12 GHz PETS conditioning with recirculation

First Analysis

CTF3 Collaboration Technical meeting

CERN, January 28th, 2009

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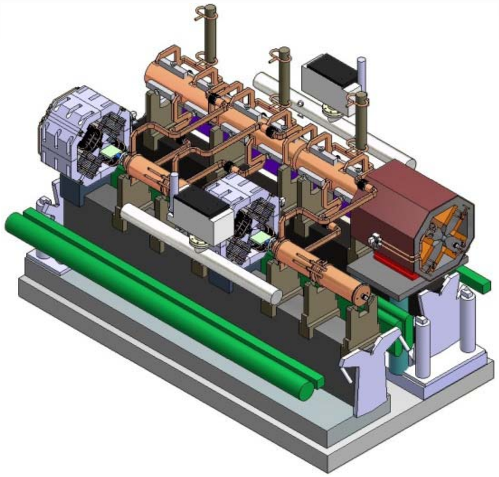
Outline

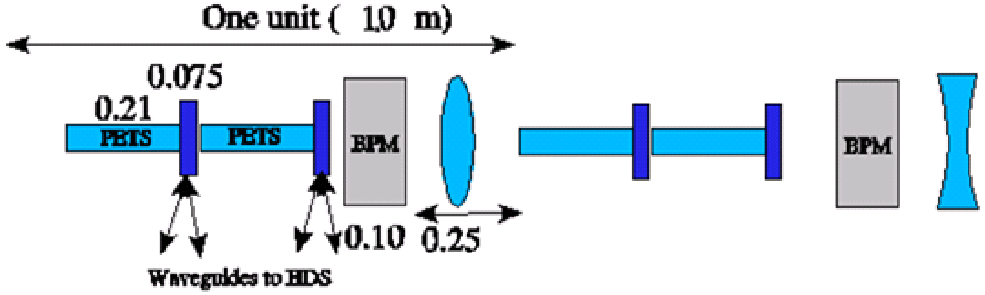
- Relevance to CLIC decelerator
- Summary PETS run 2008
- Simple model for recirculation
  - Correlation beam and RF measurements
- Pulse-shortening / break down
- Beam energy loss
  - Correlation RF and beam measurements

PETS: nominal usage in CLIC

- Reminder: PETS is the generator of the CLIC RF power
- In each Decelerator sector the 100A CLIC Drive Beam pass through ~1500 PETS, 21 cm long, each producing 136 MW RF power

I. Syratchev, D. Schulte, E. Adli and M. Taborelli, "High RF Power Production for CLIC", ***Proceedings of PAC 2007***





- The CLIC Decelerator beam dynamics has been studied extensively, e.g.

E. Adli, D. Schulte and I. Syratchev, "Beam Dynamics of the CLIC Decelerator", ***Proceedings of XBAND Workshop'08***

- TBTS: provides the **first beam tests** of the 12 GHz PETS

TBTS versus CLIC

CLIC PETS

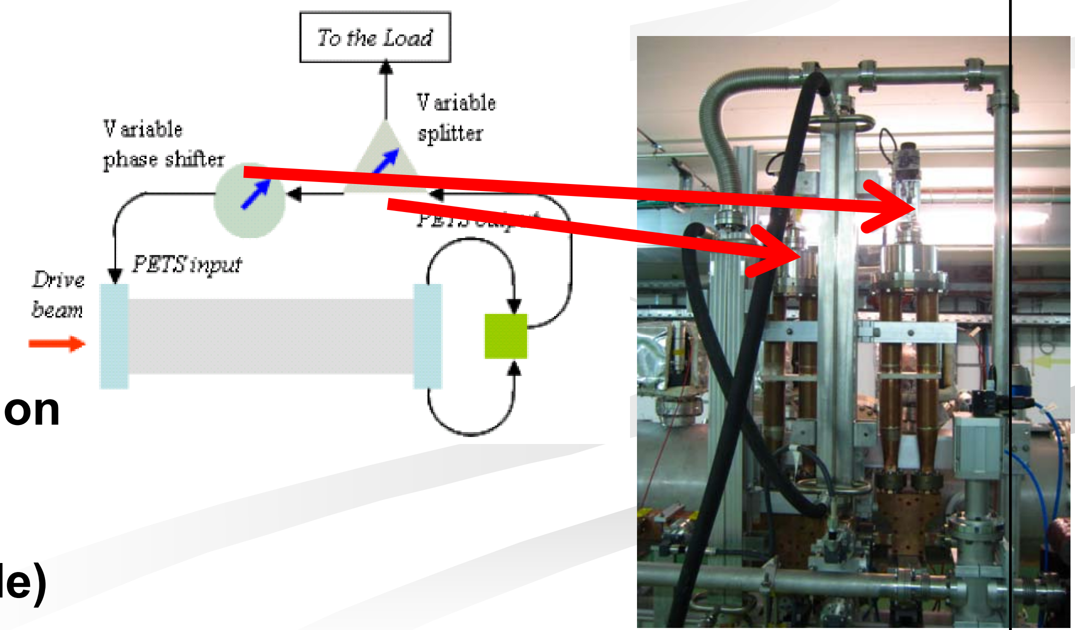
L_{pets} = 0.21 m, I = 101 A $\qquad$ $P \approx (1/4)\, I^2 L_{pets}^2\, FF^2 (R'/Q)\, \omega / v_g = 136$ MW

TBTS PETS

L_{pets} = 1 m

Would need 22 A to produce CLIC power. Max. in CTF3 this year ~ 5A

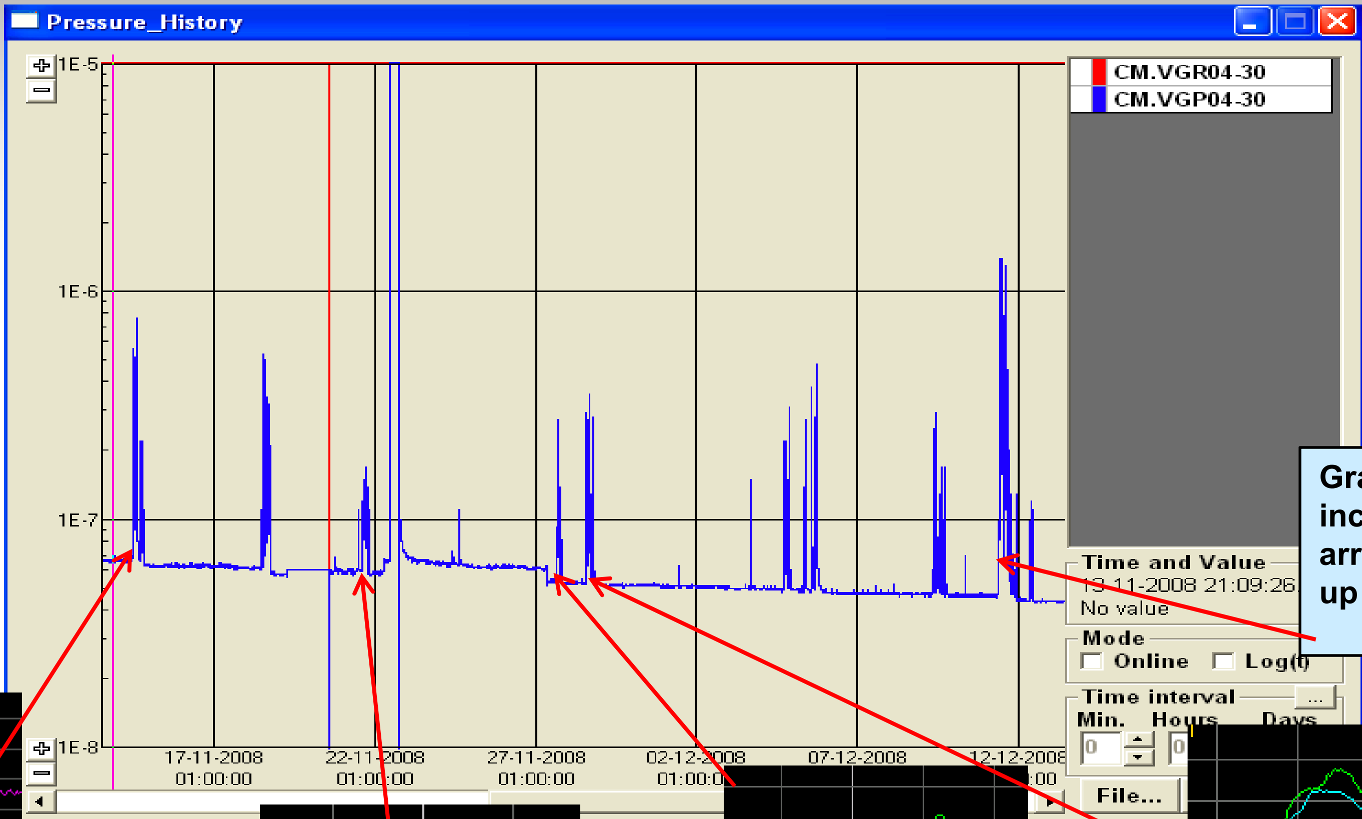
Solution of I. Syratchev:
recirculator



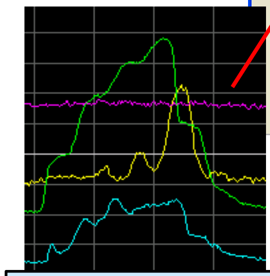
Problem 2008 run:
Splitter: stuck in undefined position (not remotely controlable)
Phase-shifter: stuck in undefined position (not remotely controllable)

Summary of run 2008

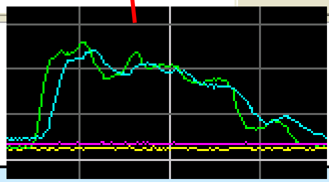
~ 30 hours integrated conditioning time (see R. Rubers talk)



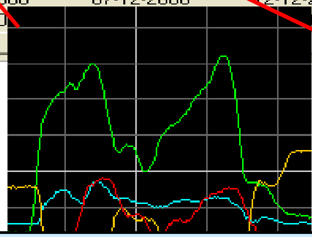
Gradually increasing current arriving at PETS, up to ~ 5A, 11/12



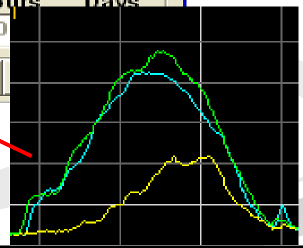
14/11: First beam
2A w/ recirculation (by chance: positive build-up!)



21/11: Manually forces splitter to extreme position: no recirculation (to verify beam generated RF power)



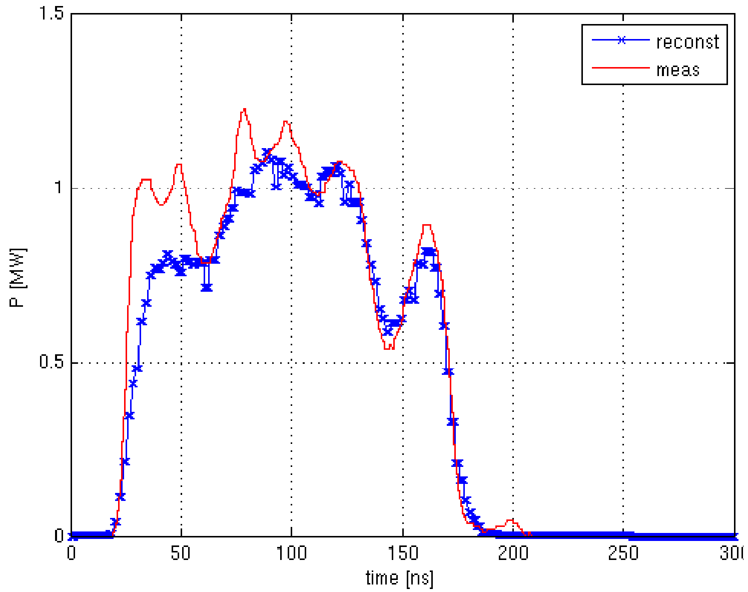
27/11: Put splitter back until stuck: destructive recirculation!

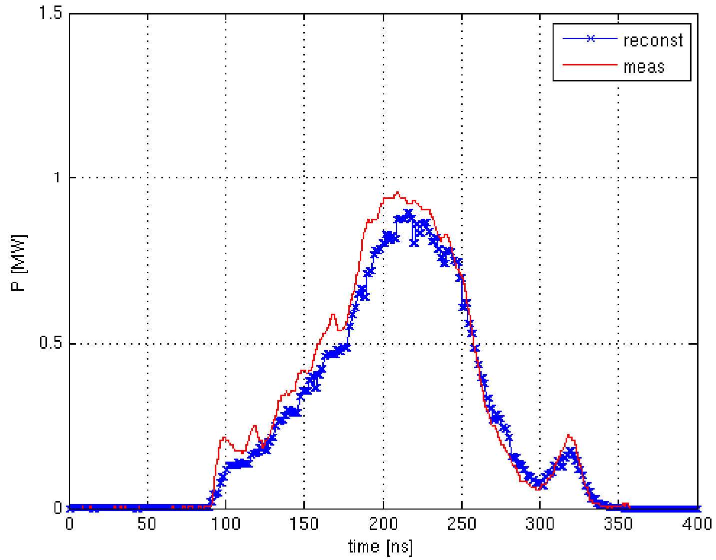


28/11 : Adjusted phase-shifter : back to constructive recirculation mode

PETS without recirulation

- Manual adjust of phase-shifter: in order to check power production for nominal operation
- Reminder before we analyse recirculating mode





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

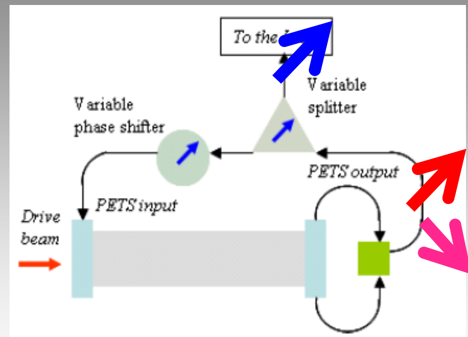
Apart from PETS parameters (tested with RF), the power should depend only on the form factor, the current^2 and eventual phase detuning.

With recirculaton

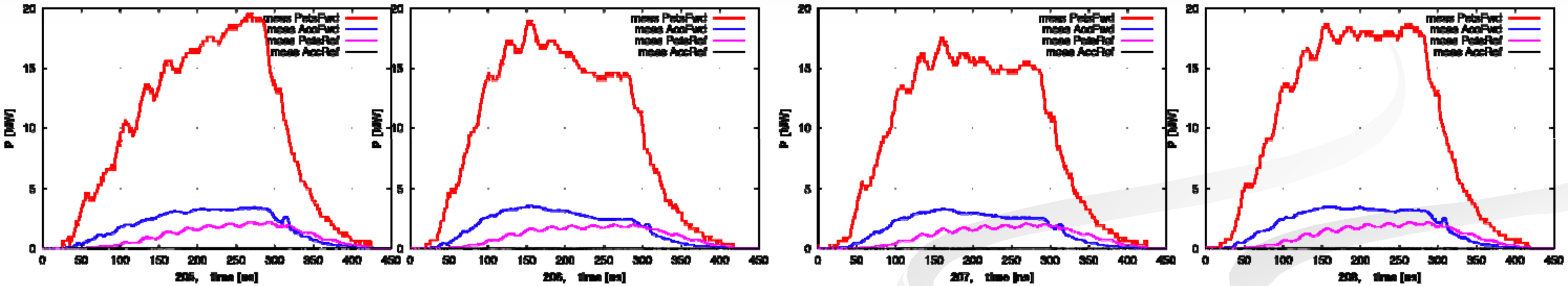
We move to last day of operation:

4-5 A with recirculation.

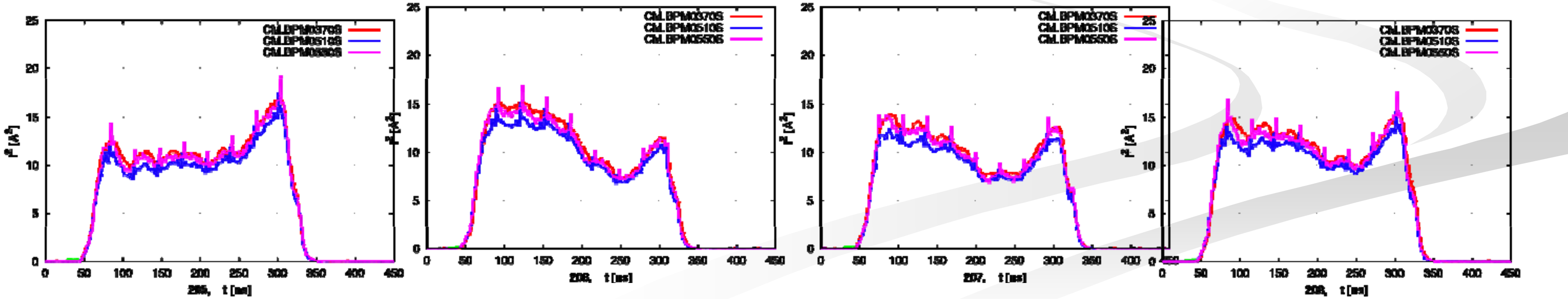
Typical power, **subsequent** pulses :



Power: PETS out (red), to load (blue), reflected (purple)

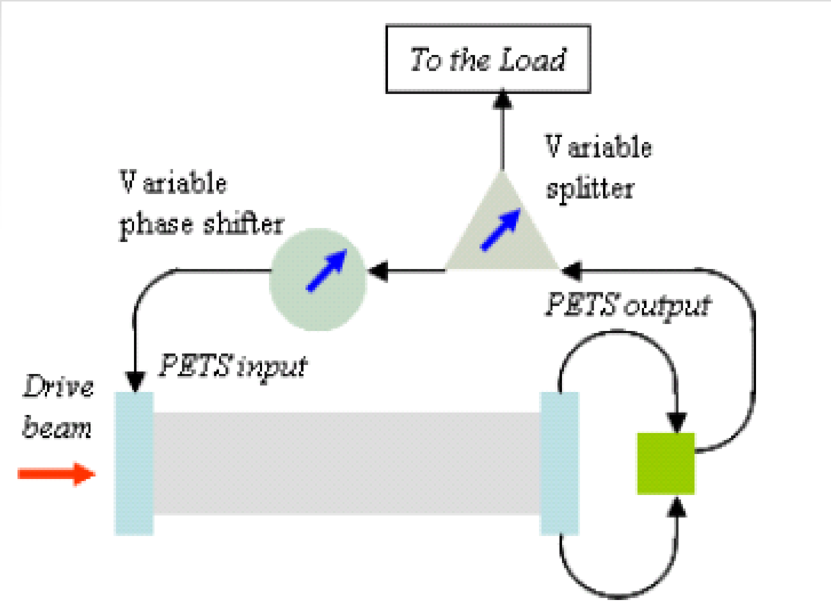


Corresponding pulse intensity^2 (the BPM before, and two first after PETS):



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 (we ignore the fill-time here):



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

$$\Downarrow$$

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

$$\Downarrow$$

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

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

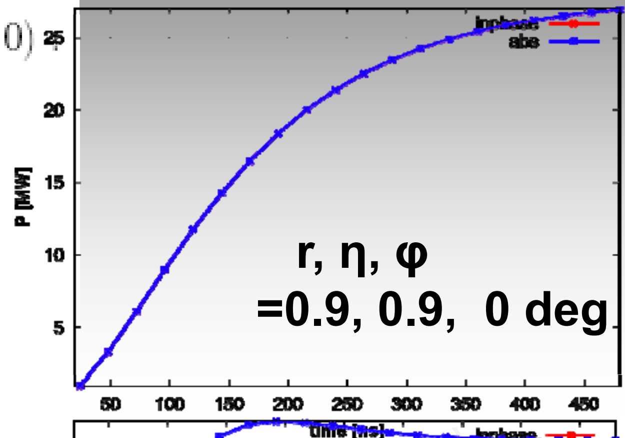
$$\lambda = r \times \eta_{ohm} \times \quad e^{j\theta}$$

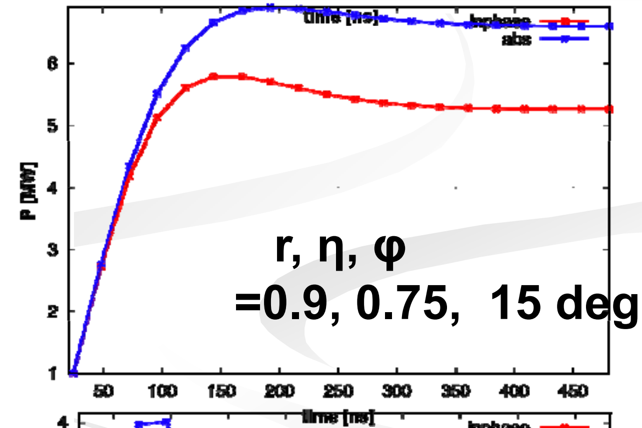
$$A = \frac{E_0}{1-\lambda}$$

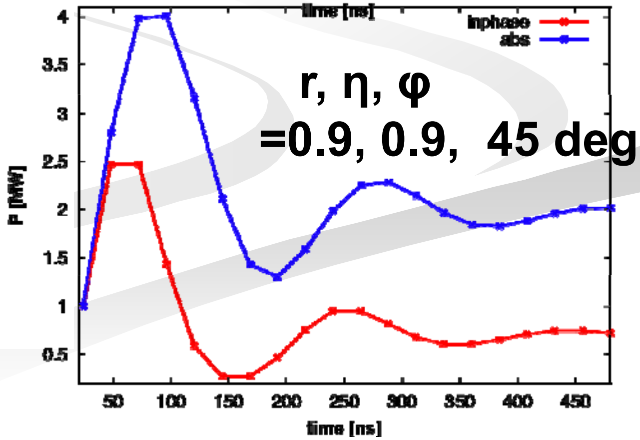
$$\tau = \frac{t_{recirc}}{(1-\lambda)}$$

$$P \propto E^2$$

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







Improved model: using measured pulse intensity

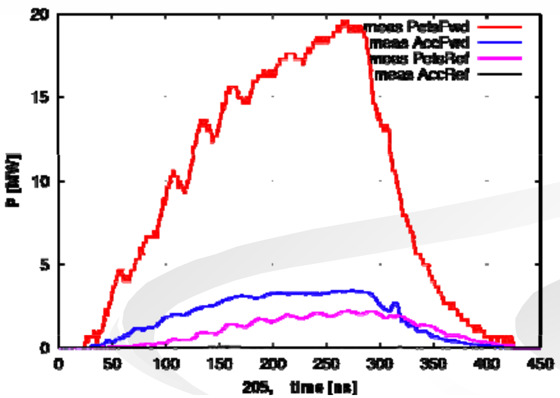
Challenge: fit this model to reality

- Challenge a-priori **neither the recirculation phase nor the split-ratio is known** (stuck at unknown position)
- Ohmic losses: **prediciton** η ~ 0.9 (in model: lumped r x η)
- **Form Factor not known** to precision
- **Bunch phases (detuning)** not known
- Some uncertainty in calibration

After trying with many pulses, trying to get both shape, e-folding and amplitude right we ended up with the following parameters :

Assumed: no detuning
r x η = 0.90 x 0.75 (expected 0.9 x 0.9)
φ=15 deg (larger would lead to too quick fall-off – but ... in principle ~10% chanche to "by accident" be at this position ?)
FF ~ **2.5mm bunch** (NB: equivalent to constant factor)

Splitter ratio can be estimated :



$$r \equiv \frac{a_1}{a_0}$$

$$a_2 = \sqrt{1-r^2}a_0$$

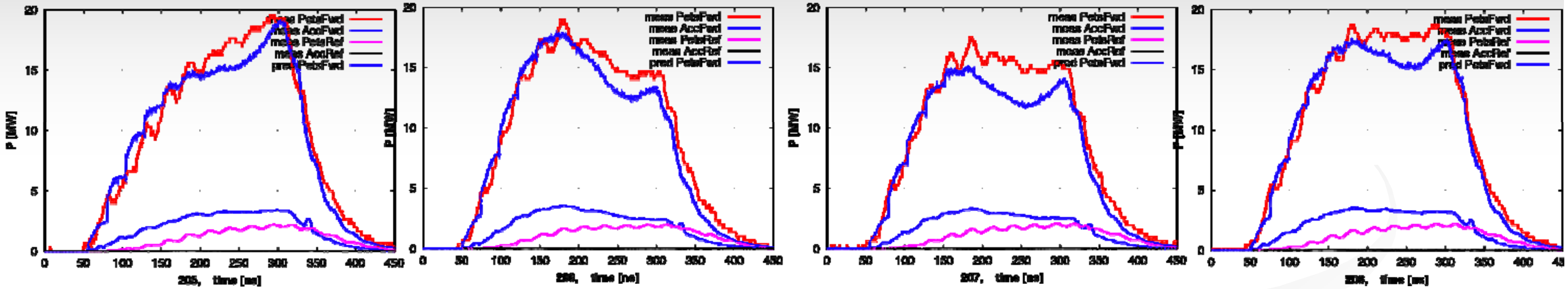
$$a_0^2 = a_1^2 + a_2^2$$

$$R_{obs} = (\frac{a_0}{a_2})^2 = \frac{1}{\frac{a_0^2 - a_1^2}{a_0^2}} = \frac{1}{1-r^2}$$

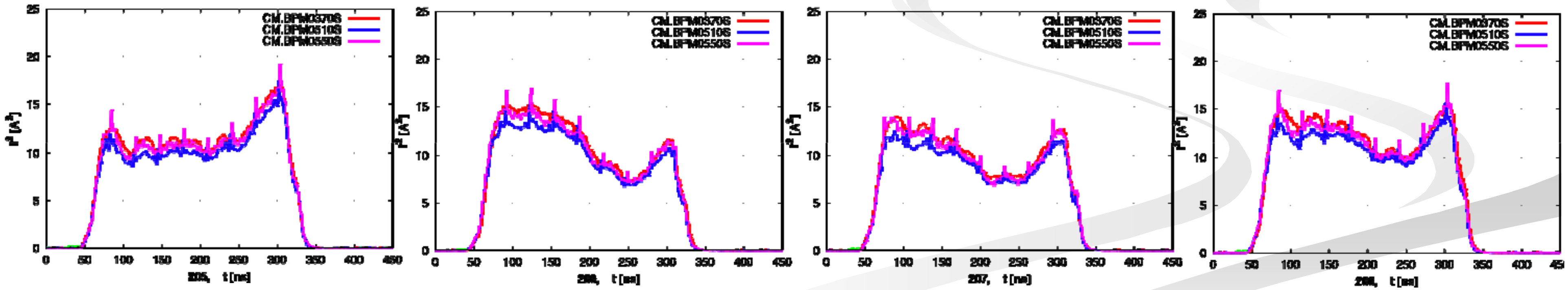
$$r = \sqrt{1 - \frac{1}{R_{obs}}} \approx \sqrt{1 - \frac{1}{5.5}} \approx 0.90$$

Measurement versus modelled power

Power: PETS out (red), modelled PETS out (upper blue)

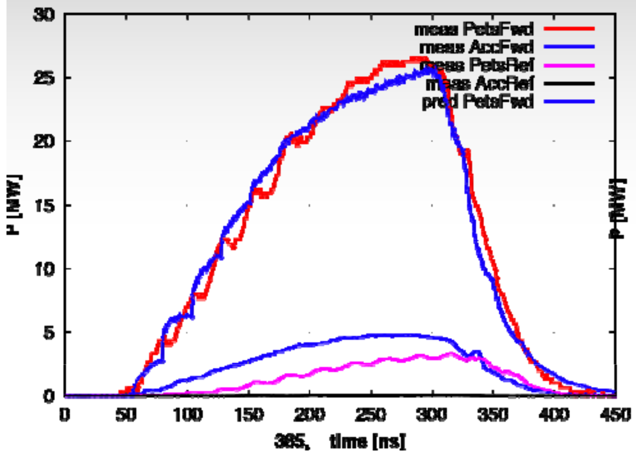


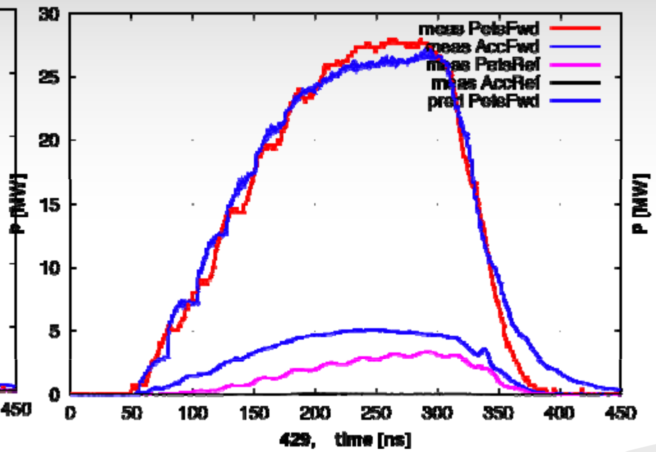
Corresponding pulse intensity (^2) :

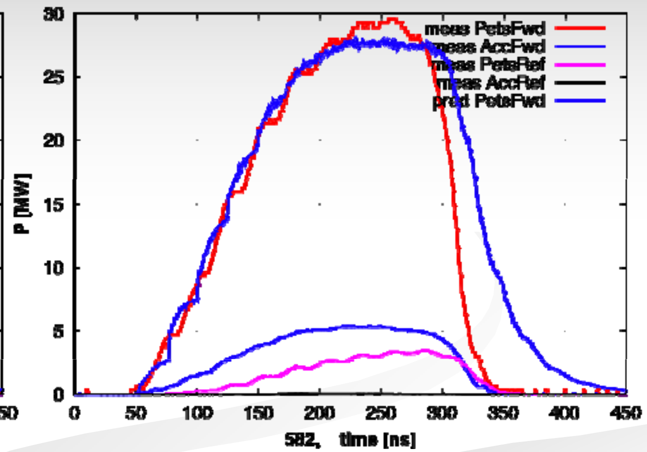


Higher current

Power: PETS out (red), modelled PETS out (upper blue)

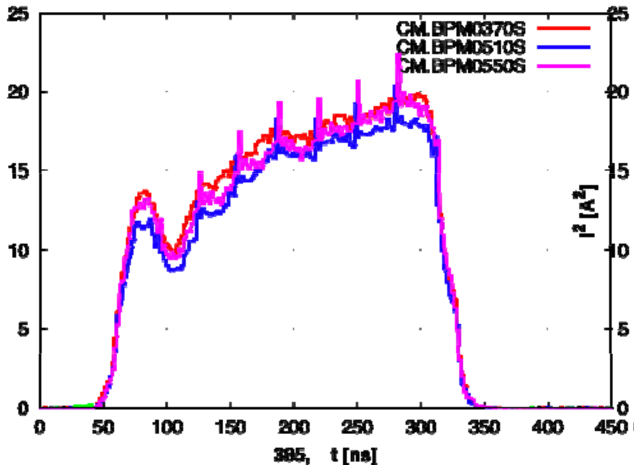


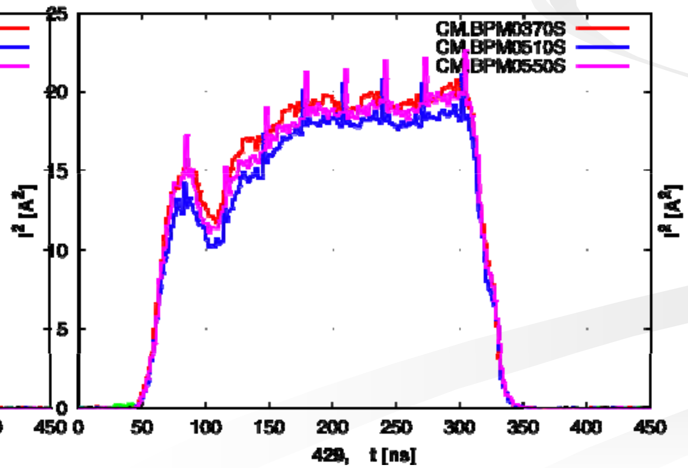


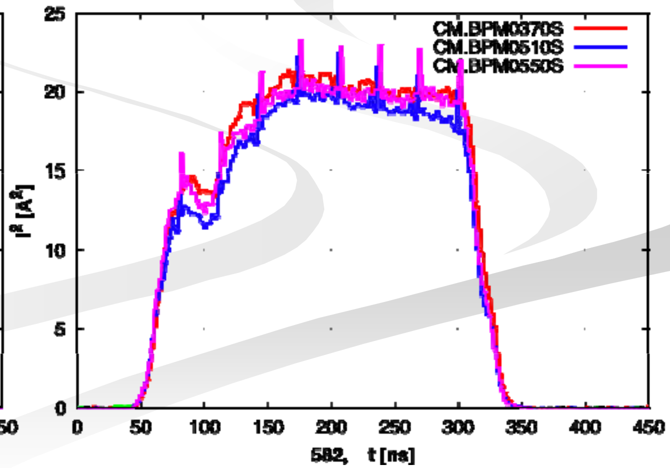


Current^2: in front of and after PETS (no losses)

(one of the highest power pulses this year: 30 mW)

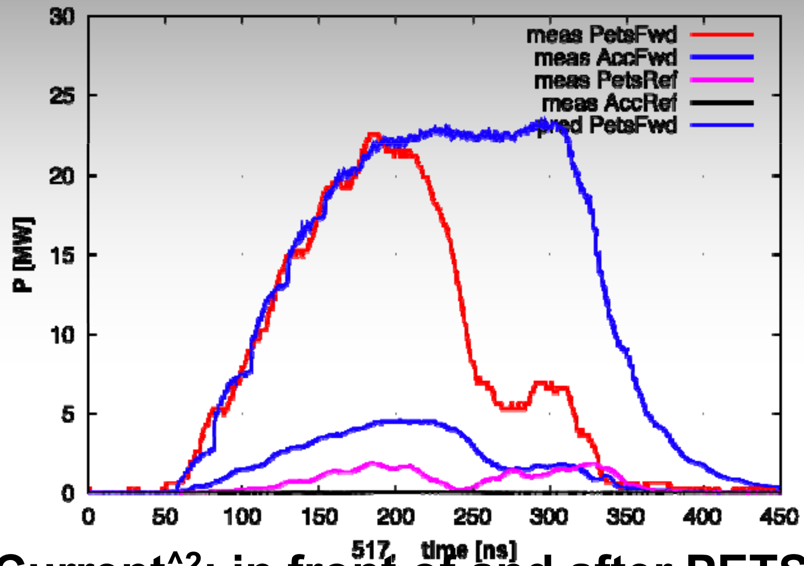


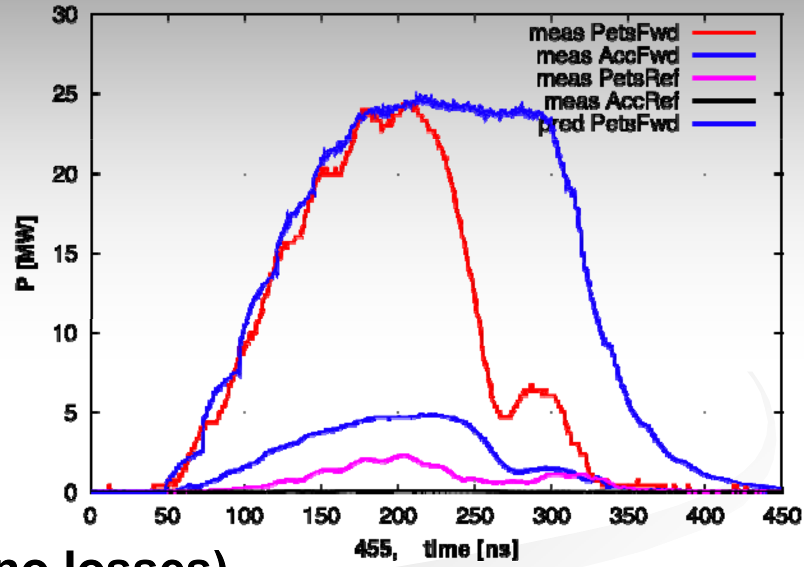




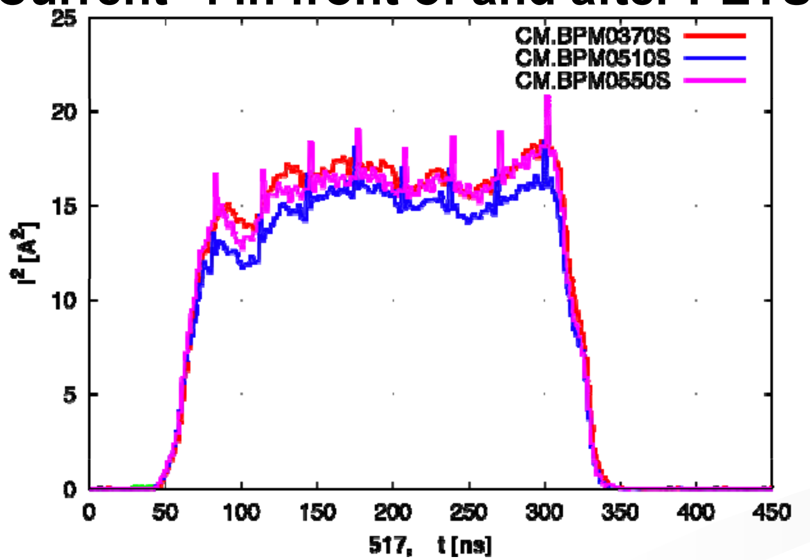
Pulse-shortening and break down

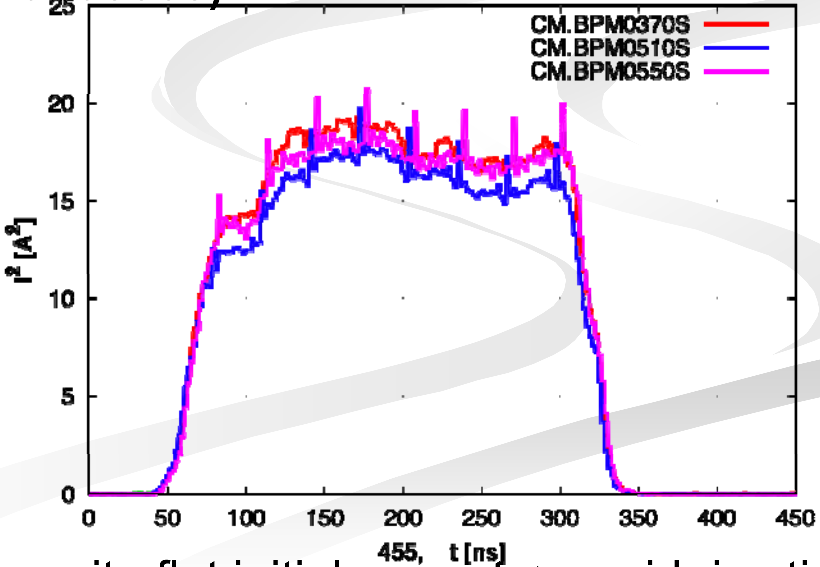
Power: PETS out (red), modelled PETS out (upper blue)





Current^2: in front of and after PETS (no losses)



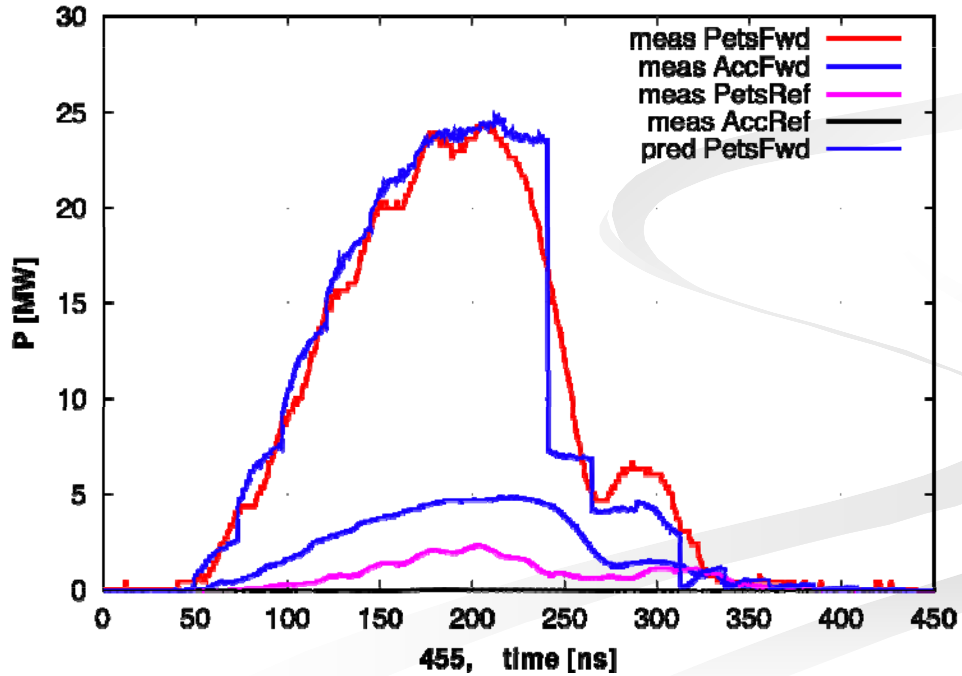


(we note that both these break downs have quite flat initial current -> rapid rise time)

Break down : modeled as phase shift ?

Random phase-shift of ~45 deg, over a period of 50-100 ns can lead to similar curves as the measured

Power: PETS out (red), modelled PETS out (upper blue), with random phase-shift on 4 steps :



Beam energy loss: model

- Basic principle to estimate beam energy loss: **energy into system must come from beam.** We try the following model:

$$\int_0^T P_{beam}(t)dt = P_{P\ FWD}\tau_{char} + \int_0^T P_{A\ FWD}(t)dt + \int_0^T P_{P\ REF}(t)dt + \int_0^T losses(t)dt$$

$$\Rightarrow P_{beam}(t) = \frac{\partial}{\partial t} P_{P\ FWD}(t)\tau + P_{A\ FWD}(t) + P_{P\ REF}(t) + losses(t)$$

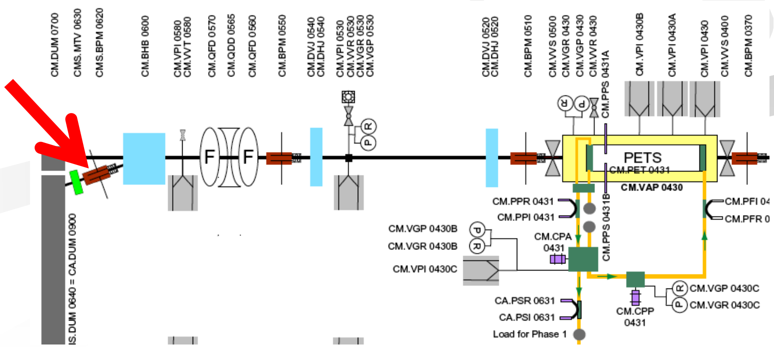
We ignore here the reflected power (not clear yet where it is going) and neglect losses, using only largerst contributors.

τ_{char} : smaller than t_recirc - here we used a factor 0.5

The we compare predicted dispersive orbit with the horizontal reading in the spectometer line :

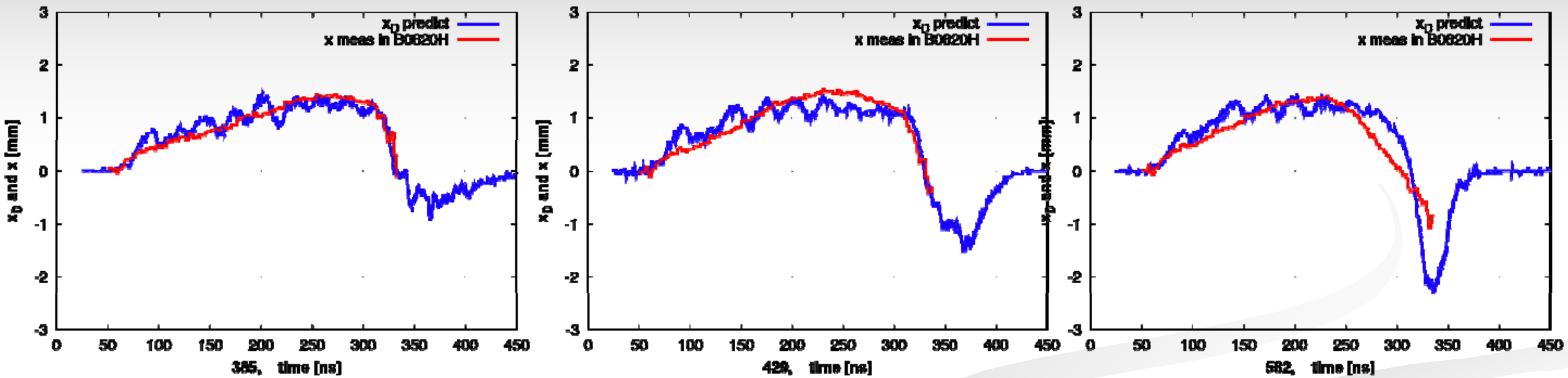
($D_{BPM0620} \approx \theta L$ = 0.2 m,
$\langle U \rangle = P / \langle I \rangle$)

(Unforunately: we do not have spectrometer data in front of the PETS to compare beams)

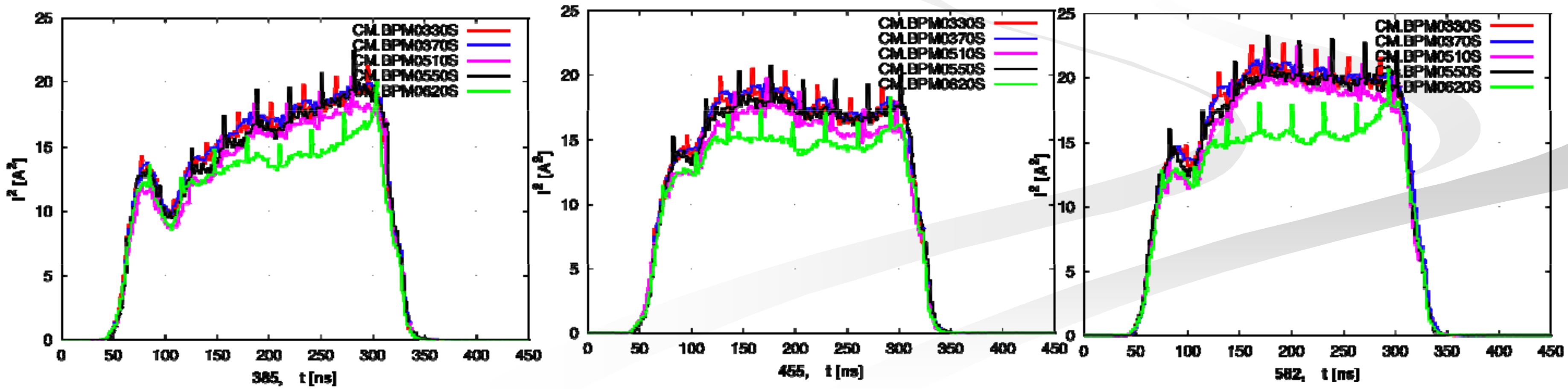


Dispersive orbit: measured (red) and predicted from model via power measurement (blue)

(Real system bandwidth not included in model)



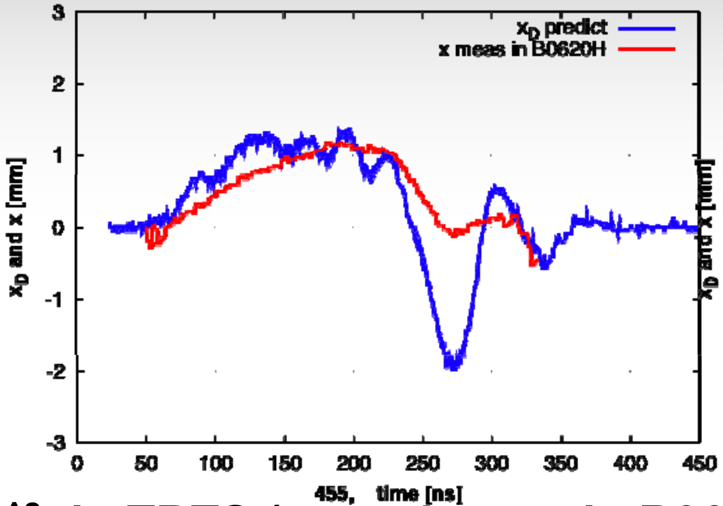
Current^2: in TBTS (some losses in B0620)

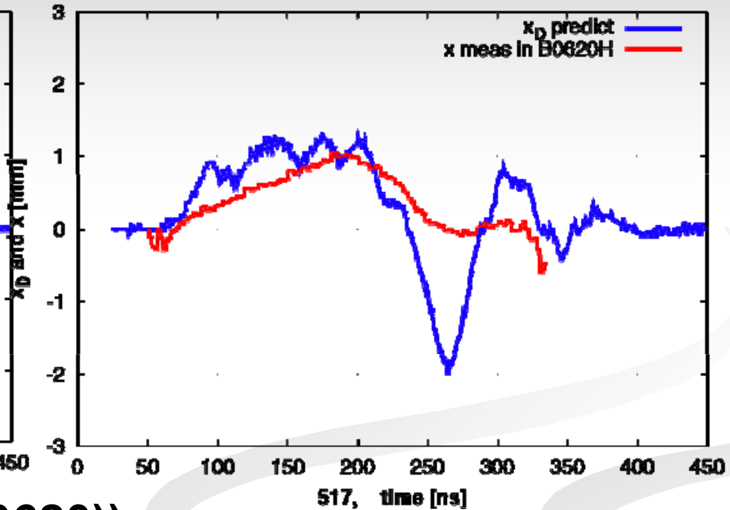


Prediction versus measurements

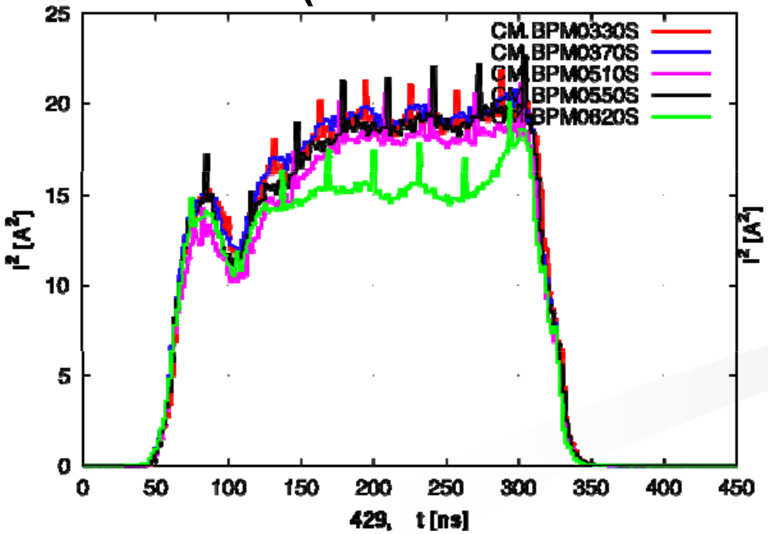
Dispersiv orbit: measured (red) and predicted from model via power measurement (blue)

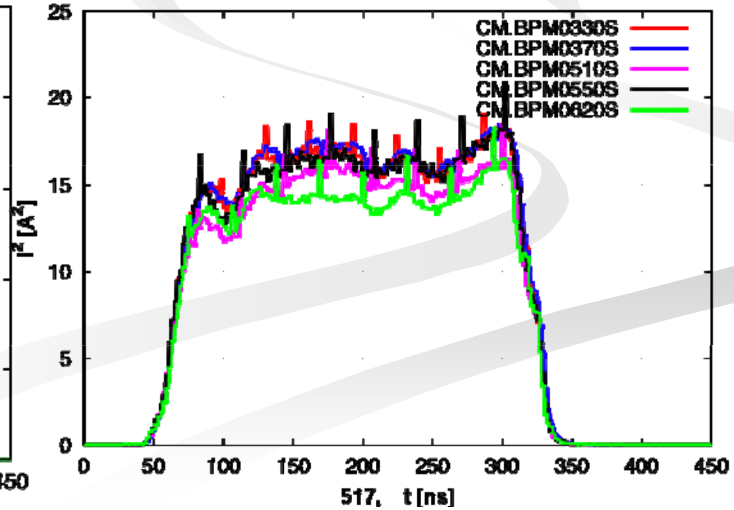
(Real system bandwidth not included in model)





Current^2: in TBTS (some losses in B0620))





Work outstanding

- Improve models / accomodating missing factors
- Combine energy measurements with kick-measurements
- Prediction versus measurement of transverse kicks (dipole modes)

  - We have not exhausted data taken yet

Improving measurements

- Phase-shifter and attenuator in order will help greatly
- Time-resolved spectrometer measurements before and after PETS (in CLEX before PETS)
  - No R&D effort needed (dump in 10 reproduced) (A.Dabrowski)
- Smaller pulse to pulse jitter
- MTV data
- Energy measurement using dog-leg

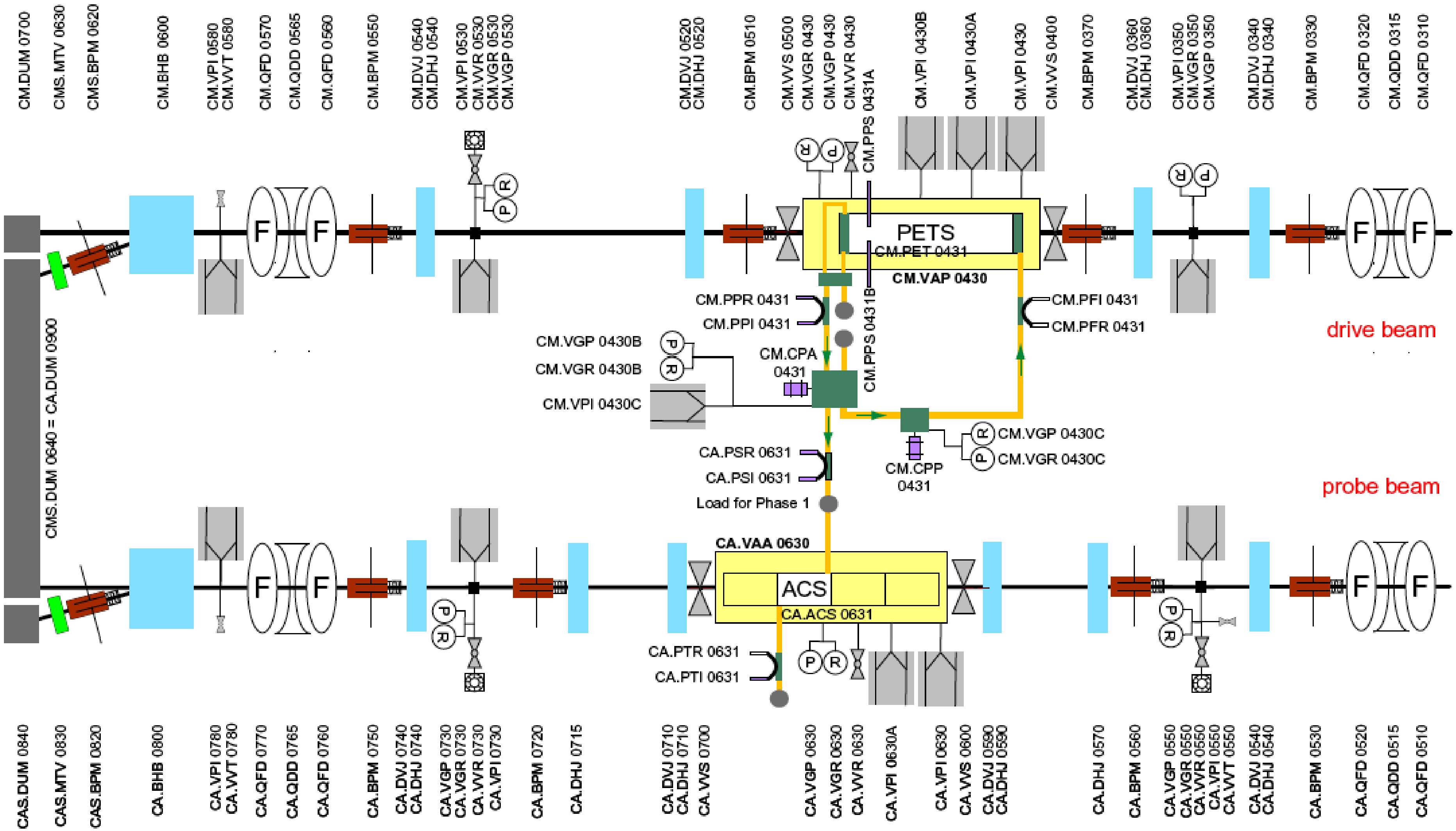
Conclusions

- The TBTS has proven to be a great tool for the first verification of interations beam/PETS

- Still a lot of work ahead, but we are on good way to understanding beam and field in the TBTS with recirculation

Thanks and acknowledgments: many valuable discussions with I. Syratchev and D. Schulte at CERN are gratefully acknowledged, and a particular thanks to the Uppsala TBTS-team for inviting to help with measurements and analysis, and to R. Ruber for all TBTS assistance.

CLIC



CM.DUM 0700
CMS.MTV 0630
CMS.BPM 0620
CM.BHB 0600
CM.VPI 0580
CM.WT 0580
CM.QFD 0570
CM.QDD 0565
CM.QFD 0560
CM.BPM 0550
CM.DVJ 0540
CM.DHJ 0540
CM.VPI 0530
CM.VVR 0530
CM.VGR 0530
CM.VGP 0530
CM.DVJ 0520
CM.DHJ 0520
CM.BPM 0510
CM.VVS 0500
CM.VGR 0430
CM.VGP 0430
CM.VVR 0430
CM.PPS 0431A
CM.VPI 0430B
CM.VPI 0430A
CM.VPI 0430
CM.VVS 0400
CM.BPM 0370
CM.DVJ 0360
CM.DHJ 0360
CM.VPI 0350
CM.VGR 0350
CM.VGP 0350
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CM.BPM 0330
CM.QFD 0320
CM.QDD 0315
CM.QFD 0310
PETS
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CM.PPI 0431
CM.PPS 0431B
CM.PFI 0431
CM.PFR 0431
drive beam
CM.VGP 0430B
CM.VGR 0430B
CM.VPI 0430C
CM.CPA
0431
CMS.DUM 0640 = CA.DUM 0900
CM.VGP 0430C
CM.VGR 0430C
CM.CPP
0431
CA.PSR 0631
CA.PSI 0631
Load for Phase 1
probe beam
CA.VAA 0630
ACS
CA.ACS 0631
CA.PTR 0631
CA.PTI 0631
F
P
R
CAS.DUM 0840
CAS.MTV 0830
CAS.BPM 0820
CA.BHB 0800
CA.VPI 0780
CA.WT 0780
CA.QFD 0770
CA.QDD 0765
CA.QFD 0760
CA.BPM 0750
CA.DVJ 0740
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CA.VVR 0730
CA.VPI 0730
CA.BPM 0720
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CA.DHJ 0710
CA.VVS 0700
CA.VGP 0630
CA.VGR 0630
CA.VVR 0630
CA.VPI 0630A
CA.VPI 0630
CA.VVS 0600
CA.DVJ 0590
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CA.DHJ 0570
CA.BPM 0560
CA.VGP 0550
CA.VGR 0550
CA.VVR 0550
CA.VPI 0550
CA.WT 0550
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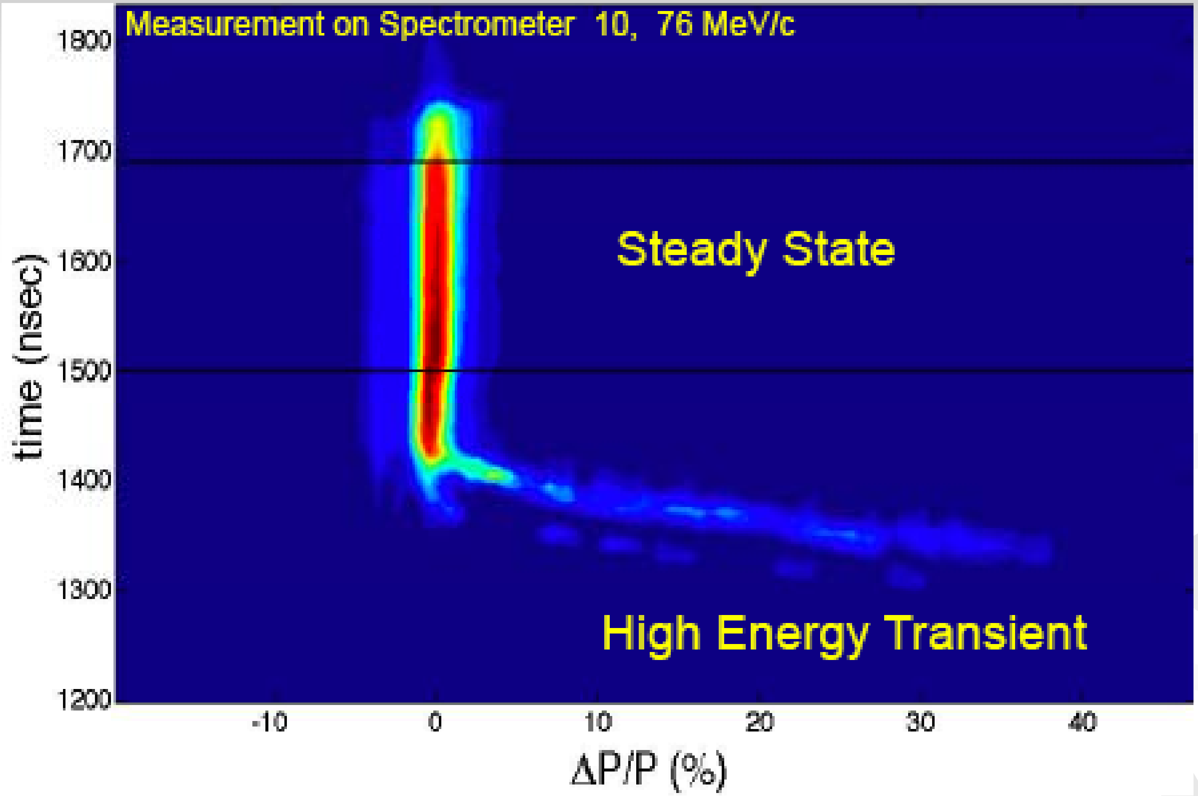
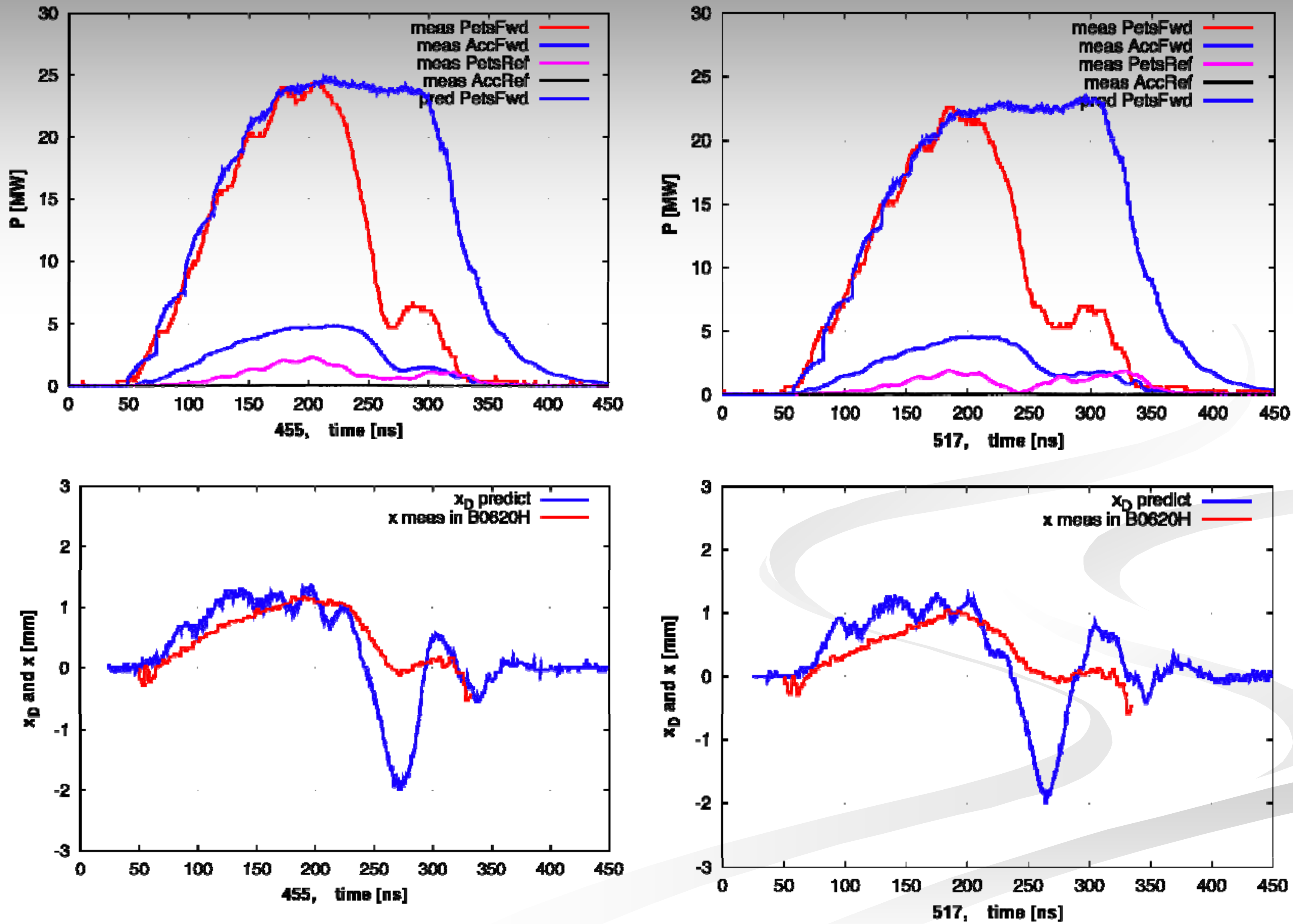
CA.BPM 0530
CA.QFD 0520
CA.QDD 0515
CA.QFD 0510

Spectrometer dump



(From A. Dabrowski)


meas PetsFwd
meas AccFwd
meas PetsRef
meas AccRef
pred PetsFwd
P [MW]
455, time [ns]
517, time [ns]
x_D predict
x meas in B0620H
x_D and x [mm]
455, time [ns]
517, time [ns]