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1 µs FMCW reflectometry for plasma density and fluctuation profile measurements

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IRW 14 Meeting
Lausanne (May 22-24 2019)

HISTORICAL

1997 : Ka band / O-mode / Heterodyne / sweep time : 1 ms → 10 µs

2002 : V&W bands / X-mode / 10 µs

2007 : 2 µs (dead time 1µs)

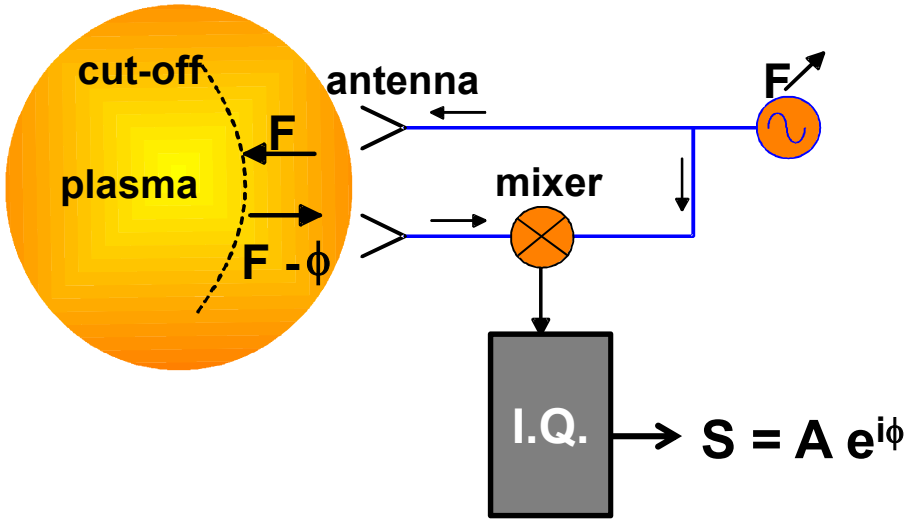
2014 : 1 µs (0.25µs)

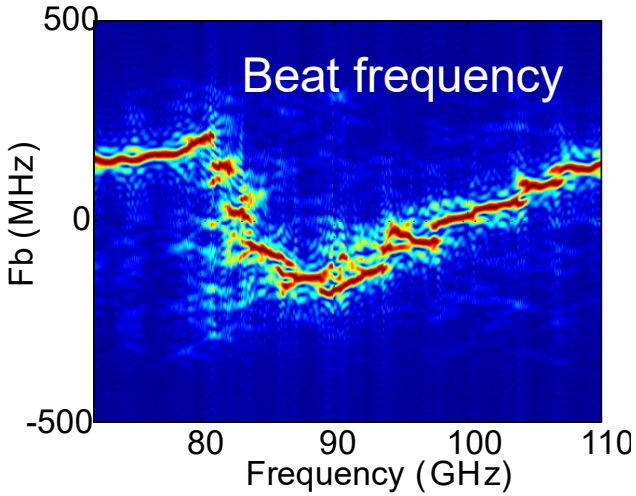
(due to TS shutdown the reflectometers were moved to AUG)

2016 : Reflectometer back to Tore Supra (now WEST)…

FMCW reflectometry

The probing wave is reflected when $F = F_{cut\text{-}off}$



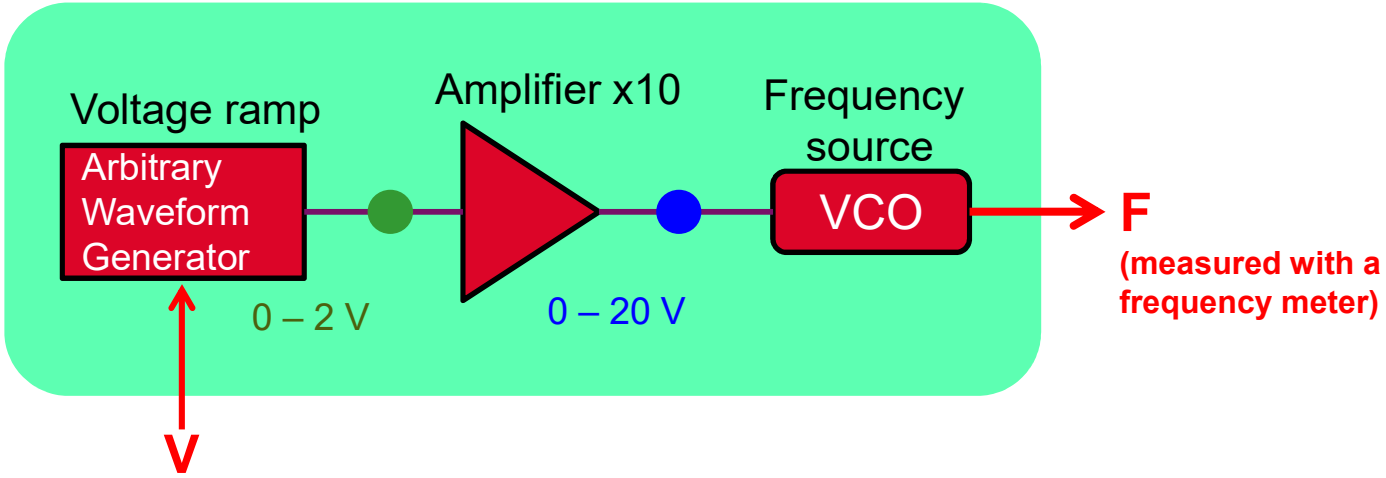


- **Frequency sweeps : Fast AWG @ 1.25 Gs/s**
- **Sweep time 1µs / dead time 0.25µs**
- **Detection bandwidht 600 MHz (± 300 MHz)**
- **Acquisition @ 1 Gs/s**

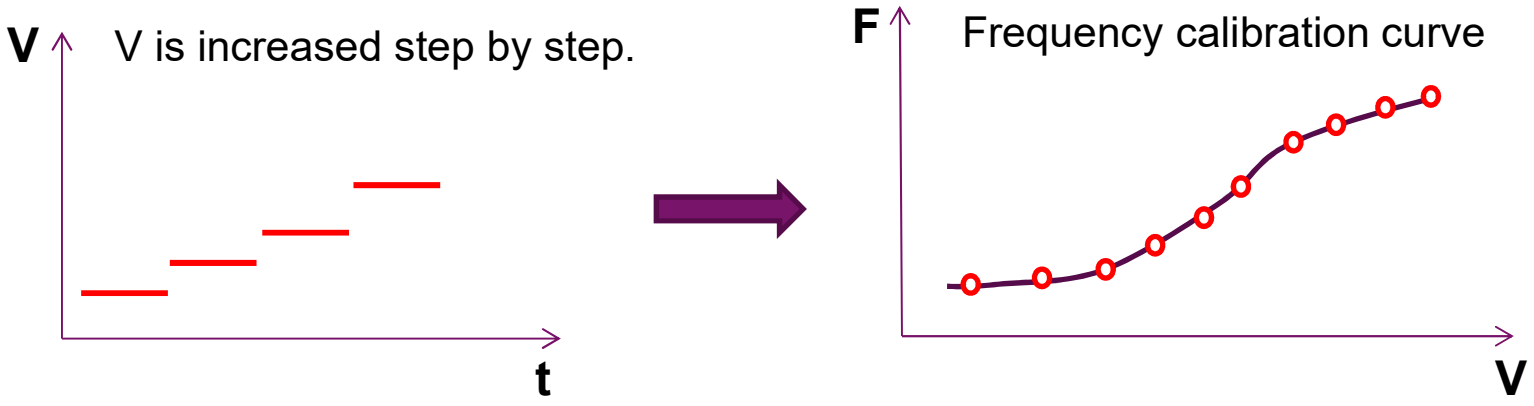
n_e and its radial position requires a precise knowledge of the probing F

Frequency calibration F(V)

Frequency sweeping of the source is provided by a ramp voltage (AWG)

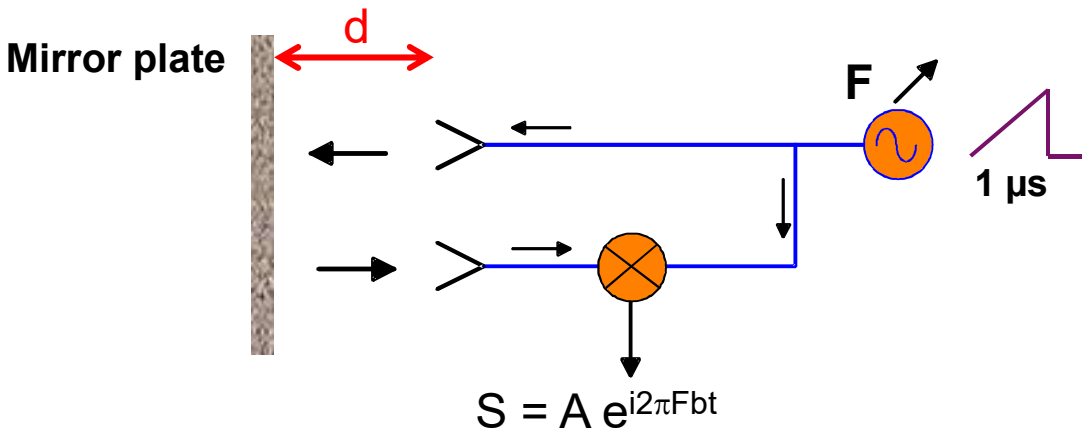


"Static" calibration procedure provides F(V)



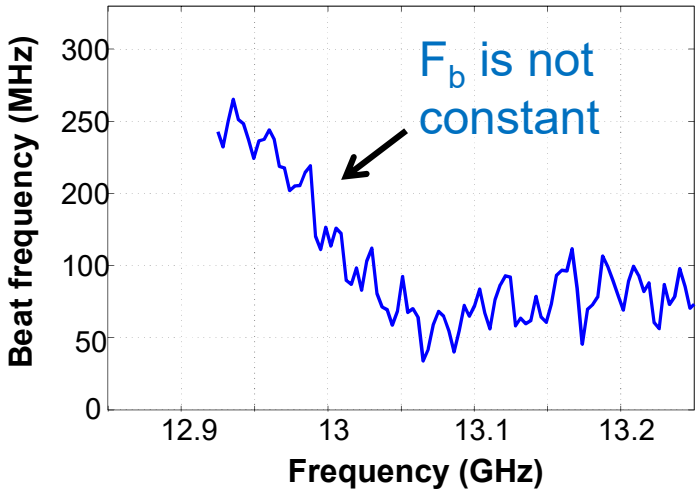
A recalculated voltage ramp is uploaded into the AWG to provide a linear frequency sweep

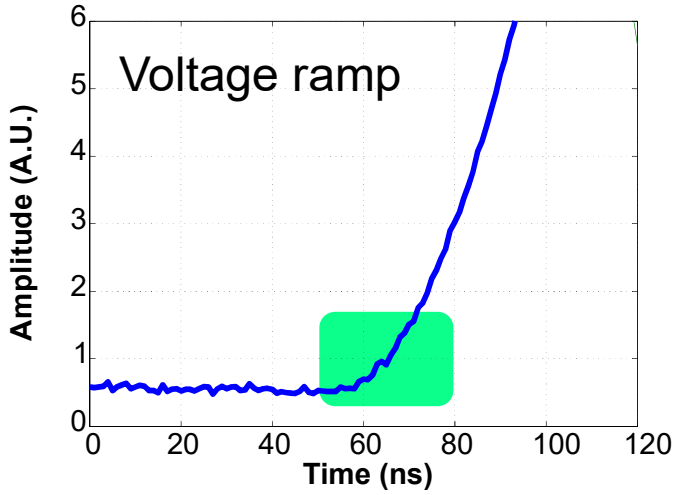
Dynamical effect



For linear frequency sweep :

$$F_b = \frac{d}{c}\frac{dF}{dt} = Cst$$





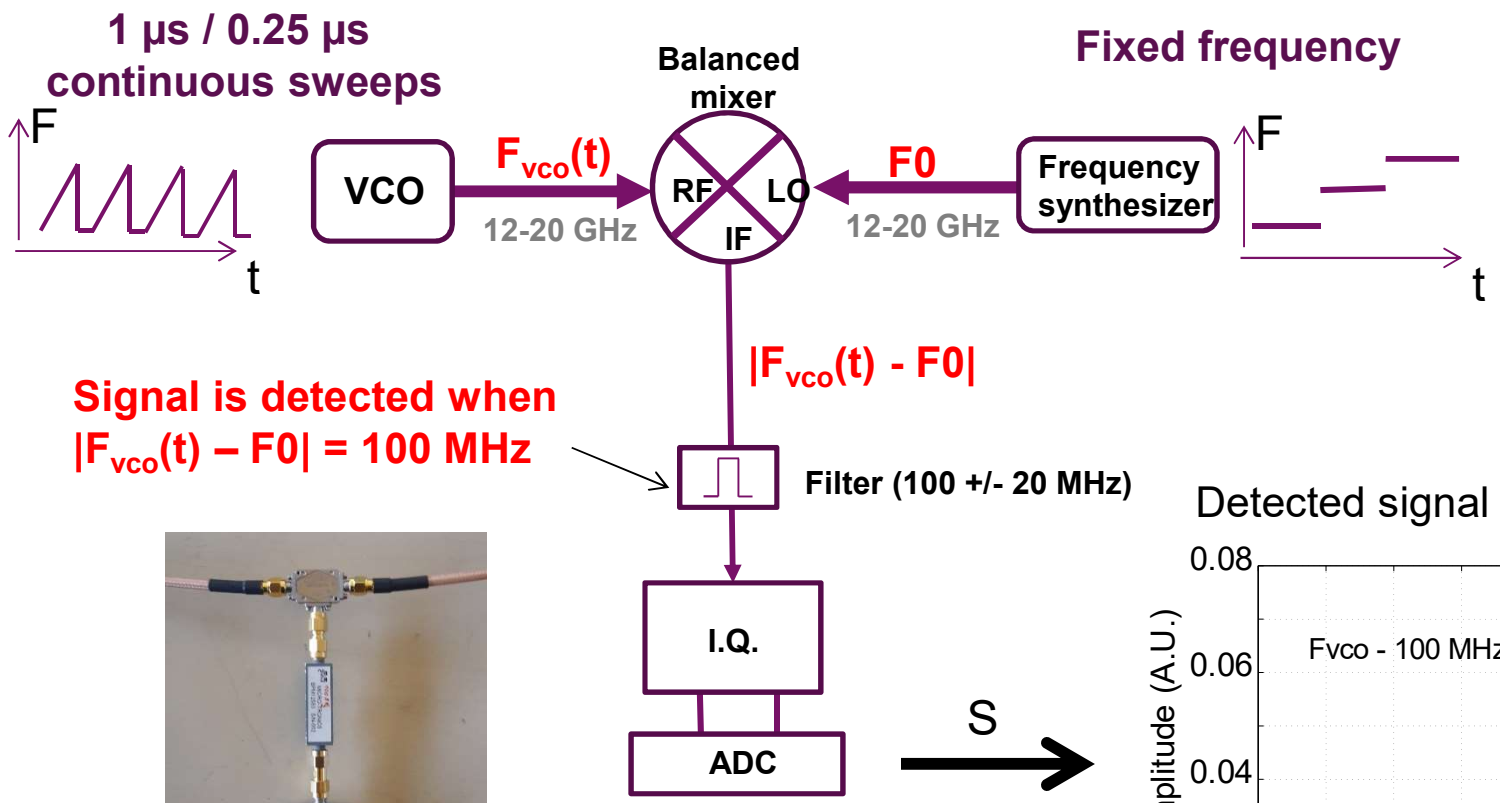
Non linearity occurs mainly at the onset of the sweep

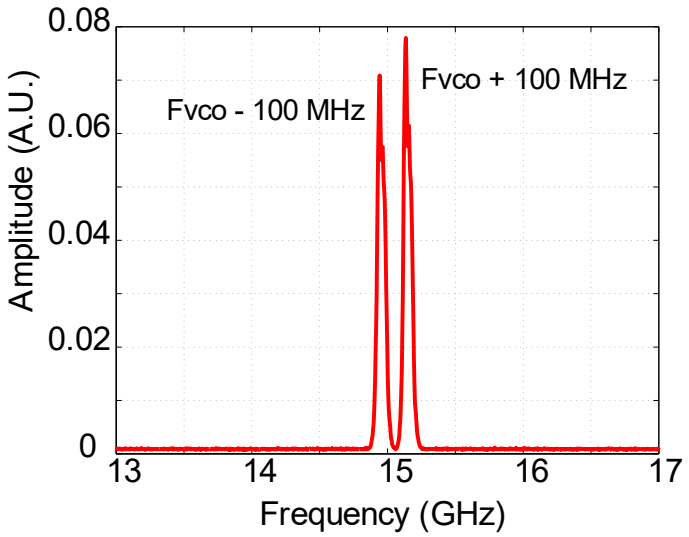
➔ **Frequency correction is required**

Dynamical frequency calibration

(Clairet et al. RSI 2017)

A. Silva et al. RSI 96



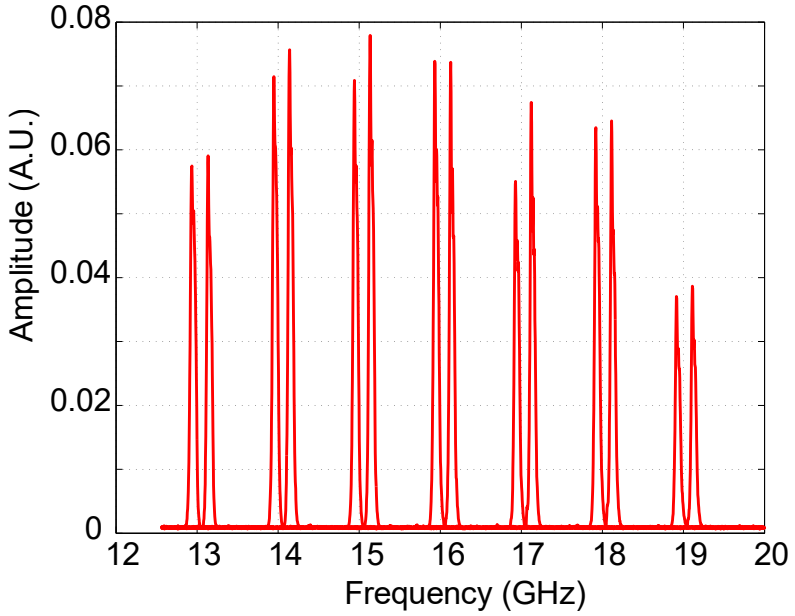


(xlabel : frequencies from static calibration)

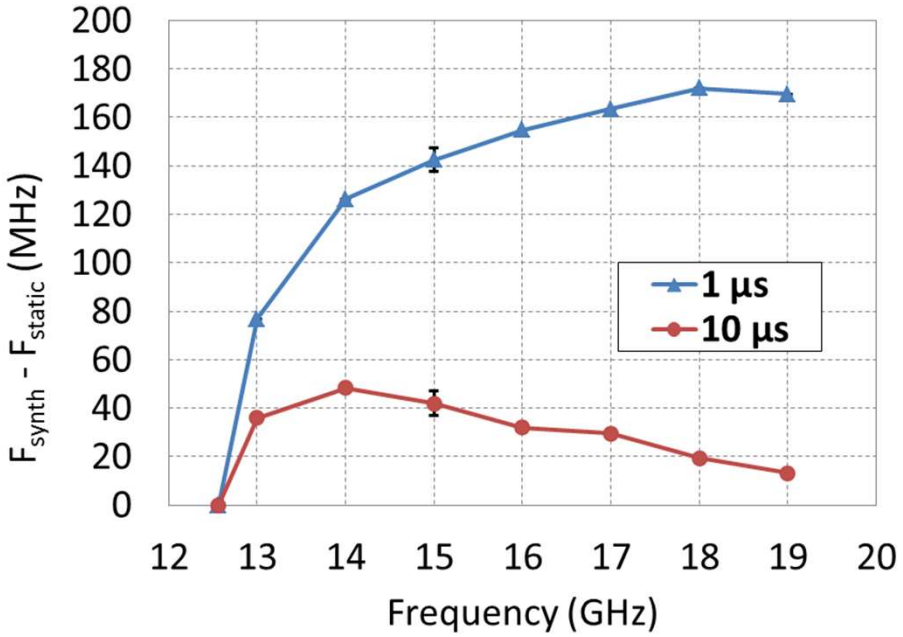
''Static'' frequency is higher than the ''dynamic'' one.

Frequency calibration correction

Successive measurements using :
F_{synth} = 13, 14, 15, 16, 17, 18, 19 GHz



Frequency departure from static calibration

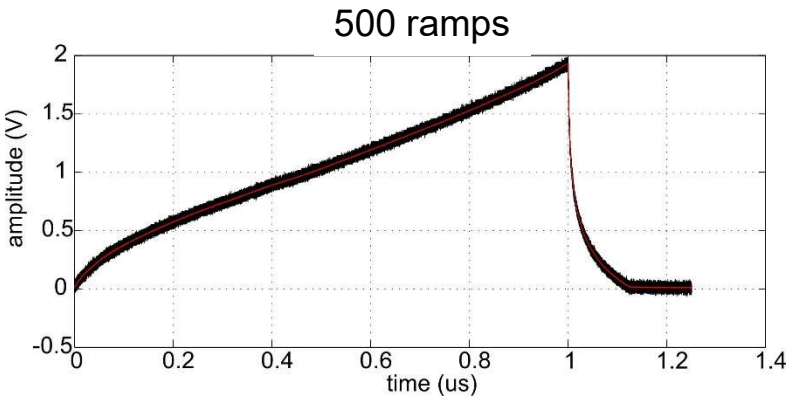


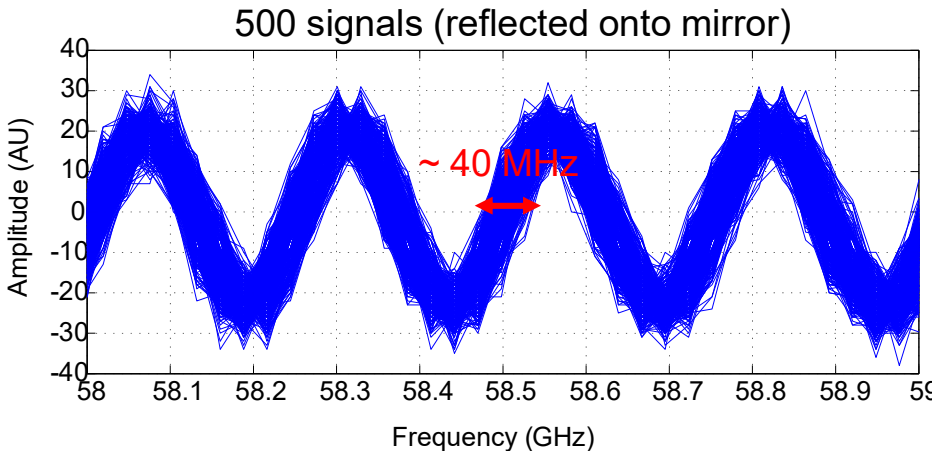
Effective probing frequencies are lower than the static calibration ones

Non-linear response of the electronic increases with the sweeping speed.

Ramp reproducibilty & Frequency stability

The frequency sweeps stabilized after a few hundreds of µs, thus the reflectometers must be continuously swept during a plasma discharge to provide the best reproducibility of the sweeps.





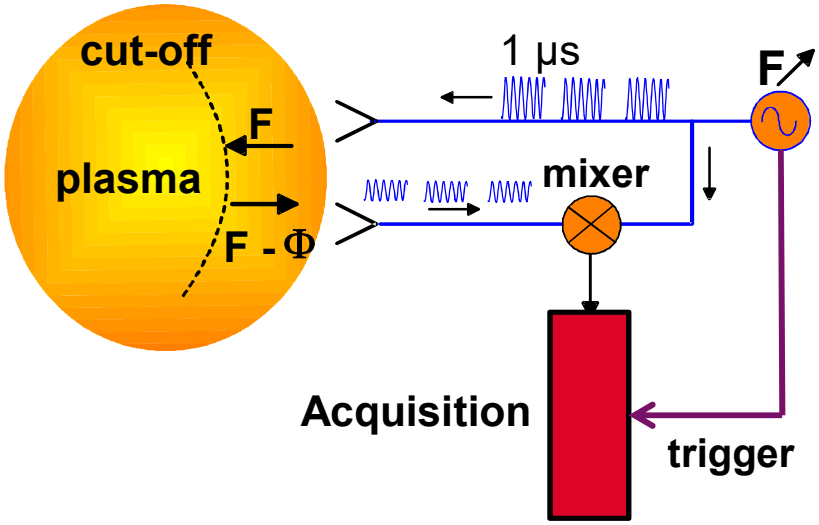
A sweep of 1GHz ≈ 1cm of plasma (roughly and gradient dependent)

➔ Scattering of 40MHz would correspond to probing uncertainty less than 1mm.

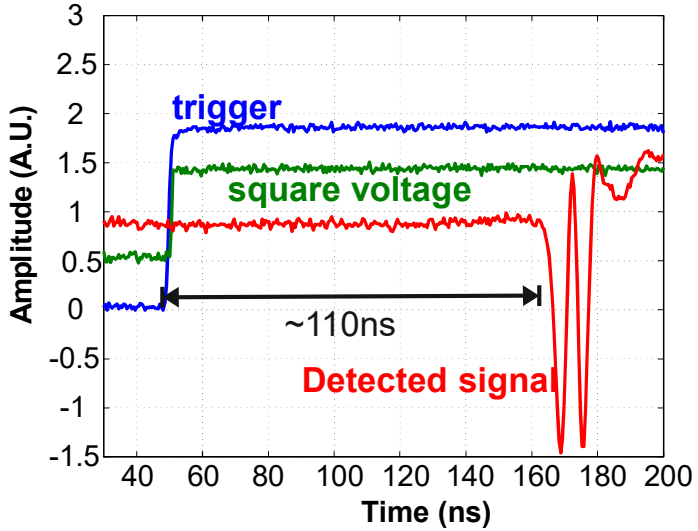
Trigger delay determination

Delay between the **probing launched signal** and the **detected reflected signal**

Delay due to transmission line + plasma



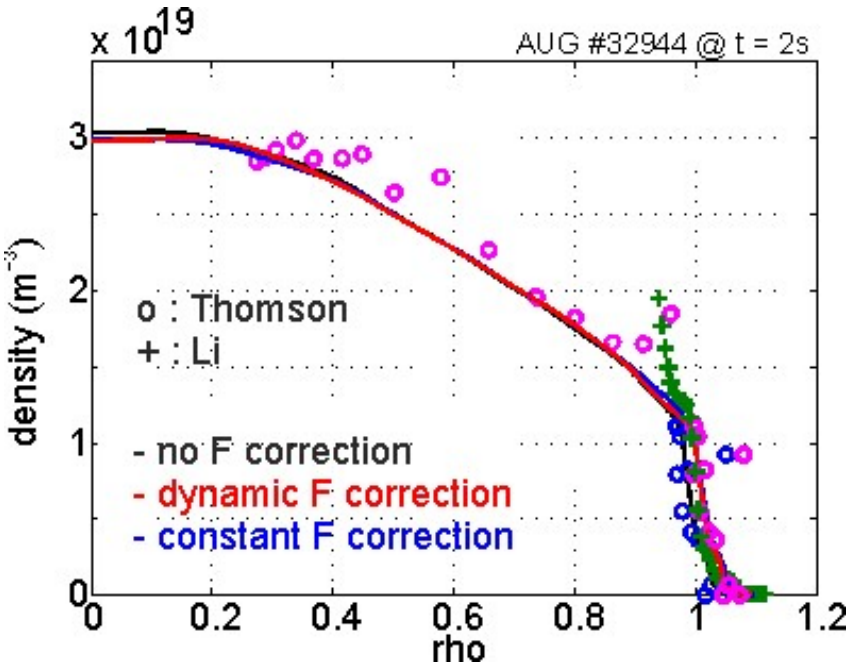
The trigger delay is adjusted using a square voltage instead of a ramp which makes a net impulse signal signature.

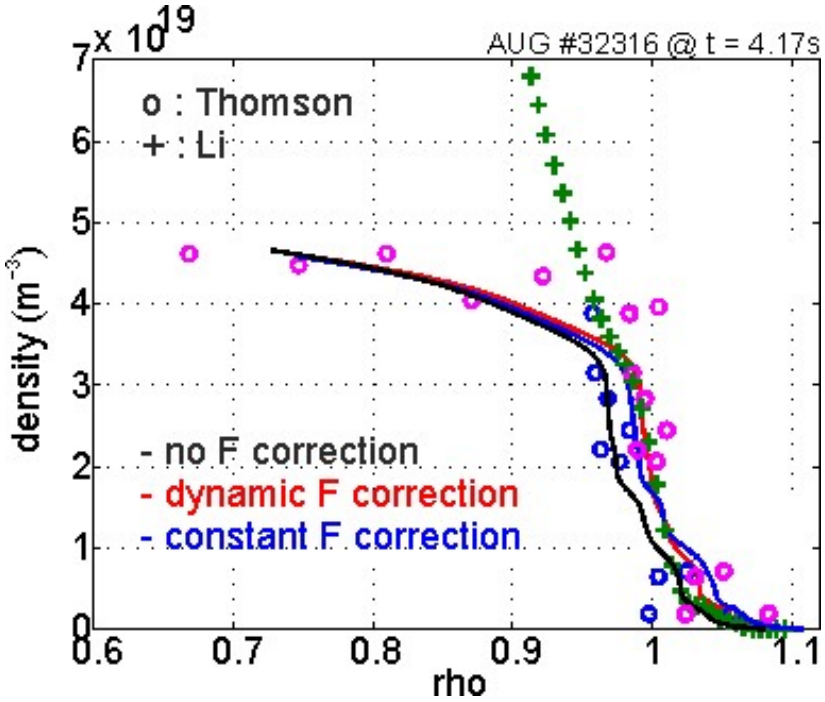


Trigger delay ~ 110 ns (uncertainty ~ 2 ns)
(corresponds to10% of the signal for 1µs sweep time)

Effect of dynamic corrections on profile reconstruction (1)

Frequency correction is applied as post treatment for profile calculation.

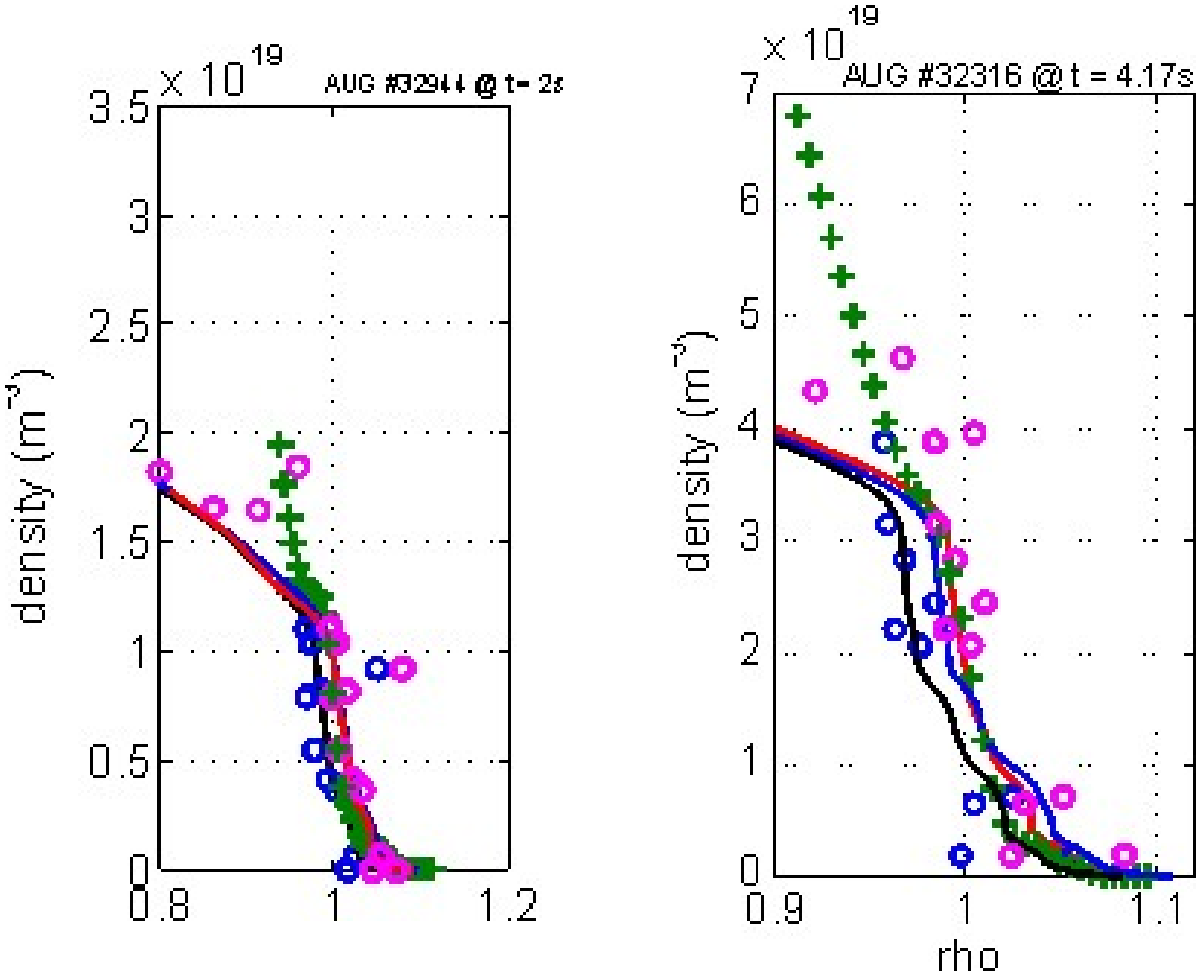




Radial shift ~ 1 cm when compared to no correction.

Effect of dynamic corrections on profile reconstruction (2)

(zoom)



o : Thomson
+ : Li

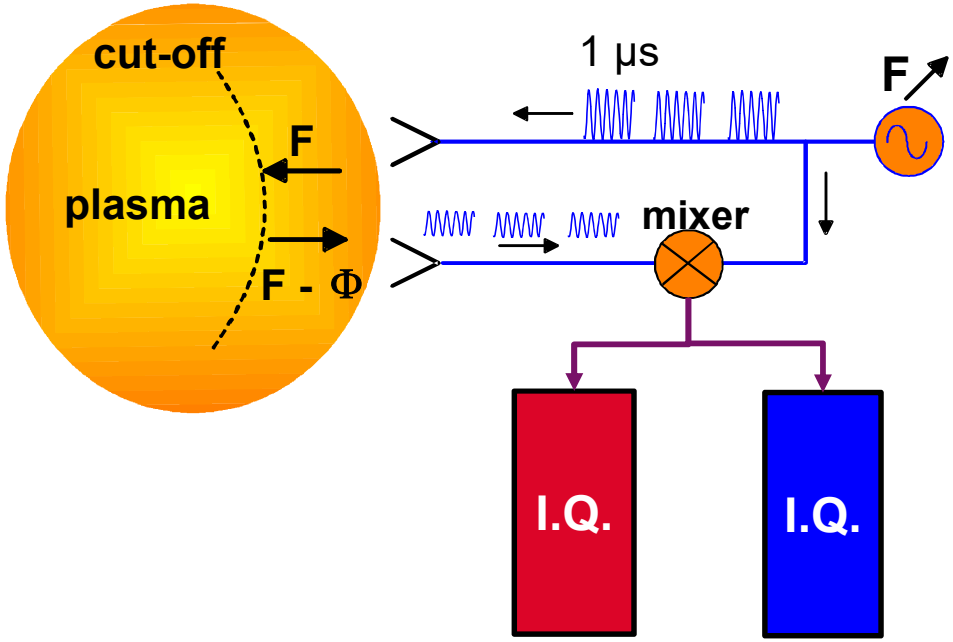
- no F correction
- with dynamic F correction
- with constant F correction

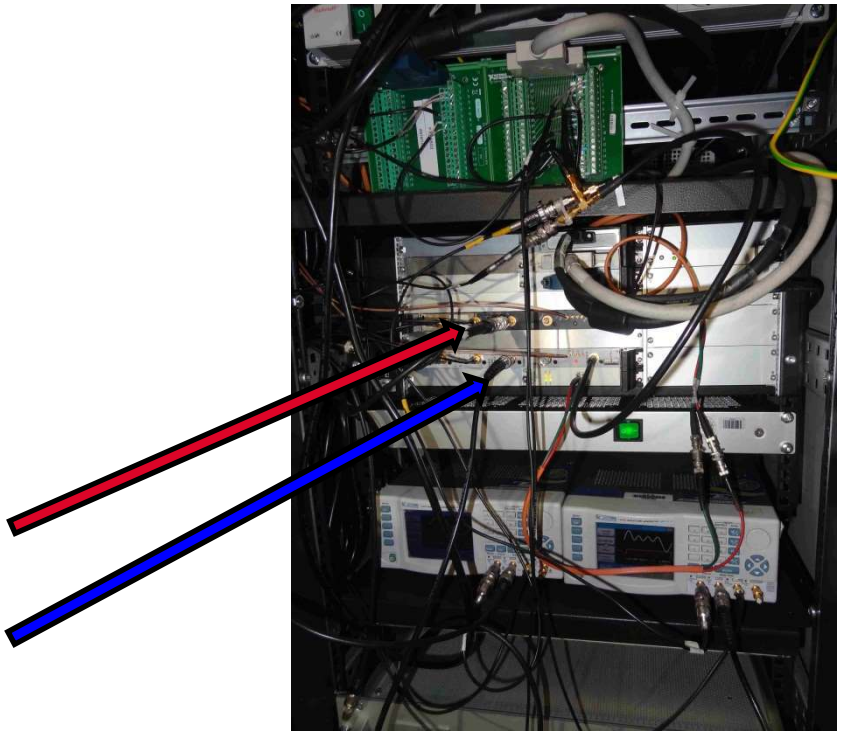
Dual acquisition system

2 acquisition modules (@1 Gs/s) :

256 Mbyte *(20 000 profiles)*

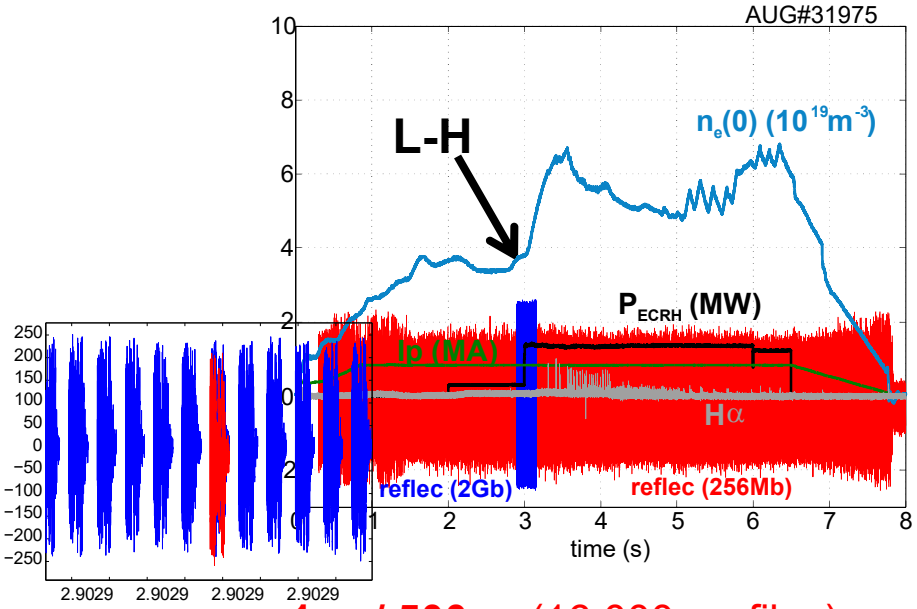
2 Gbyte *(200 000 profiles)*





Possibility to trigger both acquisitions independently at dedicated times

Two acquisition modules for fast and slow measurements



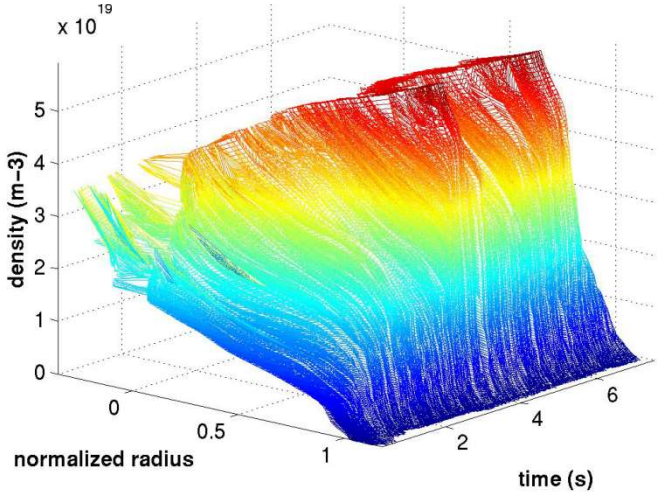
Standard mode

(dead time = 0.5ms ➔ whole discharge)

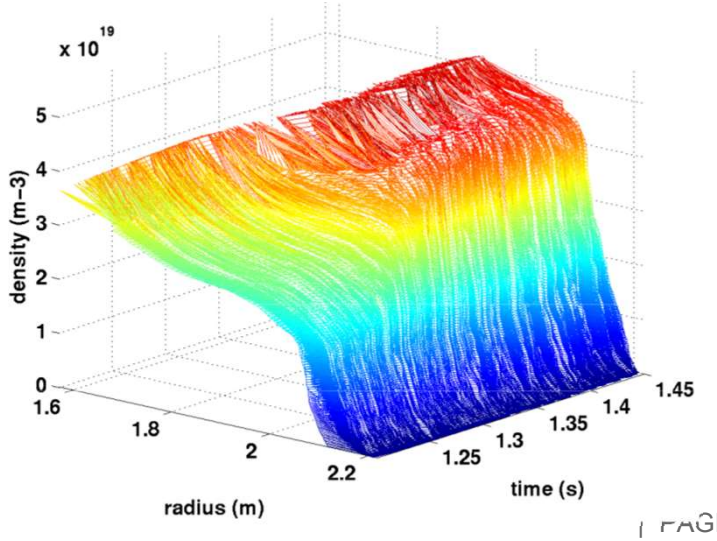
Burst mode

(dead time= 0.25 us ➔ fast events)

1µs / 500us (16 000 profiles)



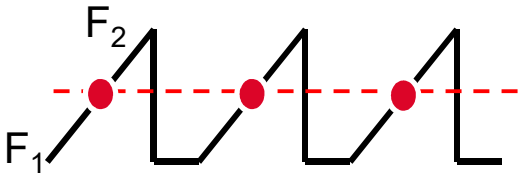
1µs / 0.25us (200 000 profiles – 250 ms)



Fast sweep rate : turbulence measurements

(Medvedeva et al. PPCF 2017 & 2019)

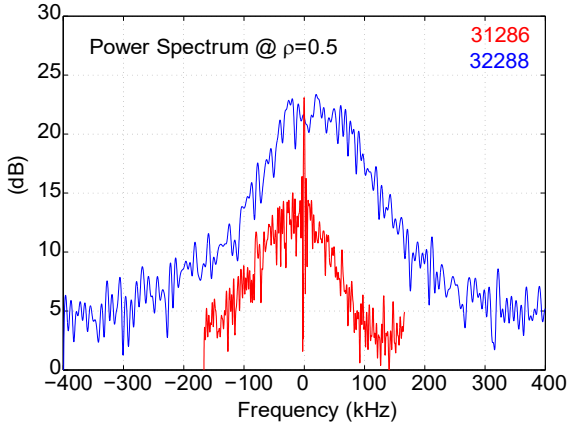
Fixed frequency analysis



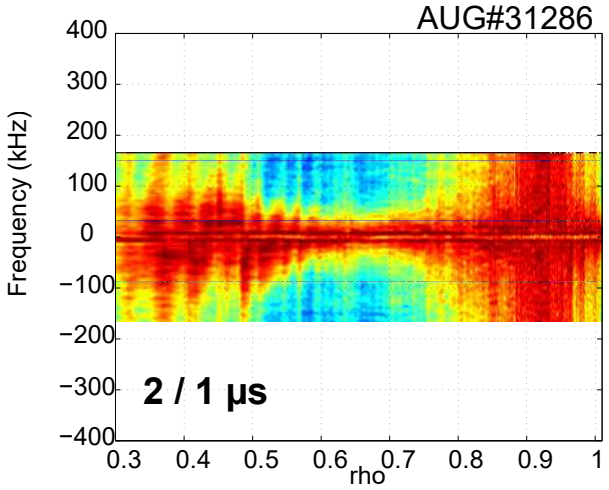
$$\mathrm{FFT}\left(A(t).e^{i\Phi(t)}\right)_F$$

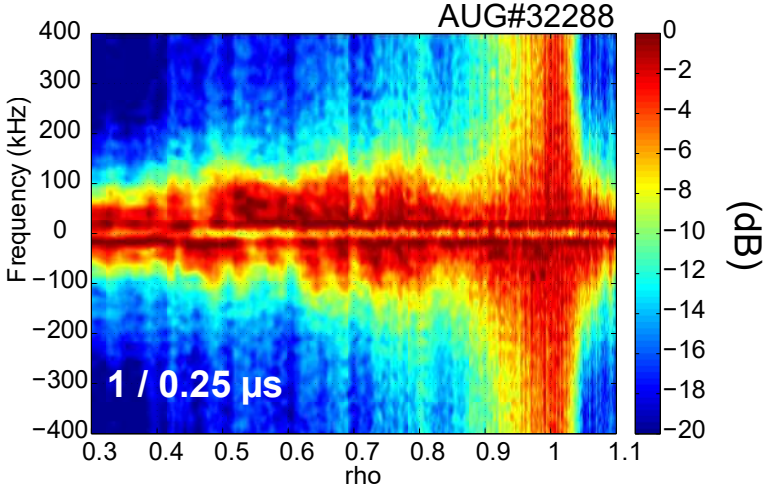
2µs / 1µs : fs = 333 kHz

1µs / 0.25µs : fs = 800 kHz



Extension of the frequency coverage spectra reduces aliasing effects.





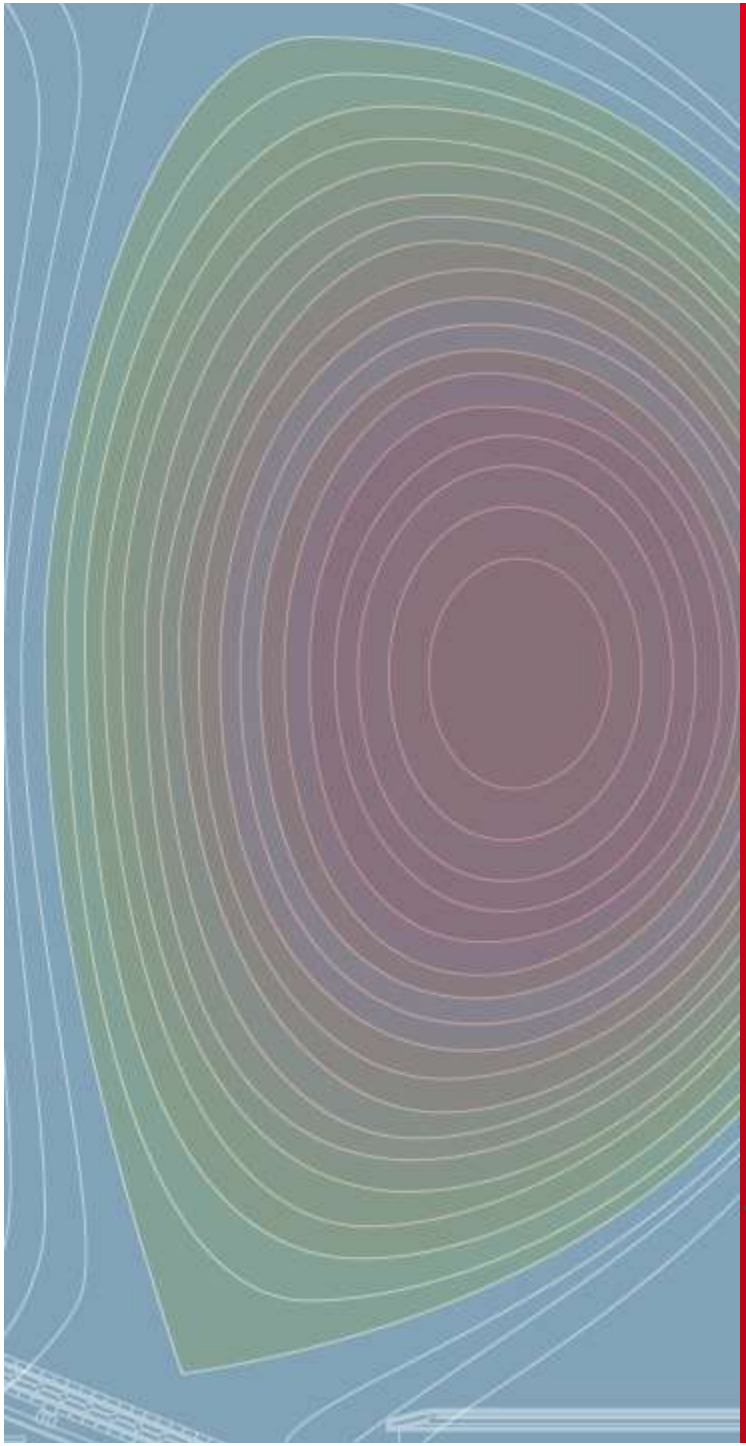
Continuous frequency sweep provides high radial resolution

Conclusion

- **Ultra-fast frequency sweeps 1µs achieved.**
- **Dynamic frequency corrections simply to performed.**
- **2 acquisition modules provide versatile physic** ***(if you're rich enough…).***
- **Continuous sweeps provide high radial resolution for turbulence.**
- **Fast repetition rate (800 kHz) compete with fixed frequency systems**
  (but doesn't achieve equivalent S/N)

THANK YOU

Questions ?



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