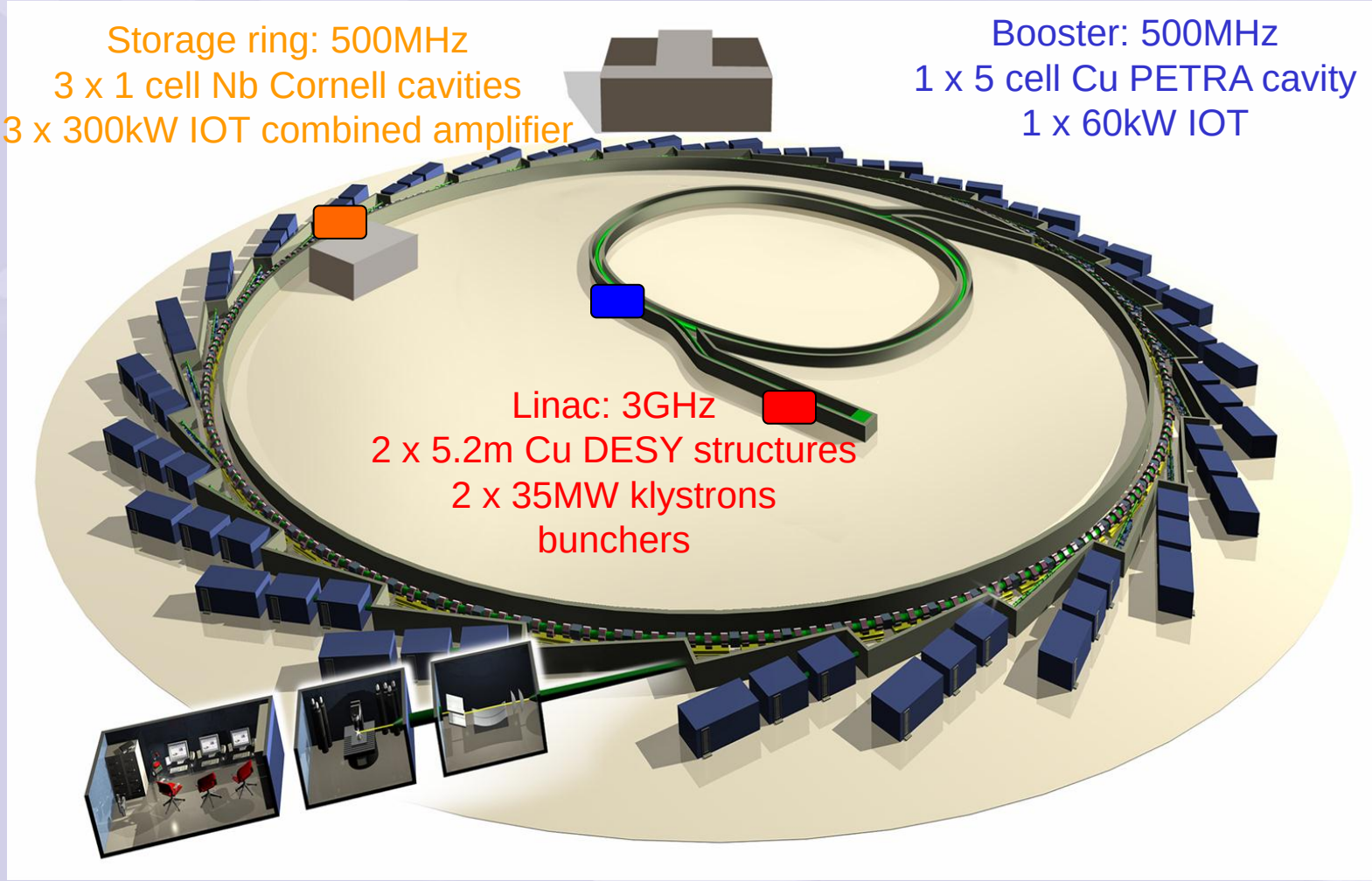
The Diamond Storage Ring IOT based High Power Amplifier

Morten Jensen
on behalf of the SR RF Group

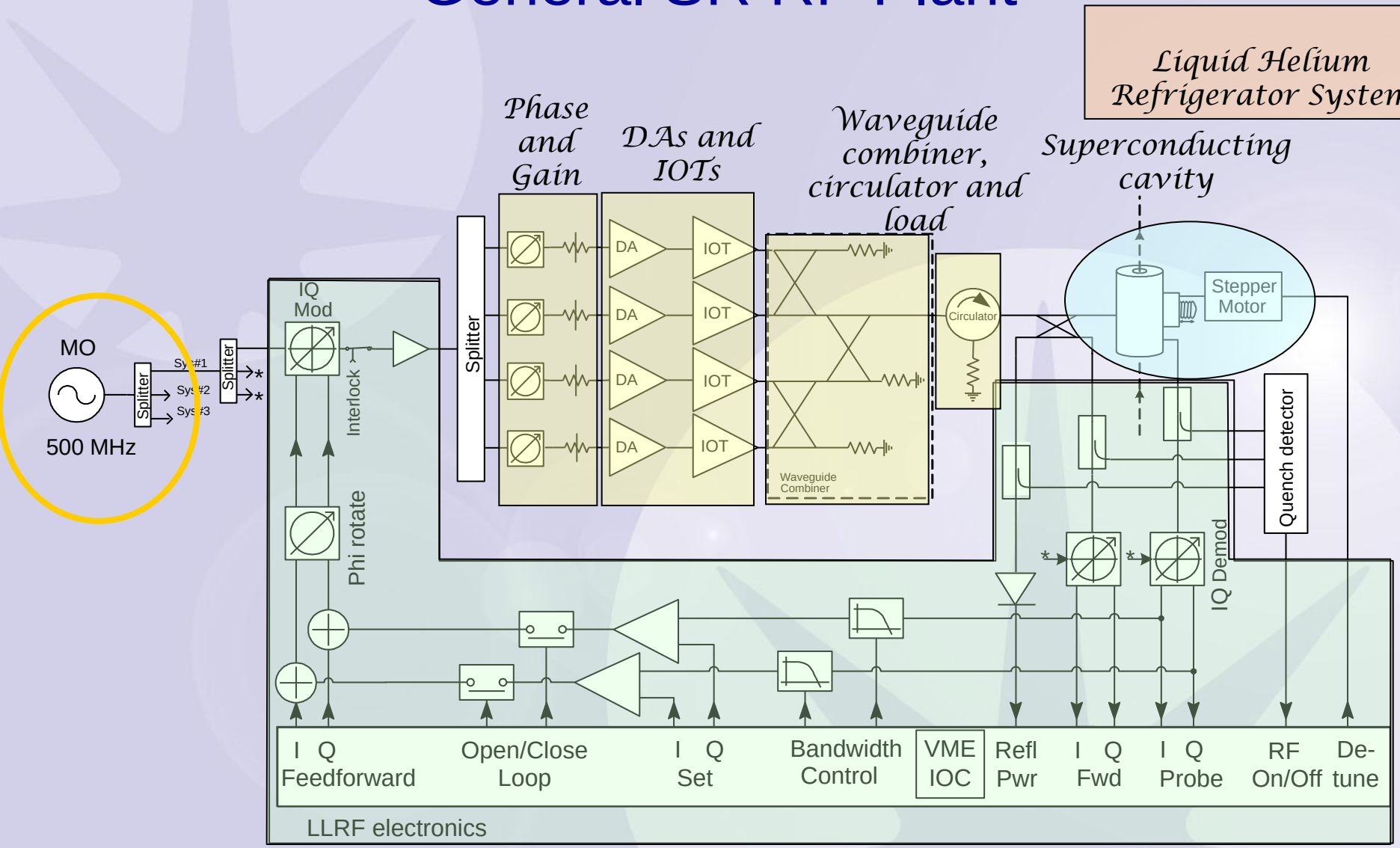
Current Key RF Beam Parameters

Beam Current	**300 mA Top up**
Synchrotron Radiation Loss	**1.0 MeV (dipoles) to 1.35 MeV (ID dependent)**
Beam Power	**405 kW**
Revolution Period	**1.873 μsec**
Orbital Frequency	**533.818 kHz**
Harmonic Number	**936**
Number bunches	**600 – 900; hybrid**
Momentum compaction	**1.7e-4**
Frequency	**499.654 MHz**
Cavity Voltage	**1.1 MV (Cavity 1), 1.4 MV (Cavity 3)**
Q_L	**2.3×10^5 Unmodified**
R/Q	**89 Ω**

RF Systems

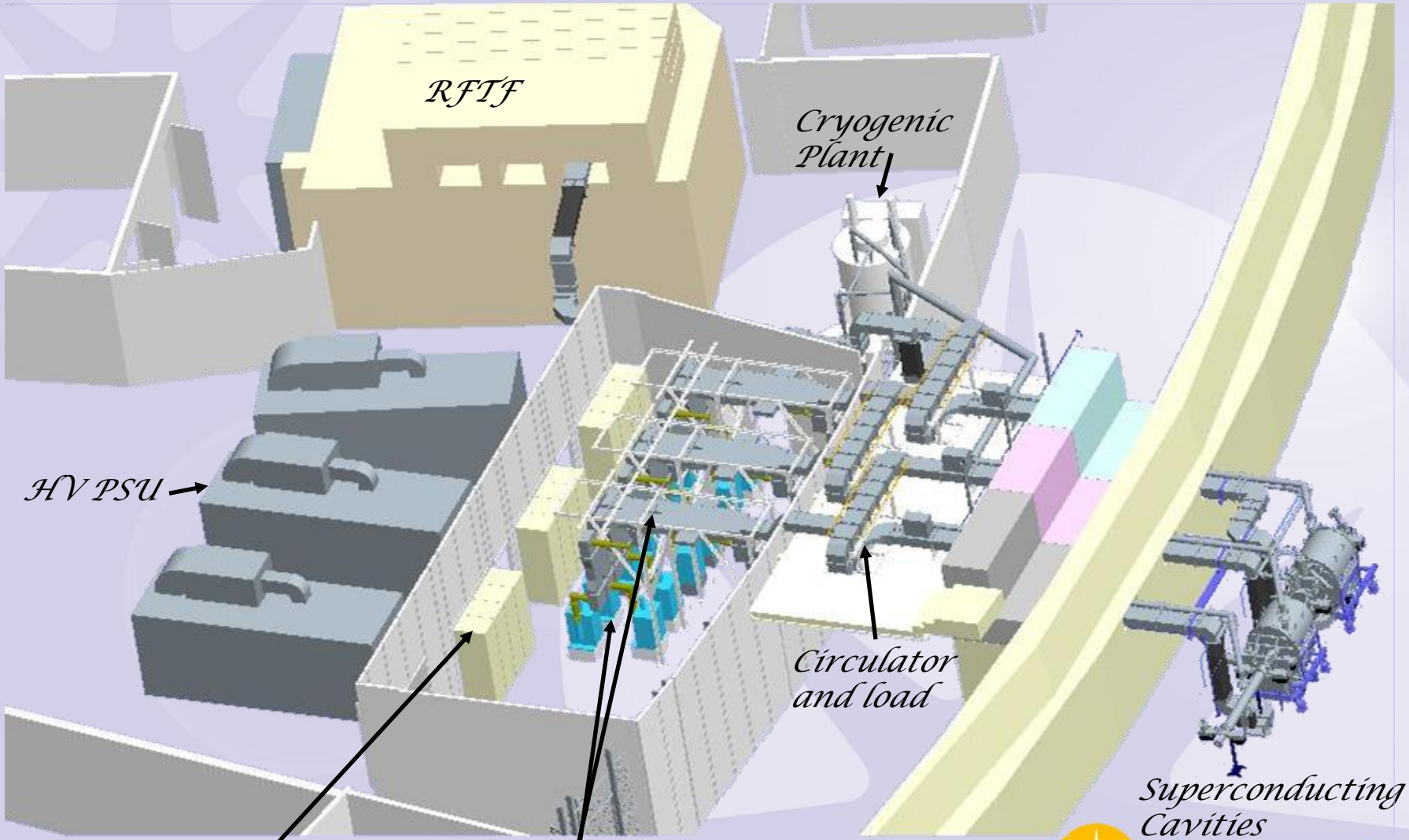

Storage ring: 500MHz
3 x 1 cell Nb Cornell cavities
3 x 300kW IOT combined amplifier
Booster: 500MHz
1 x 5 cell Cu PETRA cavity
1 x 60kW IOT
Linac: 3GHz
2 x 5.2m Cu DESY structures
2 x 35MW klystrons
bunchers

General SR RF Plant



Three cavities, each with its own RF amplifier, LLRF and control system

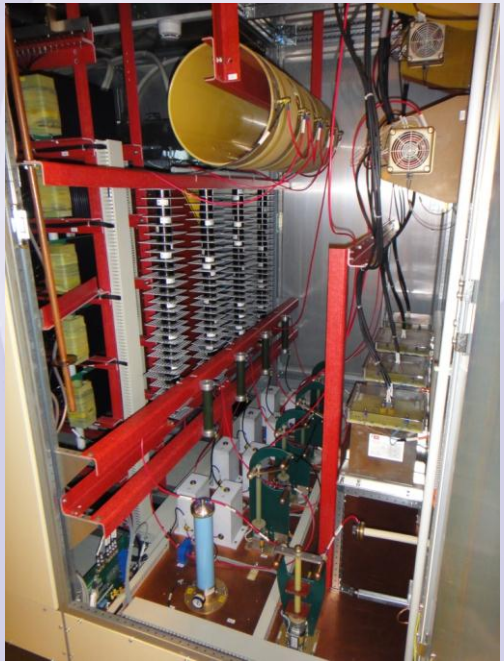
SR RF Systems



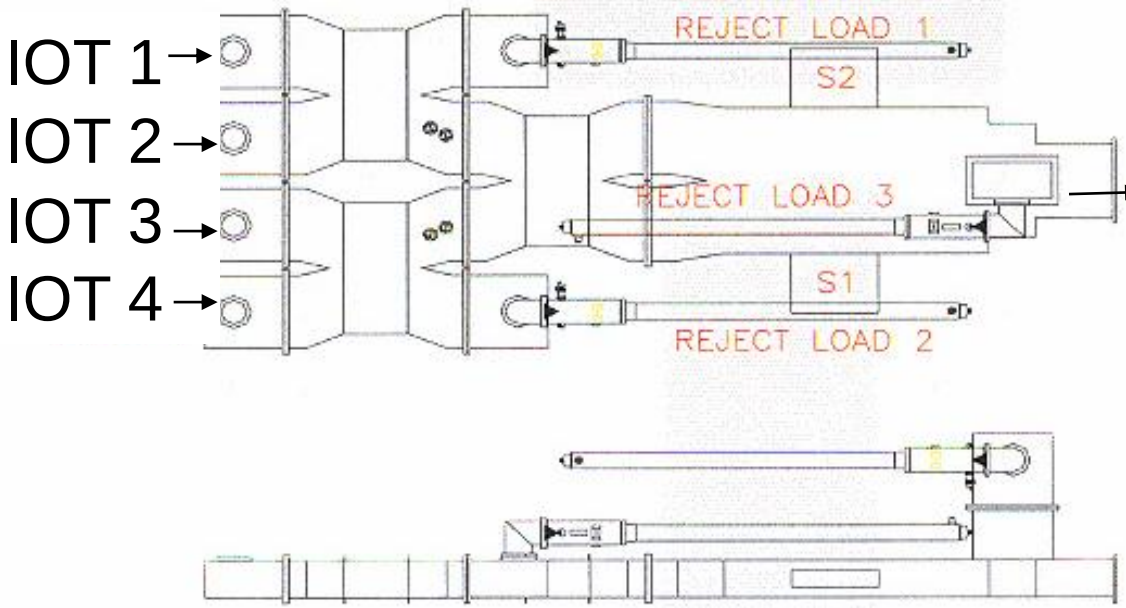
HV PSU

DC power supply based on the Pulse-Step-Modulator (PSM) technology now also common place for Klystron amplifiers.

- Fully solid state switch mode PSU with IGBT transistors
- No crowbar
- Common HV supply per system (4-IOTs)
- Separate filament, grid and ION pump supplies
- EPICS control system



Power Combining



Circulator and high power load

Power combinations

# of IOTs	Phase (deg)	Reject load power (kW)	Total output power (kW)
4	0	0	320
3	50	40	200
2 (pair)	90	0	160
1	90	40	40

IOTD2130
Design Features

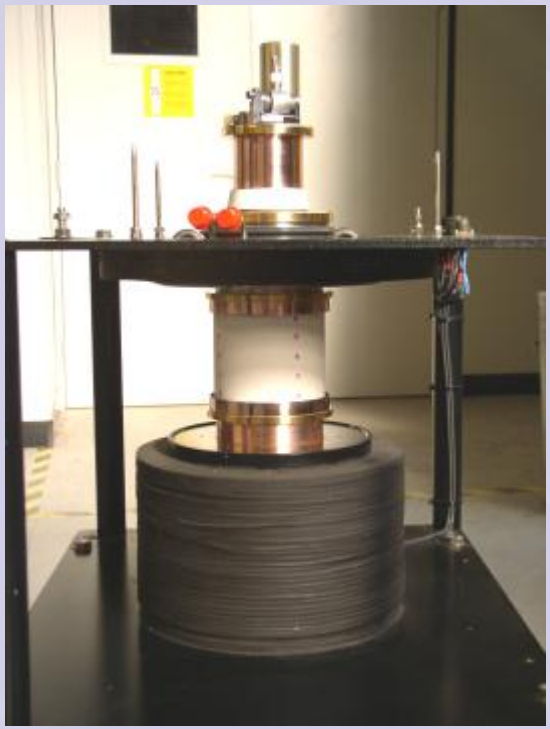
- 80 kW CW, tested to 90 kW
- Broadcast based
- 400 – 810 MHz
- High efficiency
- Single output cavity
  - Simplicity
  - Improved gain
- Enclosed input and output cavities
  - Low RF leakage
  - Easy tuning
- Low X-ray leakage

Installation
at Diamond

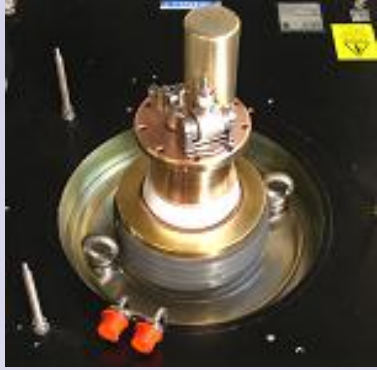
IOTD2130 Design Features

- **Direct Water Cooling of Internal Anode**
- **Solenoid Focussed**
  - **Integral pole-pieces**
  - **Low beam interception**
- **Integrated body & collector**
  - **Enhances cooling**
  - **No body current trip**

- Appendage Ion pump
  - Continuous monitoring
  - Maintains sound vacuum
- Air Cooled Cavities & Gun
  - External tuning cavities
  - Wide range of adjustment
  - Removeable in situ
- Large diameter Output Ceramic
  - Standard on all e2v UHF IOTs
  - High Purity Alumina



Courtesy of e2v



diamond

IOTD2130
Design Features

IOT is not a plug-in

- Pre-prepare complete assembly for quick IOT replacement
- Each IOT and circuit can be pre-conditioned
- Aim to operate the IOTs for 300-500 hrs prior to use on for SR

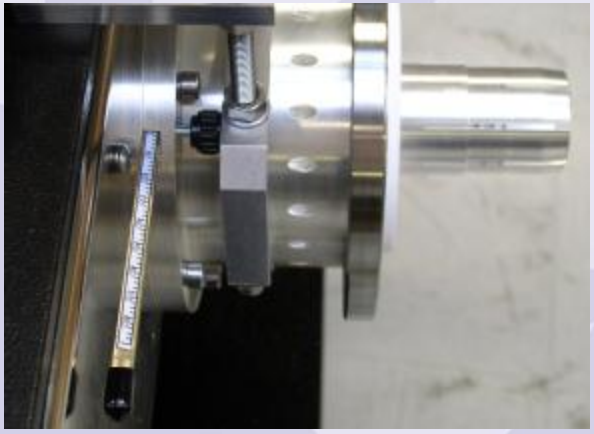
Three easy tuning controls

Input cavity tuner

Courtesy of e2v

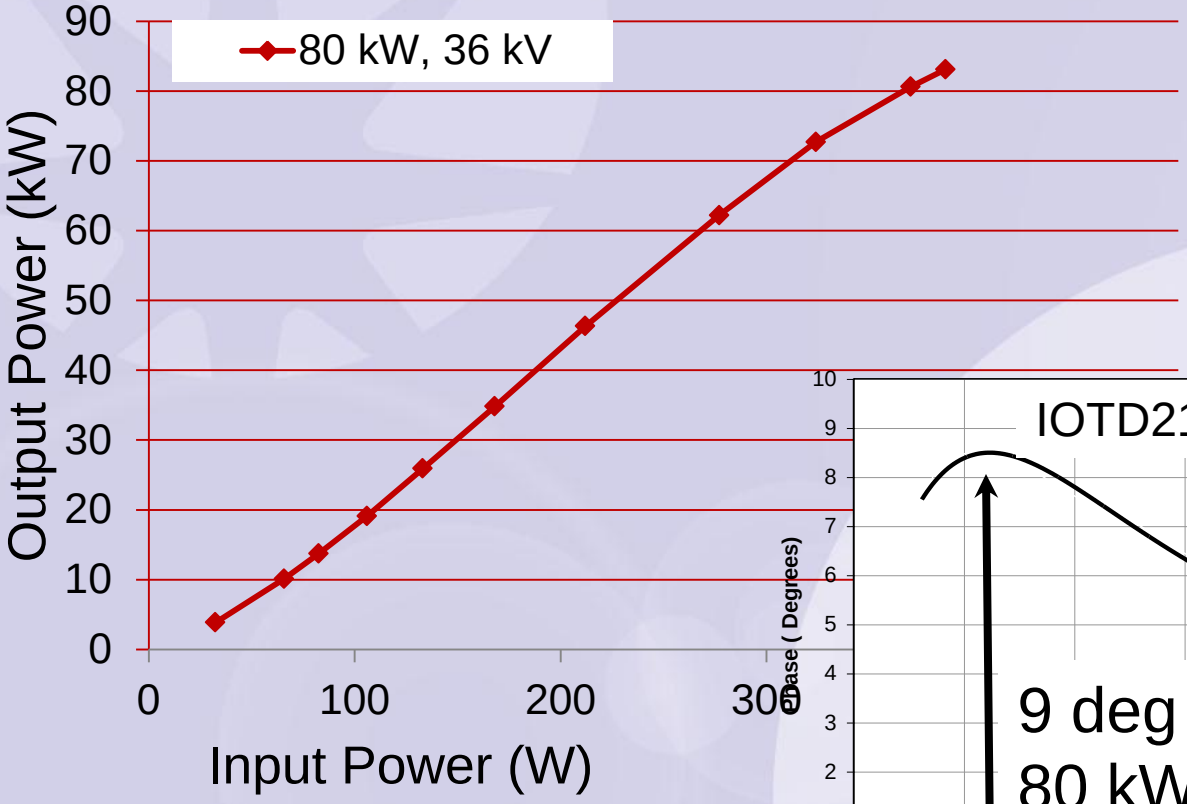
Output cavity tuner

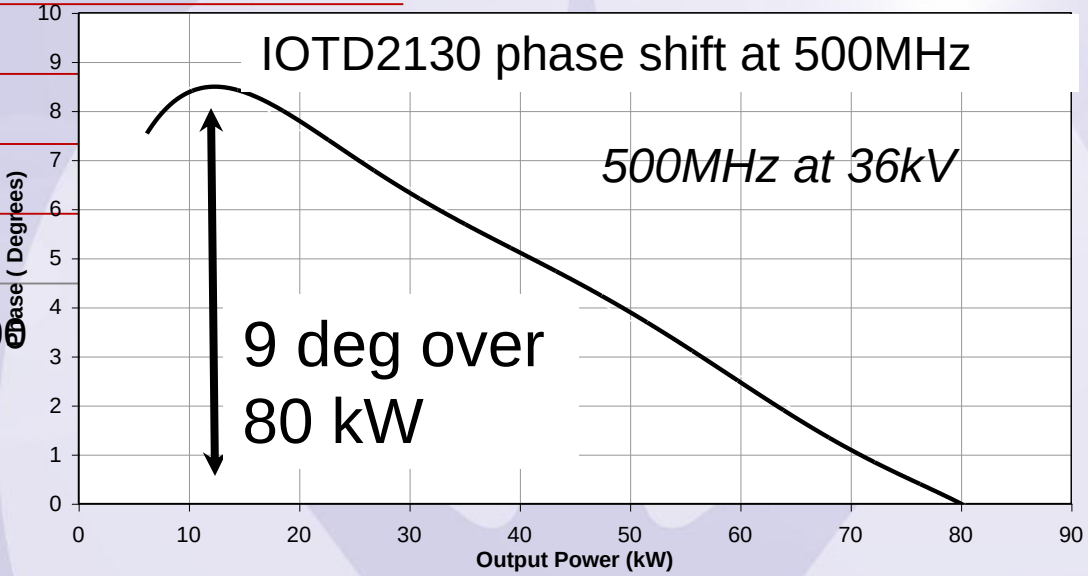
Output coupling adjustment



Transfer Curve

Tuned for 80 kW @ 36 kV

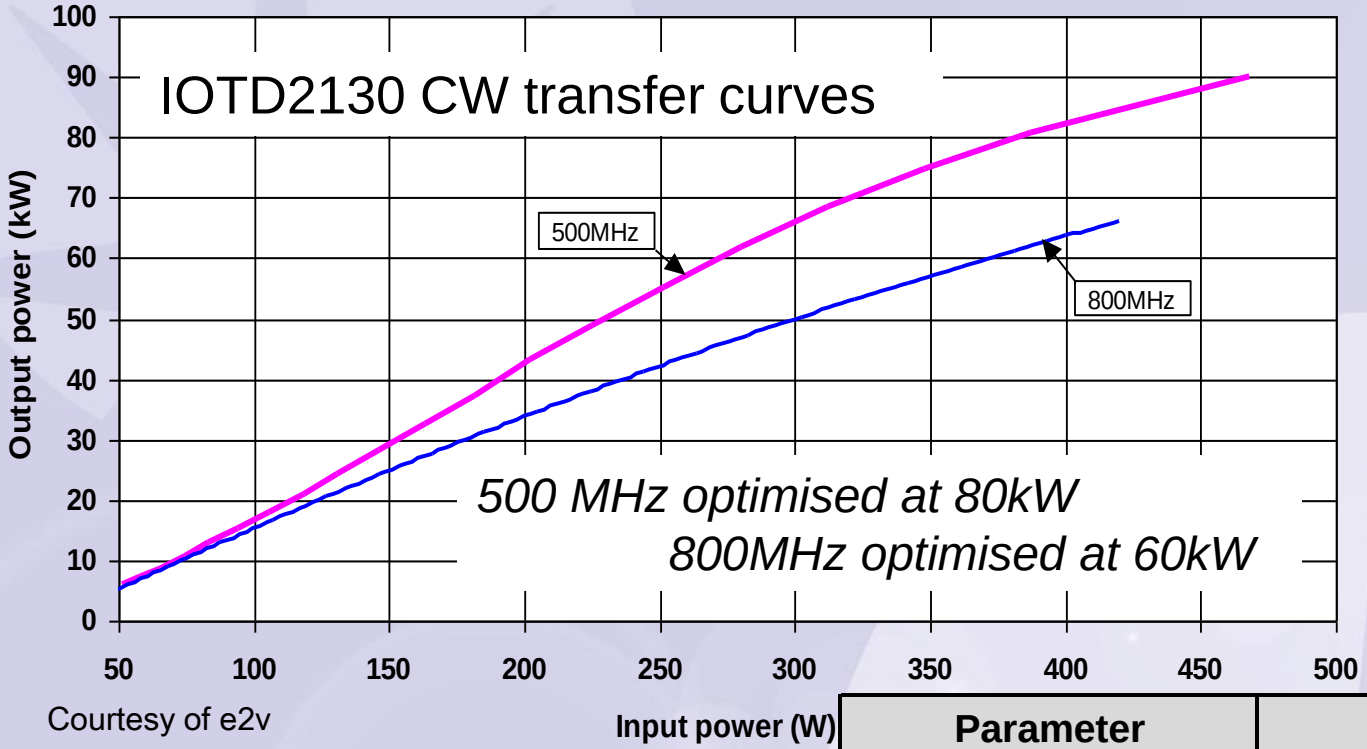




Courtesy of e2v

- **Good linearity**
- **Continuous without glitches**
- **No saturation @ 80 kW**
- **Limited by interlock setting (85 kW)**

E2V measurements at 90 kW

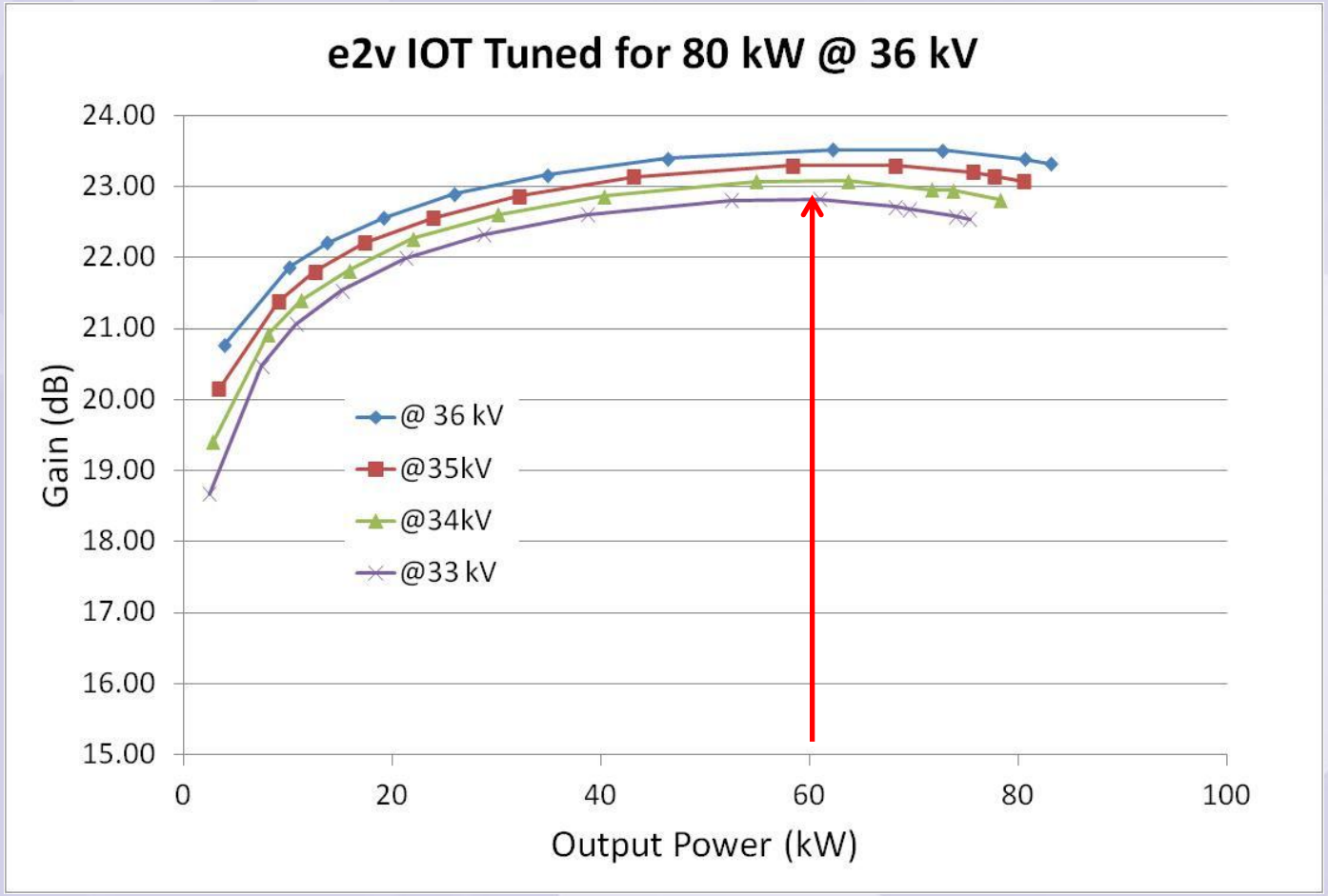


Courtesy of e2v

No change in performance during 2 hrs operation at 90kW 38kV

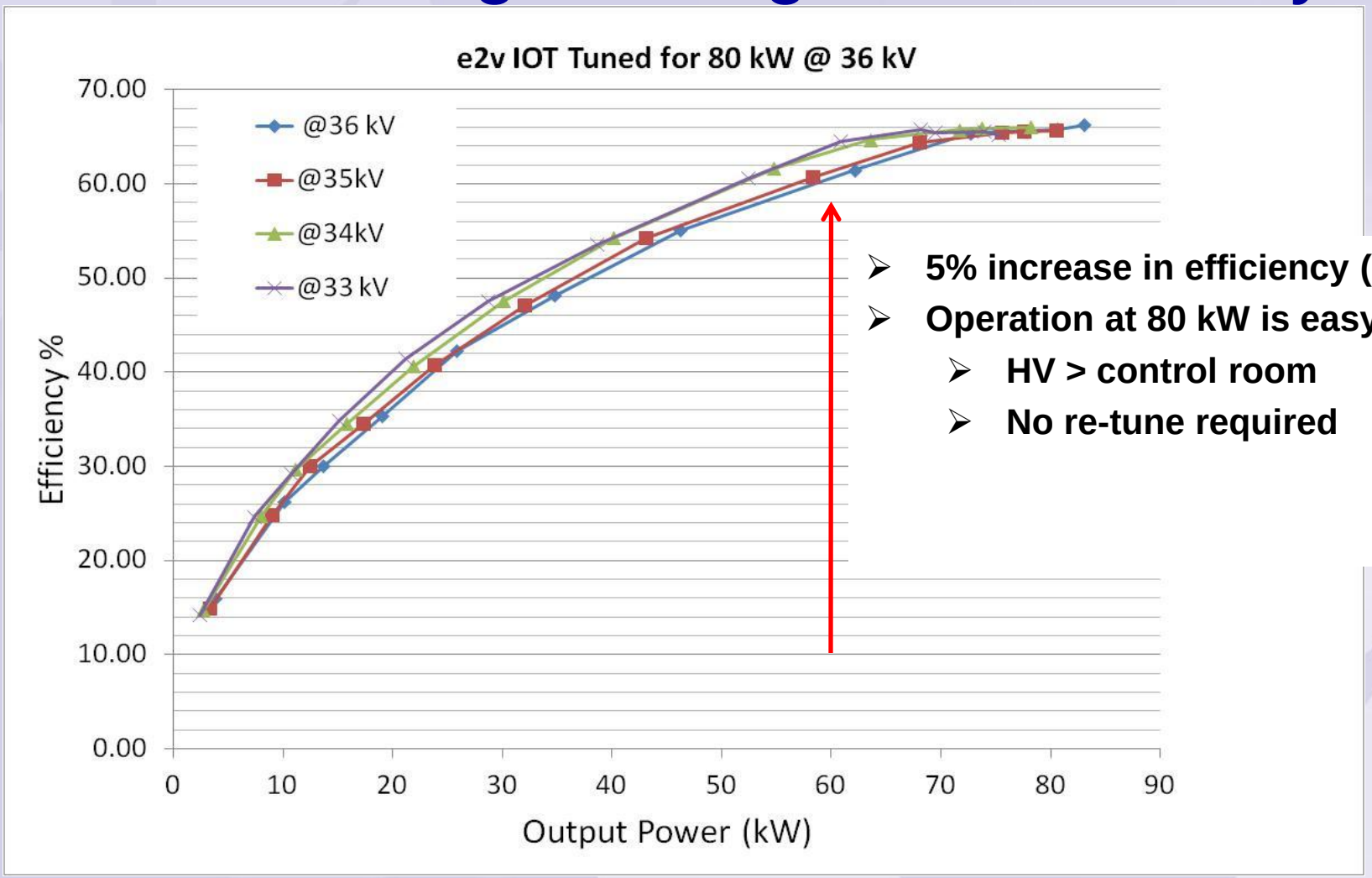
Parameter	Performance		
Beam Voltage	36kV	38kV	kV
Frequency	500	500	MHz
CW Output Power	90	90	kW
Beam current	3.8	3.64	A
Idle Current	100	100	mA
Grid Current	2	0.2	mA
Drive power	468	408	W
Gain	22.8	23.4	dB
Efficiency	65.8	66.9	%

Effect of High Voltage on Gain



- **Reduce ISC trips @ 33 kV?**
- **Gain -0.5dB (60 kW)**
- **Plenty of drive available in DA to compensate**

Effect of High Voltage on Efficiency

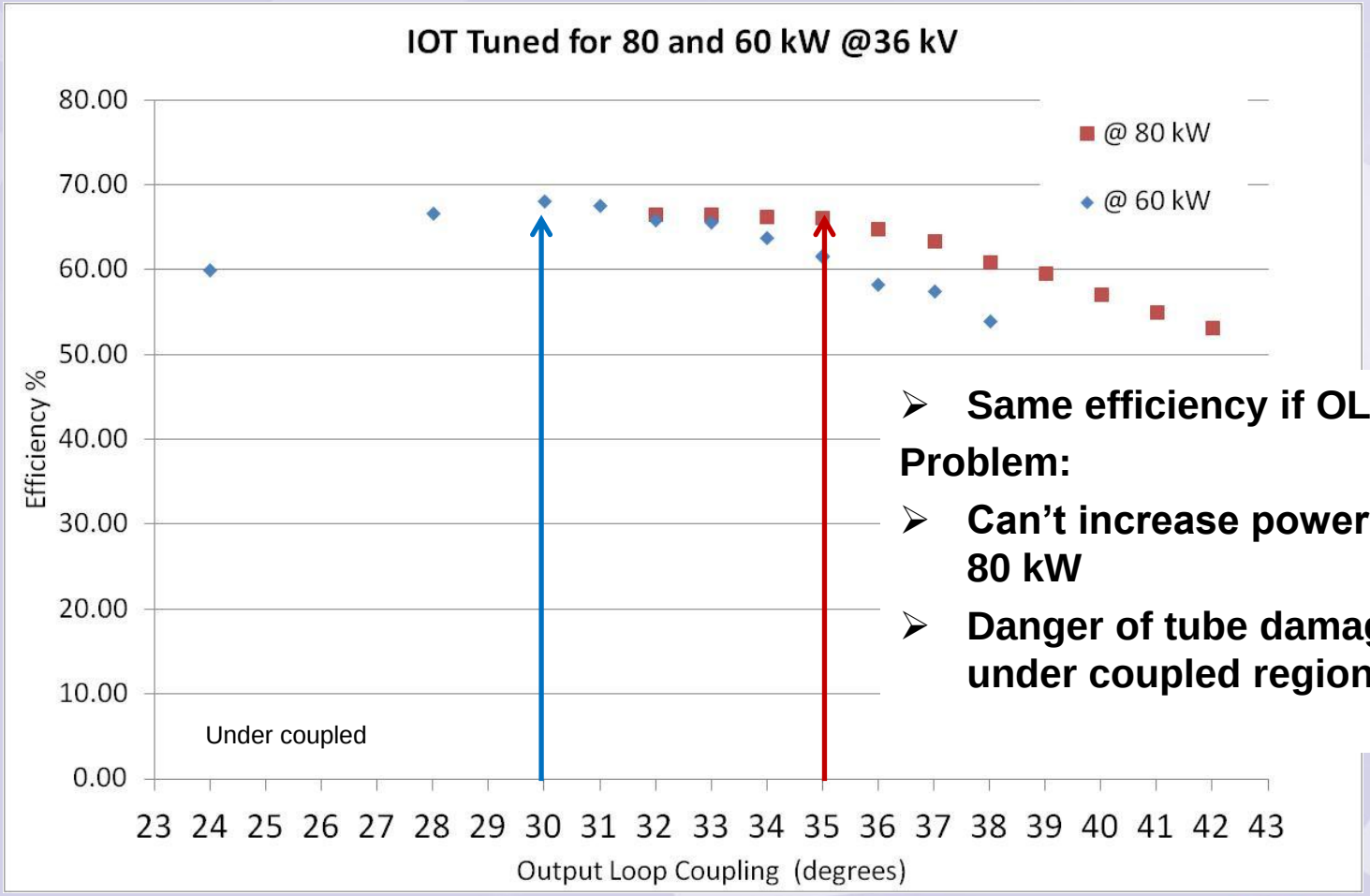


- **5% increase in efficiency (33 kV)**
- **Operation at 80 kW is easy**
  - **HV > control room**
  - **No re-tune required**

Typical IOT power demand 40-60 kW
Retains high efficiency and allows easy step up to full power

diamond

Effect of Output Coupling on Efficiency



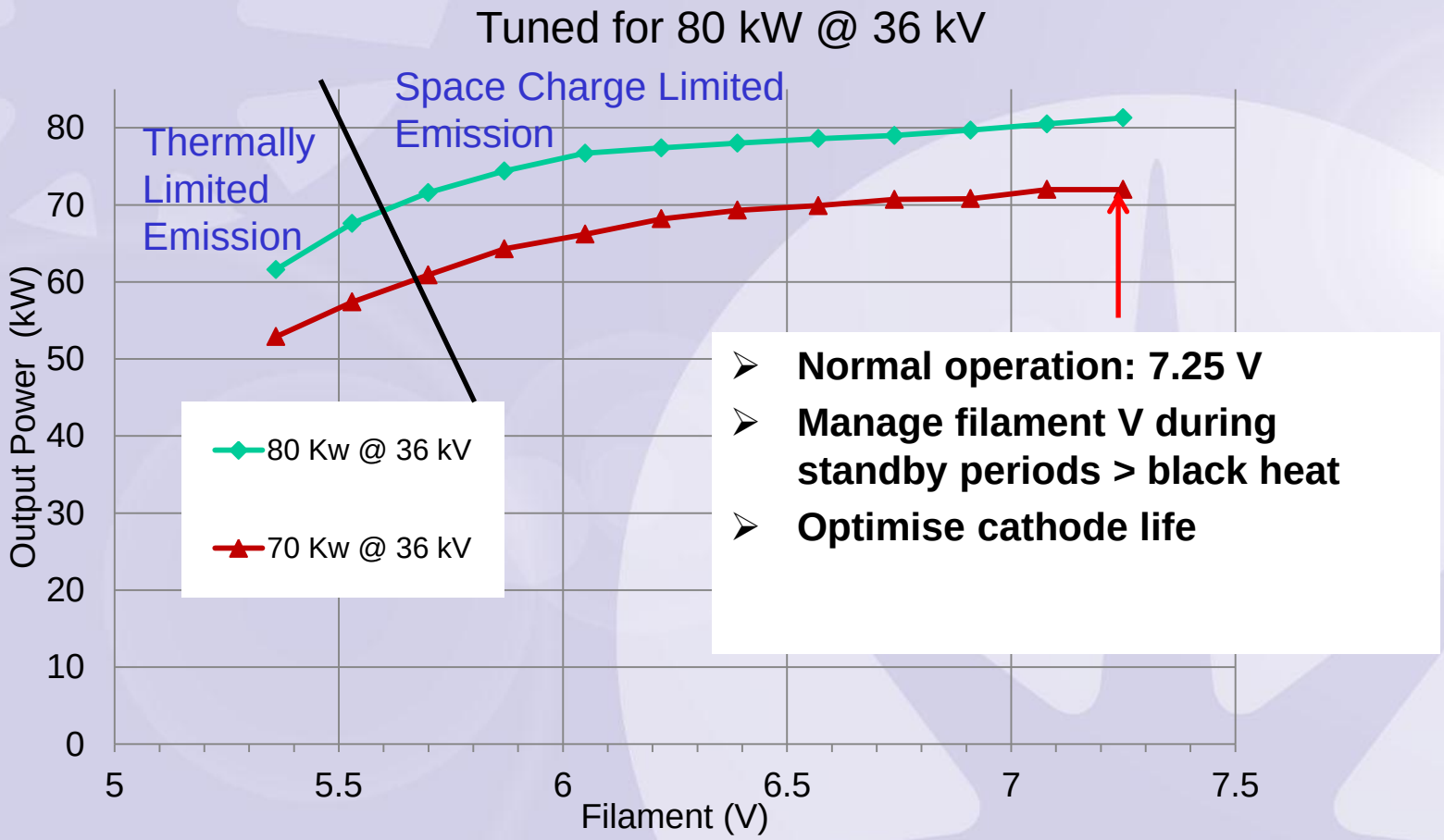
- **Same efficiency if OLC tuned**

Problem:

- **Can't increase power instantly to 80 kW**
- **Danger of tube damage if run in under coupled region**

diamond

Effect of Filament Voltage on Power

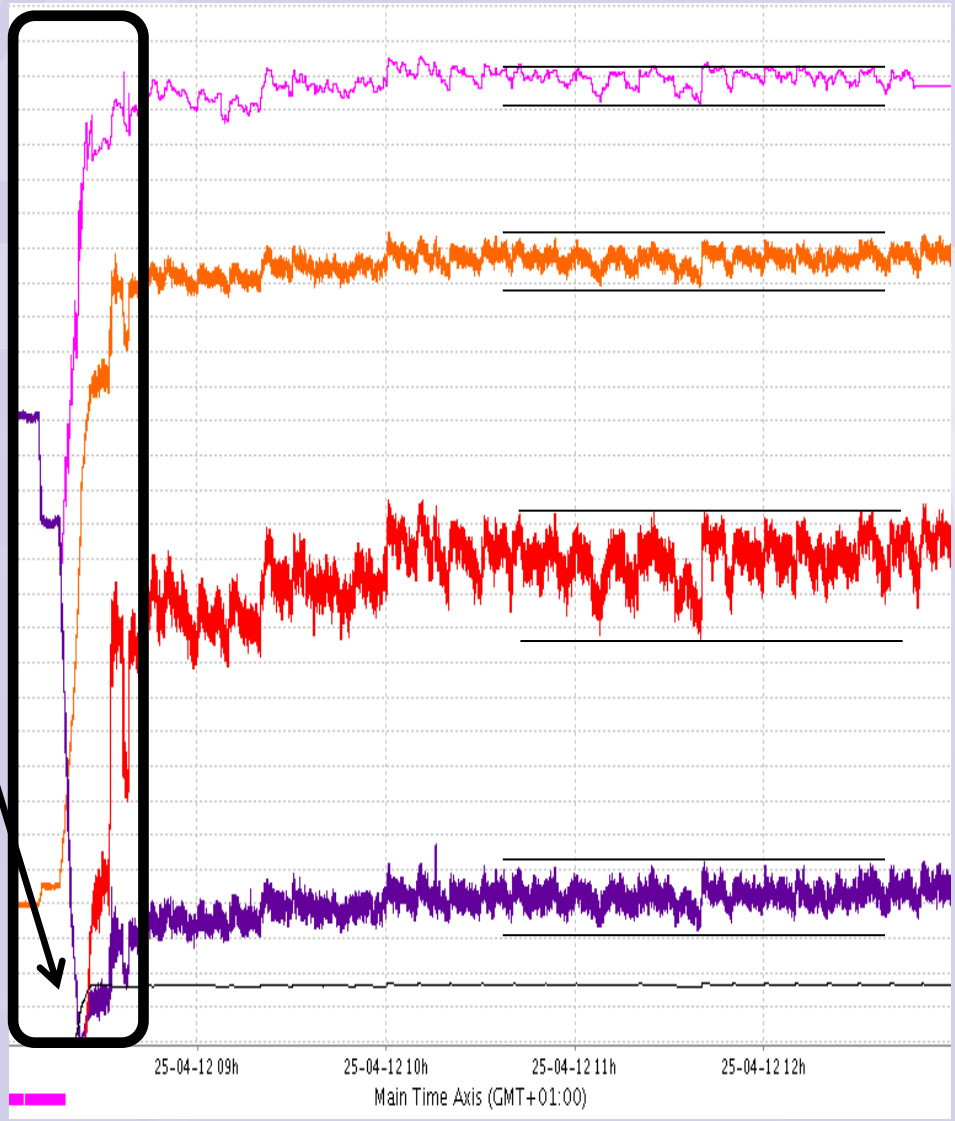


No indication yet of loss of emission

Some increase in grid current has been observed

Two Cavity Operation with Beam (April '12)

Beam injection.
Due to non-ideal Qext of the SC cavities the reflected power is increasing with increasing power



IOT Efficiency
68-70%

Amplifier 3 Output
220-230 kW

IOT 33 Output
60-65 kW

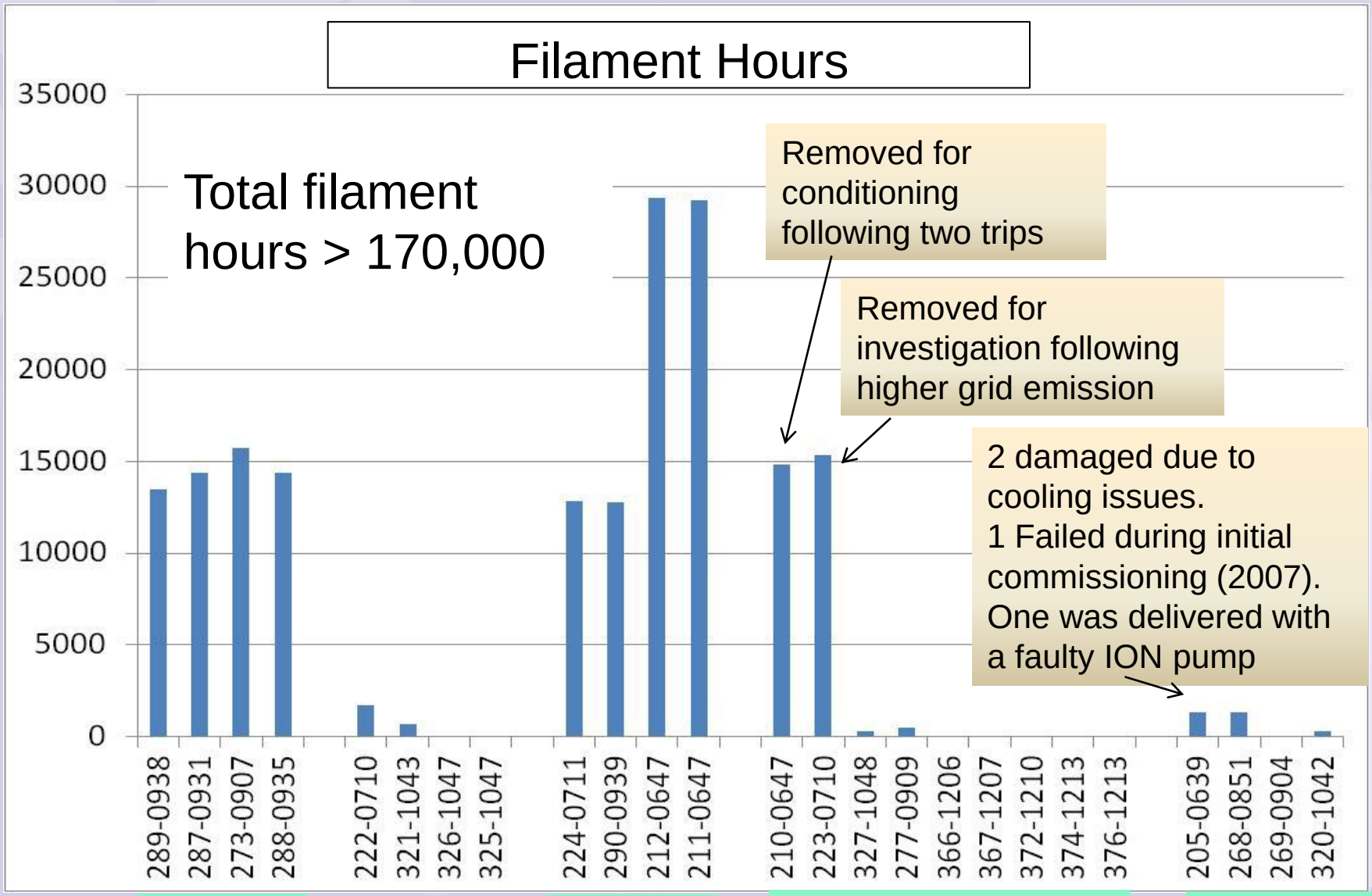
Reflected Power
7-10 kW

Beam Current
300 mA

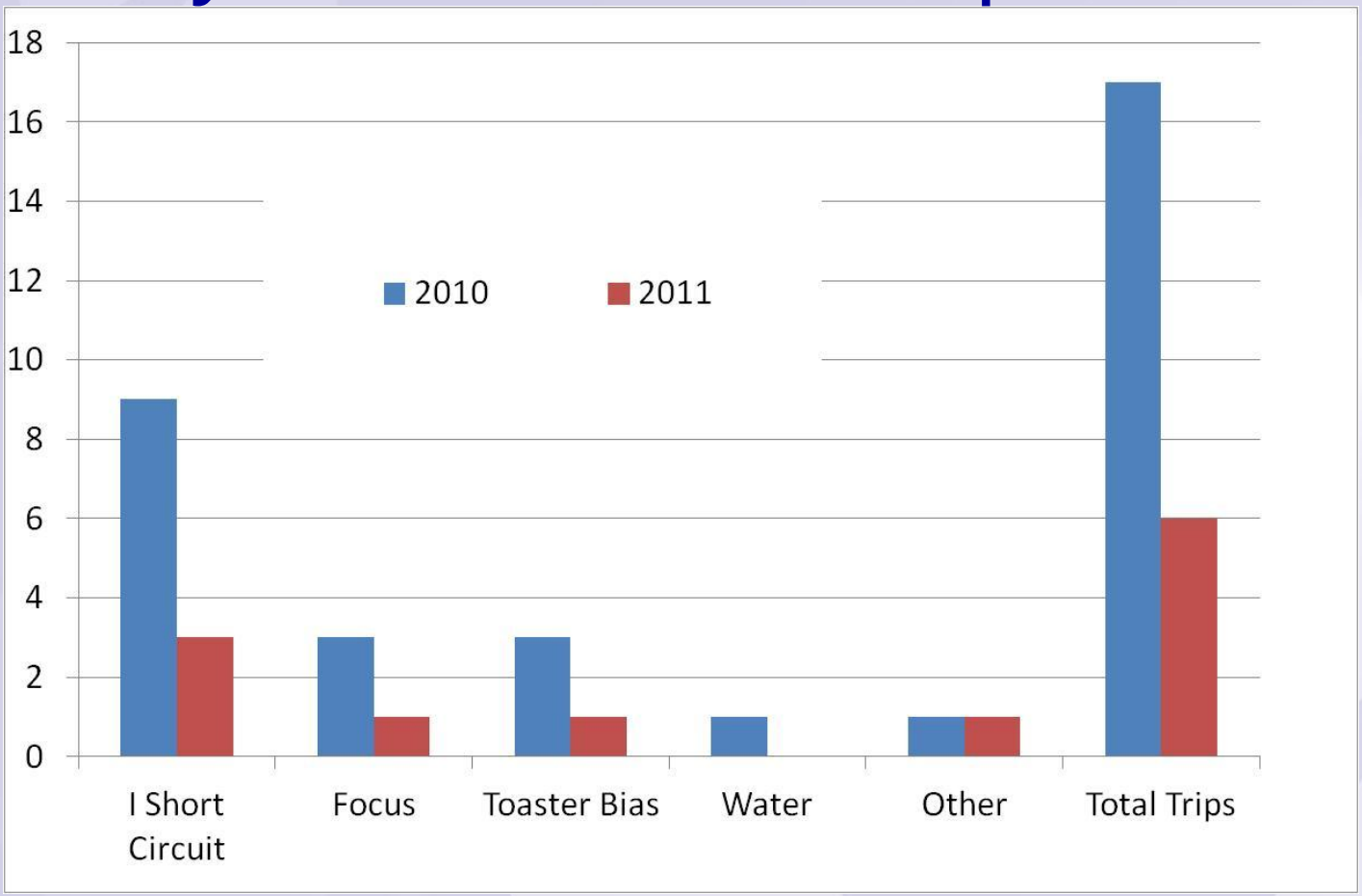
diamond

Amplifier 1 Output Power ~ 170 kW

E2V IOTs


Filament Hours
35000
30000
25000
20000
15000
10000
5000
0
Total filament hours > 170,000
Removed for conditioning following two trips
Removed for investigation following higher grid emission
2 damaged due to cooling issues.
1 Failed during initial commissioning (2007).
One was delivered with a faulty ION pump
289-0938
287-0931
273-0907
288-0935
222-0710
321-1043
326-1047
325-1047
224-0711
290-0939
212-0647
211-0647
210-0647
223-0710
327-1048
277-0909
366-1206
367-1207
372-1210
374-1213
376-1213
205-0639
268-0851
269-0904
320-1042
System 1
System 2 Used for testing
System 3
Spare IOTs
Failed or damaged

Amplifier Reliability
Two systems, 8 IOTs in operation



Steady improvement despite increased power demand

2010: 17 trips in total, 9 IOT trips (mostly new IOTs)

2011: 6 trips in total, 3 IOT

2012: 3 trips, all IOTs (year to date)

On behalf of the RF Group

Morten Jensen
Pengda Gu
Matt Maddock
Peter Marten
Shivaji Pande
Simon Rains
Adam Rankin
David Spink
Alun Watkins

Thank you for your attention

diamond