12GHz PETS Testing in the Two-beam Test Stand

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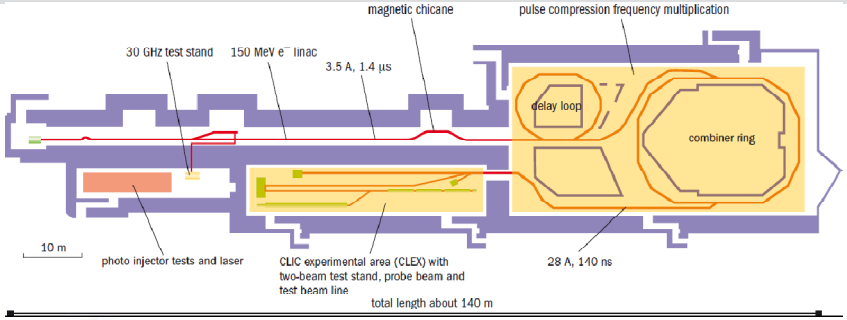
for the TBTS Team

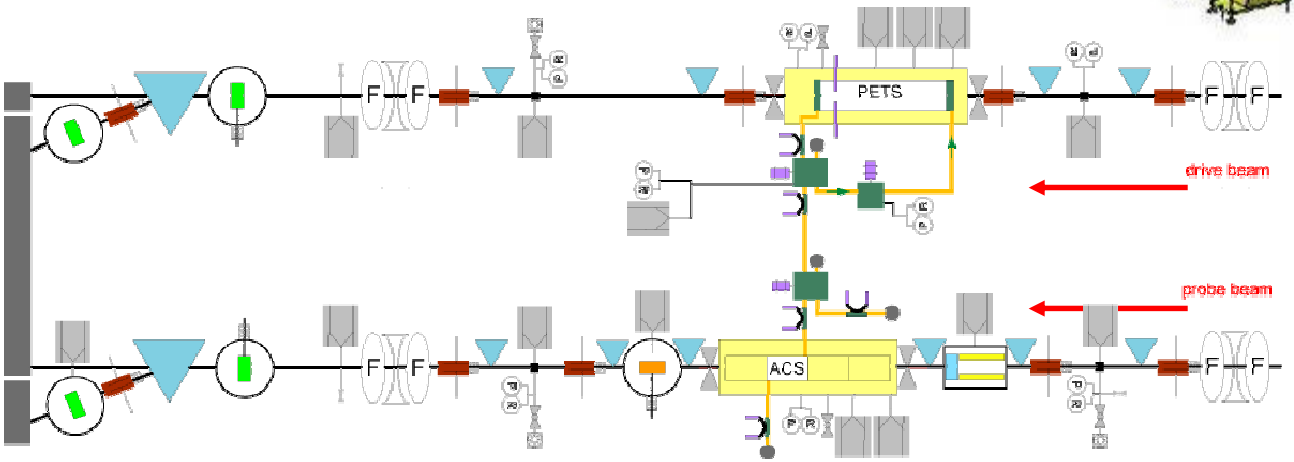
CLIC09 Workshop

15 October 2009

Two-beam Test Stand Layout

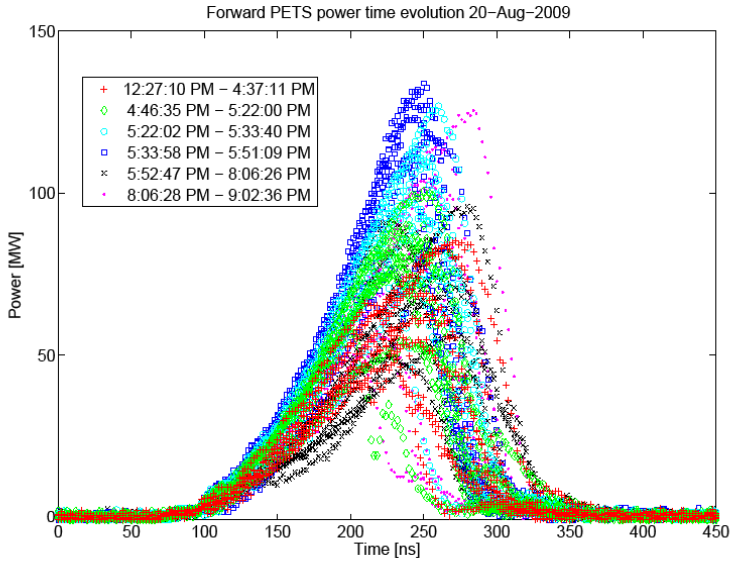
Construction supported by the Swedish Research Council and the Knut and Alice Wallenberg Foundation



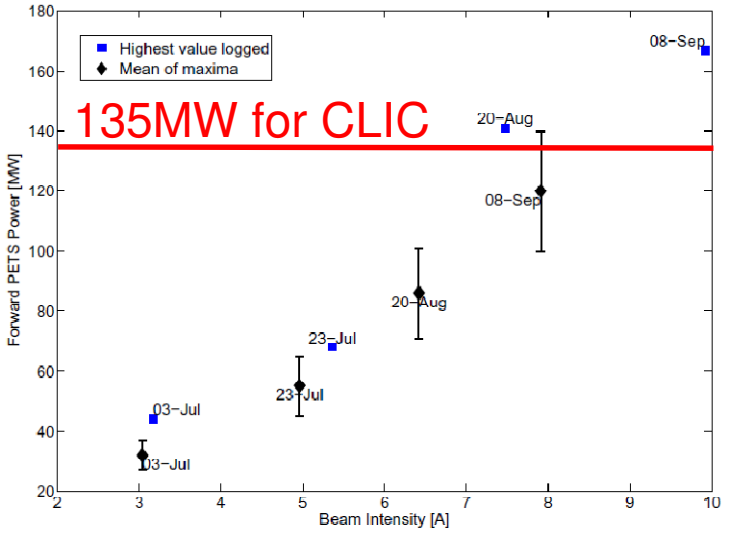


12GHz PETS Conditioning

- **Run 0**
  November/December 2008:
  - ~28 h beam time
  - Mode 1: 1.8 A, 5.2 MW
  - Mode 2, 2xCR: 5.3 A, ~30 MW



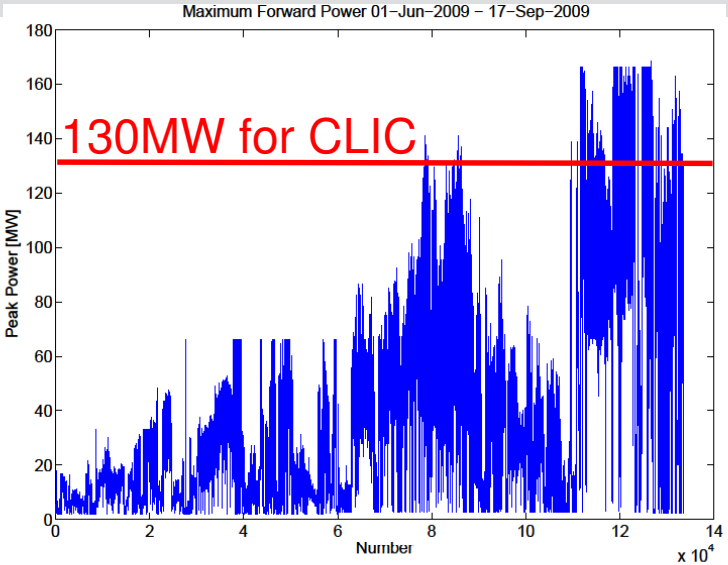
- **Run 1**
  July/August/September 2009:
  - ~60 h beam time, 2x10^5 pulses
  - Mode 2, 4xCR: ~10 A, >170 MW

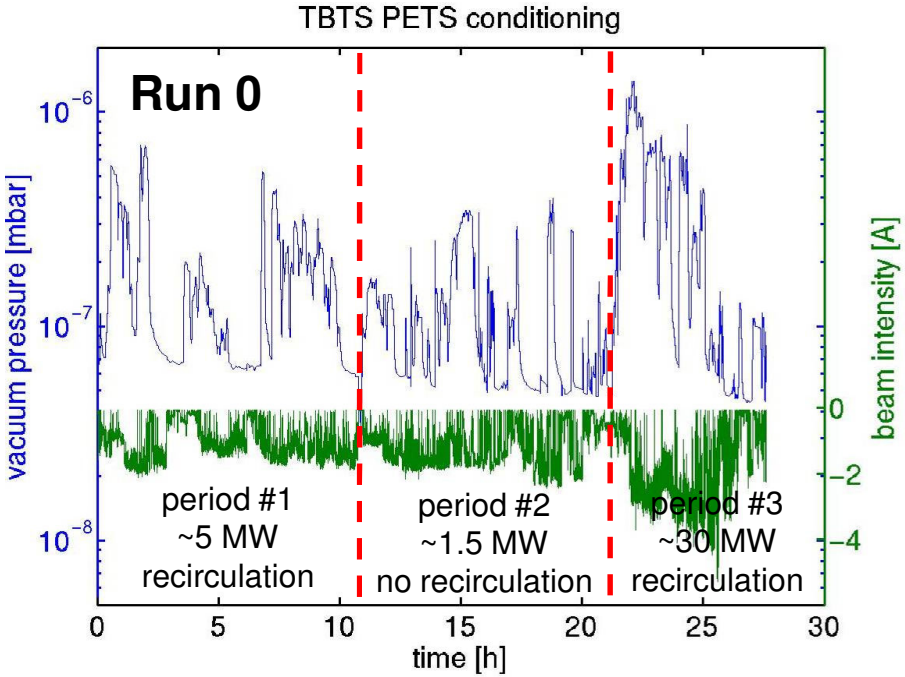


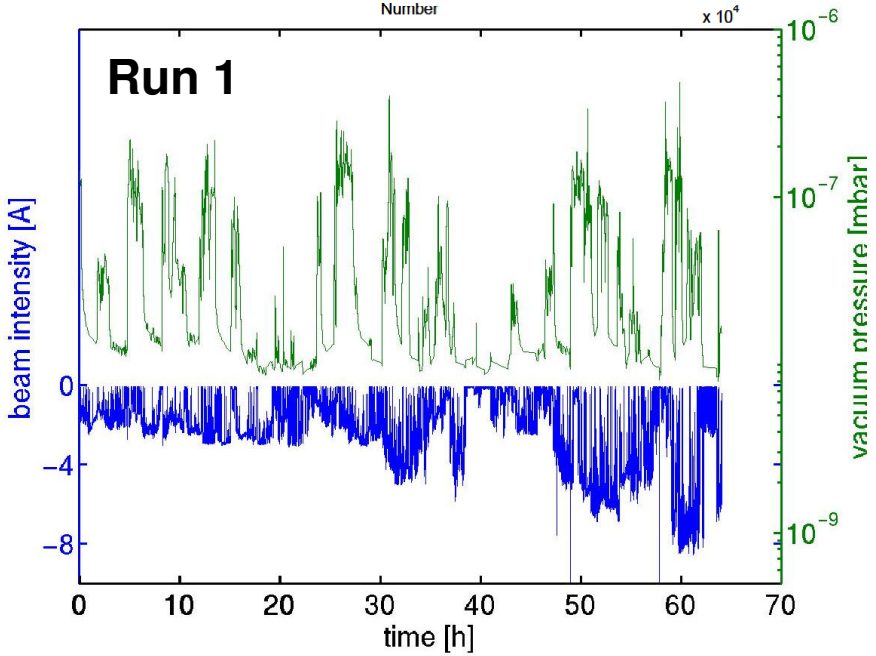
→ **reached CLIC nominal power**

Vacuum Activity during Conditioning

- gradual decrease vacuum activity during increased power → processing
- Note: intervals of several days b/w beam time during run







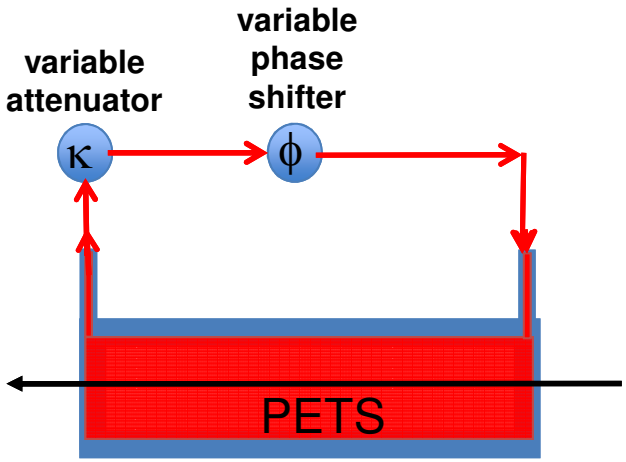
PETS Power Recirculation

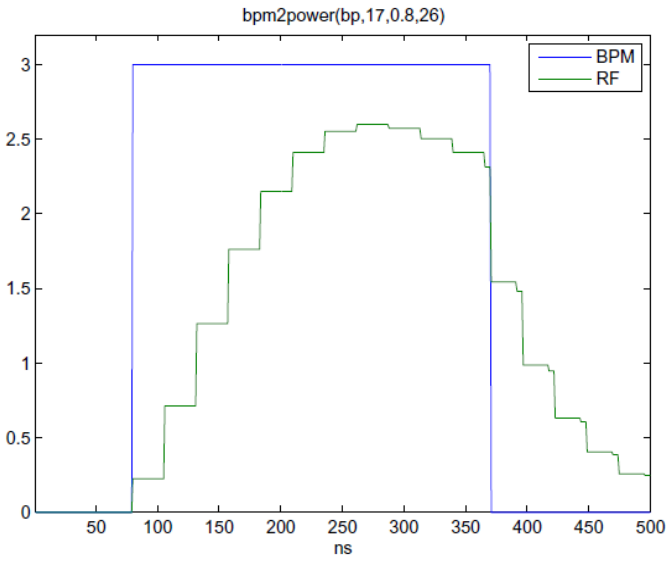
- Electron bunch generates field burst
- Field burst returns after
  - roundtrip time $t_r = 26$ ns
  - attenuation $g = e^{-\alpha}$
  - phase φ
- Output after n+1 turns $P \propto c_{cal}^2 E^2$

$$E_{n+1} = E_n g e^{i\varphi} + c_{I2E} I$$

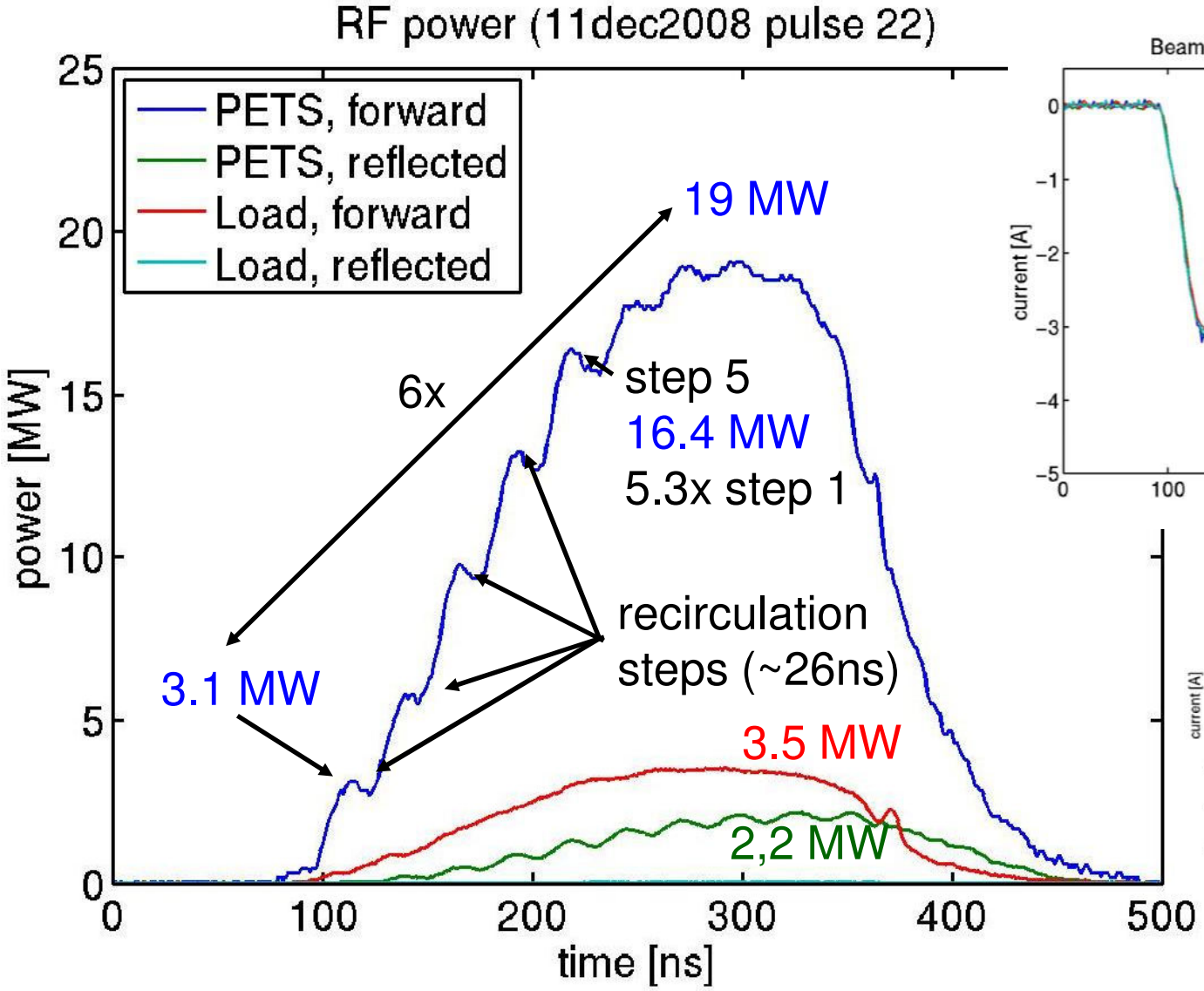
$$E_n = E_0 g^n e^{in\varphi}$$

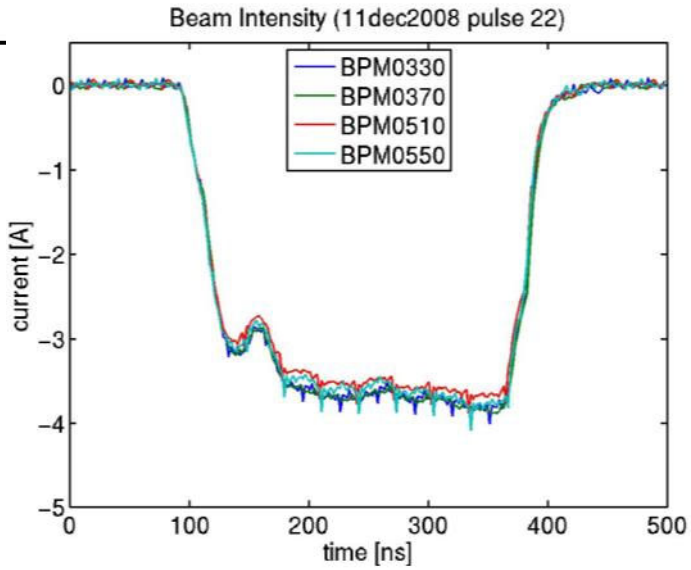
- Accurate prediction generated power
- c_{cal} from bunch length, coupling, ohmic efficiency → data fit
- 180° phase shift kills recirculation

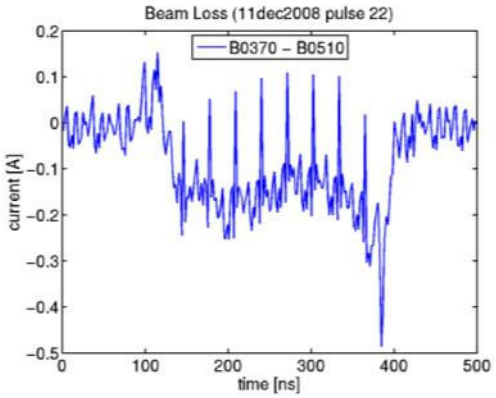




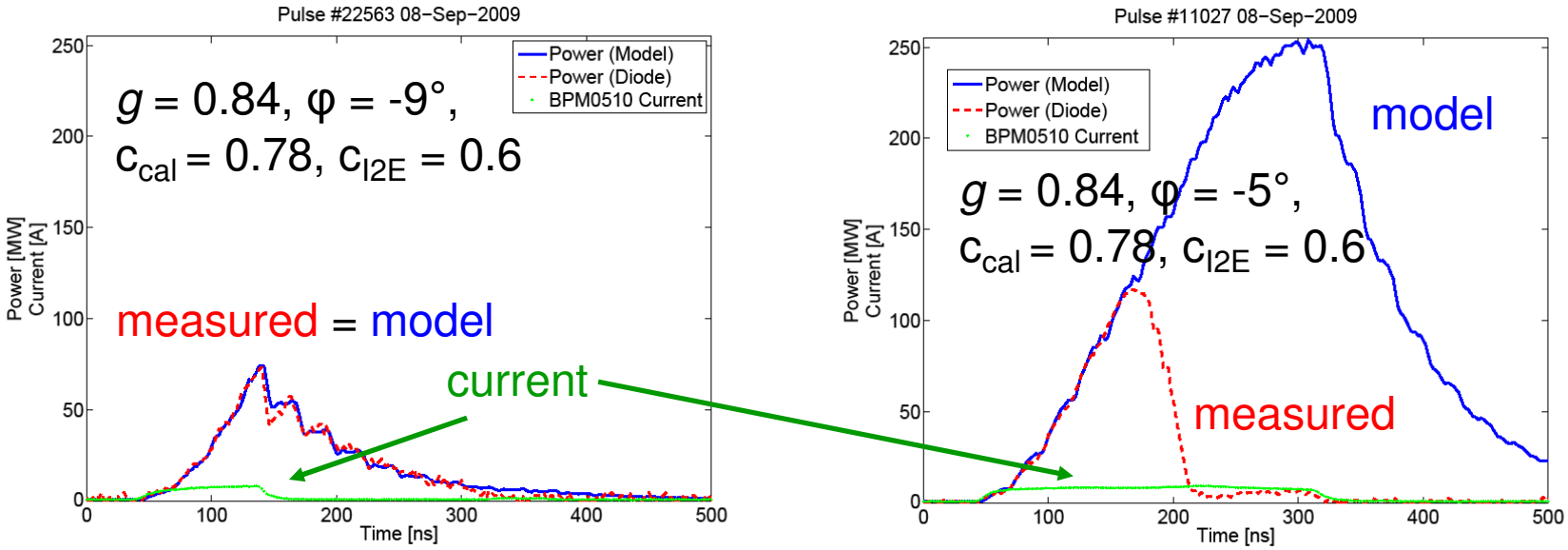
Power Production with Recirculation







Power Reconstruction



- Parameters constant during normal operation
  → predicts PETS output power
- Accurate parameter fit rising slope
  → gives recirculation loop loss factor and phase shift
- Energy difference (ε) measurement and model indicates ”pulse shortening” → breakdown indicator

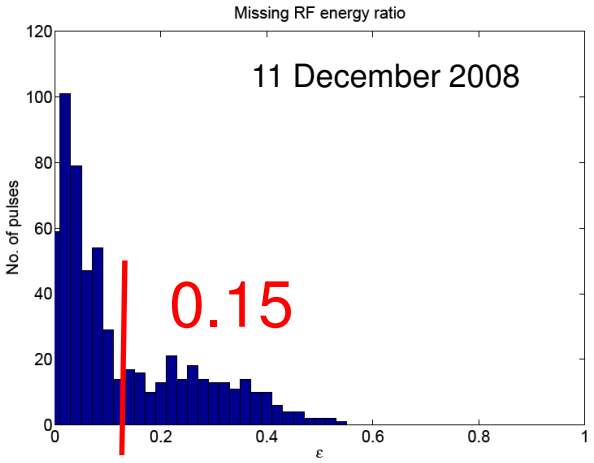
Energy difference measurement and model

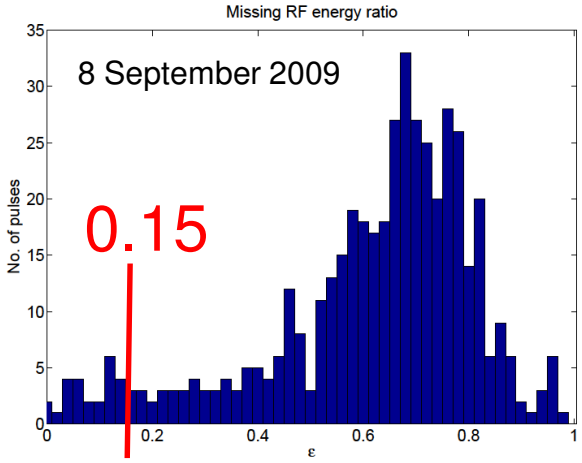
- Energy difference ε

$$\varepsilon = \left| \frac{E_{\mathrm{mod}} - E_{meas}}{E_{\mathrm{mod}}} \right|$$

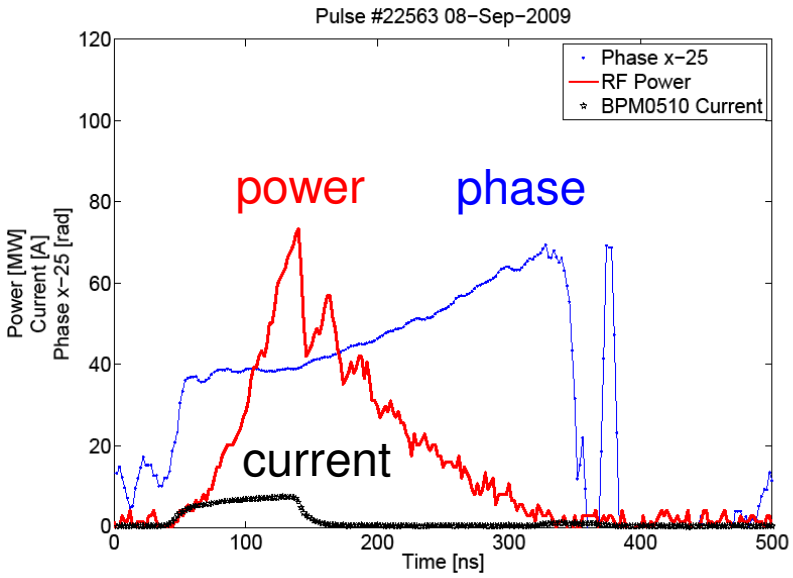
- Limitations:
  - beam current measurement
  - determine efficient value ε

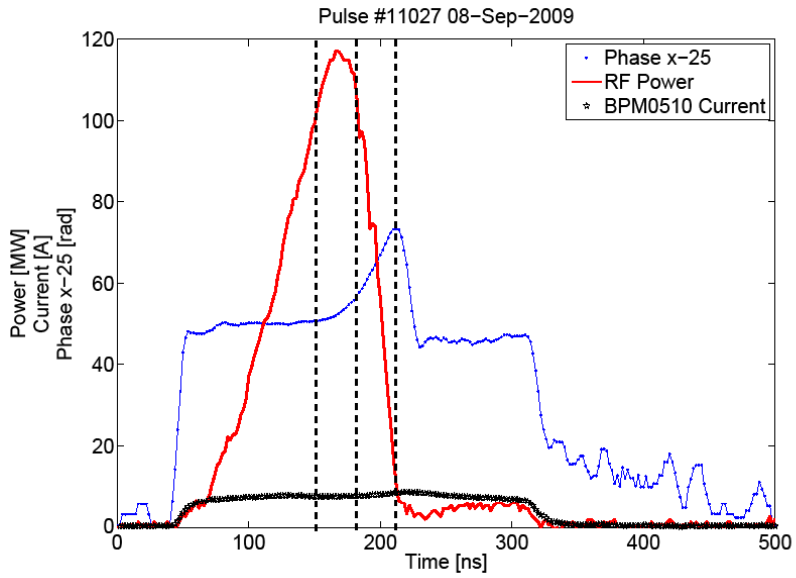
- MATLAB algorithms developed for parameter fit, reconstruction and breakdown detection





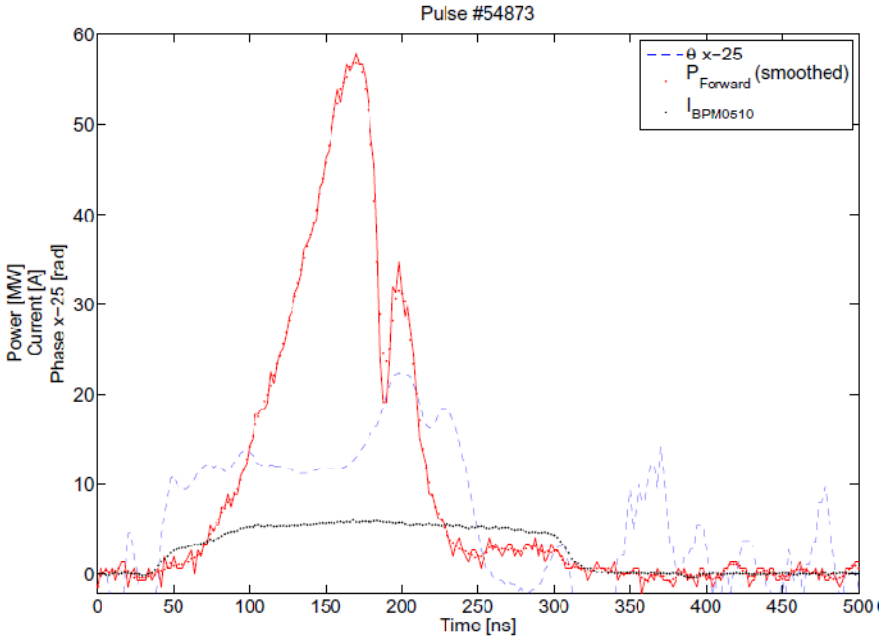
Phase Reconstruction

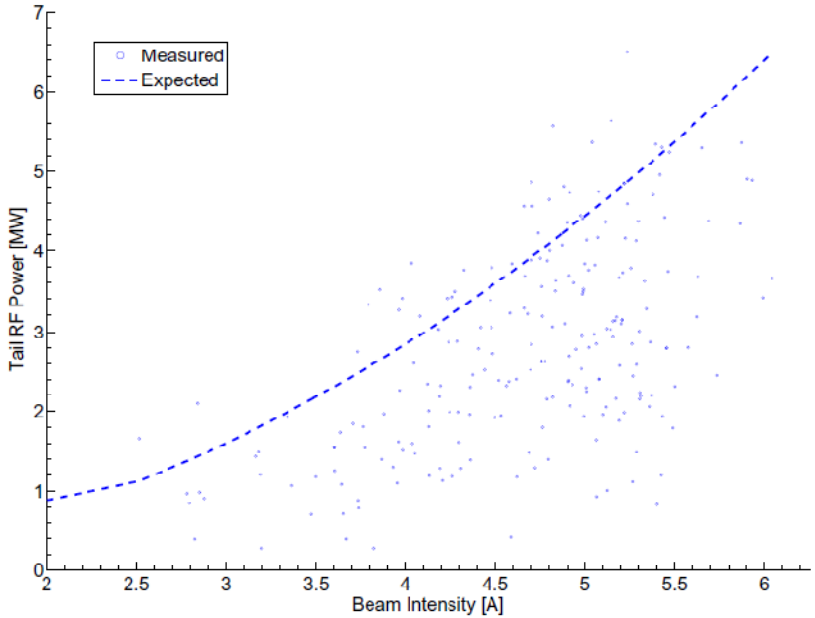




- Strong phase change around point of ”pulse shortening”
- Effect visible in all pulses with ”shortening”
  → useful for breakdown detection
- Automatic MATLAB algorithm developed,
  see CLIC report by Chris Hellenthal (http://cern.ch/ctf3-tbts)

Breakdown Recovery

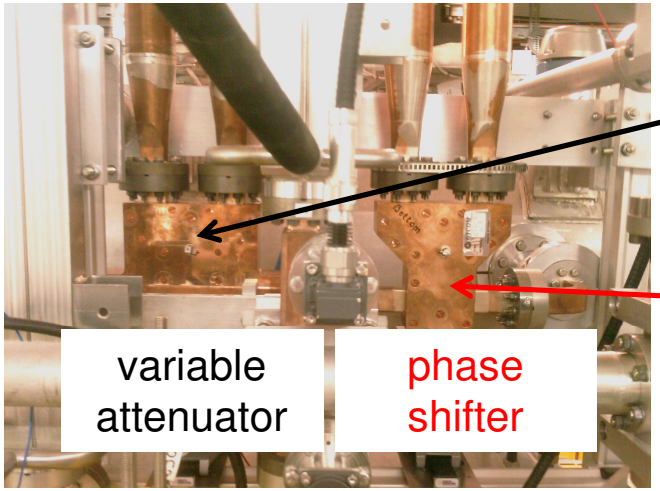


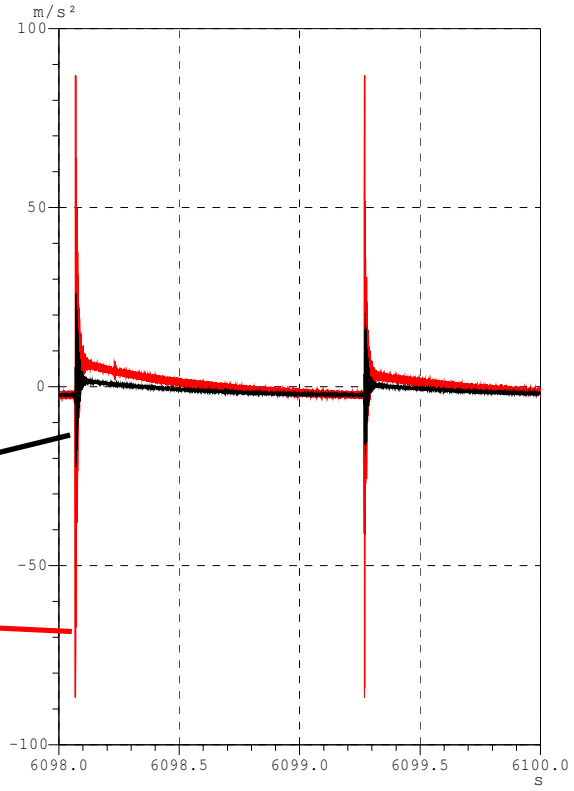


- Left: breakdown with recovery
  - Halfway falling slope, output power recovery with new peak
  - Valley-to-plateau ~16ns (compare recirculation time = 26ns)
  - No full decay of output power: stabilizes ~3MW
  - Expect 4.4MW at 5A w/o recirculation
- Right: plot of tail power

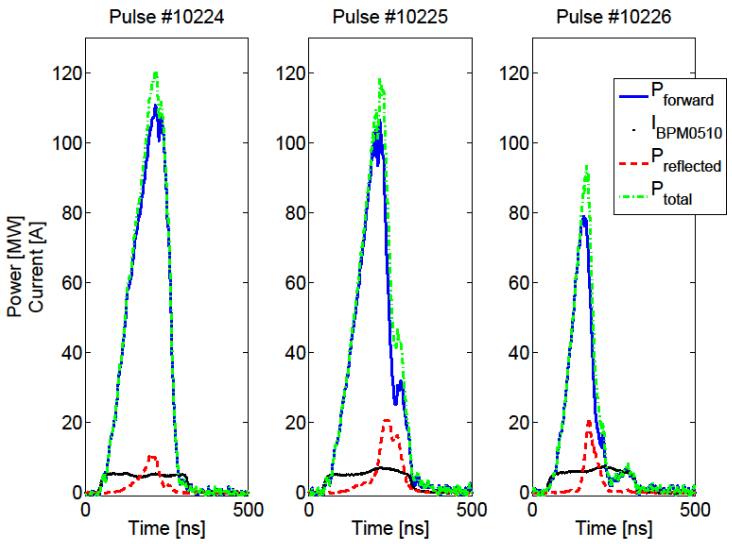
Breakdown Location

- No visible light observed in PETS
  Camera was connected for several days, nothing observed.
- Breakdown recovery expected different if breakdown inside PETS (restart recirculation)
- Accelerometer on variable attenuator and phase shifter show large activity at each pulse.

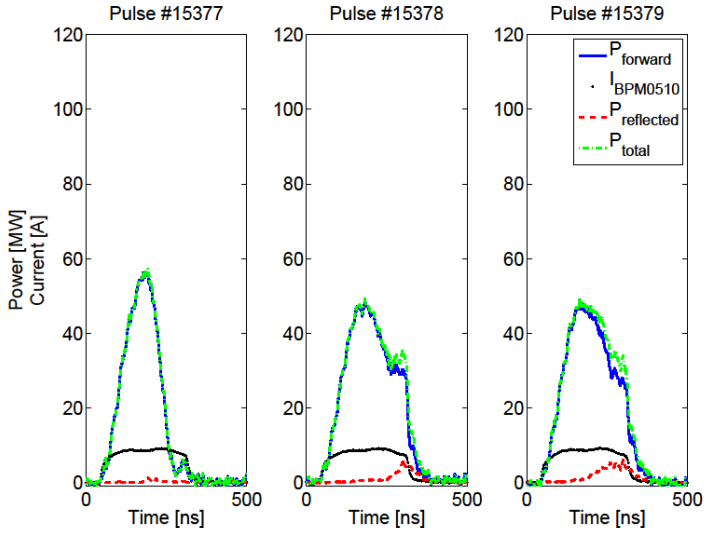




Behaviour Reflected Power

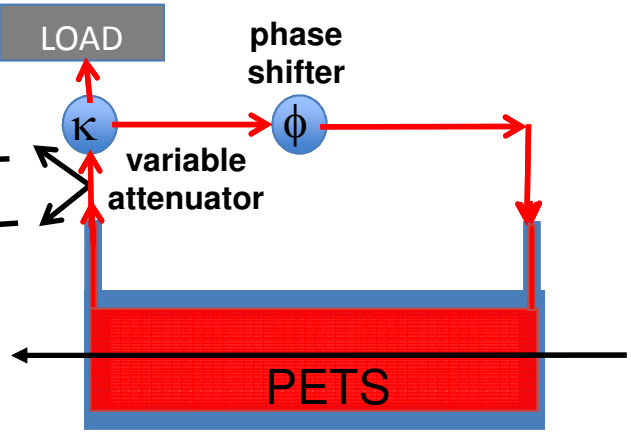


8 Sep. 2009 11:50 ($g = 0.96$, $\varphi \approx 0°$)
full recirculation

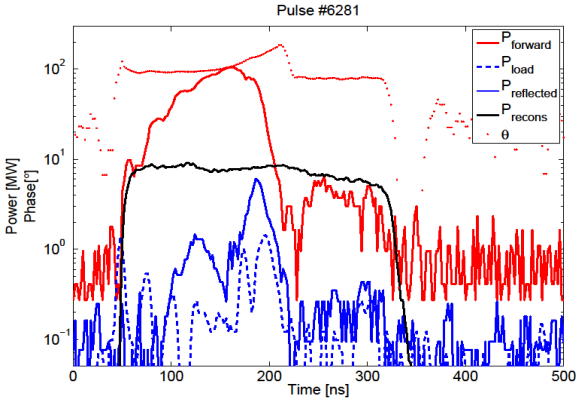


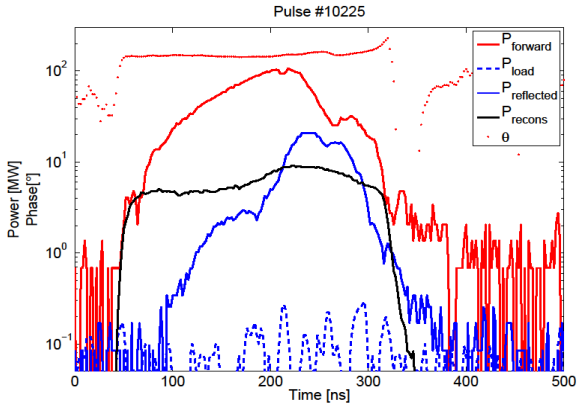
8 Sep. 2009 14:22 ($g = 0.49$, $\varphi \approx 0°$)
half recirculation

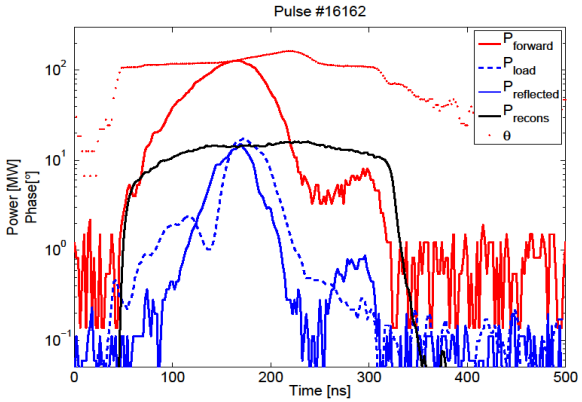
- Comparing PETS output
- Non-linear relation $P_{forward}$ and $P_{reflected}$



Activity in Variable Attenuator?

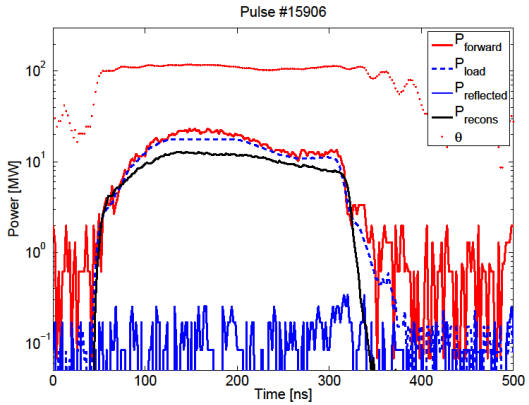






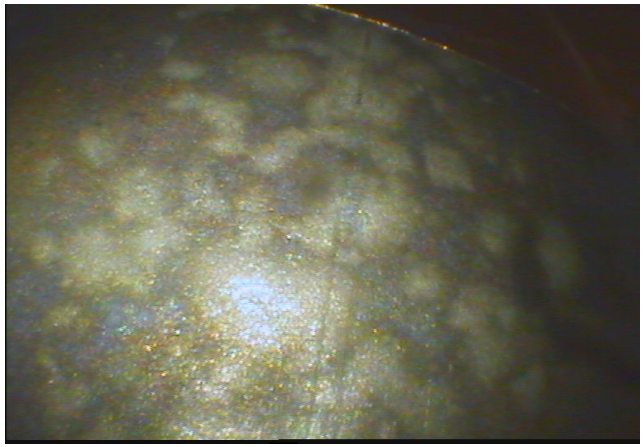
three pulses: full recirculation

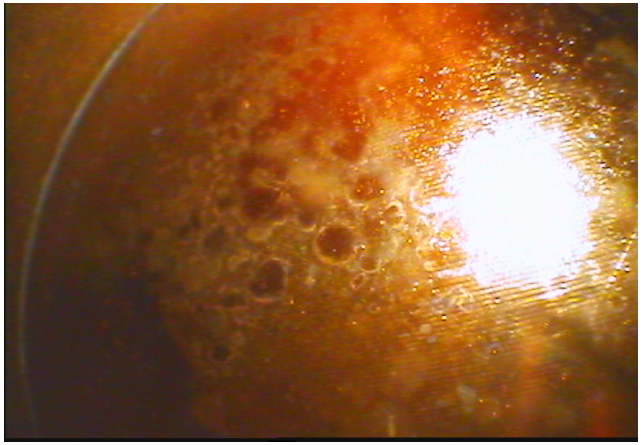
- also P_{load} not linear with $P_{forward}$
- suspect activity in variable attenuator
  →replaced by waveguide

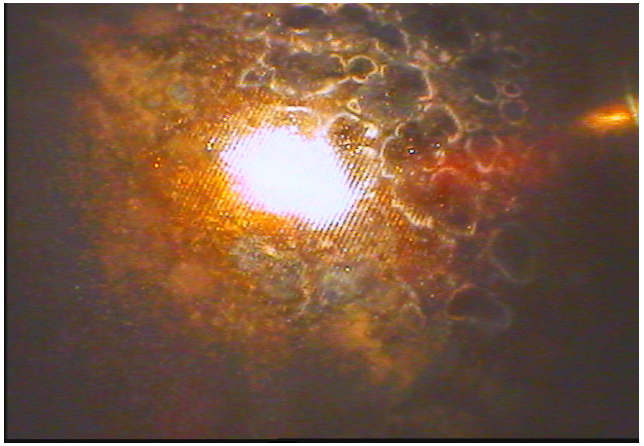


08-Sep-2009 14:38 (g = 0.22, $\varphi \approx 0°$)

Inspection Variable Attenuator







Beam Kick Measurements

- 5 BPMs: incoming angle & offset, kick angle
- dipole + BPM5 for energy measurement

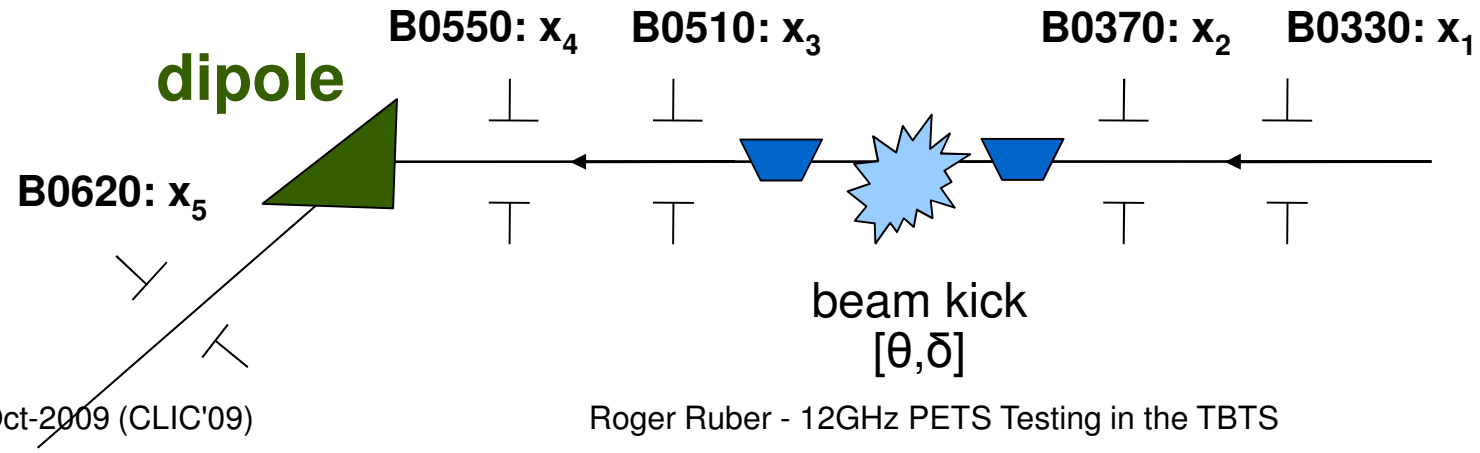
$$\vec{x} = A\vec{\theta}$$

$$\vec{\theta} = (A^t A)^{-1} A^t \vec{x}$$

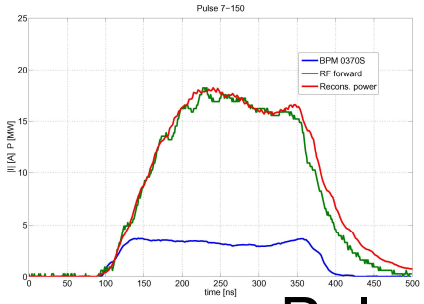
$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ R_{11}^{12} & R_{12}^{12} & 0 & 0 \\ R_{11}^{13} & R_{12}^{13} & R_{12}^{c3} & 0 \\ R_{11}^{14} & R_{12}^{14} & R_{12}^{c4} & 0 \\ R_{11}^{15} & R_{12}^{15} & R_{12}^{c5} & D^5 \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \\ \theta \\ dp/p \end{pmatrix}$$

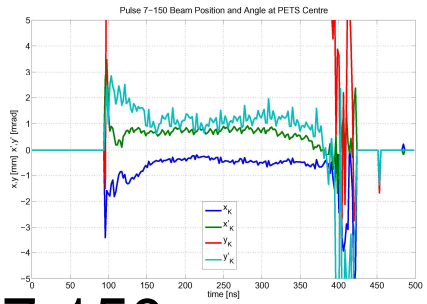
- PETS beam kick estimate: (point like bunch, 15GHz)

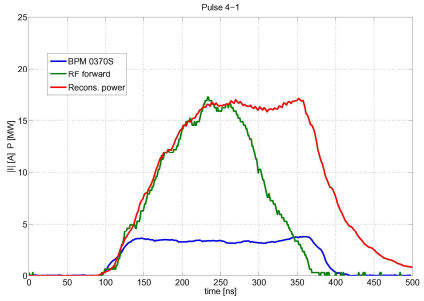
$$\theta / x_P = 2 \frac{L_{\mathrm{PETS}}}{E_{tot}} e \frac{I}{f_{\mathrm{bunch}}} k_1' = 27 \mu\mathrm{rad/mm}$$

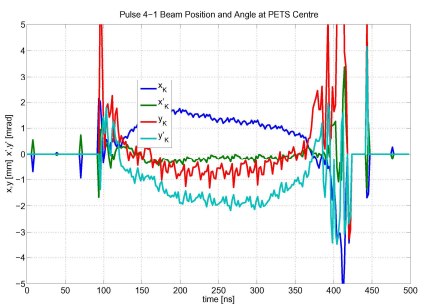


Beam Kick Measurements

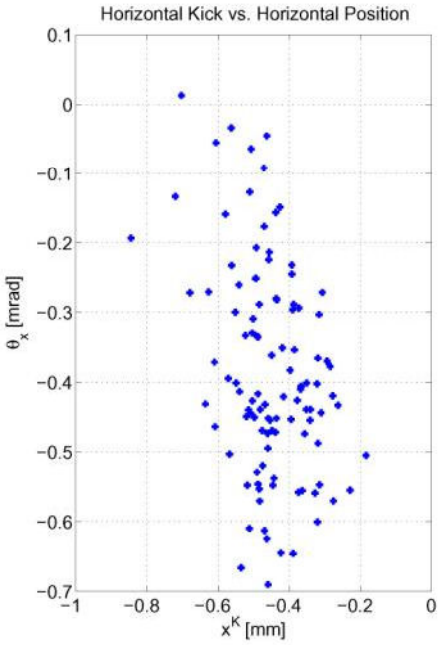


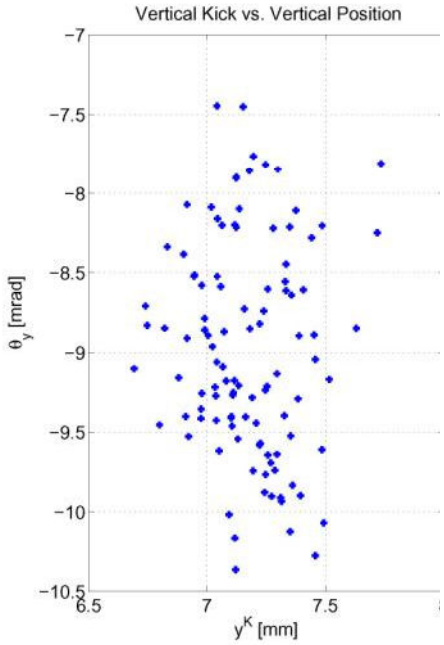




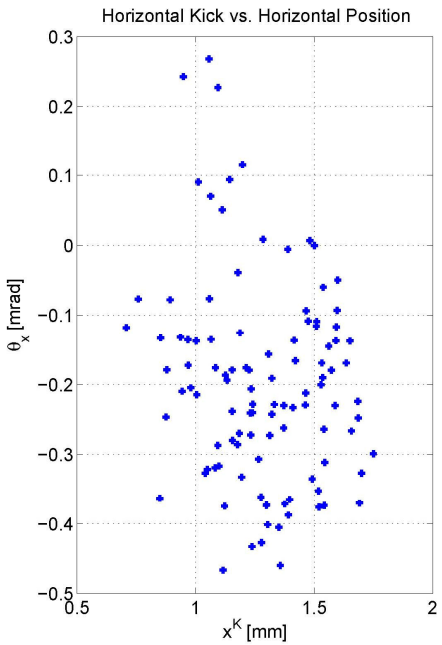


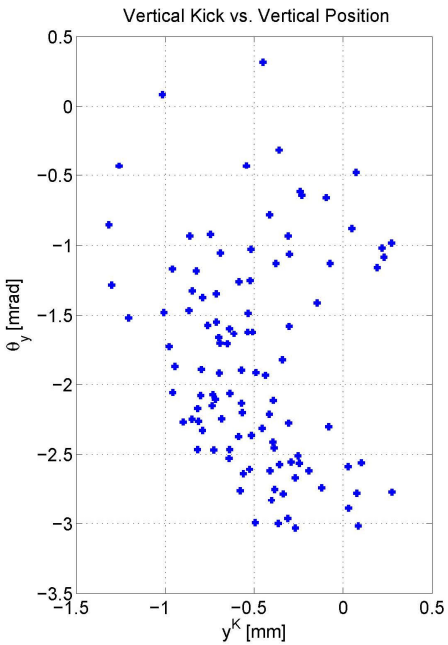
Pulse 7-150





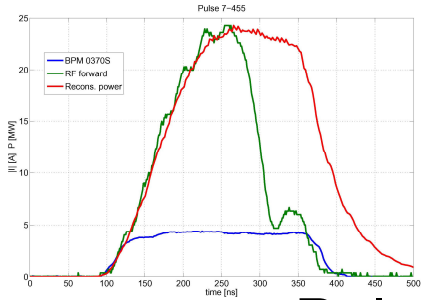
Pulse 4-1

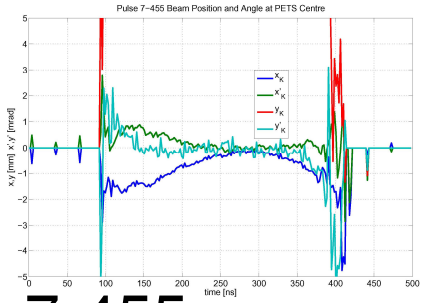


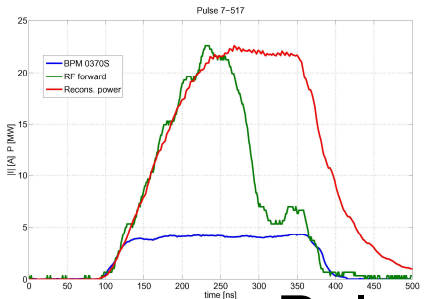


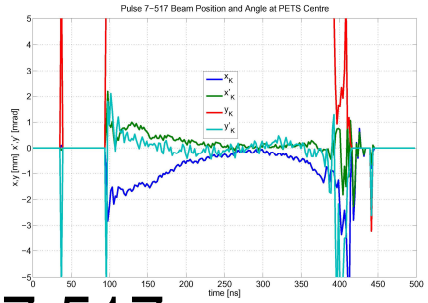
- No clear correlation b/w kick and position

Beam Kick Measurements

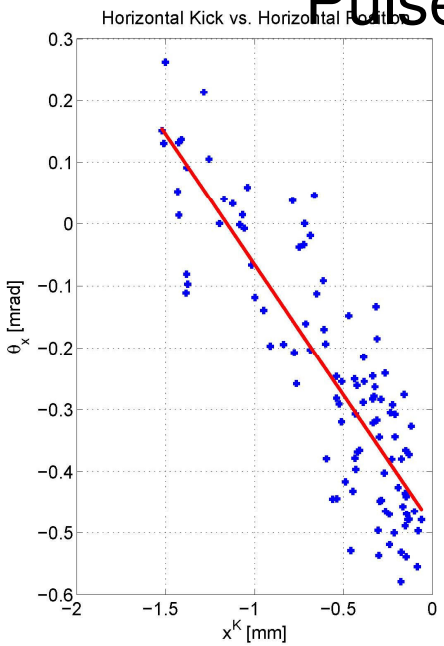


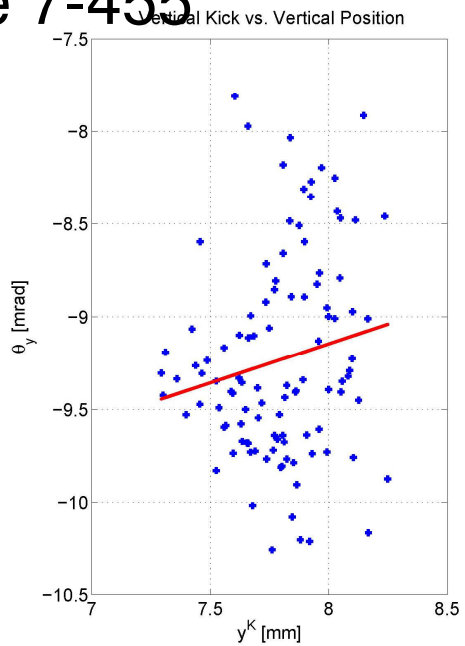




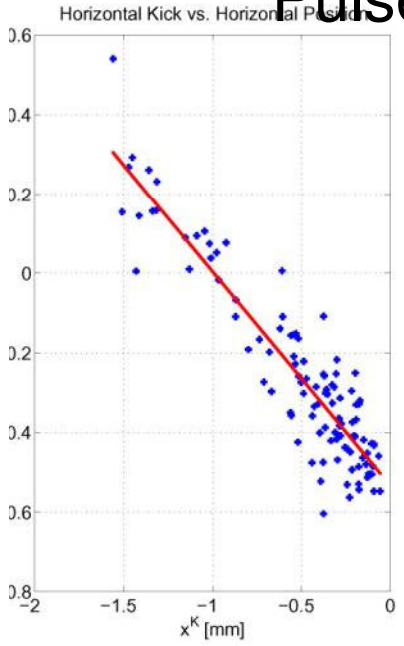


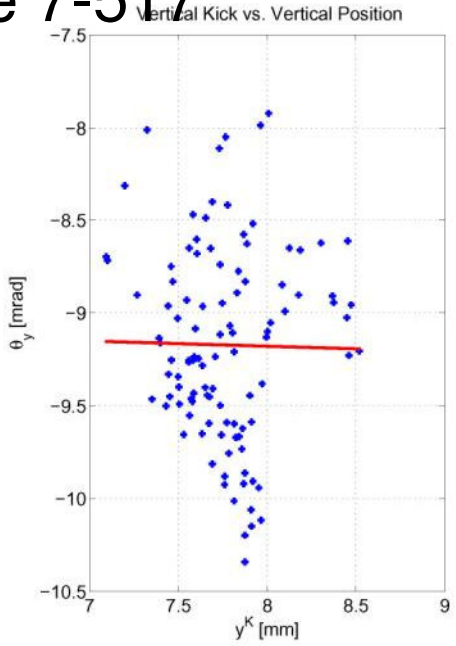
Pulse 7-455





Pulse 7-517





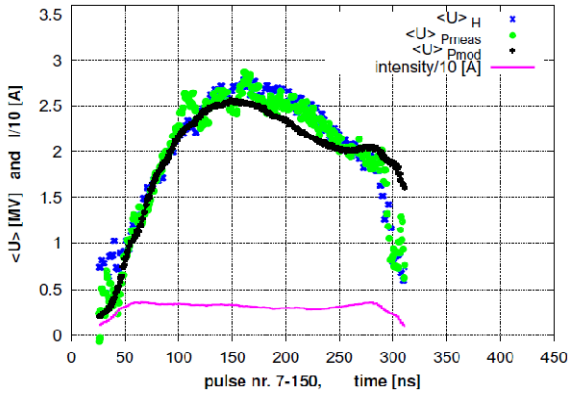
- Horizontal kick vs. position: -042 and -0.54mrad/mm
- Larger than prediction, different from pulse 4-1: WHY?

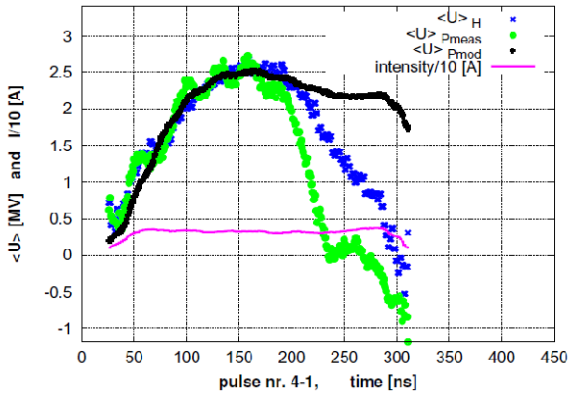
Beam Energy Loss Measurements

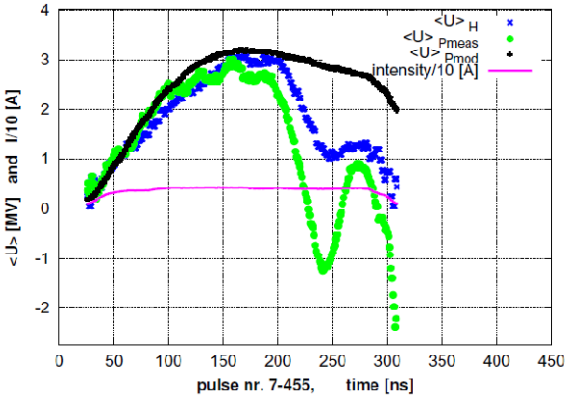
Energy loss estimation based on (see E. Adli, CTF3 Note 097)

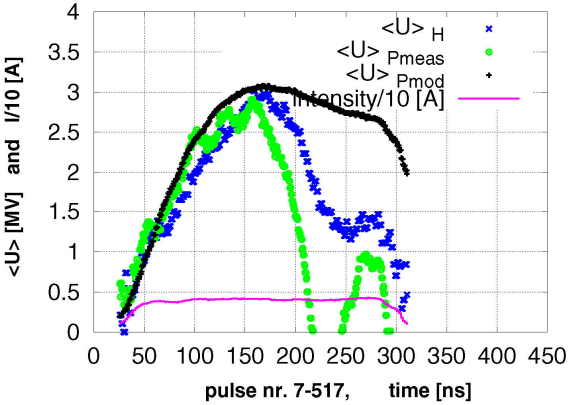
- BPM position measurements (blue)
- Beam intensity and PETS output power (green)
- Beam intensity only (black)

→ difference related to pulse shortening









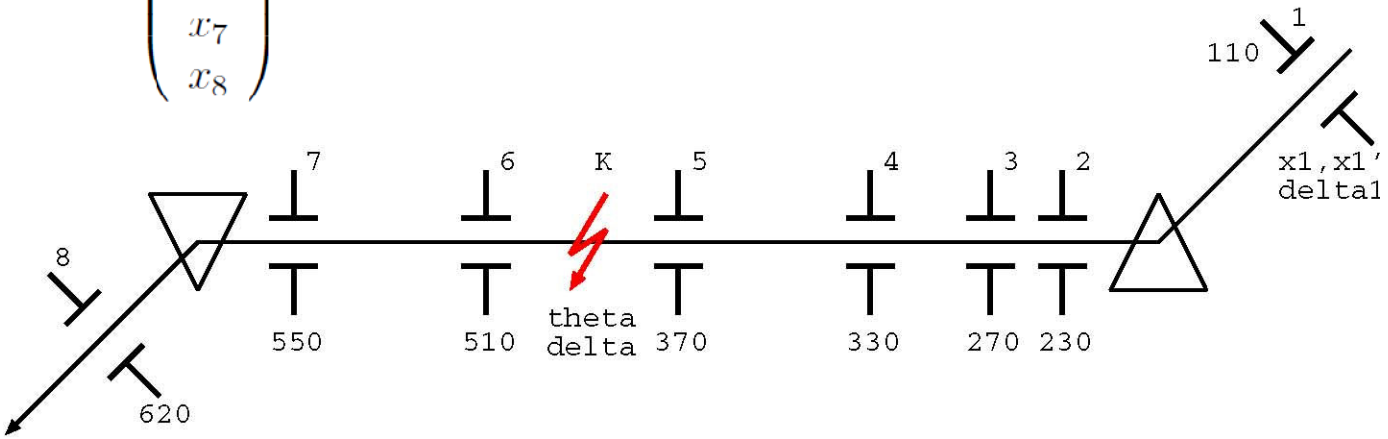
(same example pulses)

Kick Determination with Initial Energy Variation

To adjust for incoming beam energy variation:

- Add incoming beam energy: δ_1
- Now included in measurements, data to be analyzed

$$\begin{pmatrix} x_1 \\ x_1' \\ \delta_1 \\ \theta \\ \delta \end{pmatrix} = (\Lambda^t \Lambda)^{-1} \Lambda^t \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{pmatrix}$$



Conclusions

- Two-beam Test Stand up & running!
- Promising results,
  - started to study details of power production, beam kick and beam dynamics
- During winter shutdown, installation
  - accelerating structure
  - additional beam & breakdown diagnostics
- Keep an eye on our web site http://cern.ch/ctf3-tbts

- Thanks to all colleagues
  especially maintenance, operation & control teams!