MECHANISMS OF VACUUM ARCS

CHAMONIX 2013

SURFACE FLASHOVER OF HIGH PURITY ALUMINA DURING A PULSED ELECTRIC FIELD

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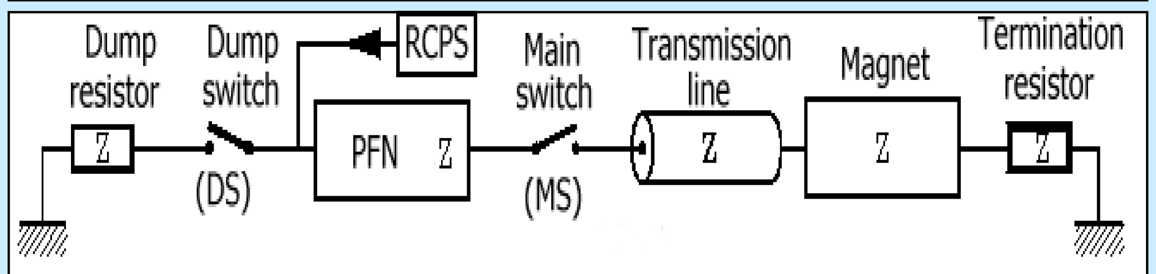
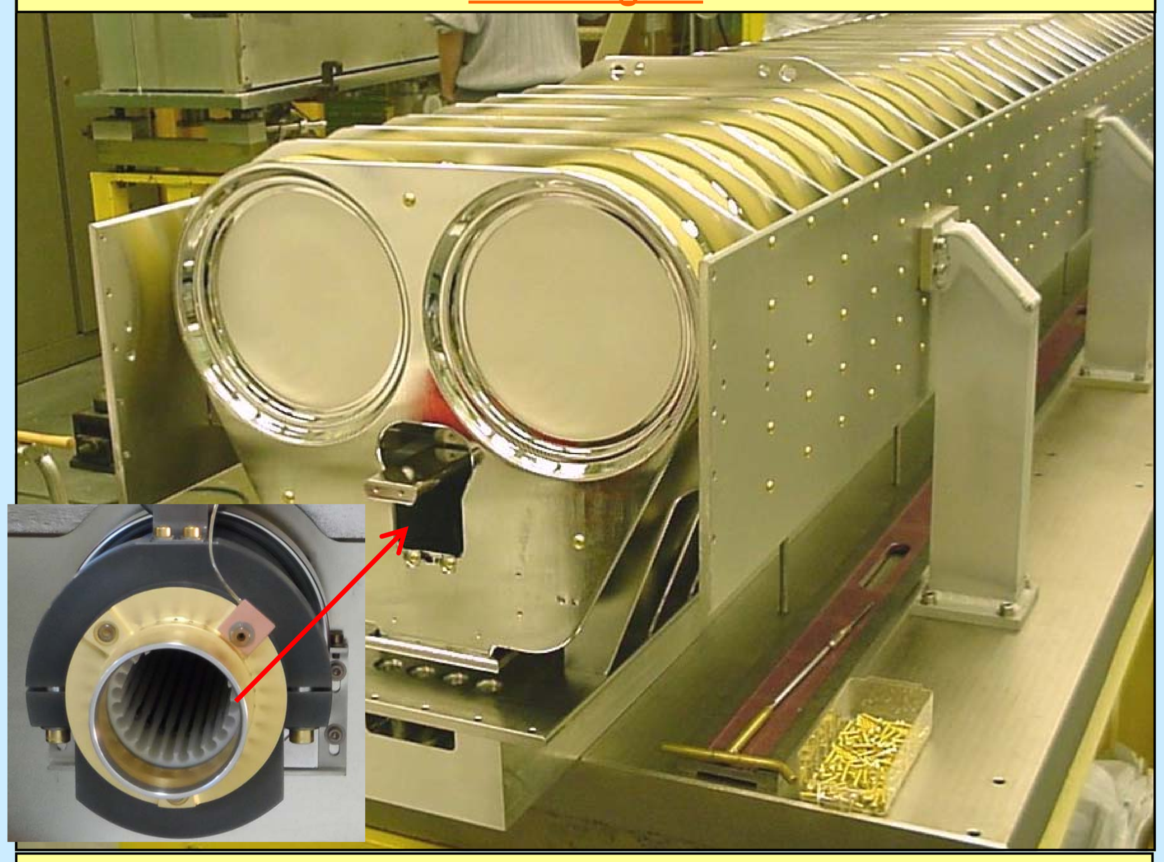
MKI kicker system



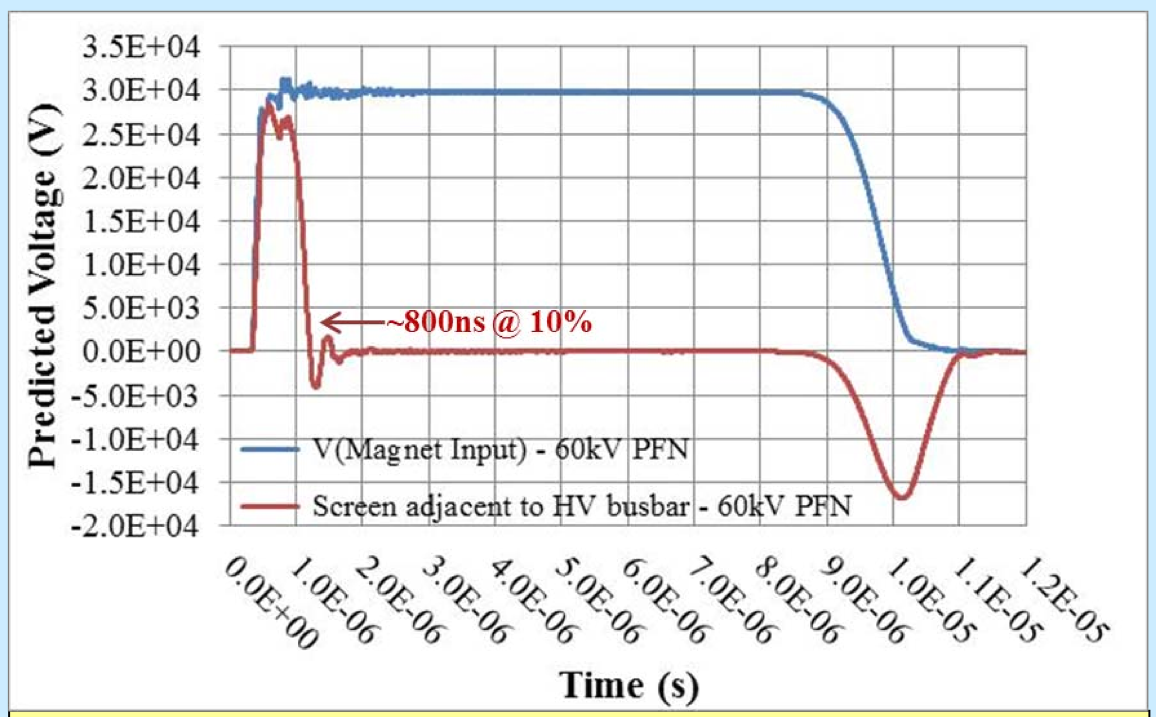
An MKI kicker system is composed of a multi-cell PFN and a multi-cell travelling wave kicker magnet, connected by a matched transmission line and terminated by a matched resistor (TMR). The impedance (Z) is 5 Ω.

MKI Magnet

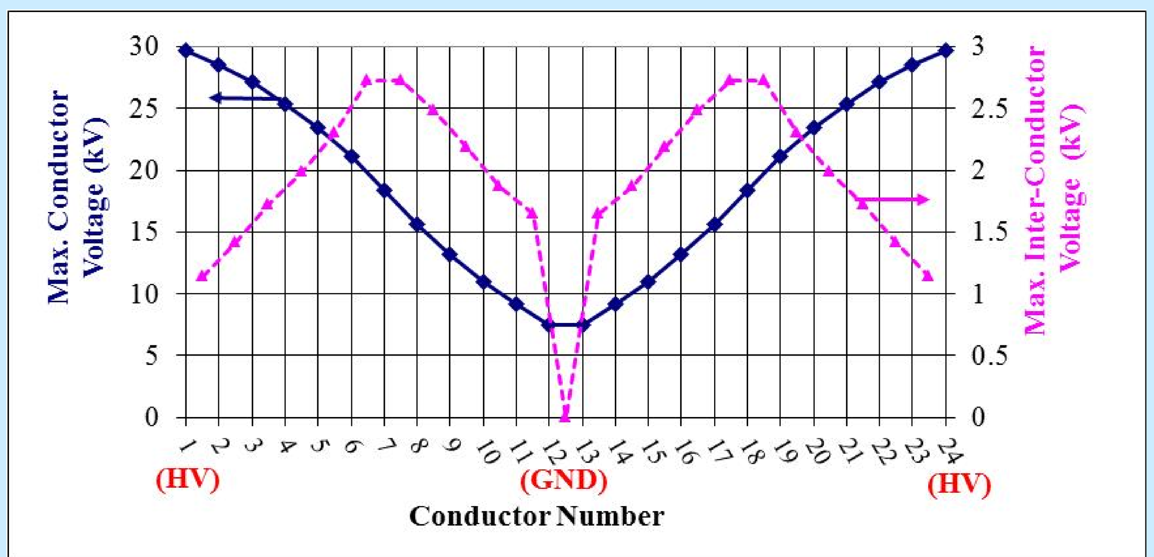


The travelling wave kicker magnet yoke is made of ferrite cores. Screen conductors mounted in a ceramic tube (lower left of figure), are placed in the aperture of the magnet: these conductors provide a path for the image current of the, high intensity, LHC beam and screen the ferrite against wake fields.

Voltage Induced on Screen Conductors



Voltage is induced on a screen conductor mainly by mutual coupling with the cell inductance. Hence the voltages, at the open end of the screen conductors, show a positive peak (max.) during field rise and a negative peak during field fall: the maximum is about twice the magnitude of the minimum.



Conductors #1 and #24 are adjacent to the HV busbar, whereas #12 and #13 are adjacent to the ground (GND) busbar. The highest maximum voltage (~30 kV) occurs for conductors #1 and #24.

Work by Sudarshan & Cross shows that Cr_2O_3 coating reduces Secondary Electron Yield (SEY) and increases surface flashover voltage of high purity alumina. Carbon coatings are also known to have a low SEY.

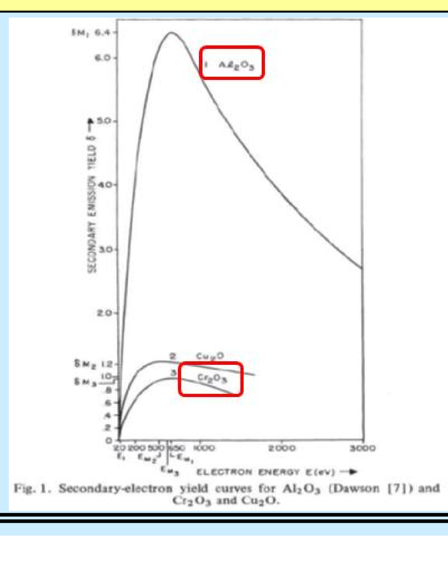


Fig. 1. Secondary-electron yield curves for Al_2O_3 (Dawson [7]) and Cr_2O_3 and CrO.

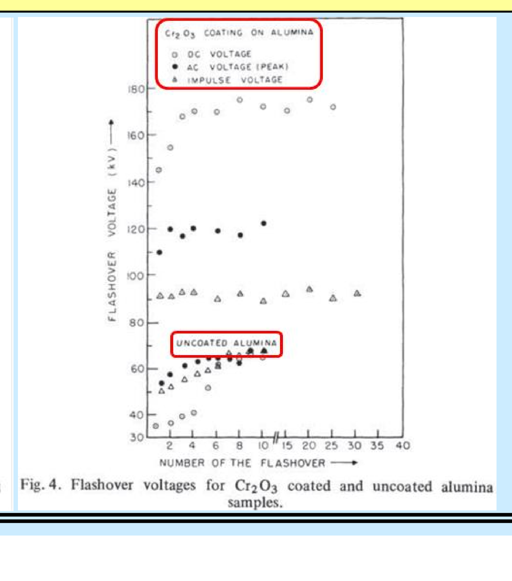


Fig. 4. Flashover voltages for Cr_2O_3 coated and uncoated alumina samples.

SUMMARY

The LHC injection kicker magnets include beam screens to shield the ferrite yoke against the effects of the high intensity beam: the screening is provided by conductors lodged in the inner wall of a high purity alumina support tube. The alumina must have a low rate of flashover. This screening will be further improved by additional conductors; however these must not compromise the good high-voltage behaviour. Extensive studies have been carried out to better satisfy the often conflicting requirements for low beam coupling impedance, fast magnetic field rise-time, ultra-high vacuum and good high voltage behaviour. The new design will be presented together with results of high voltage tests.

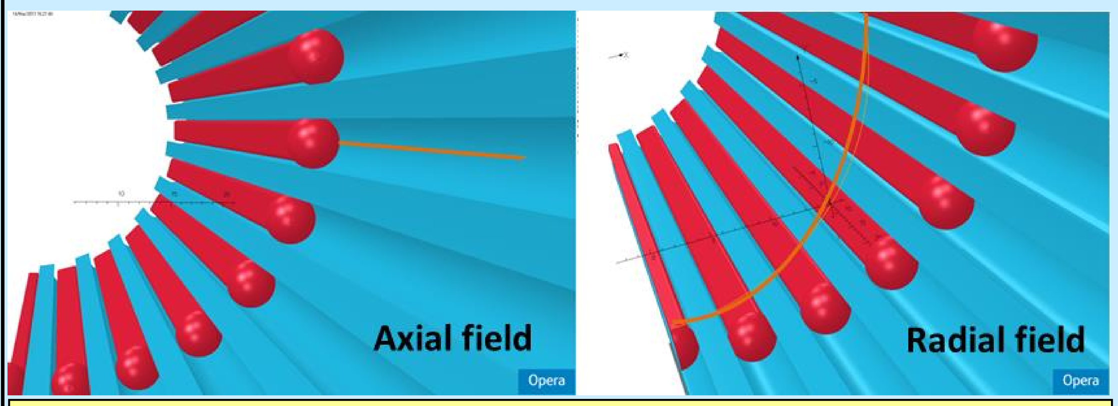
Significant pressure rises, due to electron-cloud, can occur in and nearby the alumina tube: the predominant gas desorbed from surfaces is hydrogen. Similarly temperature rise of the ferrite yoke can result in an increase in pressure. A series of high voltage tests are planned for the laboratory in which various gases are injected into a test tank: this will allow a careful and systematic study of the effect of pressure upon surface flashover of the ceramic tube. In addition various coatings are under investigation for further reducing surface flashover. The plans for these tests and a summary of the coatings under investigation will be presented.

MKI Flashover History

Screen conductor configuration	LHC PFN discharge inception voltage (kV)	Predicted field for discharge inception (kV/mm)	Comment
24 staggered (full) length conductors, metallization	30		
15 staggered (full) length conductors, metallization	49 & 54		4 MKIs*
15 graded length conductors (#8 longest), metallization	>57	>11 (axial)	3 MKIs
19 staggered length conductors with spheres, metallization	≥51	13 (radial)	1; installed in TS3

During 2012 operation, a total of 6 MKI magnet flashovers occurred: 3 of which were associated with the MKI8D installed during TS3 (all 3 believed to be on the surface of the ceramic tube).

Electric-Field Simulations

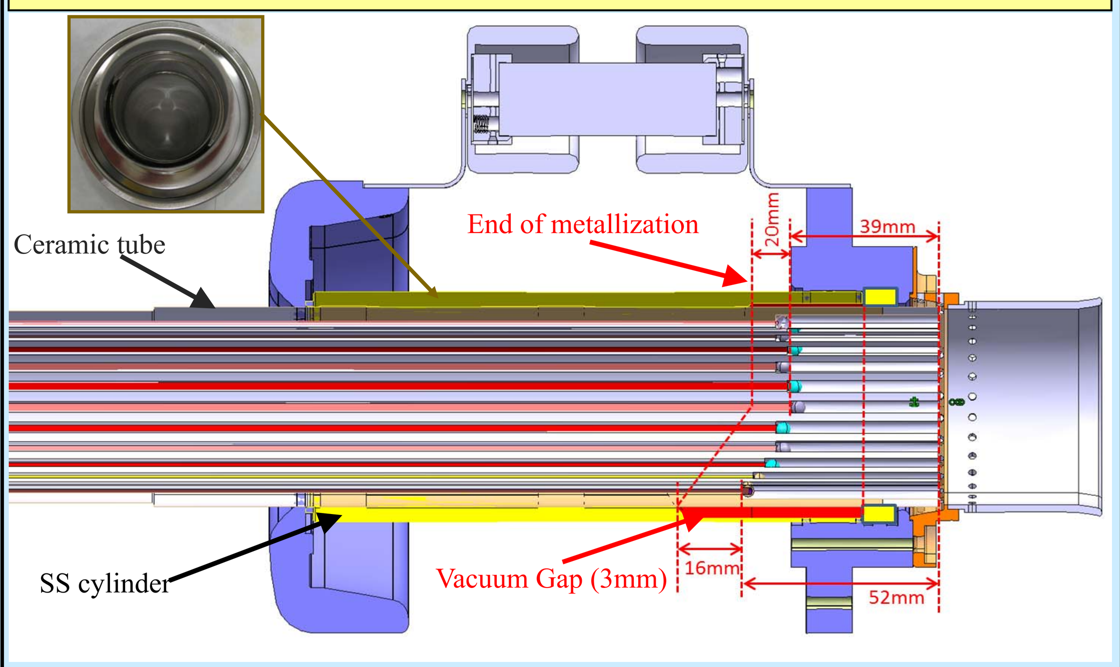


Extensive 3D electromagnetic simulations have been carried out, using the code TOSCA, to study electric fields on the surface of the ceramic. Each screen conductor is assigned the "Max." induced conductor voltage.

As a result of the high permittivity of the ceramic (~9-10) the radial surface electric field, between adjacent conductors, is a factor of almost 10 higher than what might otherwise be expected.

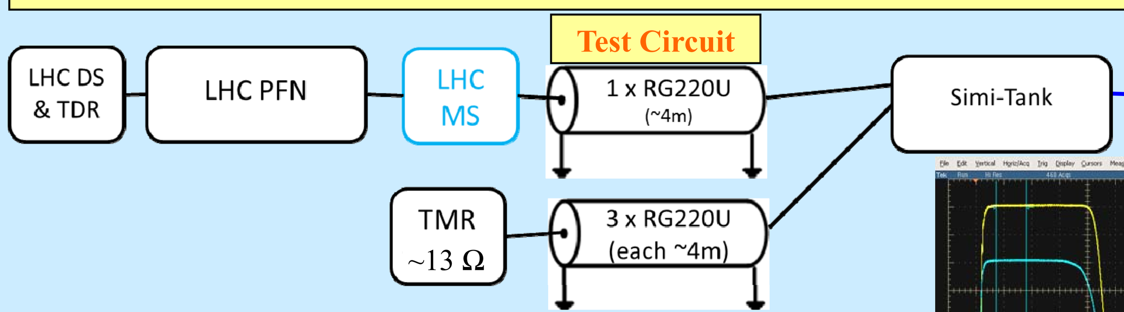
	# Conductors	Staggering	V-shape	Spheres	Image current path	Radial Field Er [kV/mm]	Axial Field (Ez) [kV/mm]	Outside Ceramic Radius
60kV LHC PFN	15	No	Variable	No	metalization	4	11.4	26.5mm
	19	10mmx19	No	Yes	metalization	15.7	8.2	26.5mm
	24	3mmx17	OptV	3.8mm Φ ball	2mm+1mm	7.5	3.9	28mm
	24	3mmx17	OptV	No	2mm+1mm	2.1	6.9	28mm

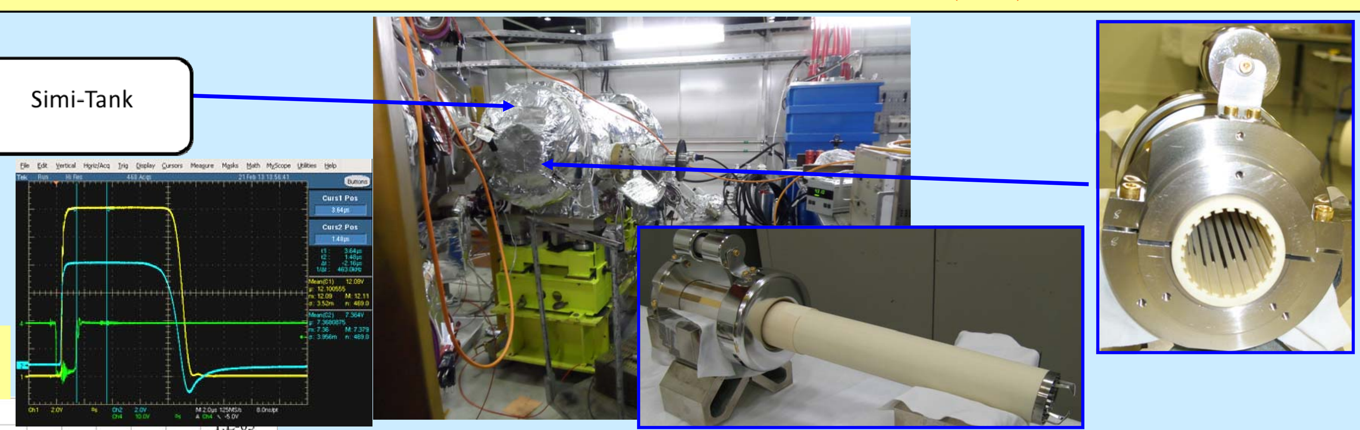
A significant benefit is obtained from removing the external metallization, from the outside of the ceramic tube, from a distance of ~20 mm behind the end of the screen conductors. Instead the path, for the beam image current, is provided by a stainless steel cylinder at a distance of between 1 mm and 3 mm from the outer surface of the ceramic tube .



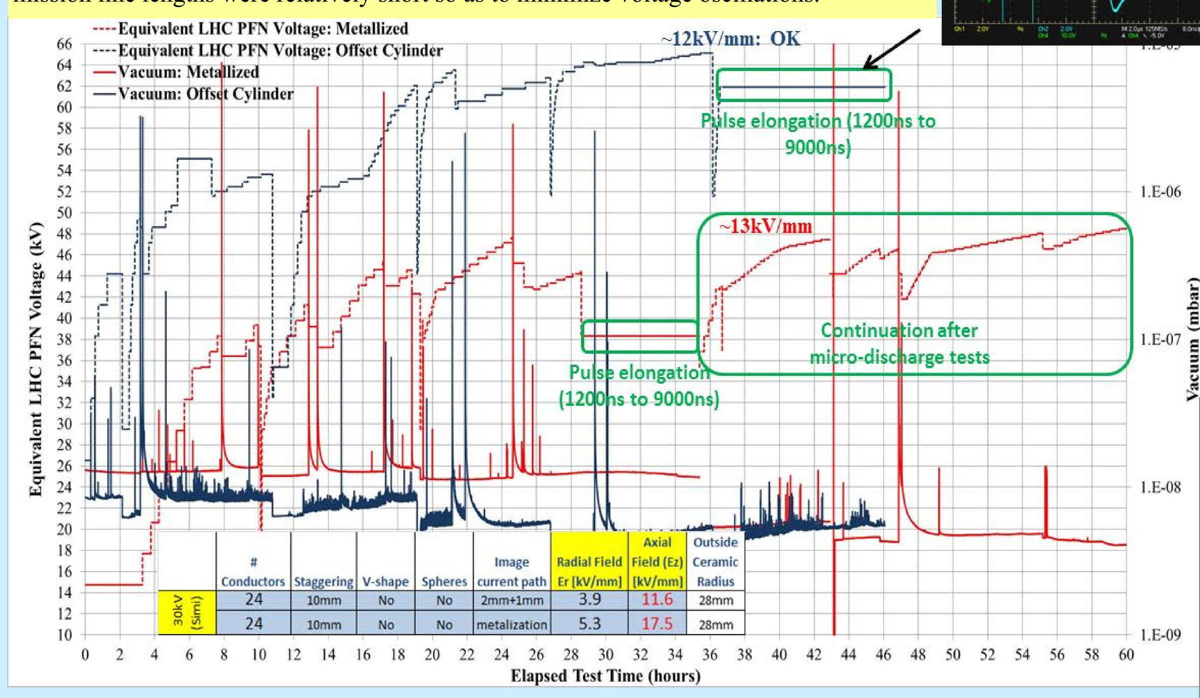
HV Laboratory Tests

Tests have been carried out to validate the electric field predictions. To permit HV testing at screen voltages well above those expected during normal LHC operation, without risking damage to a kicker magnet, the setup did not use a magnet. Instead 24 screen conductors were installed in a ~48 cm long ceramic tube, placed within a vacuum tank. All screen conductors were connected to the main switch (MS) of an LHC PFN.



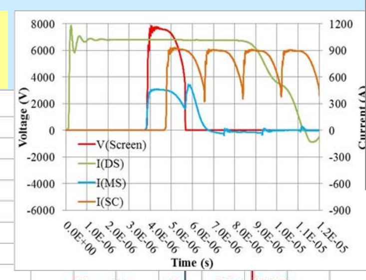


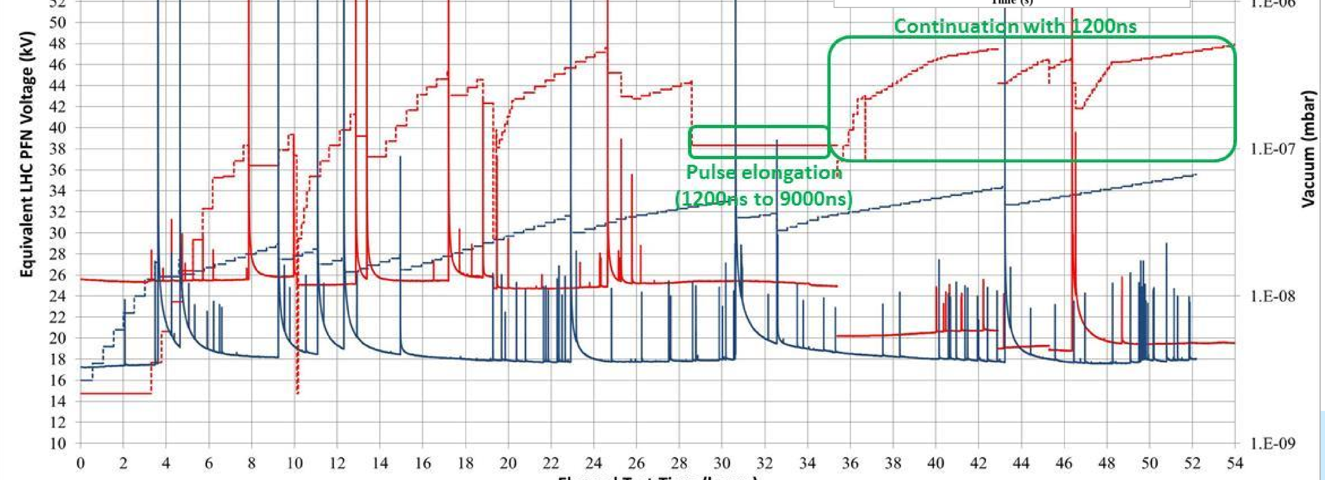
A ~13 Ω resistive terminator was connected in parallel to the output of the MS. Transmission line lengths were relatively short so as to minimize voltage oscillations.



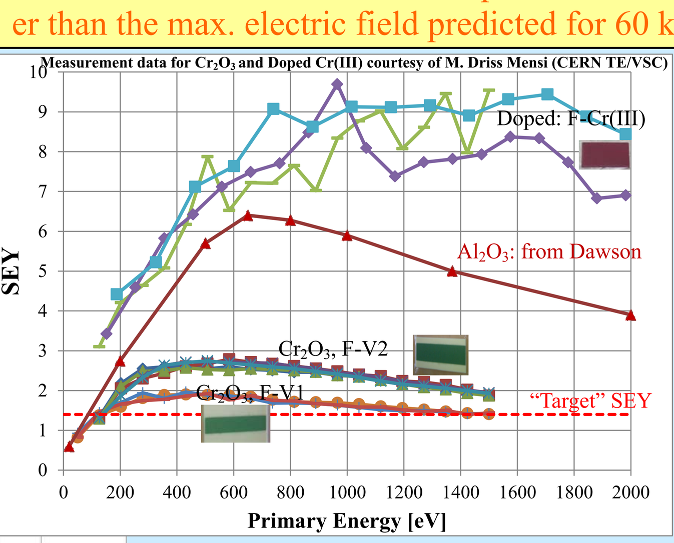
The metallized ceramic tube version was conditioned to ~47 kV equivalent PFN voltage, which corresponds to a predicted axial electric field of 13 kV/mm. This conditioning took considerably longer than for the version with the offset cylinder, which was tested to ~65 kV equivalent PFN voltage, which corresponds to a predicted axial electric field of 12 kV/mm: conditioning was stopped at this voltage to prevent puncture of the ceramic tube so that it could be used for subsequent tests. The 12 kV/mm is ~60 % greater than the max. electric field predicted for 60 kV operation in the LHC.

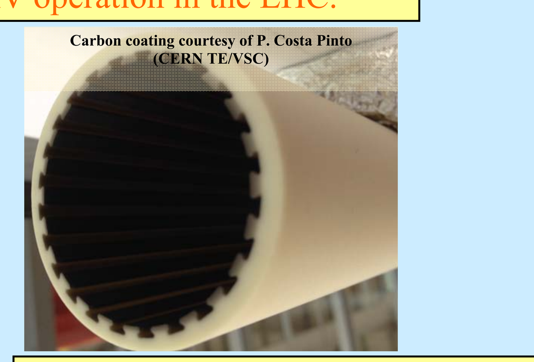
Short-circuit after 180m of cable gives bipolar voltage on the screen conductors and ~correct ratio of +ve to –ve voltage: but very fast swing to negative voltage.

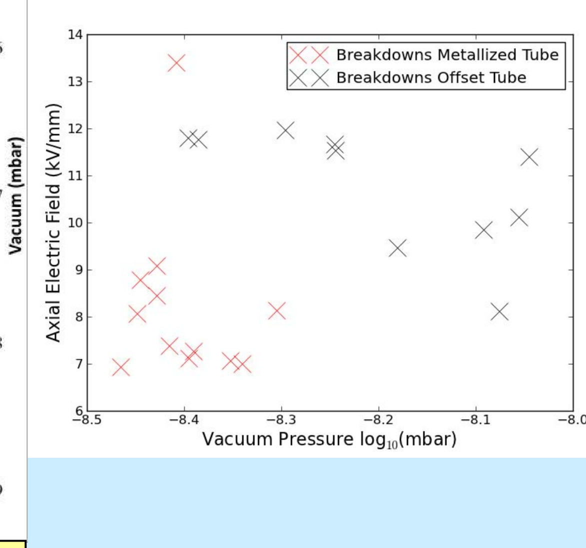




Surface flashover voltage for fast changing bipolar voltage occurs @ ~70% of unipolar PFN voltage.







Further investigations are foreseen on the relationship between vacuum pressure and surface flashover voltage, in this case in the context of setting vacuum interlock levels for increased electron cloud activity foreseen in the LHC post-LS1. In relation to this is the examination of the HV behaviour of surface coatings (Cr_2O_3 and carbon) in order to reduce SEY, again for electron cloud. There is also an open question of the relationship between SEY and the surface electric field during electric breakdown: is the relation strongly pronounced?

MeVArc, November 6, 2013.