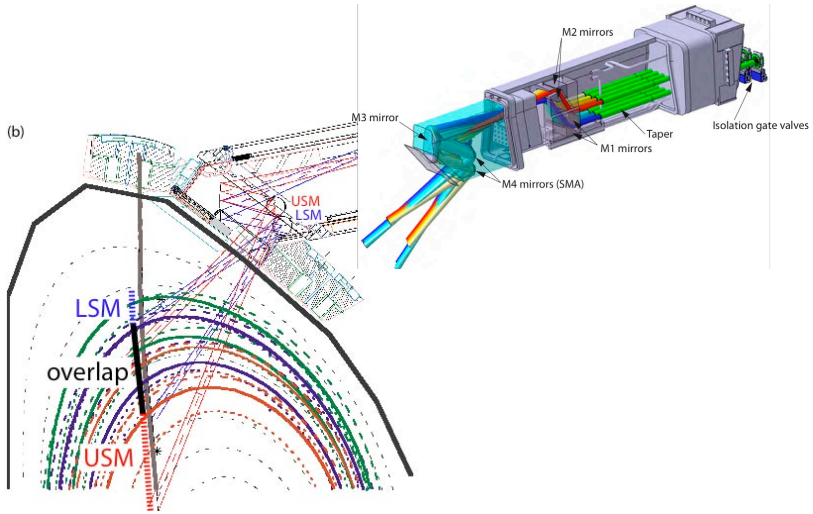
Concern for Power scaling of L to H-mode

$P_{L-H} \propto B_T$

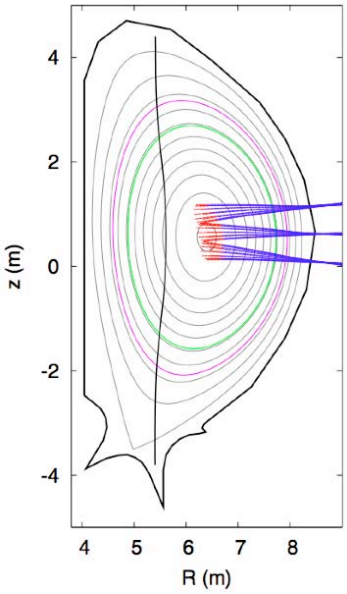
≤2023 improve scaling laws for DT in 2026

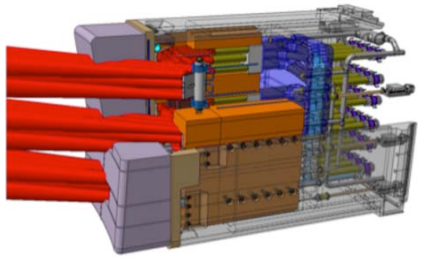
B_T window for EC inside of $\rho_T < 0.5$? $\rho_T < 0.9$?

MHD Control



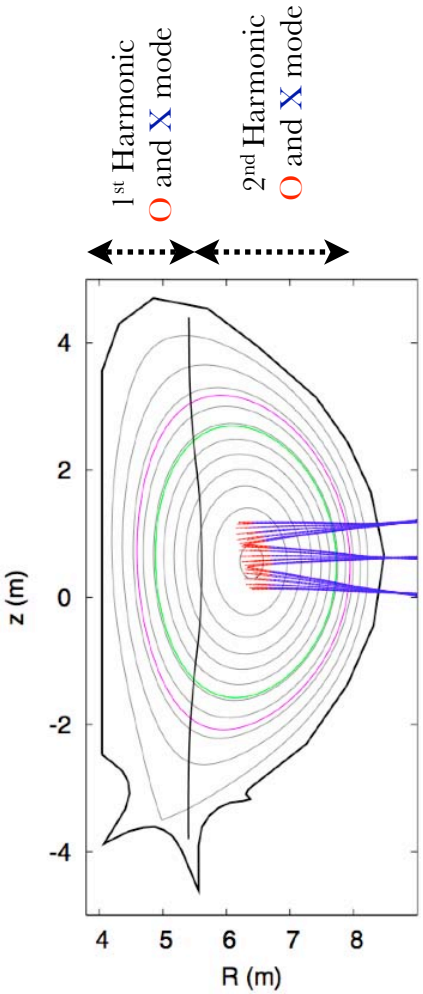
Central H&CD

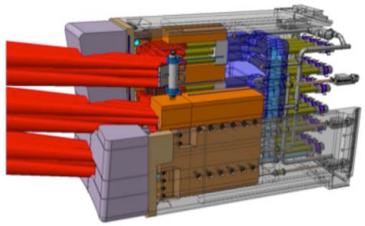




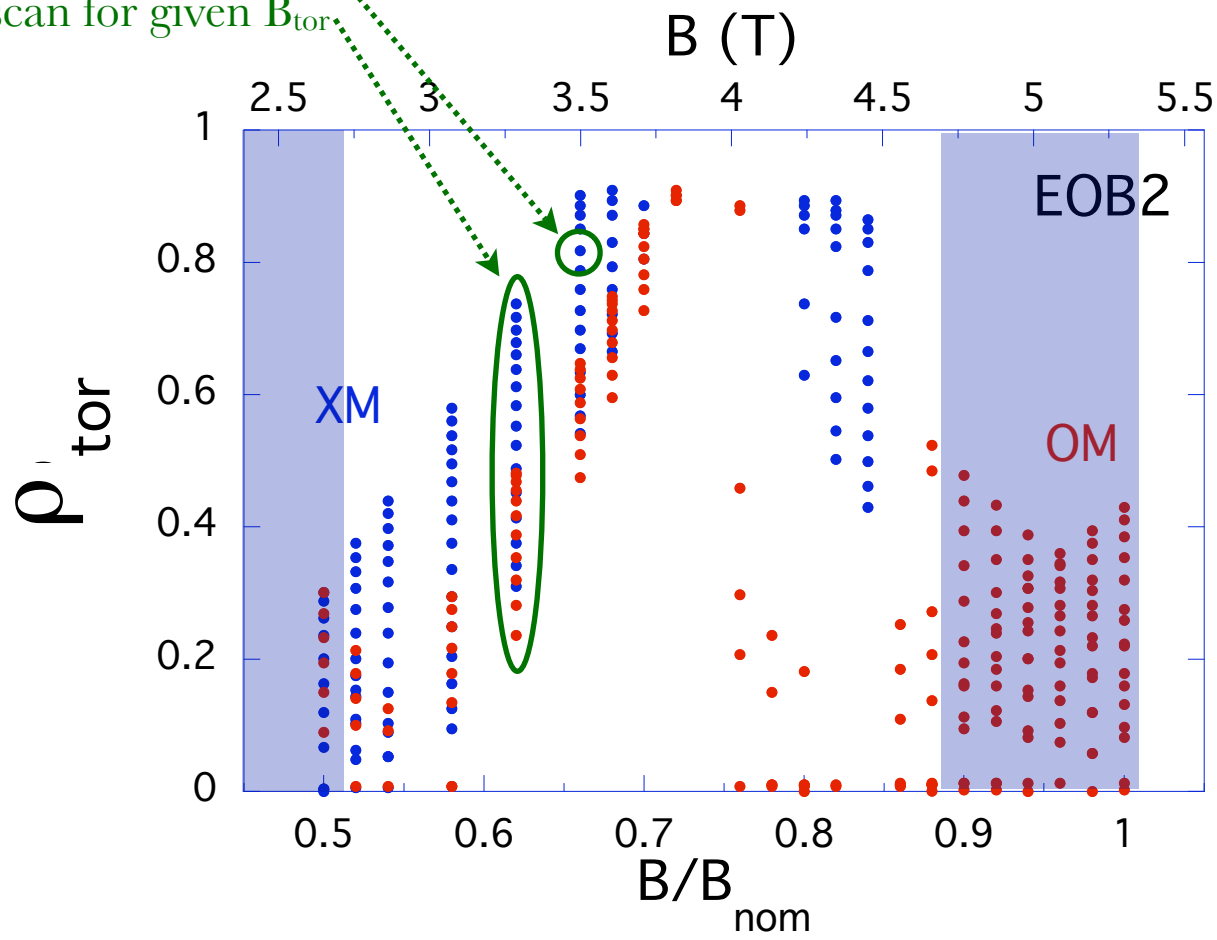
Accessibility of Equatorial Launcher

D. Farina (CNR) investigated EL accessibility between O1 and X2 ranges decreasing B_{tor}

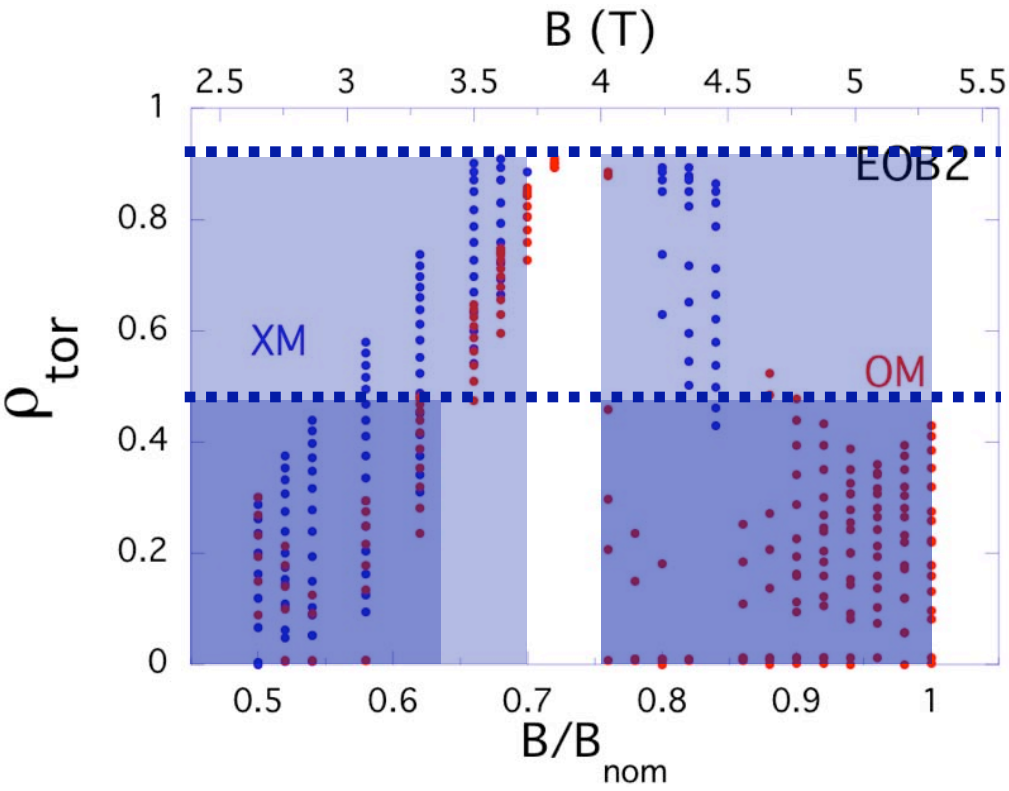




Peak in deposition for fixed angle
Toroidal scan for given B_{tor}



Increased Operational range in B_{tor}



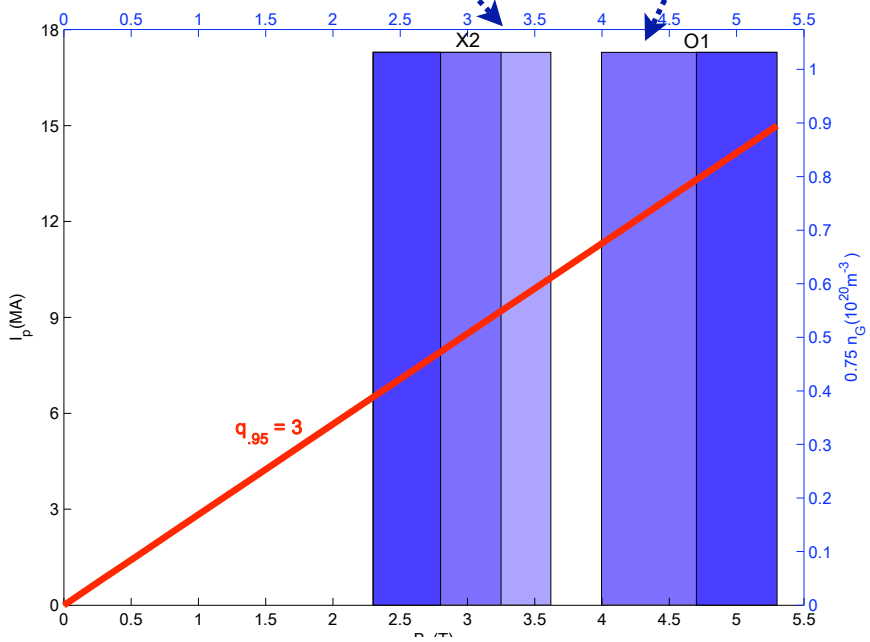
L to H-mode: Heat inside sepratrix $\rho_T \leq 0.95$

Central Heating: Power absorbed inside $\rho_T \leq 0.5$

Range of B_T increases

2nd harmonic: $2.3 \leq B_T \leq 3.7T$

3rd harmonic: (same)



Increased operating regions useful during ITER commissioning from 2018 to 2016 (D-T)

Aid in answering:

How much power is needed for L to H-mode transition prior to DT operation (2026)

EC System In-kind Procurements

5 Parties provide in-kind procurement of the 4 subsystems

EU	IN	JA	RF	US
Gyrotrons: 8MW	Gyrotrons: 2MW	Gyrotrons: 8MW	Gyrotrons: 8MW	24 T- Lines
12 H&CD PS	1 H&CD PS	1 EL		
4UL				

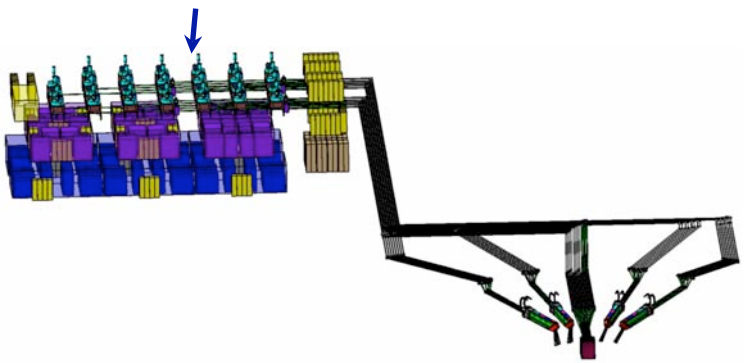
2008-9 Procurement Changes/proposals:

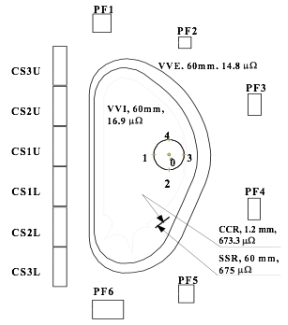
IN-DA Procures two 1MW 170GHz gyrotrons and associated PS system

IN-EU proposal to share PS procurement (8 from EU, 5 from IN)

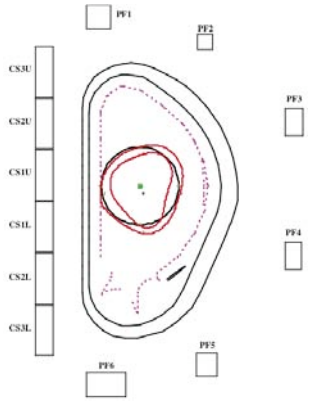
PCR-160 Startup Gyrotrons

3 127GHz + 24 170GHz gyrotrons





Outboard plasma initiation:
(R = 7.48 m, Z = 0.62 m, a = 0.8 m)



Phase	LFS with 127GHz	Central/HFS with 170GHz
Resonance in null region	Yes Limited in B_T range	Yes Limited in B_T range
Available Power	~2 MW	≤20 MW
Pulse length	10 sec (PR)	<3'600 sec
TL & launcher interface	Dual frequency window (increased cost, loading, risk)	No change
System availability	1 PS to 3 gyrotrons	12 PS to 24 gyrotrons

170GHz can achieve the required functionality for breakdown and burn through

Study concluded: Simplify EC system remove 127GHz, reduce investment costs

PCR-160 IN-DA and IO Resolution of Credits

IN-DA would procure:

- two 170GHz 1MW H&CD RF Sources
- one power supply set: MHVPS, BPS, APS (if necessary) and auxiliaries

IO encouraged:

- Minimize interface complexity, spare parts, procurement monitoring, etc.
- Request IN-DA to procure same RF source set as EU, JA or RF
- Request IN-DA to procure same power supply set as EU

Range of options:

IN-DA procurement is same as another DAs ⟷ IN-DA procurement is "Functional"

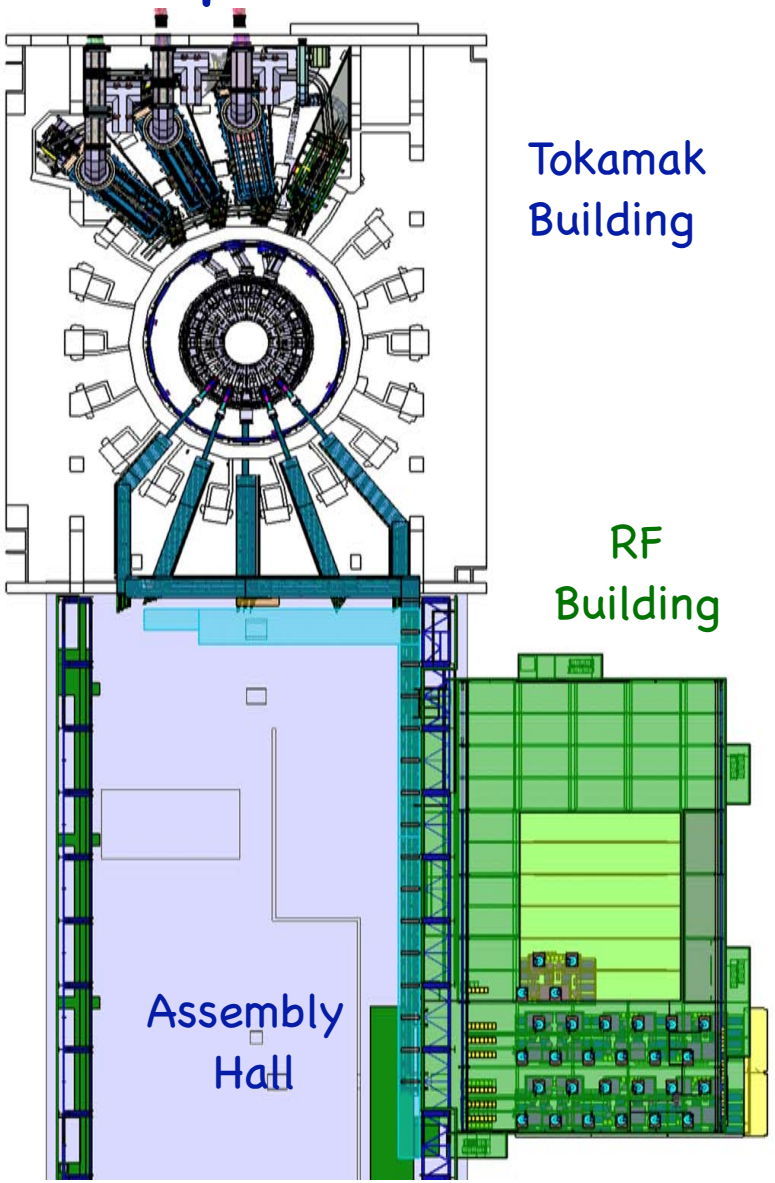
Solution?

IN-DA stance:

- IN-DA procures 2MW RF source possibly from EU, JA or RF (TBD at PA)
- IN-DA use similar components for IC PS as EC PS

EC System Layout in RF Building

Sept. '2008



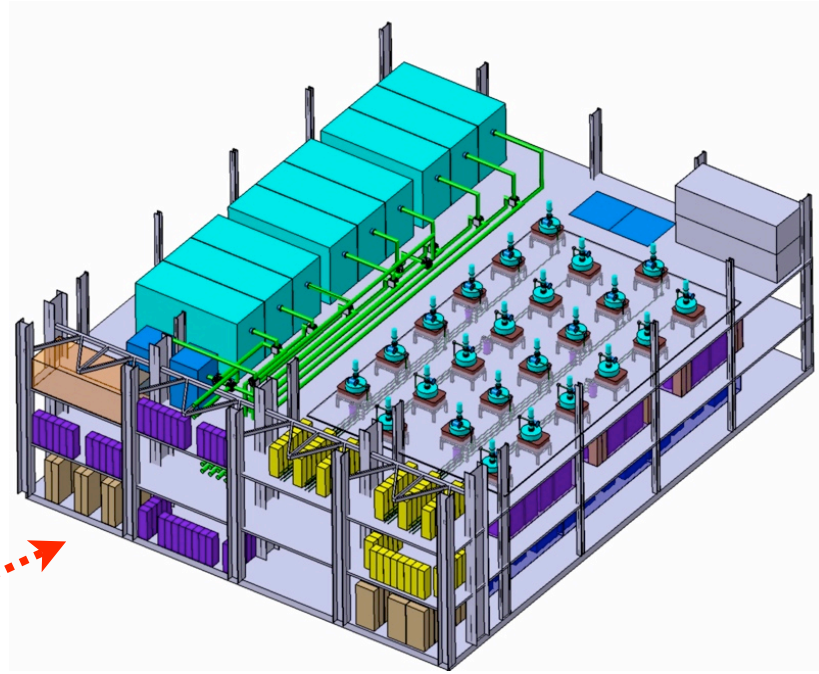
IC:
20MW

Upgrade
20MW

EC:
20MW

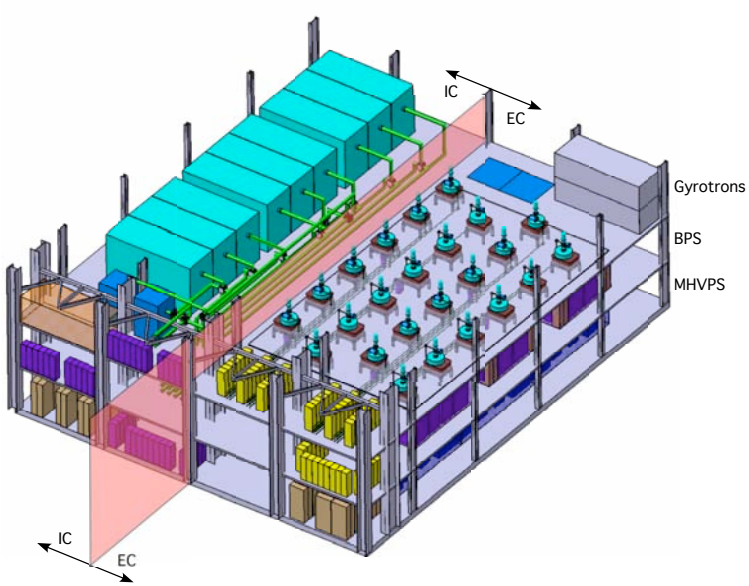
Sept. '2009

Efforts to reduce cost: reduce RF building for 40MW (no upgrade)

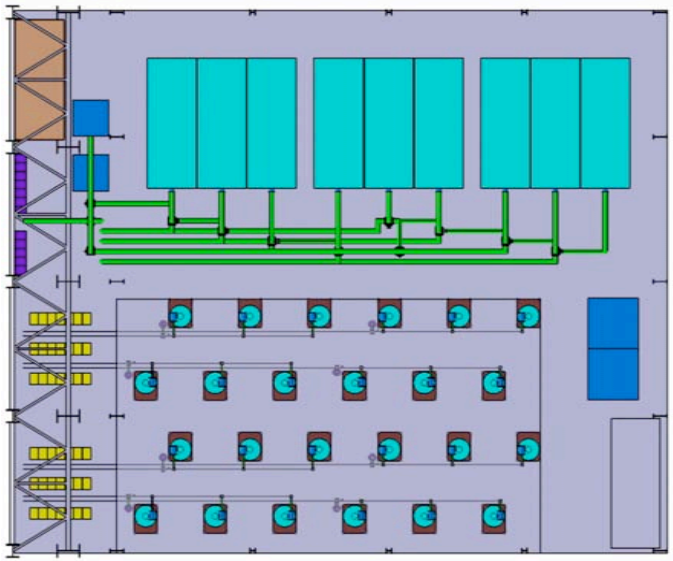


RF Building 2009

Building split in half between IC and EC



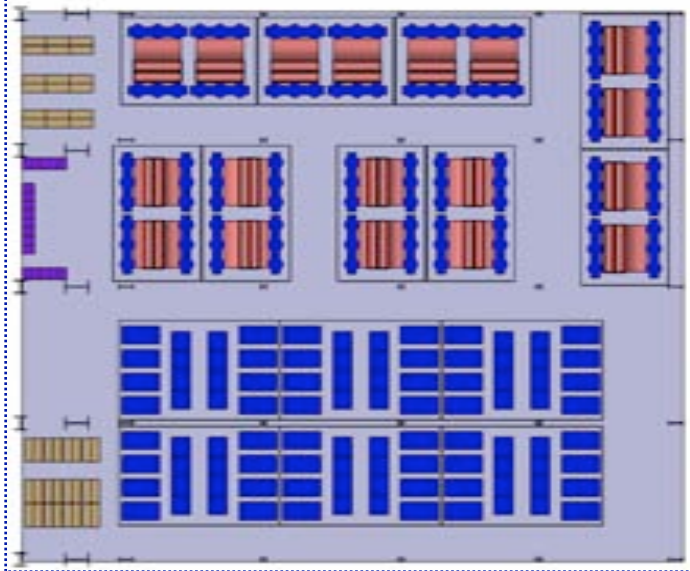
3rd Level



IC: Sources, TL

EC: Gyro, TL, InC zone

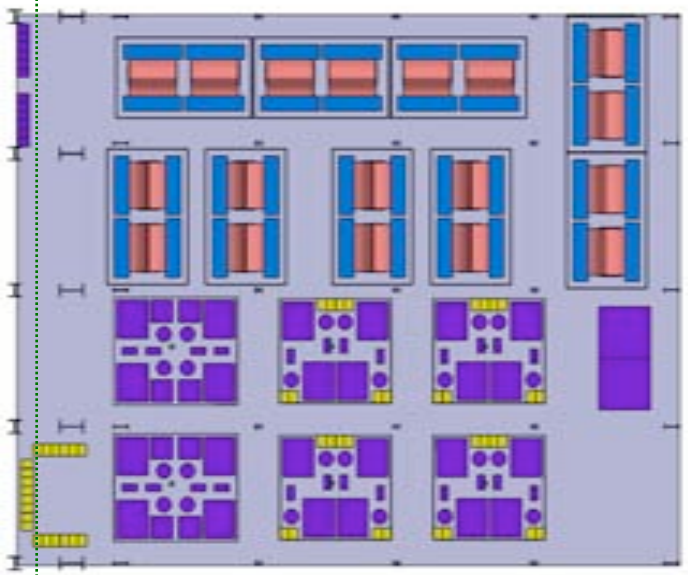
1st Level



IC: Transformers

EC: MHVPS 12+1 PS

2nd Level



IC: Modules

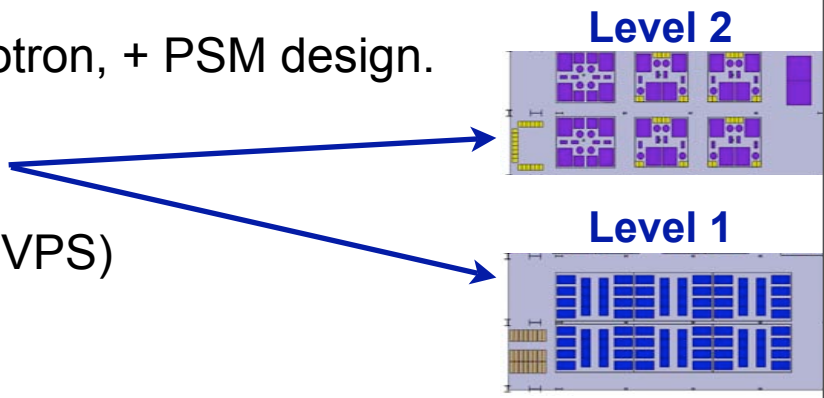
EC: BPS + APS 24+2 PS

PCR-120: Power Supplies

PCR-120 Revised the PS specifications

The proposed modifications are:

- Technical specifications: Compatibility with the 3 gyrotron types.
- Anode Power Supplies : reduce from 24 to 8 (EU & RF are diode gyrotrons)
- **Modularity** : 1 PS to two 1MW gyrotron or one 2MW gyrotron, + PSM design.
- Space allocated : The EC PS fit inside available space
- **Modulation** : ≥1kHz from 100% to 0% RF power (via MHVPS) and ≥5kHz from 100% to 50% (via BPS).
- Input voltage : 22kV rather than 66kV.

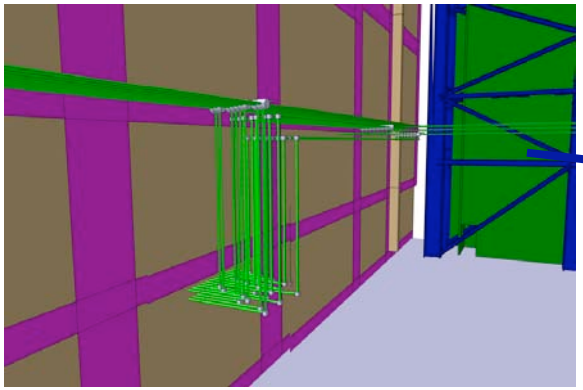


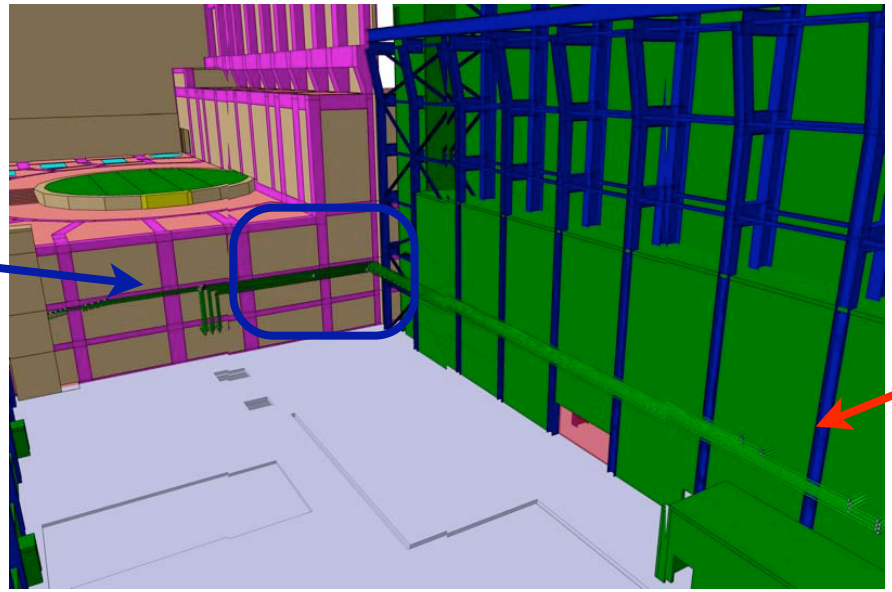
Cost Impact

- Compatibility with 3 gyrotron types: **+ 2.1M€ (taken from Gyrotron DAs)**
- Modularity (PSM based): **+1.7M€**
- Power Modulation: **+3.6M€**

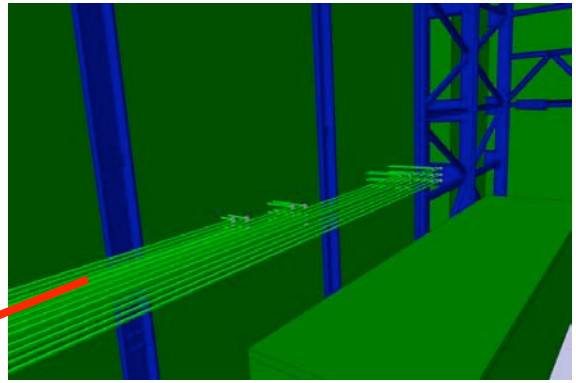
Transmission line (Conceptual Design Completed)

Switches to EL or UL

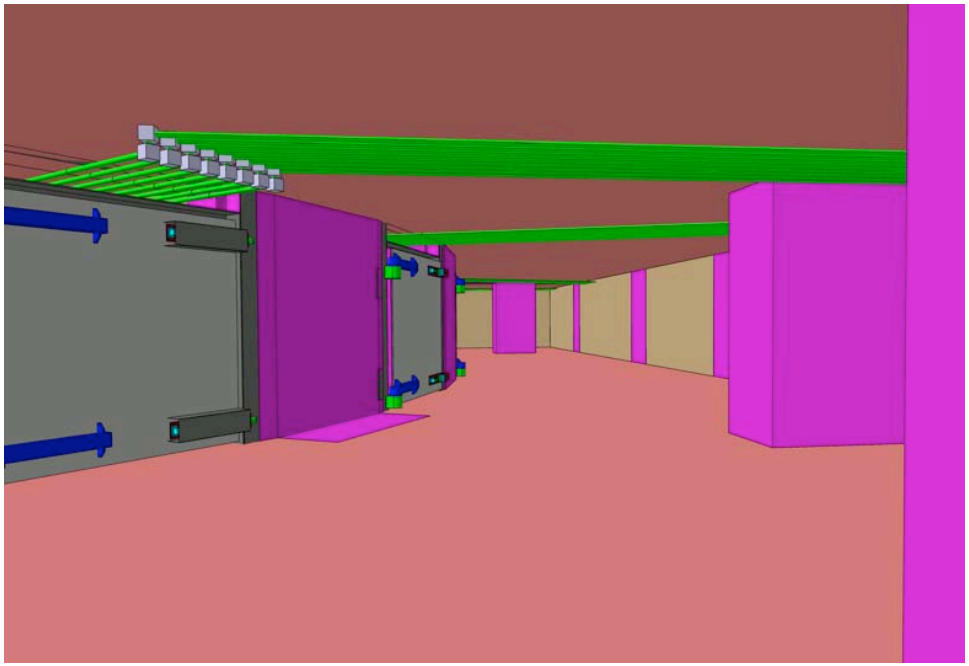




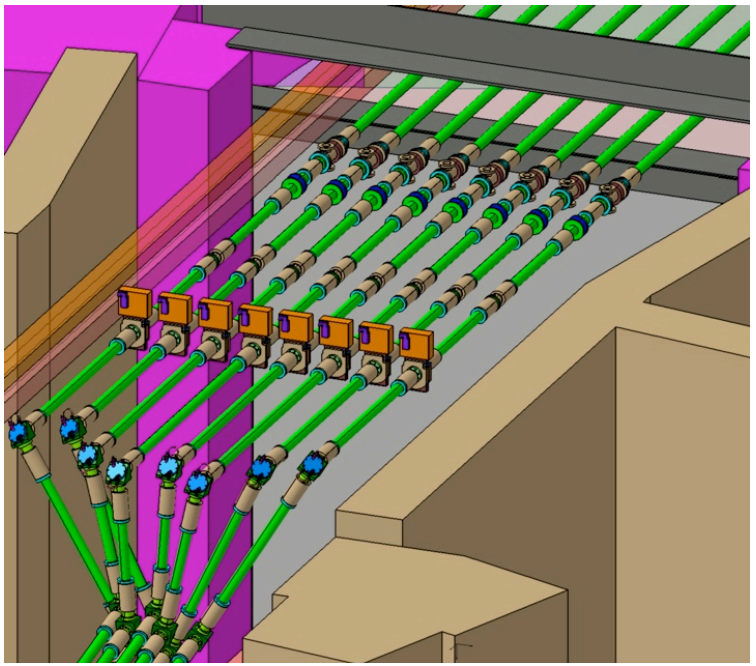
From RF building



Gallery (12 &13)

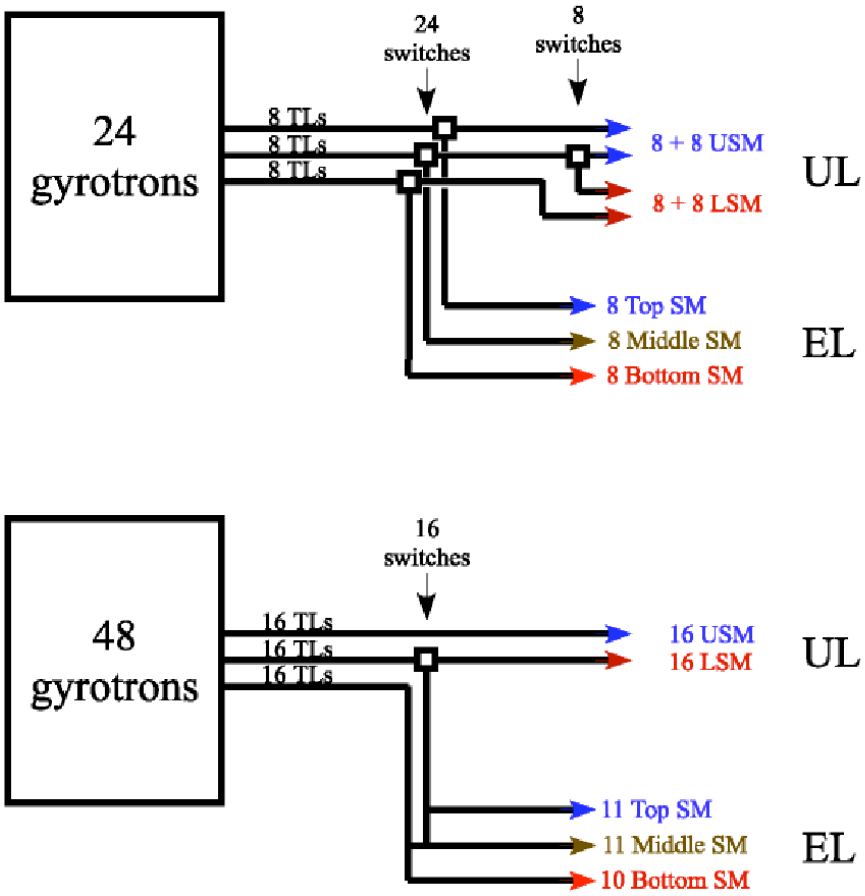


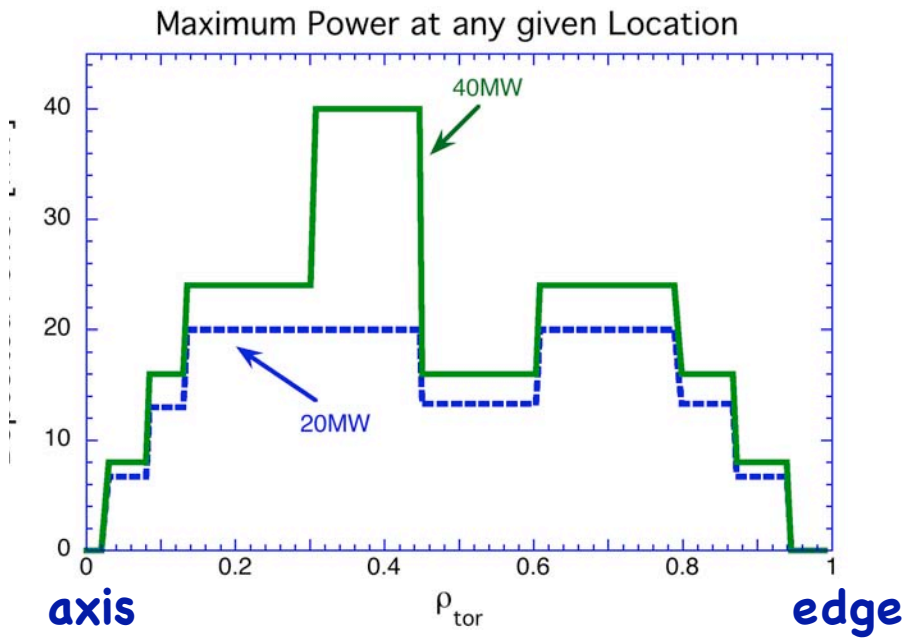
Inside Port Cell 12,13,15,16



TL to Launchers

Switching network

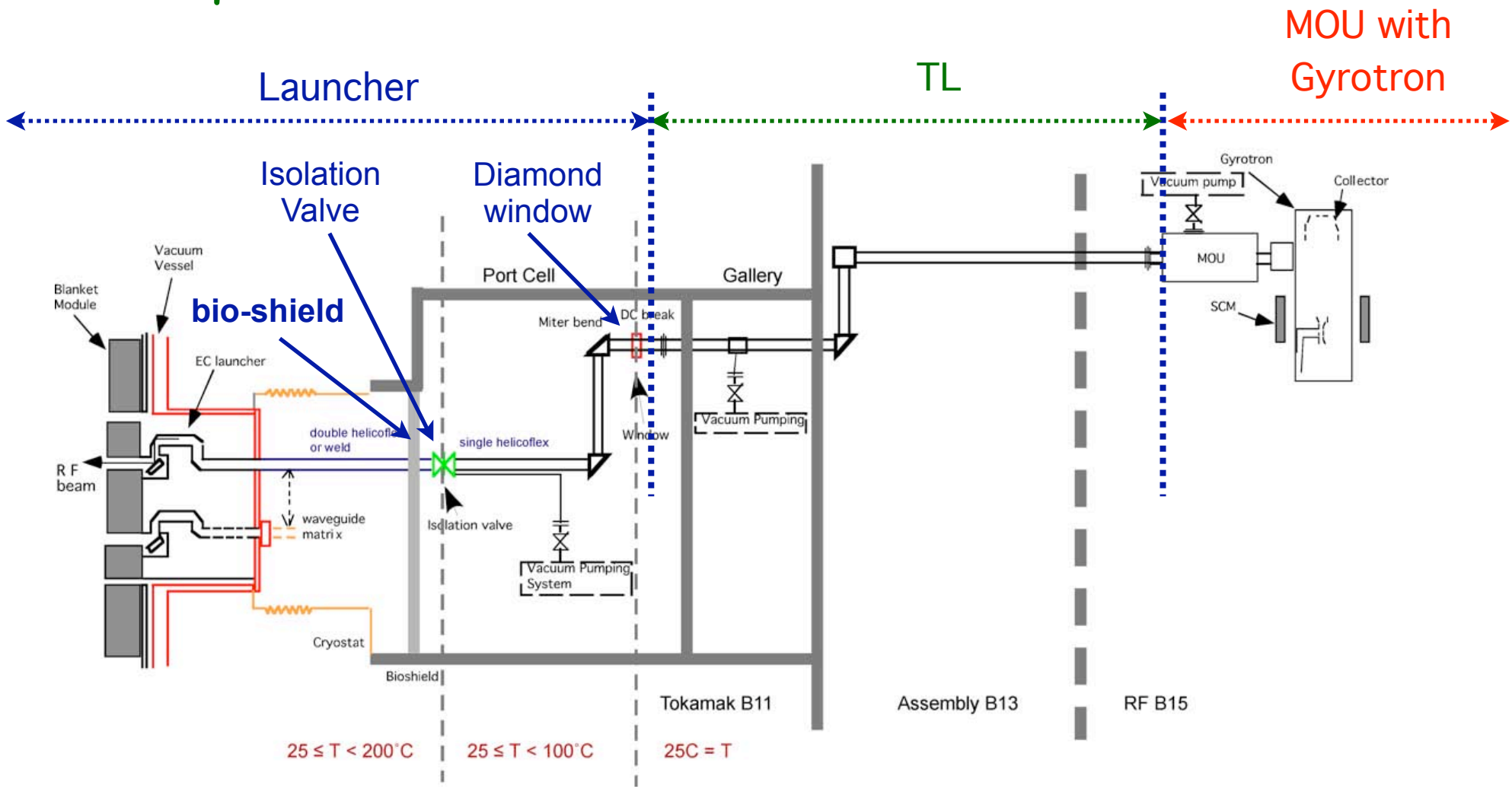




- 20MW: Provides nearly complete access across the plasma cross section
- 40MW: 40MW inside mid radius without new launchers

PCR-117: Internal Interfaces (decision tomorrow)

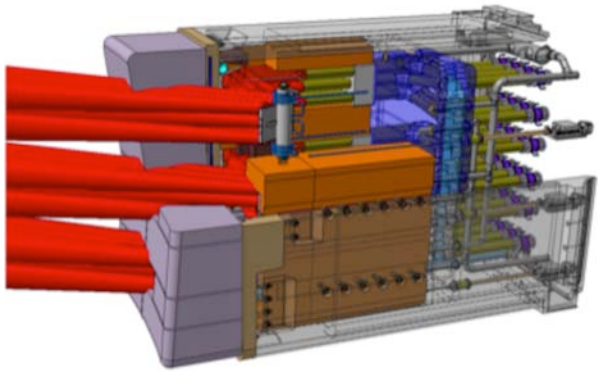
Simplification of internal interfaces and maintenance access



- in-situ and hands on maintenance of window
- in-situ diamond window leak detection
- ≤1 day access to valve and window

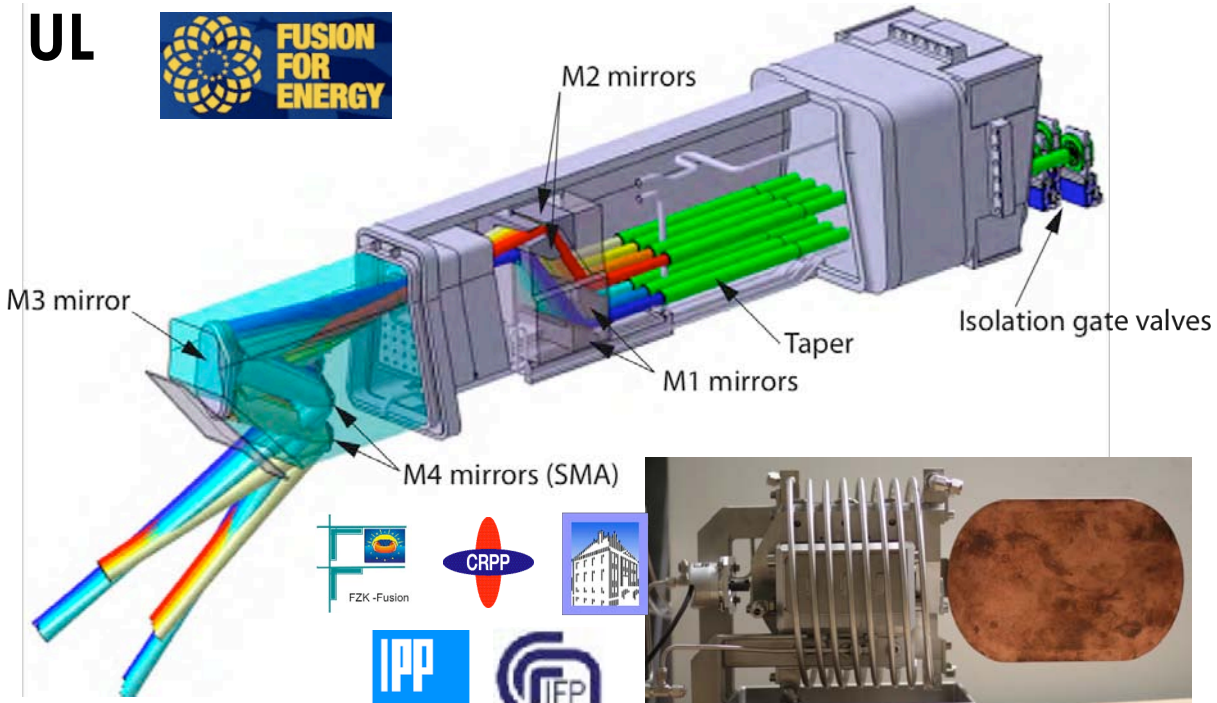
EC Launchers

EL



To be Covered by JAEA Team

UL



Preliminary Design Review for Nov. '09

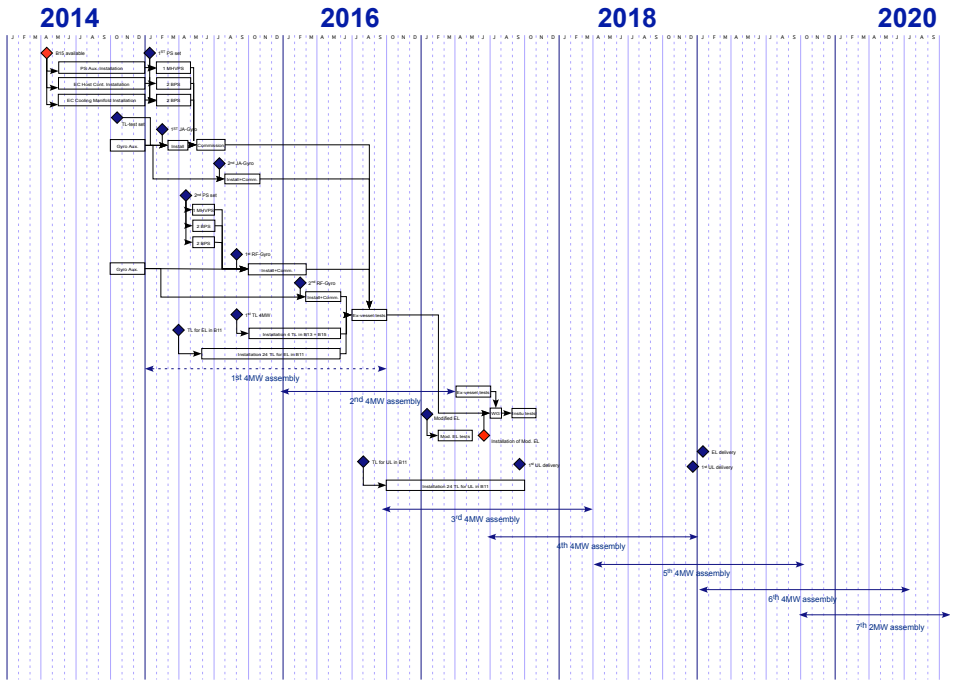
Issues under resolution:

- Cooling efficiency of BSM flange
- EM deflections of port plug
- Complete quasi-optical model
- Test of 2nd prototype steering mirror

Scenario I

Aim to spread out resource profile (economic crisis, additional costs, etc.)

- 2018: first plasma (no BSM, 4-6MW EC for plasma initiation)
- 2021: Installation of BSM, 20MW EC, 10MW IC, 16MW NBI
- 2023: Complete construction phase (73MW)
- ~2026: D-T phase



EC manufacturing and assembly relaxed (start 2015 to 2019)

- 2018: Simple EL with 8 beams, all TL and >8MW
- 2019: Full system installed, 1 year commissioning
- 2020: Full system ready, 1 year float
- 2021: Full system operating
- 2023: Upgrade could be consider for power available in 2026

Objectives and Collaborations

Initial 2010 Objectives

- Sign TL Procurement Arrangement, draft gyrotron and PS PAs
- Start final design activities for launchers
- Preliminary DR for EL, start Conceptual DR for gyrotrons
- Complete building layout, supported by an ITER Task Agreement (ITA)
- Re-write DDD
- Complete all Interface Control Documents
- Preliminary design of cooling manifold, plant host and other auxiliaries

>2010 Possible Collaborations and support

- DAs: PS design, gyrotron reliability, TL PA, EL and UL design work
- **Gyrotron: integration meeting**
- **TL: Support in HE_{11} mode monitor and tapers**
- TL: Collaborate in beam combiner high power tests
- Collaborate with FZK on launcher outgassing estimates
- Collaborate with CRPP on modeling plant host
- **All: request support for design review meetings**
- **All: open to any ideas for collaboration**