The LHC machine

G. Brianti (CERN)

LHC Main Parameters

		pp	e p	Pb-ions
Max cm energy	TeV for B=9.5T	15.4	1.36	1262
Luminosity	$cm^{-2}\ s^{-1}$	$1.6\ 10^{34}$	$2.8\ 10^{32}$	$1.8\ 10^{27}$
Number of bunches		4725	508	800
Bunch spacing	m | ns	4.5 | 15	49.4 | 164.7	31.5 | 105
Particles/bunch		10^{11}	$9.2\ 10^{10}$ $3.0\ 10^{11}$	$6.2\ 10^{7}$
Particles/beam		$4.7\ 10^{14}$	$4.7\ 10^{13}$ $1.5\ 10^{14}$	$5.0\ 10^{10}$
Number of experiments		3	1	2
β at interaction point	m (βx.βy)	0.5	0.85,0.26 32.7,3.05	0.5
r.m.s. radius at int. pnt.	μm (x,y)	15	120 37	12.4
r.m.s. collision length	cm	5.3	3.8	5.3
Crossing angle	μrad	200	0	200

STATUS REPORT on LHC MACHINE

G. Brianti March 1992

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1. INJECTORS
   SOME BEAM TESTS
2. OPTIMIZATION E vs. B
   NEW CELL LAYOUT
3. MAGNET MODELS/PROTOTYPES
   RECENT RESULTS
   PROGRAMME
4. OTHER SYSTEMS
   CRYOGENICS
   VACUUM
   RF

LHC INJECTION SCHEME

LINAC 2	50 MeV	190 mA for ≥ 7μs	1.2 μm
with RFQ 2	achieved	170 mA 20μs	1.5 μm
PSB	1.4 GeV	$1.75*10^{12}$/ring	2.5 μm
	achieved	in one PSB ring	

three- turn injection ; new RF h=1/6KV, h=2/3KV

⇩ 2 pulses

PS	26 GeV	10^{11}/bunch	3 μm
		$1.35*10^{13}$ tot.	

new RF h=140/600KV (66MHz)

⇩ 3 pulses

SPS	450 GeV	10^{11}/bunch	3.5 μm
		$4.05*10^{13}$ tot.	

new RF h=1540/2MV (66 MHz)

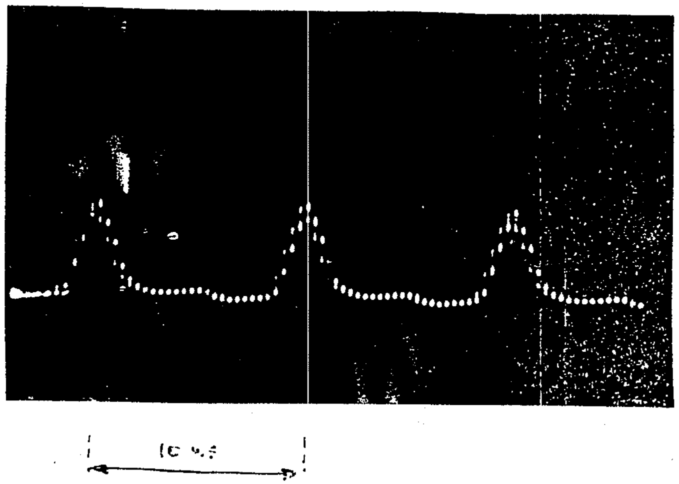
⇩ ⇩ 2*12 pulses

TWO NEW TRANSFER LINES

LHC	450 GeV=>7.7 TeV		3.75 μm
		10^{11}/bunch	
		$4.7*10^{14}$ tot.	

inject.

LHC BEAM IN THE SPS

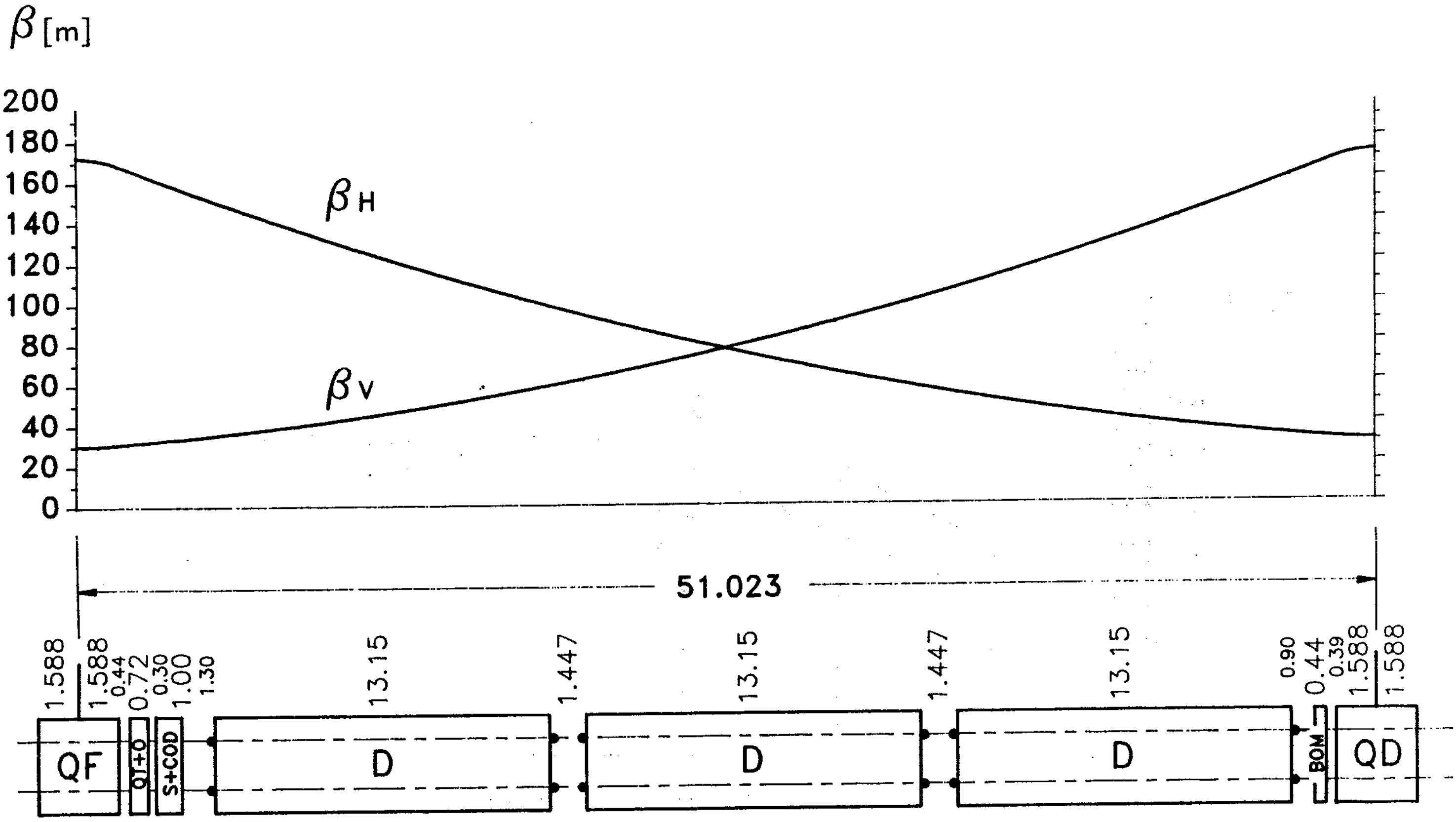


Capture of one PS batch at 26 GeV with the 100 MHz system (bunch spacing = 10 ns) and acceleration to 300 GeV with the 200 MHz RF

Achieved : $I_b \simeq 4\ 10^{10}$/bunch , A = 0.35 eVs

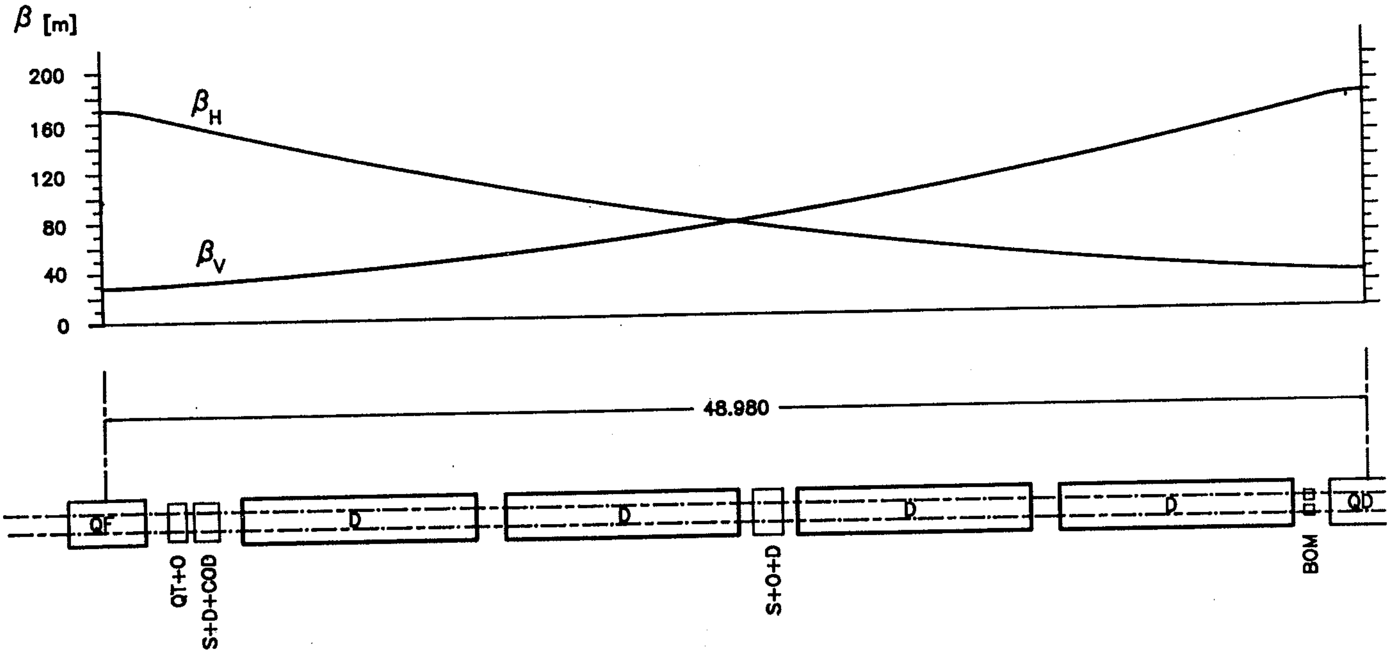
limited by η at 26 GeV.

In 1992 new experiments with Q=21 (γ_{tr} ↓) in the SPS to reach higher intensities.



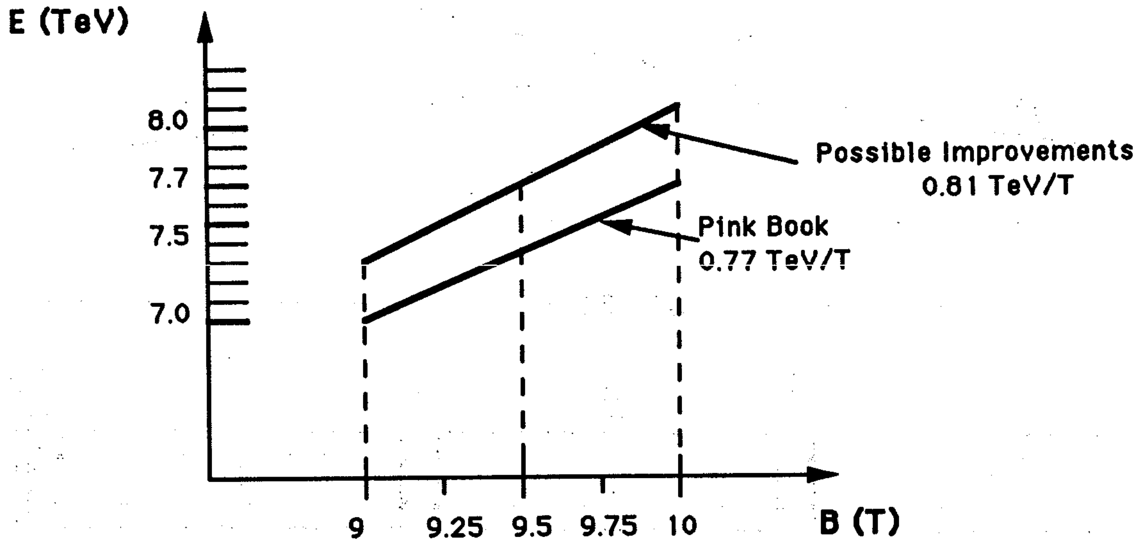
D:dipole magnets, Q:quadrupoles, QT+O:combined tuning quadrupole and octupole corrector BOM:beam observation monitor, S+COD: combined sextupole, and dipole corrector
-•-: sextupole and decapole correctors

Layout of the standard half-cell



D:dipole magnets, Q:quadrupoles, QT+O:combined tuning quadrupole and octupole corrector BOM:beam observation monitor, S+D+COD:combined sextupole, decapole and dipole corrector, S+O+D:combined sextupole, octupole and decapole corrector.

Layout of the standard LHC half-cell



LHC BEAM ENERGY vs. FIELD

NUMBER OF ELEMENTS IN NORMAL ARCS

"PINK BOOK" CELL LAYOUT :

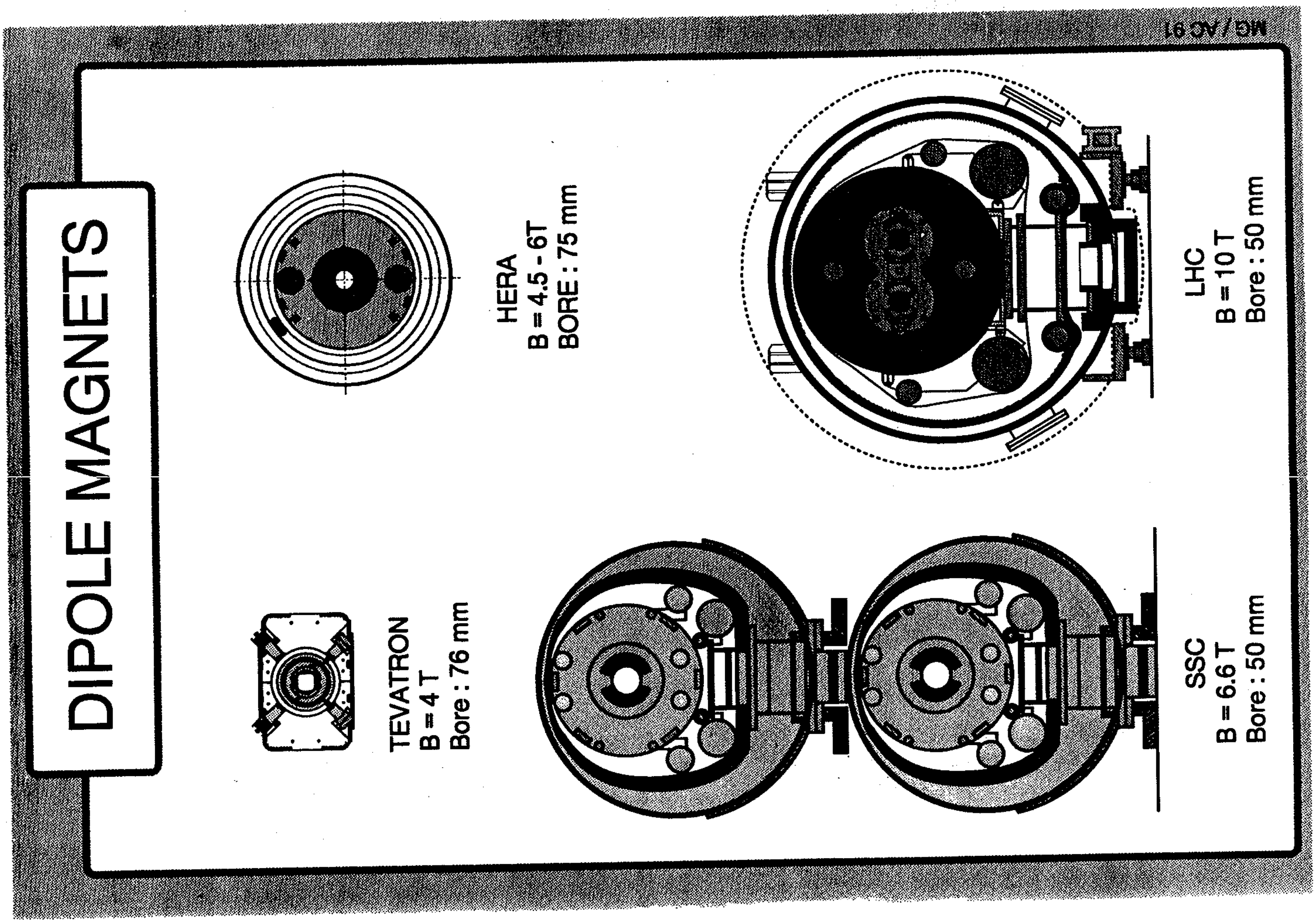
Number of Dipoles (9.45 m) => 1600

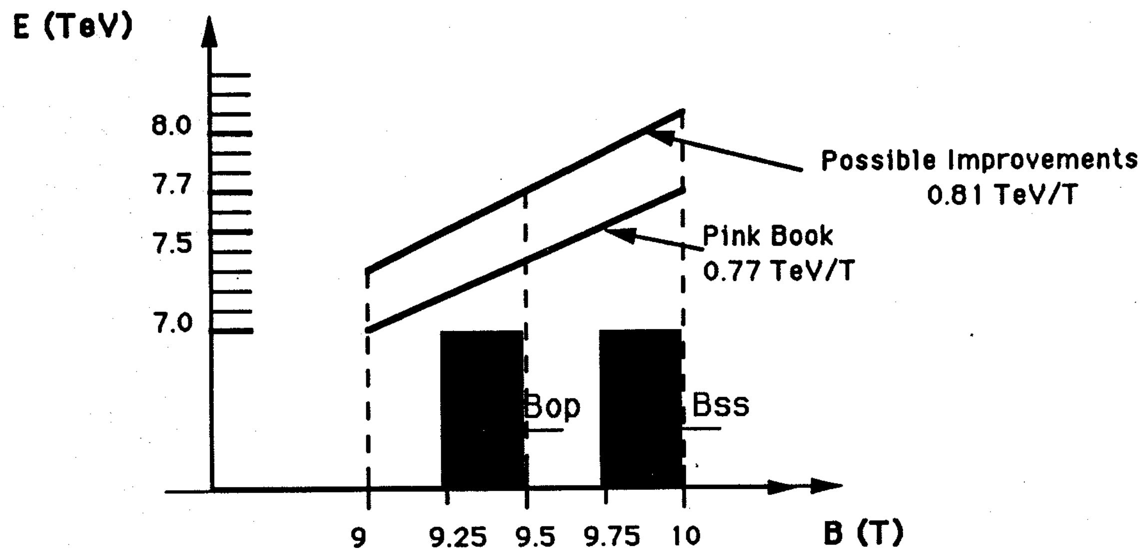
Number of Quadrupole Assemblies => 400

NEW CELL LAYOUT :

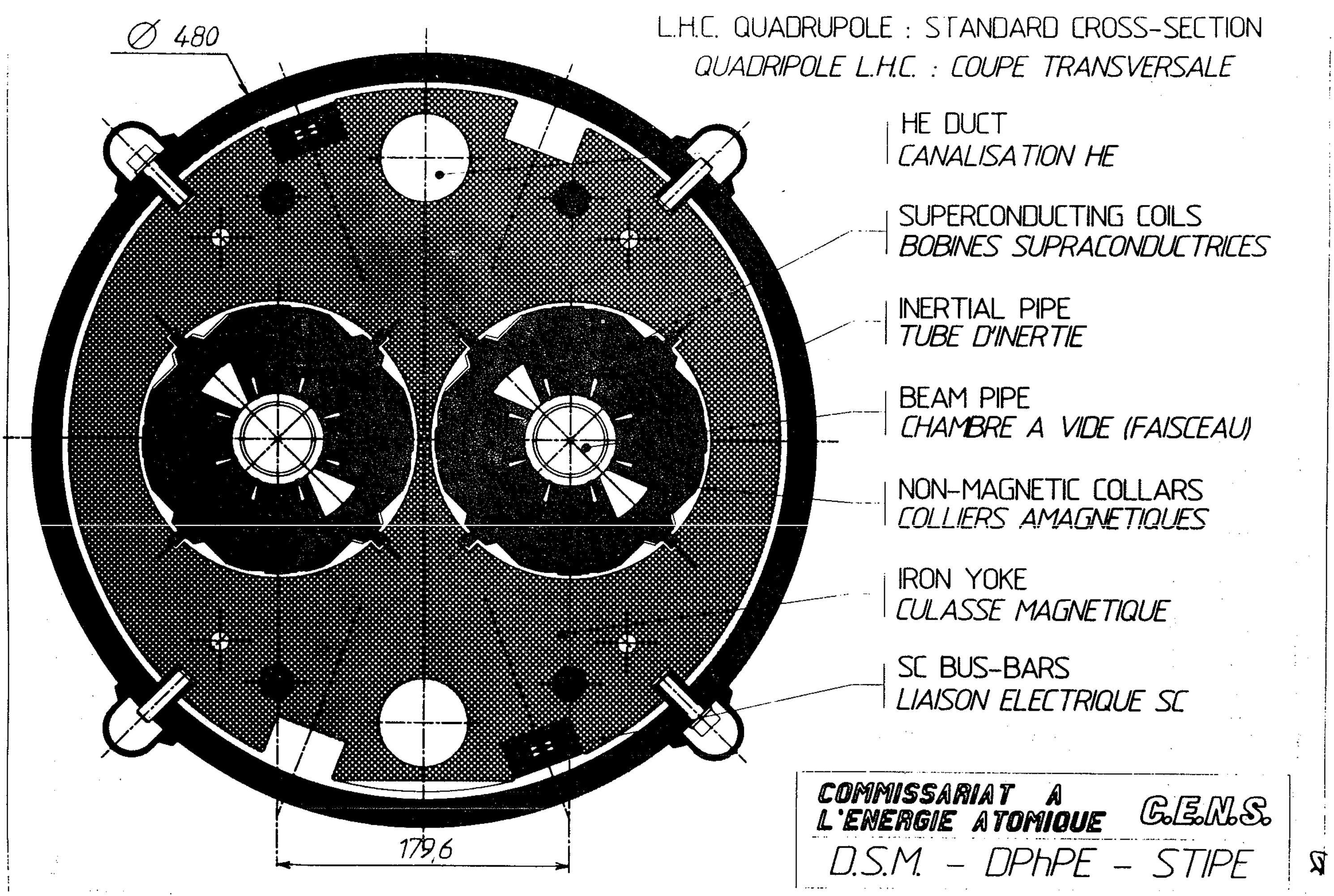
Number of Dipoles (13.58 m) => 1152

Number of Quadrupole Assemblies => 384





LHC BEAM ENERGY vs. FIELD


L.H.C. QUADRUPOLE : STANDARD CROSS-SECTION
QUADRIPOLE L.H.C. : COUPE TRANSVERSALE
Ø 480
HE DUCT
CANALISATION HE
SUPERCONDUCTING COILS
BOBINES SUPRACONDUCTRICES
INERTIAL PIPE
TUBE D'INERTIE
BEAM PIPE
CHAMBRE A VIDE (FAISCEAU)
NON-MAGNETIC COLLARS
COLLIERS AMAGNETIQUES
IRON YOKE
CULASSE MAGNETIQUE
SC BUS-BARS
LIAISON ELECTRIQUE SC
179,6
COMMISSARIAT A L'ENERGIE ATOMIQUE
C.E.N.S.
D.S.M. - DPhPE - STIPE

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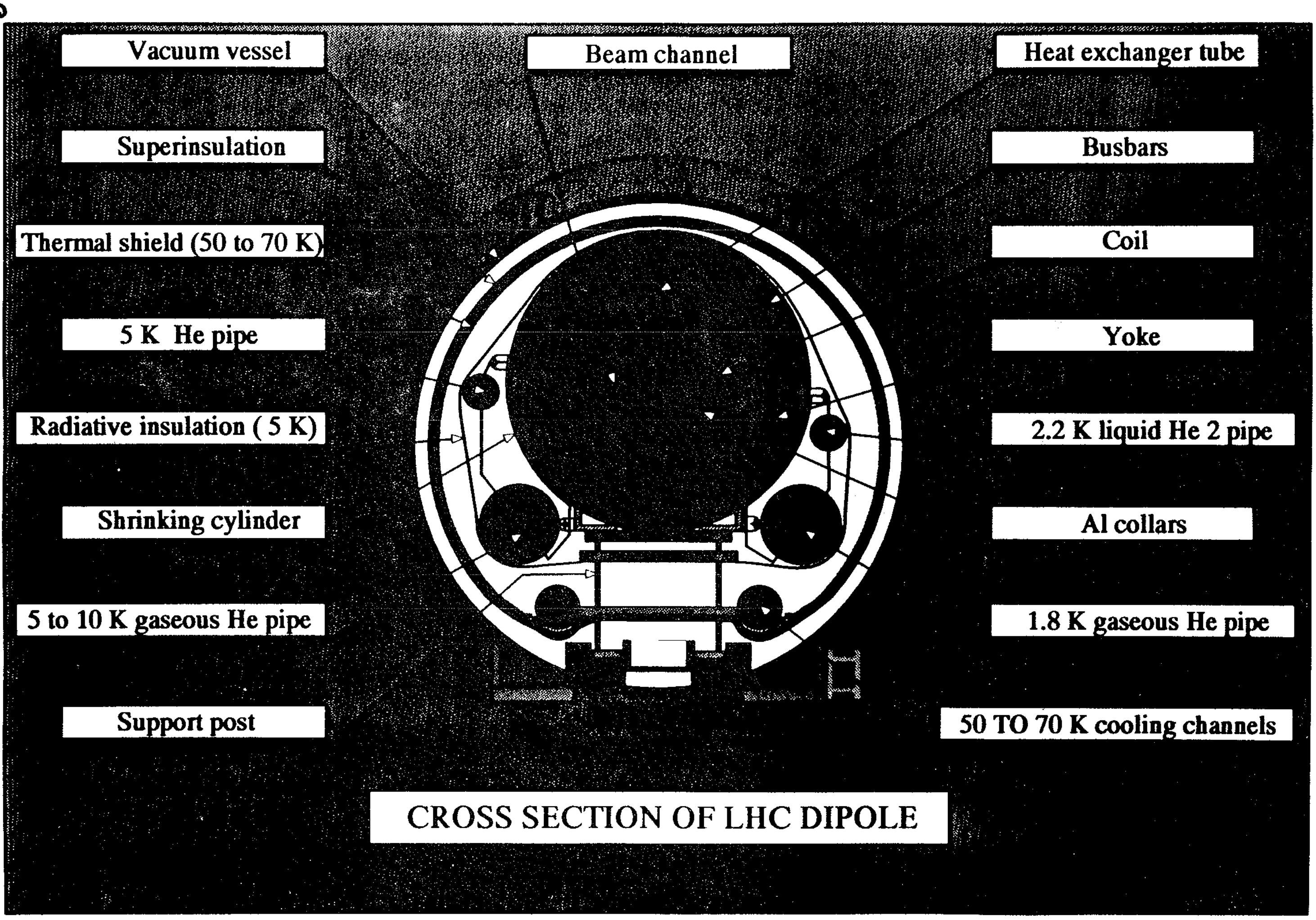
Vacuum vessel
Beam channel
Heat exchanger tube
Superinsulation
Busbars
Thermal shield (50 to 70 K)
Coil
5 K He pipe
Yoke
Radiative insulation (5 K)
2.2 K liquid He 2 pipe
Shrinking cylinder
Al collars
5 to 10 K gaseous He pipe
1.8 K gaseous He pipe
Support post
50 TO 70 K cooling channels
CROSS SECTION OF LHC DIPOLE

HE107

CENTRAL FIELDS of a SUPERCONDUCTING MAGNET

Bss => Maximum "short sample" field
It corresponds to the max. (critical) current that the cable can carry (as measured in a short sample submitted to an independent external field).

Bq => Maximum field at which the magnet quenches after the initial training

Bo => Maximum operational field for the nominal machine parameters

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Normally : Bss = Bq

Bo = Bq - margin (He temperature, "worst" magnet installed, etc.)

margin => - 0.5 to 0.8 T

MAGNET MODEL TESTS

In October 1991, a TWIN-APERTURE MAGNET MODEL (photograph) reached 10 T. The peak field seen by the superconductor was at least 10.2 T and the current corresponded to the short sample limit of the cable. Another MTA tested in Feb. 1992 reached its short sample field of 9.8 T.

TENTATIVE CONCLUSIONS

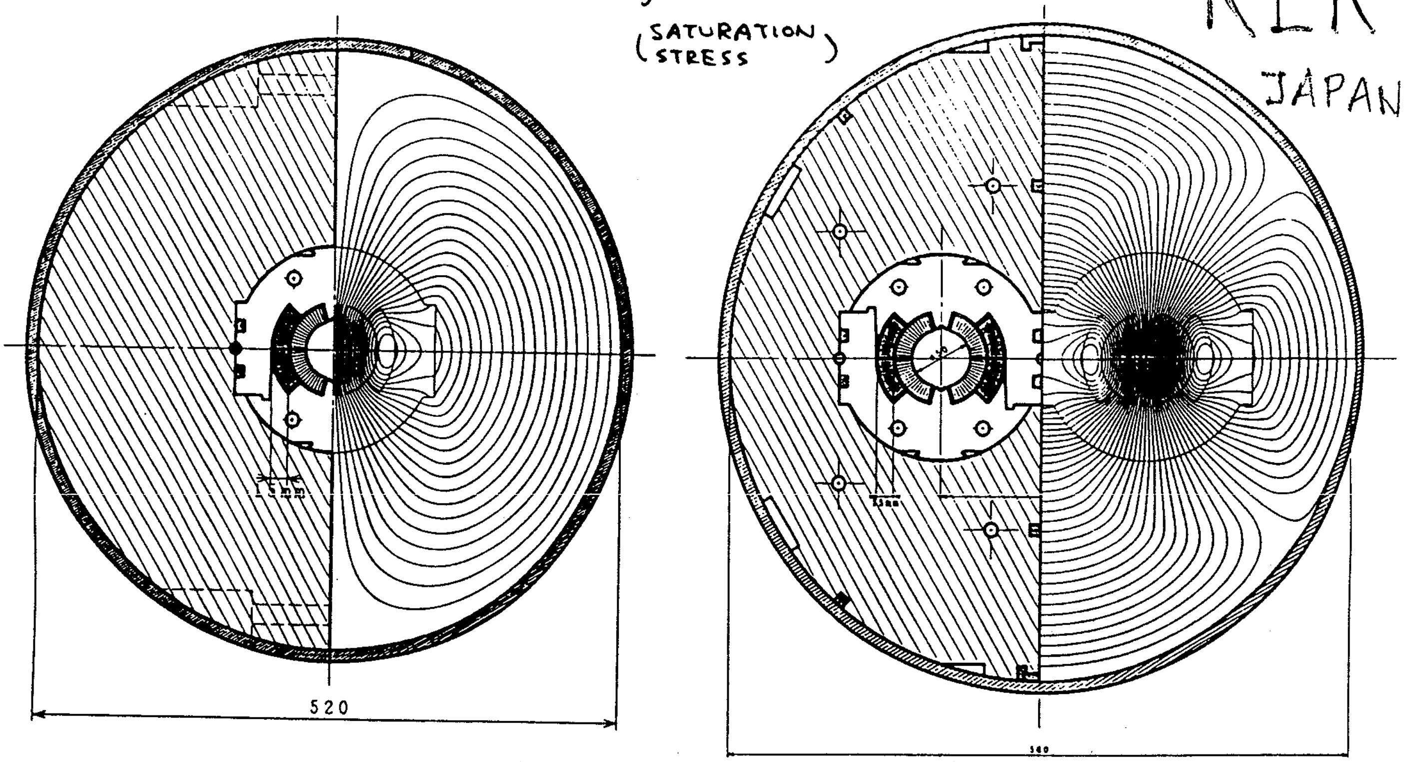
1. A field Bq = Bss = 10 T can be reached
   Note that cables available to-day could sustain a Bss > 10 T.

2. No indication that the TWIN Structure "per se" influences the behaviour.

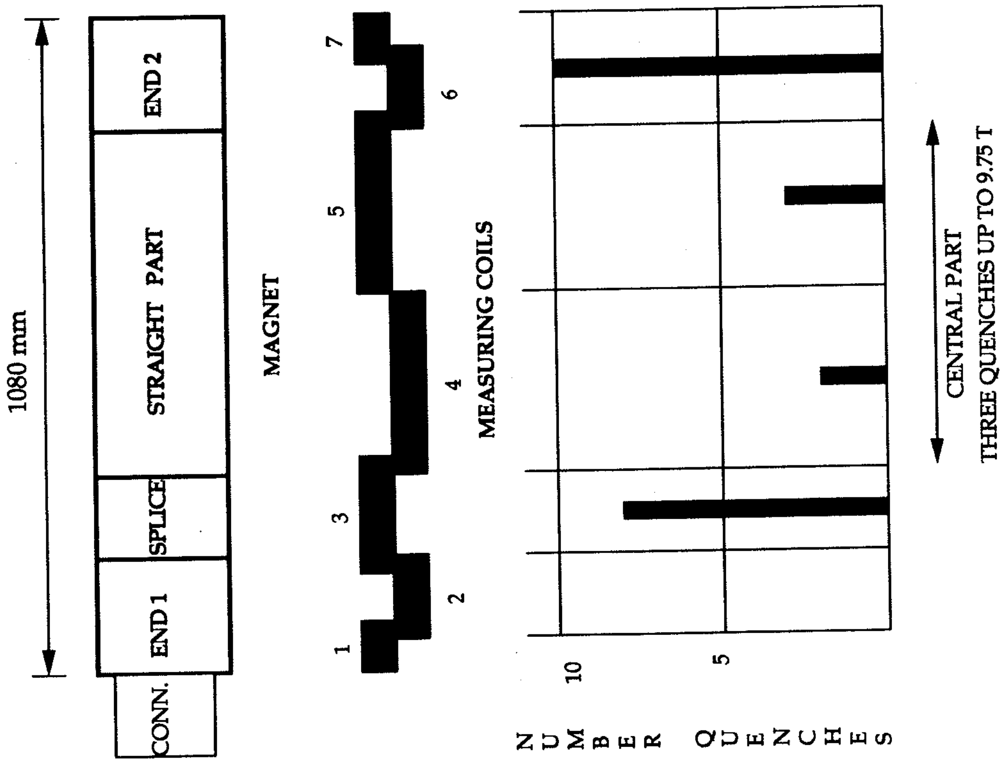
3. Quenches occur mostly in the coil ends.

IRON CONTRIBUTION & μ EFFECTS ON FIELD (SATURATION, STRESS)

KEK JAPAN



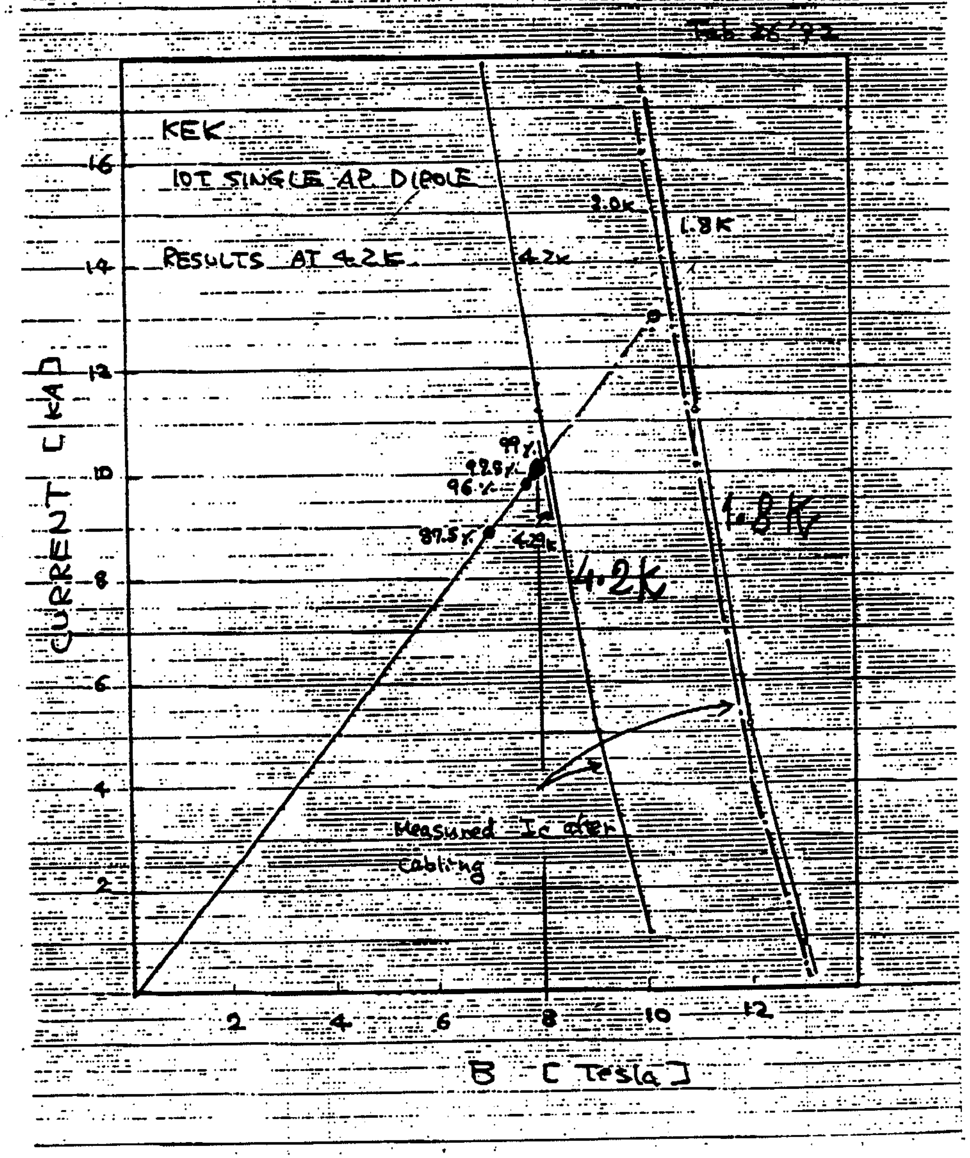
EFFECT OF IRON IN THE LHC MAGNET

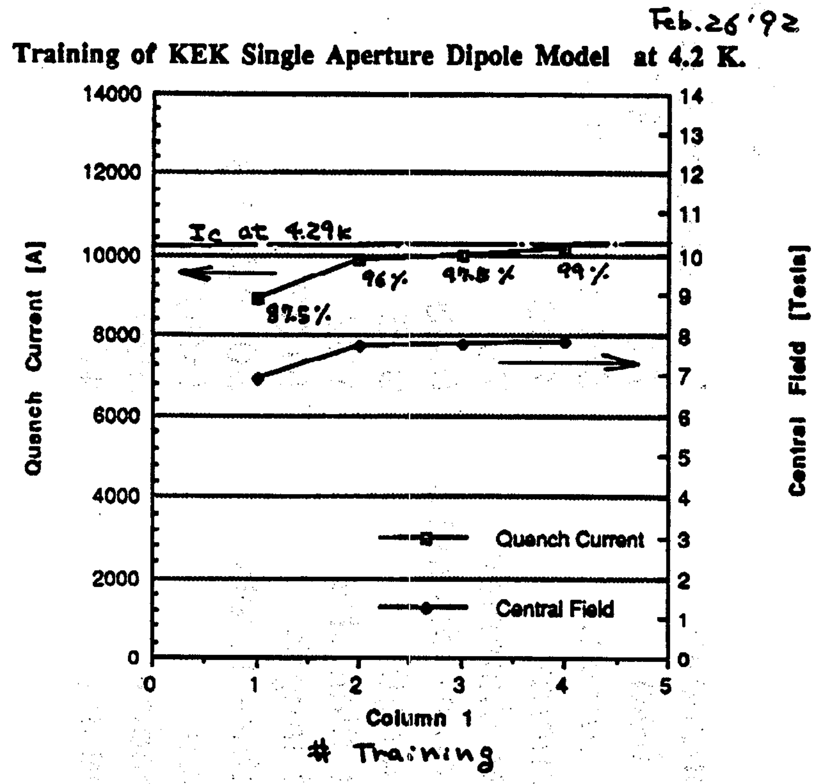


RESULTS of TWIN APERTURE MODEL - H

KEK - JAPAN

LHC MOD. SINGLE APERTURE





TAP CRYOMAGNET PARAMETERS

		ACHIEVED	
Superconductor	NbTi/copper cable		
Nominal field	7.5	8.3	T
Nominal current	8625	9500	A
Stored energy	4.06		MJ
Coil inner diameter	75		mm
Magnet outer diameter	0.58		m
Magnet length	9.15		m
Cryostat diameter	1.02		m
Cryostat length	10.33		m
Temperature levels	80, 4.5, 1.8		K
Cold mass	15000		kg
LHe capacity	390		l
LN2 capacity	40		l

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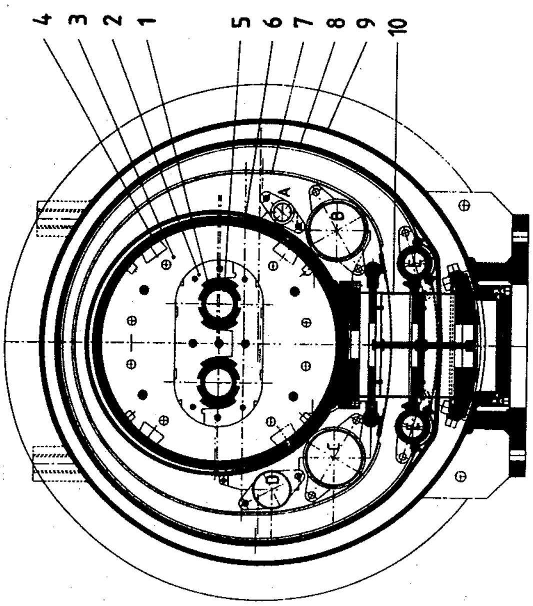


Figure 1 Transverse cross-section of the cryomagnet

1: HERA-type superconducting coils
2: collars
3: magnetic circuit
4: shrinking cylinder
5: cold bore tube
6: helium vessel
7: radiation screen
8: superinsulated LN2 screen
9: vacuum vessel
10: support post

A & B: 1.8 K helium pipes
C & D: 4.5 K helium pipes
E: liquid nitrogen pipes

TAP

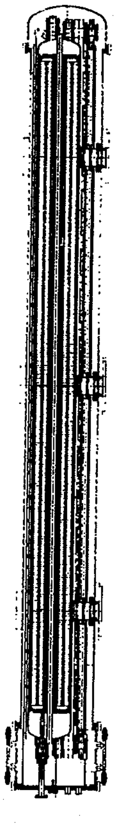
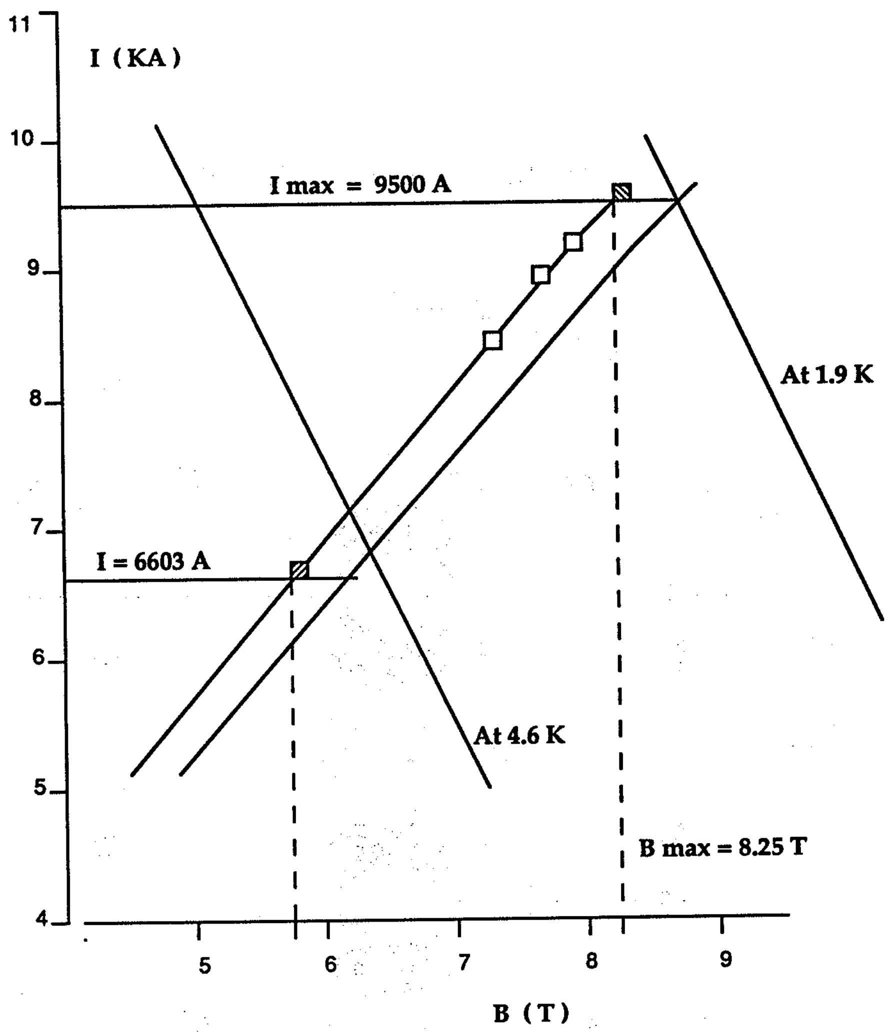


Figure 2 Longitudinal cross-section of the cryomagnet



TWIN APERTURE PROTOTYPE (10 m - long, HERA coils)

OTHER MAGNETS

QUADRUPOLES

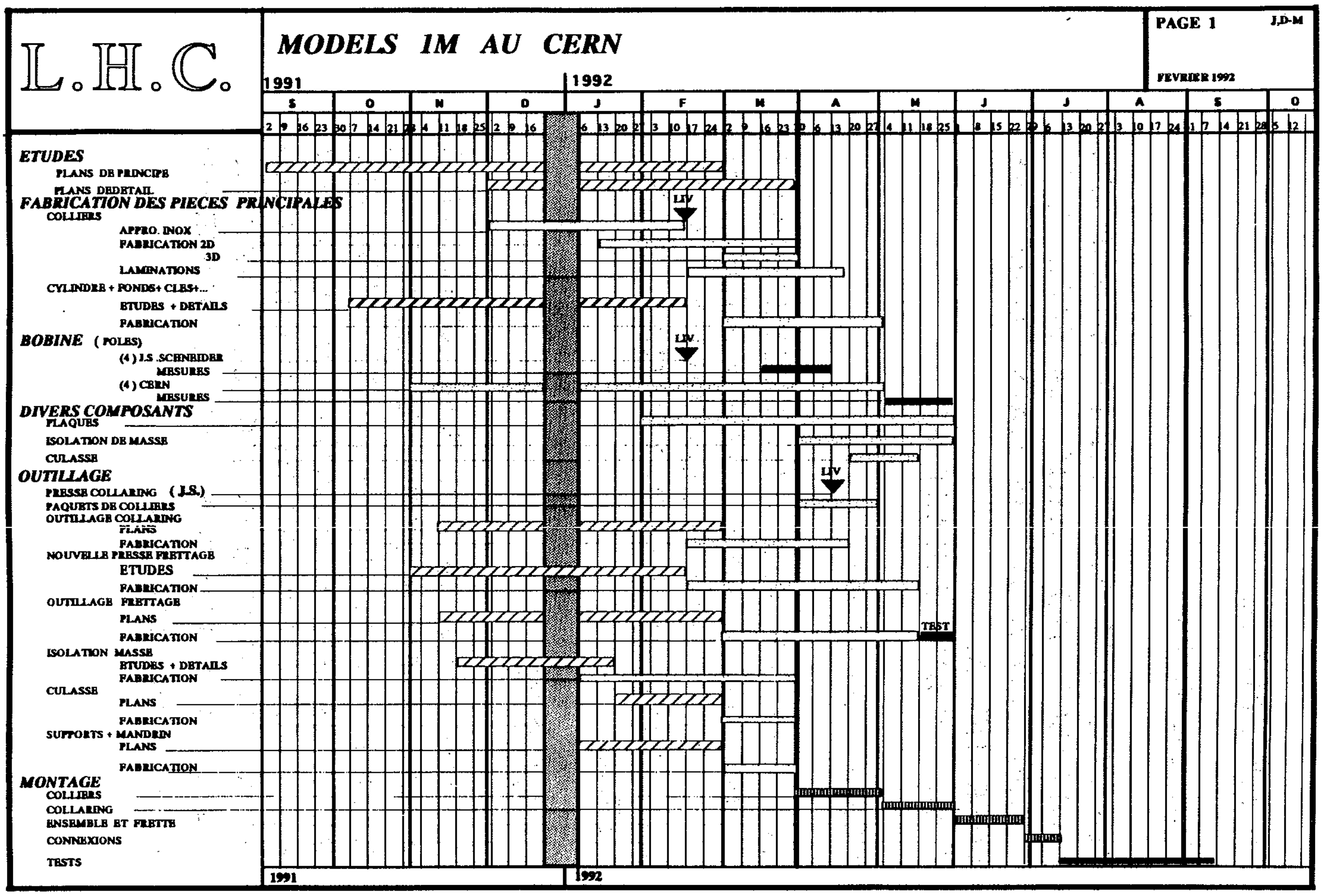
THE DESIGN OF THE LATTICE QUADRUPOLES (COLLABORATION WITH CEA SACLAY) IS COMPLETED AND THE MAIN TOOLS ARE OPERATIONAL.
COIL WINDING IS STARTING.

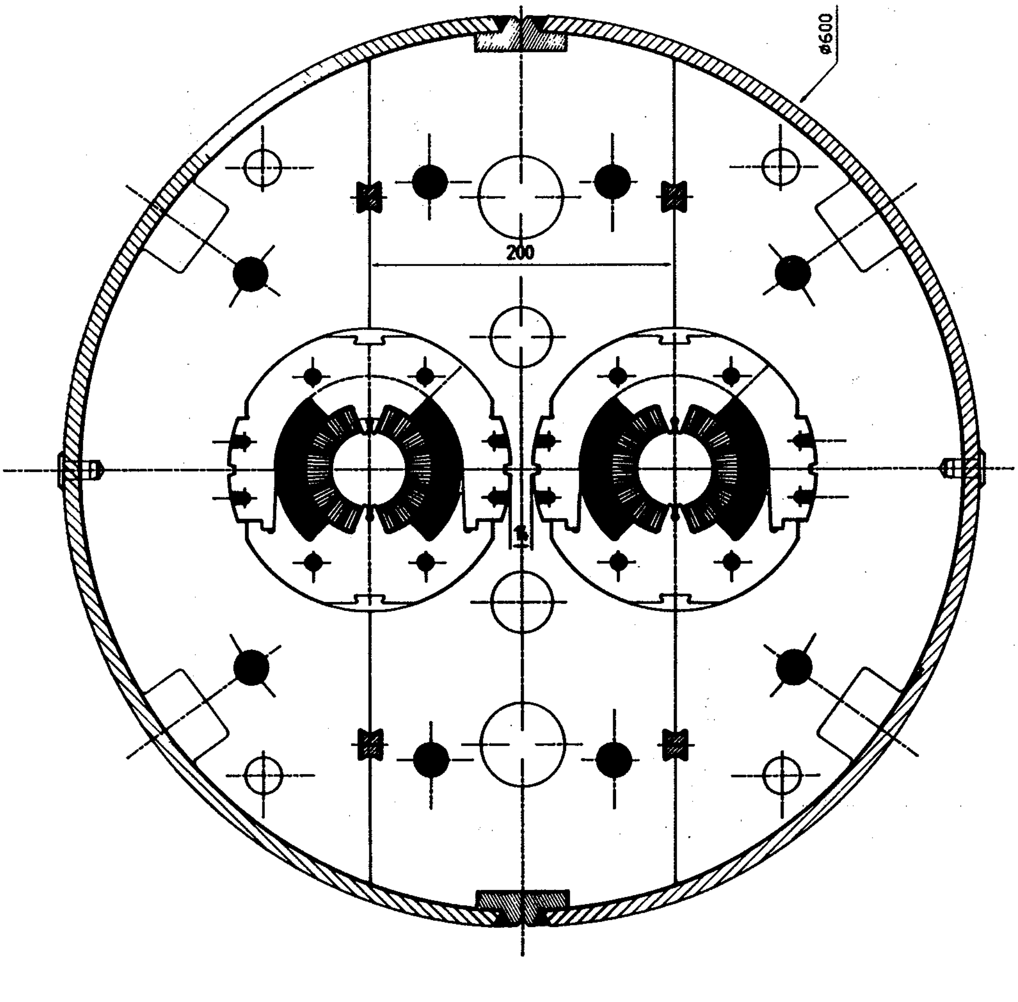
CORRECTOR MAGNETS

THE PROTOTYPE SEXTUPOLE/DIPOLE CORRECTOR MAGNET, MANUFACTORED BY A BRITISH FIRM IN COLLABORATION WITH RAL AND CERN WAS SUCCESSFULLY TESTED IN RAL.

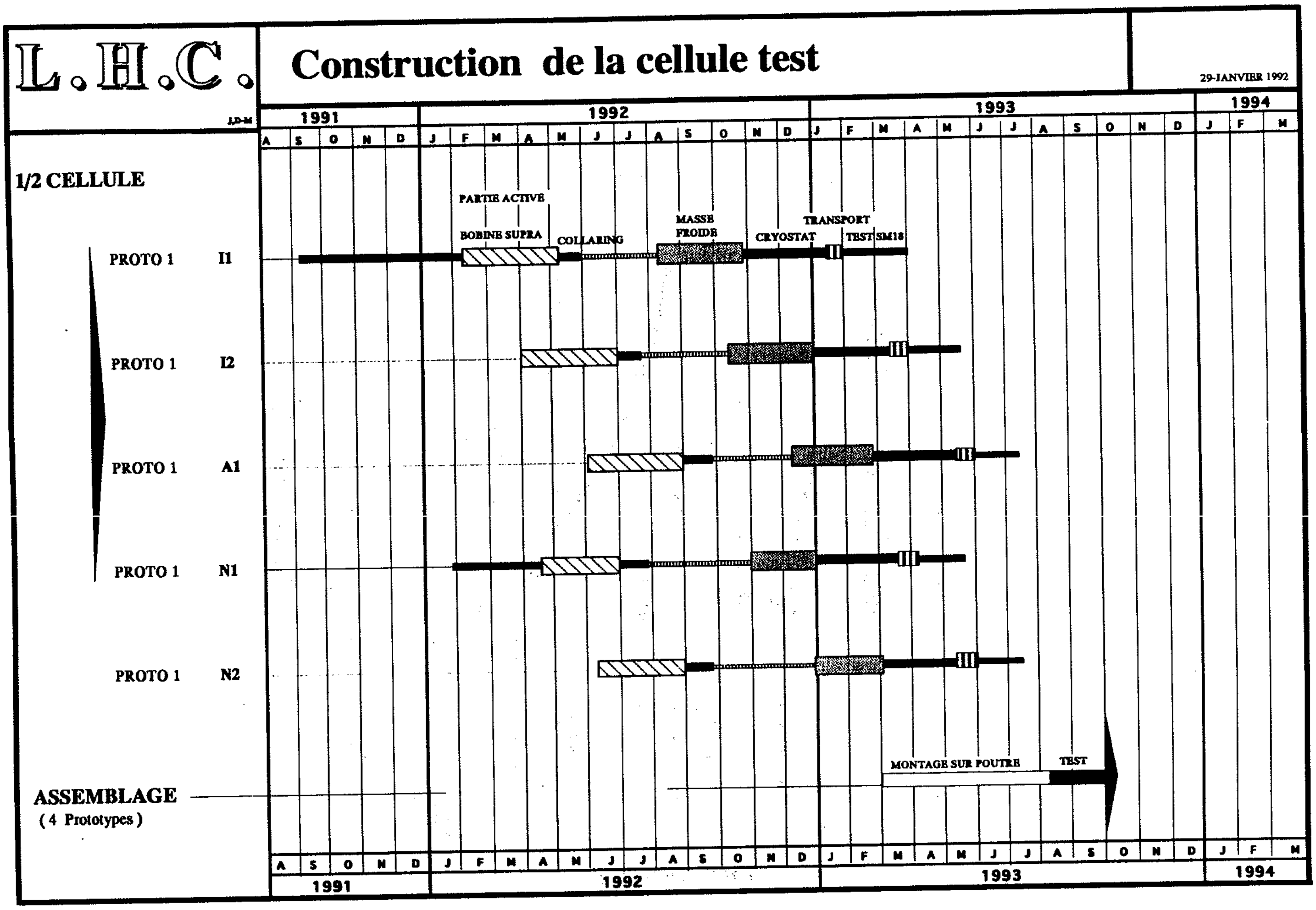
CRYOGENICS

AN IMPORTANT TEST OF THE RING COOLING SYSTEM WITH SUPERFLUID HELIUM WAS CARRIED OUT IN AN EXPERIMENTAL INSTALLATION SIMULATING 25 m OF THE MACHINE. IT PROVED THAT THE EXPECTED POWER DEPOSITED IN THE COILS DURING MACHINE OPERATION CAN BE ABSORBED WITH SOME MARGIN.





CROSS SECTION PROTOTYPE DIPOLE 2/1



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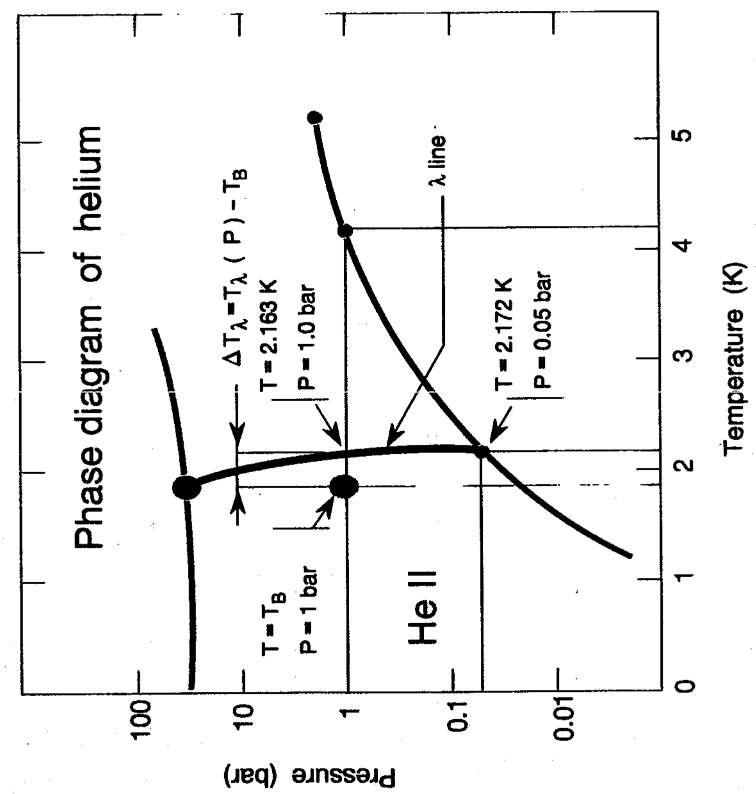
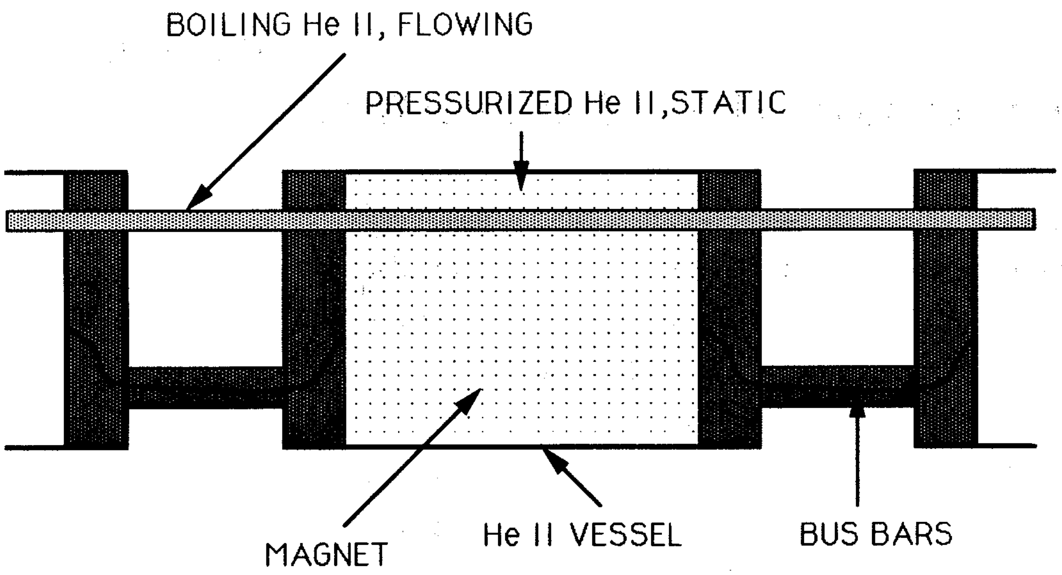
Feb. 1992

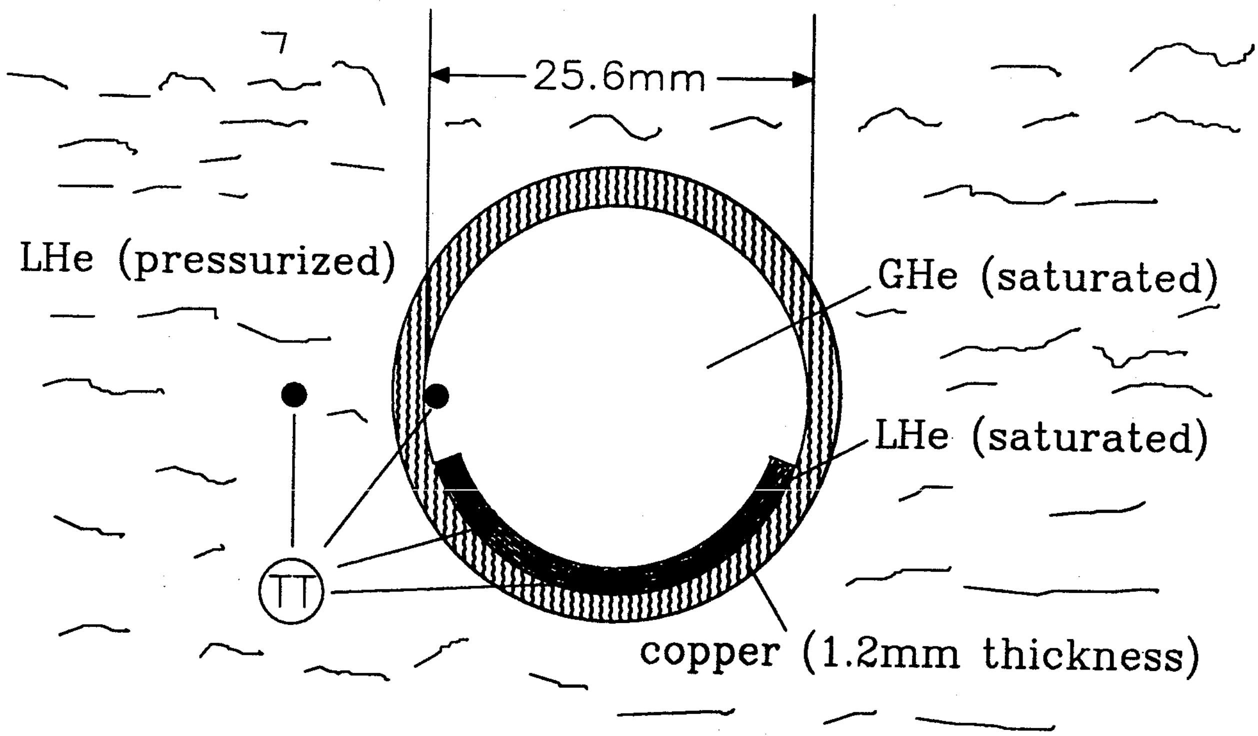
NEW LHC MAGNET MODELS/PROTOTYPES

FIRM	MODEL	PROTOTYPE
ALSTHOM./J.S.	1 MTA-1	1 MBP-3
ANSALDO	1 MTA-1	3 MBP-1
ELIN	1 MTA-1, 1 MSA-2	
HOLEC	1 MTA-1	
ELIN/HOLEC		1 MBP-2
NOELL		2 MBP-1
CERN	1 MTA-2	
	1 MTA-3	
CEA-SACLAY		2 MQP-1
ABB/FBM		1 TAP (Hera coils)





PRINCIPLE of LHC MAGNET COOLING



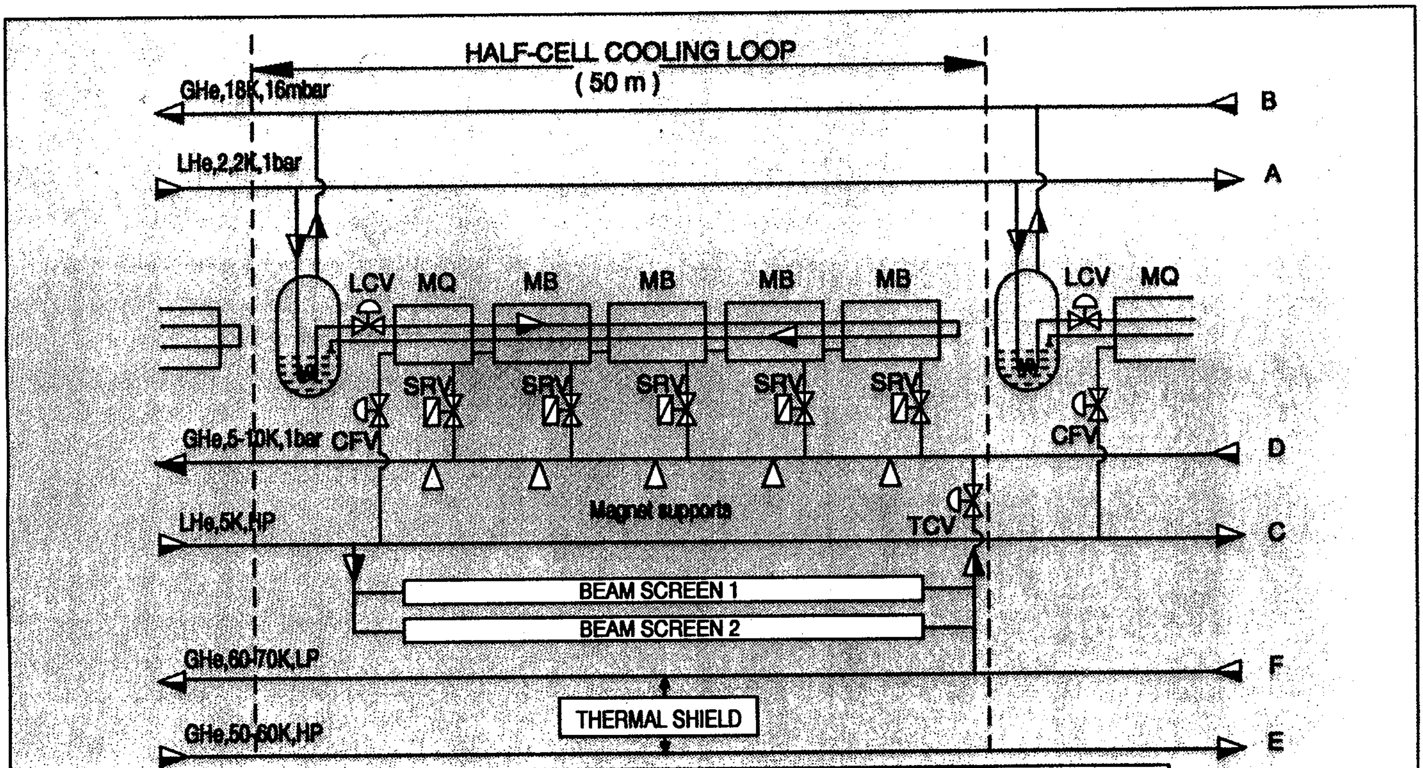


Fig 4 FLOW-SCHEME OF LHC CRYOGENIC LOOP

MQ Quadrupole magnet
MB Dipole magnet
CFV Cool-down and fill valve
LCV Level controlled valve
SRV Safety relief valve
TCV Temperature controlled valve

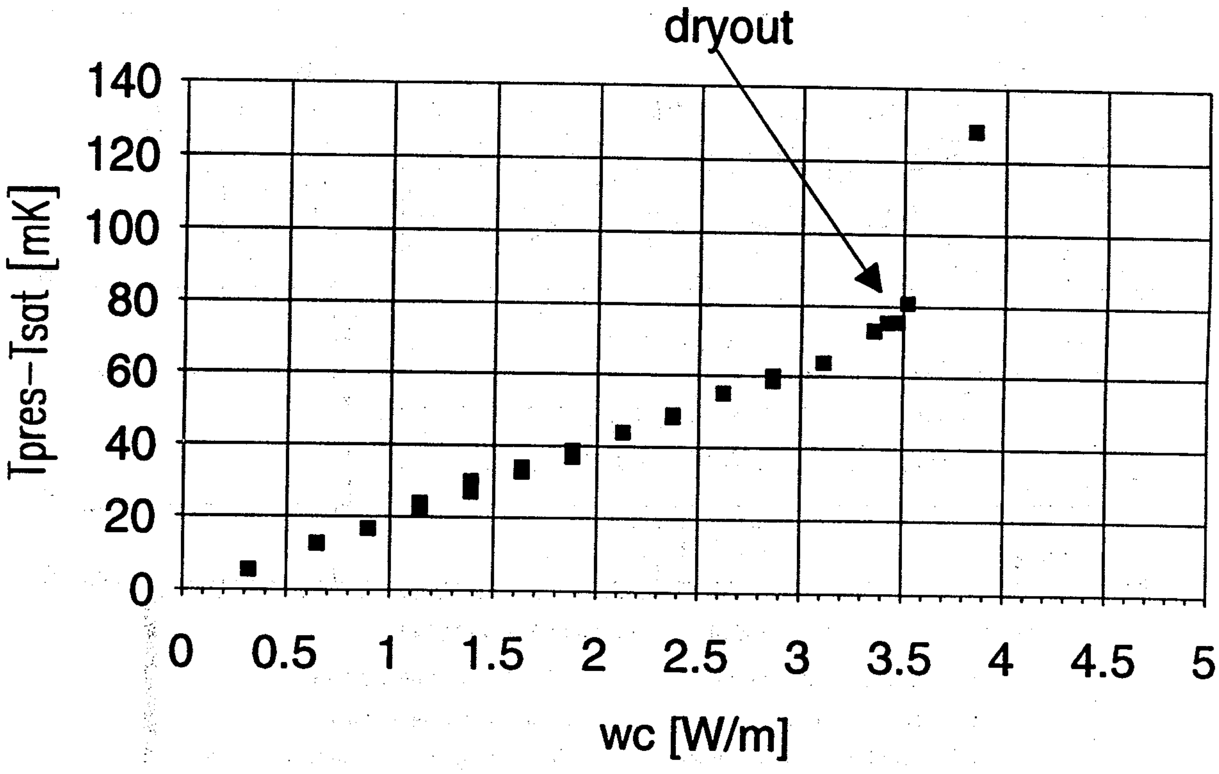
DISTRIBUTED HEAT LOADS IN STEADY OPERATION [W/m]

Temperature	50-75 K	5-10 K	1.9 K
Heat inleakage*	6	0.4	0.15
Resistive heating	-	-	0.15
Beam-induced losses**	-	1.7	0.01
Total	6	2.1	0.31

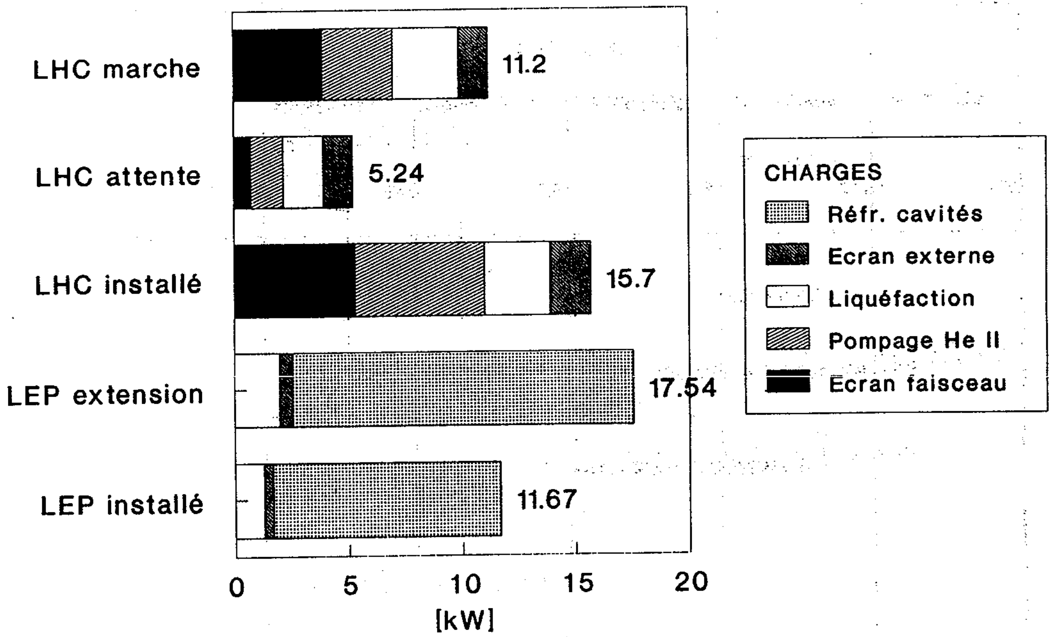
* no contingency

** singular heat load of 25 W/50 m not included

PhL/1991



REFRIGERATEUR D'OCTANT LHC
PUISSANCES EQUIVALENTES @ 4,5 K



PhL/1992

L. TAVIAN
NOTE LHC 164

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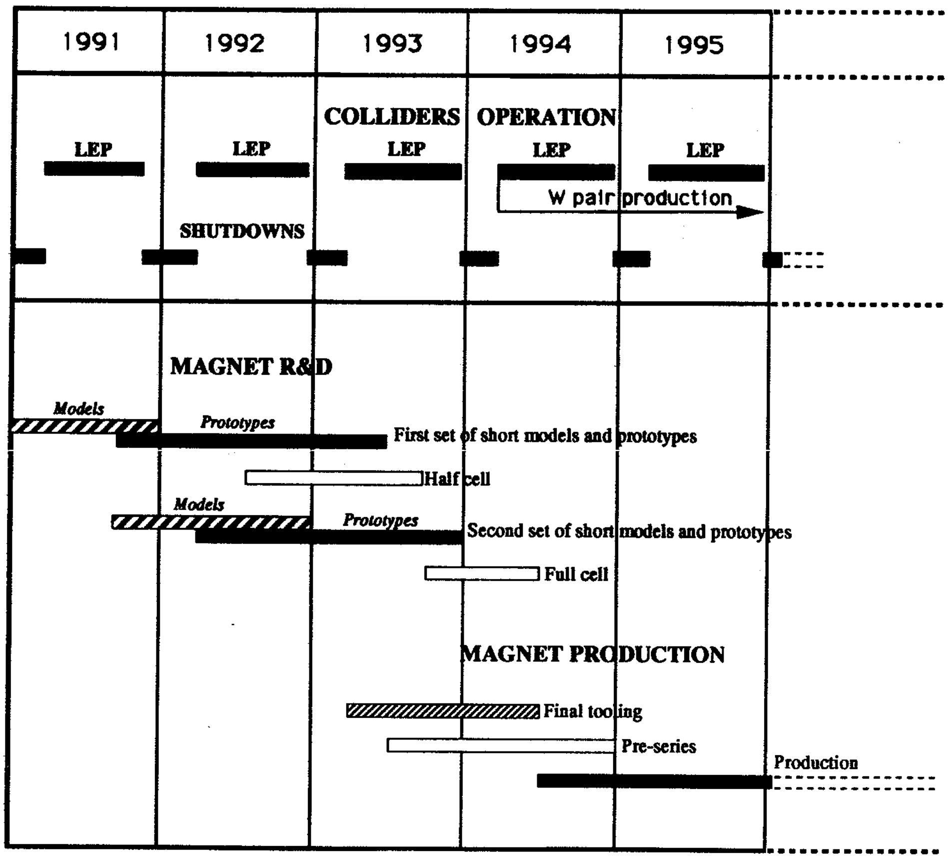
LHC DIPOLE CRYOSTAT
ESTIMATED HEAT INLEAKS [W]

Temperature [K]	50-75	5-10	1.9
Support posts	7.3	1.2	0.06
Radiation	49.6 *	0.4 **	0.82 **
Relief valve	1.1	-	0.24
Instrumentation	0.3	-	0.17
Total	58.3	1.6	1.29

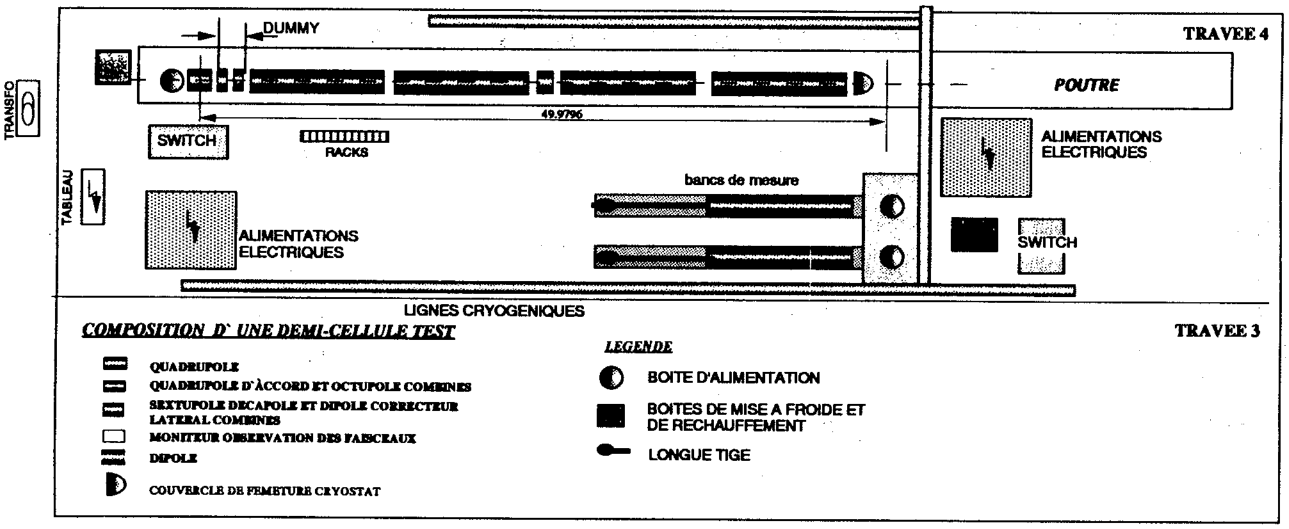
* 30 layers aluminized film insulation
** 10 layers aluminized film insulation

PhL/1991



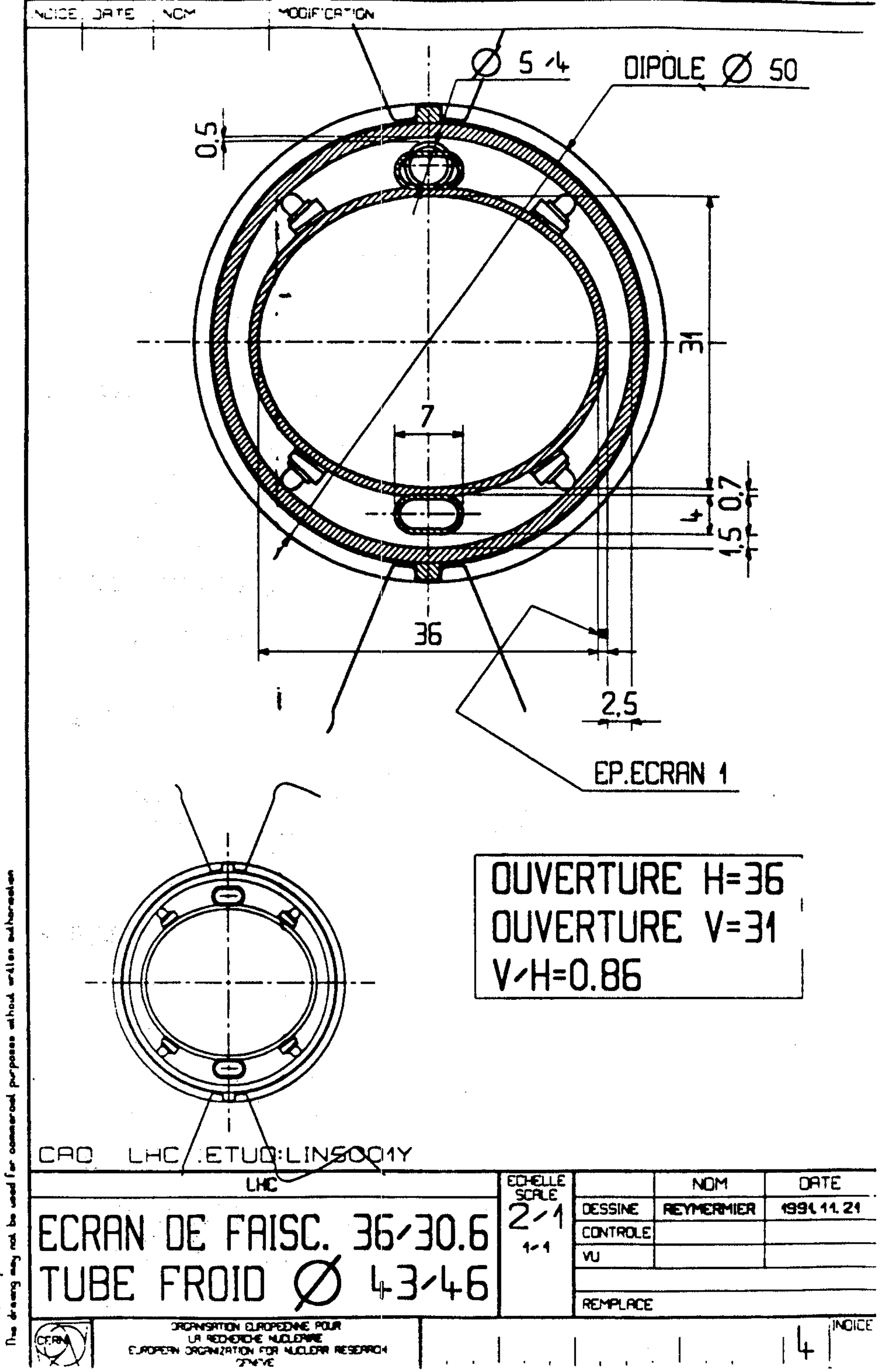
SCHEDULE OF LHC MAGNET R&D AND START OF PRODUCTION

SCHEMA DE MONTAGE DE 1/2 CELLULE AU SM18



BEAM SCREEN DESIGN CRITERIA

- electrical conductivity < 5 10^{-10} ohms m in 10 T
- able to withstand quench forces (~1.5 ton/m)
- evacuate the synchrotron radiation power (~0.6 W/m) at a temperature >1.9 K
- provide sufficient aperture for beam (36 mmX32.6 mm)
- acceptable heat leak to 1.9 K
- low photon induced gas desorption
- contain holes for pumping to the 1.9 K surface
- provide acceptable beam impedance



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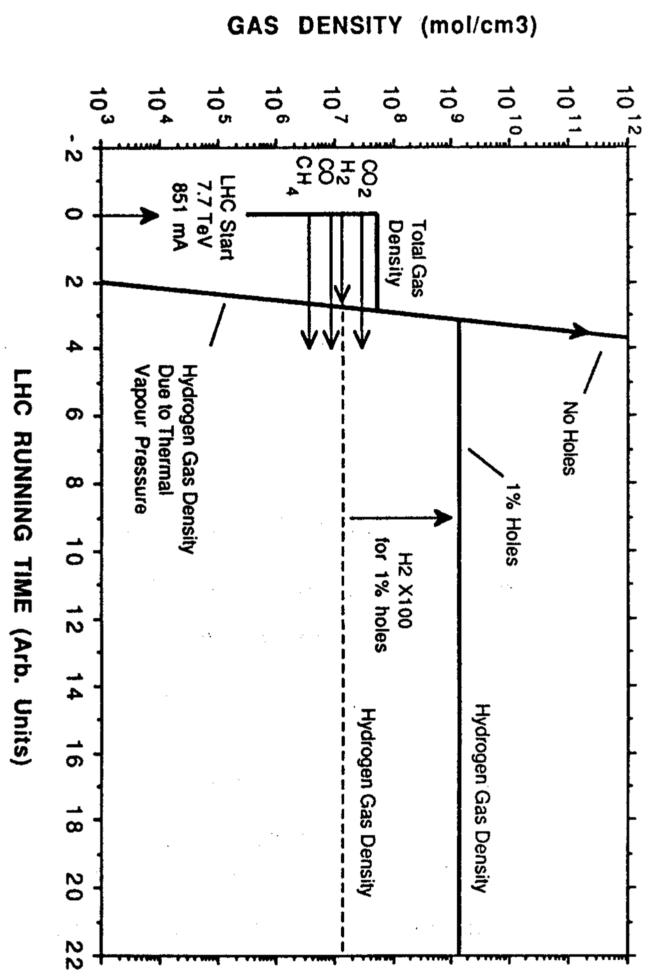


POSSIBLE TREATMENTS TO REDUCE PHOTON INDUCED GAS DESORPTION

1) TEMPERATURE

Easy to apply to long thin tubes
170°C 1hour OK - RRR better
340°C 1hour OK - RRR better
950°C 2hours BAD - RRR unacceptable
check other temperatures and times

2) IONS

D.C. Glow discharge
Difficult to apply to long thin tubes
Needs central wire, hence supports
Risk of mechanical damage to 0.1 mm Cu layer
Implantion of ions into surface-effect on RRR

3) ELECTRONS

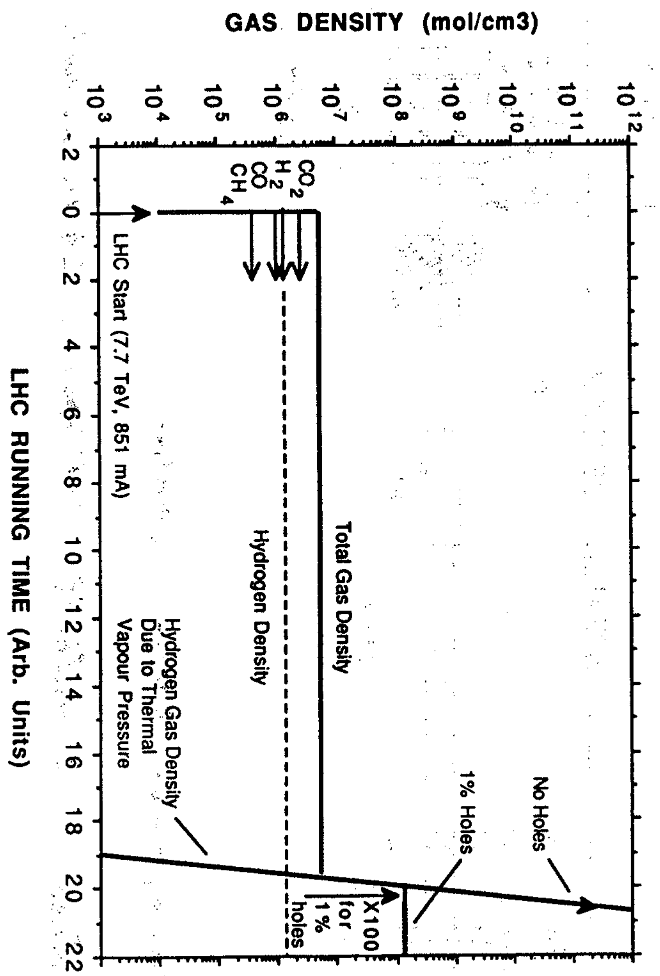
Difficult to apply to long thin tubes
Needs long, linear electron source

4) REACTIVE GASES

NO, O_3 (ozone generator or UV light)
Easy to apply to long thin tubes
May have to be done at few 100°C
Security problems but workable

5) REACTIVE PLASMAS

O_2 or H_2 containing RF discharges
No central electrode
No ion implantation
Must propagate in long, thin tubes - check
Effect on RRR - check



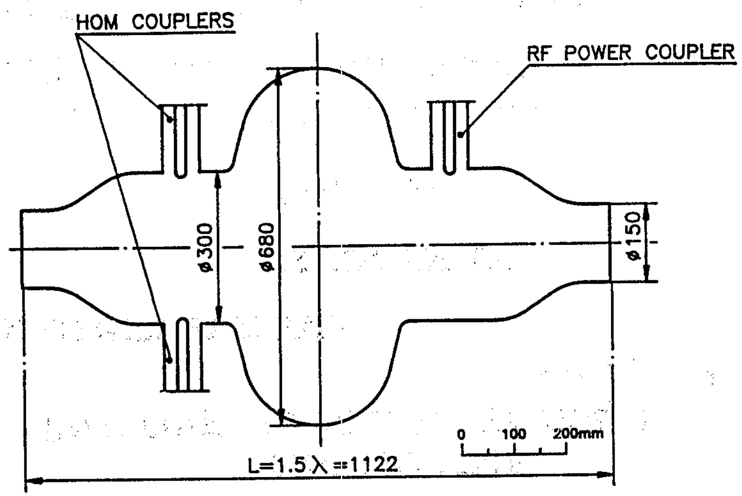


Fig.8.1 Single-cell superconducting cavity for acceleration of both beams.

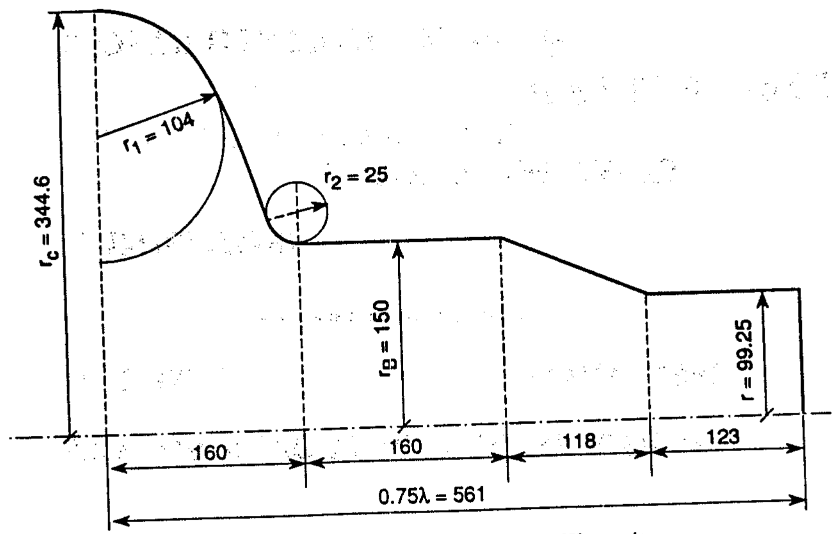


Figure 4: Geometry of a tapered 400 MHz cavity.

STATUS REPORT on LHC MACHINE

G. Brianti **March 1992**

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1. INJECTORS

SOME BEAM TESTS

in LINAC, BOOSTER, SPS

VERY ENCOURAGING

2. OPTIMIZATION E vs. B

NEW CELL LAYOUT

3. MAGNET MODELS/PROTOTYPES

RECENT RESULTS

PROGRAMME

POSITIVE DEVELOP. TOWARDS FINAL MAGNETS

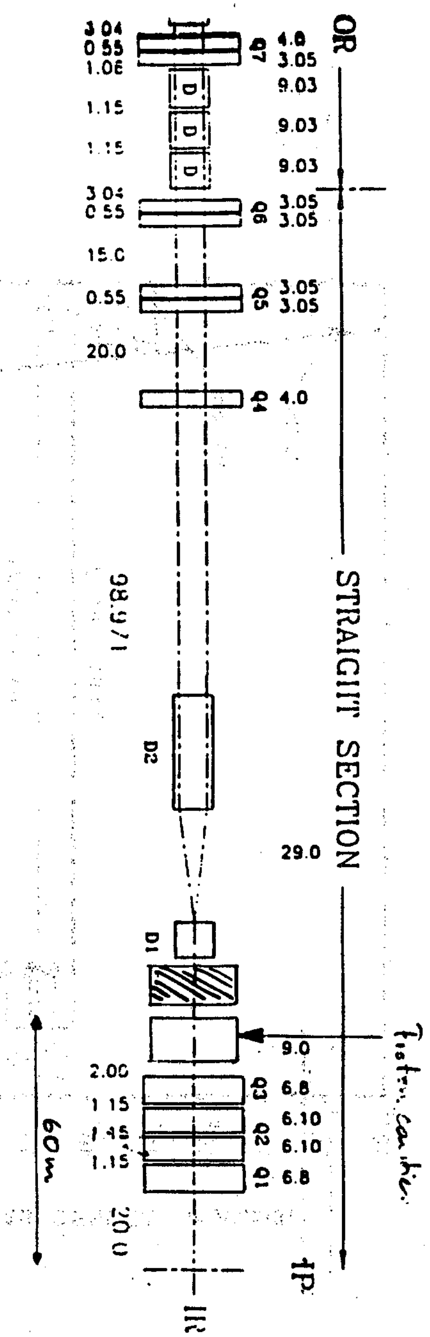
4. OTHER SYSTEMS

CRYOGENICS

VACUUM

RF

SOLID INDICATIONS THAT PROJECT READY TO TAKE OFF AT T_i



Max beam separation ± 6 mm (protons)

Additional Ion cavities : 3 multicell (LEP type) = 24 MV on each side of IR.