Solid State Thyratron Replacement for the LHC Klystron Crowbar

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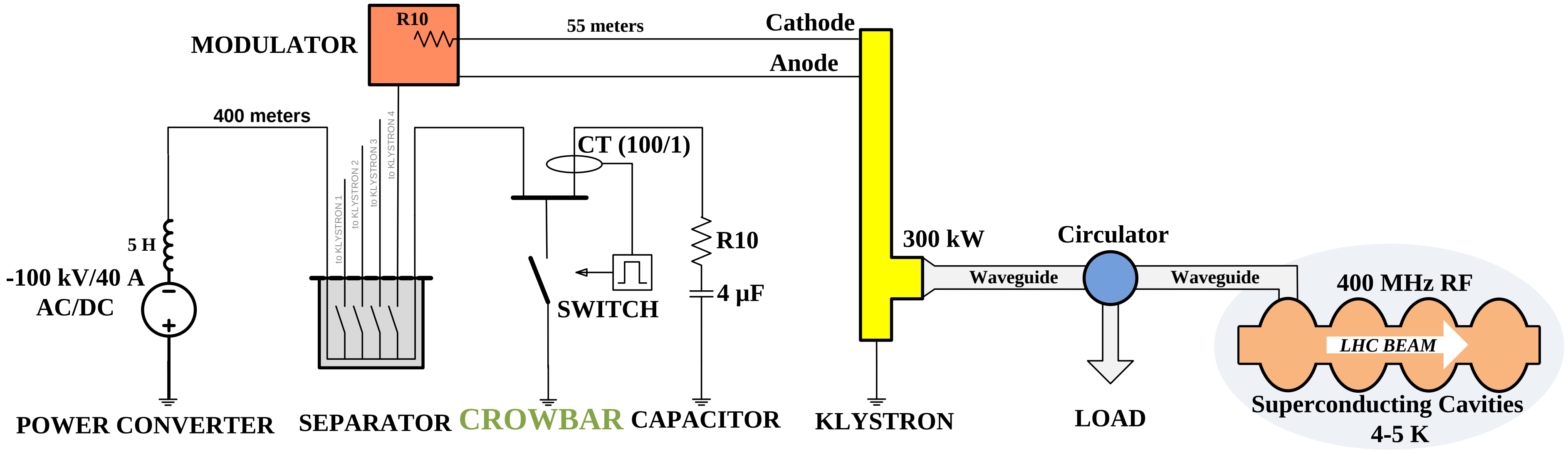
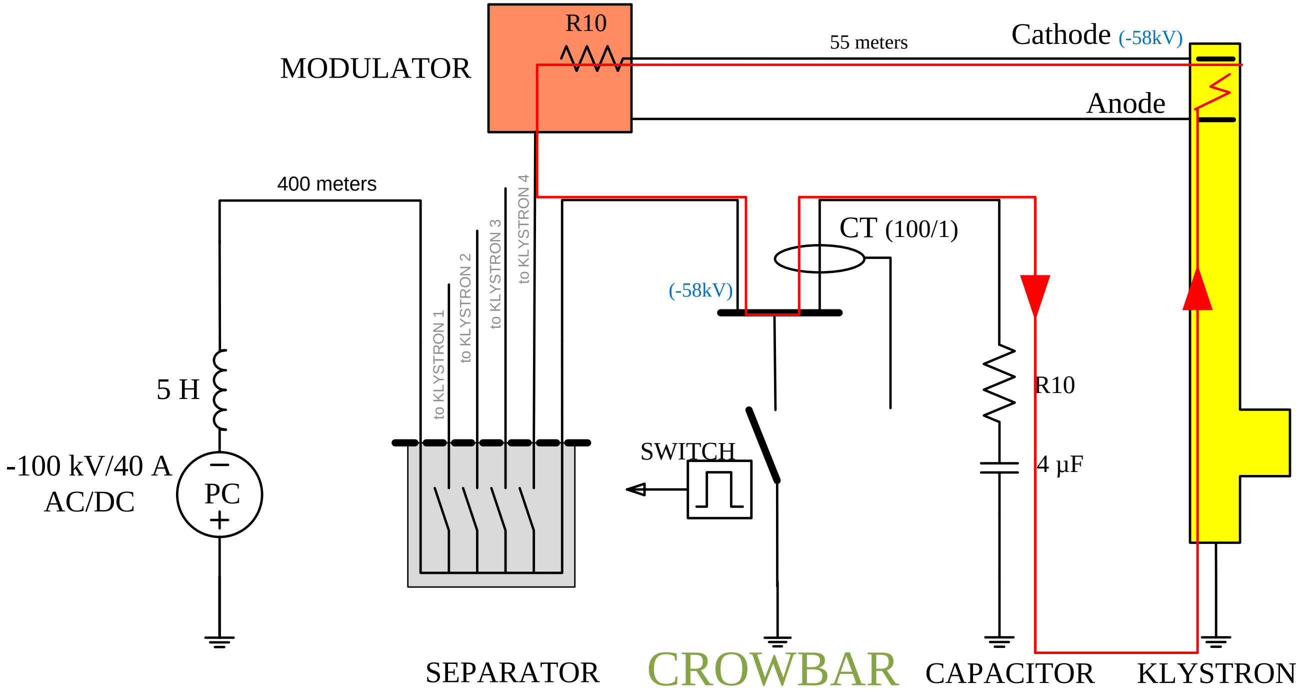
LHC Klystron HV interface

- LHC is powered by 16 CW, 400 MHz/300 kW klystrons
- Four klystrons are powered by one 100 kV/ 40A HV power supply
- Each “unit of four” is protected by a thyratron based crowbar system



Crowbar function

- Crowbar fires only in case of a fault (arc) to protect the klystron by grounding the HV power supply
- Beams are dumped in case of any RF trip (~1300 interlocks, including the crowbar)



Crowbar key components

Thyratron (till now)

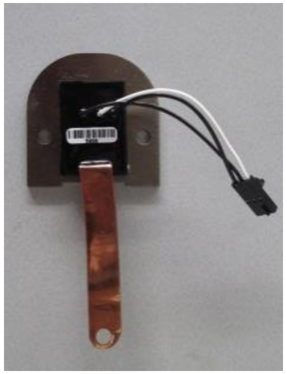
- Model CX1194/B (EEV)
- Double ended, 5 gap thyratron

\+ Traditional, reliable, klystron protection

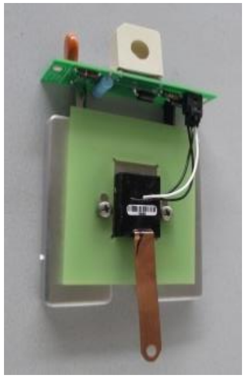
\- Auto firing
\- Unsure long term availability

Solid state (from end of 2014)

- Model 56SA-18E (APP)
- Stack of 18 thyristors



Single thyristor



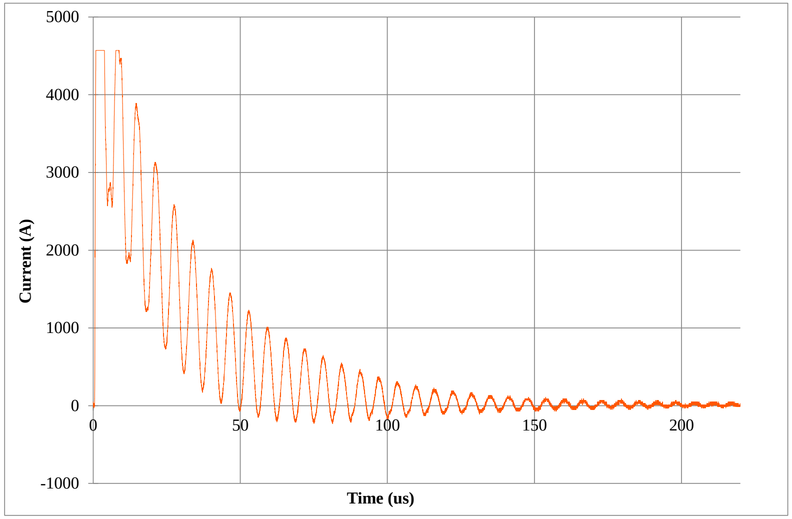
Complete stage (thyristor+snubber)

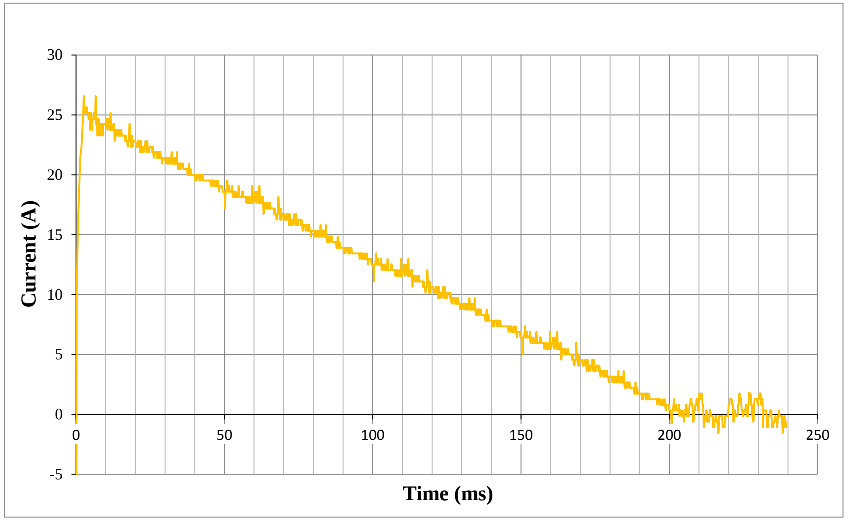
Crowbar performance

- Maximum allowed spark energy dissipated without klystron damage (no real information available)
- Holding voltage 60kV (No auto-firing, switches rated for nominal 72kV)
- Trigger delay and di/dt
- Need to be compared with the current thyratron system (reliable in LEP and LHC)

Thyratron performance

- Thyratron currents:





Fast part:

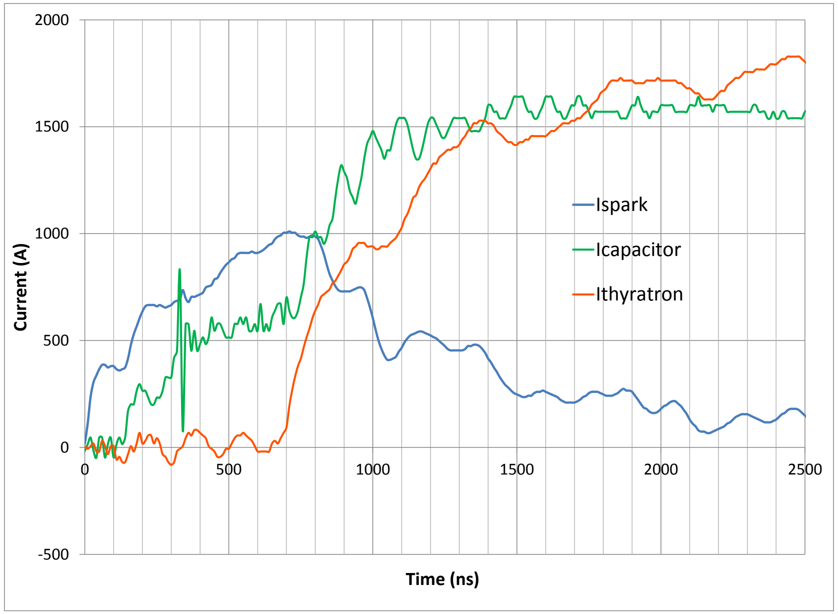
- Coaxial cables
- 4μF capacitor (~6000A, 200μs)
- Polarity reversal (2-ended thyratron)

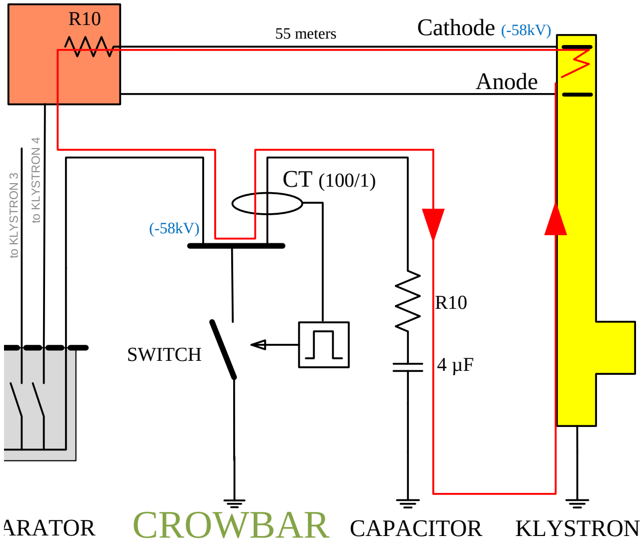
Slow part:

- Discharge of the power supply 5H inductor
- ~45A, 300ms in LHC

Thyratron performance

- Thyratron trigger timing/firing





~ 550 ns Turn ON Delay, 1200 ns rise time

Thyristor performance

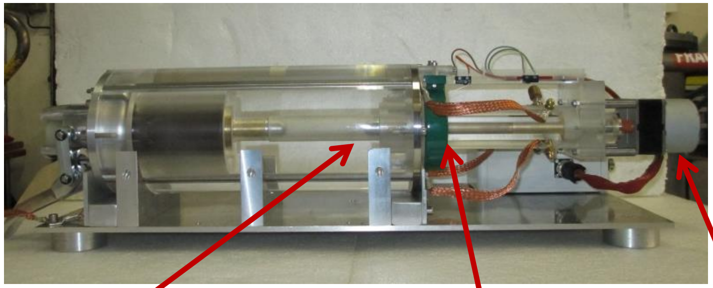
- Similar measurements repeated with the Solid State device S56A-18E.
- Able to handle 40kA/µs, 14kA peak and damped-oscillating currents.

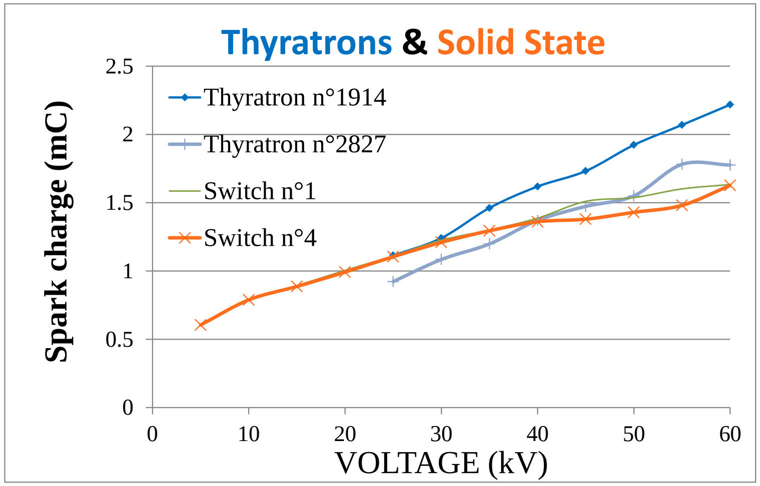
Device	Turn ON delay (ns)	Rise time (ns)
Thyratron (CX1194/B)	550	1200
Solid state (S56A-18E)	350	2500

- Not easy to evaluate…
- Analyze the spark current (amount of charge transferred by the arc) to benchmark the performance

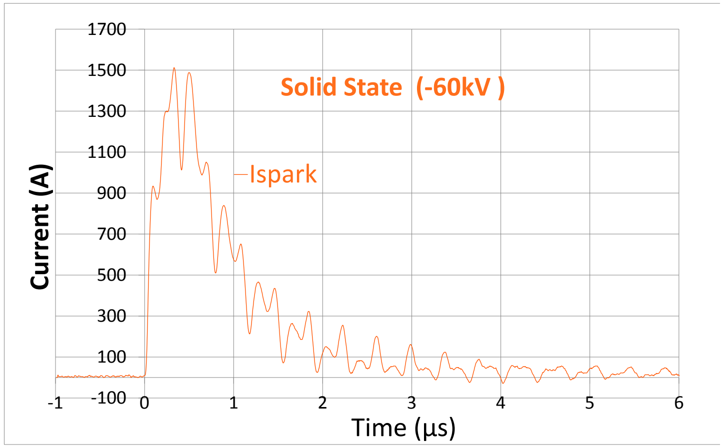
Charge transferred by the arc

A motorized spark-gap has been developed in order to reproduce fault conditions at the nominal operating voltage (60 kV)

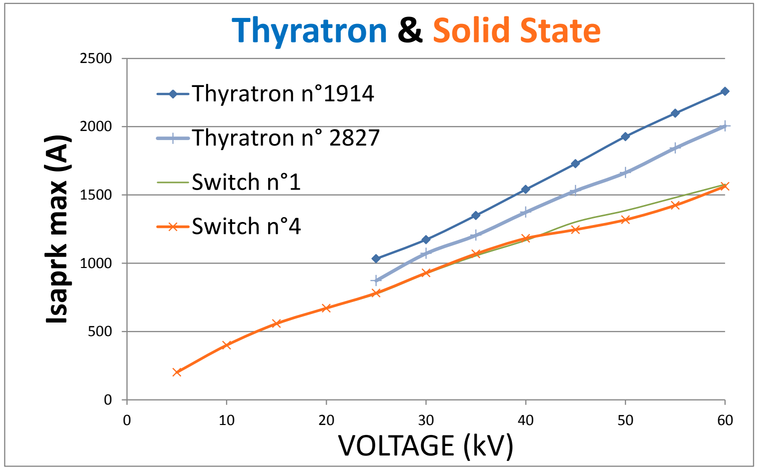




Solid State has equal or even better performances than thyratron.



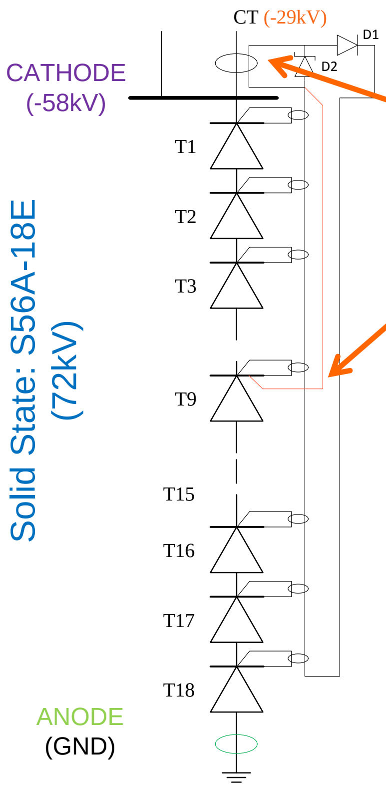
1500A/ 4µs spark current



Thyratrons are less reproducible.

Solid State crowbar improvements

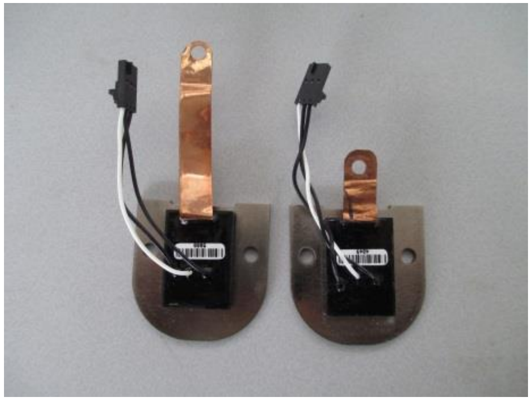
- First tests using the original APP trigger board (model EB0046C) showed better results using a thyratron
- An improved homemade trigger board (higher & faster currents) did not bring significant improvement either



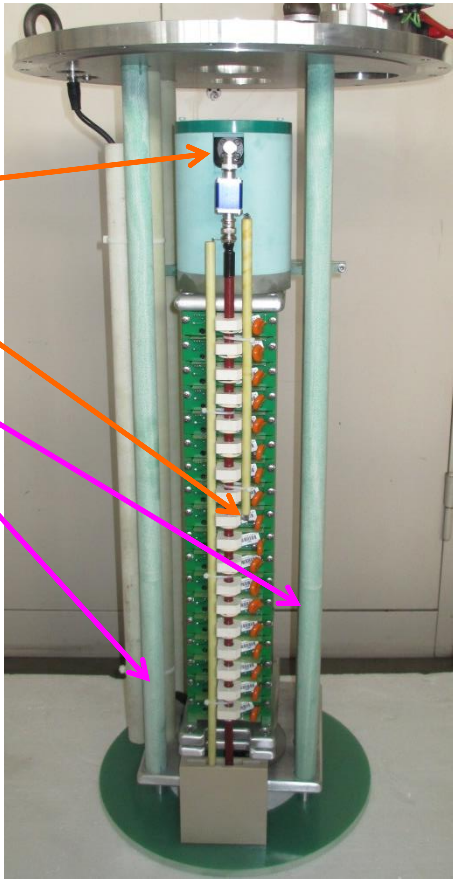
Trigger board removed & trig directly with the current transformer output

Reference the CT output to V/2

Use a better adapted coaxial assembly



Shortened the thyristor leads



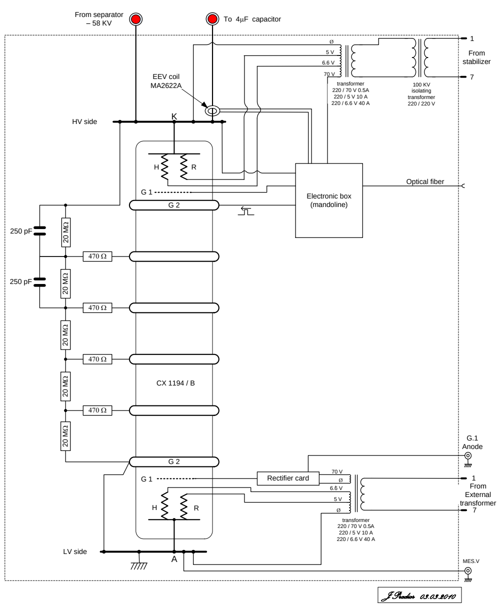
Solid state crowbar reliability

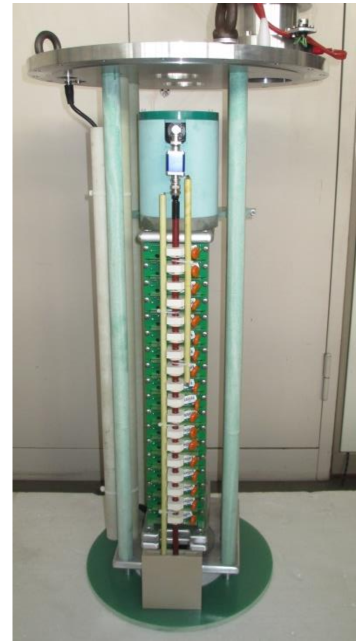
- First prototype installed in the LHC:
  - 1 real crowbar
  - After 3 months repeated (1-2 per day) auto-firing due to electrostatic discharges on the periphery of the trigger cable

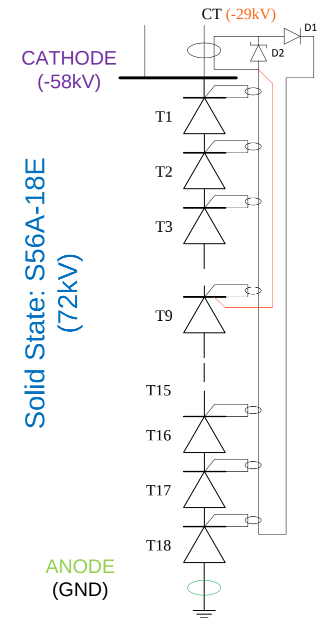
- Remedy:
  - Trigger referenced to $V_{cath}/2$ (less stress on the trigger cable)
  - Use of a better polyethylene trigger cable (model 2149 60kVDC)
  - Additional glass fiber insulator shield (around the trigger cable)

- Second prototype installed in the LHC:
  - 2 real crowbar triggers
  - No false trigger in 5 months of operation

Solid state crowbar for LHC RF (summary)







- Relatively complex circuit
- Fine adjustment (reservoir, heater)
- Need for water/oil cooling (~ 400 W)
- Oil volume 350 liters
- Thyratron price ~16000 €
- Unsure availability in the future
- Typical lifetime 1 – 3 years

- Relatively simple circuit
- No adjustments needed
- Very low power dissipation (~10 W)
- Oil volume 90 liters
- Thyristor stack price ~9000 €
- 10 units in production for LHC
- Unlimited (?) lifetime (wait and see)

References

CERN-ATS-2012-149

Ravidà, G (CERN) ; Brunner, O (CERN) ; Valuch, D (CERN): Performance of the Crowbar of the LHC High Power RF System

Conf. Proc. C1205201 (2012) pp.THPPD056

3rd International Particle Accelerator Conference 2012, New Orleans, LA, USA, 20 - 25 May 2012, pp.3641

More results will be published once the LHC machine is restarted after the Long Shutdown 1 in spring 2015.