PETS Conditioning and Breakdown Analysis

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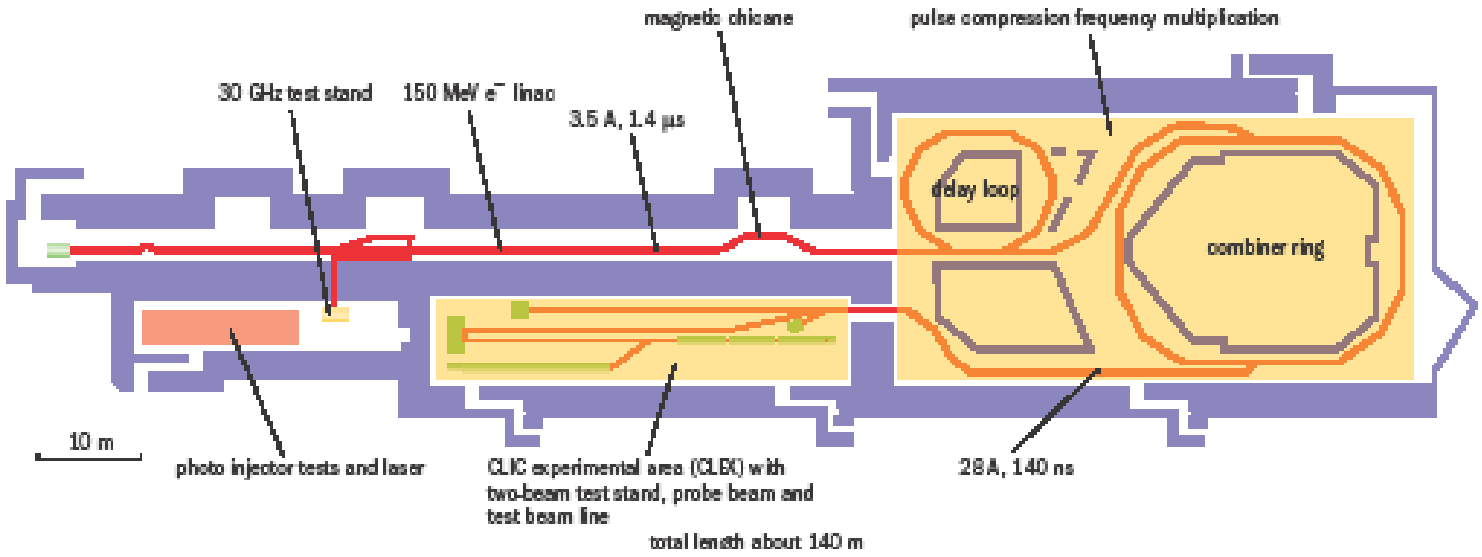
CTF3 / TBTS


magnetic chicane
pulse compression frequency multiplication
30 GHz test stand
150 MeV e⁻ linac
3.5 A, 1.4 μs
delay loop
combiner ring
10 m
photo injector tests and laser
CLIC experimental area (CLEX) with two-beam test stand, probe beam and test beam line
total length about 140 m
28 A, 140 ns

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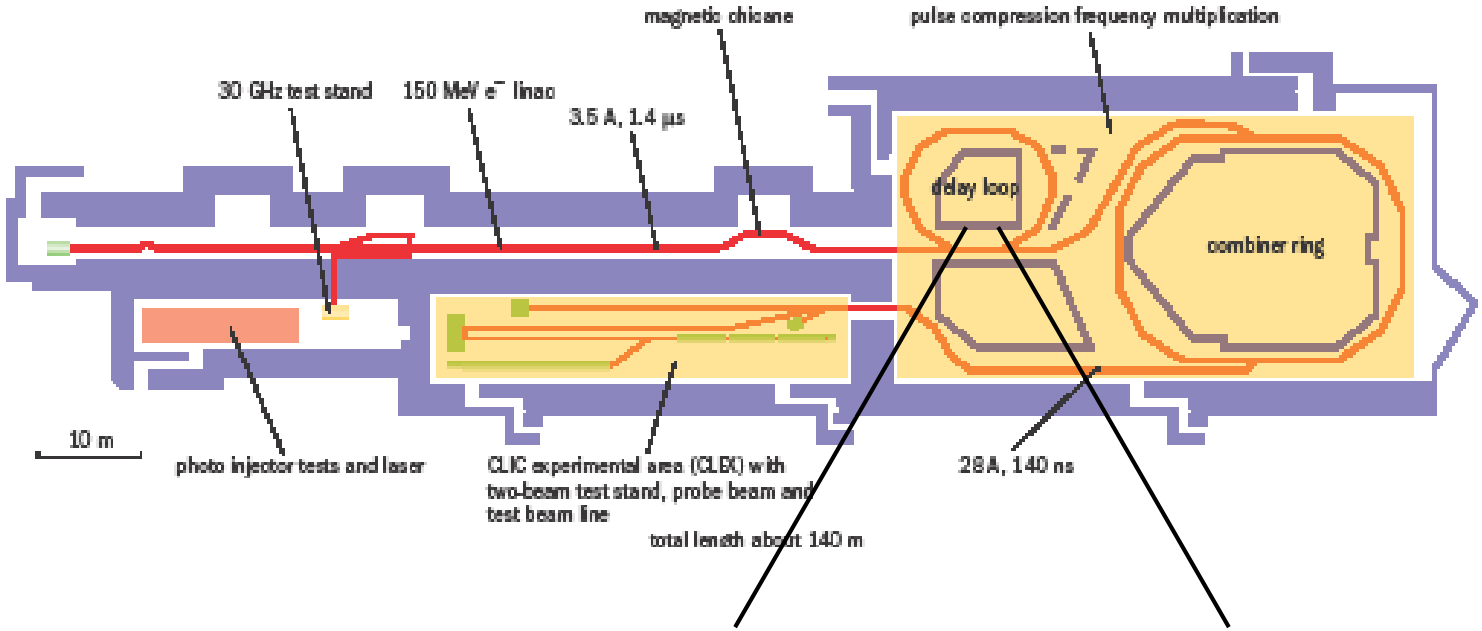

[1]

[1] Courtesy F. Tecker

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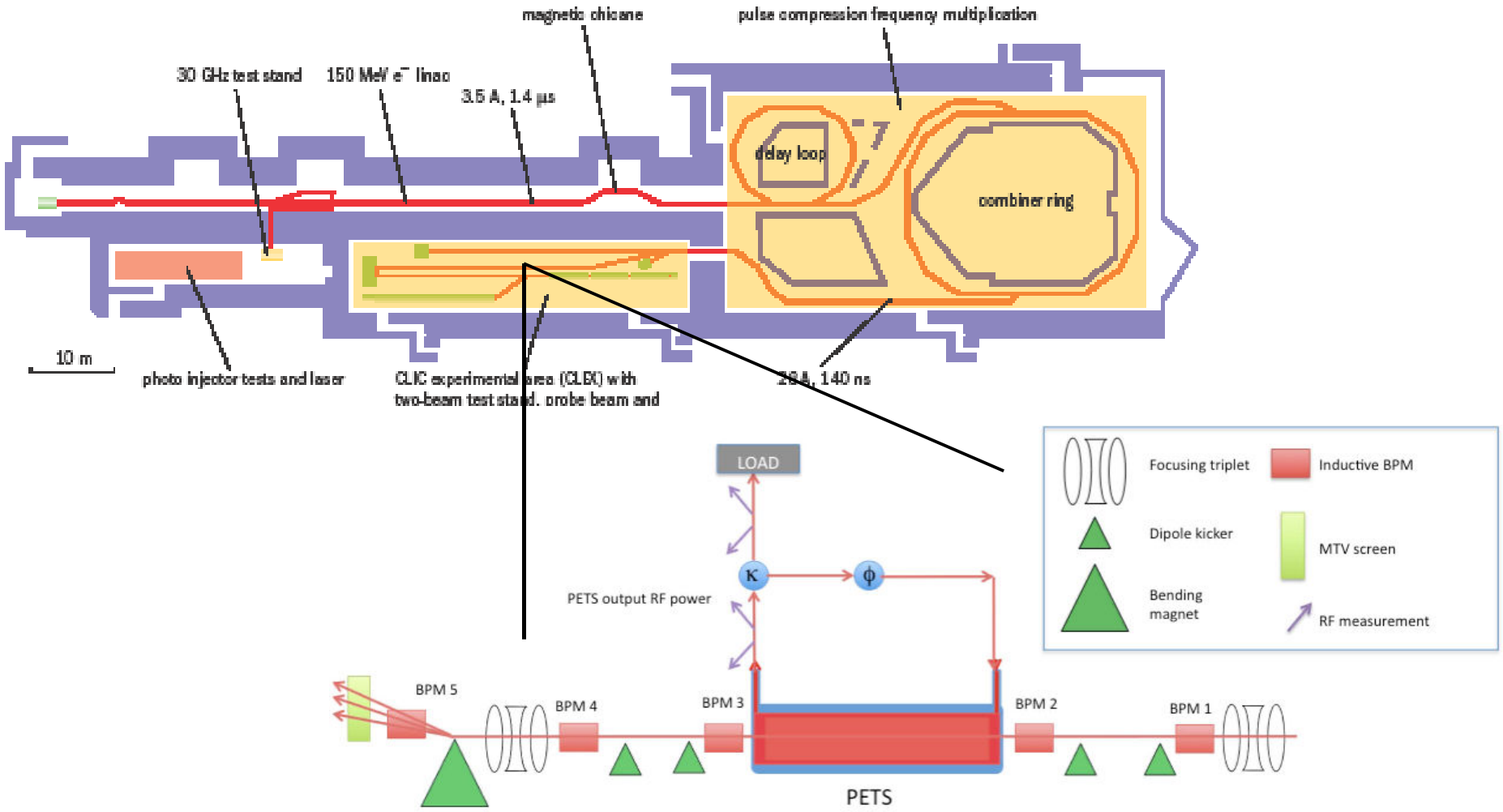
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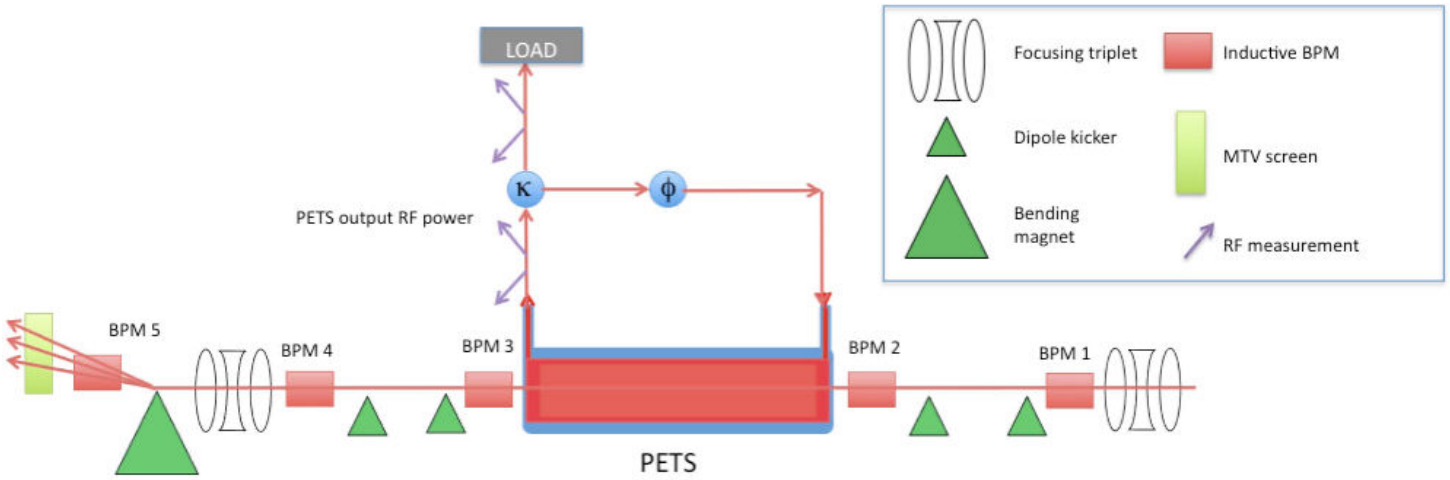
CLIC experimental area (CLEX) with two-beam test stand, probe beam and
28 A, 140 ns
LOAD
PETS output RF power
κ
ϕ
BPM 5
BPM 4
BPM 3
BPM 2
BPM 1
PETS
Focusing triplet
Inductive BPM
Dipole kicker
MTV screen
Bending magnet
RF measurement

Recirculation

$$E_n = E_0 g^n e^{in\varphi}$$ (Single Bunch)

$$E_{n+1} = E_n g e^{i\varphi} + c_{I2E} I_{beam}$$ (All bunches)

$$P_n \propto c_{cal}{}^2 E_n{}^2$$



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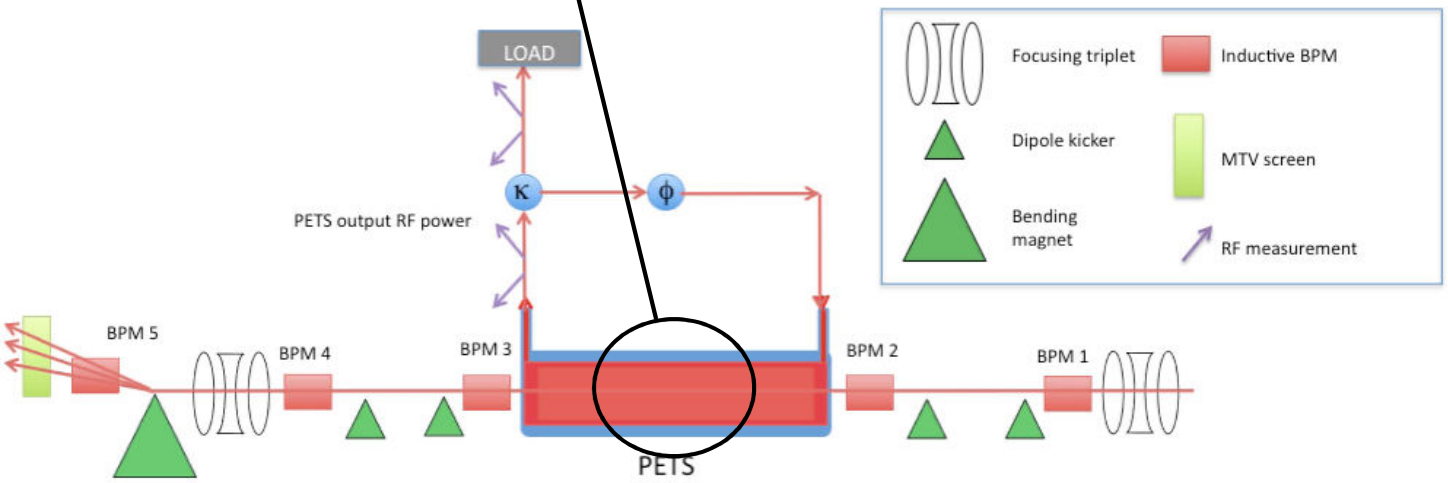

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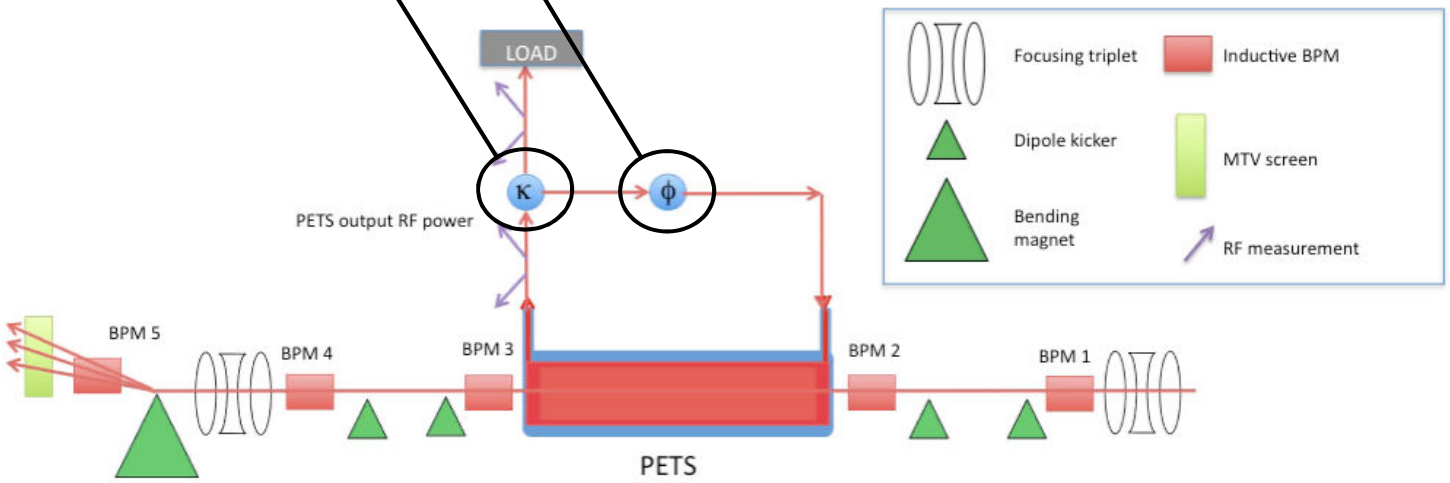

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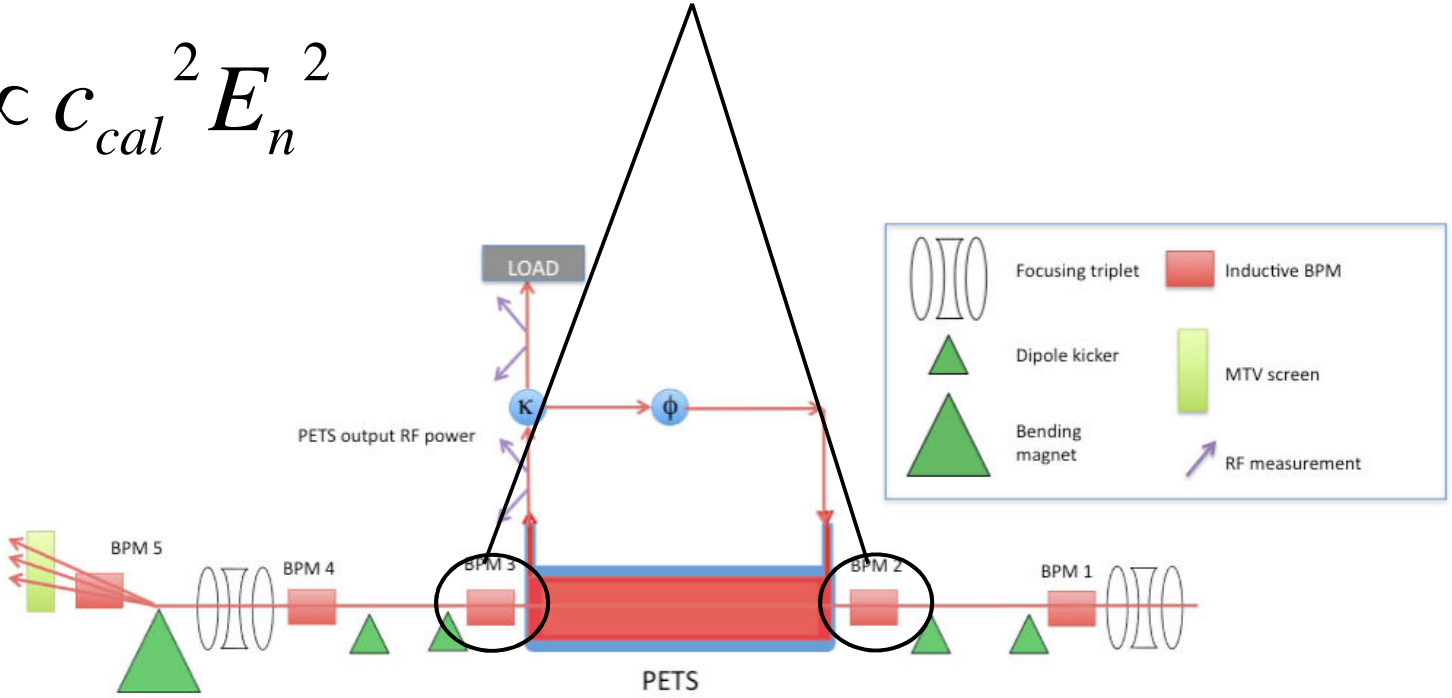
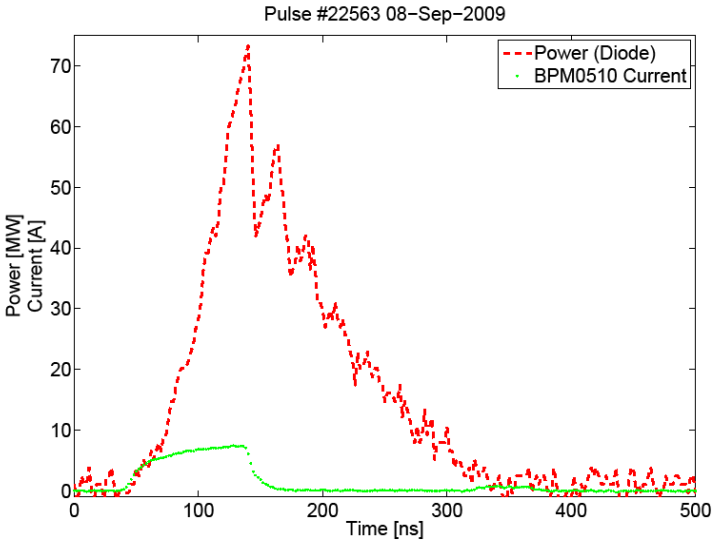


Power Reconstruction

- Parameters will be constant during normal operation
  - So power production can be predicted

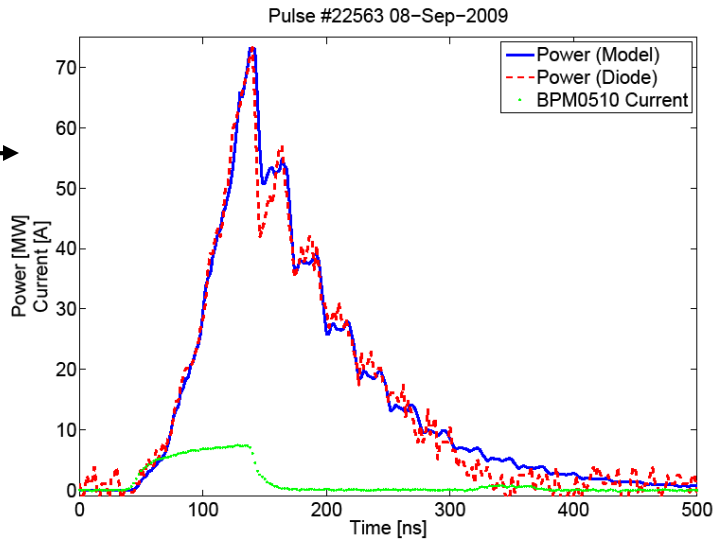


$g = 0.840$

$\phi = -9°$

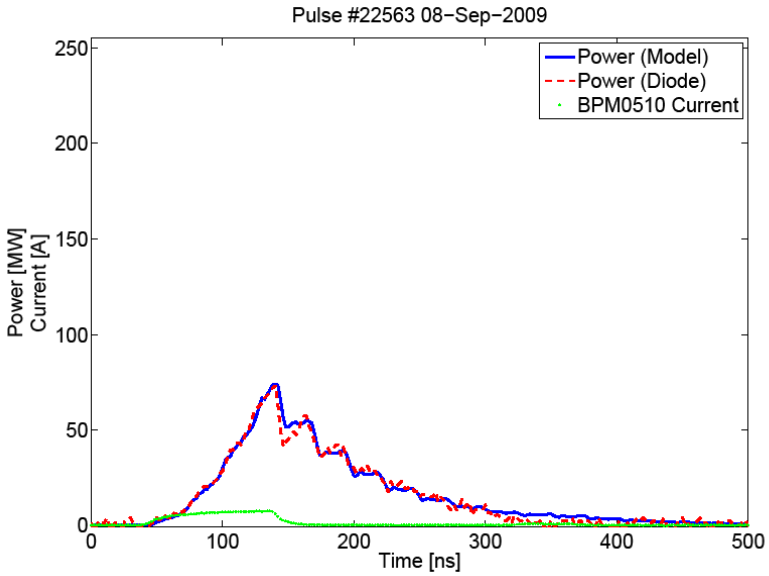
$c_{cal} = 0.78$[1]

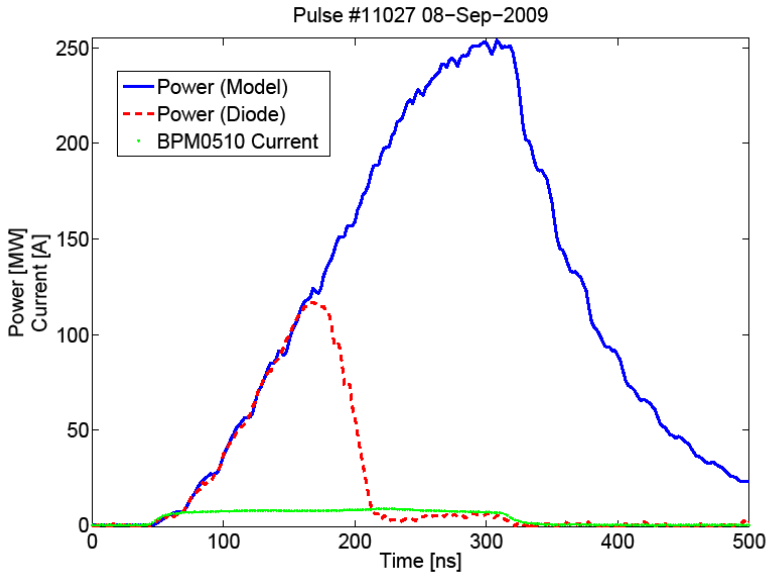
$c_{I2E} = 0.6$[1]



[1] E. Adli, CERN CTF3 Note 96

Power Reconstruction - Breakdown





g = 0.840 c_{cal} = 0.78

ϕ = -9° c_{I2E} = 0.6

g = 0.837 c_{cal} = 0.78

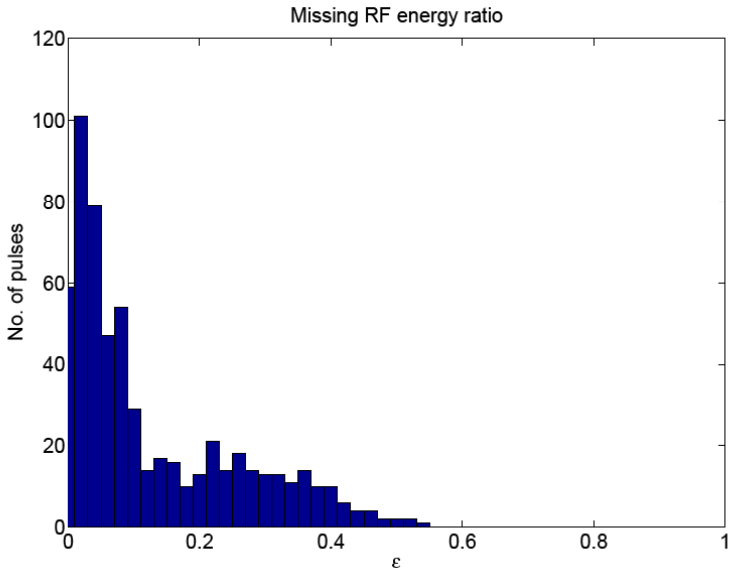
ϕ = -5° c_{I2E} = 0.6

Parameters no longer constant during/after breakdown

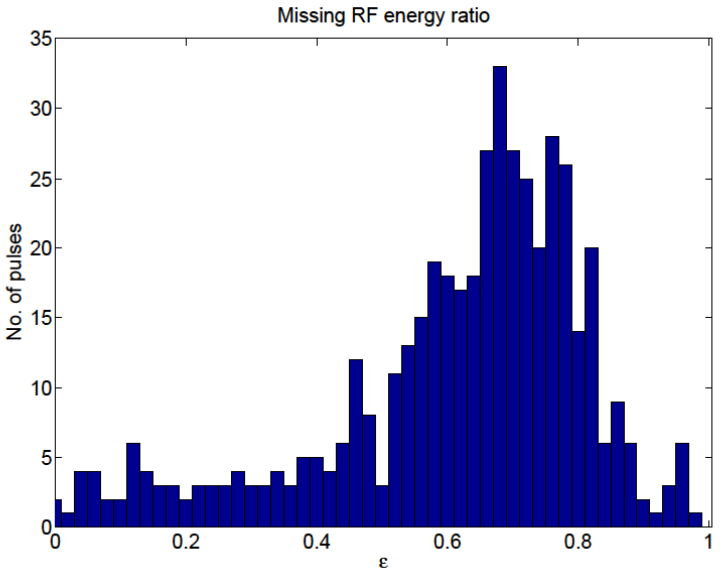
Breakdown Detection - Missing Energy

- Parameters typically fit rising slope closely
  - Therefore, reconstruction based on these parameters will over-estimate produced power in case of breakdown
- Define 'missing energy ratio': $\varepsilon = \left| \frac{E_{\mathrm{mod}} - E_{meas}}{E_{\mathrm{mod}}} \right|$
- Gives a single value that indicates the closeness between model and measured power
  - And thusly the probability of a breakdown occurrence
- Some limitations apply:
  - Accuracy of beam intensity measurements
  - Accuracy of logged/fitted parameters
  - Pulse to pulse fluctuations in system gain and system phase shift
  - Finding an efficient limit of ε

Missing Energy

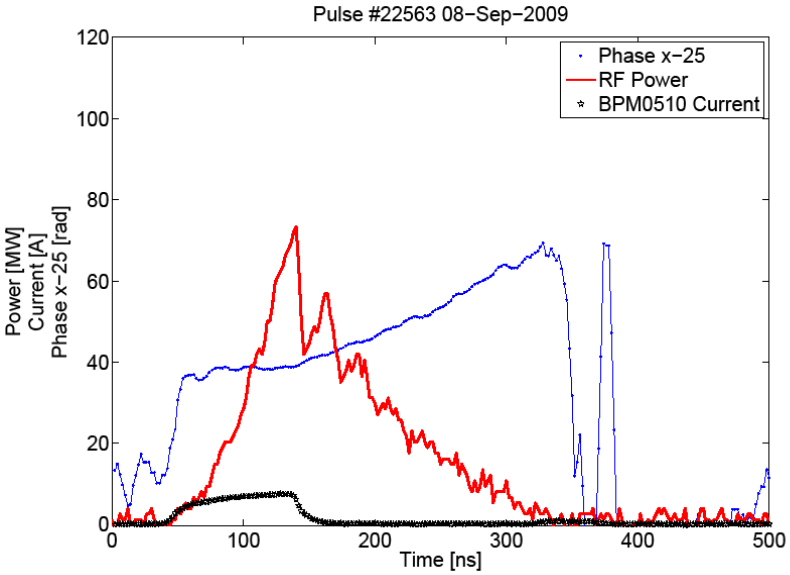


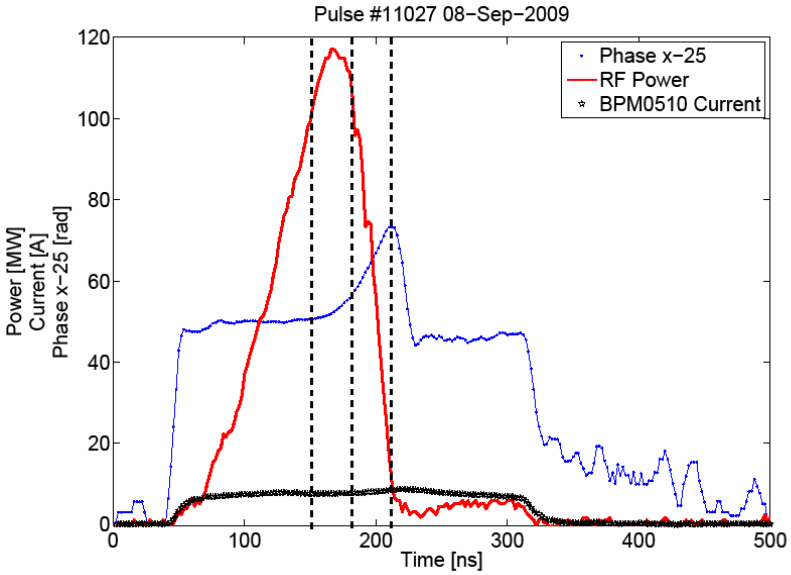
December 11th 2008



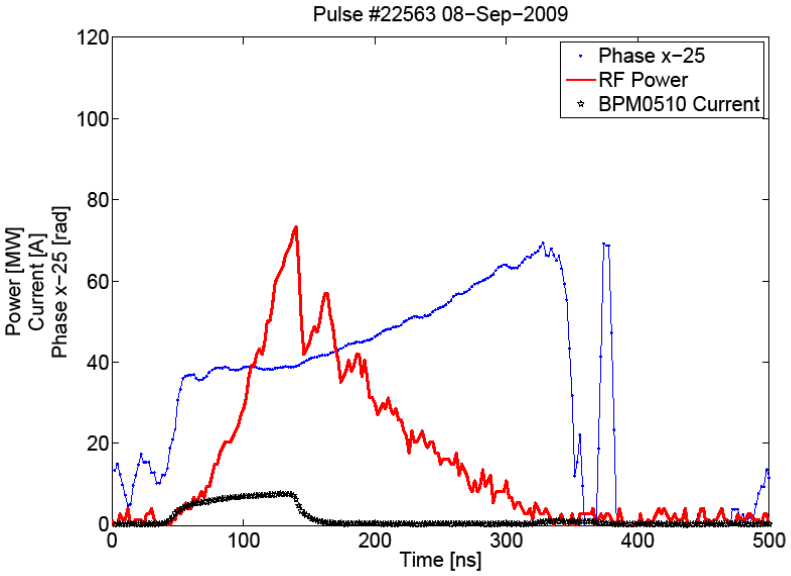
September 8th 2009

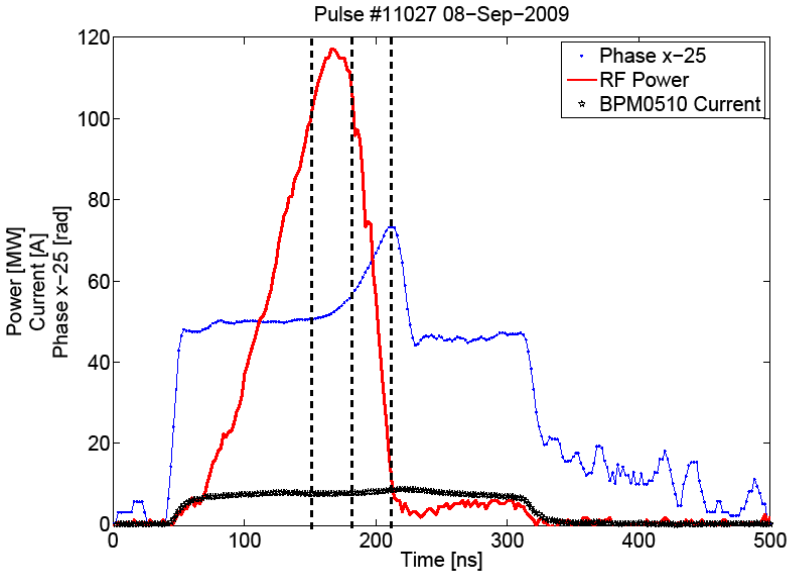
Field Phase


Pulse #22563 08−Sep−2009
Phase x−25
RF Power
BPM0510 Current
Power [MW]
Current [A]
Phase x−25 [rad]
Time [ns]
0
20
40
60
80
100
120
0
100
200
300
400
500


Pulse #11027 08−Sep−2009
Phase x−25
RF Power
BPM0510 Current
Power [MW]
Current [A]
Phase x−25 [rad]
Time [ns]
0
20
40
60
80
100
120
0
100
200
300
400
500

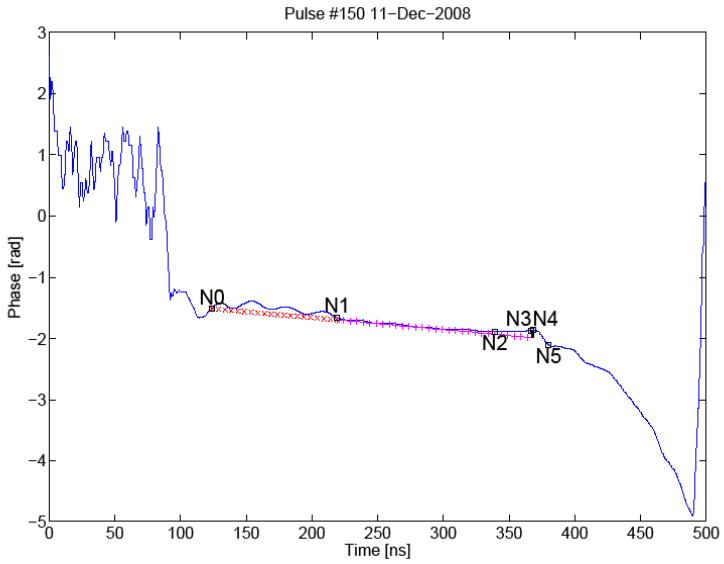
Field Phase

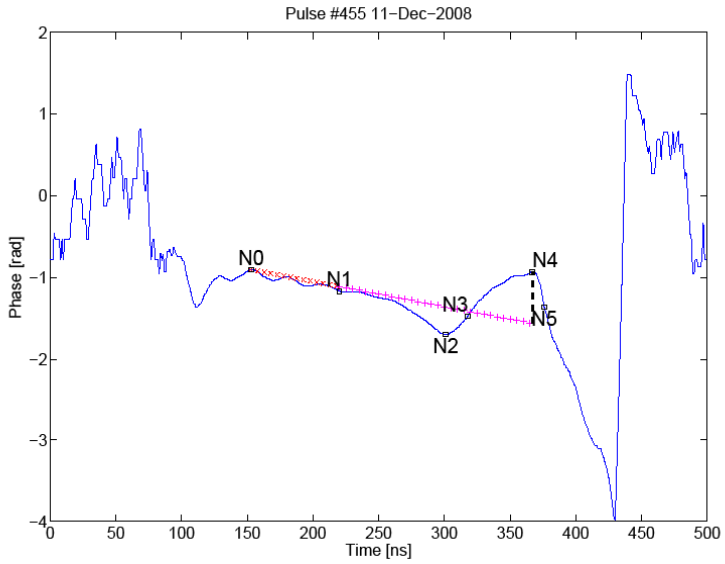




- This effect has been observed for nearly all breakdown pulses
  - Making it a good basis for another detection algorithm

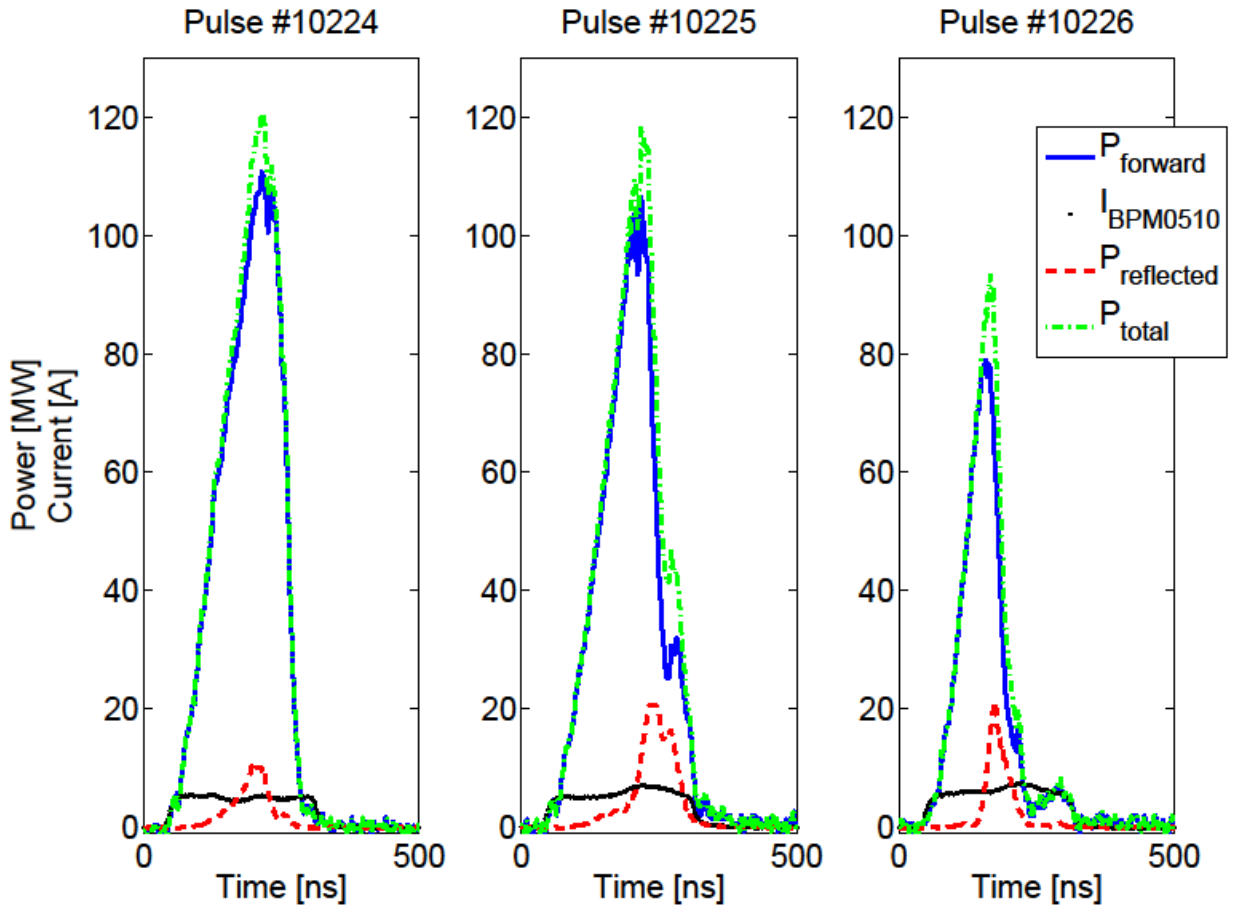
Breakdown Detection - Field Phase





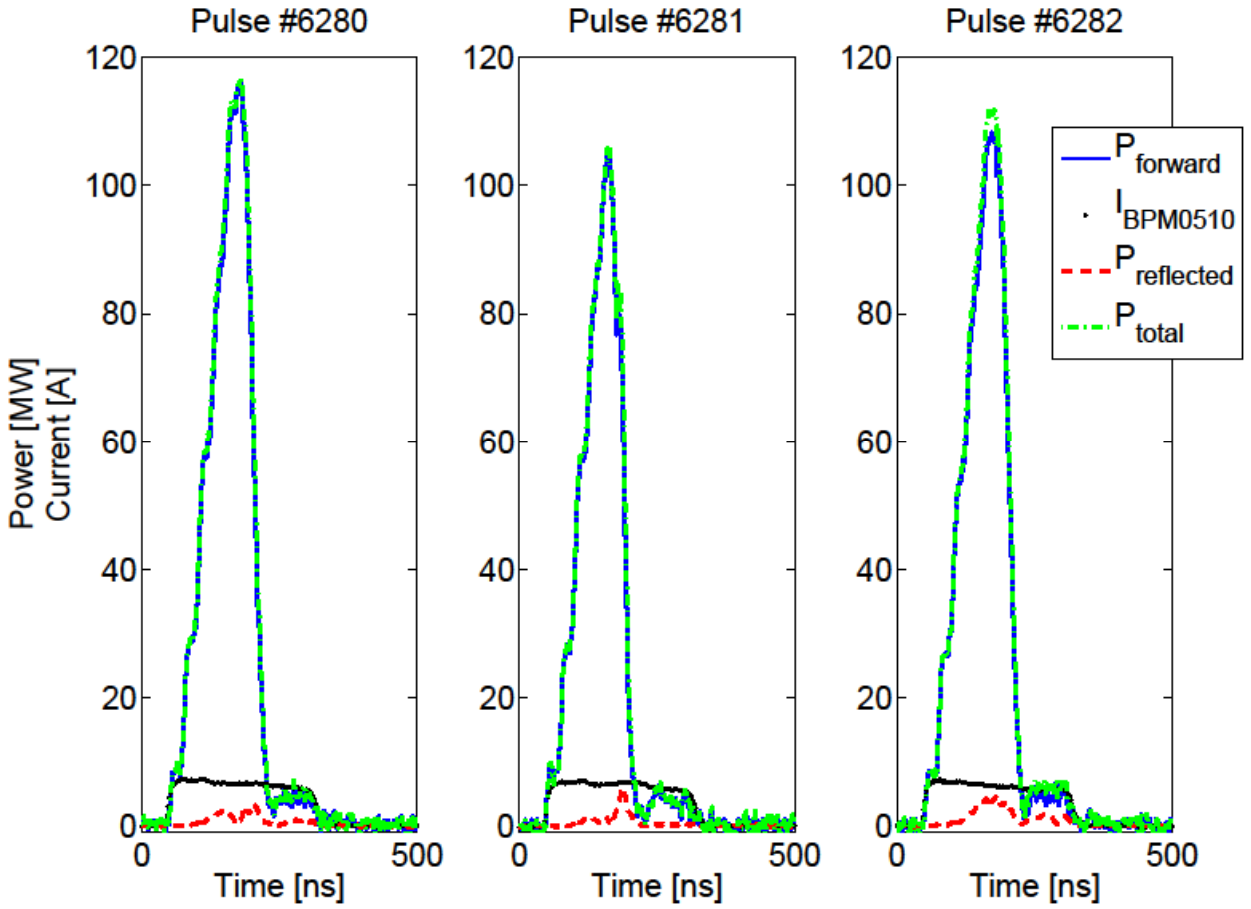
- Analyze interval where $I_{beam} \approx I_{max}$ (N0 – N5)
- Determine nominal slope (N0 – N1)
- Extrapolate slope (N1 – N4) and check actual vs. expected value
- Check difference between values at N2 and N4

Reflected Power



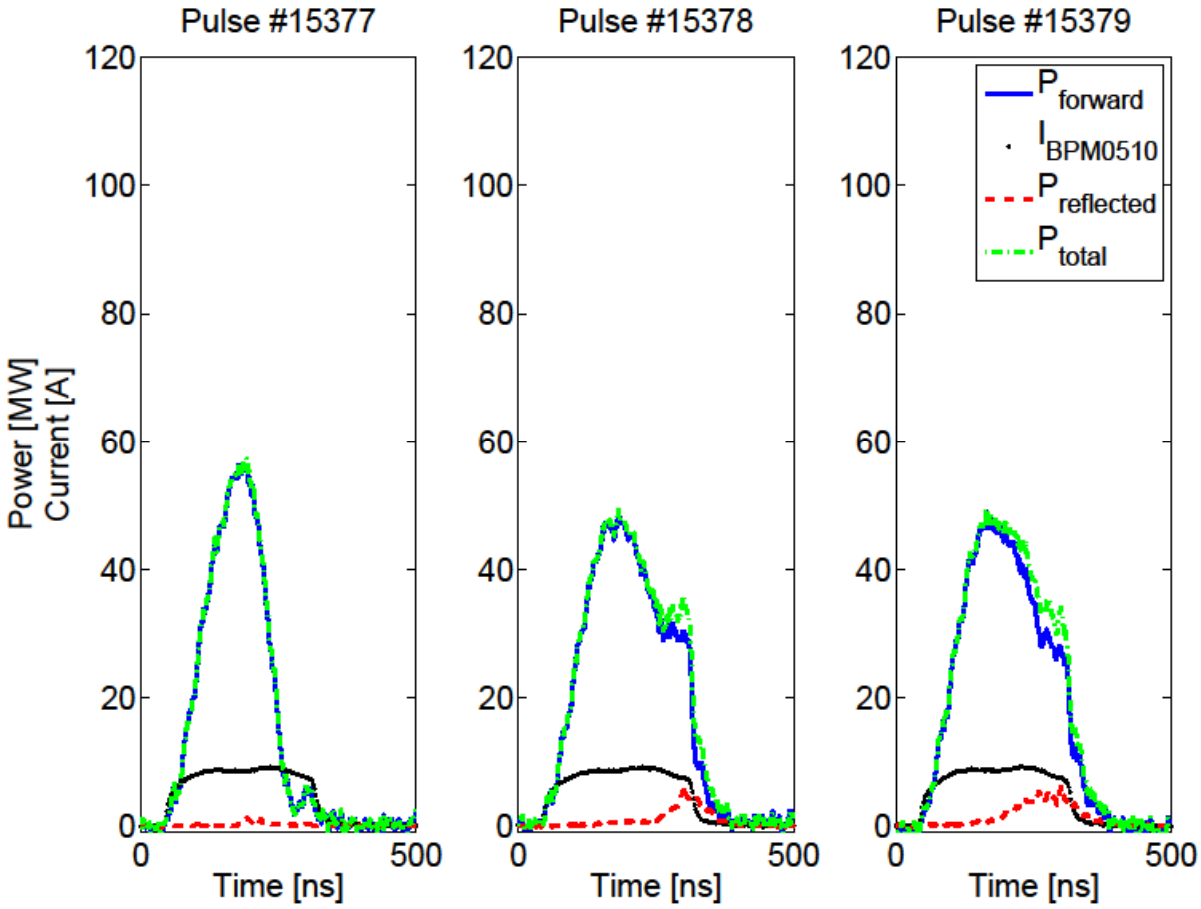
September 8th 11:50, full recirculation ($g = 0.96$, $\varphi \approx 0°$)

Reflected Power



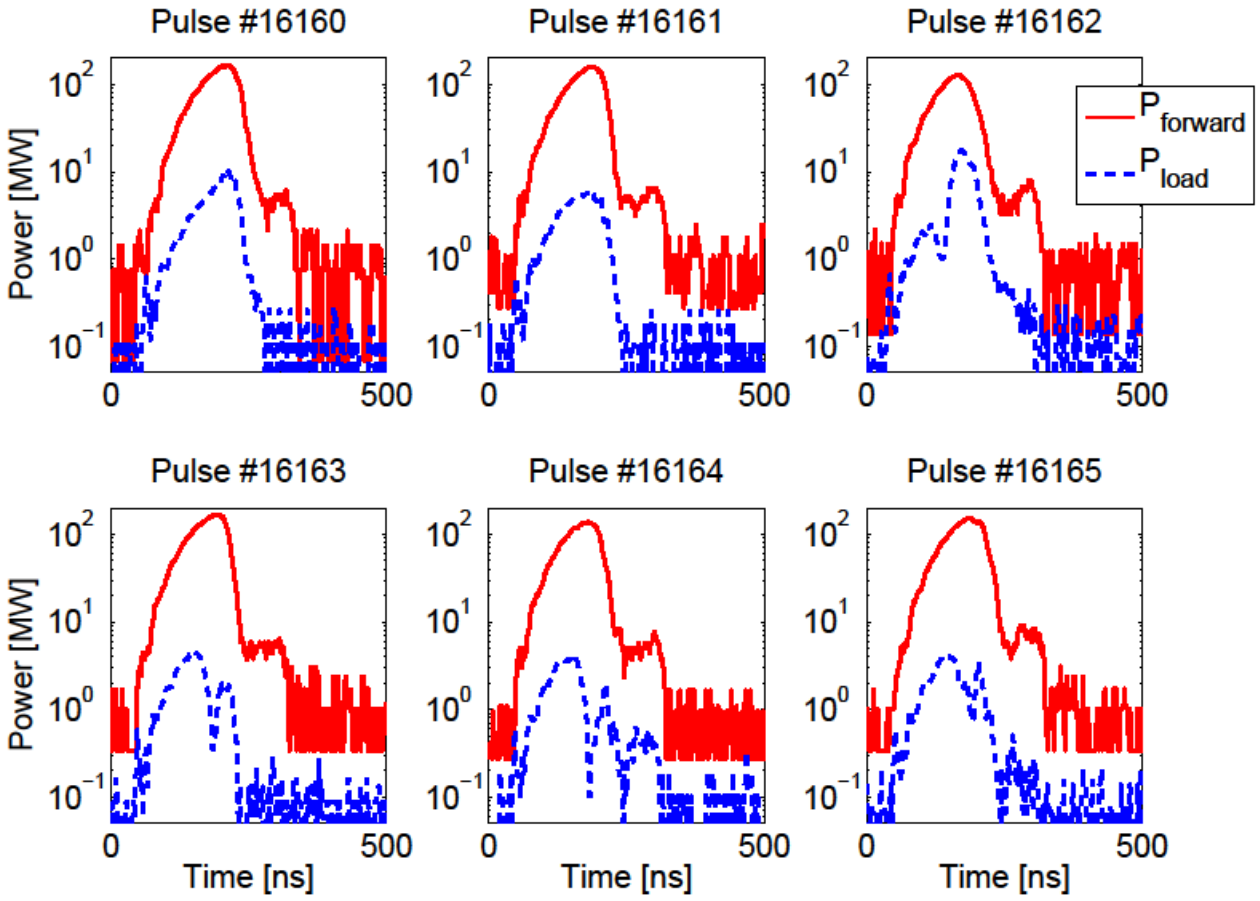
September 8th 9:51, full recirculation (g = 0.96, $\varphi \approx 0°$)

Reflected Power



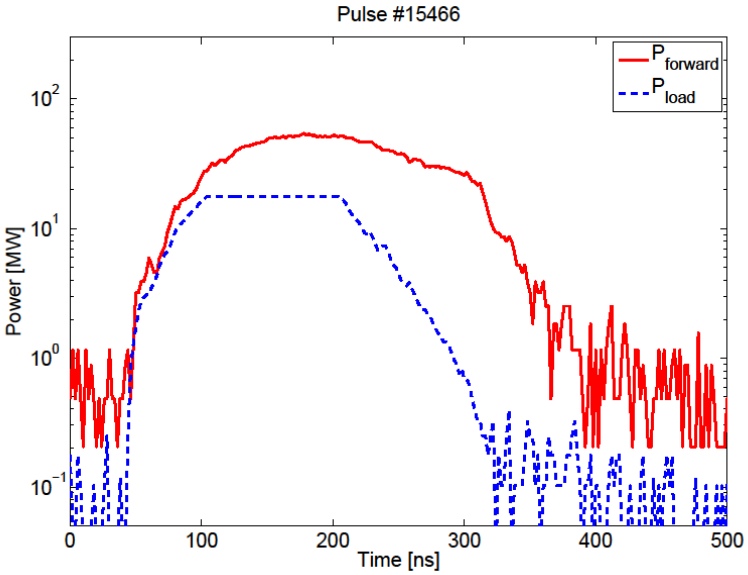
September 8th 14:22, half recirculation (g = 0.49, $\varphi \approx 0°$)

Transmitted (Load) Power



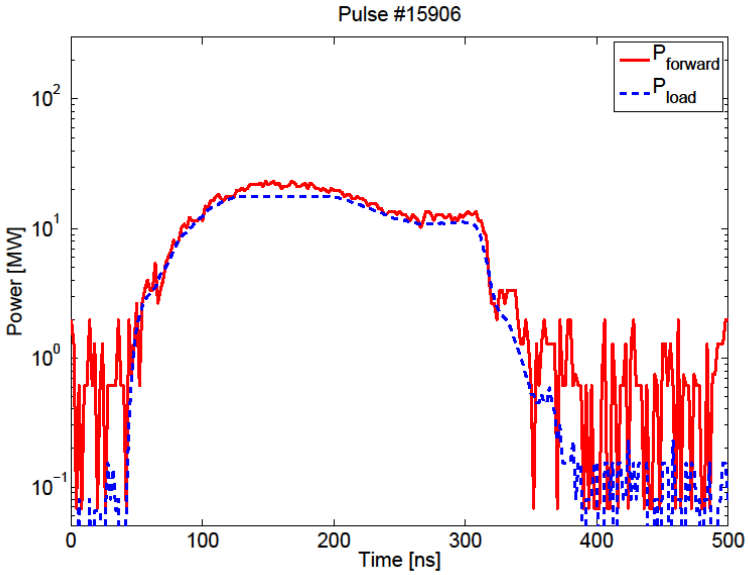
September 8th 14:45, full recirculation (g = 0.96, $\varphi \approx 0°$)

Transmitted (Load) Power



September 8th 14:25,

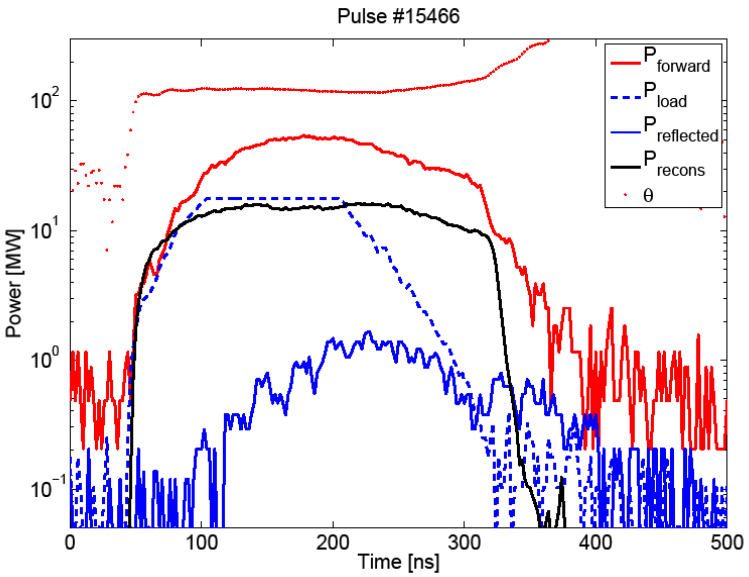
(g = 0.50, $\varphi \approx -16°$)



September 8th 14:38,

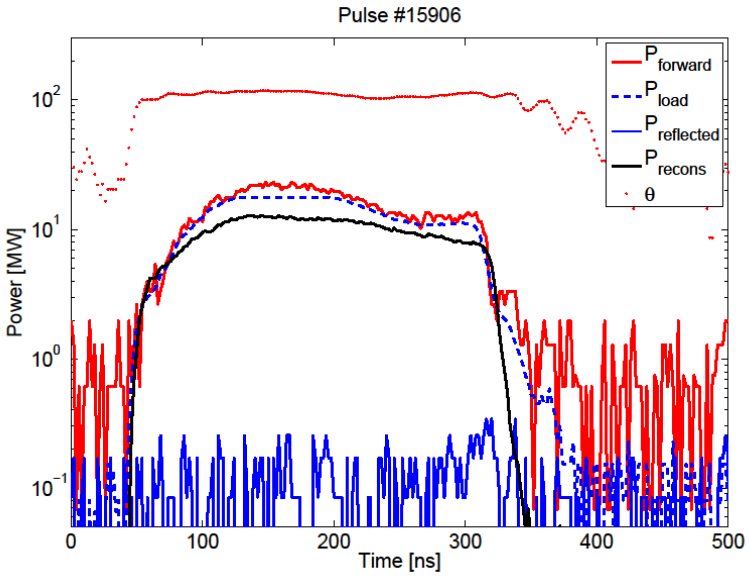
(g = 0.22, $\varphi \approx 0°$)

Composite Plots



September 8th 14:25,

(g = 0.50, $\varphi \approx -16°$)



September 8th 14:38,

(g = 0.22, $\varphi \approx 0°$)

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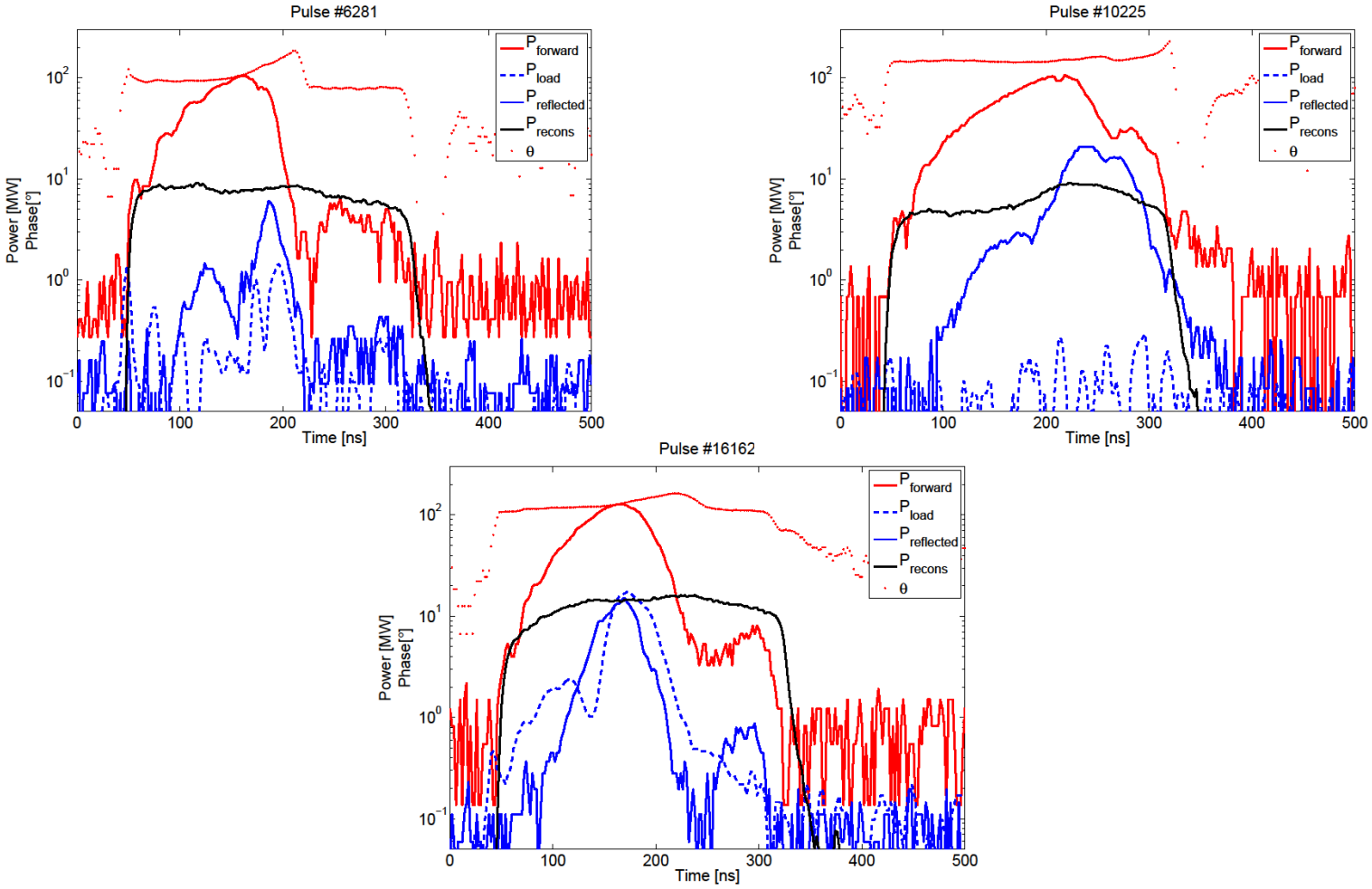
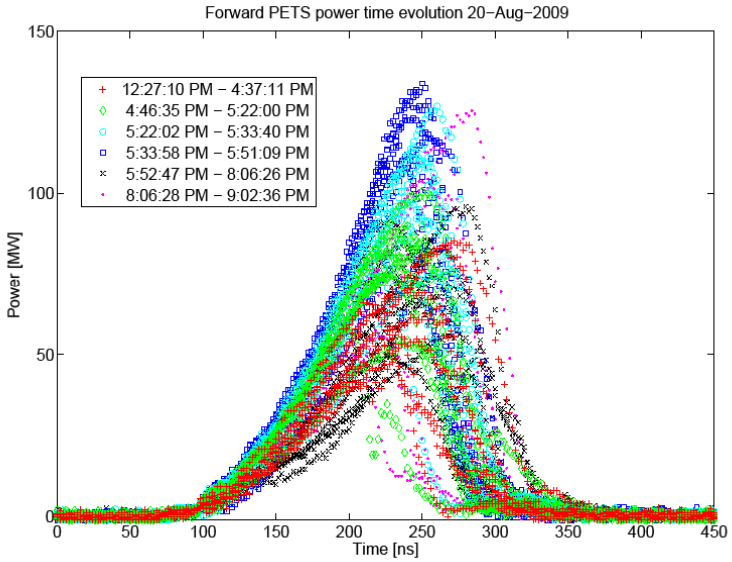
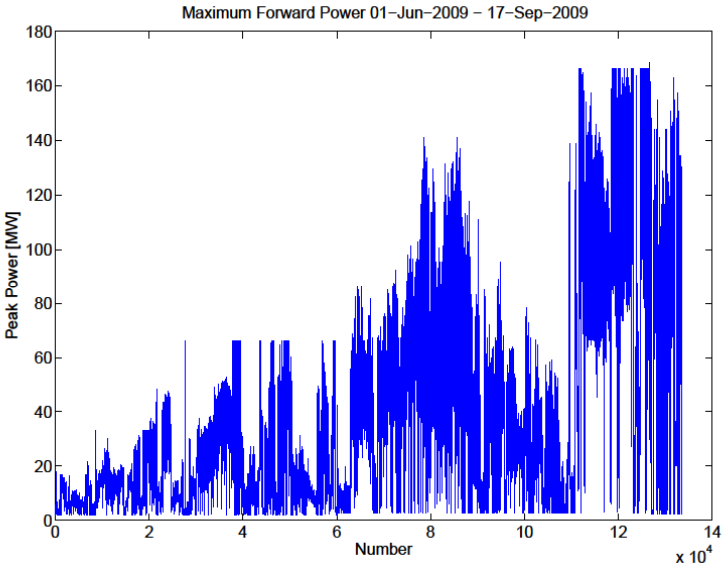


Full recirculation for all pulses

Conditioning

Gradual increase in RF power breakdown threshold





Total beam time ≈ 60 hours

Total amount of pulses ≈ $2 \cdot 10^5$

Conclusions

- Breakdown events are automatically detectable
  - Using algorithms based on pulse-shortening or field phase changes
- Study of the reflected and transmitted powers suggests that the attenuator is responsible for at least part of all breakdown events
- The breakdown threshold of the system has been improved significantly within 60 hours of beam time

Thanks to R. Ruber, I. Syratchev, E. Adli, A. Dubrovskiy and V. Ziemann for discussions and general advice and the CTF3 crew for operation