Implication of increased beam energy on QPS system, EE, time constants

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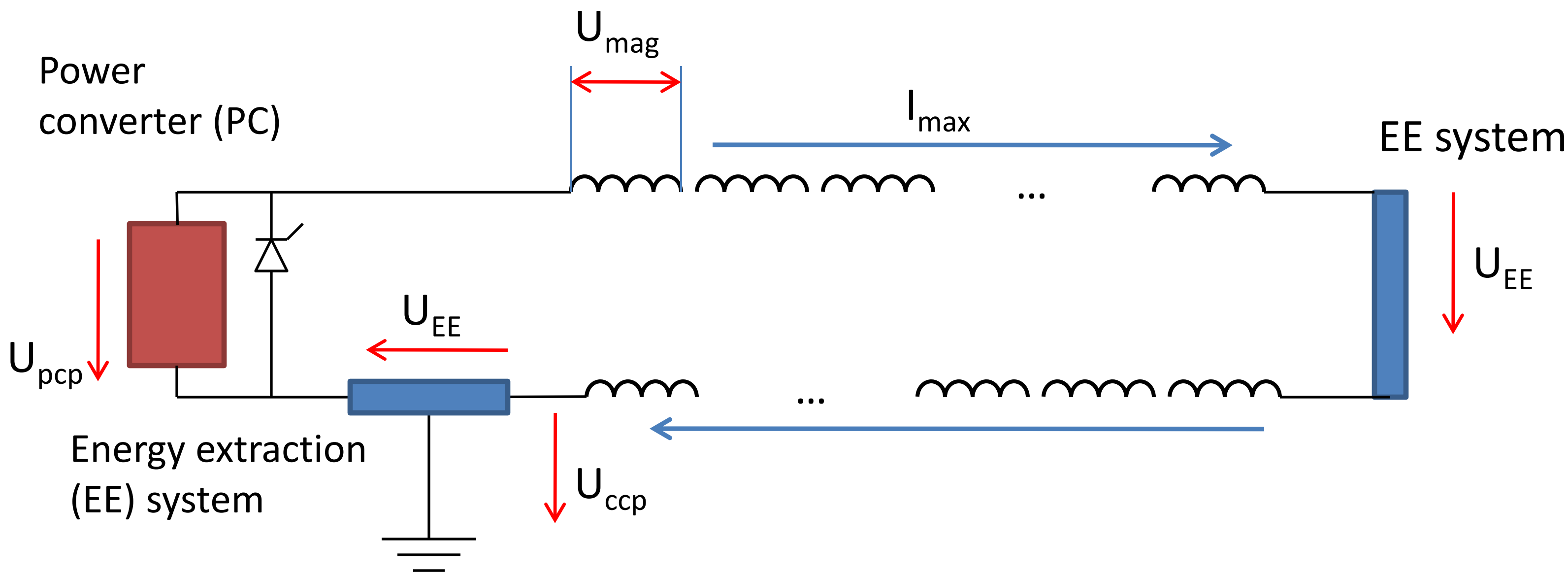
Thanks to:
MPE colleagues for input !

Topics

- System Overview
- System Limits (general)
- Operational parameters vs. limits
- Relevant systems details
- Scenarios
- Conclusion

System parameters



U_{mag}: Voltage over a single magnet
U_{EE}: Voltage over energy extraction switch
U_{ccp}: Cold cirucit peak voltage to ground
U_{pcp}: Power converter common mode peak voltage
τ: Time constant
I_{max}: Peak current

Two variables: Current and extraction resistance (discrete steps)

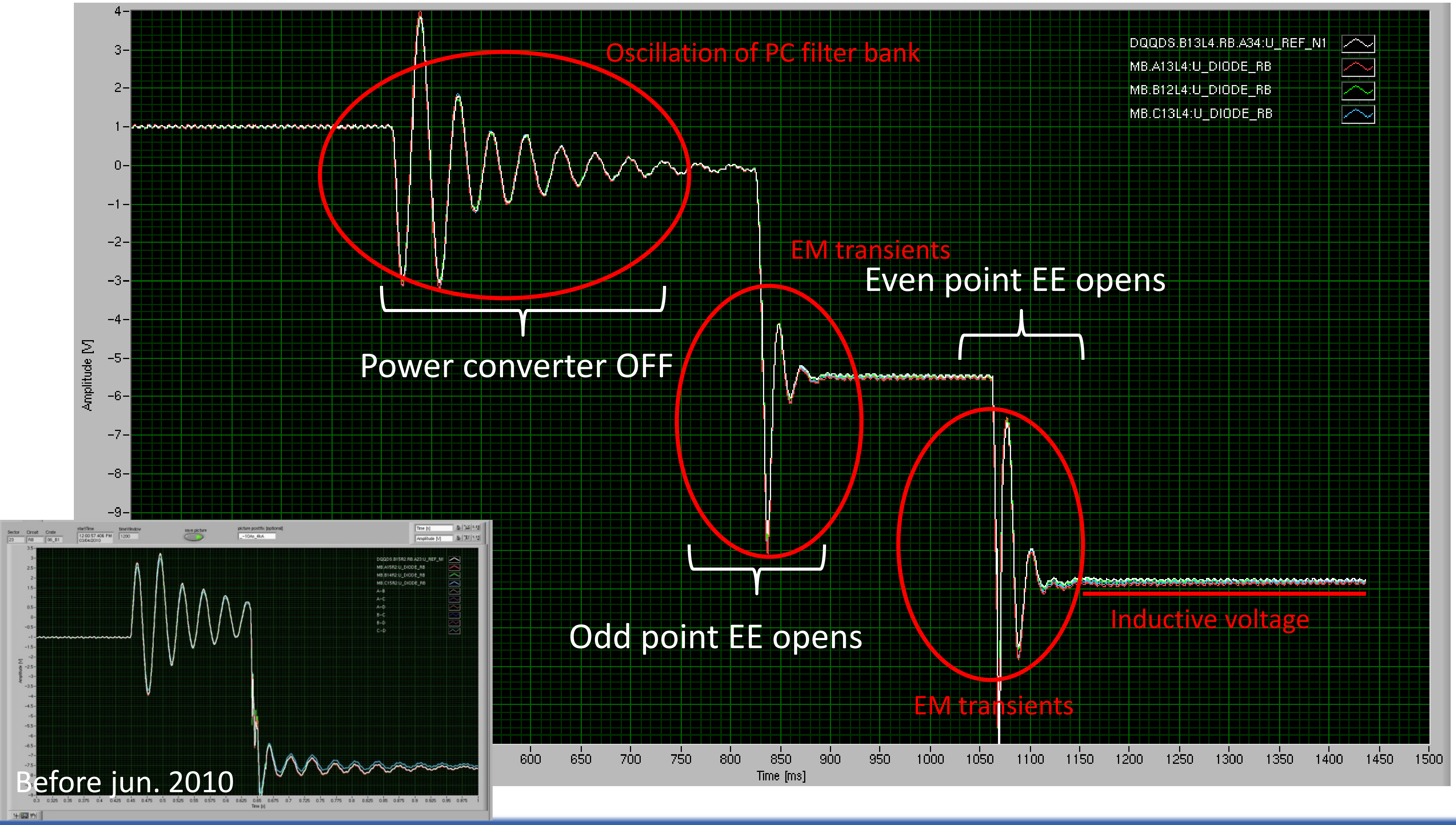
Challenging point in operation for QPS and EE systems

- Fast power abort during ramp is the most challenging state of operation for QPS & EE system due to EM transients and high inductive/resistive voltages
- EM transients causing:
  - Spurious triggers in nQPS if threshold is too low and adaptive filter out of function*
  - Spurious triggers in oQPS if combined with high di/dt **
- High inductive voltage:
  - If time constant is too short U_{mag} of SymQ reaches saturation voltage of ADC
- High resistive voltage:
  - Exceeding the maximum ratings for energy extraction switch

* 50 quenches in Feb 23 2010 → LMC march 10 2010
** multiple spurious triggers in 2010 commissioning campaign

Signals during FPA nQPS U_{mag}

Energy extraction from 5.8kA ramping with 10A/s (event de-phasing since June 2010)



System Limits (general)

System	Main Dipoles	Main Quadrupoles
Cold circuit peak voltage U_{ccp}	< 1900V (1600V)	< 240V
Energy Extraction U_{ee}	< 1300V	< 200V
Common mode power converter U_{pcp}	< 1000V (will reach value only in case of earth fault and fuse of earth detection system blown)	< 420 V (earth fault detection system)
Max di/dt magnets (for nominal current)	120 A/s	350 A/s
oQPS max di/dt	dI/dt < 150A/s	< 1000A/s
nQPS SymQ U_{mag}	U_{mag} <|14.5V|	U_{mag} <|14.5V|

Operational parameters

For QPS and EE, 3.5TeV/52s is equivalent to nominal settings (7TeV/104s) !

Values for U_{mag} without quenching magnets

	τ [s]	I_{RB} [A]	I_{RBc} [A]	U_{EE} [V]	U_{mag} [V]	di/dt [A/s]	τ [s]	I_{RQc} [A]	U_{EE} [V]	U_{mag} [V]	di/dt [A/s]
Circuit	**RB**						**RQD/RQF**				
3.5TeV	52	5900	6000	882	11.5	116	10	6000	174	2.3	609
4 TeV	52	6734	6800	999	13*	130	10	6400	187	2.4	655
4 TeV	68	6734	6800	768	10	100	15	6400	120	1.6	421
4.5 TeV	52	7578	7650	1125	14.6	146	10	7200	209	2.7	731
4.5 TeV	68	7578	7650	864	11.2	112	15	7200	135	1.7	747
5 TeV	52	8423	8500	1250	16.2	162	10	8000	232	3	812
5 TeV	68	8423	8500	961	12.5	125	15	8000	150	1.9	527

→ **Beyond 4TeV a time constant 52s cannot be maintained**

*15 quenching magnets will increase this value to 14.5V

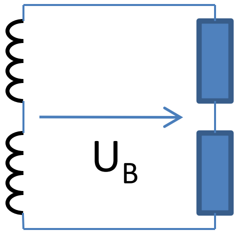
System details: Energy Extraction

Limits	Dipole switch:	1300V
	Quadrupole switch:	200V

- Dipole switch rating is not an issue
- Quadrupole rating is a hard limit
- RB time constant can be varied in discrete steps: 34s, 52s, 68s and 104s (nominal) possible
- Next practical higher values for the quadrupoles would lead to τ=12s or τ=15s
- Snubber capacitors parallel to the EE switches will considerably reduce arcing
  → reduced EM transients

System details: oQPS

Limits: di/dt and EM transients
unbalancing the bridge

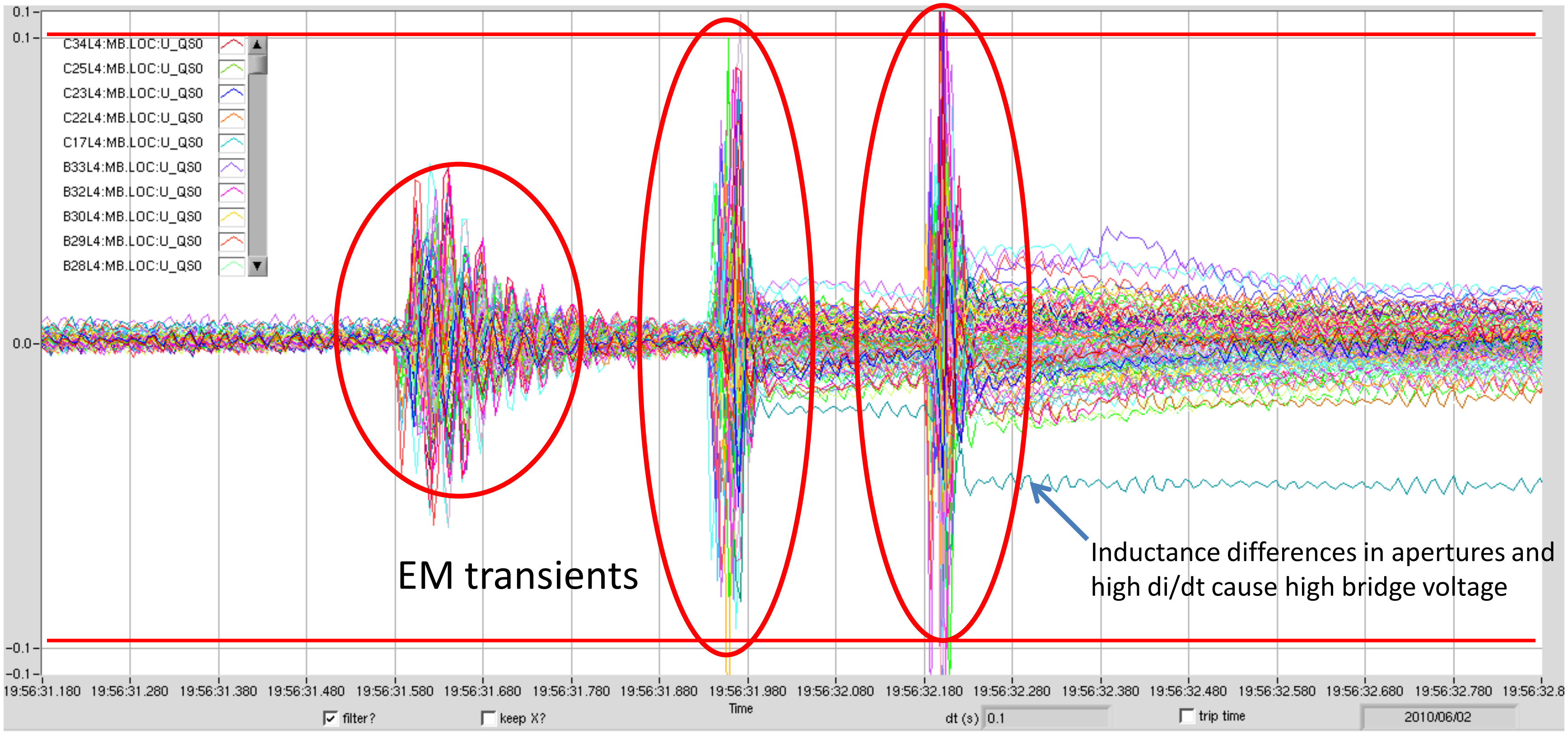


- oQPS compares the two apertures of a dipole magnet in a measurement bridge. Detector triggers on U_B
- Differences in L of magnet apertures adds an offset on the bridge voltage UB if current changes
- EM transient signals unbalance the bridge further more*
- In the present situation only a small number (or none) magnets will quench during an EE.
- If current is increased it cannot be excluded that more magnets will quench
  (higher di/dt + increased EM transients)

*delayed switch introduced june 2010 mitigates that

Signals during FPA oQPS U_{QS0}

Energy extraction from 5.8kA ramping with 10A/s



Effects on oQPS: - EM-Transients

- Inductance differences in apertures in combination with high di/dt

System details: nQPS SymQ

Limit: U_{mag} **<|14.5V|**

- ADC of SymQ will saturate at |15.5V| input
- Symmetric quench detection might be blind when saturated
- No asymmetric quench protection in case of UPS1 failure when SymQ is blind at beginning of EE
- |14.5V| should not be exceeded during normal operation
- Detection threshold (currently 800mV) has to be revised for currents >6kA*

* B. Auchmann @ TE-TM, March 2010

Scenarios

→ Within the boundary conditions presented, several scenarios of operation are possible

Scenario1: 4TeV/52s, no HW changes

	RB limits	RB values	RB, 10xq	RQx limits	RQx values
Cold circuit U_{ccp}	<1900	990 V	990 V	<240V	185 V
EE U_{EE}	< 1300V	990 V	990 V	<200V	185 V
Power convert U_{PCP}	<1000V	990 V	990 V	<420V	185 V
oQPS di/dt	di/dt < 150A/s	129 A/s	129A/s	di/dt < 1000V	648 A/s
nQPS U_{mag}	Umag < 14.5V	13 V	**13.9V**	Umag < 1000V	2.4

Pro

- No Hardware changes
- Physics gain

Contra

- Increased system load (could lead to more quenches)
- Lower nQPS thresholds required
- Increased EM transients
- Increased risk to burn interconnects ~ factor 5* to 3.5TeV

*by A. Verweij

Scenario2: 4TeV/52s + RB snubbers

	RB limits	RB values	RB, 10q	RQx limits	RQx values
Cold circuit U_{ccp}	<1900	999 V	999 V	<240V	187 V
EE U_{EE}	< 1300V	999 V	999 V	<200V	187 V
Power convert U_{PCP}	<1000V	999 V	999 V	<420V	187 V
oQPS di/dt	< 150A/s	130 A/s	130A/s	< 1000V	655 A/s
nQPS U_{mag}	< 14.5V	13 V	13.9 V	< 1000V	2.4 V

Pro

- Physics gain
- **Reduced EM transients (reduced spurious heater firing)**

Contra

- Increased system load (could lead to more quenches)
- Lower nQPS thresholds required
- Increased risk to burn interconnects ~ factor 5* to 3.5TeV

*by A. Verweij

Scenario3: 4TeV + RB snubbers + τ=68s

	RB limits	RB values	RB, 10 quench	RQx limits	RQx values (τ=15s)
Cold circuit U_{ccp}	<1900	768 V	768 V	<240V	120 V
EE U_{EE}	< 1300V	768 V	768 V	<200V	120 V
Power convert U_{PCP}	<1000V	768 V	768 V	<420V	120 V
oQPS di/dt	< 150A/s	100 A/s	100 A/s	< 1000V	421 A/s
nQPS U_{mag}	< 14.5V	10 V	10.8 V	< 1000V	1.56 V

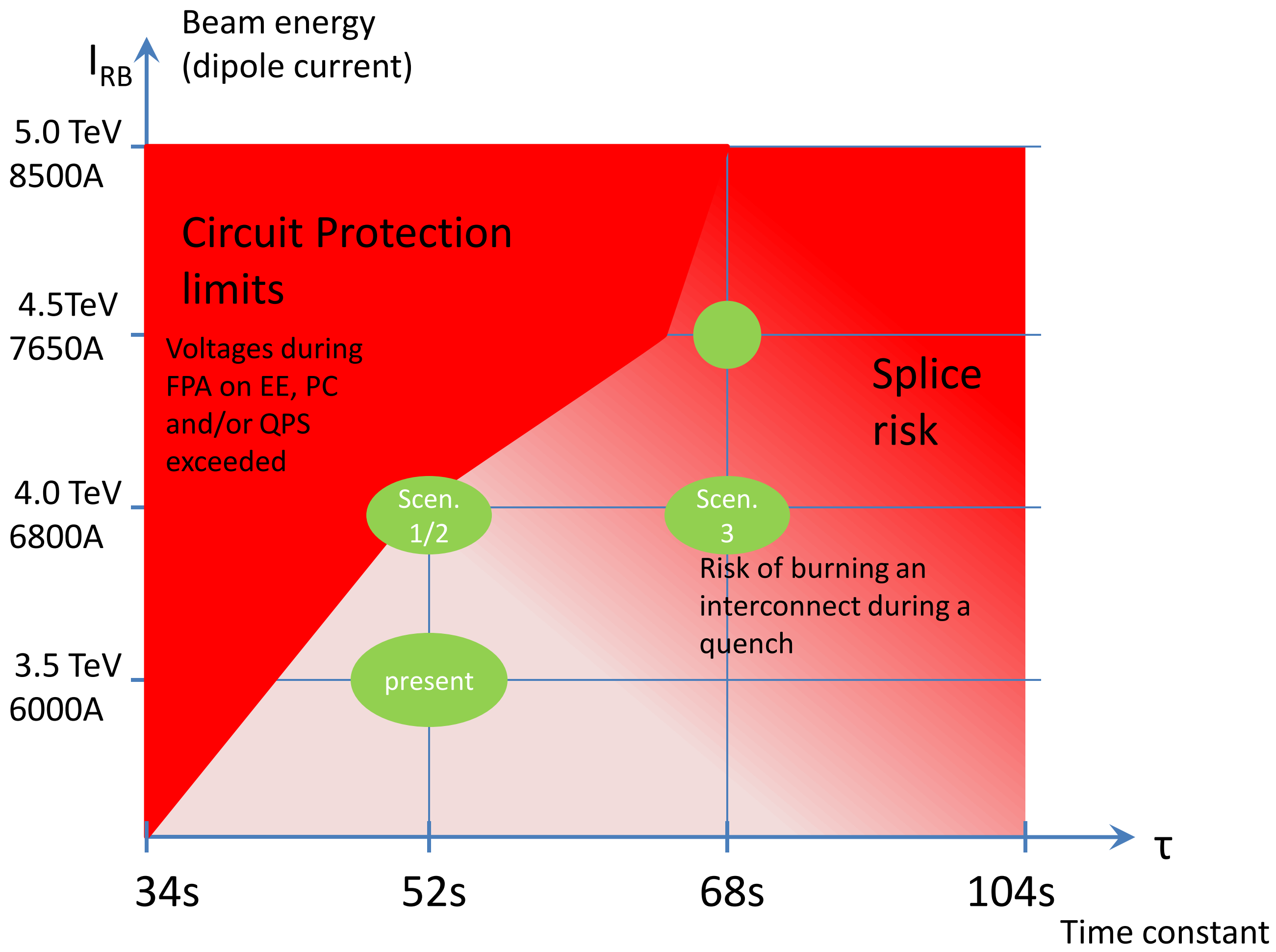
Pro

- Physics gain
- Reduced EM transients
- Decreased system load
  → reduced false triggers

Contra

- Lower nQPS thresholds required
- Further increased risk to burn interconnects compared to 4TeV/52s

I_{RB} vs. τ vs. QPS limits vs. splice risk



Plot only for visualization, not to scale !

Conclusion

- From circuit protection point of view Scenario3 would be the best due to **parameters well below critical values** and **reduced risk of multiple quenches** due to EM transients
- In terms splice protection Scenarios with shorter time constant are beneficial !
- Scenario2 (**4TeV+snubbers**) could be a good compromise
- 4.5 TeV/68s not excluded from CP point of view

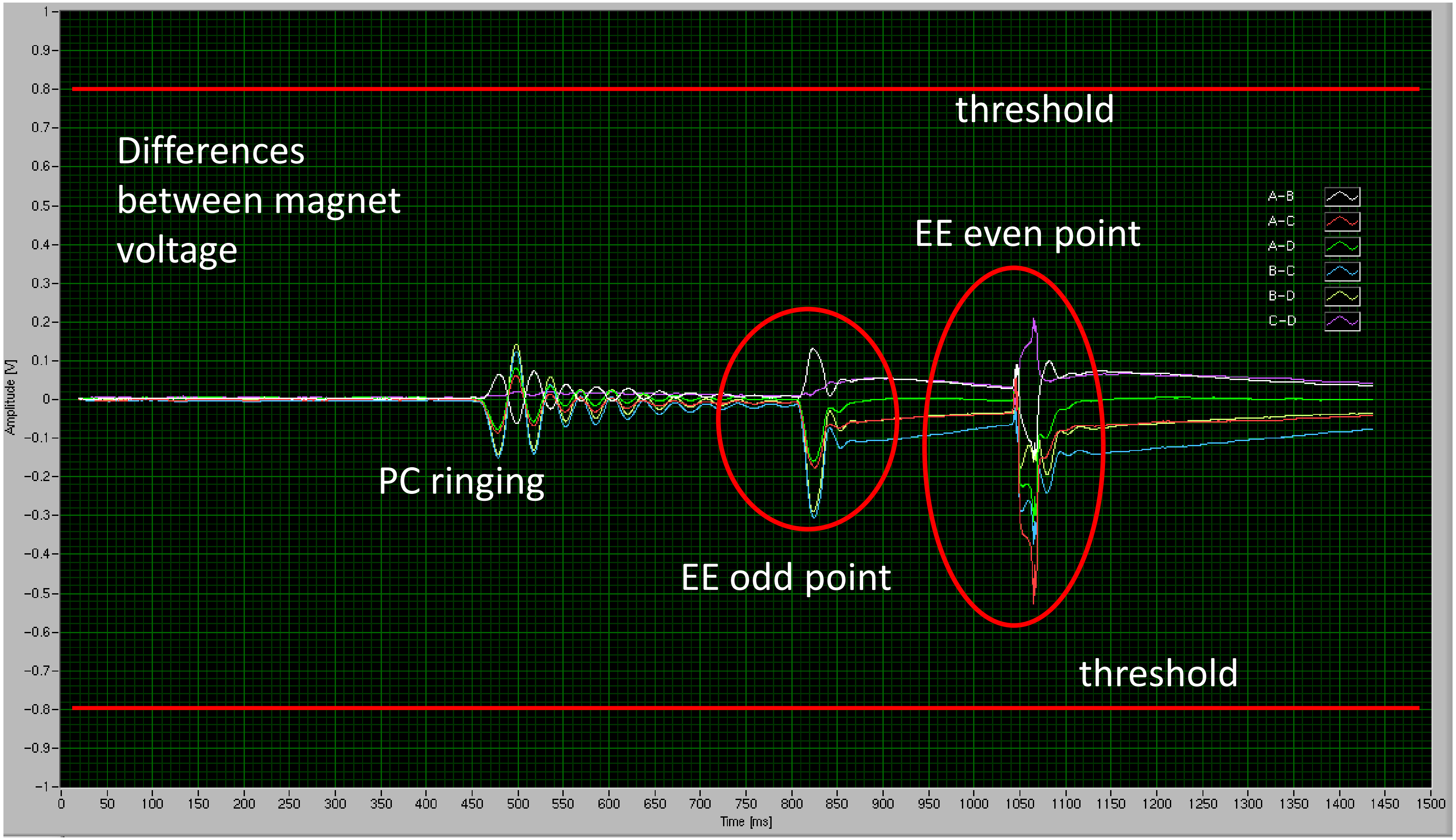
Thank you!

Questions ?

Optional slides

nQPS SymQ during FPA

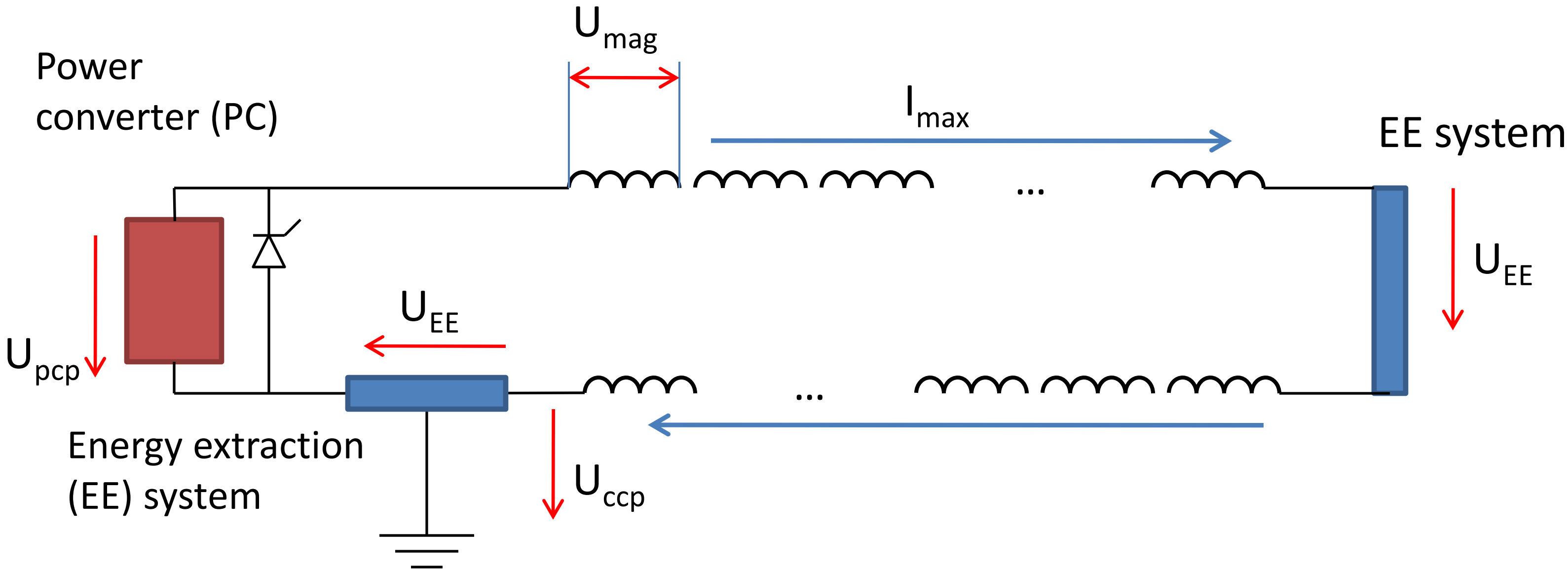
Energy extraction from 5.8kA ramping with 10A/s. Signals of SymQ



→ EM transients have to be reduced !

System Overview

System parameters



$$U_{mag} = \frac{(2 * R_{dump} * I + m * U_{diode})}{154 - m}$$

Voltage drop over one magnet

$$\frac{dI}{dt} = \frac{I}{\tau}$$

Current rate

$$\tau = \frac{L}{2 * R_{dump}}$$

Time constant

$$U_{EE\max} = R * I$$

Voltage over switch

Two variables: Current and extraction resistance (discrete steps)

Scenario0: Present situation

	RB limits	RB values	RB, 10 quenches	RQx limits	RQx values
Cold circuit U_{ccp}	<1900	882 V	882 V	<240V	174
EE U_{EE}	< 1300V	882 V	882 V	<200V	174
Power convert U_{PCP}	<1000V	882 V	882 V	<420V	174
oQPS di/dt	< 150A/s	112 A/s	112 A/s	< 1000V	609
nQPS U_{mag}	< 14.5V	11.2 V	12.3 V	< 1000V	2.3

Pro

- No Hardware changes
- No increased risk for interconnects

Contra

- No Physics gain

ScenarioX: 4.5TeV + RB snubbers + τ=68s

	RB limits	RB values	RB, 10 quench	RQx limits	RQx values (τ=15s)
Cold circuit U_{ccp}	<1900	864 V	768 V	<240V	135 V
EE U_{EE}	< 1300V	864 V	768 V	<200V	135 V
Power convert U_{PCP}	<1000V	864 V	768 V	<420V	135 V
oQPS di/dt	< 150A/s	112 A/s	100 A/s	< 1000V	747 A/s
nQPS U_{mag}	< 14.5V	11.2 V	10.8 V	< 1000V	1.7 V

Pro

- More physics gain
- Reduced EM transients
- Decreased system load
→ reduced false triggers

Contra

- **Lower nQPS thresholds required**
- **Further increased risk to burn interconnects compared to 4TeV/68s**