Reflectometry diagnostics in TCV

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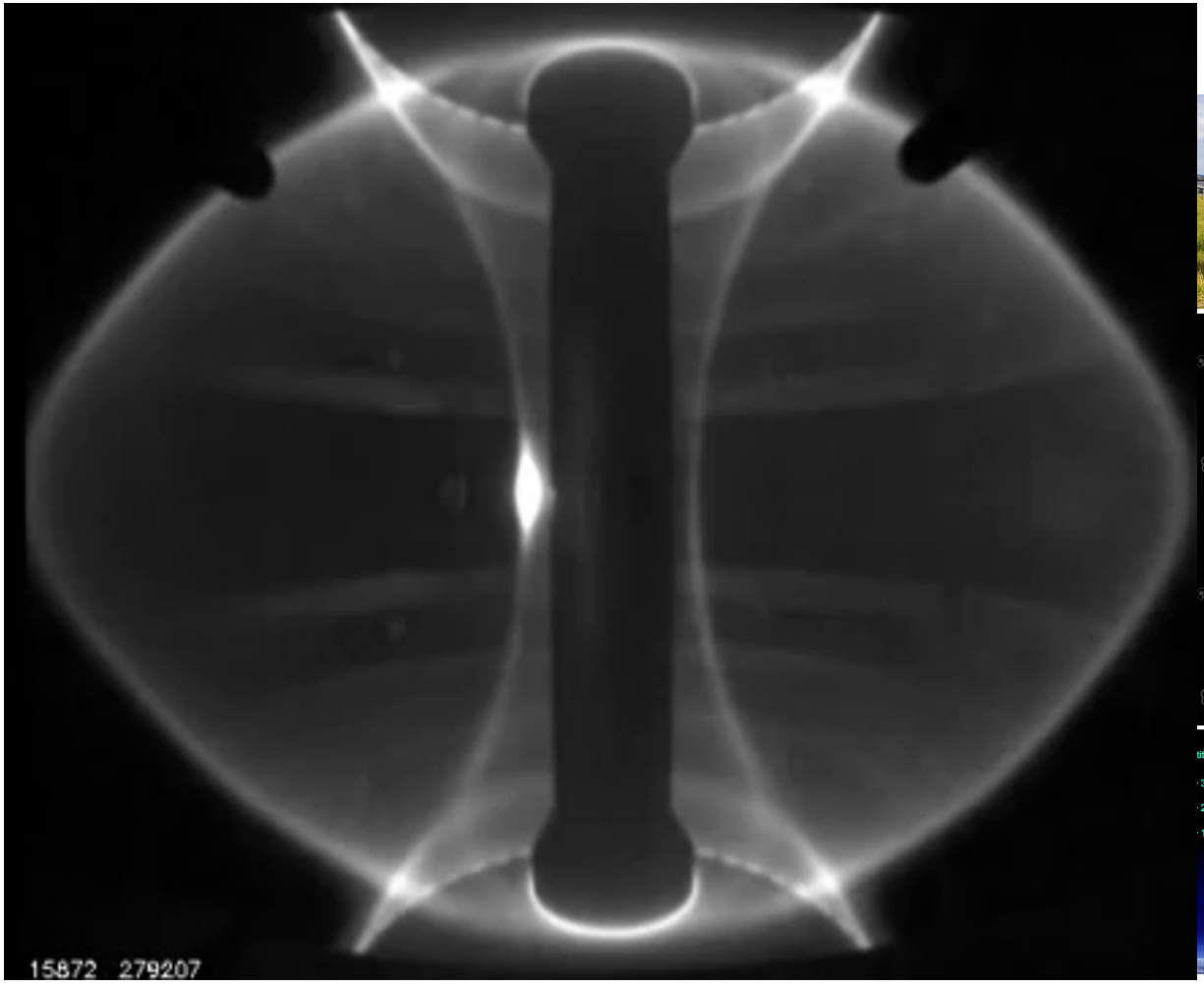
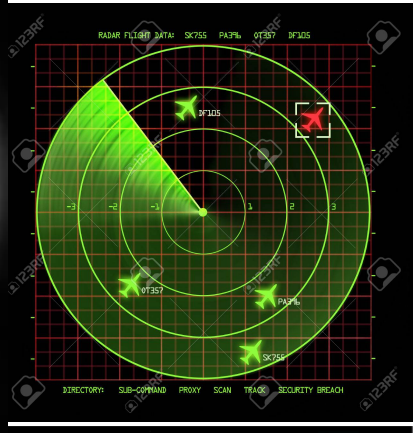
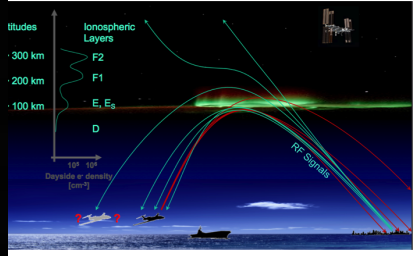
Ph.D. event Nov 7-9th 2018

Fast events need faster sensors

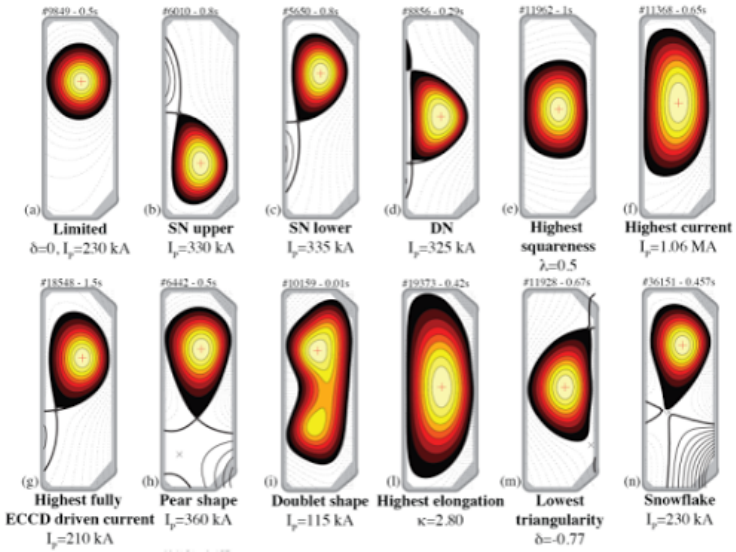






TCV tokamak at Swiss Plasma Centre

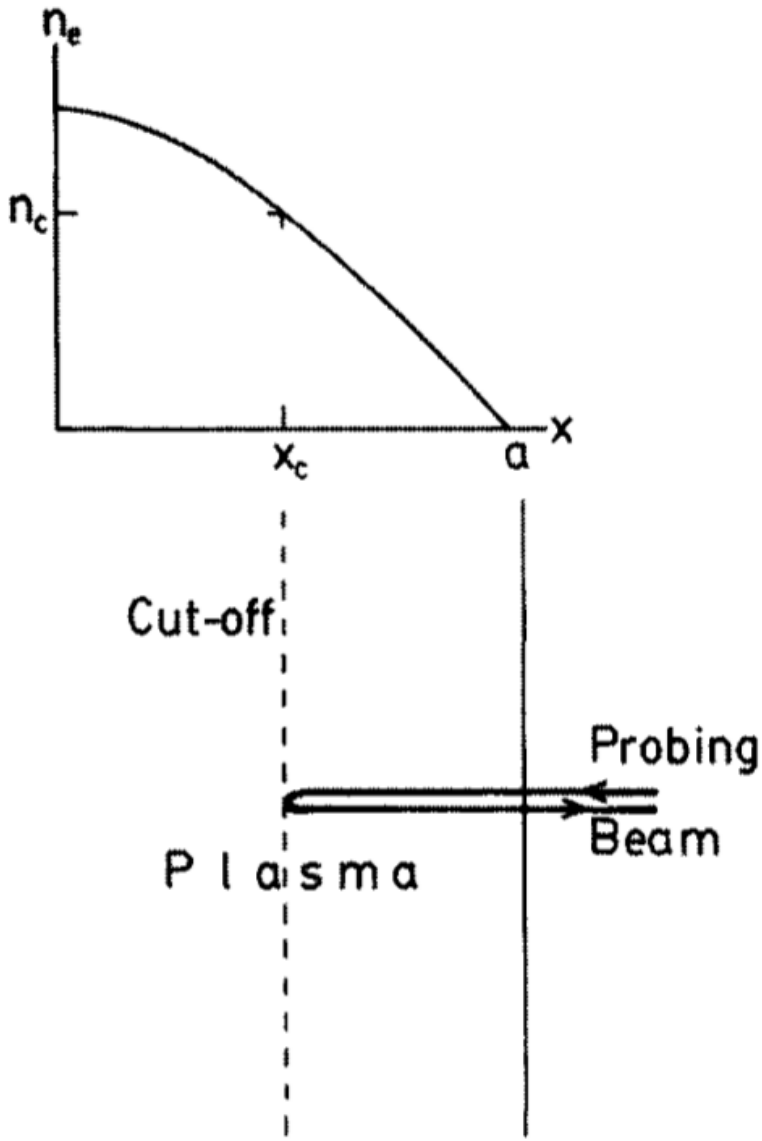
- TCV: Tokamak à Configuration Variable
- Ip $<$ 1MA
- $B_{Tor} < 1.54T$
- R/a: 0.88/0.25
- Shape: κ <2.8, -0.6< δ <0.9
- Electron heating: 4MW
- Neutral-beam heating: 1MW
- Carbon walls
- Open divertor



TCV edge diagnostics

Name	Parameter	dR [cm]	Span [ψ]	dt
TS	T_e, n_e	1.5/0.3	0-1	16 ms
CXRS	$v_\perp$, $v_\parallel$	1	v_ϕ 0-1 v_θ 0.4-1	60-90 ms
FRP	T_e, n_e, ϕ_p, v_{id}	0.2	> 1(SOL)	50-2μs
SXR	$T_e > 1$keV	2.5	0-1*	10 μs
(C)ECE	T_e, δT_e (k_ρ)	2	0-1*	100-1μs
TPCI	δn_e (k_ρ)	0.25	0-1*	100-0.6μs
REF	n_e, $\delta n_e(k_\rho)$	f(λ) 4-8 mm	0**-1	$<$2 μs
DBS	$\lvert\delta n_e\rvert$ ($k_\perp$), S($k_\perp$), $v_\perp$	f(λ) 4-8 mm	0**-1	$<$1 ms

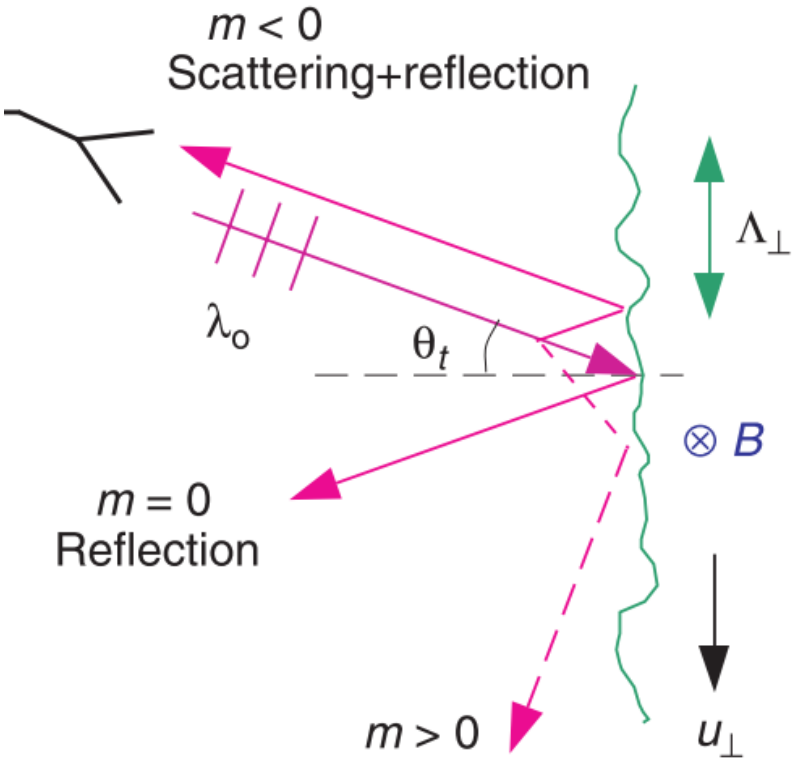
Reflectometry? Reflect from cut-offs

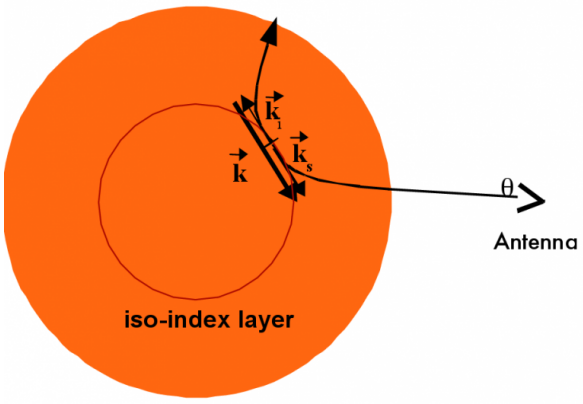


Bounce waves from cut-off: $N^2=0$
$\vec{k} \perp \vec{B}_o \rightarrow$ two solutions

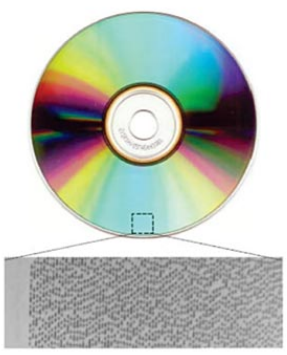
- O mode $\vec{E}_1 \parallel \vec{B}_o$ $N^2=0$ at $\omega_{pe}^2 = \frac{n_e e^2}{\epsilon_o m_e}$
  - f(n_e)
- X mode $\vec{E}_1 \perp \vec{B}_o$ $N^2=0$ at $\omega_{R,L} \approx \frac{1}{2}\sqrt{\Omega_e^2 + 4\omega_{pe}^2} \pm \Omega_e$
  - f(n_e, B)

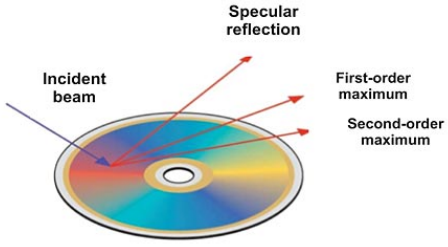
Doppler backscattering principles

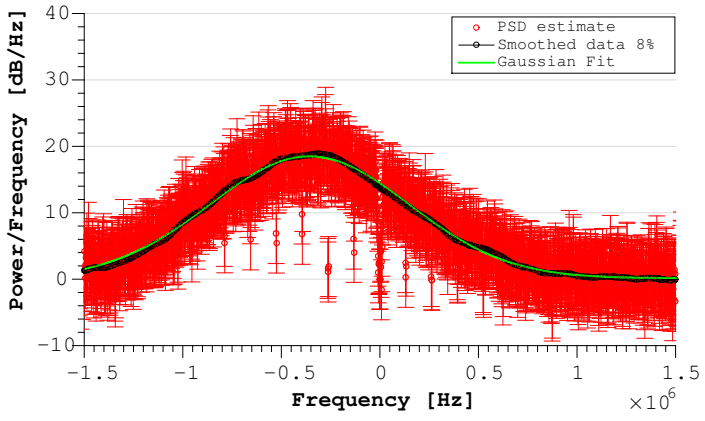




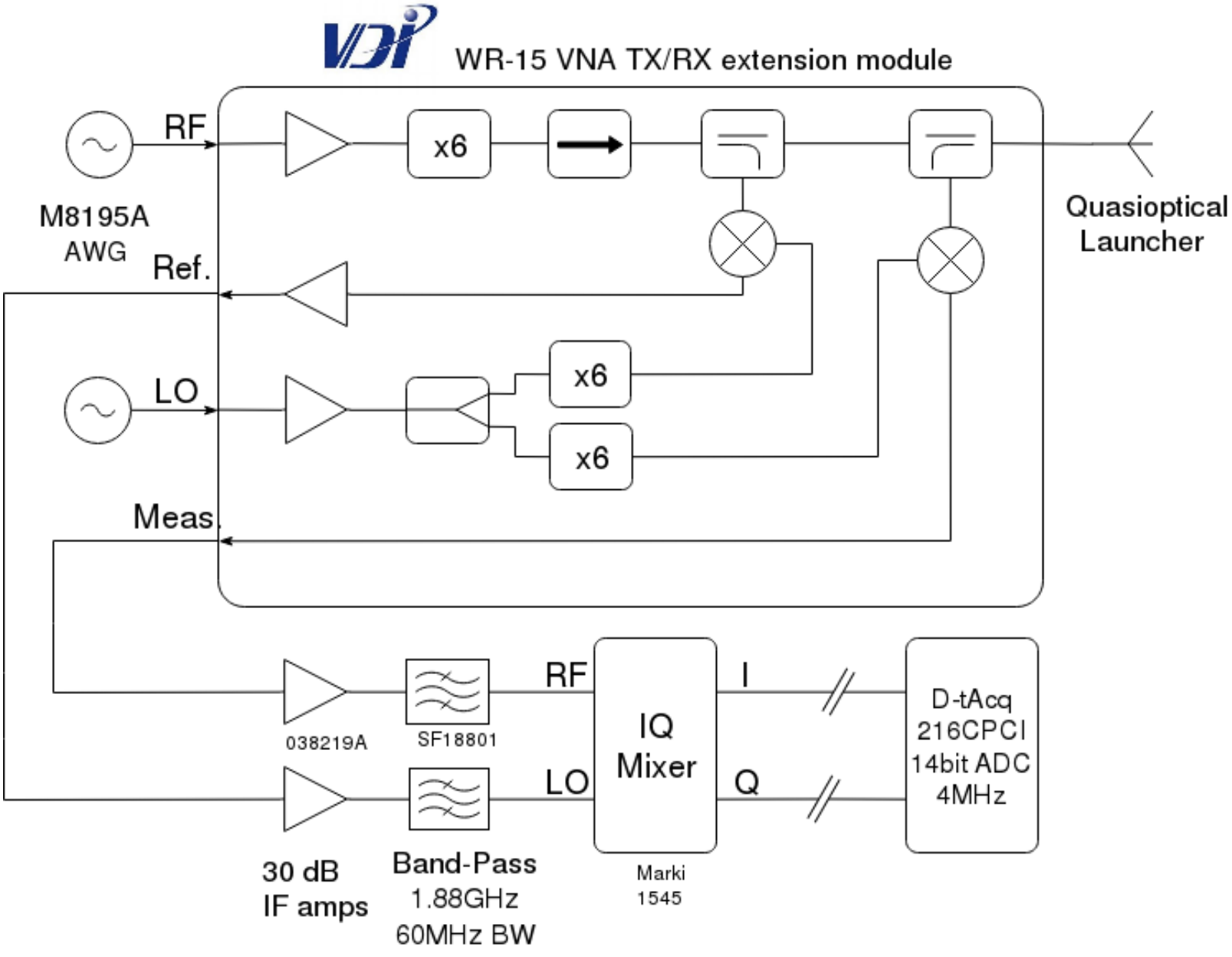
- Bragg condition:
  $\mathbf{k} = -2\mathbf{k}_i$
  $k = 2k_o \sin(\theta_t)$
- Doppler shift $\rightarrow u_\perp(f(r))$



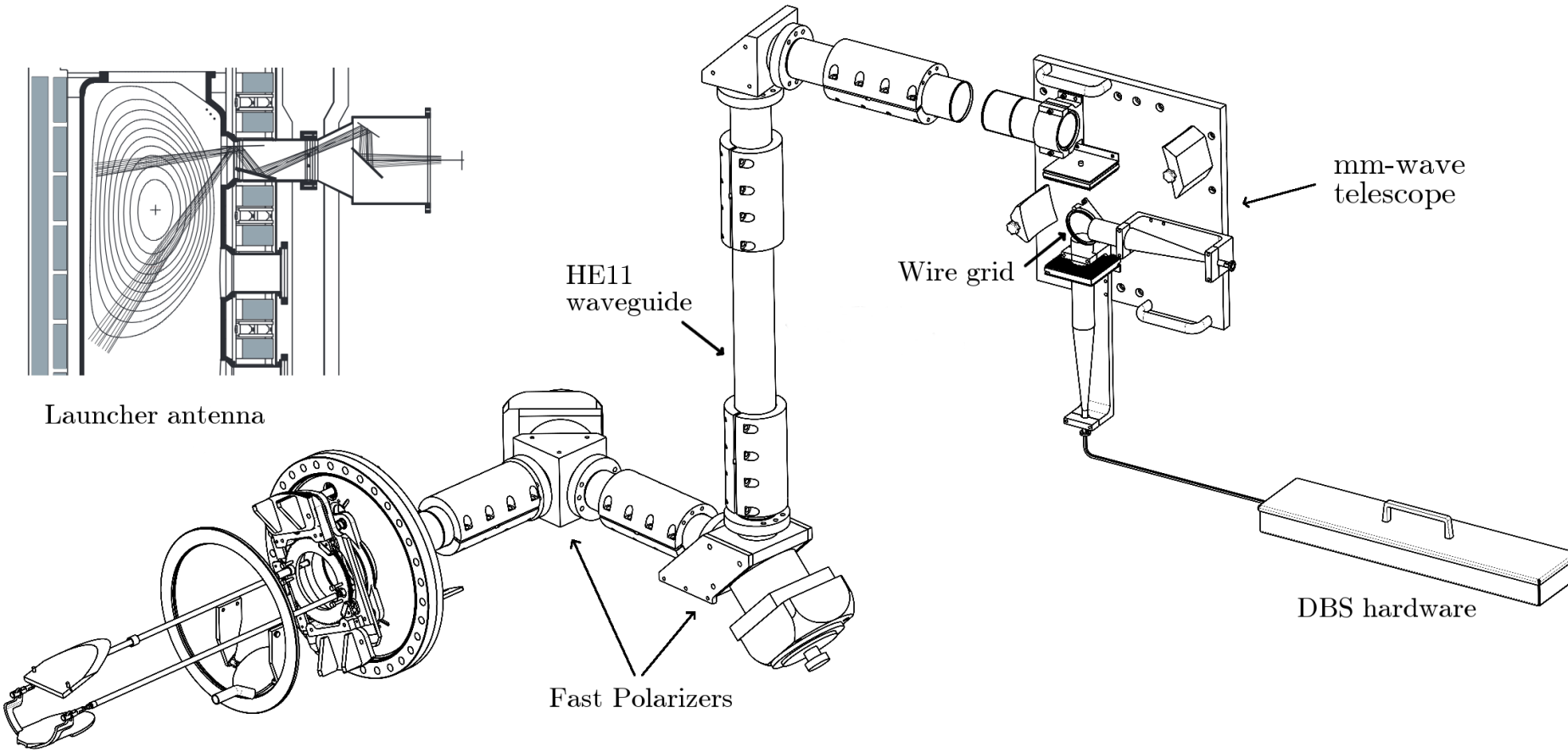




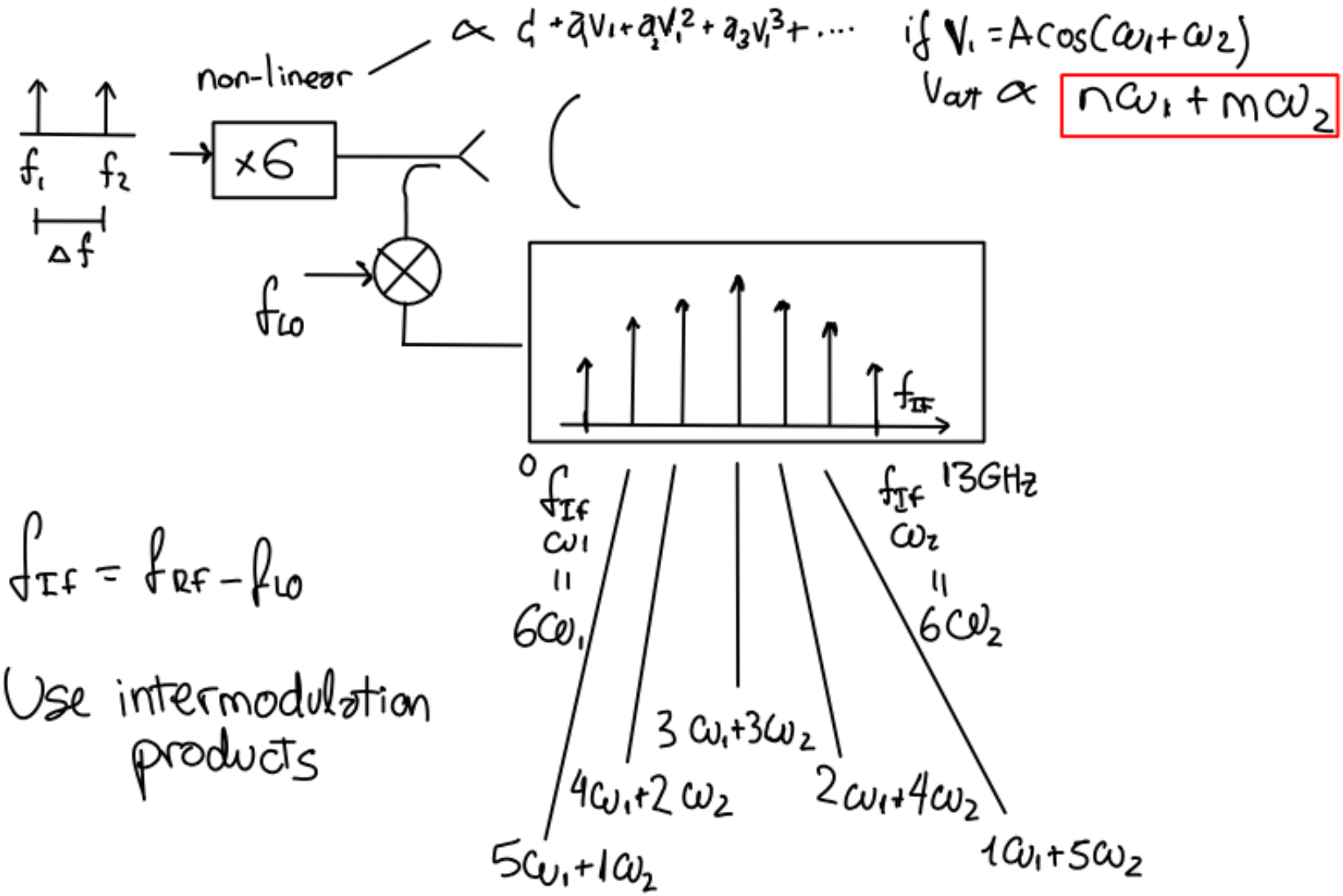
TCV's DBS hardware



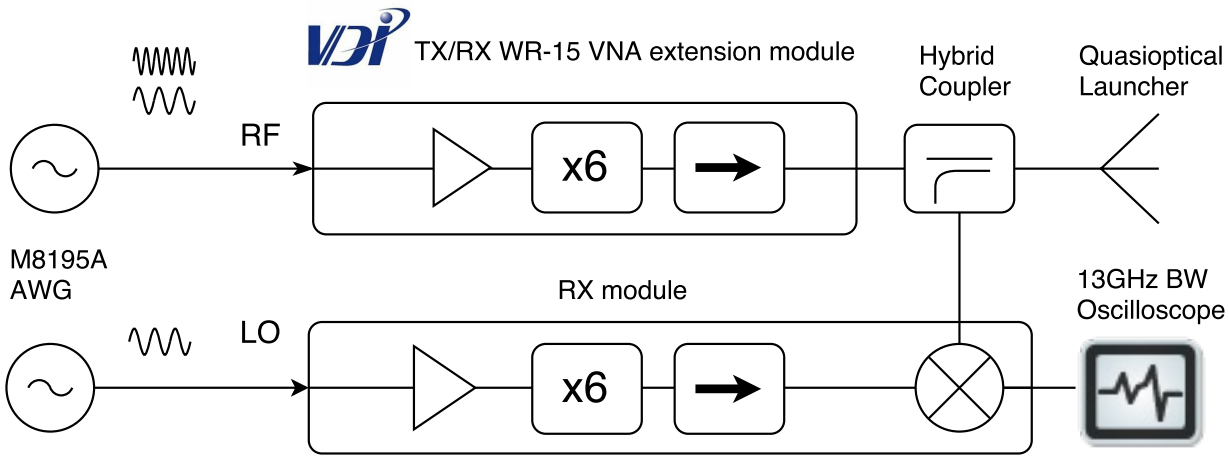
Antenna: quasi-optical diagnostic launcher

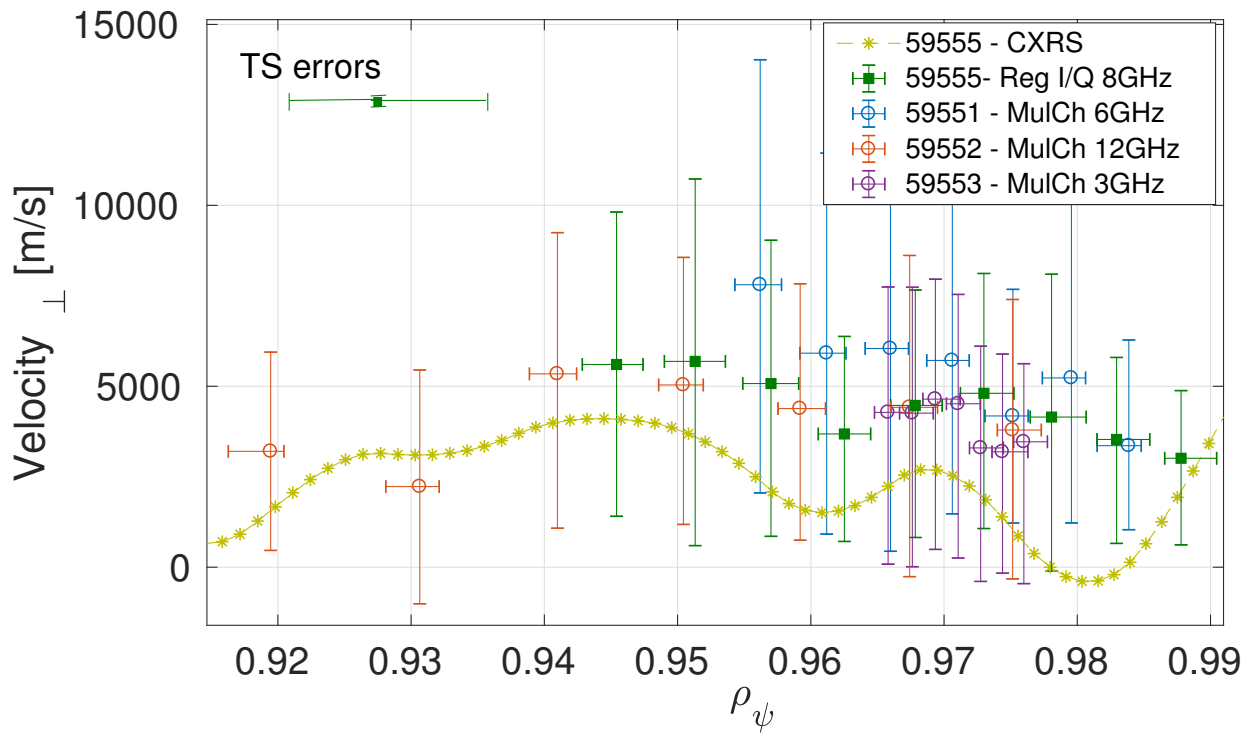


Sample multiple points at once: multifrequency DBS

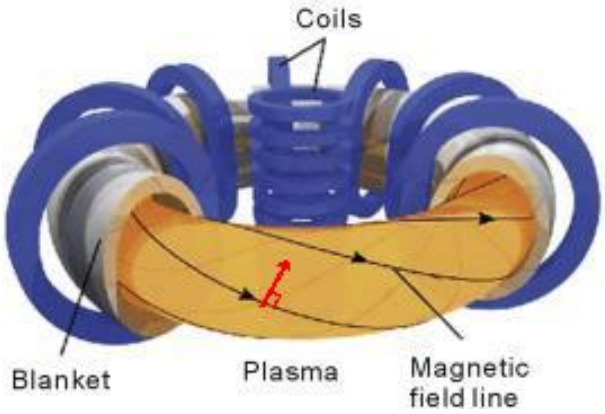


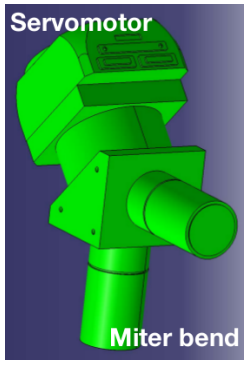
New approach to multi-freq DBS

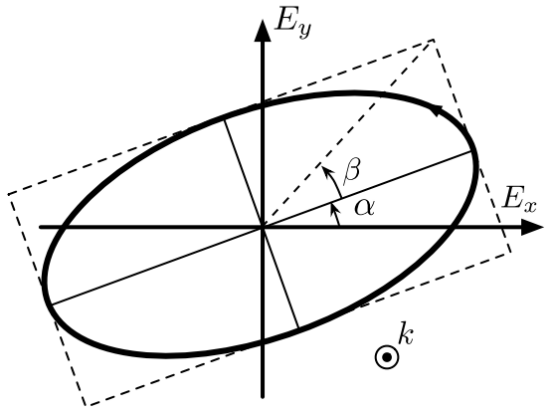


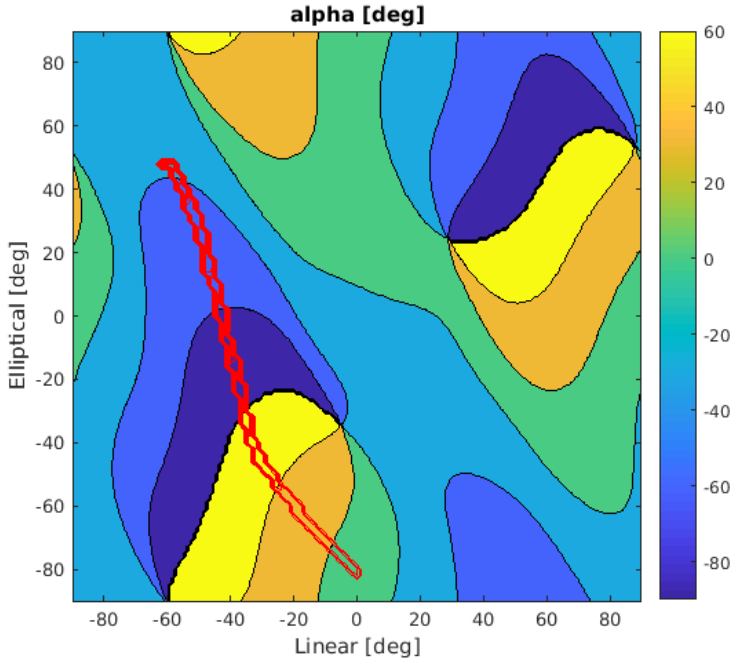


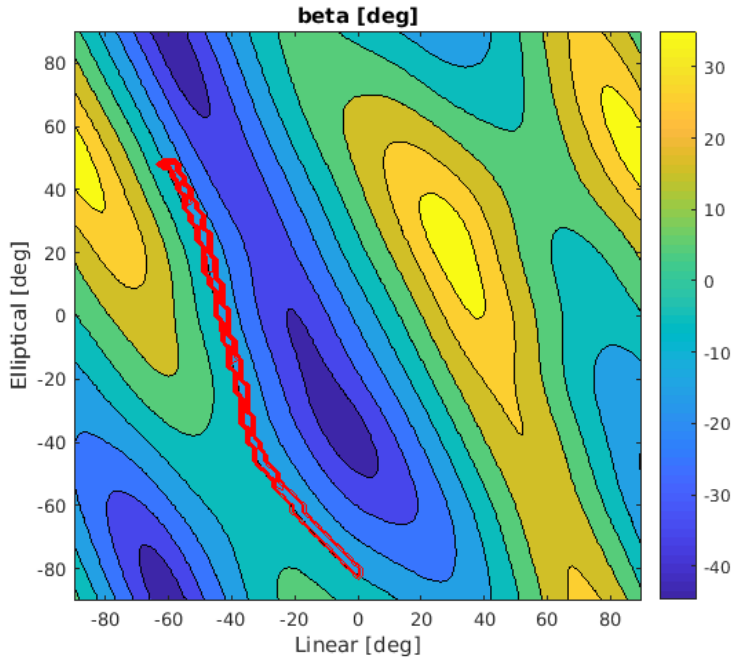
In-shot polarization rotation



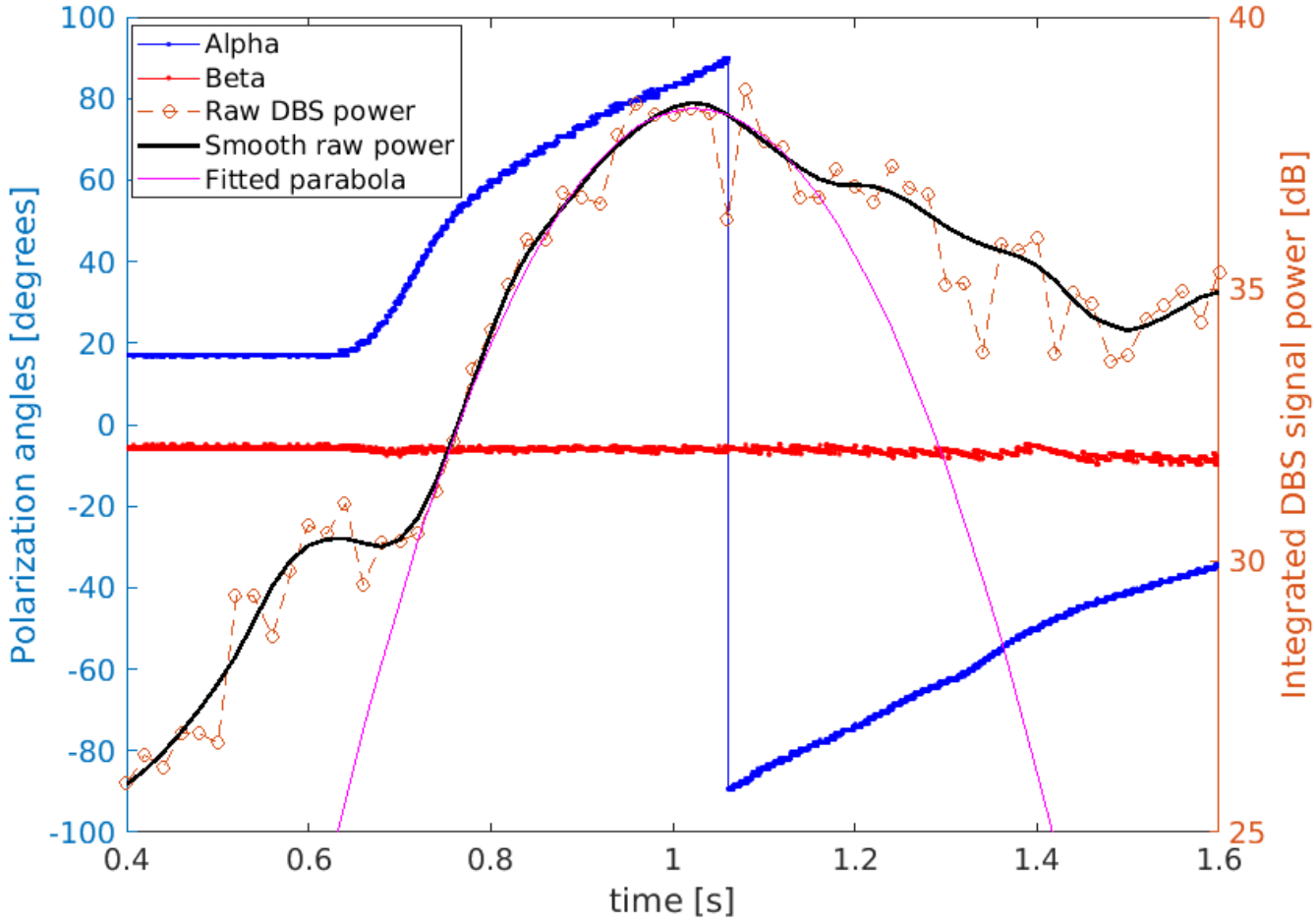






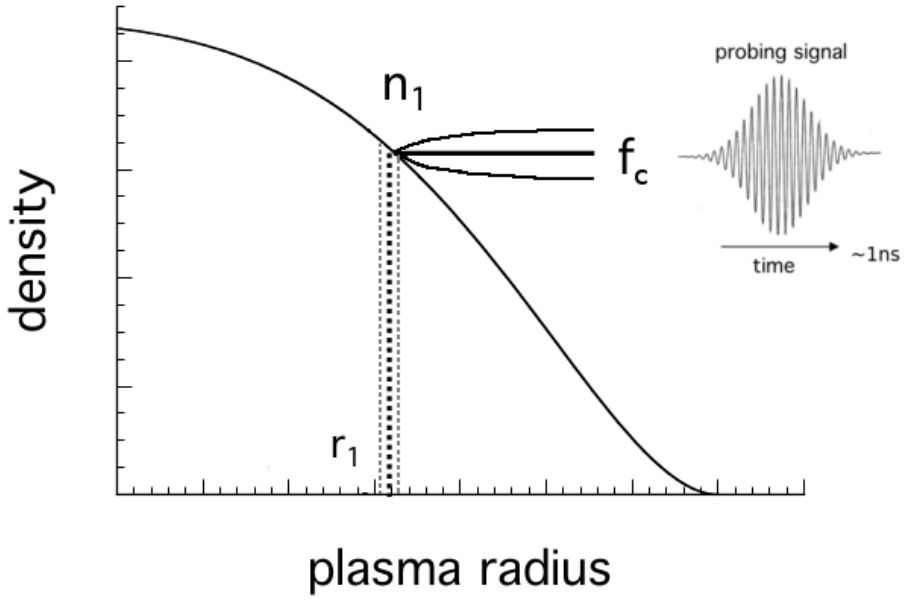


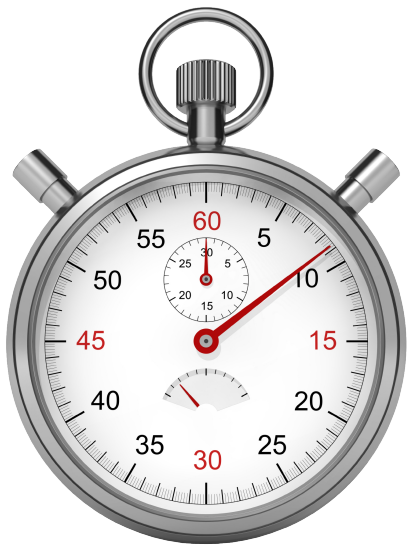
B-field line pitch measurement: optimum coupling X-mode



Expected 81.7$\pm$0.4^o. Peak coupling at 1.02$\pm$0.01[s] where $\alpha = 84.5\pm3^o$.

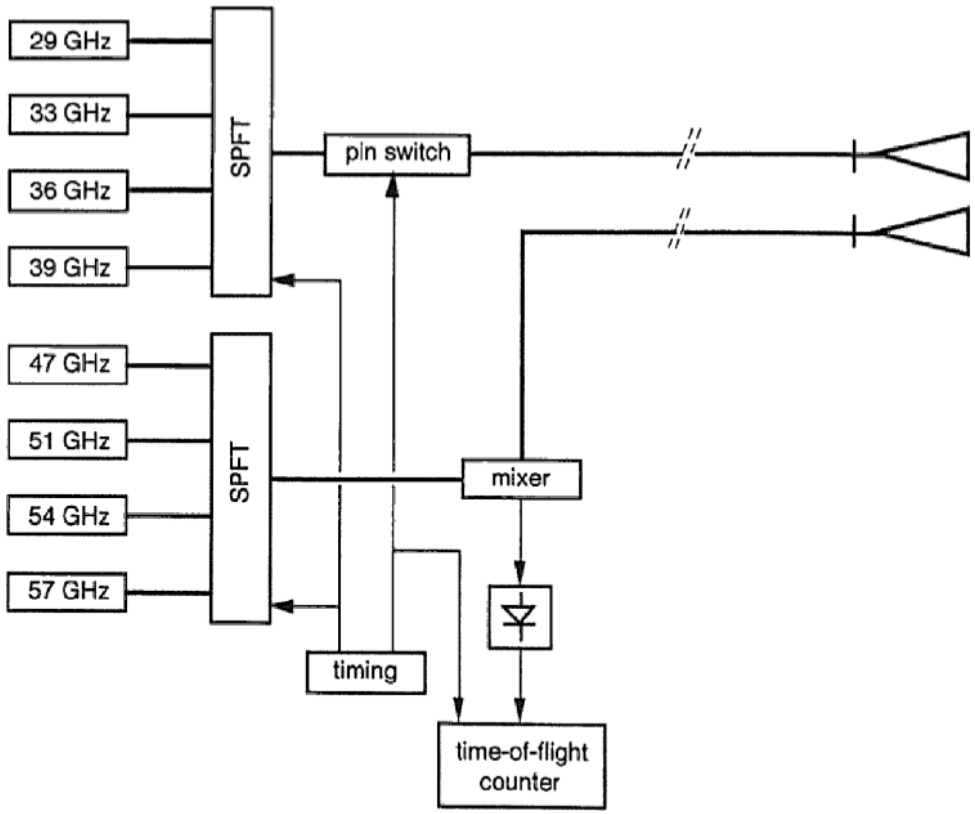
Short pulse reflectometry - $n_e(\rho)$

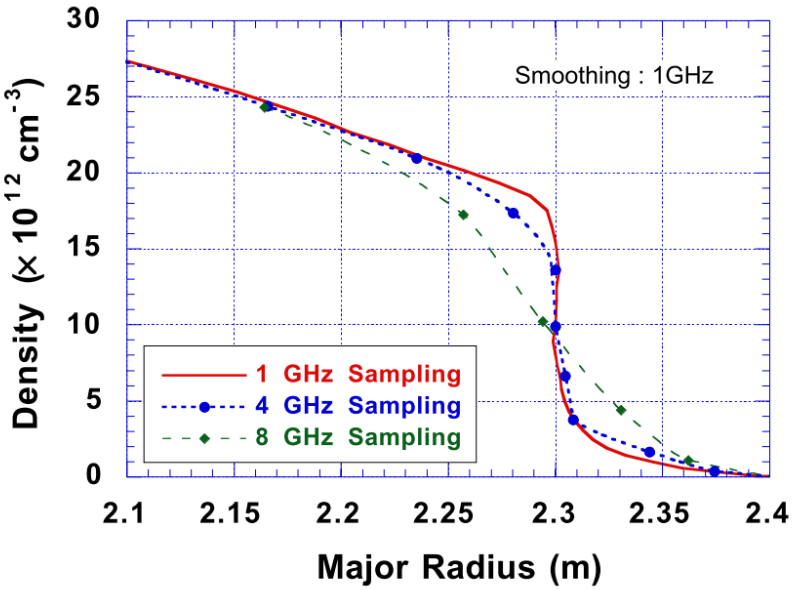




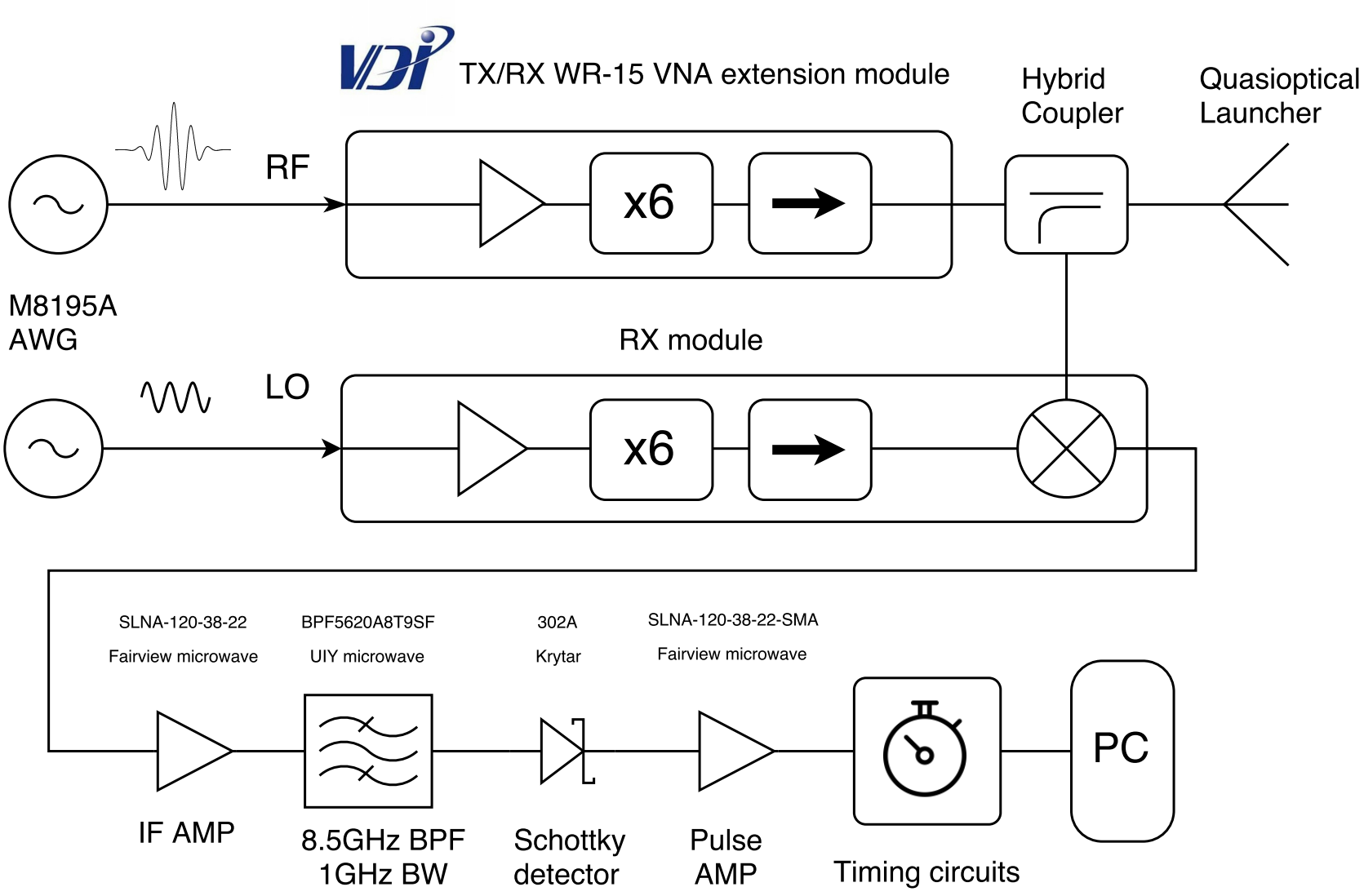
- Pulse time of flight $\tau_g = d\phi/d\omega$
- $\tau_g(f) \rightarrow$ Abel inversion $\rightarrow n(r)$
- 2.5mm error $\rightarrow$ **17ps**
- CWFM 1.25μs/profile $\rightarrow$ 16MHz

Traditional short-pulse REF



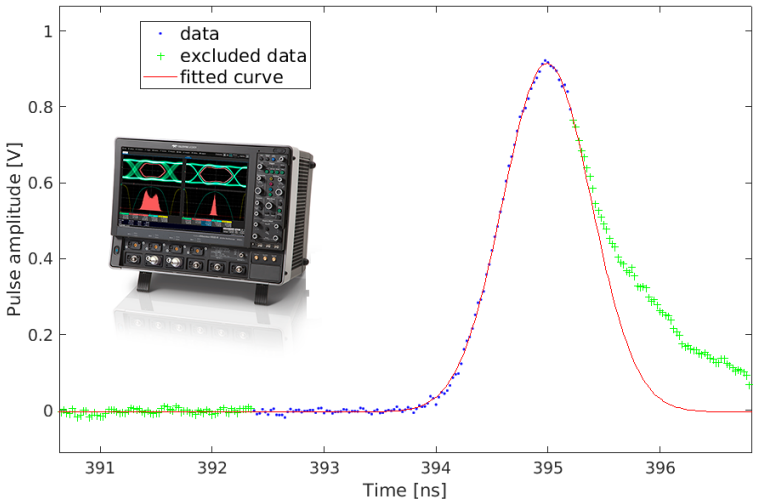


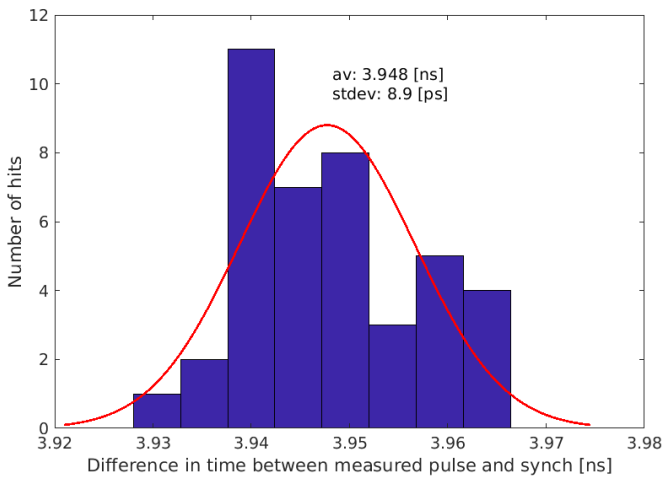
SPR Hardware Set-up



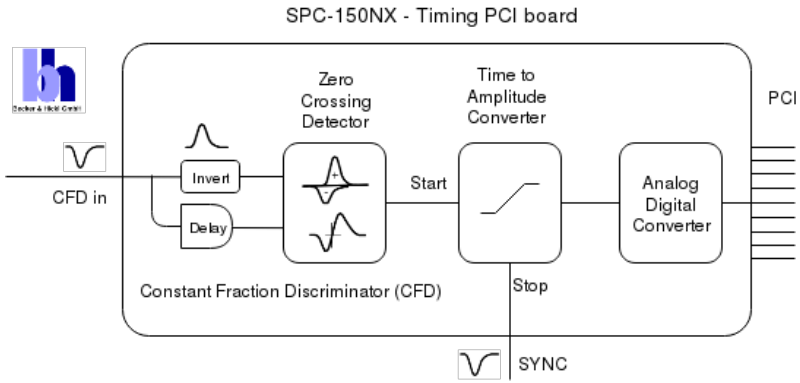
Timing circuit approaches

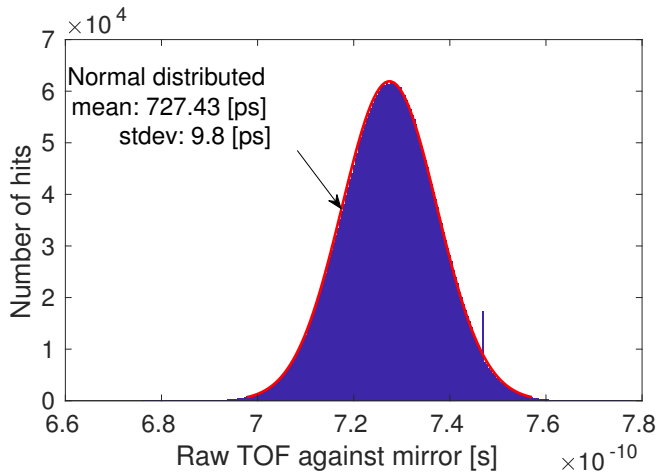
Direct Sampling



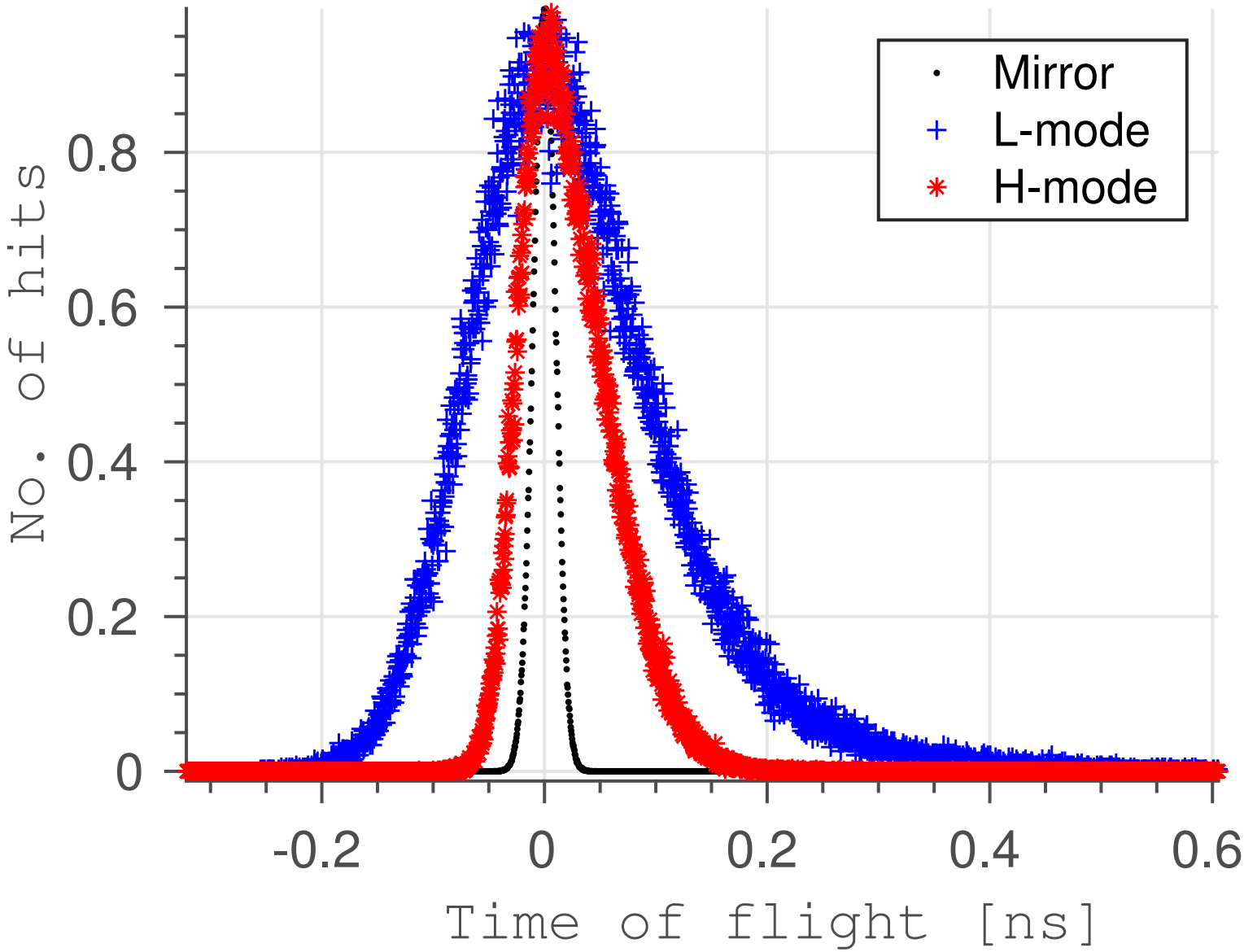


Analog CFD+TAC

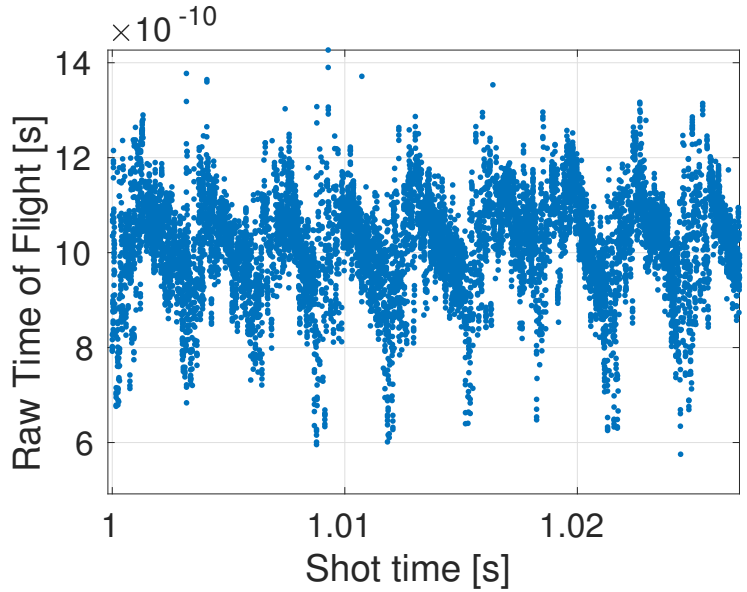


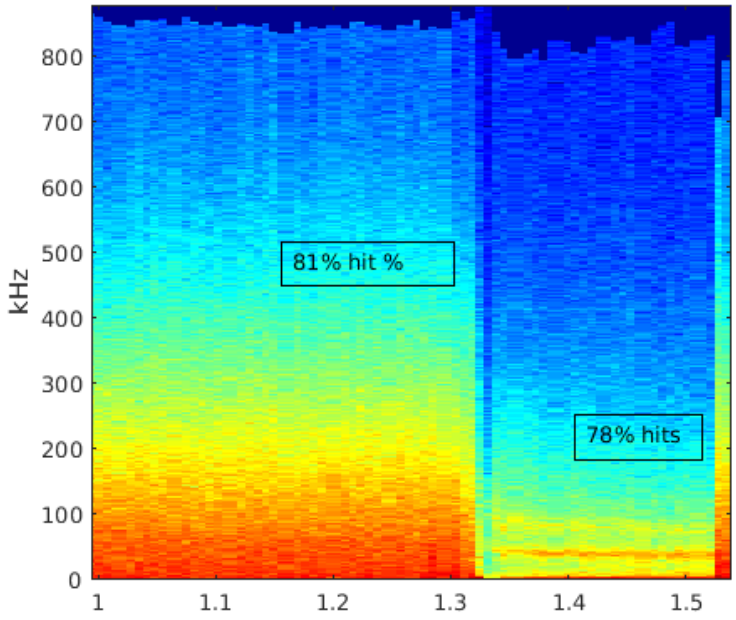


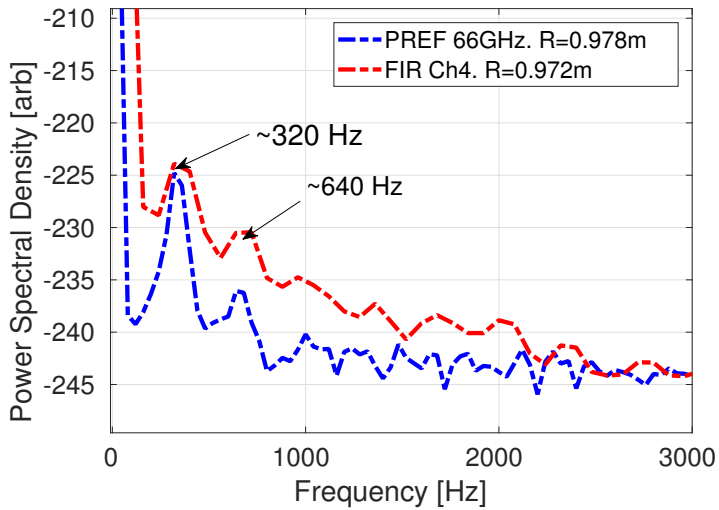
Raw group-delay histograms

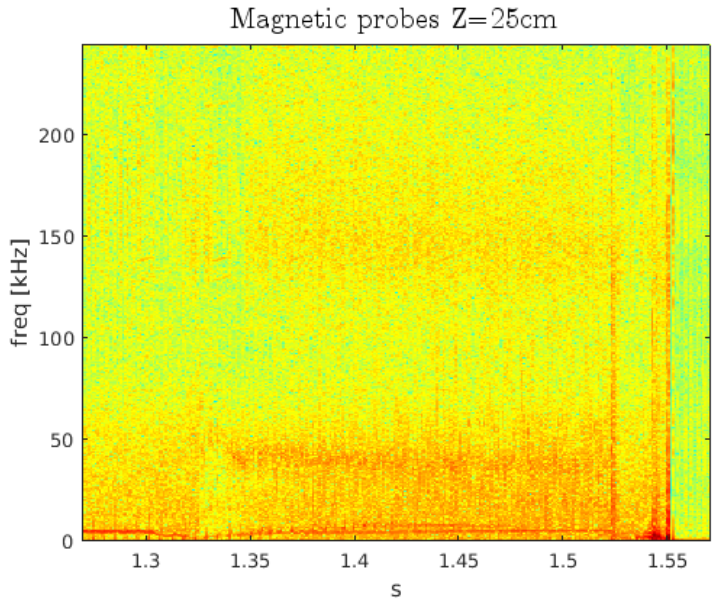


Density fluctuations: sawteeth and quasi-coherent modes

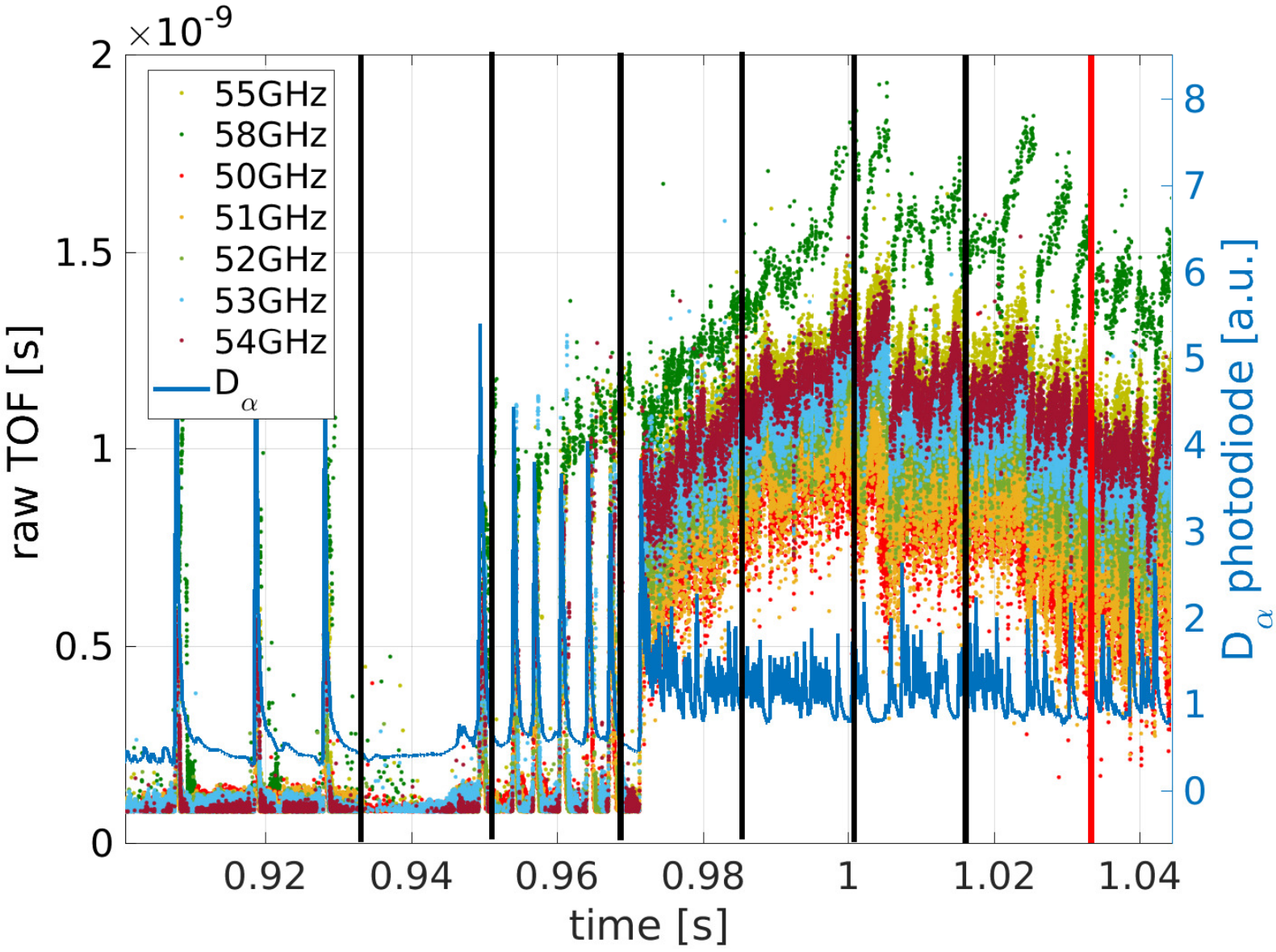




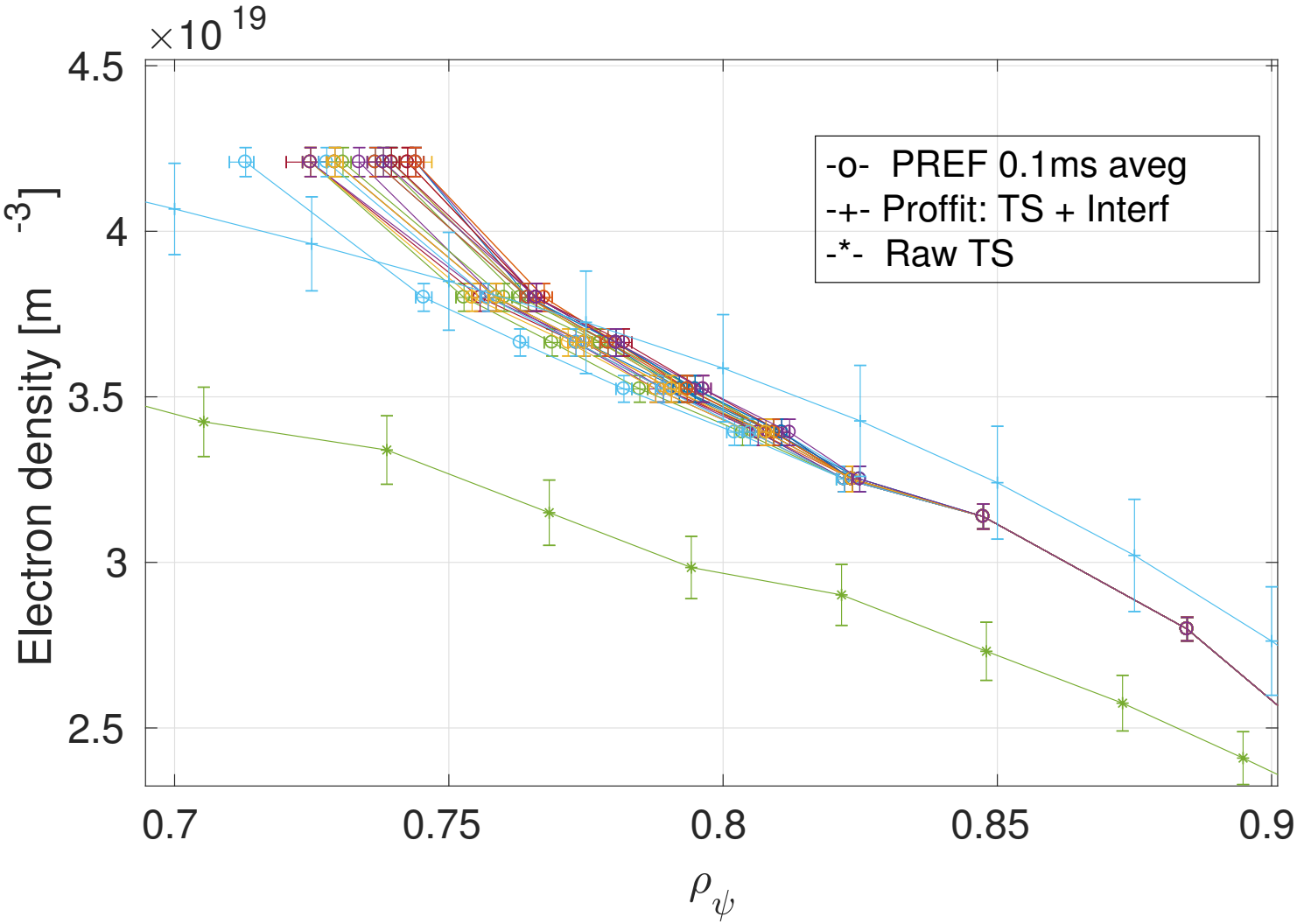




Density profiles: $\times 1000$ more data!



Current status: validate average profiles



Future: L-H transition and ELM dynamics