Synchronization issues and crab cavity update

Speaker

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On behalf of crab cavity and Xbox teams

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Overview

- Categories of timing problems
- Clock to accelerator cavity
- CLIC crab cavity synchronisation
- Double balance mixer measurements
- Active waveguide path length control experiments
- Crab cavity testing

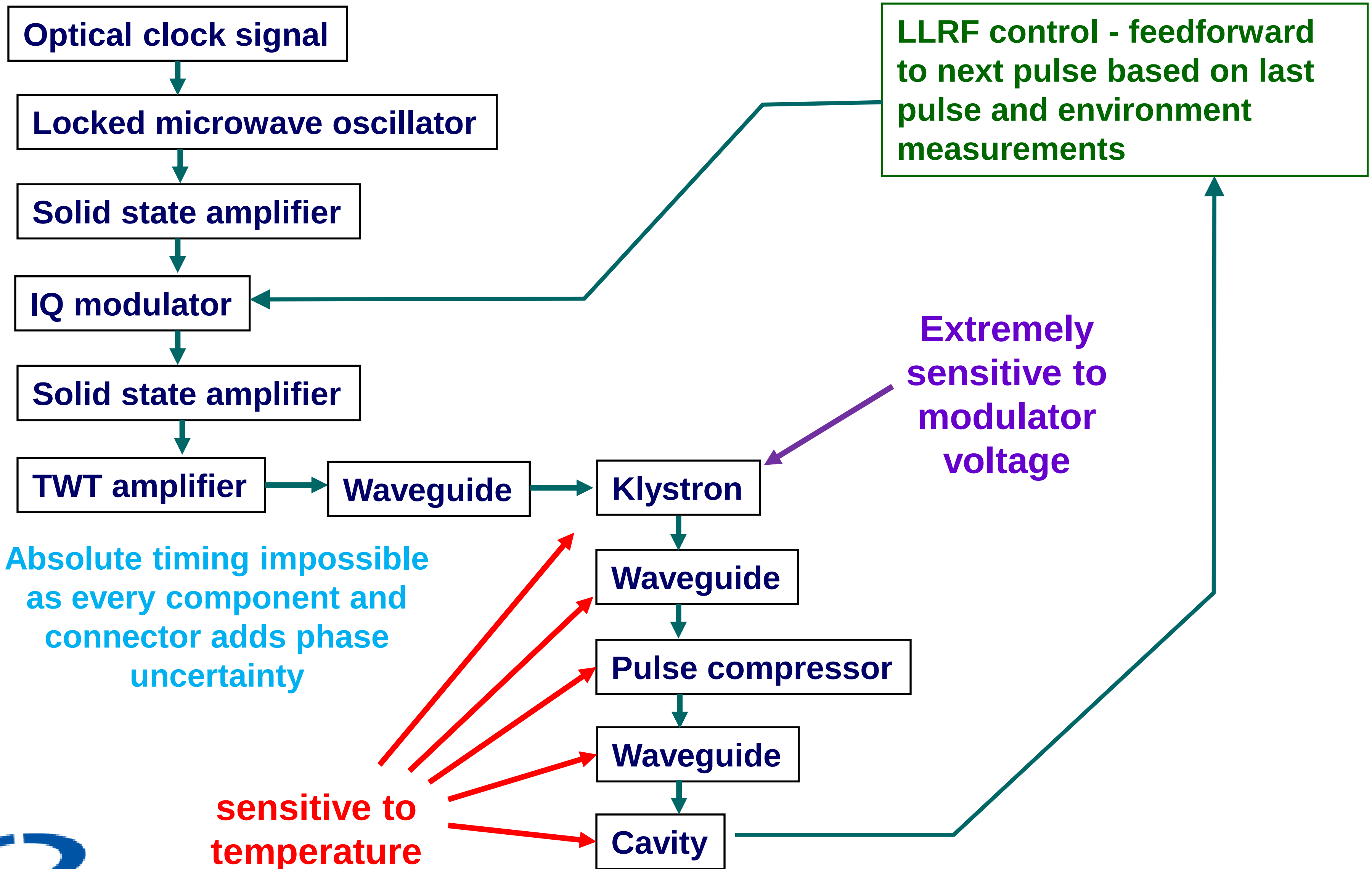
Categories of Timing Problems

- **Stability**
  - Oscillators shift period with temperature, vibration etc.
  - Voltage Controlled Oscillator (VCO) shifts period with applied voltage
  - Atomic clock $\Delta f/f \sim 10^{-14} \sim$ 60 fs per minute

- **Synchronisation**
  - Two clocks with different periods at same place (Phase Locked Loop)
  - Identical delivery time/phase at two places (Crab Cavity Problem)
  - Same clock at two places
    - Resynchronisation requires constant propagation time of signal
    - Detector with high resolution and low noise

- **Trigger an event at a later and a different location**
  - Needs two stable clocks which are synchronised (FEL problem)
  - Must be able to generate event from clock pulse with tiny jitter
  - Work at DESY and MIT suggest 10fs achievable

Clock to cavity



CLIC Cavity Synchronisation

CLIC bunches ~ 45 nm horizontal by 0.9 nm vertical size at IP.

Cavity to Cavity Phase synchronisation requirement

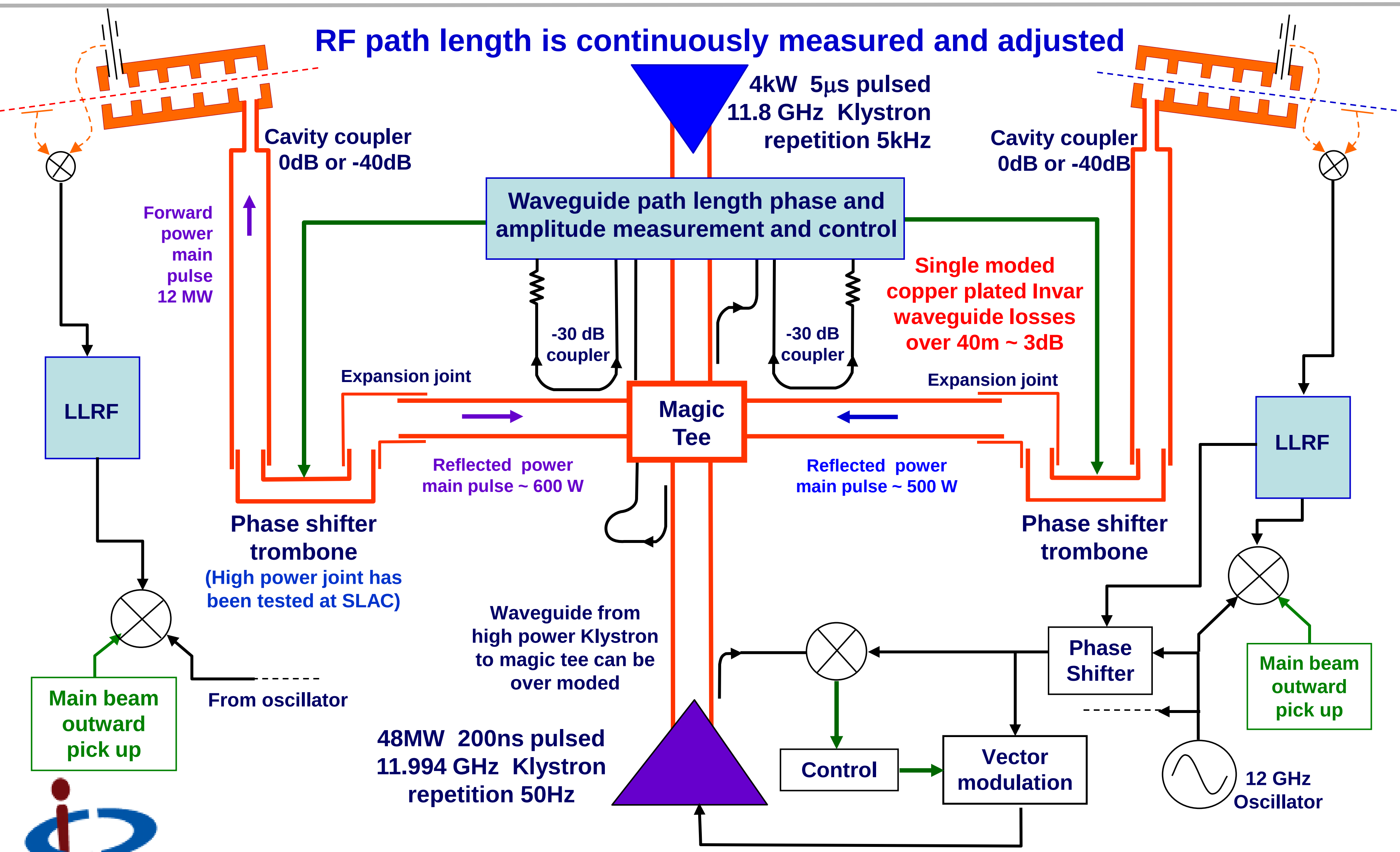
$$= \frac{720\sigma_x f}{c\theta_c}\sqrt{\frac{1}{S_{rms}^4}-1} \quad \text{degrees}$$

Target max. luminosity loss fraction S	f (GHz)	σ_x (nm)	θ_c (rads)	ϕ_{rms} (deg)	Δt (fs)	Pulse Length (μs)
0.98	12.0	45	0.020	0.0188	4.4	0.156

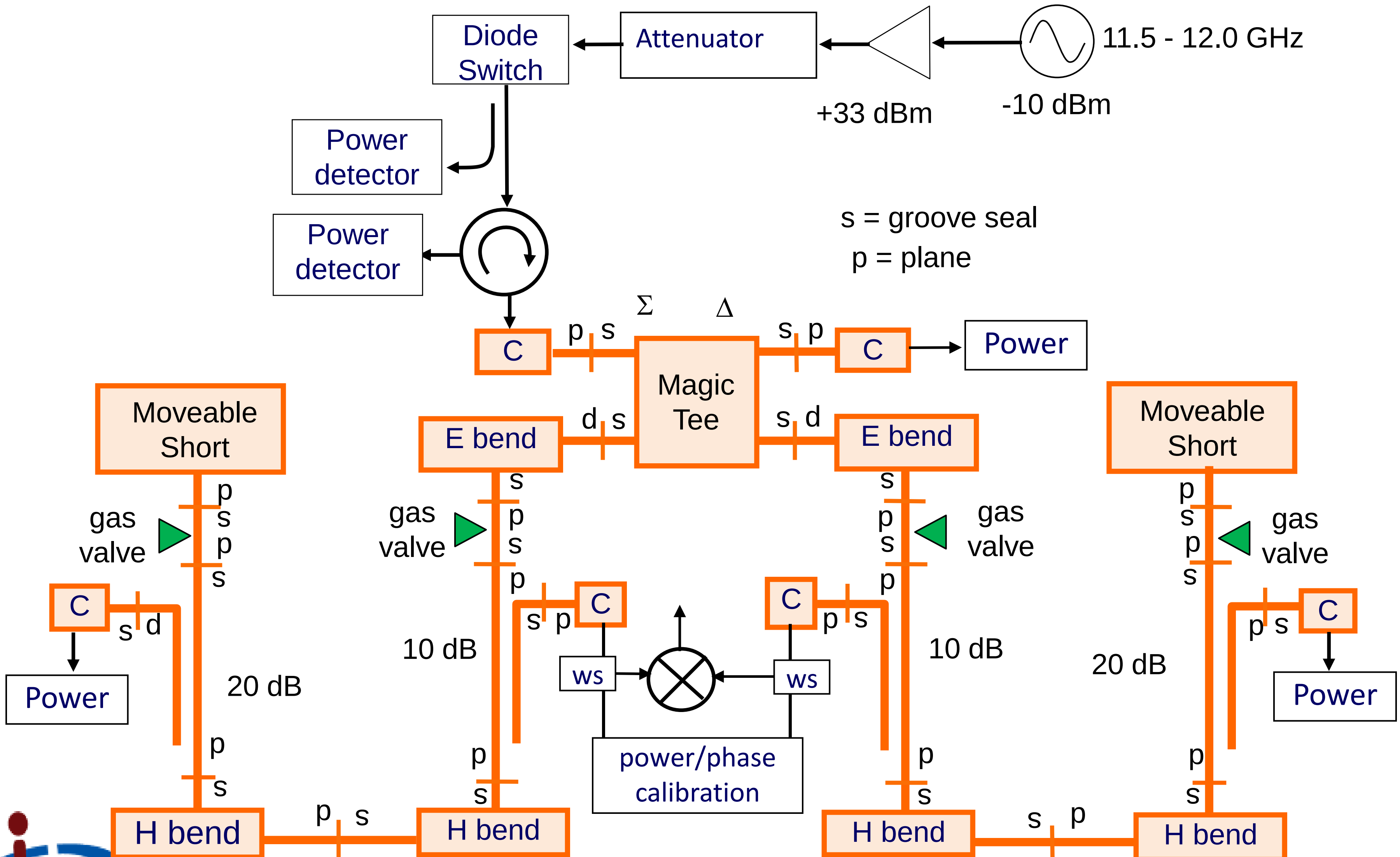
So need RF path lengths identical to better than c Δt ~ 1.3 microns

RF path length measurement

RF path length is continuously measured and adjusted



Layout for initial waveguide test

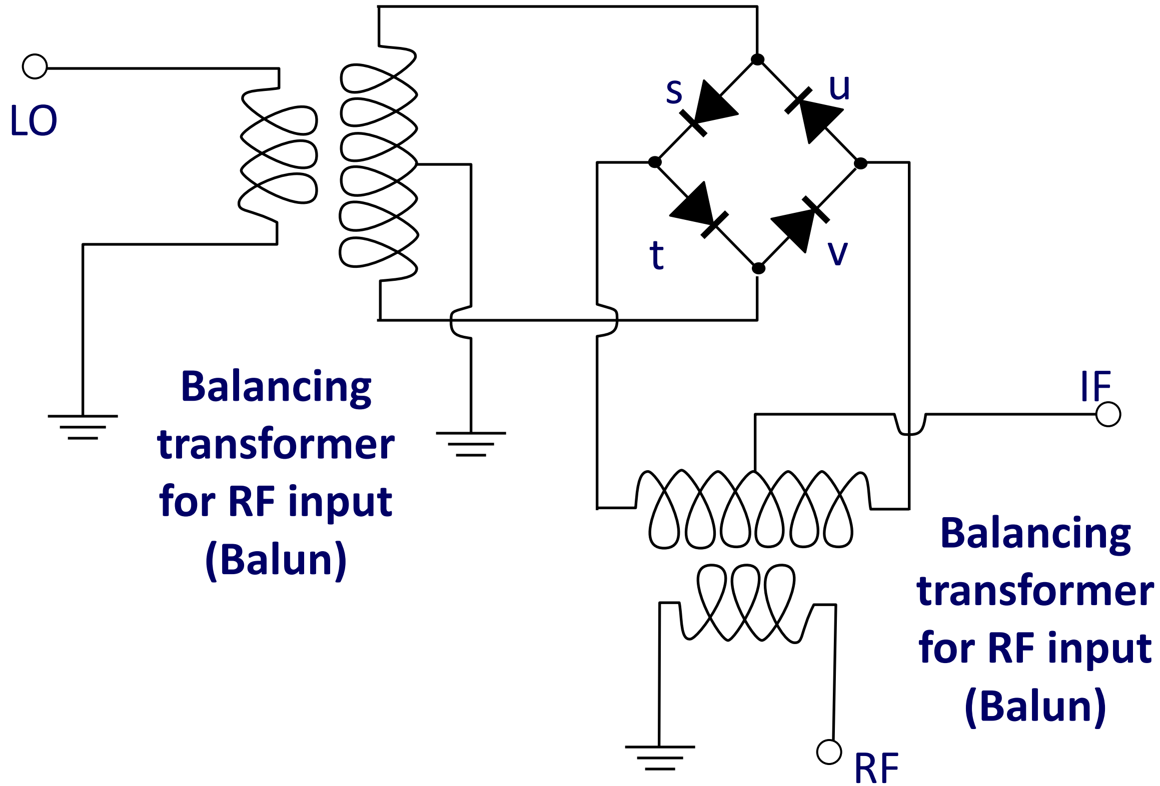


Double balanced mixer

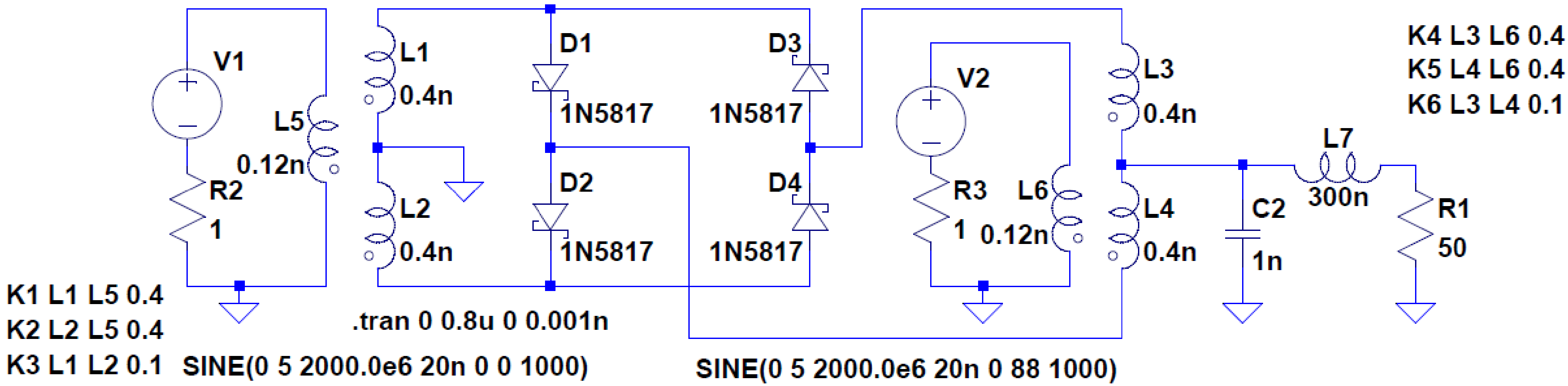
Simplistic noise calculations indicate that resolution at the level of 1 milli-degree for a micro second pulse is theoretically possible with packaged double balanced mixers.

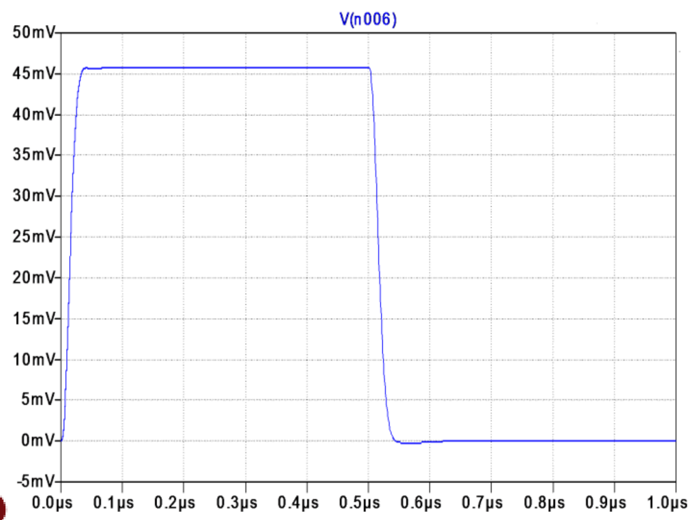
Propose using Mini-circuits 20GHz SIM_24MH+ level 13 mixer, for 12 GHz LO input at 13dBm and low power 12.03 GHz RF input, Conversion loss = 5.8 dB, LO-RF isolation =36dB, LO-IF isolation~19dB, VSWR RF = 2.0, VSWR LO ~ 3.5

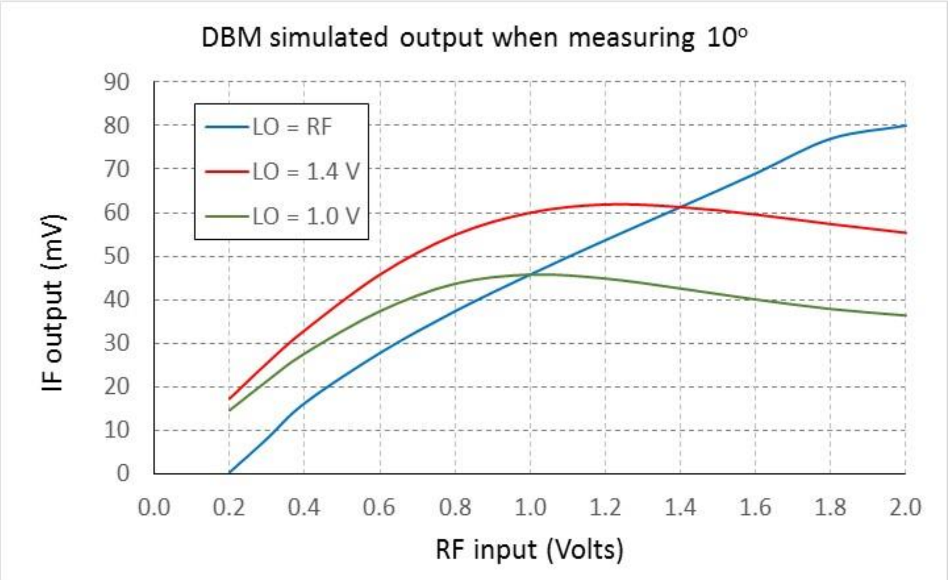
We plan to use mixer with LO and RF inputs that are equal in magnitude and frequency. And it is of interest to consider performance for this case.



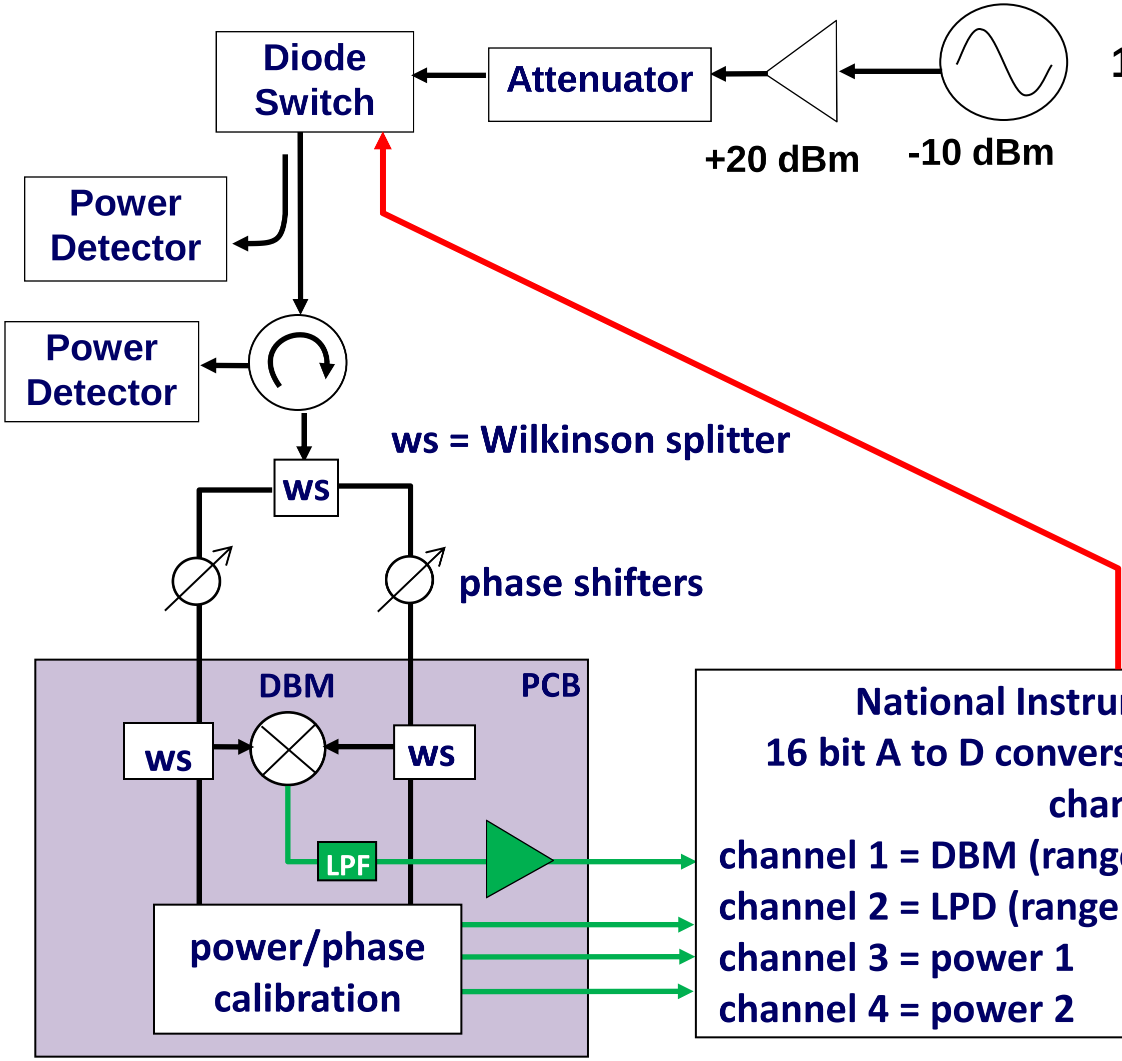
DBM with equal inputs







Calibrating phase measurement PCB

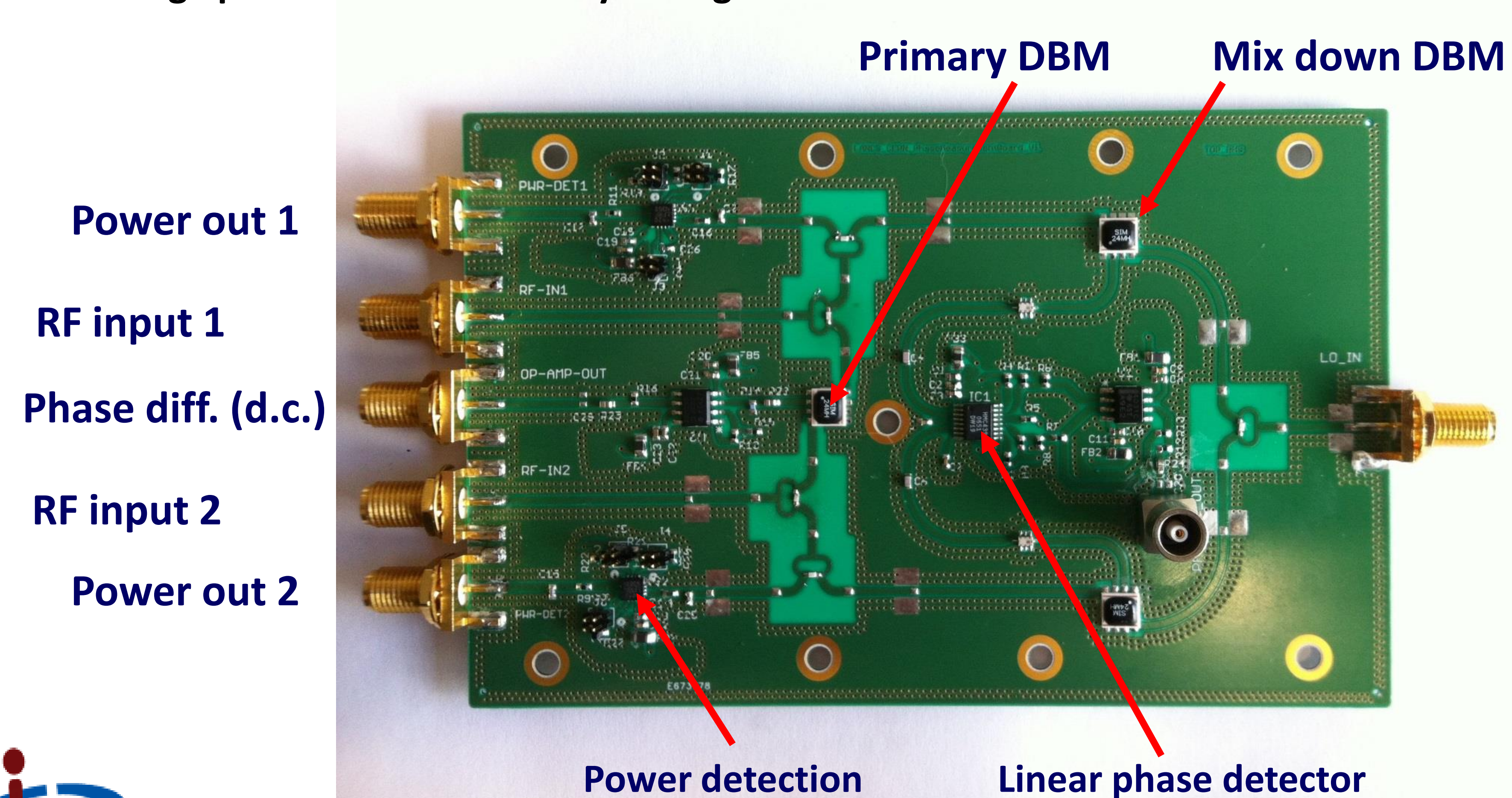


DBM voltage output depends on power input . Need to shift one path on board by 90 so that zero output corresponds to identical phases arriving from waveguides.

National Instruments PXI Crate
16 bit A to D conversion at 120Mb/s on 4 channels
channel 1 = DBM (range~ 30°)
channel 2 = LPD (range ~ 360°)
channel 3 = power 1
channel 4 = power 2

Phase measurement PCB

Signal is split before primary DBM so that power on both channels can be measured. Additional signals can be mixed down and measured with a linear phase detector hence large phase shifts induced by waveguide trombones or short scan be calibrated.



Staged waveguide testing

1. Calibration of detector electronics

2. Accurate phase measurements on a minimal system in a controlled environment.

3. Measurements of phase fluctuations on longer lengths of copper waveguide in an accelerator environment.

4. Controlling phase of reflections using actuators on moveable shorts.

5. Use of interferometry to set transmission length at the measurement frequency below 11.9 GHz and then to check path synchronisation at the high power cavity RF frequency of 11.994 GHz.

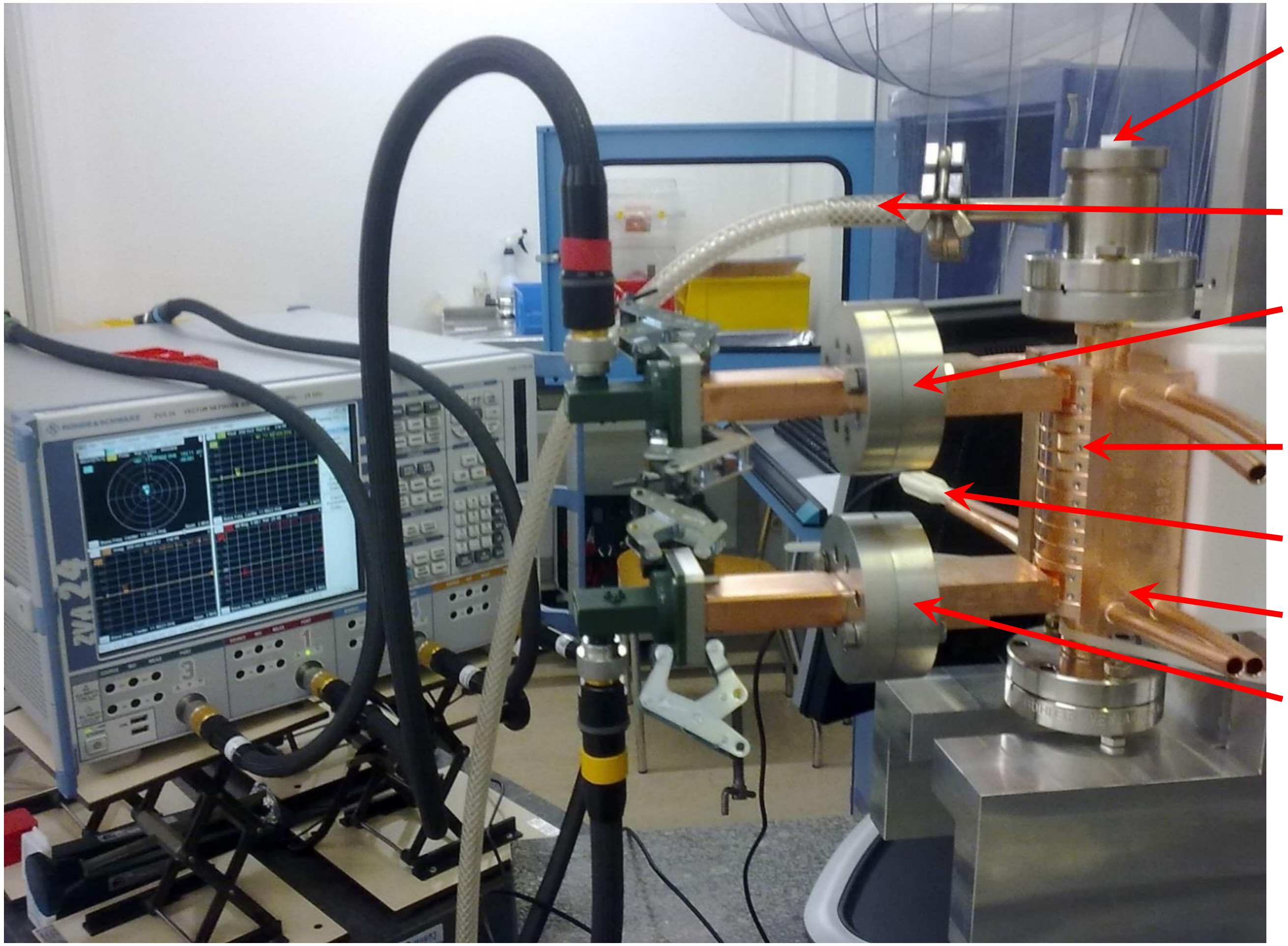
6. Development and testing of trombone sections or bespoke phase shifters to replace moveable shorts.

Schedule

	Task	Effort weeks	Start	Finish
1	Fabricate and test structures and component on measurement pcb	2	16.3.15	3.4.15
2	Fabricate, test and calibrate prototype measurement pcb	4	6.4.15	1.5.15
3	Program PXI for data collection	3	20.3.15	5.1.15
4	Procure amplifiers, diode switches and circulator	0.5	1.3.15	1.5.15
5	Complete fabrication and testing of 12.0 GHz and 11.7 GHz PLLs	3	6.4.15	8.5.15
6	Design corrections and fabrication of second measurement pcb	3	4.5.15	30.5.15
7	Final calibration of phase measurement board.	1	1.6.15	5.6.15
8	Fabricate stand for minimal waveguide test stage 1	1	6.4.15	24.4.15
9	Test stage 1 calibrations for minimal waveguide system	1	8.6.15	19.6.15
10	Flow graph analysis on system reflections affecting accuracy of measurement	1	6.7.15	24.7.15
11	Test stage 1 long term drifts of minimal system in environmental chamber	1	15.6.15	27.6.15
12	Fabricate stands for extended waveguide tests stages 2-5	1	15.6.15	27.6.15
13	Test stage 2 measure phase fluctuations in accelerator environment	2	29.6.15	29.8.15
14	Design and procure actuators for moveable shorts	4	15.6.15	7.8.15
15	Test stage 3 close loop to control transmission lengths	6	31.8.15	17.10.15
16	Test stage 4 control at 11.9 GHz for transmission at 12.0 GHz	2	19.10.15	23.10.15
17	Test stage 5 development of bespoke phase shifters	12	26.10.15	5.2.16
18	Test stage 5 validation of bespoke phase shifter	3	8.2.16	26.2.16

Bead pull of undamped crab cavity

E. Daskalaki, A. Degiovanni, C. Marrelli, M. Navarro Tapia, R. Wegner, B. Woolley



centring V guiding the wire for bead-pull measurements

nitrogen supply

input (chosen and marked)

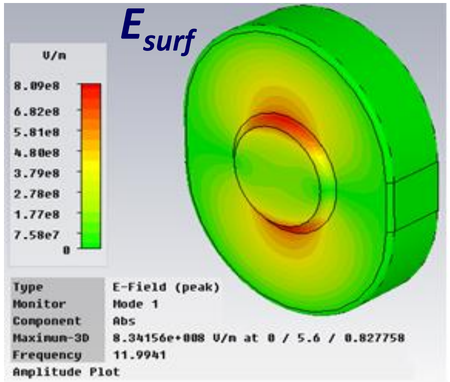
tuning pins (4 per cell)

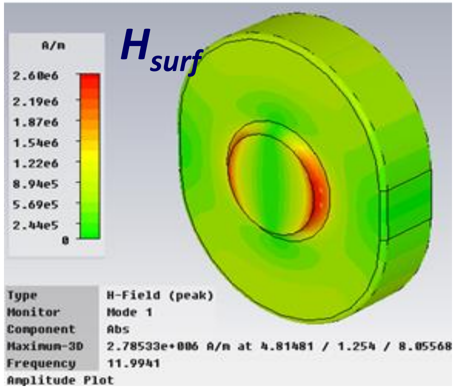
temperature sensor

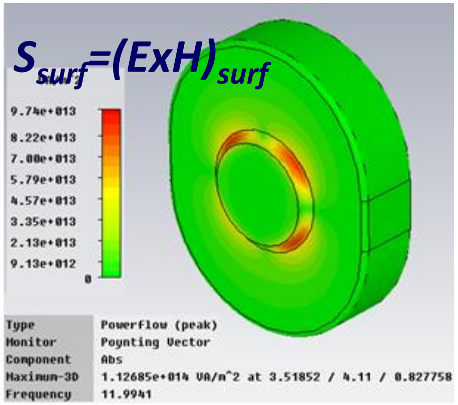
cooling block

output (marked)

Crab cavity cell under test



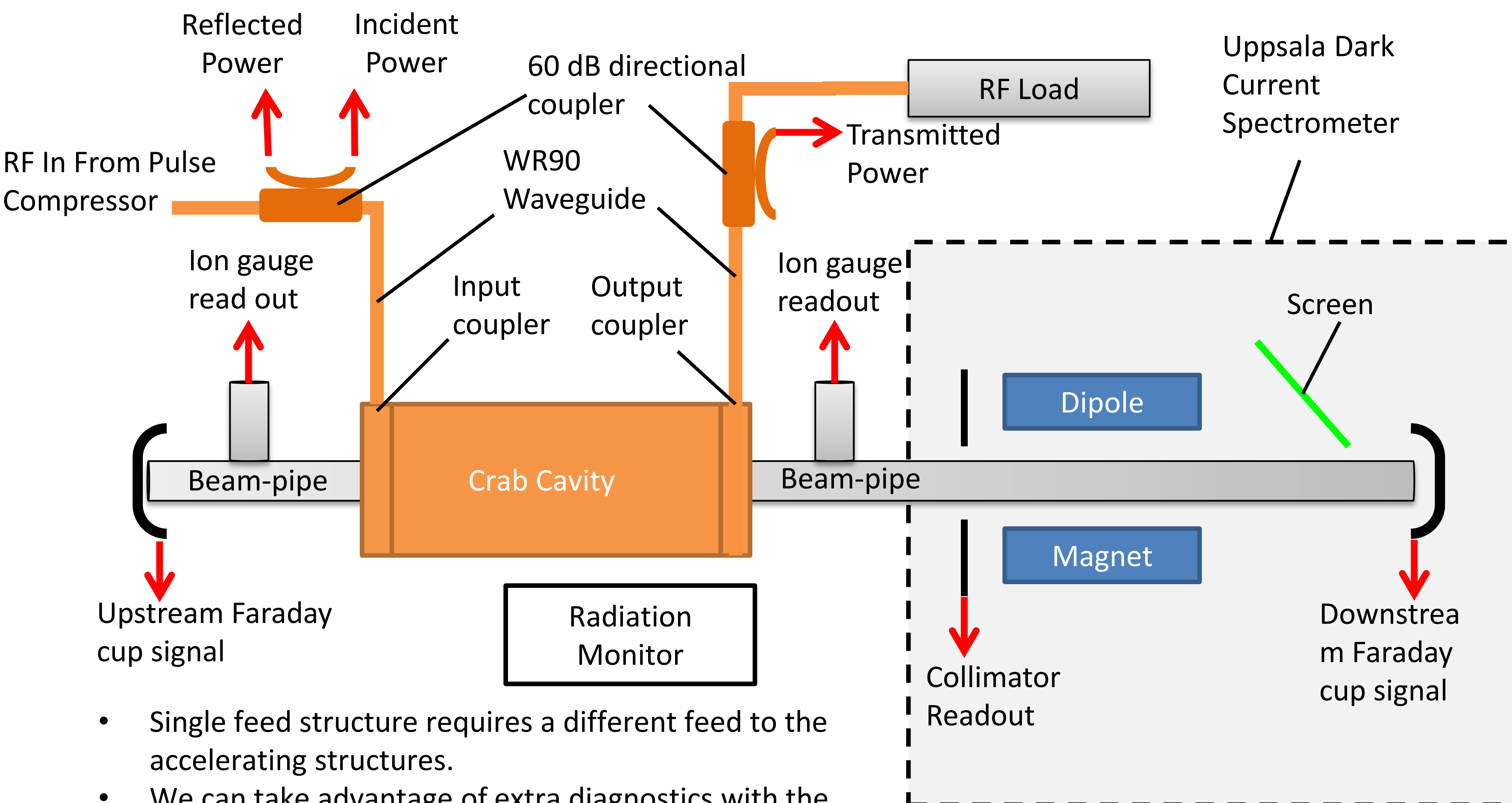




- **Peak electric and magnetic fields of the dipole mode are located 90 degrees from each other on the iris**
- **Surface Poynting flux S_{surf} is however at 45 deg to both E and H**
- **Location of the breakdown on the iris provides critical information about the role of magnetic field in breakdown.**
- **The cavity has a large Sc but relatively low E and H fields at the surface so this also provides an independent verification of new theories.**

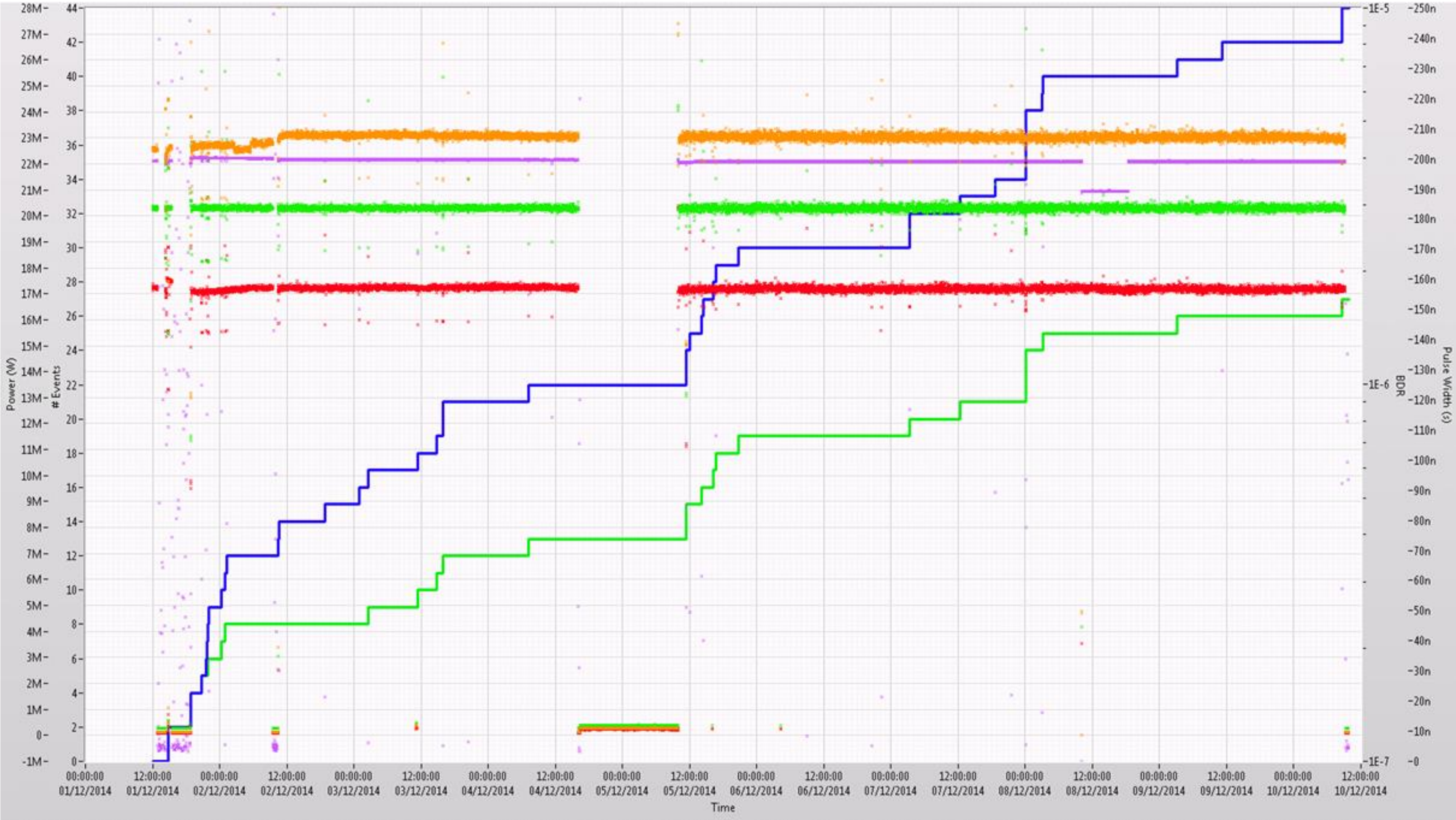
Property	Crab cavity	CLIC_G
Mode	120° , 11.9942 GHz	120° , 11.9942 GHz
Q	6247	6100-6265
V_{group}	-2.9 %c	1.66-0.83 %c
Kick	2.55 MV	
Gradient	26 MV/m	100 MV/m
Power	13.35 MW	42 MW
E_{surf}	103 MV/m	190 MV/m
H_{surf}	348 kA/m	410 kA/m
ΔT (200ns)	26 K	21 K
Sc	3.32 W/mm^2	3.8 W/mm^2

High power crab cavity testing



- Single feed structure requires a different feed to the accelerating structures.
- We can take advantage of extra diagnostics with the Uppsala dark current spectrometer.

20 MW December 2014



No pulse compressor

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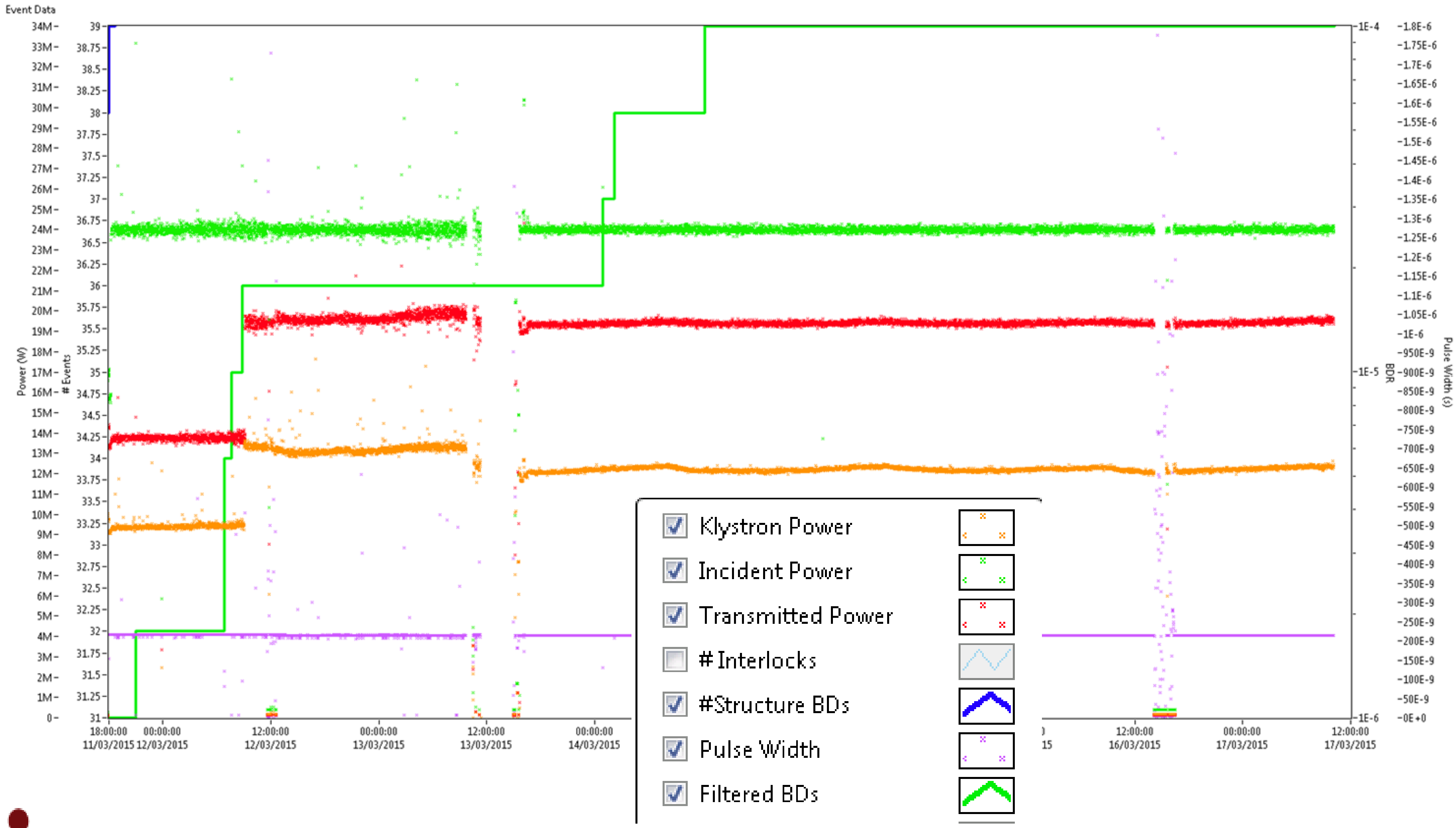
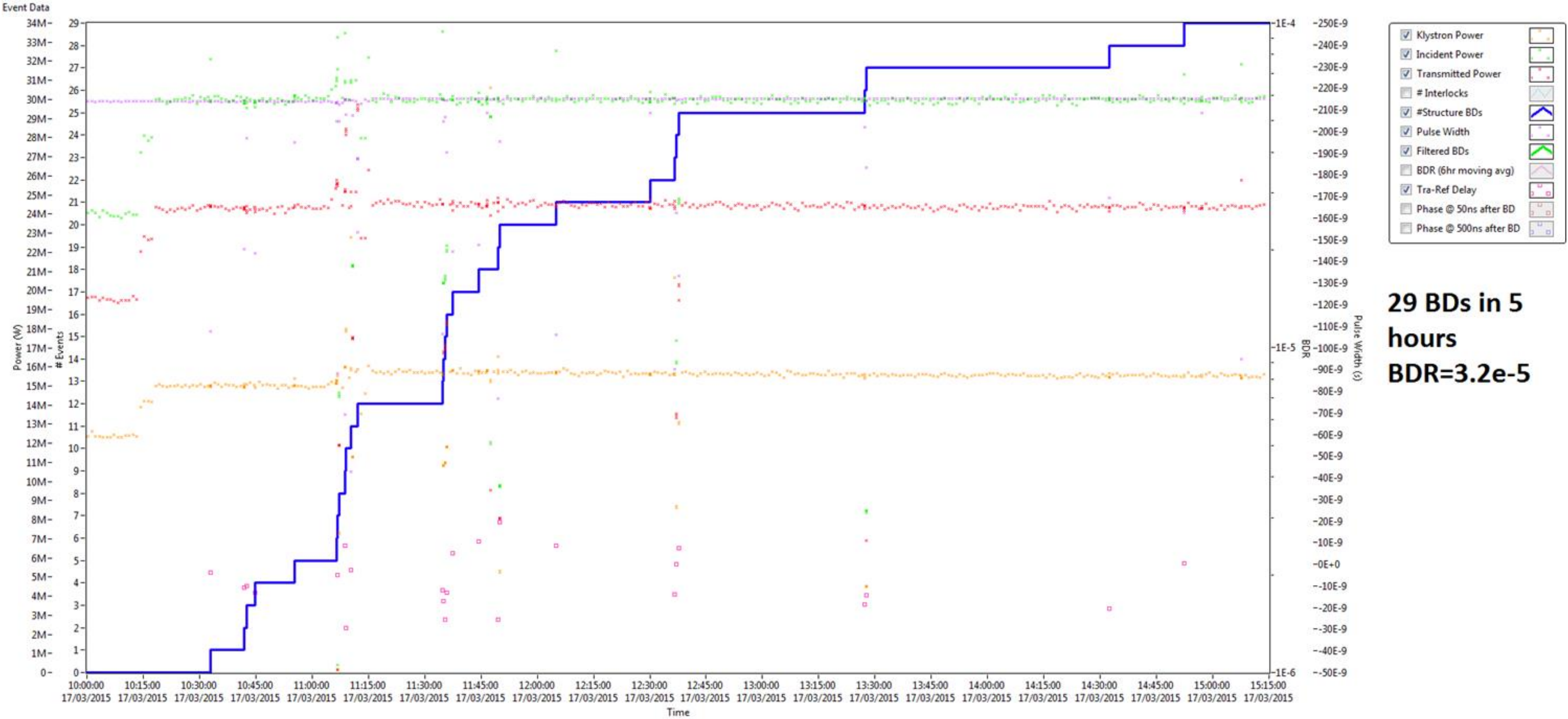
24 MW Run 11-17th March BDR: 3.2e-7



30 MW Run 17th March: BDR: 3.2e-5



29 BDs in 5 hours
BDR=3.2e-5

Crab testing

- **Very low breakdown rate at CLIC power level**
- **Acceptable breakdown rate at double CLIC power level**
- **More data needed to establish breakdown rate dependence on SC parameter**
- **For CLIC could consider less cells and a lower group velocity.**

(CLIC constraints,

power flow >> worst case beamloading

only have 50MW, after waveguide losses ~ 13 MW per cavity

would like to reduces wakefields to reduce vertical kicks hence less cells could be beneficial.)

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Progress this year

- Twelve cell undamped crab cavity tuned
- High power testing of undamped cavity commenced
- Manufacture of damped cavity cells underway
- Waveguide for stabilisation experiment procured
- NI PXI create for fast data capture procured
- Planning of tests well advanced
- Electronic boards still under development
- Calibration procedures being devised