Application of a simple recirculation model to first 12 GHz PETS tests with beam

Assumptions and validity

CLIC RF meeting

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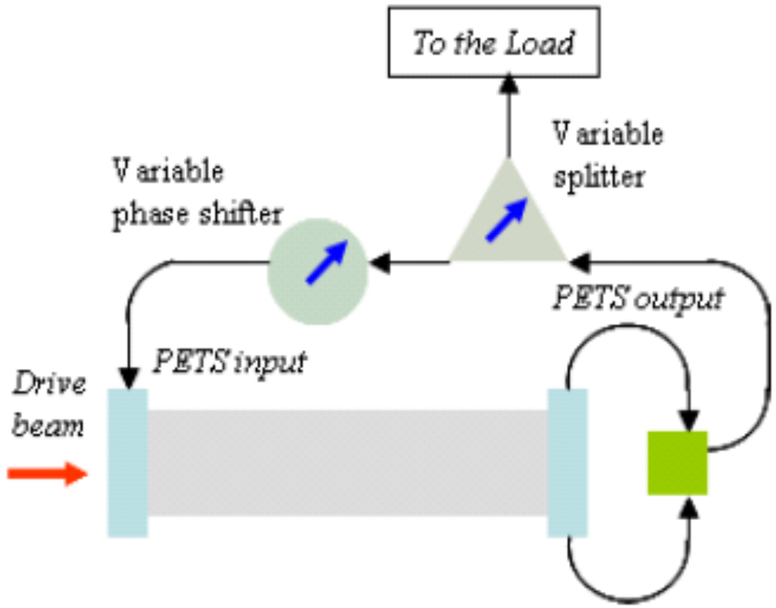
Outline

- MODEL
- MEASUREMENT
- FIT
- REALITY CHECK
- APPLICATION TO NORMAL PULSES SERIES
- APPLICATION TO SHORTENED PULSES SERIES
- ATTEMPT TO PHASE-FIT SHORTENED PULSES

Simple model of recirculation

In an attemt to the recirculated power and predict the power for a given current we assume the following simple field model :



$$E_{n+1} = \lambda E_n + E_0$$

$$\Downarrow$$

$$E_{n+1} - E_n = (\lambda - 1)E_n + E_0$$

$$\Downarrow$$

$$\frac{E_{n+1} - E_n}{\Delta t} = \frac{(\lambda - 1)}{\Delta t}E_n + \frac{1}{\Delta t}E_0$$

r : the ratio of the field being recirculated

η : estimated ohmic losses around the circulation

φ : the field phase change after one recirculation

λ = r × η × exp(jφ) : field reduction factor after one recirculation

Simple model: predictions

Approx as differential eq, with solution (for initial condition $E(0) = 0$):

$$E(t) = \frac{E_0}{1-\lambda}(1 - \exp(-(1-\lambda)t/\Delta t)) = A(1 - e^{-t/\tau})$$

thus

$$E(t) = A(1 - e^{-t/\tau})$$

with

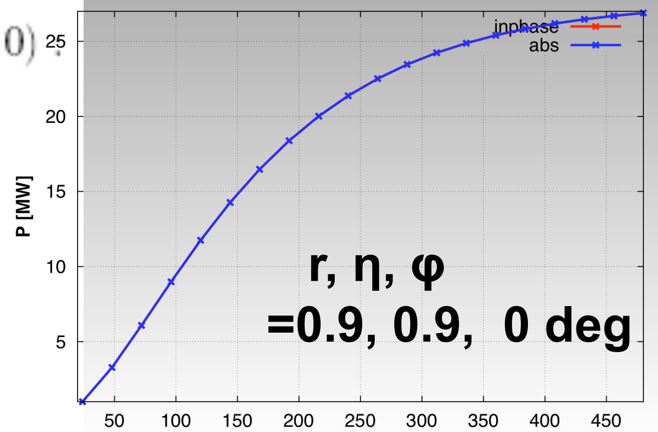
$$\lambda = r \times \eta_{ohm} \times \quad e^{j\theta}$$

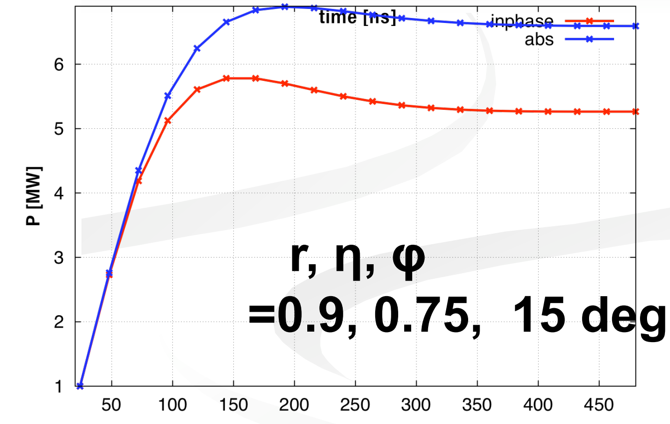
$$A = \frac{E_0}{1-\lambda}$$

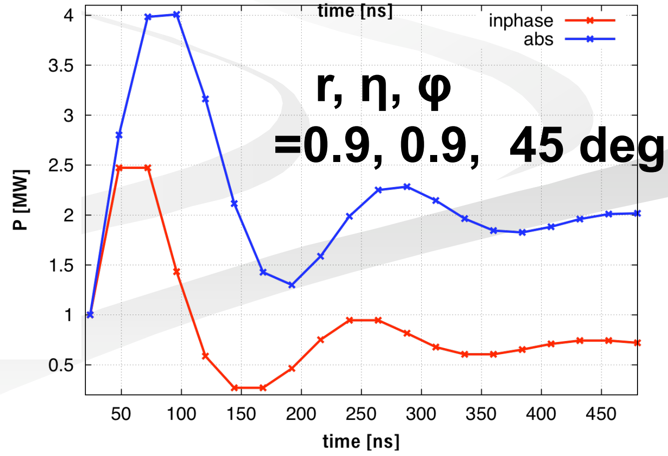
$$\tau = \frac{t_{recirc}}{(1-\lambda)}$$

$$P \propto E^2$$

complex solution:
real(E) : works on beam
abs(E)^2 α measured P







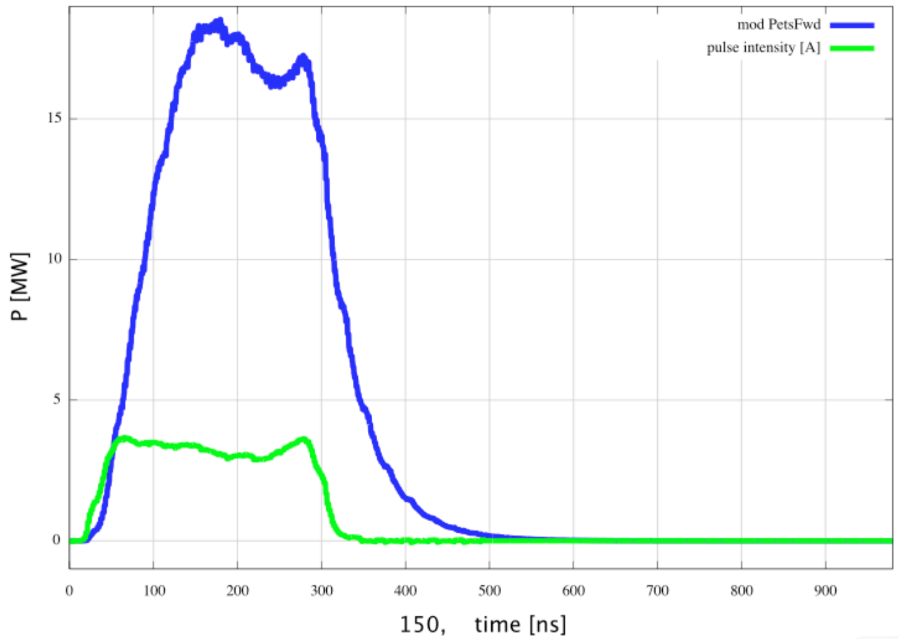
Recirculation reconstruction with beam pus

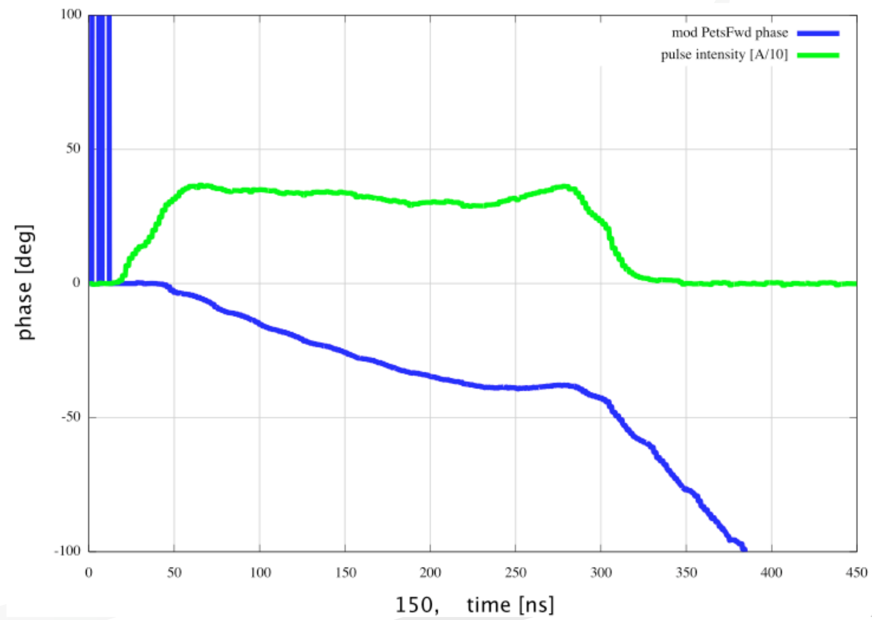
$$E_{out,n} = c\bar{I}_n$$

$$E_{out,n} = c\bar{I}_n + c\lambda\bar{I}_{n-a} \qquad \lambda = A\exp(j\phi) \qquad a = t_{circ} f_{BPM}$$

$$E_{out,n} = c\sum_{m=0}^{M}\lambda^m \bar{I}_{n-am}$$

3 parameter model:
c, A, phi





P,n=const (E_out,n)^2 **theta,n= arctan(Im(E_out,n) / Re(E_out.n))**

CODE

- The computer algorithm becomes very simple

```
for m=0:n_recirculations,
  recirced_field = [zeros(1,round(n_recirc_step*m))   (lambda^m)*I_beam(1,:)];
  E_mod_total = postpad(E_mod_total, length(recirced_field),0,2);
  E_mod_total += recirced_field;
end
```

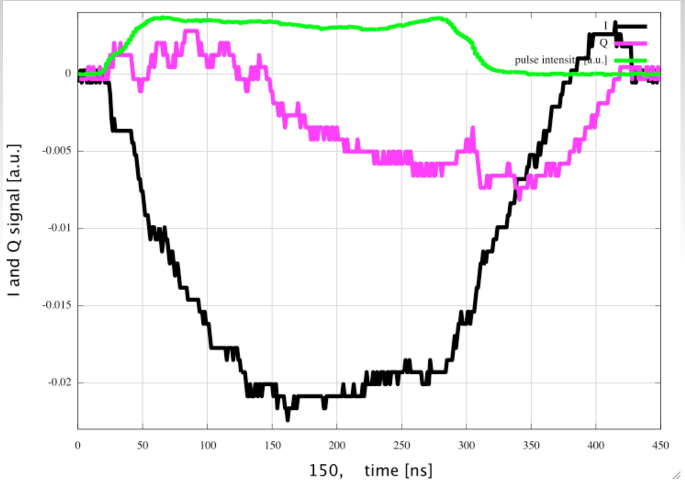
RF MEASUREMENTS

- Diode (calibrated at time of run)
  - less noise than IQ signal
- I and Q channel, field measurements with pi/2 relative phase (calibration not known at time of run)
  - However: with IQ both RF power and phase can be reconstructed, so we use IQ for fit
  - Diode is used to compare absolute values of model and measurements

Power and phase from RF signals

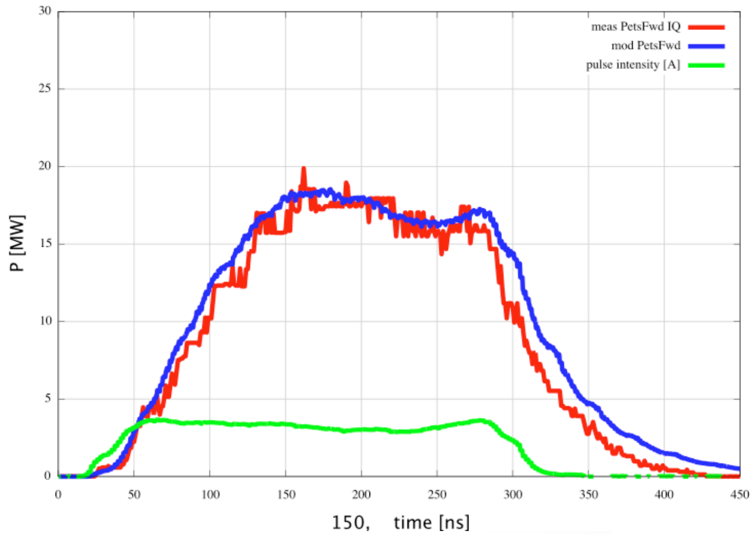
Using I and Q channel :

Needed timing adjustment (IQ to pulse) "~10 ns scale"
- *same shift* for most bunches (some timing jitter)

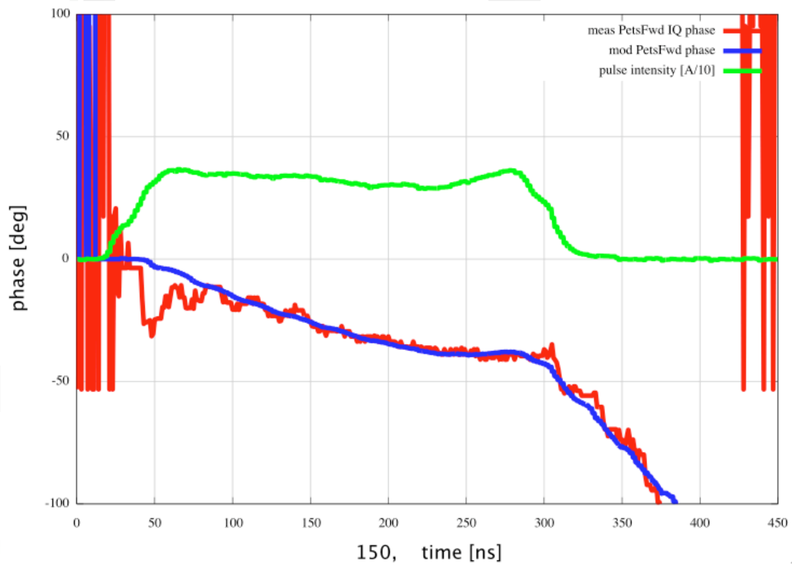


Needed phase adjustment "~10 ps scale"
-*variable shift* for bunches required1

P_meas = const (I^2 + Q^2)



theta_meas = arctan(I / Q)



ROBUST FIT?

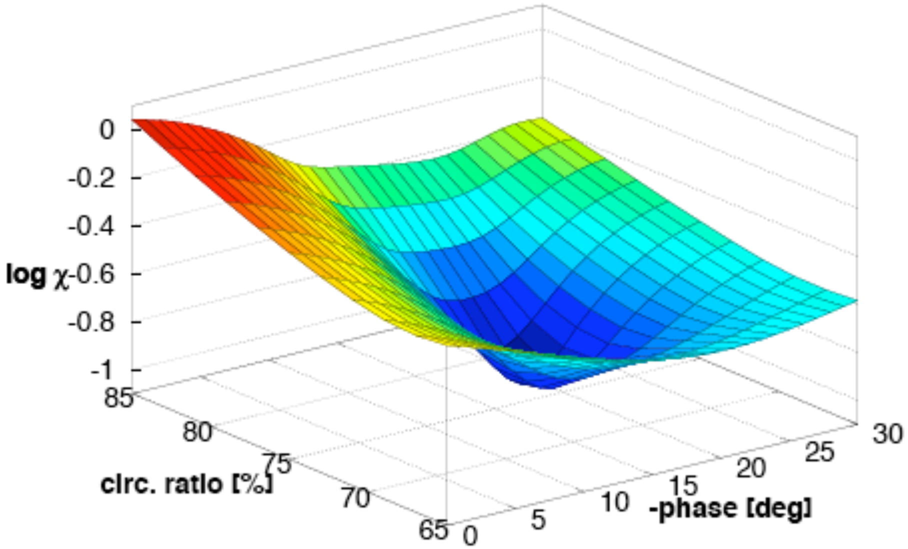
Performed: scan in 3D parameter space (c, A, phi)

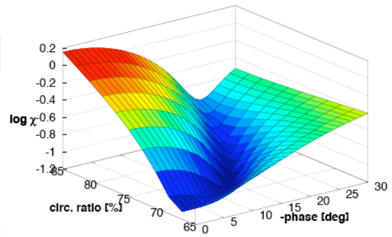
- scan over 200 consequtive pulses in time window w/o pulse shortening

Minimized metric (both P and theta) :

$$\chi^2(c,A,\phi) = \frac{1}{N_p}\Sigma_{N_p}\{[P_{meas} - P_{mod}(c,A,\phi)]^2/\text{pulselength}/\max(P_{meas})\}$$

$$+c_{PP}\frac{1}{N_p}\Sigma_{N_p}\{[\theta_{meas} - \theta_{mod}(c,A,\phi)]^2/\text{pulselength}\}$$

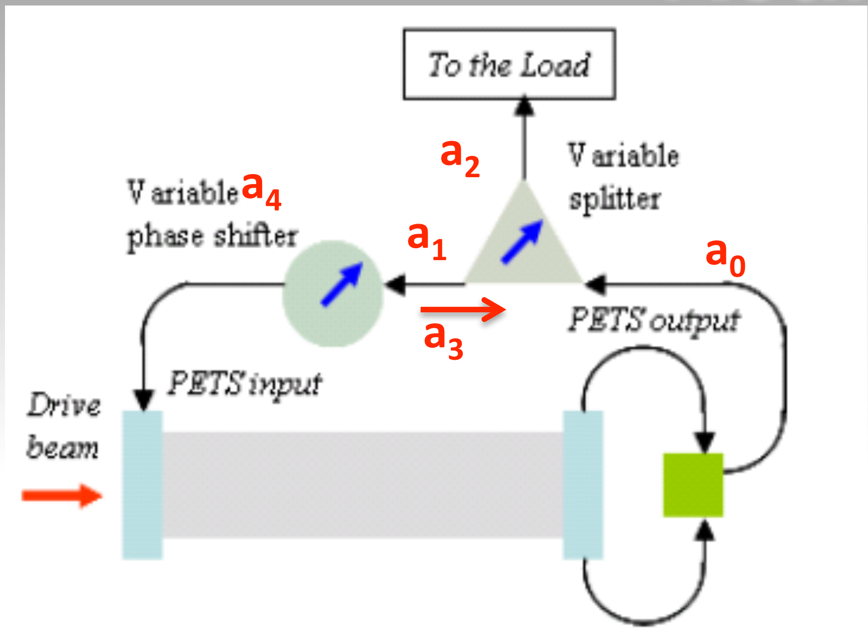


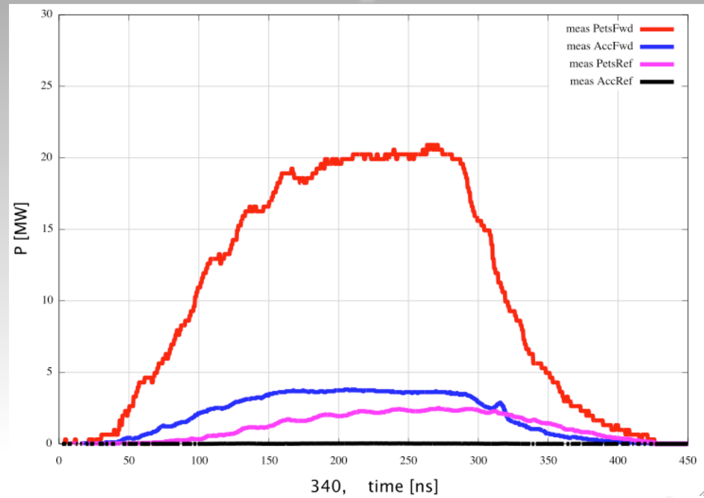


(power fit alone did not give very well defined minimum)

well defined **minimum result: A=0.75, phi=18 deg -> indicates robust model**

Reality check: splitter ratio





a_0: FIELD amplitude of PETS output -P_{FWD}
a_1: FIELD amplitude of recirc. arm of splitter
a_2: FIELD amplitude of field ot load -A_{FWD}
a_3: FIELD amplitude field reflected (believed: from splitter) -P_{REF}
a_4: FIELD amplitude recirculate field

Measurement :

$$r \equiv \frac{a_4}{a_0}$$

where

$$a_0^2 = a_1^2 + a_2^2$$

and

$$a_1^2 = a_3^2 + a_4^2$$

yielding

$$r^2 = (\frac{a_4}{a_0})^2 = \frac{a_1^2 - a_3^2}{a_0^2} = \frac{a_0^2 - a_2^2 - a_3^2}{a_0^2} = 1 - \frac{A_{FWD}}{P_{FWD}} - \frac{P_{REF}}{P_{FWD}} = 1 - 0.19 - 0.11 = 0.70$$

thus

$$r_{meas} = 0.84$$

Model fit :

Our fit gave:

$$A = \eta_{ohm} \times r_{fit} = 0.75$$

and we estimate $\eta_{ohm} = 0.9$ giving

$$r_{fit} = 0.83$$

-> Seems consistent

Reality check: constant factor

Comparing the RF signal from the calibrated diode with the RF signal from model (using the BPMs, calibrated with test-current, but be confirmed end-to-end calibration) :

P_meas = 0.67 x P_mod(FF=1)

sources :

$P \approx (1/4)\, I^2\, L_{pets}^2\, FF^2\, (R'/Q)\, \omega / v_g$

- calibration
- FF (Form Factor)
- detuning beam frequency wrt. PETS fundamental mode

If we assume ok calibrations and no detuning:

P_meas = P_mod(FF=0.82)

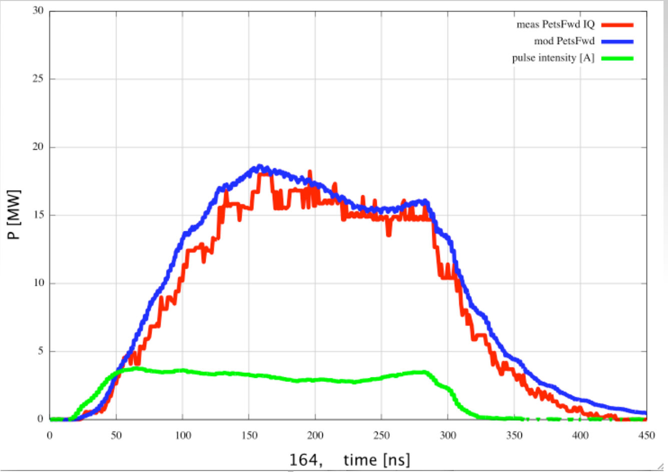
-corresponding to an rms bunch length of 2.5 mm

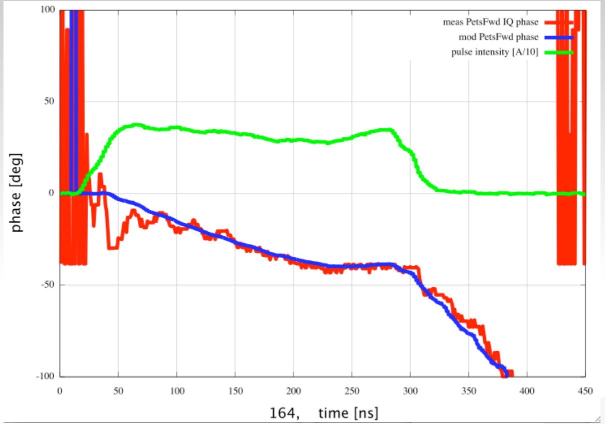
-> numbers seam reasonable

-> however we stress again: good rms bunch length measurement is imperative to compare measurement and model

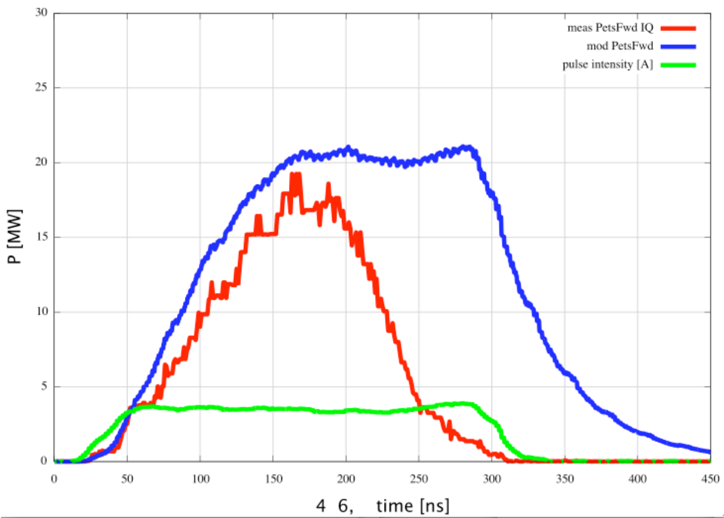
Demonstration of goodness of fit

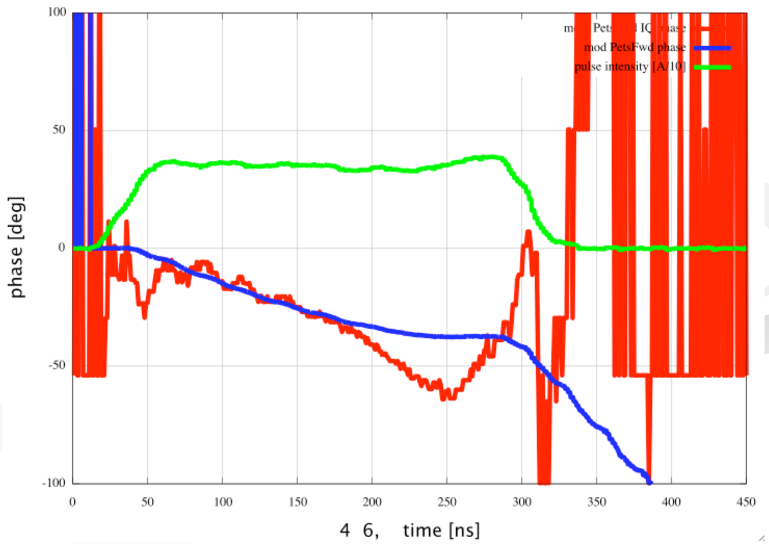
- Pulses w/o pulse shortening (demo: many pulses)





- Pulses w/ pulse shortening (demo: many pulses)

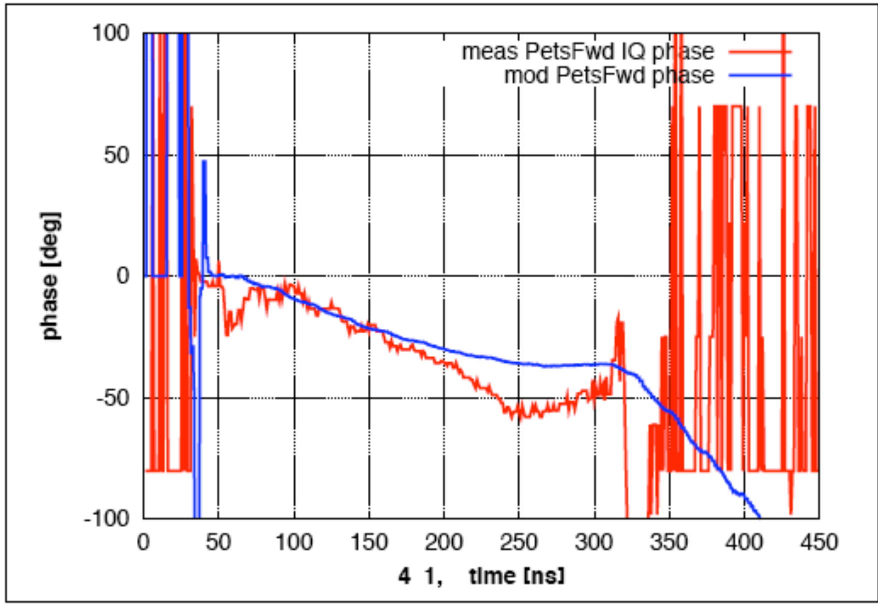




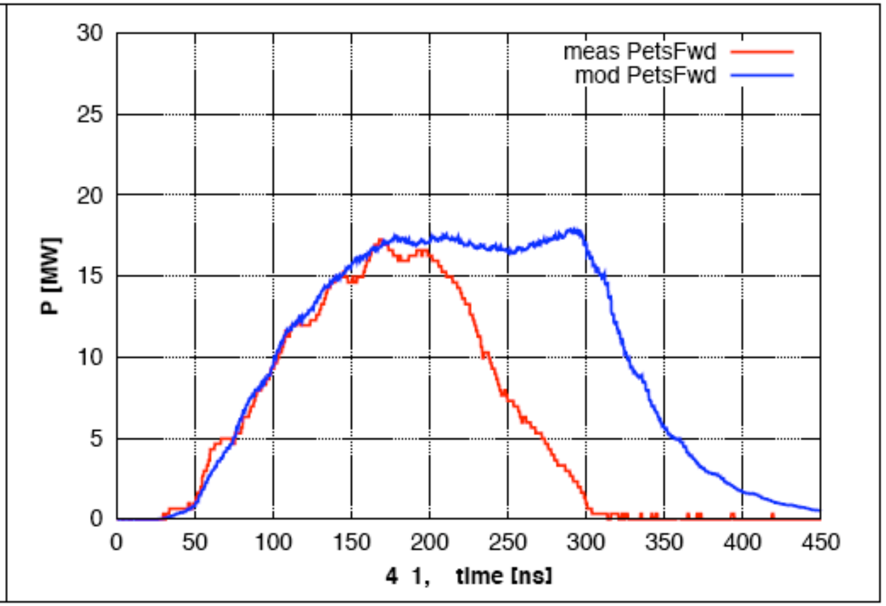
Phase behaviour of pulses w/ pulse shortening

- With fit parameters

Constant recirculation phase :



PHASE: IQ versus MOD

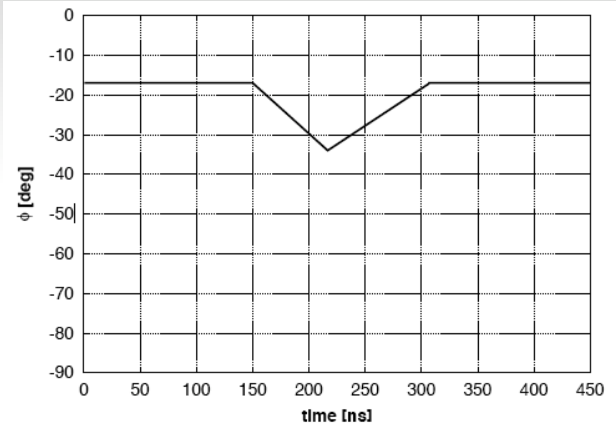


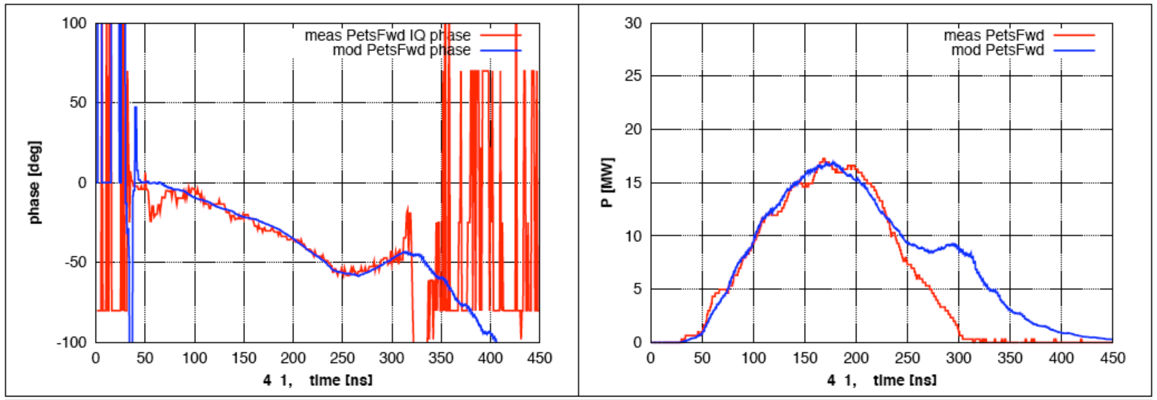
AMPL: DIODE versus MOD

Phase behaviour of pulses w/ pulse shortening

- Adjusting recirc phase to fit beam phase

Phase-dip in recirculation phase





PHASE: IQ versus MOD - SHAPED PHASE | AMPL: DIODE versus MOD - SHAPED PHASE

If attenuation is also adjusted we can also fit the measured power much better
-> however, physical models of break down is out of my current scope