Heater delays: Simulations and experimental data

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LARP

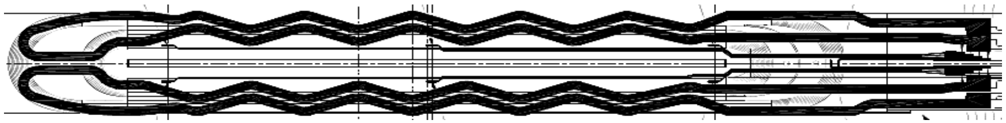
TAMPERE UNIVERSITY OF TECHNOLOGY

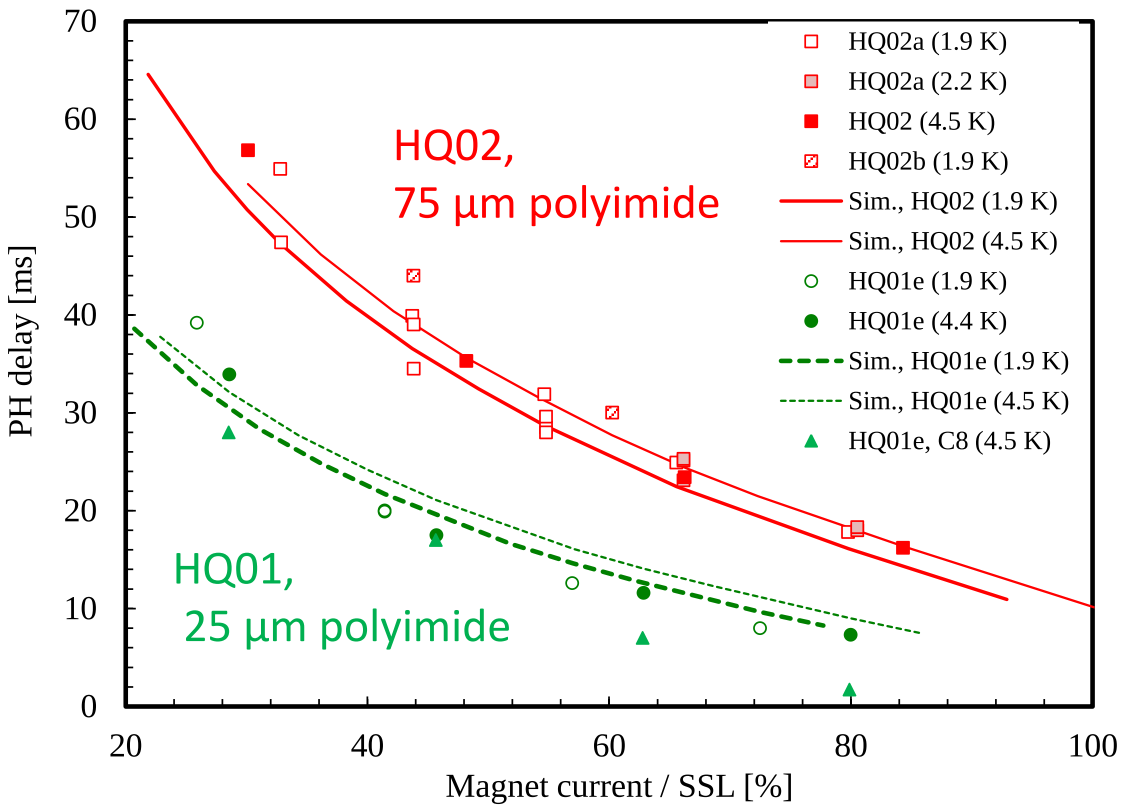
Outline

- Delays in HQ
- Delays in LQ
- Delays in 11 T
- Delays in QXF
- Summary of delays and modeling uncertainties at 80% and 50%
- References
- Additional material: Delays in HD3, Simulation uncertainty analysis, simulation parameters

HQ01 and HQ02 – Outer layer

PH peak power = 50-55 W/cm^2,
τ = 40-45 ms

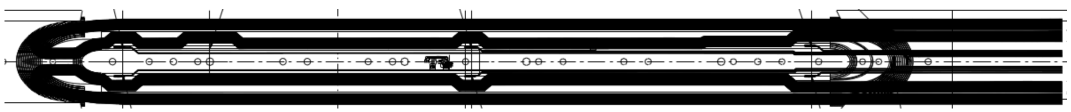


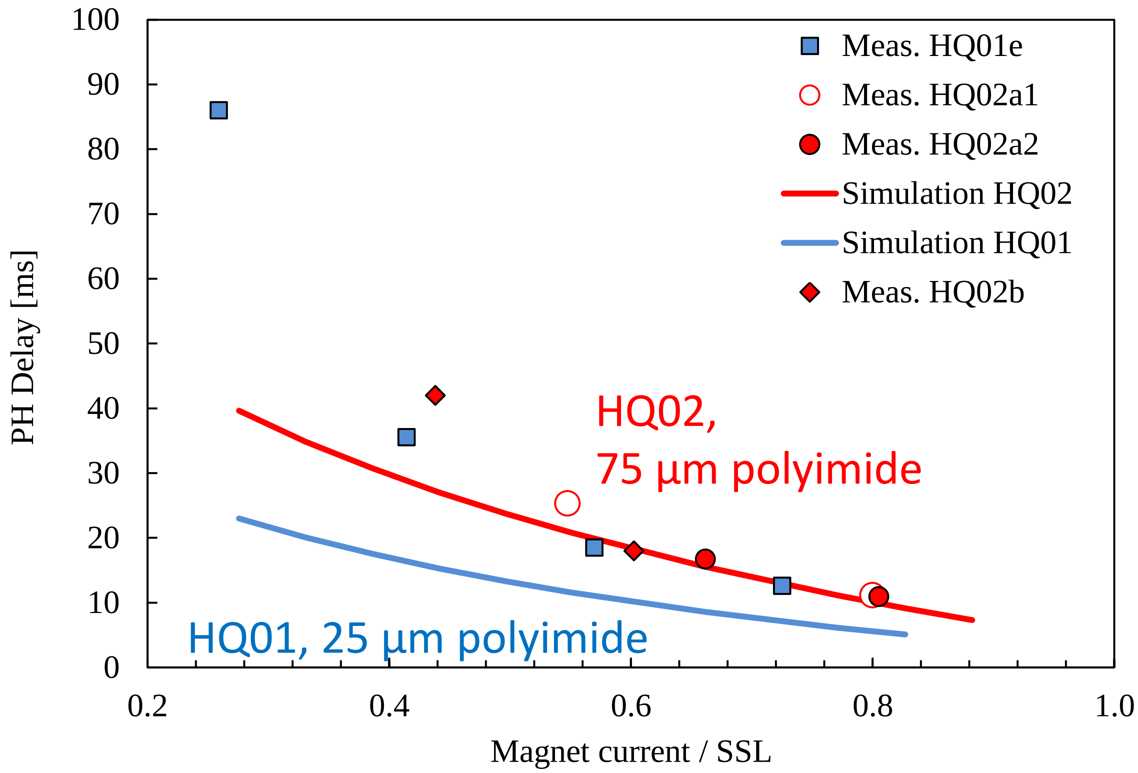


- Thicker insulation:
  10 – 30 ms longer delay
- Impact of T_{op} negligible
- Different coils and test stations: Exp. variation up to 10 ms
  - Same, well controlled test specification
- Very good modeling agreement

HQ01 and HQ02 – Inner layer

PH peak power = 50-55 W/cm^2,
τ = 40-45 ms
T_{op} = 1.9 K

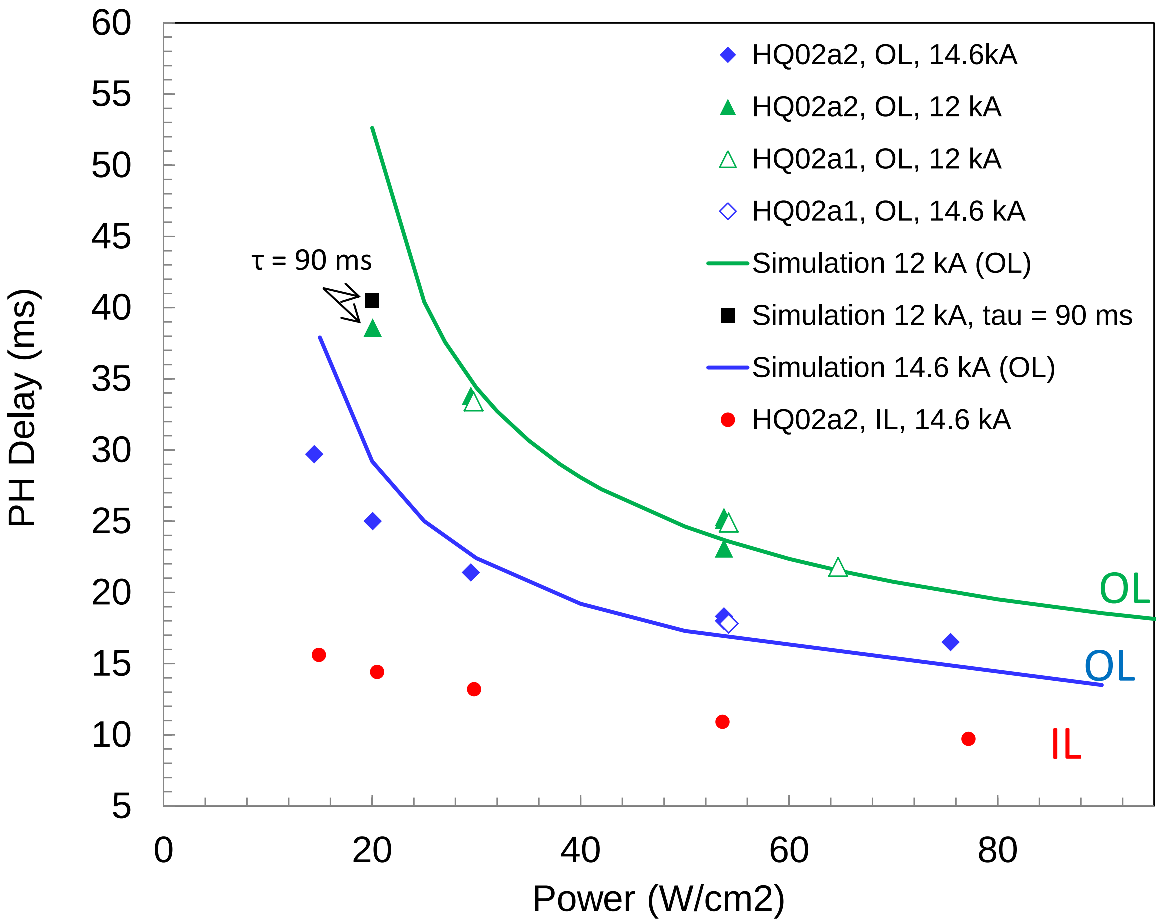




- No difference in exp. btw HQ01 and HQ02
  - Not clear why
- Stronger increase of delay at lower current than in OL
- Model match well HQ02 at high current, but does not catch the low current behaviour
- HQ01 delays longer than predicted by model

HQ02 – Delay vs. power

T = 1.9 K, τ = 40-45 ms
Kapton thickness = 75 µm

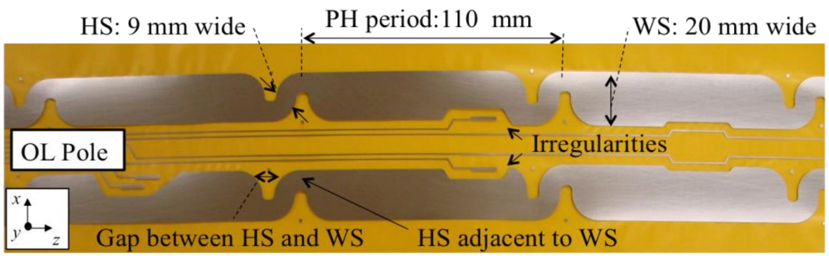


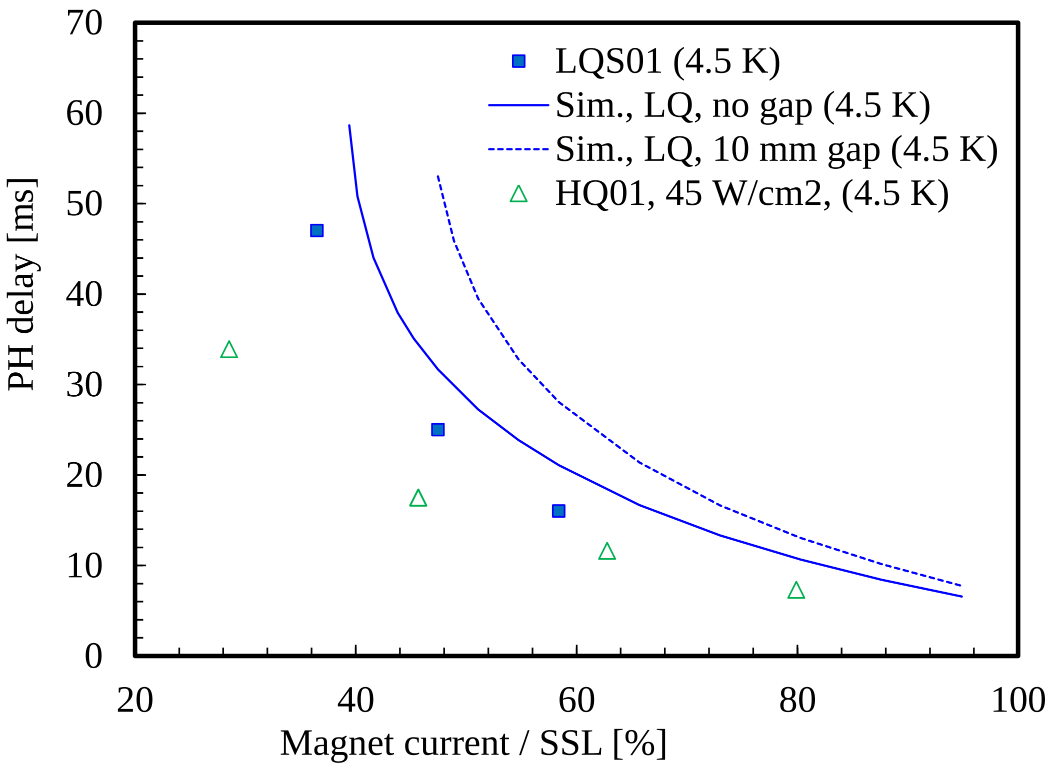
- Saturation around 50 W/cm^2
  - A few ms gain possible above that

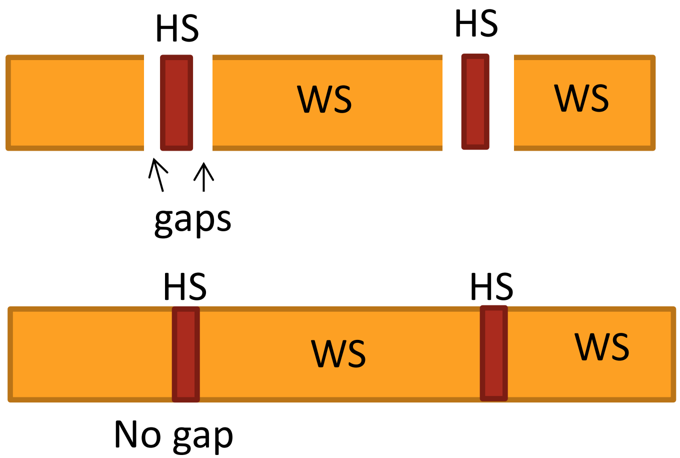
- Good modeling agreement for OL
  - (IL not yet done)

LQ

PH peak power = 40 W/cm^2,
τ = 35 ms
Kapton thickness = 25 μm



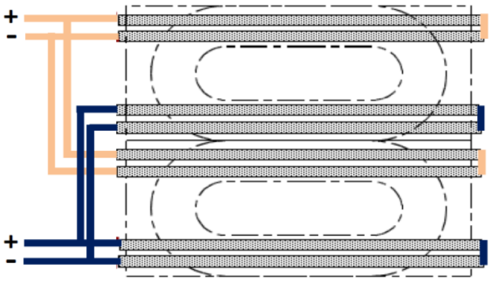




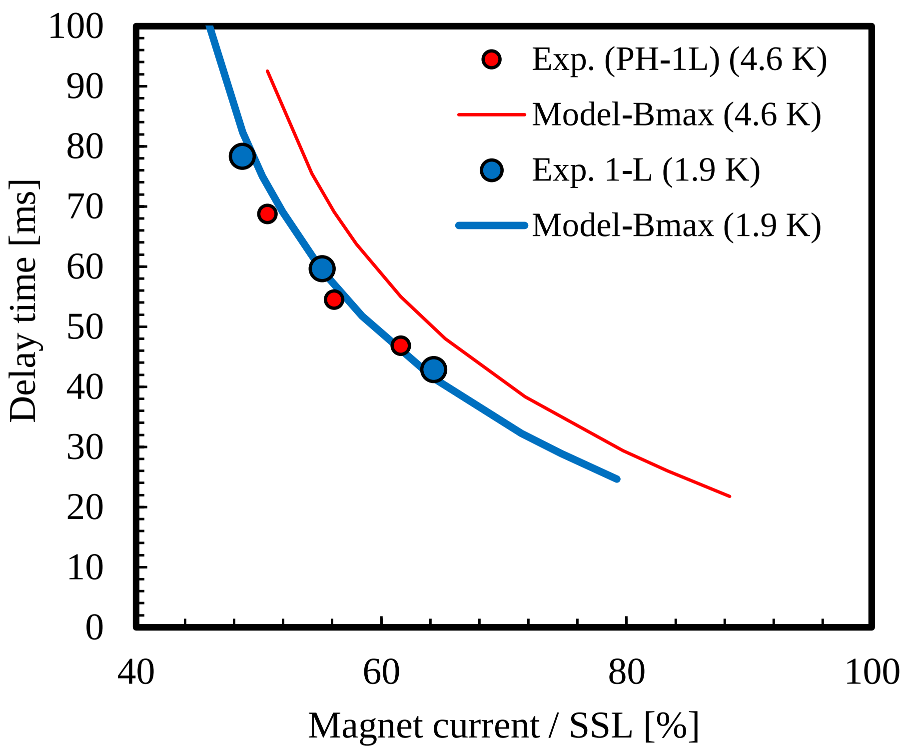
- Longer delay than in HQ01
- Wide segment (WS) has 5 times less heating power but is still important

11 T (MBHSP01) - Delays

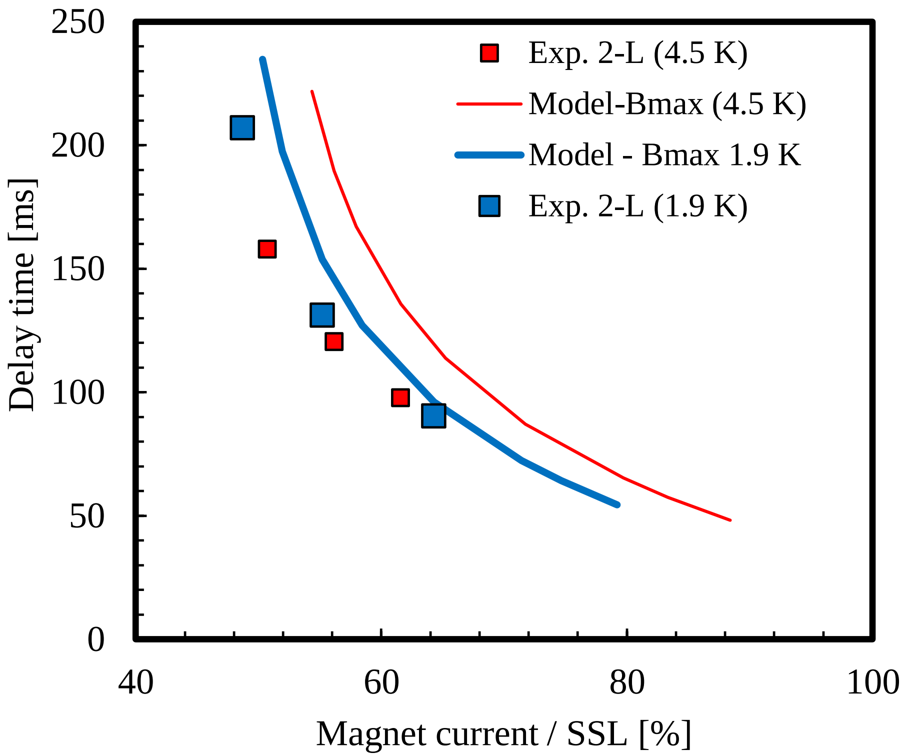
PH peak power = 18.5 W/cm^2,
τ = 25 ms
Kapton 76 or 203 μm
- Simulation for cable B_{max}



Kapton 76 μm

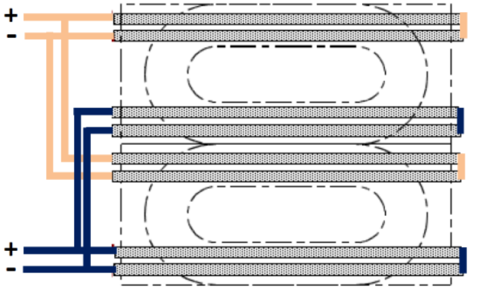


Kapton 203 μm

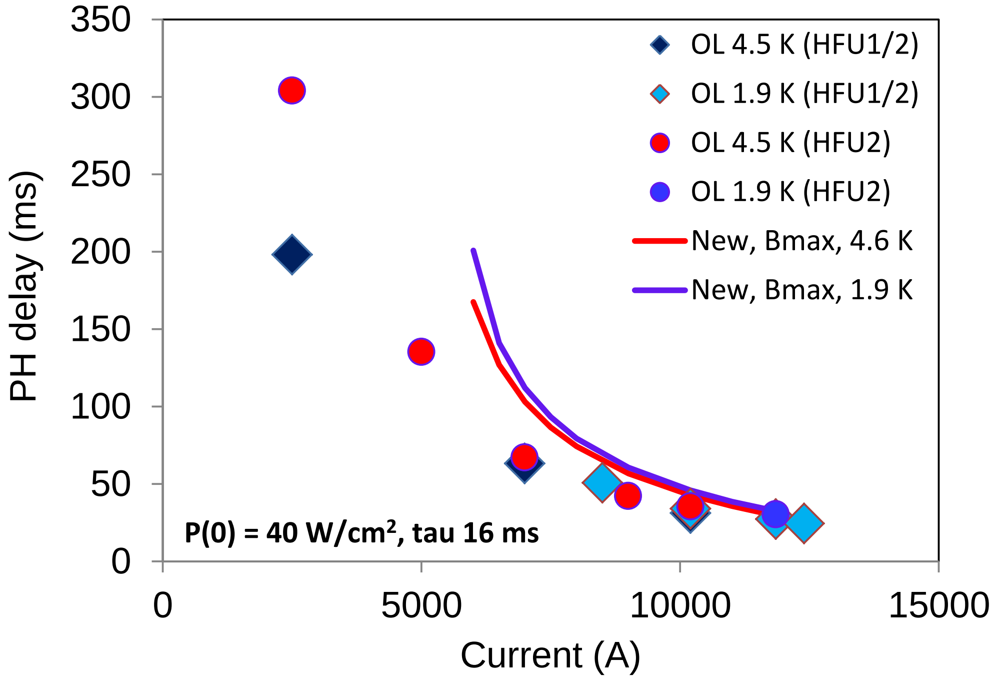


11 T (MBHSP02) - Delays

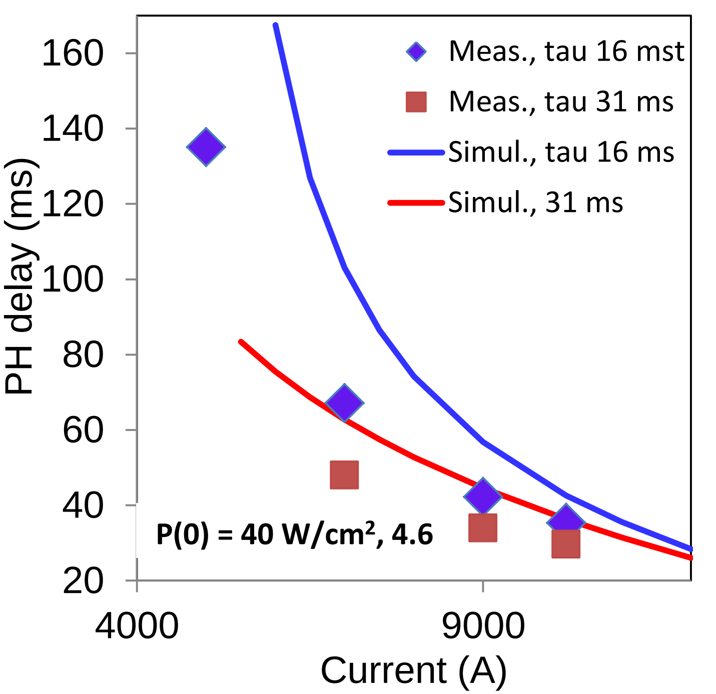
PH peak power = 40 W/cm^2,
τ = 16 or 31 ms
Kapton 114 μm (incl. adhesive)
- Simulation For Bmax



Kapton 114 μm
Delays vs. I_{mag} and T_{op}

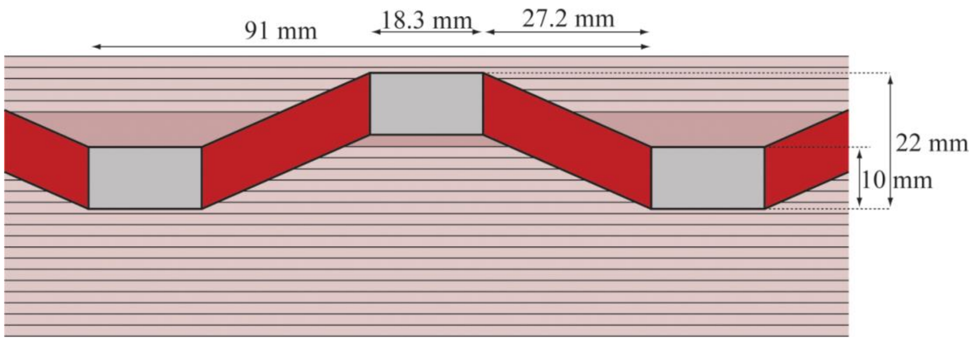


Impact of tau (RC)

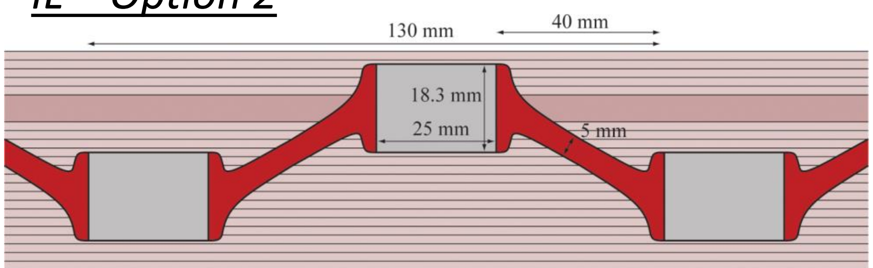


Q XF

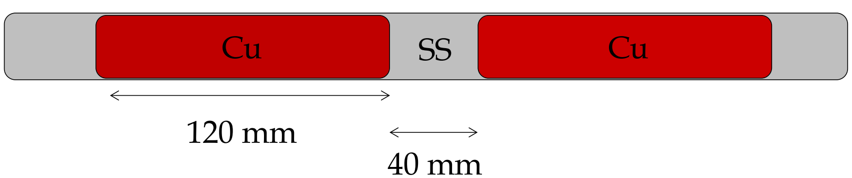
IL – Option 1



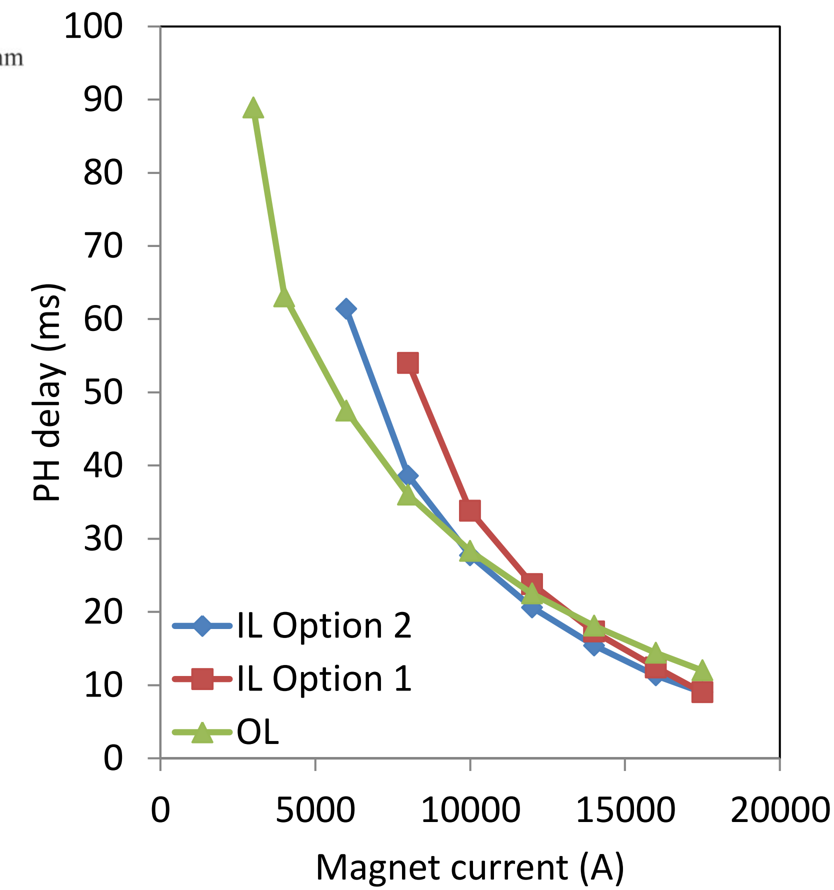
IL – Option 2



OL



Simulation for 100 W/cm^2, τ = 47 ms



All with polyimide 50 µm

Summary – Delays at ~80% SSL

Magnet	Ins. Btw. PH and bare cable	PH power and τ (RC)	Measur.	Simulat.	Delta (ms)	|Delta| (%)
HQ01e (C9) – OL	25 μm Kapt + 90 μm G10	45 W/cm^2 40-45 ms	8	10	2	25
HQ01e (C9) – IL	25 μm Kapt + 90 μm G10	50 W/cm^2 40-45 ms	13	7	-5	46
HQ02a1 (C20) – OL	75 μm Kapt + 90 μm G10	55 W/cm^2 45 ms	18	16	-2	11
HQ02a1 (C20) – IL	75 μm Kapt + 90 μm G10	55 W/cm^2 50 ms	11	10	-1	9
LQ (OL)	25 μm Kapt + 90 μm G10	40 W/cm^2 35 ms	-	11	-	-
11 T* (MBHSP01) (Thinner ins.)	76 μm Kapt + 200 μm G10	~19 W/cm^2 25 ms	-	25	-	-
11 T* (MBHSP01) (Thicker ins.)	203 μm Kapt + 200 μm G10	~19 W/cm^2 25 ms	-	55	-	-
11 T* (MBHSP02)	114 μm Kapt + 200 μm G10	~40 W/cm^2 16 ms	24	29	5	19
QXF (OL)	50 μm Kapt + 150 μm G10	100 W/cm^2 47 ms	-	12	-	-
QXF (IL)	50 μm Kapt + 150 μm G10	100 W/cm^2 47 ms	-	9	-	-

Summary – Delays at ~50% SSL

Magnet	Ins. Btw. PH and bare cable	PH power and τ (RC)	Measur.	Simulat.	Delta (ms)	|Delta| (%)
HQ01e (C9) – OL	25 μm Kapt + 90 μm G10	45 W/cm^2 40-45 ms	20	22	2	10
HQ01e (C9) – IL	25 μm Kapt + 90 μm G10	50 W/cm^2 40-45 ms	19	12	-7	37
HQ02a1 (C20) – OL	75 μm Kapt + 90 μm G10	55 W/cm^2 45 ms	40	37	-3	8
HQ02a1 (C20) – IL	75 μm Kapt + 90 μm G10	55 W/cm^2 50 ms	25	21	-4	16
LQ (OL)	25 μm Kapt + 90 μm G10	40 W/cm^2 35 ms	16	21	5	24
11 T* (MBHSP01) (Thinner ins.)	76 μm Kapt + 200 μm G10	~19 W/cm^2 25 ms	82	78	-4	5
11 T* (MBHSP01) (Thicker ins.)	203 μm Kapt + 200 μm G10	~19 W/cm^2 25 ms	207	235	28	13
11 T* (MBHSP02)	114 μm Kapt + 200 μm G10	~40 W/cm^2 16 ms	69	51	-18	36
QXF (OL)	50 μm Kapt + 150 μm G10	100 W/cm^2 47 ms	-	28	-	-
QXF (IL)	50 μm Kapt + 150 μm G10	100 W/cm^2 47 ms	-	34 (opt. 1) 28 (opt. 2)	-	-

Some references

Model and simulations:
- T. Salmi, et al., IEEE, trans. on appl. supercond., 24 (3), 2014
- T. Salmi, et al., IEEE, trans. on appl. supercond., 24 (4), 2014
- T. Salmi, et al., Proc. WAMSDO, 2013

HQ delay measurements and parameters:
- H. Bajas, et al., IEEE, trans. on appl. supercond., 23 (3), 2014
- G. Chlachidze, et al., IEEE, trans. on appl. supercond., 24 (3), 2014
- F. Borgnolutti, et al., IEEE, trans. on appl. supercond., 24 (3), 2014

LQ delay measurements and parameters:
- G. Ambrosio, et al., IEEE, trans. on appl. supercond., 21 (3), 2014
- G. Chlachidze, et al., TD-10-001, 2001
- T. Salmi, et al, Proc. CEC, vol. 57, 2012

11 T delay measurements and parameters:
- A. V. Zlobin, et al., IEEE, trans. on appl. supercond., 24 (3), 2014
- G. Chlachidze, Proc. WAMSDO, 2013
- E. Barzi, et al., FERMILAB-TM-2552-TD

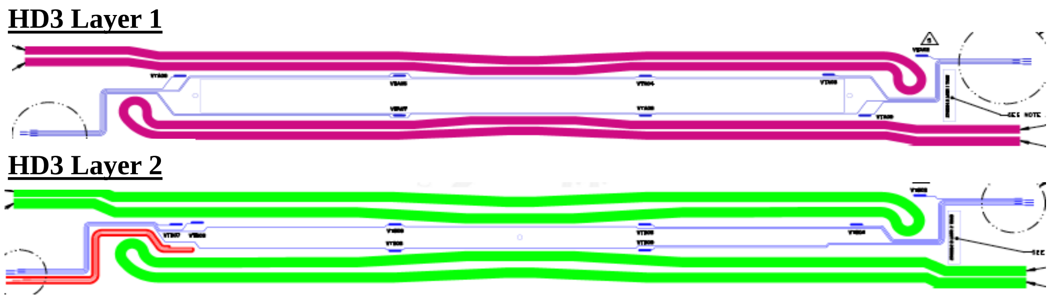
QXF parameters:
- SQXF1 design report v2b, downloaded from the US LARP plone site, March 14, 2014

Also information, data, and input from Guram C., Fred N., Helene F., Bernhard A, Maxim M., ……

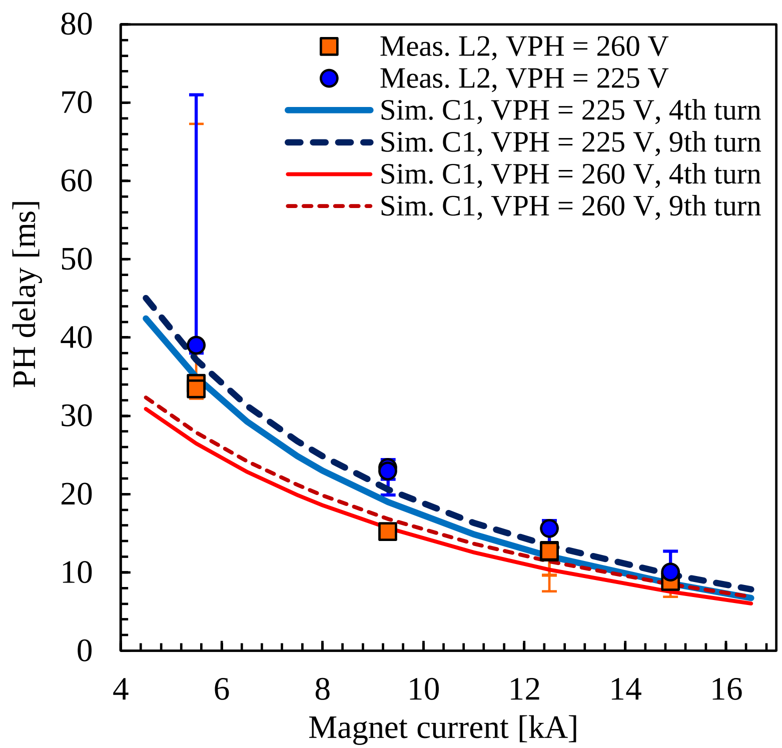
Additional material

HD3

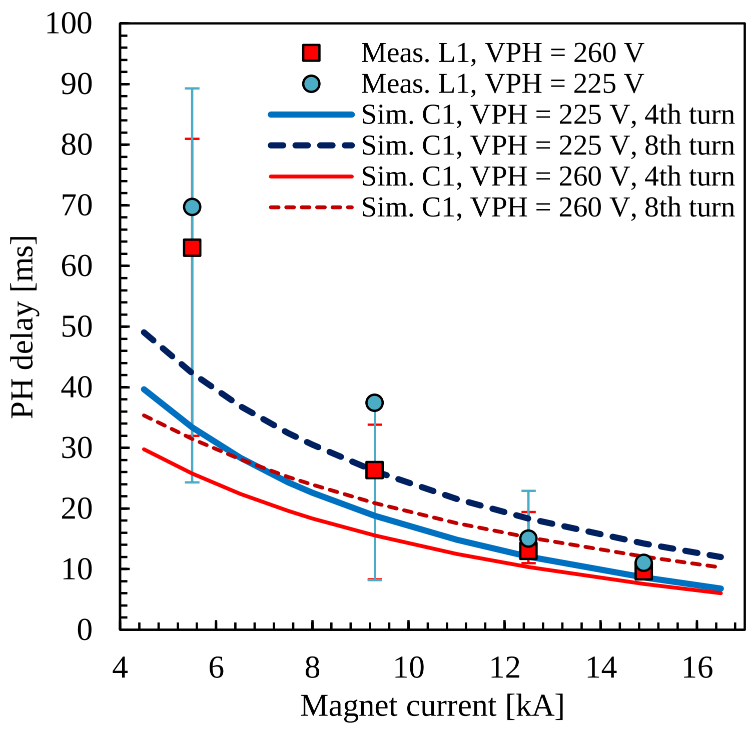
PH peak power =
42 W/cm^2 (V = 225 V),
55 W/cm^2(V = 260 V),
τ = 48 (L1), 42 (L2) ms
Kapton thickness = 25 µm



Layer 2 (outer)

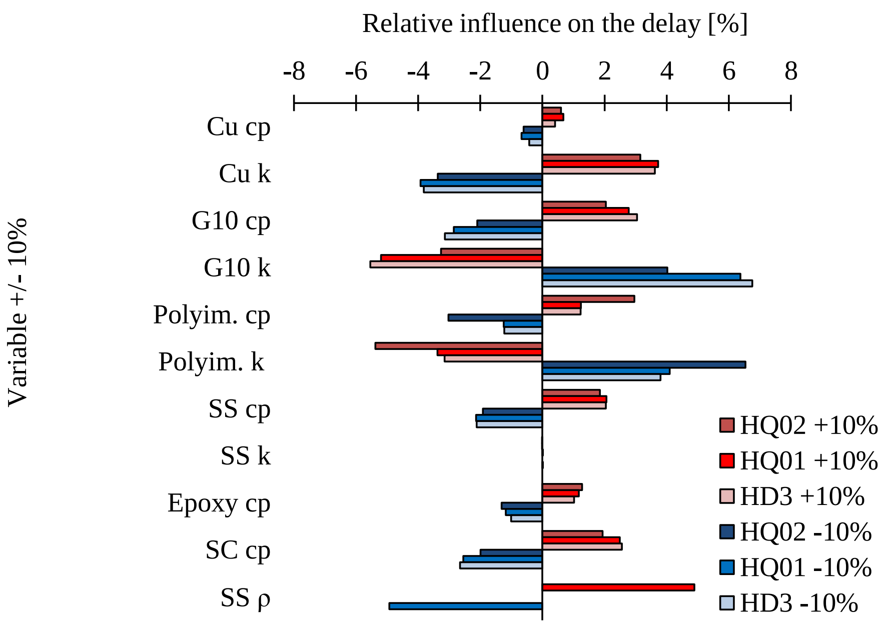


Layer 1 (inner)

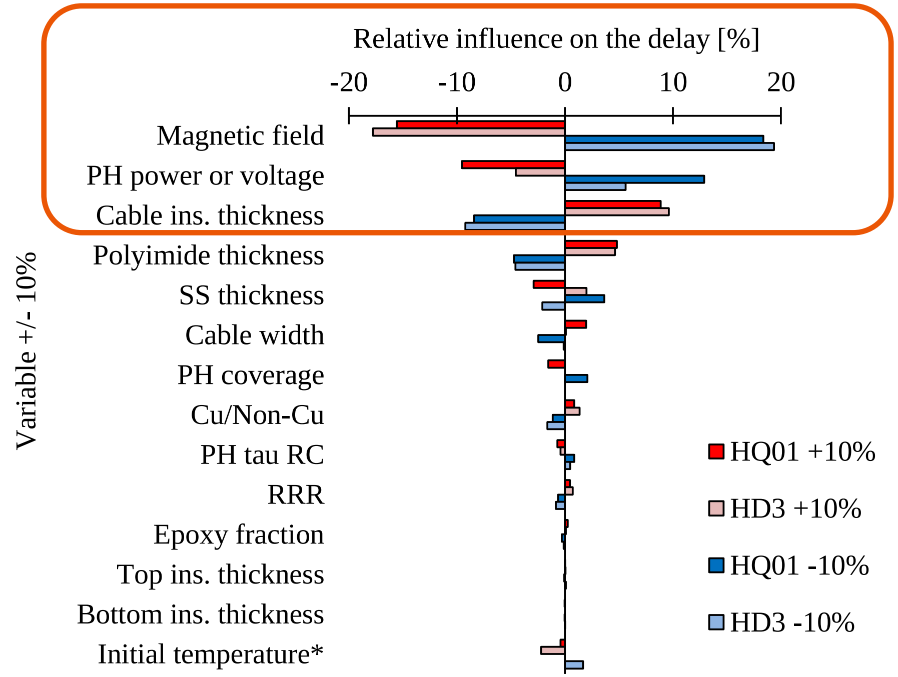


Simulation sensitivity analysis

- An individual input parameter, or material property, is varied by +/- 10%
- The relative delay response is studied
- A delay at 80% of SSL



Biggest impact: Field, PH power and **cable insulation** thickness



Simulation parameters (to be completed)

	QXF	HQ01/HQ02	11 T (MBHSP01 / MBHSP02)	HD3 (C3, C1)
SSL @ 1.9 K (kA9		19.3 / 18.3	15.4 / 16.0	20.7 (C3)
SSL @ 4.4 K (kA)		17.5 / 16.6	13.8 / 14.3	18.7, 18.9
Operation current	17500 A			
Bpeak field at Iop	12.1 T			
Transposition pitch (mm)	109			
# of strands	40	35	40	51
Strand diam. (mm)	0.85	0.8 / 0.778	0.7	
Cu fraction	0.55	1.05 / 1.20	1.02	0.83, 0.65
RRR	150	190 / 155	100	150, 100
Reacted cable width (mm)	18.5	15.0	14.9	22.0
Insulation (mm)	0.15	0.09 / 0.1	0.1 + 0.1	0.1
Voids fraction (epoxy)	0.15	0.12 / 0.15	0.12	0.12
Bc20m and C for Jc fit	30.88 T and 1519 TA			
Midplane thickn. (per coil) (mm)	0.250	0.35	0.35	0.55
Insulation btw IL ss heater and the bore (mm)	0.150	0.25	-	0.635 (to L1)