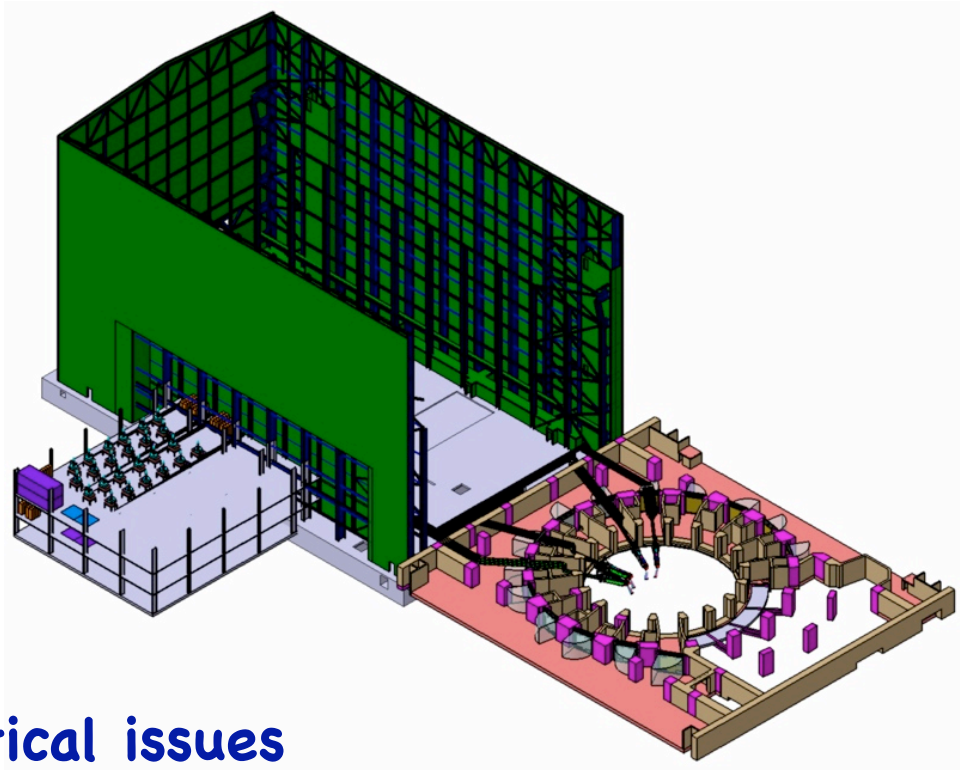
ITER EC system a Steeping Stone to ITER

ITER EC system is half way between an experiment and DEMO

Problems (or not) related to DEMO for:

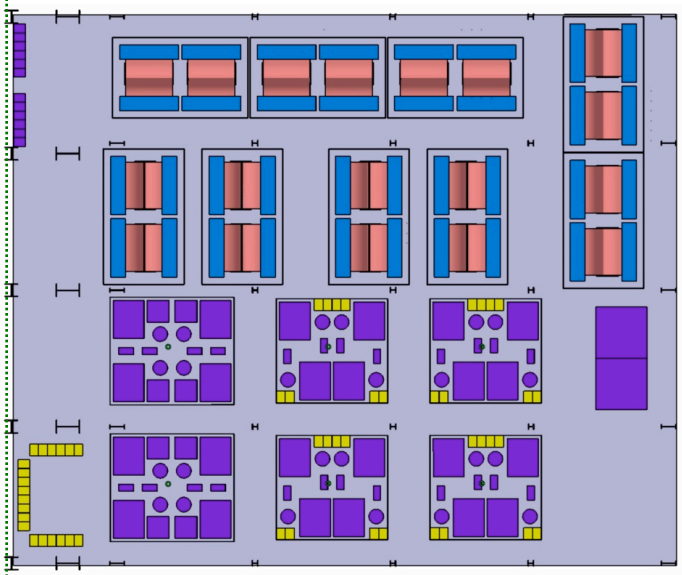
- Power Supplies
- Gyrotrons
- Transmission Lines
- Launchers
- Control System



Not included are cost and political issues

ITER Power Supplies

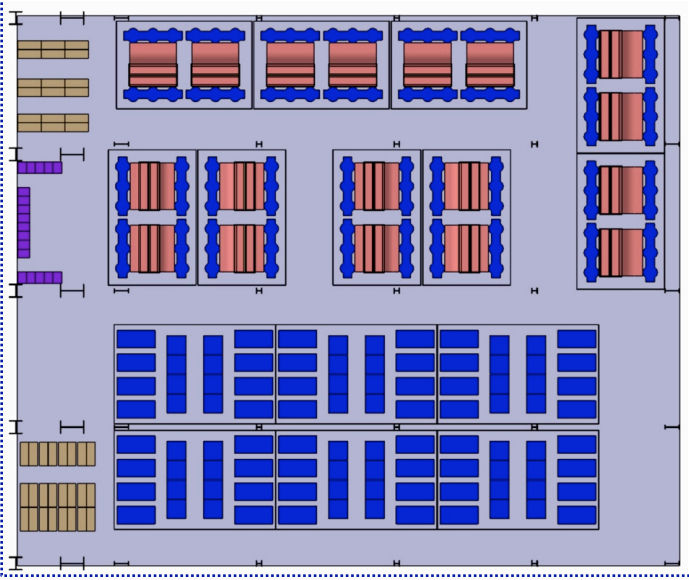
2nd Level



IC: Modules

EC: BPS + APS
24+2 PS

1st Level



IC: Transformers

EC: MHVPS
12+1 PS

PS are relatively advanced:

- Efficiency: >97%
- PSM based provides P_{EC} control
- MHVPS compact
- BPS and APS not compact

Reduce space by 30% w/ GA example

Unipolar Positive P0621P
+30 kV at ±20 mA

Unipolar Negative P0621N
-30 kV at ±20 mA

Slew Rates greater than
350 V/μs

DC Voltage Gain Accuracy
better than 0.1% of full scale

Located under gyrotron

Plug to Plasma Efficiency Bet

3 Bottles of red wine: What is the overall Efficiency of the EC system?

Norbert HoltKamp: <32.5%

ITER EC Section: >32.5%

Plug to Plasma Efficiency Bet

3 Bottles of red wine: What is the overall Efficiency of the EC system?

Norbert HoltKamp: <32.5%

ITER EC Section: >32.5%

Answer: 35 to 44%

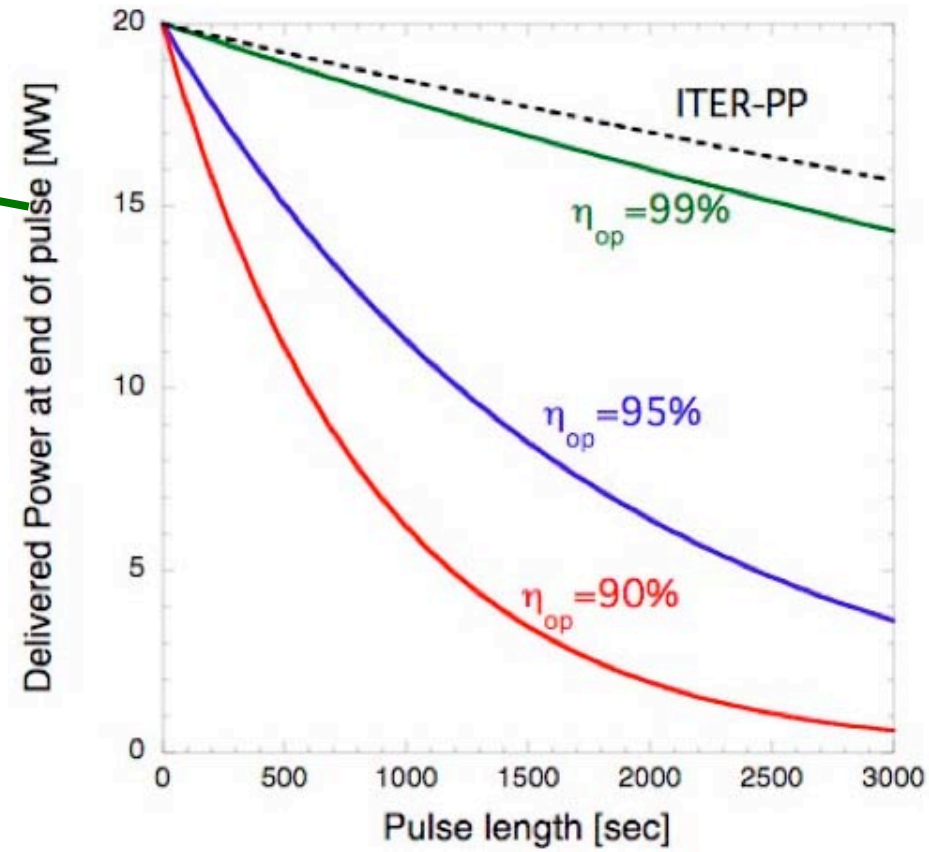
But we need to aim higher

	Lower Limit		Upper Limt		Comment
	η_{trans}	P_{out}	η_{trans}	P_{out}	
22kV feeds	-	50.5MW		45.0MW	
PSM PS	95%	48MW	97%	43.6MW	Published results from TCV
Gyrotron	50%	24MW	55%	24.0MW	Published results from JAEA
MOU	~95%	22.8MW	96%	23.0MW	Published results from JAEA
T-line	~91.5%	20.9MW	96%	22.1MW	Published results from JAEA
Launcher	~95%	19.8MW	97%	21.5MW	JAEA and F4E estimate
Plasma	>99.5%	19.7MW	>99.5%	21.3MW	Codes & Exp. results
Total	**39%**	**19.7MW**	**47.5%**	**21.3MW**	
Aux.		2.5MW		2.2MW	Based on JT-60U EC system
Cooling		3.0MW		1.25MW	Assume 5 to 10% of dissipated power
Total	**35.2%**	**56.0MW**	**43.9%**	**48.5MW**	

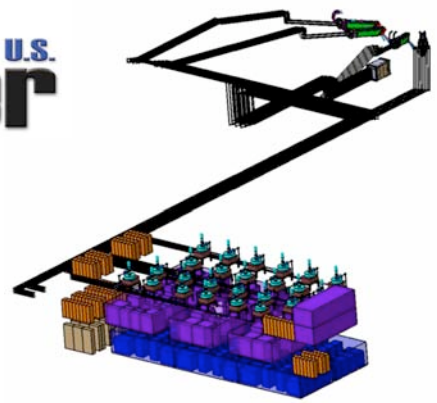
ITER Gyrotrons toward DEMO

Issues:

- **Reliability >98%**
  Need: Restart after arc
- **Longevity: ≤5 years**
  ~10 years
- **Output Power?**
  ITER: 1.2 to 2.0MW
  Demo: ??? (1.2 to 4MW)
- **Efficiency is 50%**
  Aim toward >60 to 65%
- **HE_{11} coupling: >95%**
  Aim toward ≥99%
- **Cooling efficiency ΔT between 6 and 15°C (EC plant uses ~700kg/s)**
  Aim at ΔT=30°C (1kg/s costs 27k€ investment + 2.8k€ operation)
- **Single Frequency**
  (and single procurement)



Transmission Line

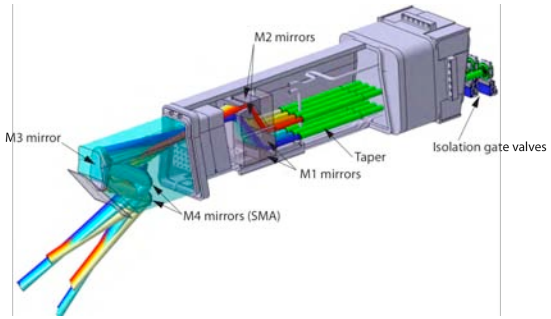


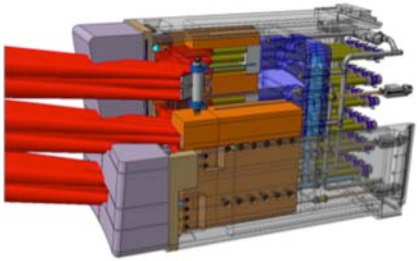
Issues:

- **2MW compatibility**
  (higher power requires larger diameter waveguide)
- **Power Monitoring: accurate P_{EC} measured from applied voltage**
- **Mode Purity Measurement (cross check of ≥99% HE_{11})**
  Avoid stray power could damage window and launchers
  Useful for waveguide alignment and TL efficiency
- **Efficiency is ≥90%**
  Aim toward >92 to 94%
- **Adjustable Polarizers**
  2MW compatible (may be less required for DEMO)
- **Mechanical Switch between EL-UL is sufficient for ITER (≥99.5%)**
  DEMO: will there be MHD activity?
  Beam combiner only useful if $P_{gyro} \leq 1.0$MW and efficiency improved

EC launchers

ITER Launchers to provide maximum reasonable flexibility





A Demo Launcher depends strongly on Physics requirements:

- H & CD at mid radius ← Simple launcher no steering
- NTM Control? ← Control in deposition location
- Sawtooth Control?
- Central heating?

Launcher with Deposition Control

Options depend on steering range required

Large Steering Range

- Front Steering Mirror ← Robust steering mechanism
- Remote Steering Mirror ← High power densities
  Increased transmission losses
- Step Tunable Gyrotron ← multi-frequency window
  gyrotron technology and reliability
  Is gyrotron best tool?

Limited Steering Range

- Front Steering Mirror ← Robust steering mechanism
- Remote Steering Mirror ← Lower power densities
  Increased transmission losses

Control System

One of greatest challenges for ITER EC system

- Automated operation ← TCV: 1 person/6 gyrotrons
  ITER: 1 person/ ≥8 gyrotrons
- Automated conditioning after arc ← Task for community today
- Compatible with multiple venders
- Control system for MHD control ← 11 actuators for position control
  multiple targets (q=2, 3/2, 1)
  24 gyrotrons

DEMO should be less complicated

Plug to "DEMO" Plasma

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