Generation of high pulsed magnetic field using a low inductance surface switch

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Context

Laser – matter and laser plasma interaction in presence of a high magnetic field is a hot topic.

- laser- plasma Pollock et al, Rev. Sci. Instrum 77 (114703 (2006), Froula et al. PRL 98, 135001 (2007)
- neutron production Keskelidou, Moustaizis et al., Applied Radiation and isotopes, 63 (2005) 671-680

B field can ensure the condition of an extended confinement time for charged particles

Larmor radius $\rho_L = mv / qB = (2E_{kin}\, m)^{1/2} / q\, B$

Electrons	Protons
$\omega_{ce} / 2\pi$ [GHz] = 28 B [T]	$\omega_{pe} / 2\pi$ [MHz] = 15 B [T]
$\rho_{Le} = 2.8\ (E_{kin}$ [eV]$)^{1/2}$ / B [G]	$\rho_{Le} = 1.4\ (E_{kin}$ [eV]$)^{1/2}$ / B [G]

B-field is generated by Helmholtz coils (Pollock et al. 2006, Froula et al. 2007, Courtois et al. Rutherford Lab Annual report 2002-3 P. 91) or driven by a large HPP generator (Presura et al., IEEE TPS 36 (2008) p. 17-21)

Experiments should be conducted in semi- or non-destructive conditions

Main objective

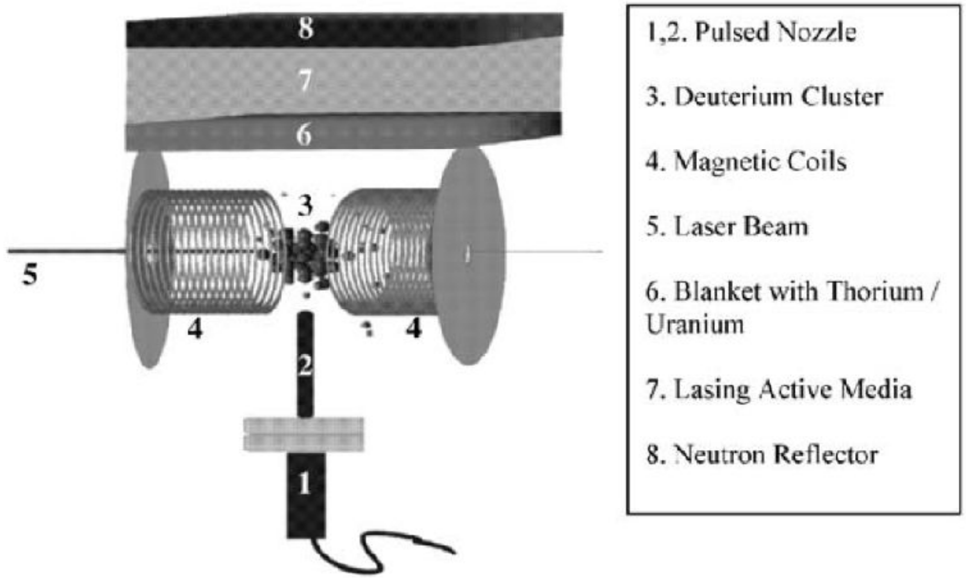
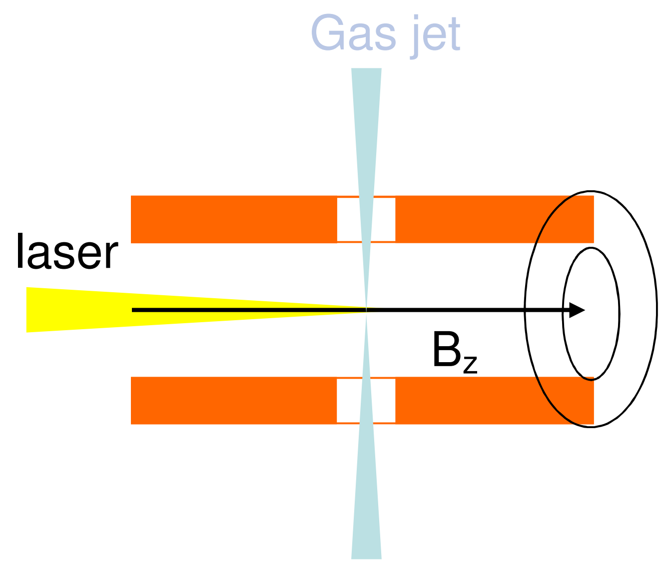


Fig. 2. Proposed experimental setup for the study of both the neutron pump laser scheme and the appropriate gas mixture of the excimer cavity. The block of the three layers (6,7 and 8) has a cylindrical form, surrounding the pulsed magnetic field and the pulsed gas nozzle. Both the nozzle and the magnetic field can operate at 10 Hz and are synchronized with the 10 Hz high-intensity laser beam. Two mirrors (not visible in the figure), a plane and a spherical one (3 m focal distance), and a monochromator allow one to study the fluorescence from the laser cavity.

Keskelidou, Moustaizis et al., Applied Radiation and isotopes, 63 (2005) 671-680

From theory and numerical simulation, the objective is to create a cm-size interaction zone with a magnetic mirror geometry in the 50 Teslas range



Objectives

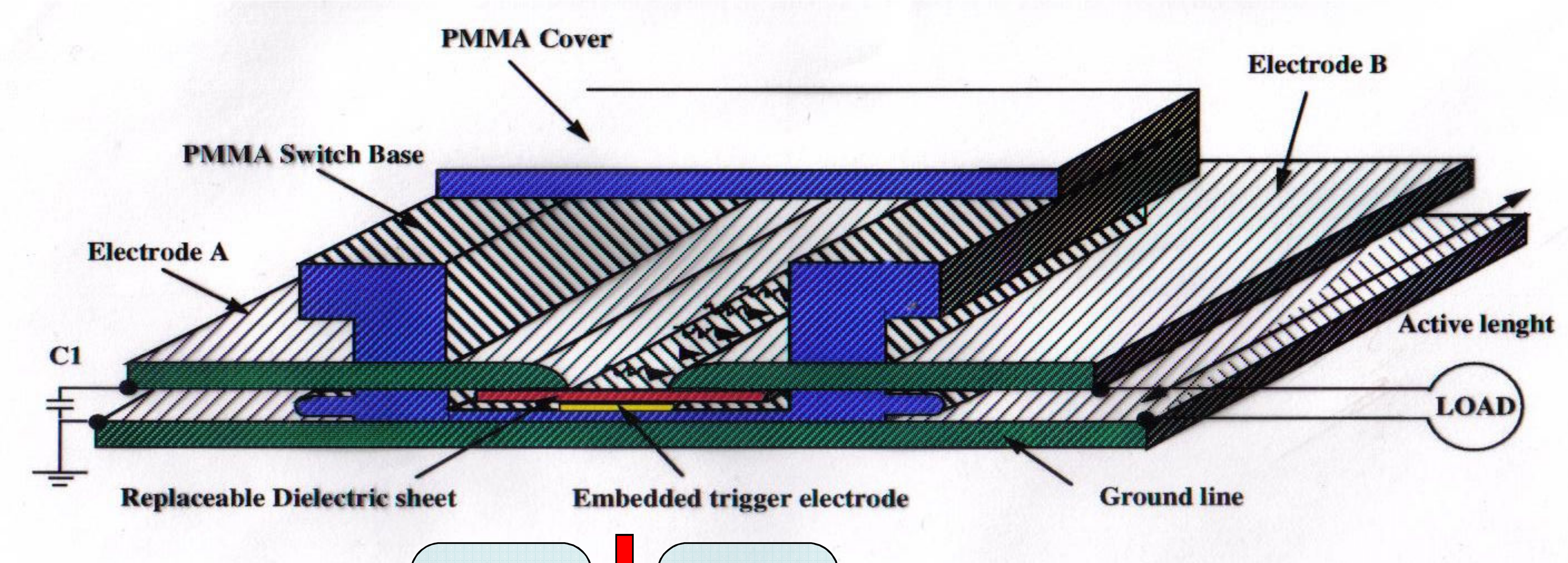
▪ A compact generator	Typ. a few sq.meter
▪ A high pulsed current	
~1 MA	Capacitive storage
in a μs regime	Very low inductance switch
into a cm-bore single turn coil	
▪ Calibration of the B-field	Alternative operation < kHz
▪ Compatibility with a laser created plasma experiment	Non destructive experiment

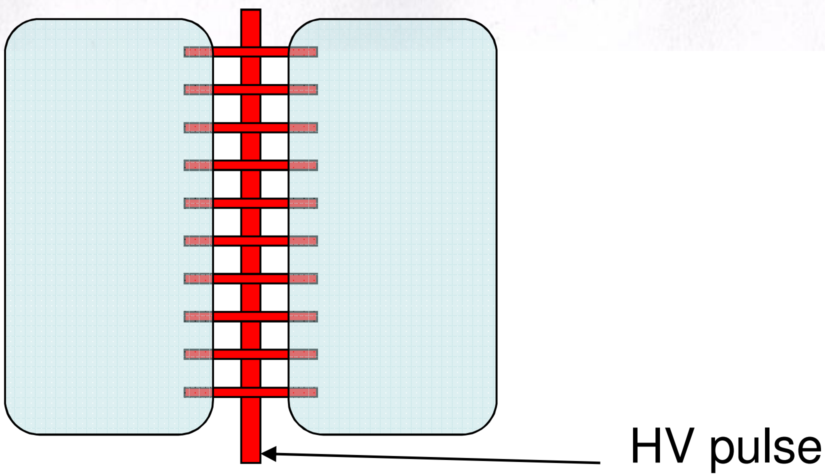
Content

1. Surface switches in Polytechnique Plasma Lab
2. Preliminary setup
3. Calibration
4. High current tests
   4.A Two caps bank
   4.B Four caps bank
5. Conclusion

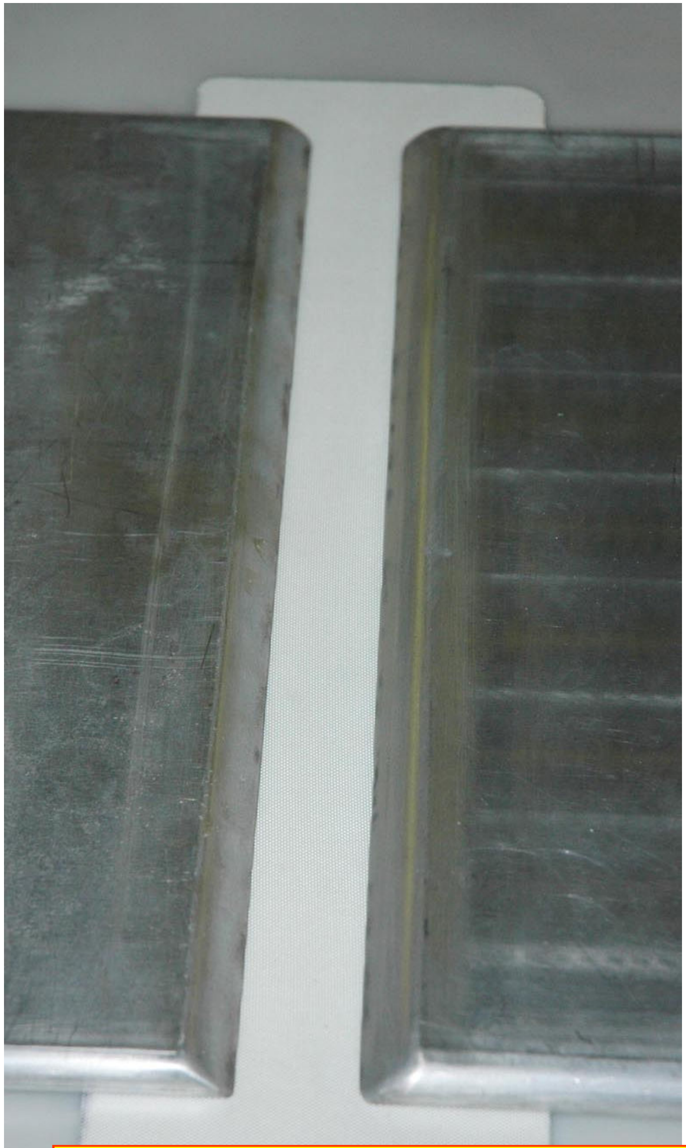
1. Surface switches

Originating from the work by Sarjeant et al. (IEEE Tr. Elec. Devices ED-26 (1979) p1414), the Polytechnique Plasma lab has developed different surface switches (Buzzi et al., RSI 61 (1990) p. 852, Etlicher et al. IEEE PPC 1995 digest p 243-8).



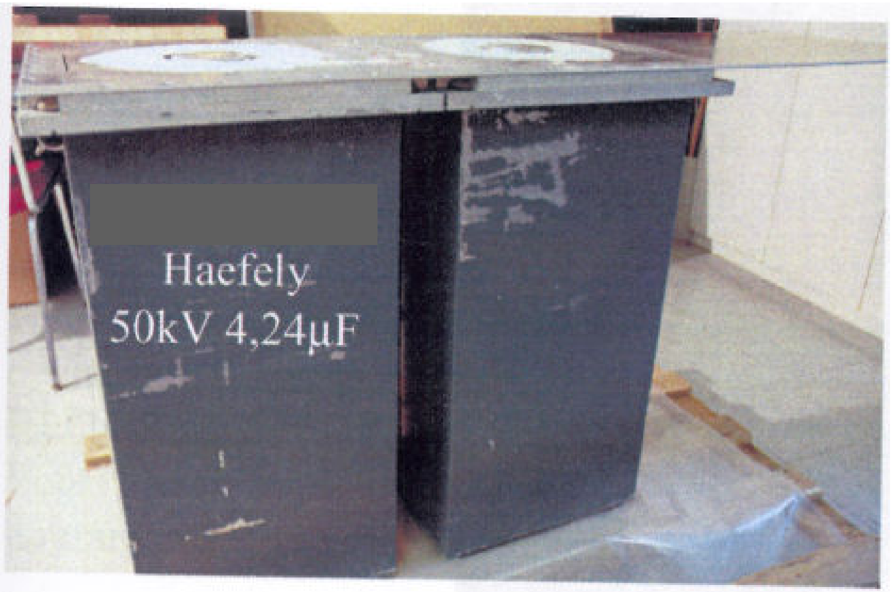


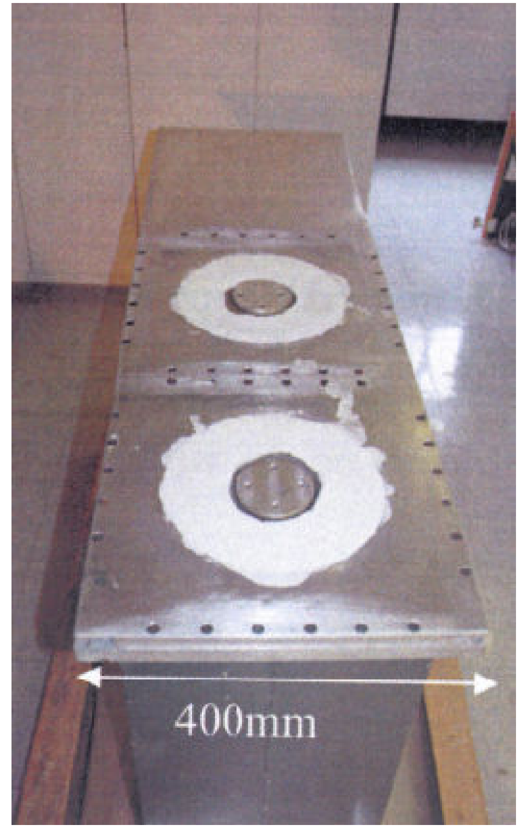
Surface switch design and operation



1mm thick glass reinforced melamina sheet is a convenient substrate for heavy duty surface discharge switching in air

2. Preliminary setup





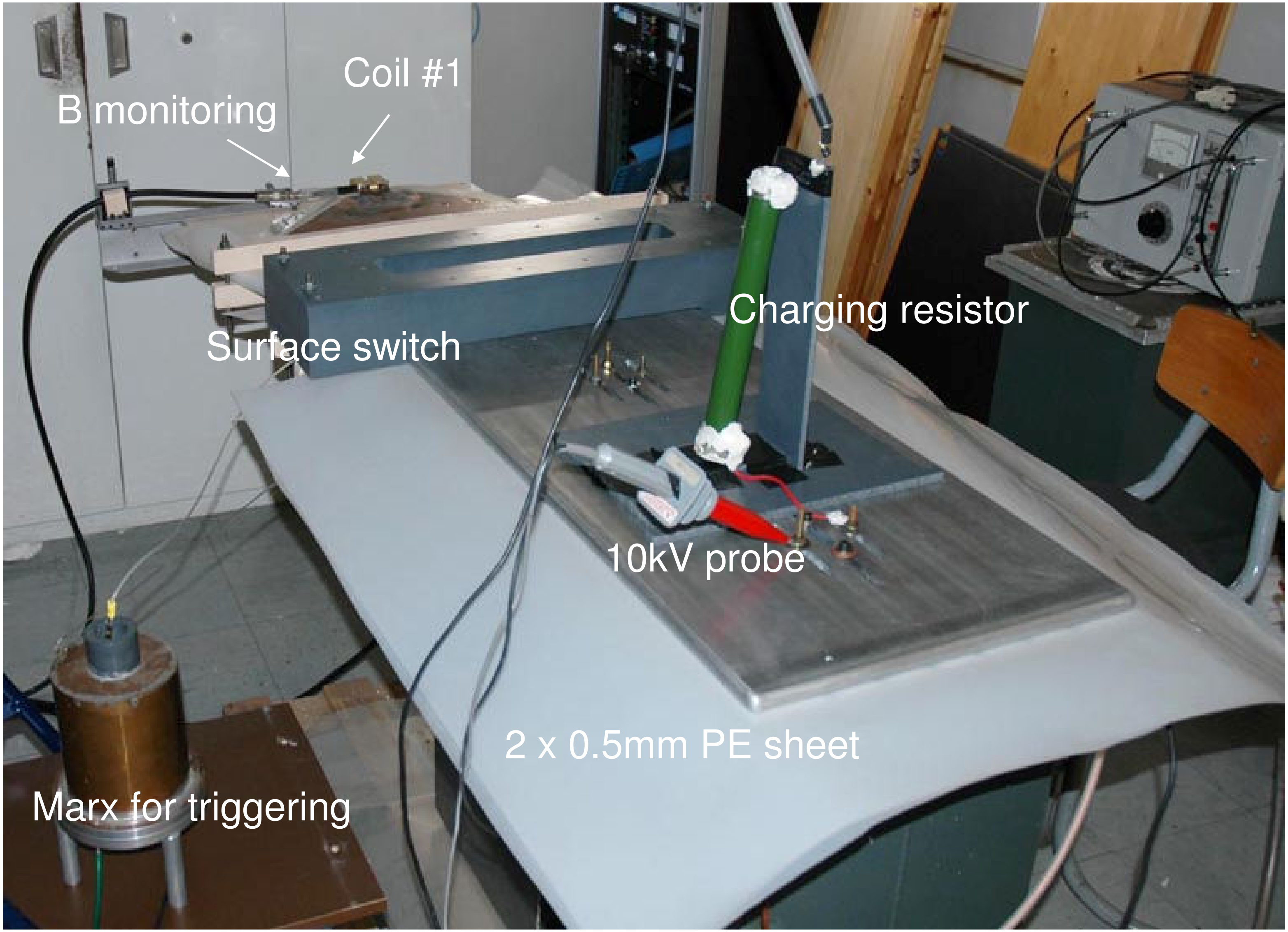
LC circuit :
flat line   PE insulated
2 x 4.24µF bank

Caps rather old
Operation in atmospheric air

Operating voltage 20-30 kV

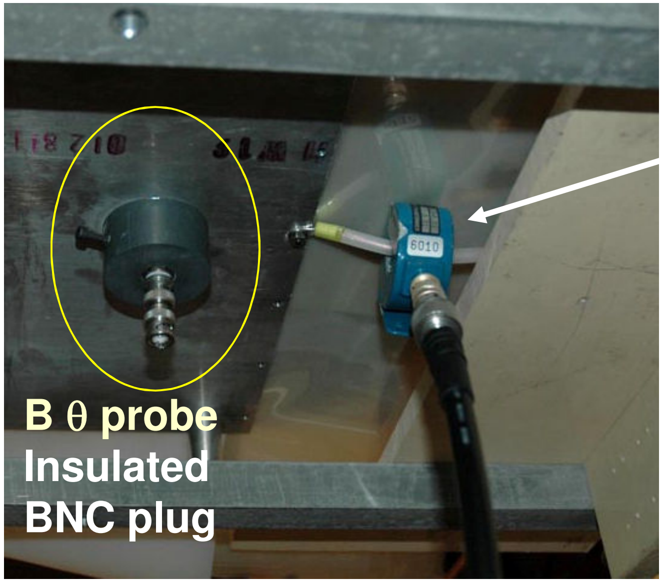
May create difficulties to trigger the surface switch

Setup with a 2 x 4.24μF bank



Current monitoring

B θ probe   4-turns 1-mm wire coil



CT on the return current wire
for low currents (kA) only

Bottom view

In order to get L, the current intensity is crossed checked with a model of LC oscillating discharge

measurement may be influenced by current distribution in the flat line

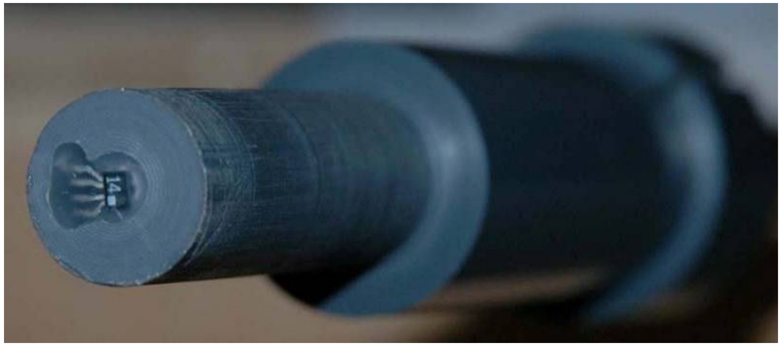
B-field monitoring

STATIC
GN206 gaussmeter

B

Comparison using magnets
125 µV / G

Hall effect probe
Siemens KSY14
Typ. < 1 kHz



B

Comparison at low frequency

B-dot

One-turn coil Ø2.5mm

Insulated BNC plug

3. Calibration

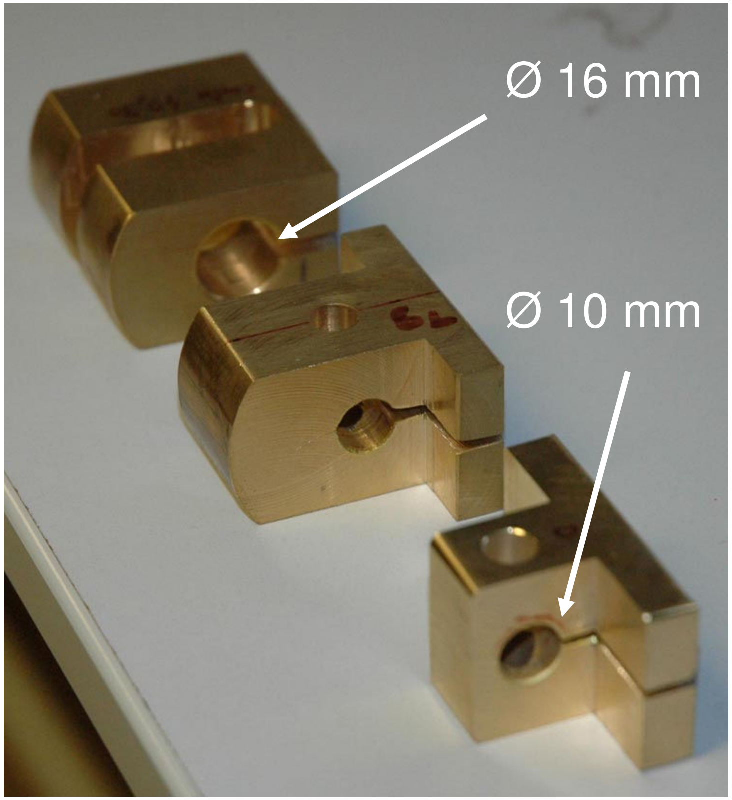
At very low current

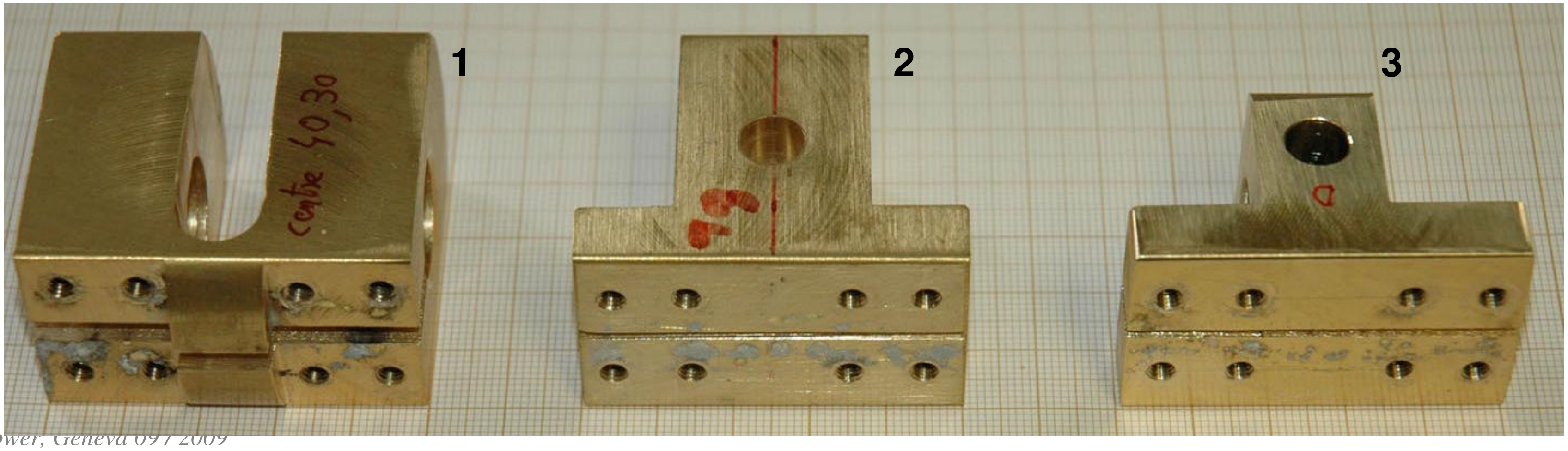
In quasi static conditions (<kHz)

- A 1000µF cap is inserted in the circuit, charged up to 300 V
- The switch is a pneumatically driven one
- The coil bore is compatible with Hall probe (i.d. 10 - 16mm)

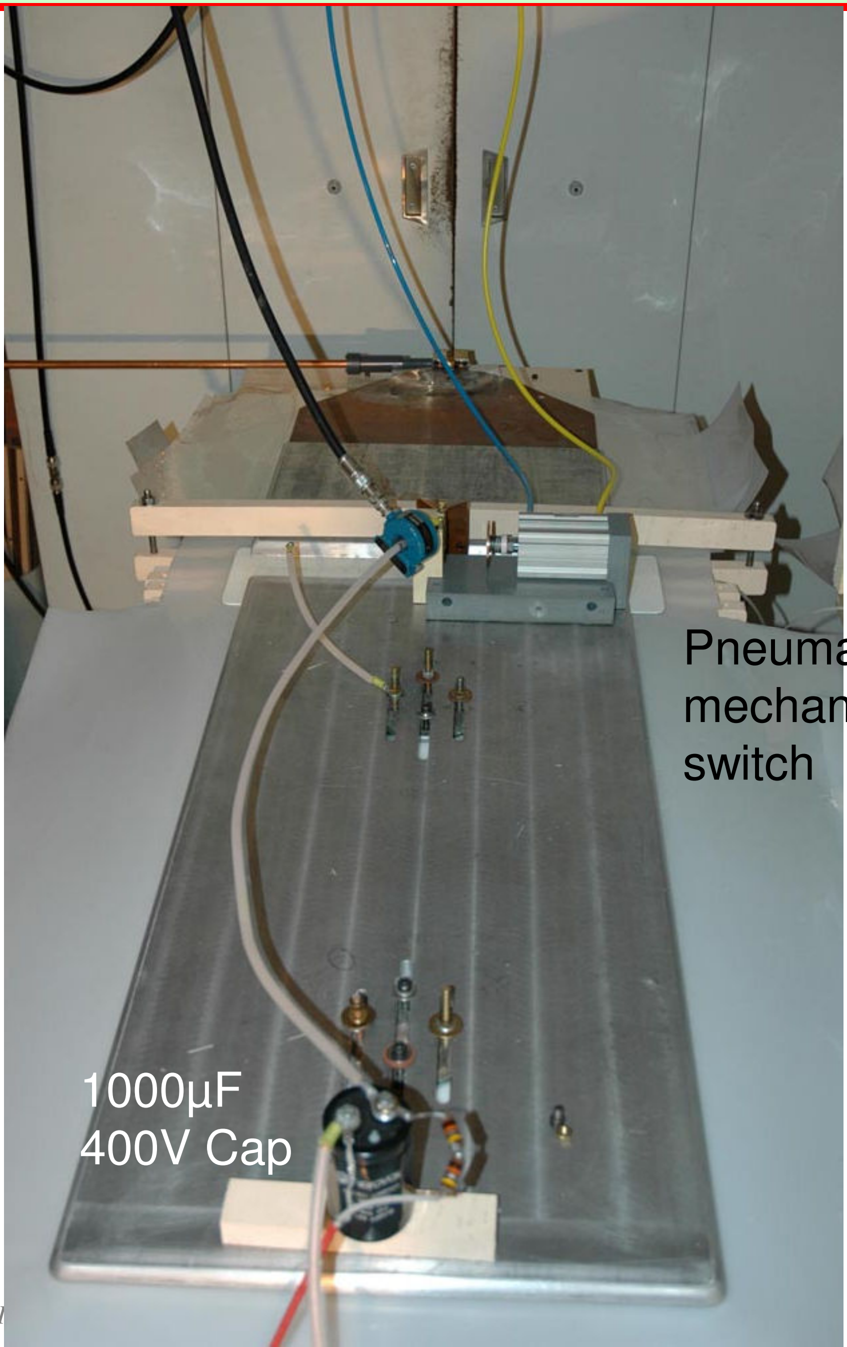
Three coils are tested to increase B value and axial uniformity :

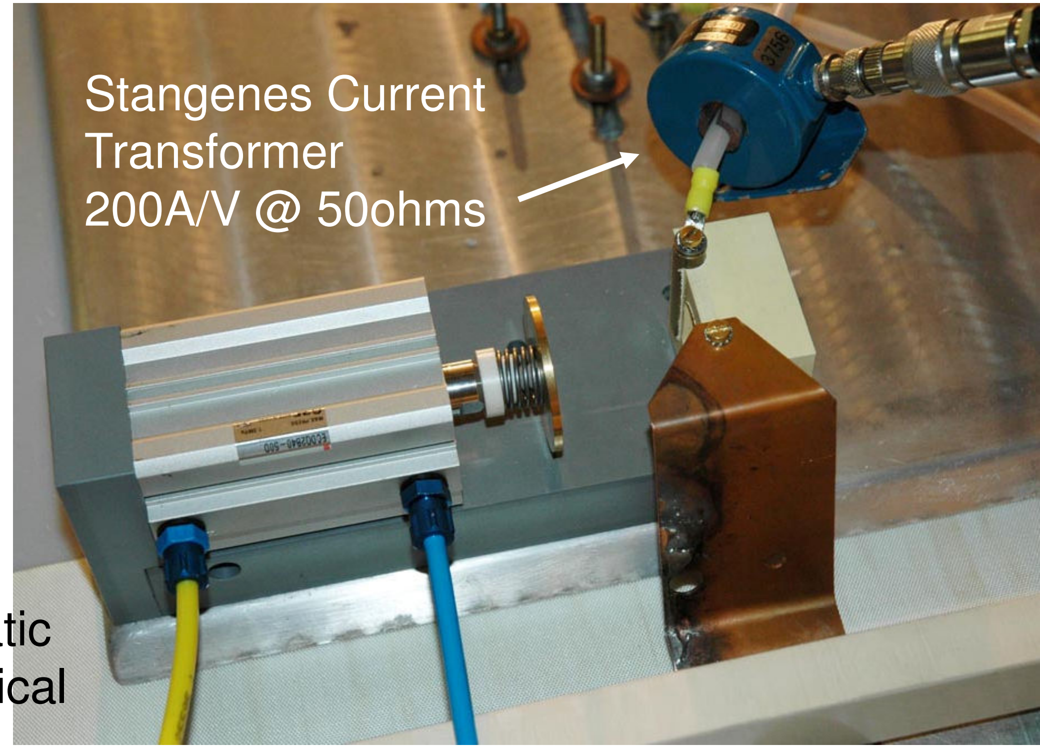
1. Large slit and long coil
2. Side-on hole and long coil
3. Side-on hole and short coil

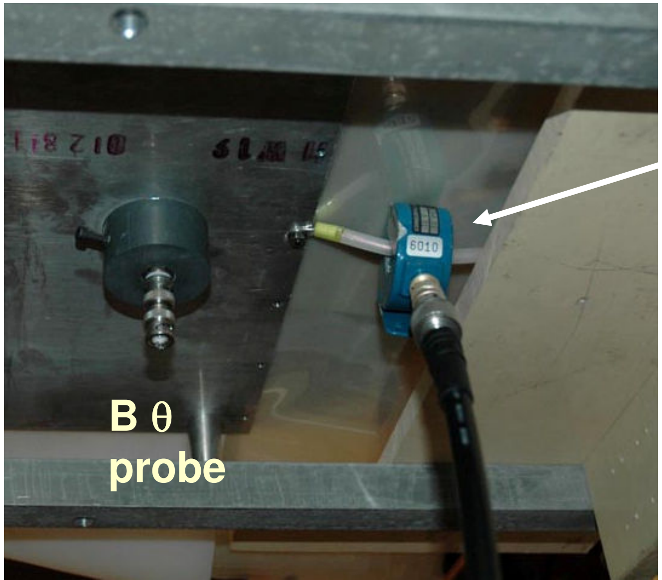




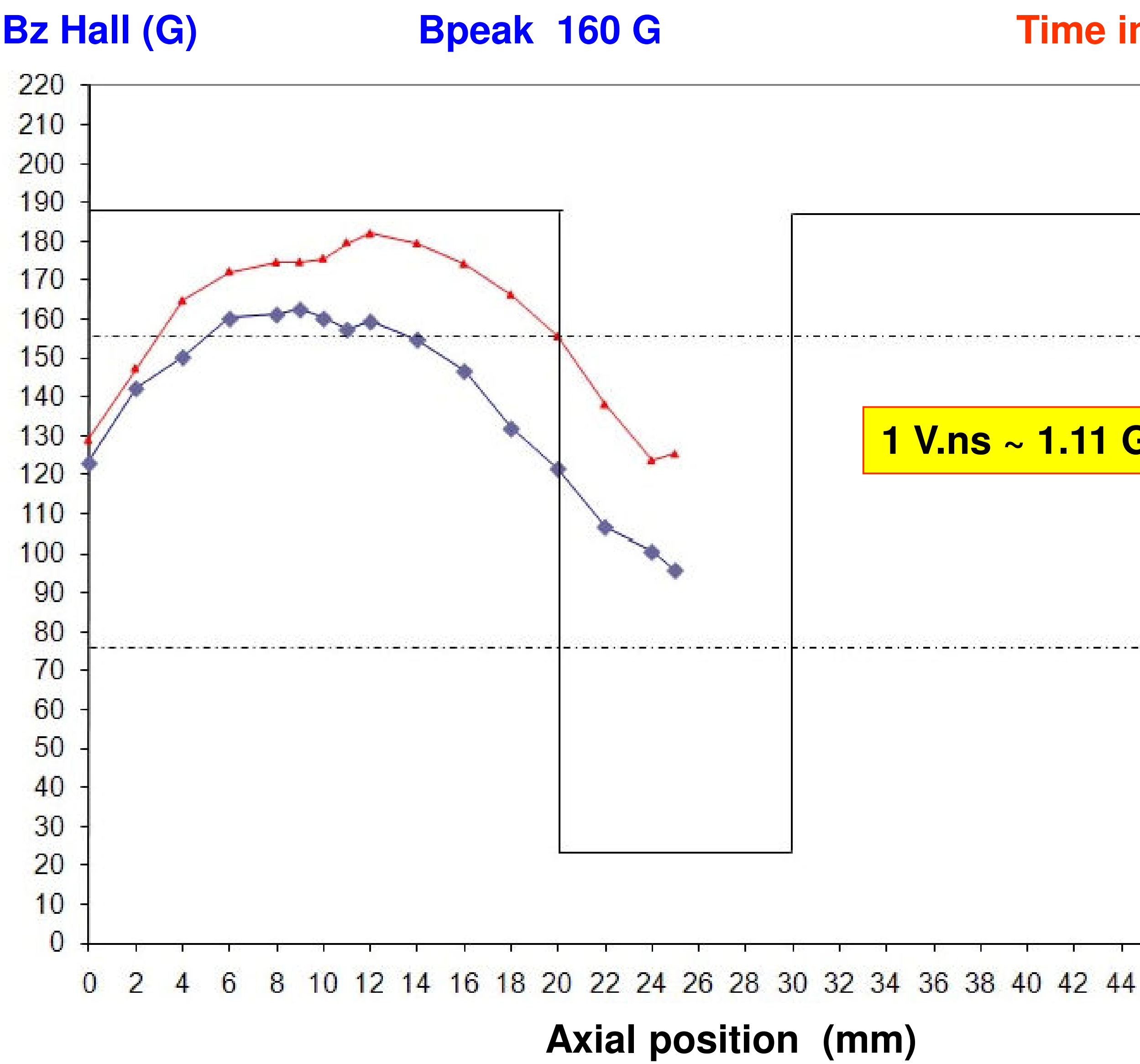
Calibration setup

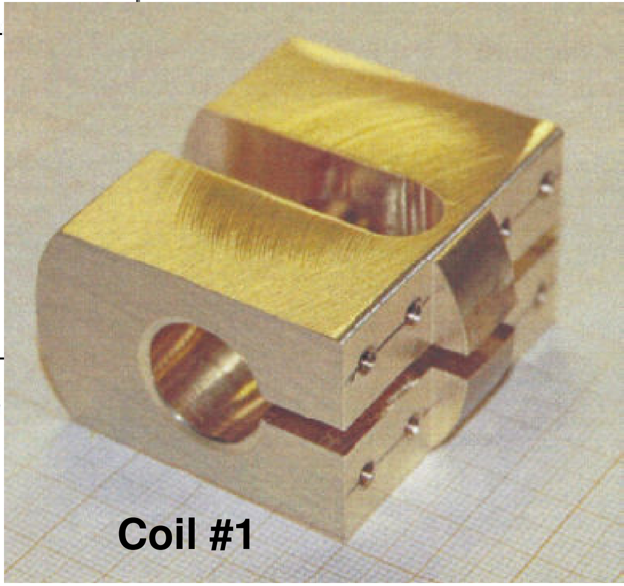






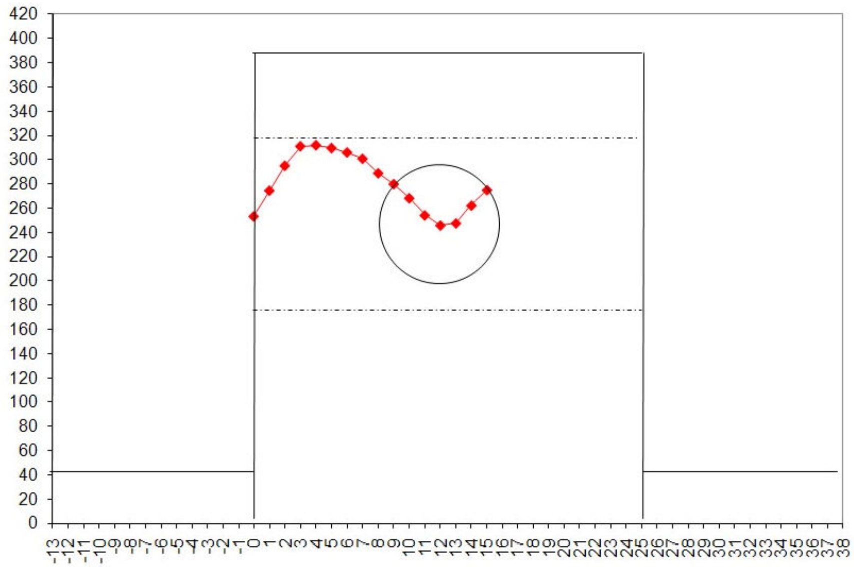
Calibration result - coil #1

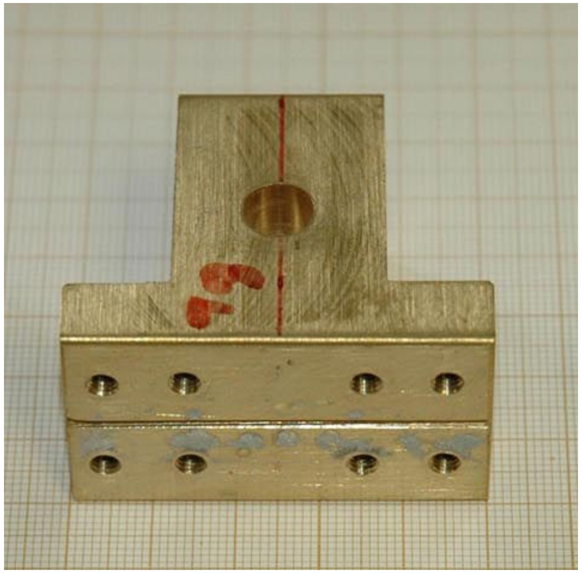




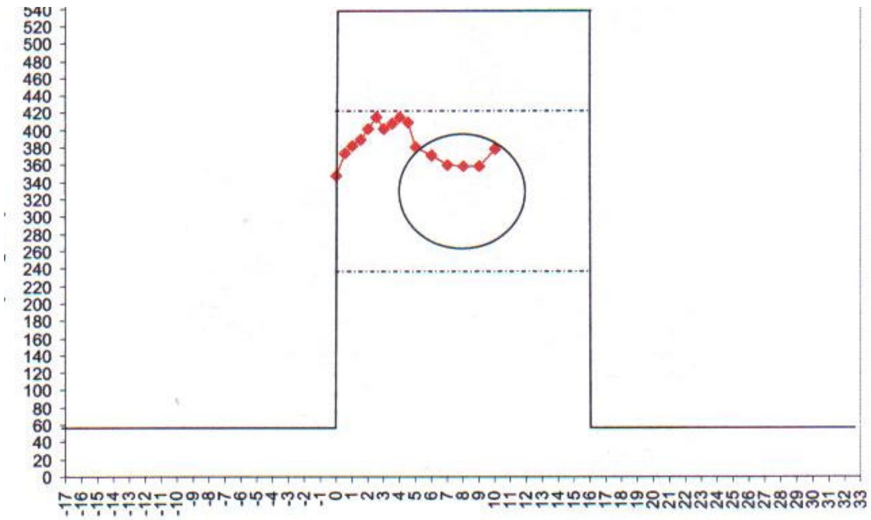
Calibration results - coils #2 - 3

Bz (G) coil 2 **B peak 311 G**





Bz (G) coil 3 **B peak 410 G**



4.A. High current tests - 2 x 4.24 µF bank

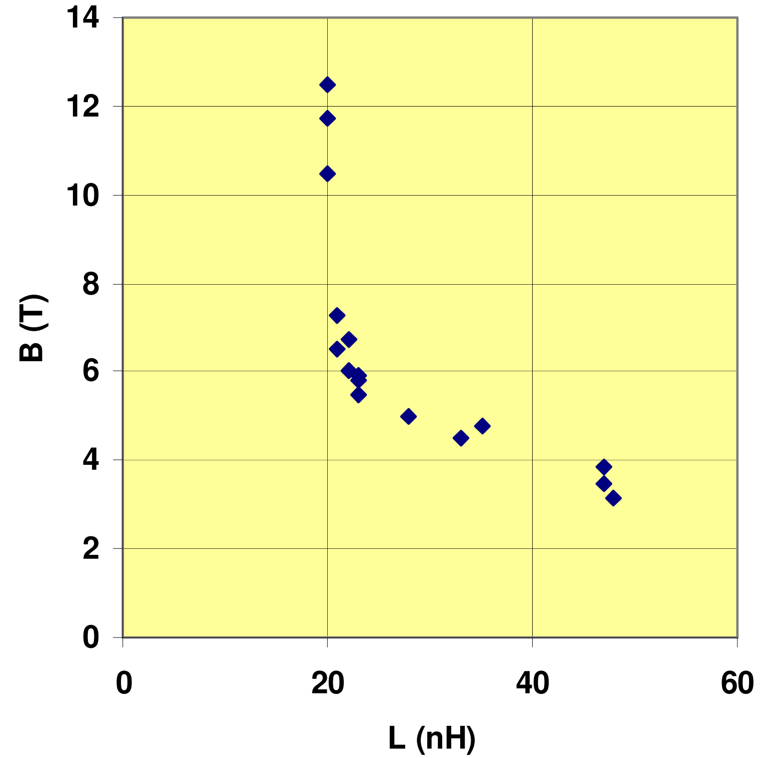
The setup is as described before.

The tests are conducted :

- at growing charging voltage 20 kV – 30 kV
- for various HV pulser to trigger the surface switch
- for decreasing flat line spacing
- for the three coils

Two-caps tests   influence of total inductance

insulation	coil	V charge kV	T/4 ns	Imax kA	B T	L nH
2mm PE	1	20	1280	222	3,15	48
2mm PE	1	23	1220	257	3,5	47
2mm PE	1	25	1235	280	3,85	47
1,5mm PE	1	25	945	353	5	28
higher energy	triggering Marx					
1,5mm PE	1	25	812	398	5,8	23
new triggering Marx						
1mm PE	1	25	887	390	5,5	23
1mm PE	1	25	779	413	6	22
1mm PE	1	25	819	403	6	22
1mm PE	1	25	843	399	5,9	23
1mm PE	1	26	806	429	6,5	21
1mm PE	1	26,5	1044	342	4,5	33
1mm PE	1	27,5	812	444	6,75	22
1mm PE	1	30	1086	380	4,78	35
1mm PE	1	30	801	494	7,25	21
1mm PE	2	25	778	419	10,5	20
1mm PE	2	27,5	775	462	11,7	20
1mm PE	**2**	**30**	**771**	**499**	**12,5**	**20**
1mm PE	3	30	830	na	**15,9**	na



The minimal inductance of 20 nH gives a maximum B up to 15 T

4.B. High current tests - 4 x 4.24 µF bank

Parallel mounting :

C is increased

L is expected to decrease

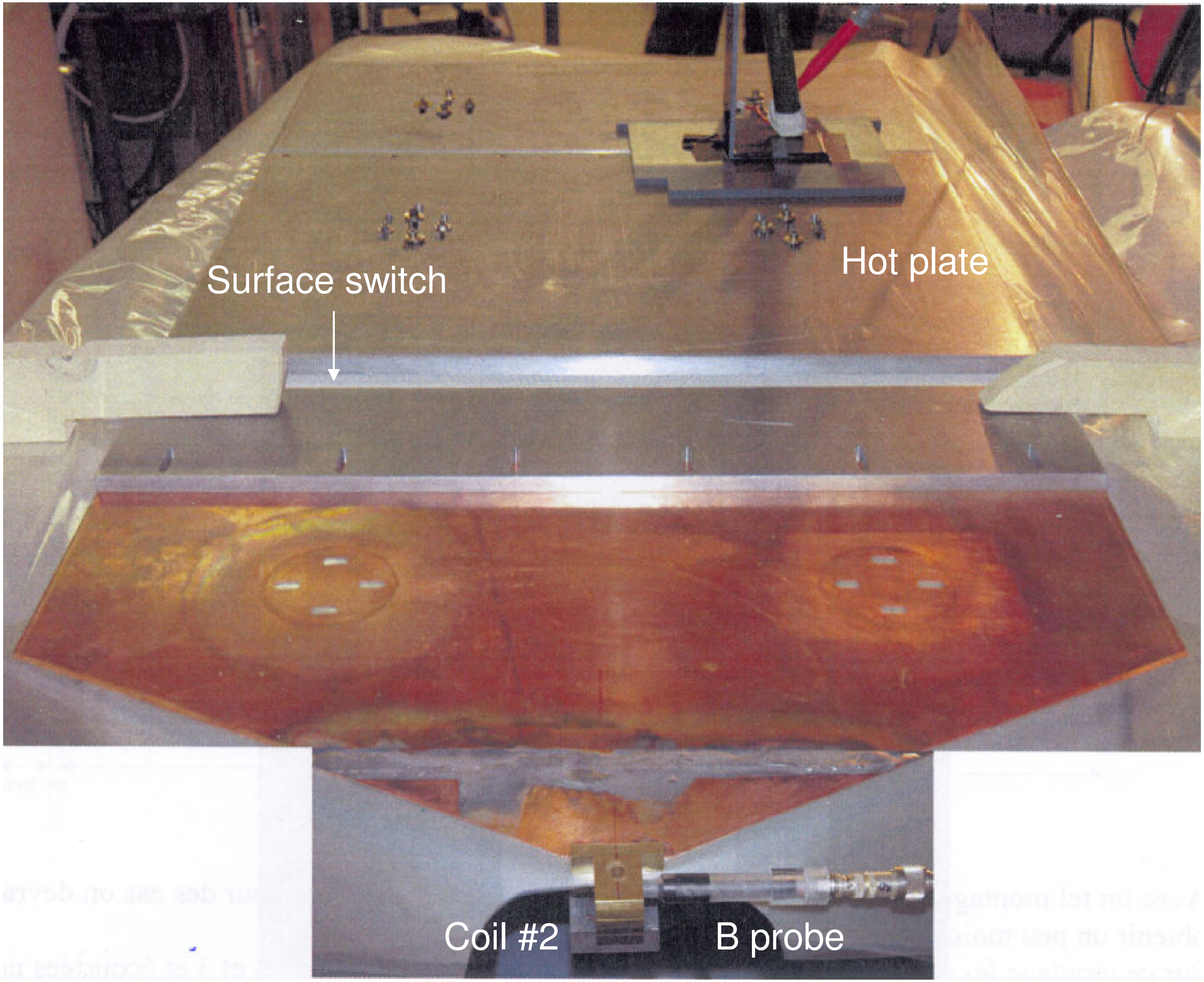
Wider line

I and B are expected to be x 2 or less

The tests are conducted :

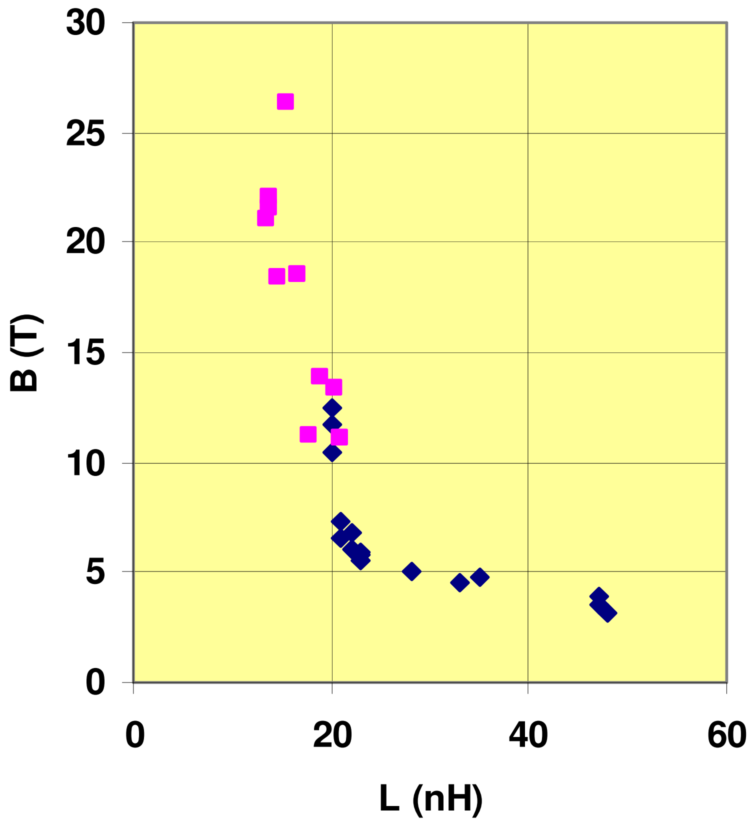
- at growing charging voltage 25 kV – 30 kV
- for various HV pulser to trigger the surface switch
- for coils 2 and 3

Setup with a 4 x 4.24μF bank



Four-caps tests — influence of total inductance

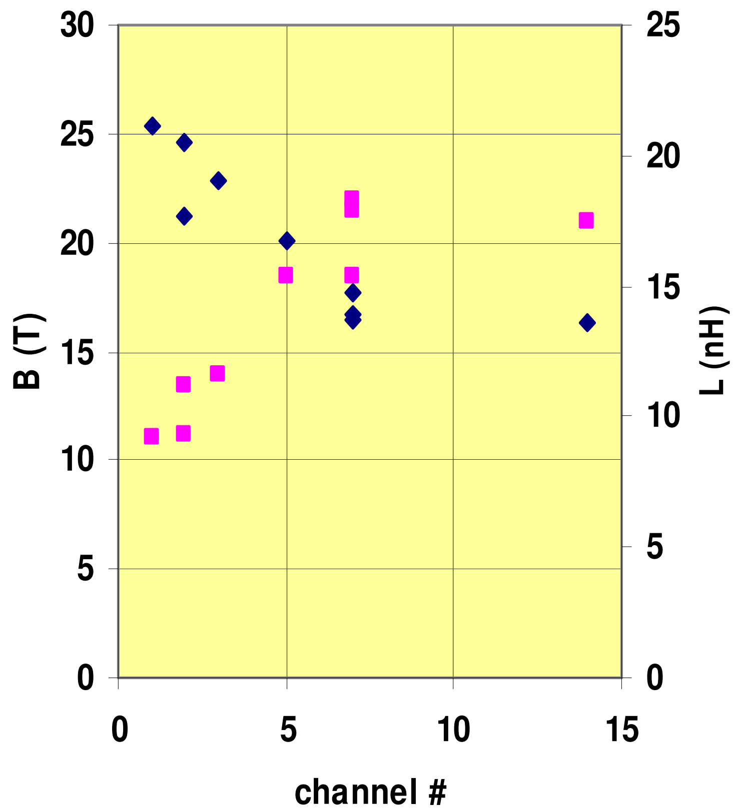
insulation	coil	channel number	V charge kV	T/4 ns	I max kA	B T	L nH
1mm PE	2	2	25	1220	390	13,4	20,5
1mm PE	2	2	25	1257	413	11,2	17,7
1mm PE	2	1	25	1284	403	11,1	21,1
1mm PE	2	3	25	1283	399	13,9	19
1mm PE	2	7	26	1135	429	18,4	14,7
1mm PE	2	5	26,5	1071	342	18,5	16,7
higher energy	triggering Marx						
1mm PE	2	14	30	908	856	21	13,6
1mm PE	2	7	30	906	857	21,5	13,7
1mm PE	2	7	30	918	849	22	13,9
1mm PE	3		30	990	838	26,3	15,4



The minimal inductance of 14-15 nH gives a maximum B up to 26 T

Four-caps tests influence of channel number

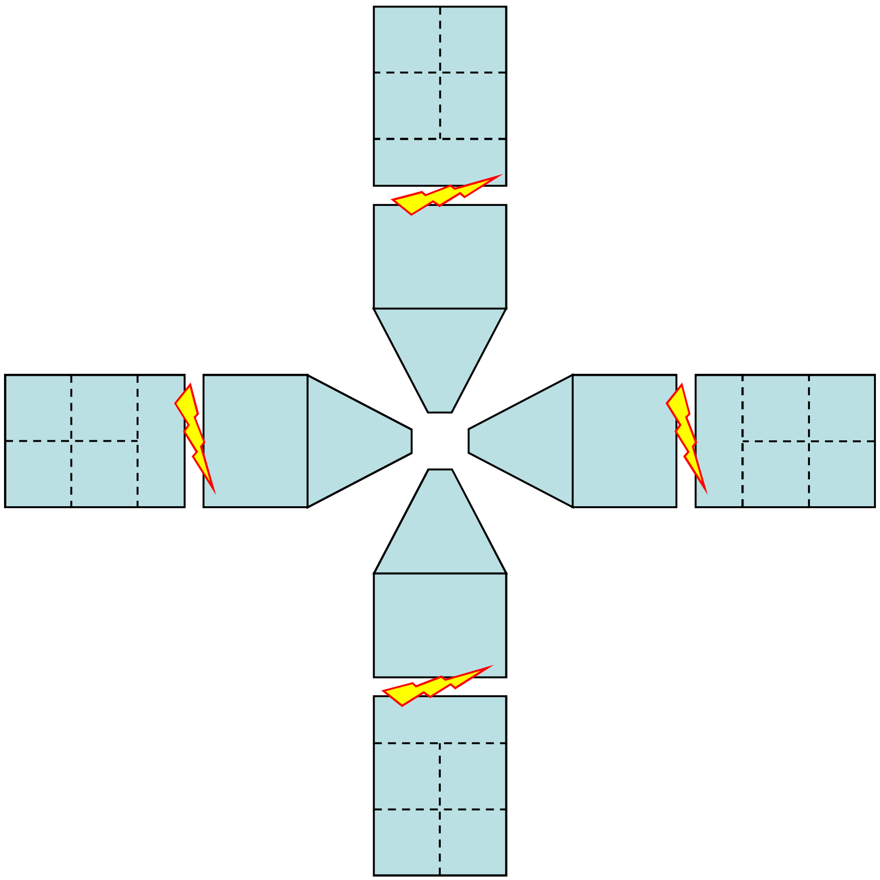
insulation	coil	channel number	V charge kV	T/4 ns	I max kA	B T	L nH
1mm PE	2	2	25	1220	390	13,4	20,5
1mm PE	2	2	25	1257	413	11,2	17,7
1mm PE	2	1	25	1284	403	11,1	21,1
1mm PE	2	3	25	1283	399	13,9	19
1mm PE	2	7	26	1135	429	18,4	14,7
1mm PE	2	5	26,5	1071	342	18,5	16,7
higher energy	triggering Marx						
1mm PE	2	14	30	908	856	21	13,6
1mm PE	2	7	30	906	857	21,5	13,7
1mm PE	2	7	30	918	849	22	13,9
1mm PE	3		30	990	838	26,3	15,4



The maximum of B is strongly influenced by the number of channels below 1 ch / 10 cm

Future work

Larger B-fields can be reached by decreasing inductance and increasing charge storage at constant voltage.
The 4-caps banks is a typical element for a compact parallel mounting.



QUESTIONS

ANSWERS

Questions		Answers
Synchronization of the surface switches	⇒	Multi gap multi channel sw.
Adding currents		Low inductance convolute

5. Conclusion

✓ the medium voltage operation of a large surface switch is reliable for generating 800 – 900 kA with 500 ns risetime

✓ the STC design is a rather optimized solution for nondestructive applications

✓ 26 T are obtained in a 10-mm bore with a non fully optimized bank (footprint 2sq.m) at moderate charging voltage (30 kV).

✓ the 50 T objective is not reached so far

✓ as increasing Vch is not compatible with atmospheric air operation, larger B could be reached mainly by 2 ways :

- adding currents is possible with 2-4 banks providing a sufficient synchronization is achieved

- the design the convolute section where currents converge on the STC is a key issue.