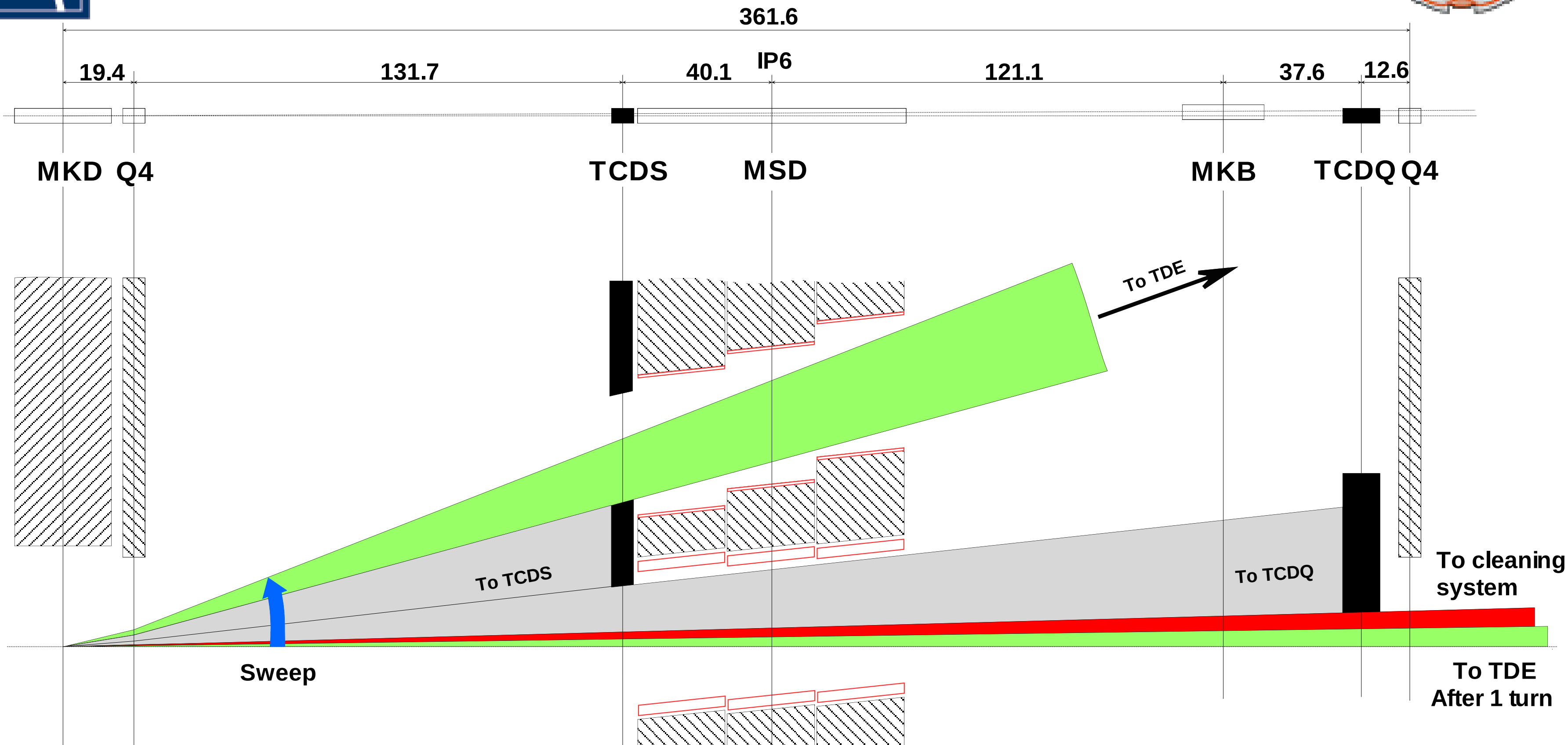
Technology
Department

TCDS material selection and qualification

W. Weterings

20-01-2015

INTRODUCTION



PERFORMANCE OBJECTIVE TCDS

- **What:** dilute about 6.1 MJ, ~ 1.7% of LHC beam energy.
- **When:** Event of an unsynchronised beam abort of the MKD kickers at baseline luminosity and 1.2 μs delay.

CONCEPTUAL DESIGN - 1

TCDS Design V1
[EDMS 393973 v.1.0]

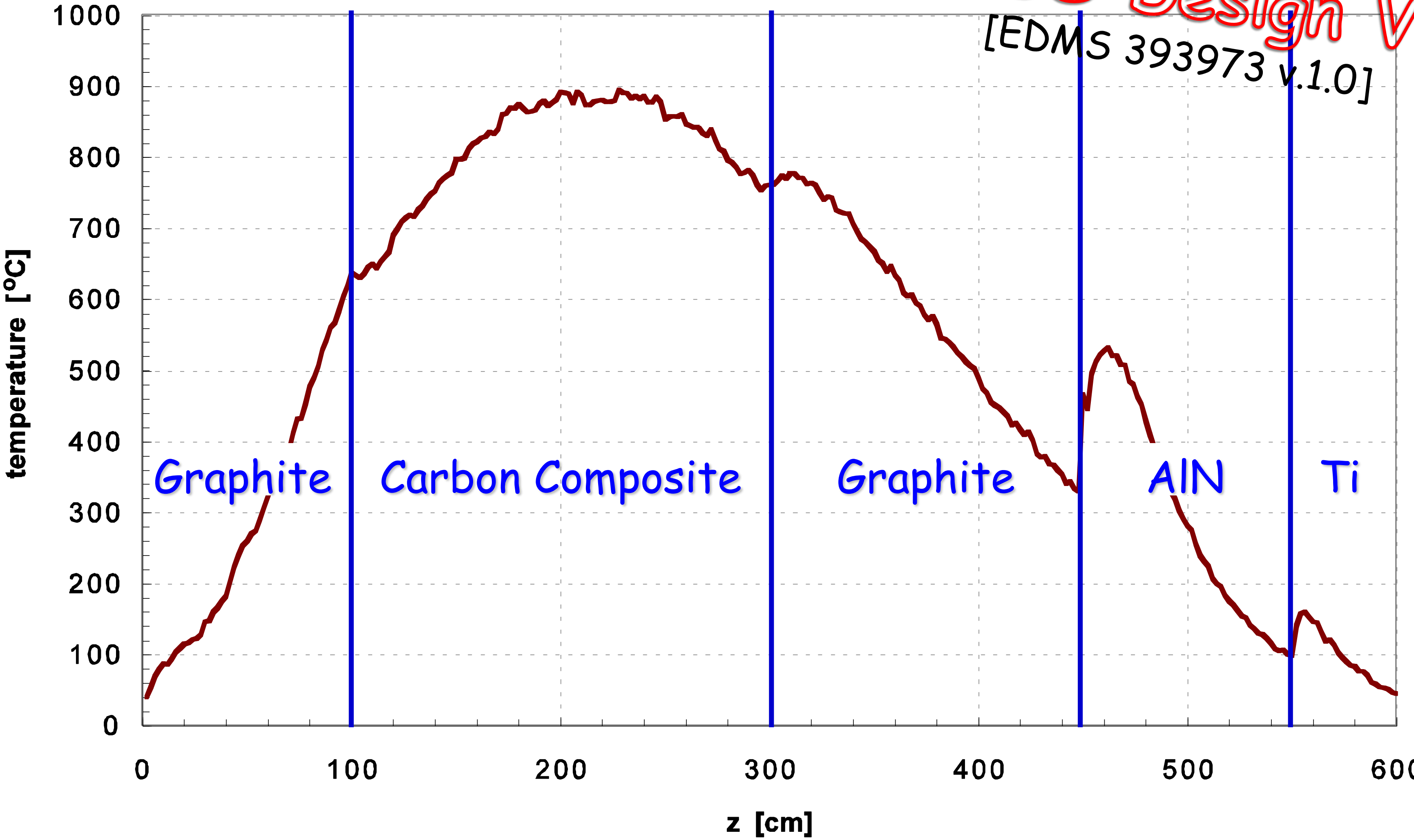
CONFIGURATION

- **Considering Maximum Temperatures:**
  - MSD Vacuum chamber (300°C)
  - MSD Steel Yoke (100°C)
  - Absorber materials
- **Baseline Solution [6]:**
  - 1m Graphite (density 1.77 g/cm^3)
  - 2m C-C composite (density 1.4 g/cm^3)
  - 1.5m Graphite (density 1.77 g/cm^3)
  - 1m Aluminium nitride (density 3.31 g/cm^3)
  - 0.5m Titanium (density 4.5 g/cm3)

CONCEPTUAL DESIGN - 2

TCDS Design V1

[EDMS 393973 v.1.0]

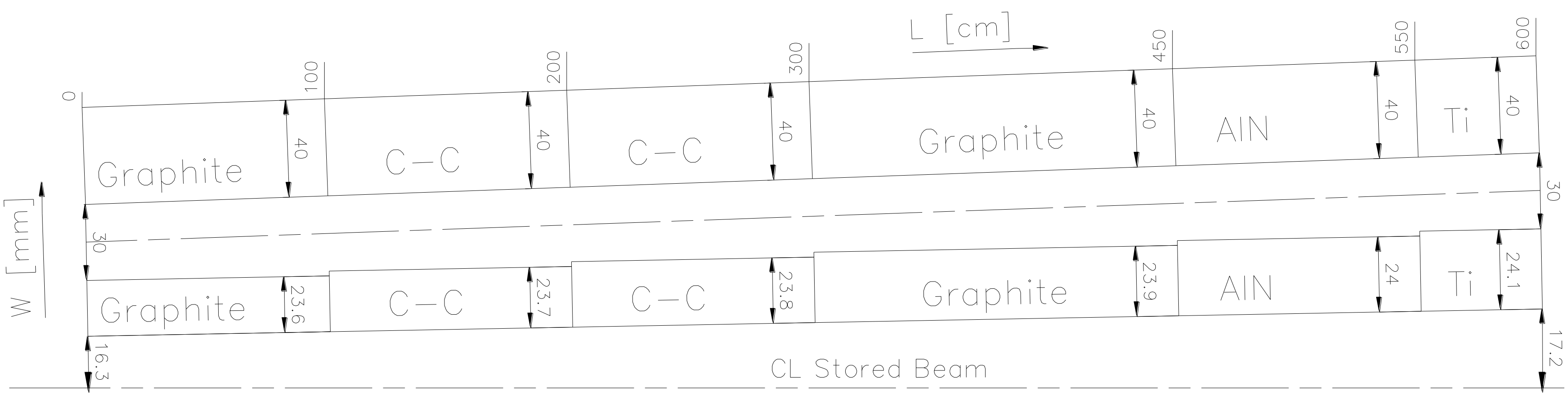


CONCEPTUAL DESIGN - 3

TCDS Design V1
[EDMS 393973 v.1.0]

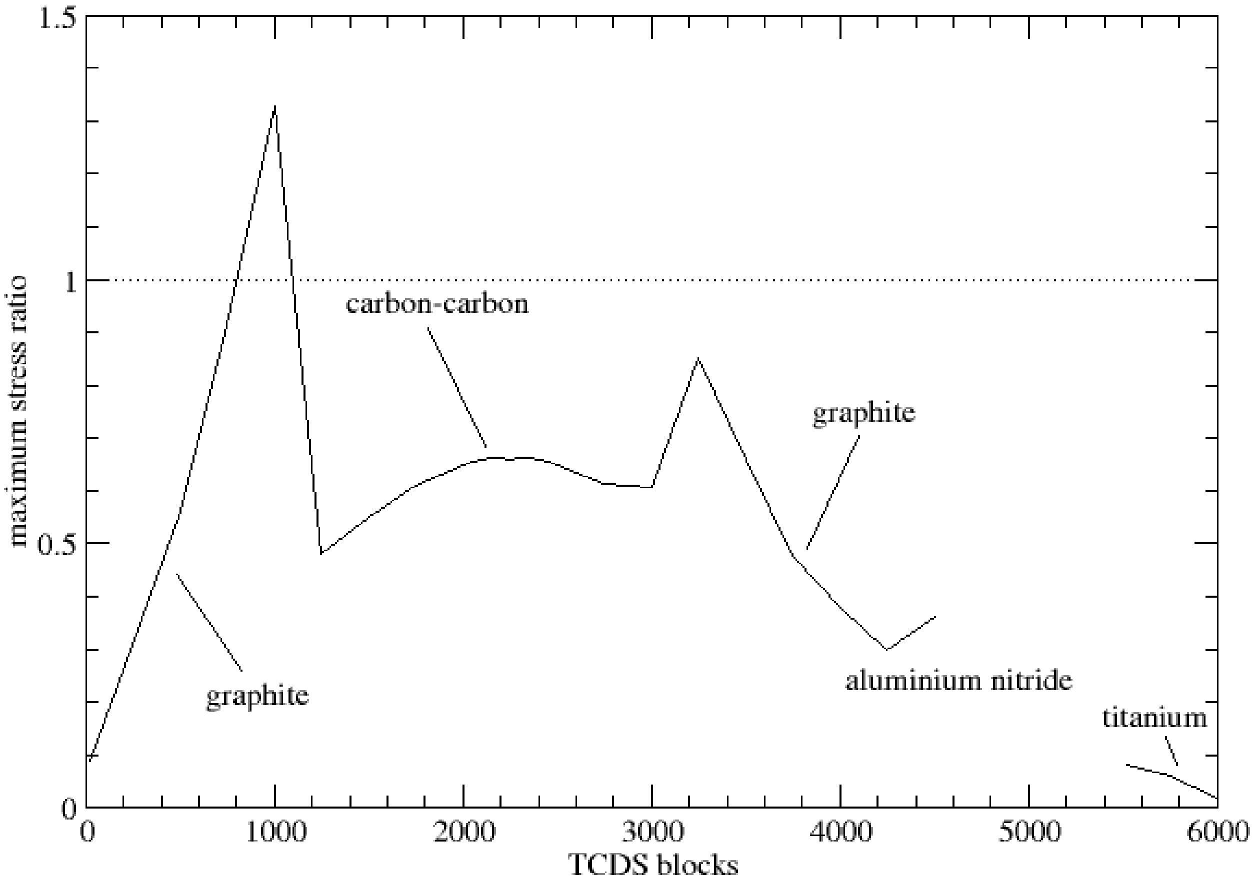
Baseline Solution:

- 1m Graphite (density 1.77 g/cm^3)
- 2m C-C composite (density 1.4 g/cm^3)
- 1.5m Graphite (density 1.77 g/cm^3)
- 1m Aluminium nitride (density 3.31 g/cm^3)
- 0.5m Titanium (density 4.5 g/cm3)



Studies in 2004 showed:

- The 2nd part of the graphite section would not survive;
- And the Titanium section was scarcely loaded.
- No material data was available at that time for ALN



TCDS Design V2

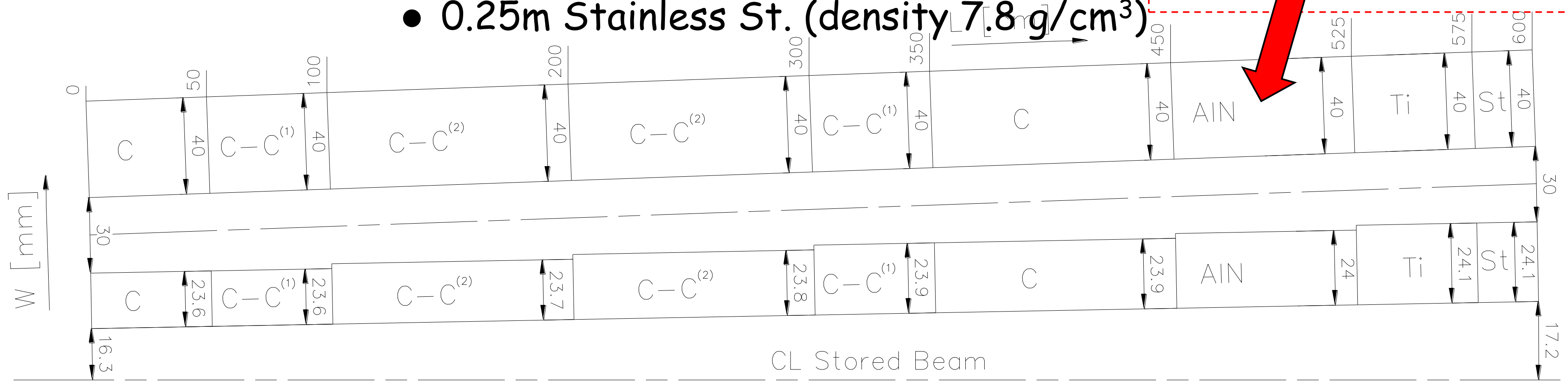
[EDMS 458836 v.1.0, EDMS 716298]

Revised Solution:

- 0.5m Graphite (density 1.77 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 2.0m C-C composite (density 1.4 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 1.0m Graphite (density 1.77 g/cm^3)
- 0.75m AlN(density 3.31 g/cm^3)
- 0.5m Titanium (density 4.5 g/cm^3)
- 0.25m Stainless St. (density 7.8 g/cm^3)

Graphite replaced by high density CfC

Calculations later showed that AlN or optional hBN/TiB2 Compound (density 2.7 g/cm3) have stress values 6 times above the allowed limit



(1) high–density C–C composite
(2) C–C composite 1501G

In 2004 we did a Search for High Density C-C Composite:

Many products found in literature, often used for F1 brake disks, but not so easy to buy:

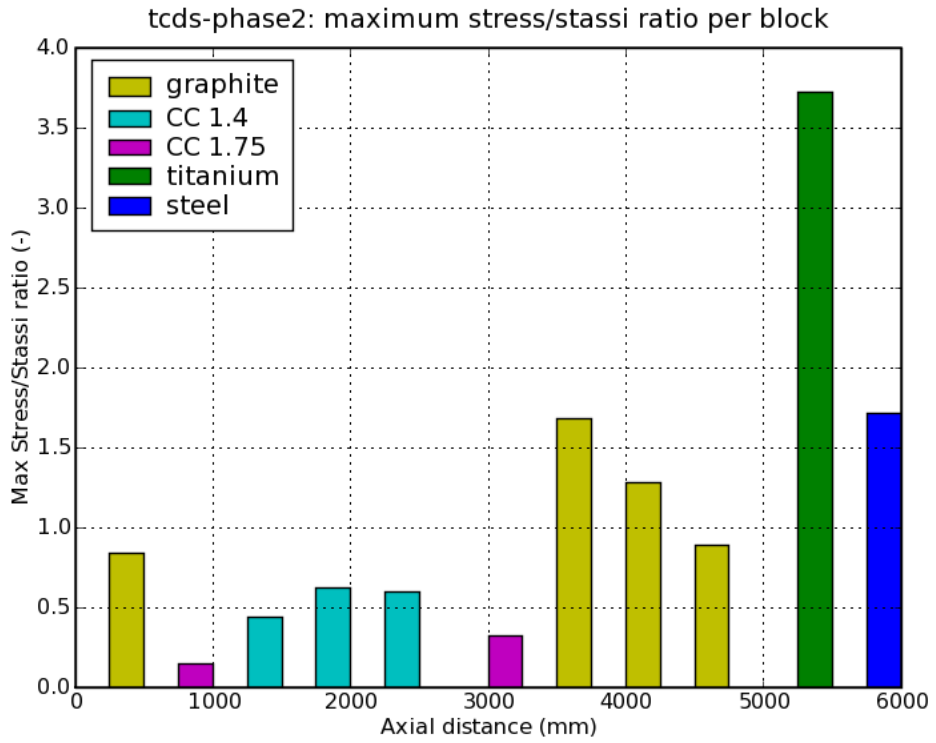
- **CHEMCARB from HITCO** (density 1.8 g/cm^3)
  - Very expensive ($5000/block -> US Dept. of State export license delay of 4 to 6 months.
- **CERACARB from HITCO** (density 2.04 g/cm^3)
  - The bulk density would be too high.
- **3D SEPCARB NB31 from SNECMA** (SEP = Société Européenne de Propulsion)
  - At that time prototype material for ITER, negative reply from the company for delivery.
- **3D SEPCARB N11 from SNECMA**
  - Possible, but delivery would be too late for LHC start-up.
- **SIGRABOND from SGLCARBON** (density max. 1.6 g/cm^3)
  - Material properties promising, but the bulk density would be too low.
- **RNFF-sag from SINTEC** (density > 1.75 g/cm^3)
  - CfC composite material with advanced graphitization process. This material was chosen.
  - Many material test done to qualify the material for input of CRS4 calculations.

Target Collimator Dump Septum

- In the first design the TCDS was 3.0 long and had the following material composition: 1m of graphite, 2m of a carbon composite, 1.5m of graphite again, 1m of aluminum nitride and 0.5m of a titanium alloy
- The core had a wedge shape determined by the extreme orbit trajectories and is realized by a set of parallelepiped blocks (80mm high, ~24mm thick and 25mm long)
- In the revised design the core consists of 24 blocks, each 250mm long with the following materials: 0.5m of graphite, 0.5m of high density carbon composite, 2m of low density carbon composite, 0.5m of high density CC, 1.75m of graphite again, followed by 0.5 of a titanium alloy and 0.25m of a nickel alloy

TCDS phase 2 results: max stress ratio

- High stresses are found on the second part of graphite blocks and on the titanium and steel blocks
- Values higher than unity imply a failure or a yielding



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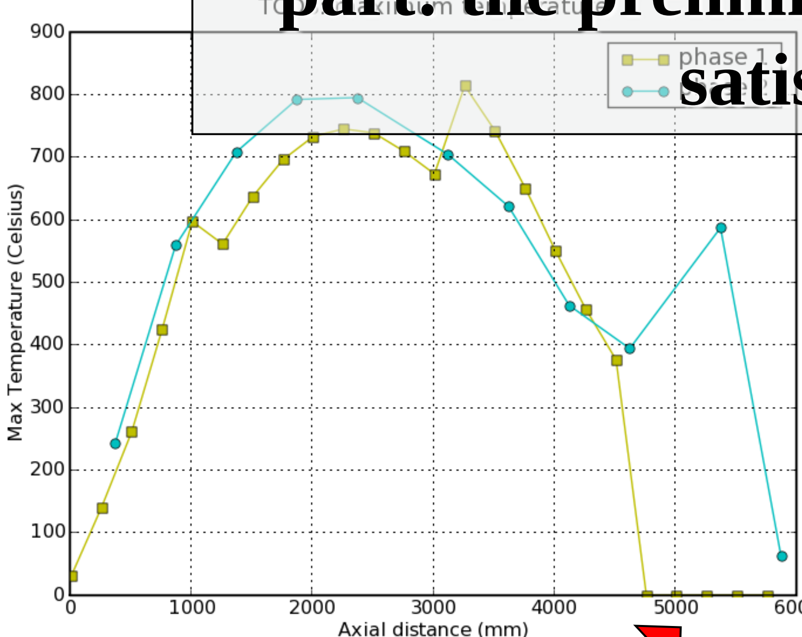
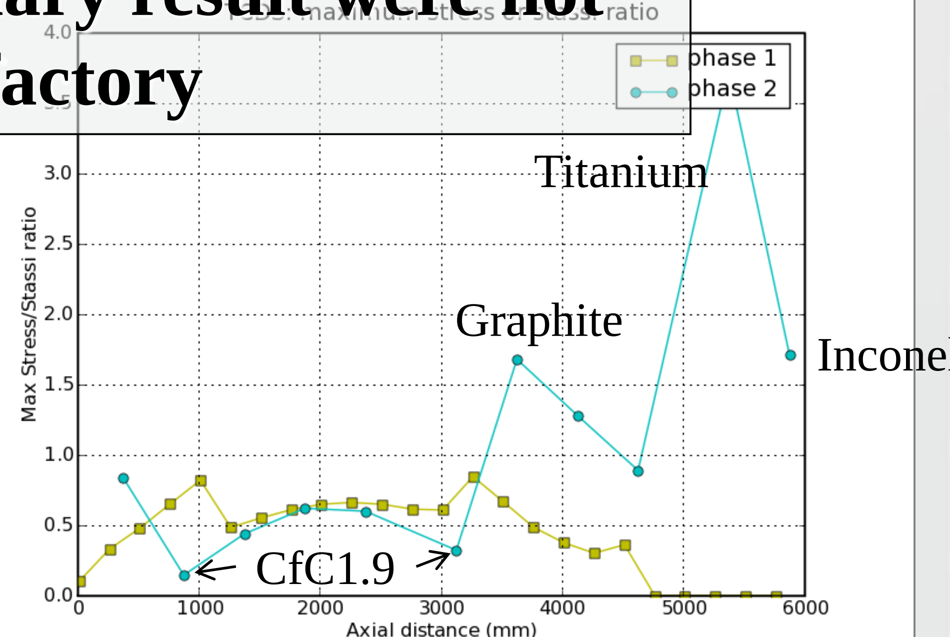
TCDS results comparison

It was necessary to extend the graphite portion of the target to avoid the AlN part: the preliminary result were not satisfactory

The results for phase 1 appear to be better than phase 2!





Initially no data for Aluminium Nitride

Later calculations showed AlN having stress values 6 times above the allowed limit

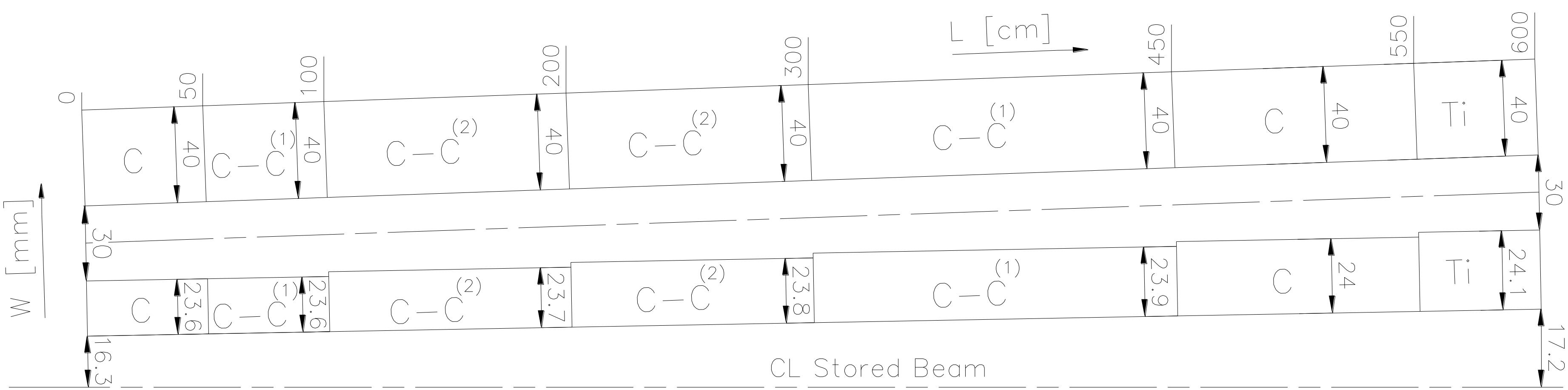
TCDS Design V3

[EDMS 458836 v.2.0, EDMS 716298, EDMS 393973 v.2.0]

Final Solution:

- 0.5m Graphite (density 1.77 g/cm³)
- 0.5m C-C composite (density 1.9 g/cm³)
- 2.0m C-C composite (density 1.4 g/cm³)
- 1.5m C-C composite (density 1.9 g/cm³)
- 1.0m Graphite (density 1.77 g/cm³)
- 0.5m Titanium (density 4.5 g/cm³)

high density CfC >1.75g/cm³ was the best we could find



(1) C−C composite density 1.9g/cm3
(2) C−C composite density 1.4g/cm3

TCDS conclusions: phase 3

- A new design has then been adopted by CERN that appears as a good compromise
- Some graphite blocks are substituted by high density carbon composite, the steel block is no longer present and the two titanium blocks are moved at the end of the target; the following materials are adopted: 0.5m of graphite, 0.5m of high density carbon composite, 2m of low density carbon composite, 1.5m of high density CC, 1.0m of graphite again and 0.5m of a titanium alloy
- The results were satisfactory throughout the whole target. The highest stresses are found in the 23rd block, made from titanium, in which a temperature increase of 401° C and a maximum Stassi ratio of 2,08 are reached. This value reduces to 1,65 when an offset beam is considered

EDMS 716298

CRS4 – Centre for Advanced Studies
Research and Development in Sardinia

DYNAMIC STRUCTURAL ANALYSIS OF THE TCDS COLLIMATOR

L.MASSIDDA AND F.MURA

Abstract

The dynamic structural behaviour of the TCDS collimators protecting the LHC extraction septa (MSD) was studied in the event of an asynchronous firing of the extraction kickers (MKD) during operation at ultimate intensity in proton mode.
The deposited energy densities, estimated by the high energy particle transport code FLUKA, were converted to internal he... dependence of the extracted beam. The... obtained by solving the coupled heat trans... spectral-element code ELSE.
Temperature and stress results are disc... absorbing blocks, with a particular focu... findings, a change of material is deemed... an optimization of its core is suggested.

Cagliari, Italy
January, 2004

EDMS 458836

Geneva, 22 March, 2004

MEMORANDUM

A/To: Brennan Goddard, Marta Sans Merce, Luca Bruno, Benoit Riffaud

De/From: Wim Weterings

Concerne/Subject: Modification of TCDS Baseline Configuration

Following the results [i] of the study of the TCDS thermal behaviour after impact, the longitudinal distribution of the carbon in the TCDS cored will be revised. Furthermore, since the titanium section is scarcely loaded, the aluminium nitride section will be shortened, the titanium section moved upstream and a stainless steel section will be added. The modified baseline solution is now as follows:

- 0.5m Graphite (density 1.77 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 2.0m C-C composite (density 1.4 g/cm^3)
- 0.5m C-C composite (density 1.9 g/cm^3)
- 1.0m Graphite (density 1.77 g/cm^3)
- 0.75m Aluminium nitride (density 3.31 g/cm^3)
- 0.5m Titanium (density 4.5 g/cm^3)
- 0.25m Stainless Steel (density 7.8 g/cm^3)

Depending on Aluminium nitride material tests, this part could be replaced by a hBN/TiB_2 Compound (density 2.7 g/cm^3) or other suitable material.

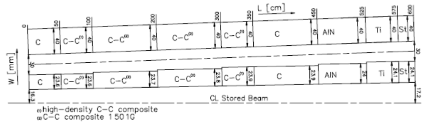


Figure 1 - Dimensions and position of TCDS diluter blocks.

[i] L.Massida, F.Mura, Dynamic Structural Analysis of the TCDS Collimator, CRS4-Centre for Advanced Studies Research...

EDMS 716298

Structural Analysis o... TCDS Collimator Ne... Design

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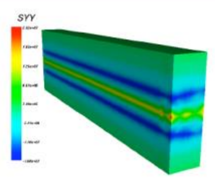
1 February 2006



ABSTRACT

The dynamic structural behavior of the TCDS was studied in the event of an asynchronous firing of the extraction kickers during operation at ultimate intensity in proton mode. The deposited energy densities, as estimated by an high energy particle transport code, were converted to internal heat; the transient response to this thermal load is obtained by solving the dynamic thermal-elastic problem on a specifically developed code. Temperature and stress results are discussed for the most significant TCDS blocks.

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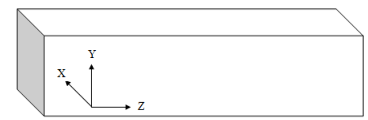
At Room Temperature		SEPCARB NB31	SINTEC RFF-g	SINTEC RNFF-sag
Density	Kg m^{-3}	1910	1680-1730	
Elastic modulus (Ex)	MPa	12000	7800	10000
Elastic modulus (Ey)	MPa	107000	3400	2800
Elastic modulus (Ez)	MPa	15000	7800	10000
Compressive strength (σcx)	MPa	31	144.4	88.6
Compressive strength (σcy)	MPa	102	98.5	69.6
Compressive strength (σcz)	MPa	31	132.1	82.4
Tensile strength (σtx)	MPa	19		84.2
Tensile strength (σty)	MPa	130	12.8	
Tensile strength (σtz)	MPa	30	48.9	61.3
Thermal expansion coefficient (αx)	10^{-6} K^{-1}	2.1	2.8	
Thermal expansion coefficient (αy)	10^{-6} K^{-1}	0.4	5.3	
Thermal expansion coefficient (αz	10^{-6} K^{-1}	1.0	2.8	
Ktx {σt[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		7.5	22.4	
Kty {σt[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		30.4	7.1	
Ktz {σt[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		20.0	22.4	
Kcx {σc[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		12.3	66.1	
Kcy {σc[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		23.8	54.7	
Kcz {σc[MPa]/(E[GPa]·α[10^{-6}K^{-1}])}		20.7	60.5	

* 50% of 3-point bending strength, measured by SINTEC, value between 170-190 MPa, Young's modulus 38-40 GPa, thermal conductivity 110 W/mK with layer direction, 91 W/mK perpendicular to the layers, the electrical resistivity is 12.5 Ωμm.



SINTEC RFF-g Test results:

Compression		Rm (MPa)	E(GPa)		Tensile		Rm (MPa)
X- Direction	1	140.2	7.5		Y- Direction	1	7.9
	2	146.8	8.3			2	13.8
	3	148.3	7.7			3	13.8
	4	135.8	7.6			4	15.6
	5	150.7	7.7			Average	**12.8**

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project **LHC Project ...**

Dynamic Stresses in the LHC TCDS Diluter from 7 TeV Beam L...

B. Goddard, L. Massidda[1], A. Presland, W. Weterings
CERN, Geneva, Switzerland

Abstract

In the event of an unsynchronised beam abort, the MSD extraction septum of the LHC system is protected from damage by the TCDS diluter. The simultaneous constraints of obt... beam dilution while ensuring the survival of the TCDS make the design difficult, with... induced dynamic stresses occurring in the material needed to attenuate the particle showers... primary beam impact. In this paper, full 3D simulations are described where the worst-case b... been used to generate the local temperature rise and to follow the resulting time evolution o... stresses. The results and the accompanying design changes for the TCDS, to provi... performance margin, are detailed.

1) CRS4, Sardina, Italy.

Presented at EPAC'06, Edinburgh, UK, June 26-30, 2006

CERN,
CH-1211 Geneva 23,
Switzerland
Geneva, June 2006

MATERIAL PROPERTIES

Substrate Ceracarb 537 Coating None
Ply Orientation As Noted Thickness (in) 0.15 or Less
Molding Method Autoclave
Thickness per Ply (mils) 12.5 Bulk Density (g/cc) 2.04

Property	Layup 0/90	Layup ±45	Layup 0/90/±45
Ultimate Tensile Strength (ksi)	30	21	25
Tensile Modulus (msi)	9.4	6.1	9.2
Strain to Failure (%)	0.34	0.55	0.33
Ult Compressive Strength (ksi)	66	33	54
Compressive Modulus (msi)	10	5.5	8.5
Ult Flexural Strength (ksi)	46	38	43
Flexural Modulus (msi)	8.2	6.2	8.9
Ultimate Shear Strength (ksi)	11	–	16
Shear Modulus (msi)	2.1	–	3.0
Ult Bearing Strength (e/D=3) (ksi)	65	–	52
Double Notch Shear (0.25") (ksi)	5.1	7.3	5.2
Interlaminar Tension (ksi)	3.2	4.1	4.0
Poisson's Ratio	0.07	0.37	0.21
CTE (In-Plane) (ppm/°C)*	4.0	–	–
CTE (X-Ply) (ppm/°C)*	4.5	–	–
Therm Cond (In-Plane) (W/mK)**	–	–	7.7
Therm Cond (X-Ply) (W/mK)**	–	–	4.5
Notched Izod Impact (ft-lb/in)	1.5	2.1	1.7
Fracture Toughness (SENB) (ksi$\sqrt{in}$)	13	–	–

* (23 – 1000°C) ** (23 - 500°C)