TEC | Tecnológico de Costa Rica

Implementation of the Spherical Tokamak MEDUSA-CR: Stage 1

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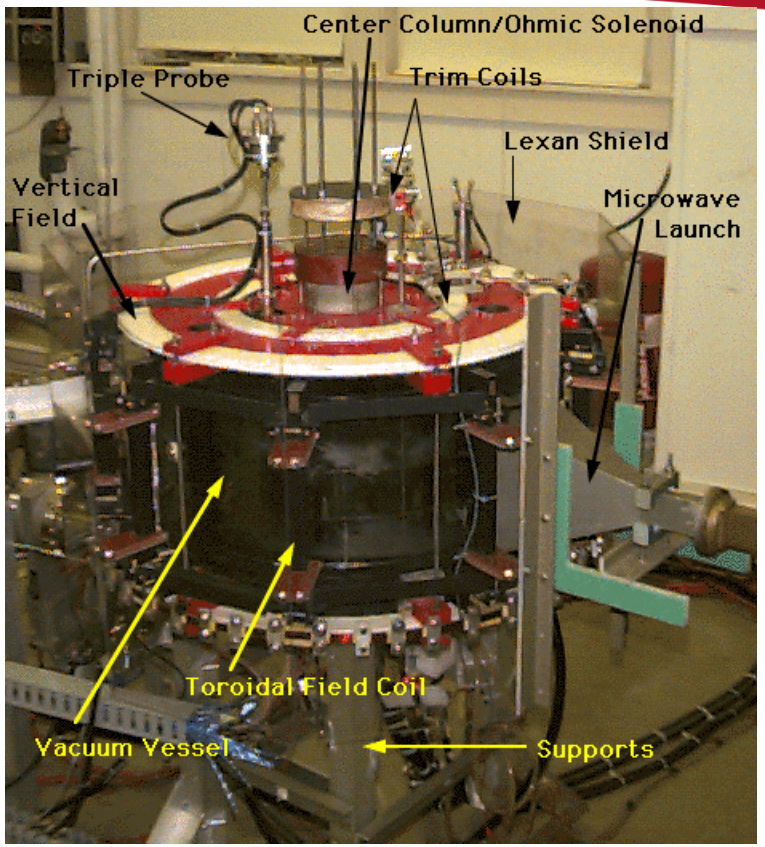
Short History about MEDUSA

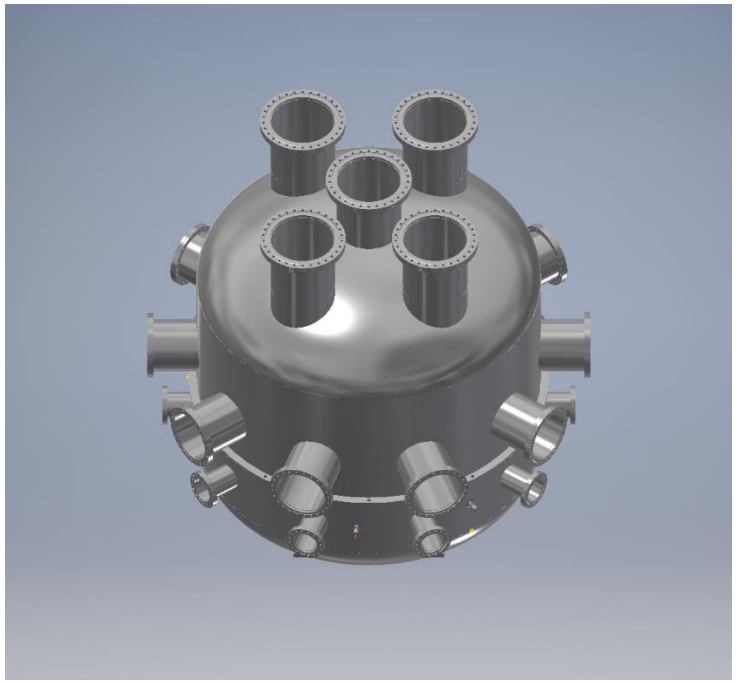


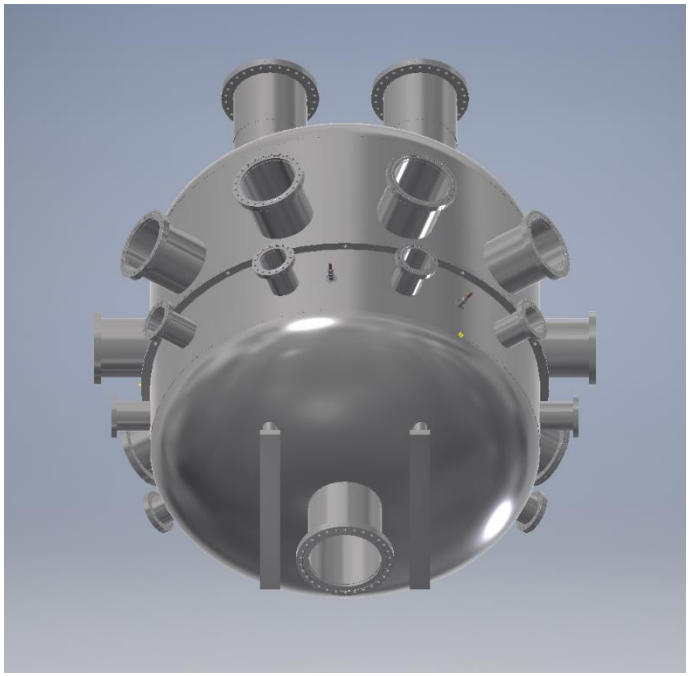
The low aspect ratio spherical tokamak (ST) MEDUSA (**M**adison **EDU**cation **S**mall **A**spect ratio tokamak) was operational in the 1990s in the University of Wisconsin-Madison, USA (Oct 94-Dec 96?)

Ref. [1] G. D. Garstka: “Startup and Stability of a Small Spherical Tokamak”, PhD thesis, University of Wisconsin at Madison (1997).

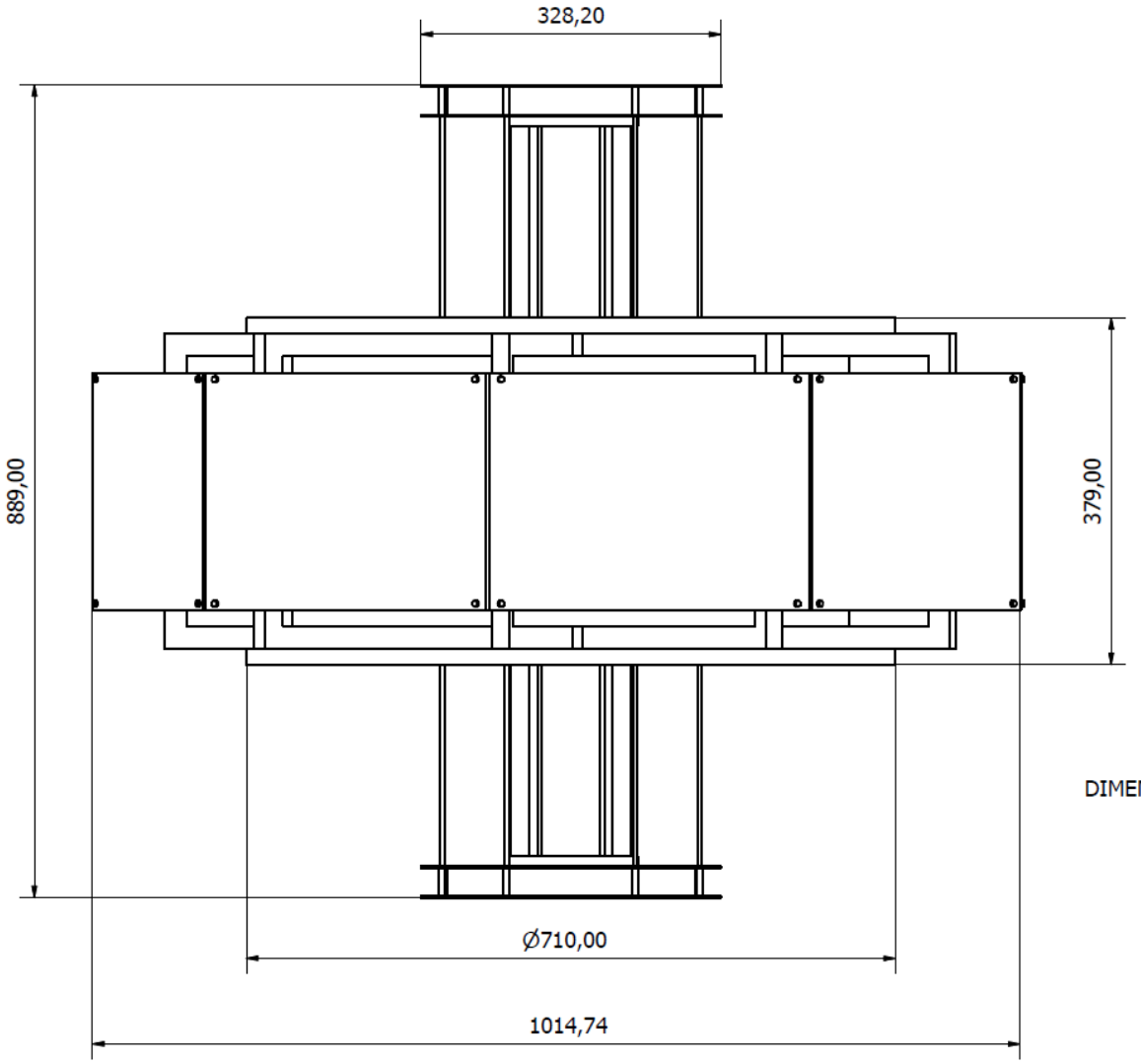
MEDUSA-CR CAD model

Material Stainless steal 304L
6x CF port 13”
11 x CF port 6”
11x CF port 4-5/8”
Coils inside of the vacuum vessel.

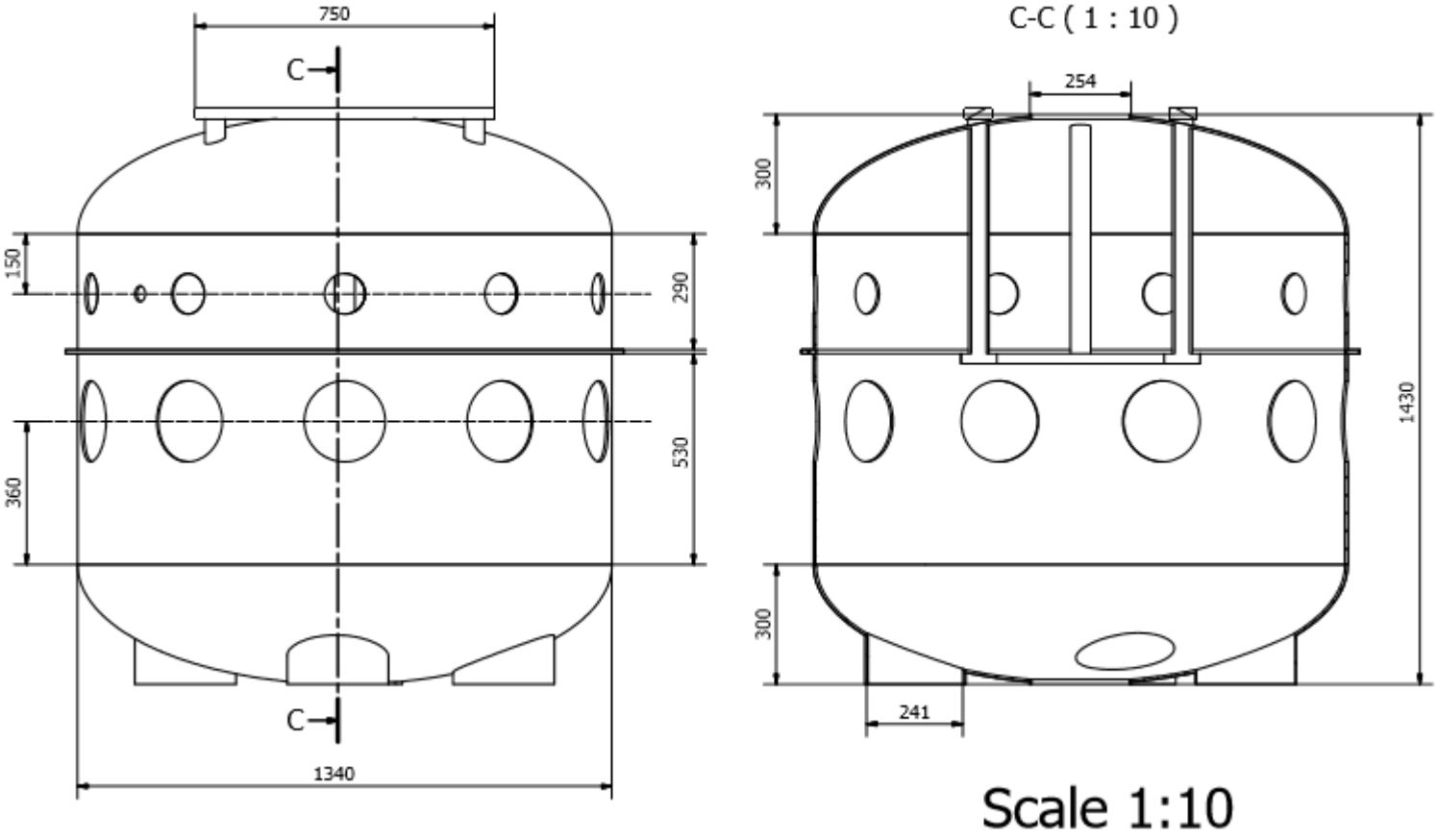




MEDUSA-CR Dimensions

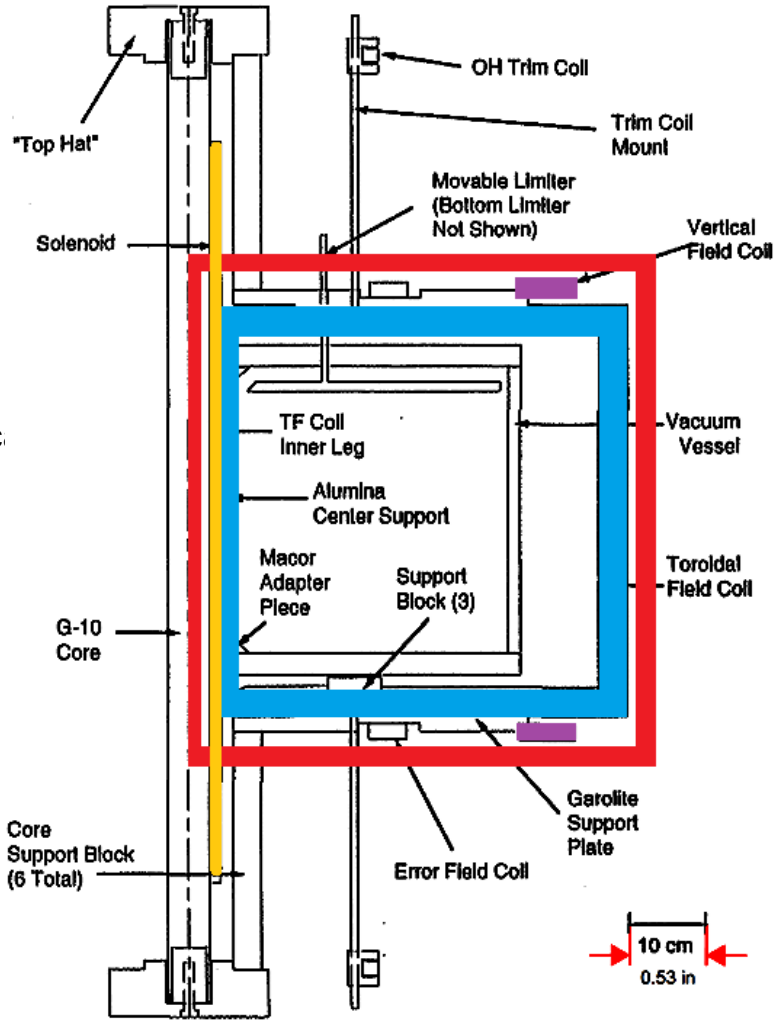


MEDUSA-CR Vacuum Vessel Dimensions



MEDUSA-CR Components

HFS: B_T = 0.90T(typic
1.5T(max)



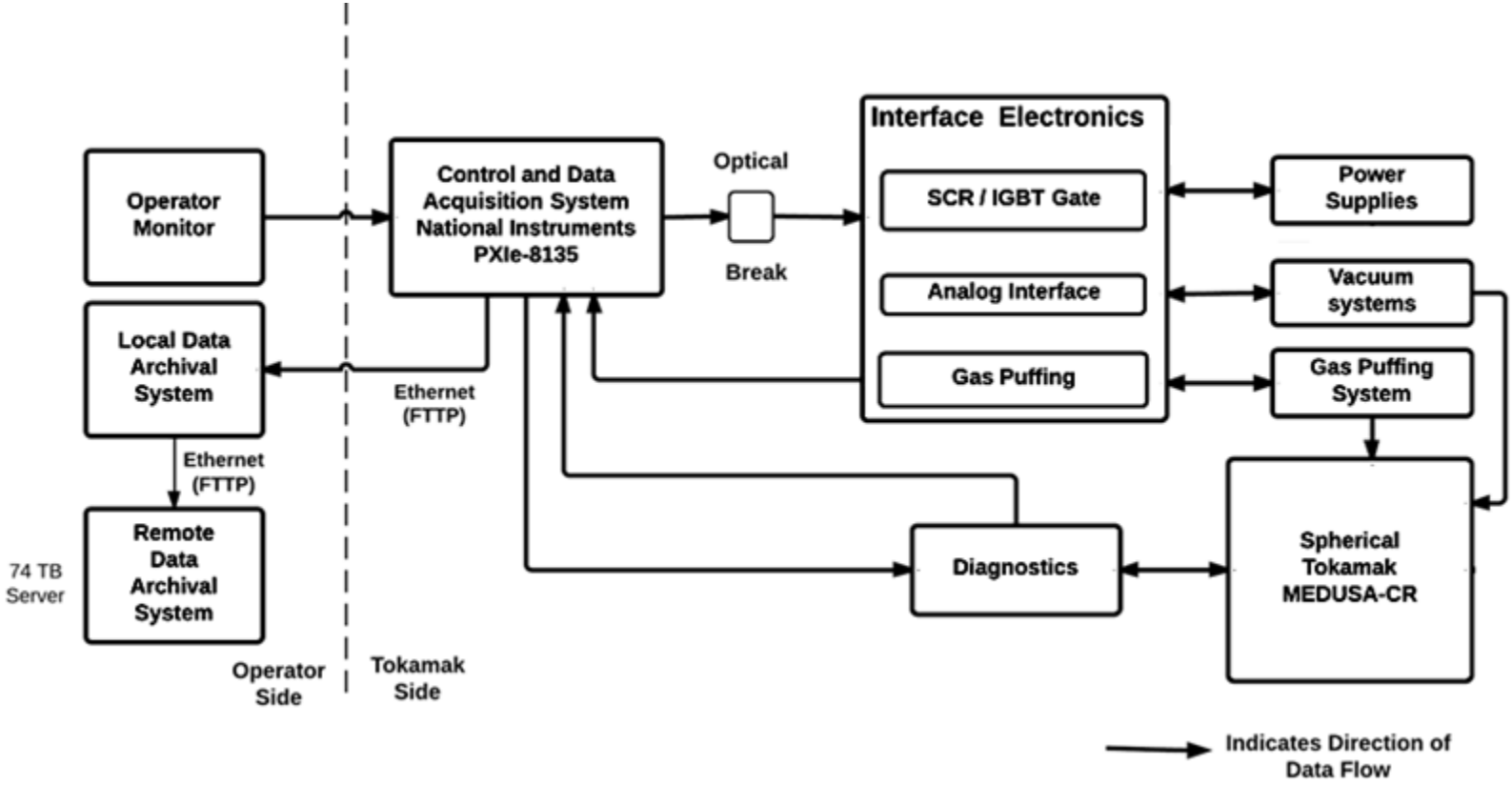
B_T = 0.18T(typical)
0.30T(max)

MEDUSA-CR main parameters

Parameter	Typical Value
Major Radius	0.09 m – 0.14 m
Minor Radius	0.04 m – 0.10 m
Aspect Ratio	1.5 (1.35 min)
Plasma Current	20 kA (40 kA max)
Toroidal Field	0.3 T (0.5 T max)
Pulse Length	1 ms (3 ms max)
OH Flux Swing	10 mV – s (single swing)
Plasma Vertical Elongation	1.2
Toroidal Field	41 kJ
Ohmic Heating	116 kJ
Vertical Field	17 kJ
P(base)	$5x10^{-8}$ torr
T_e (0)	< 140 eV
n_e (0)	< $2x10^{20}$ m^{-3}

MEDUSA-CR Control System

Control and data acquisition for will be performed by desktop computers coupled with interface electronics as shown below.



We have also developed a graphical Human Machine Interface for control and visualization of all processes using LabView

Ref [2]: J. Gonzalez, C. Ribeiro et al. APS, Denver, 2013.

MEDUSA-CR PXI-NI for Control System

PXI (PCI eXtensions for Instrumentation)
- Industrial standard
- Robust
- High synchronization
- Modular : Chassis with several PXIe-6

PXIe-6358 cards

- 16 simultaneous channels,
  analogical differential input
  1.25 MS/s/ch
  16 bits resolution with a range of +/- 10 V

- 4 channel of analogical ouputs
  3.33 MS/s
  16 bits resolution with range of +/- 10 V
  48 lines of digital I/O of them: 32 channels with up 10 MHz hardware-timed

- 4 counter/timers with 32-bits for PWR, encoder, frequency, event counting applications, etc.

- Analog and Digitaltriggerung and timing with NI-STC3 technology

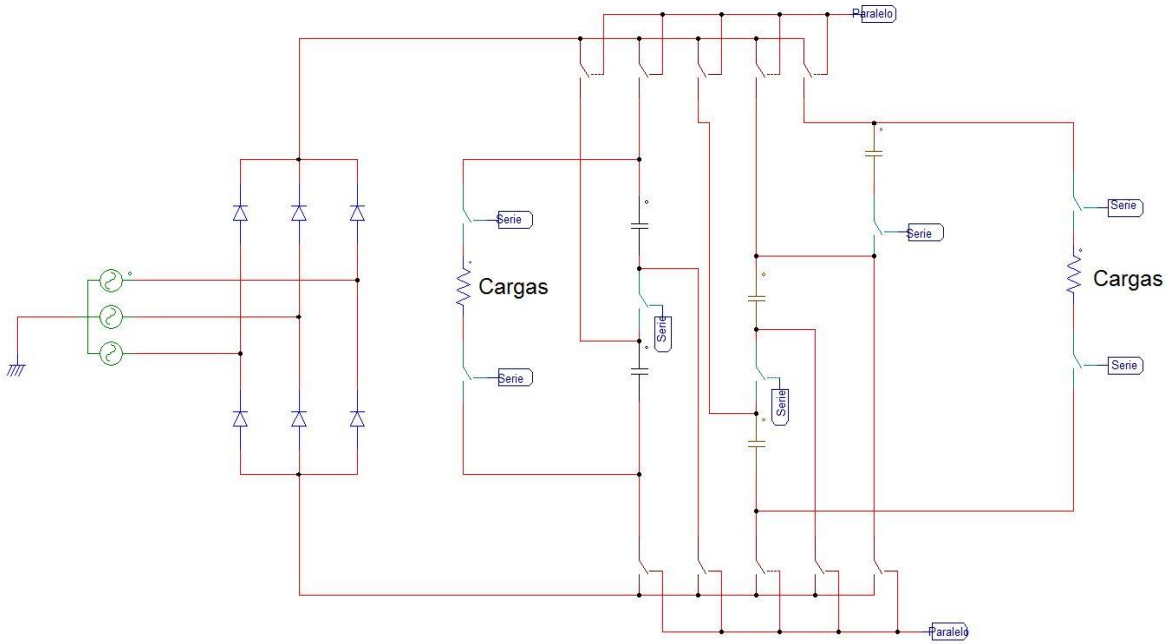
- Support for Windows 7/Vista/XP/2000

MEDUSA-CR Power Supplies

The load of the power supply are describe below

Coil	Maximum current	Inductance	Resistance
Toroidal field	10 kA	2.9x10-4 H	29 mΩ
Ohmic induction set	16 kA	9.7X10-5 H	35 mΩ
Vertical equilibrium	1 kA	1.8x10-4 H	15 mΩ
Error field correction	less than 100 A	-	-

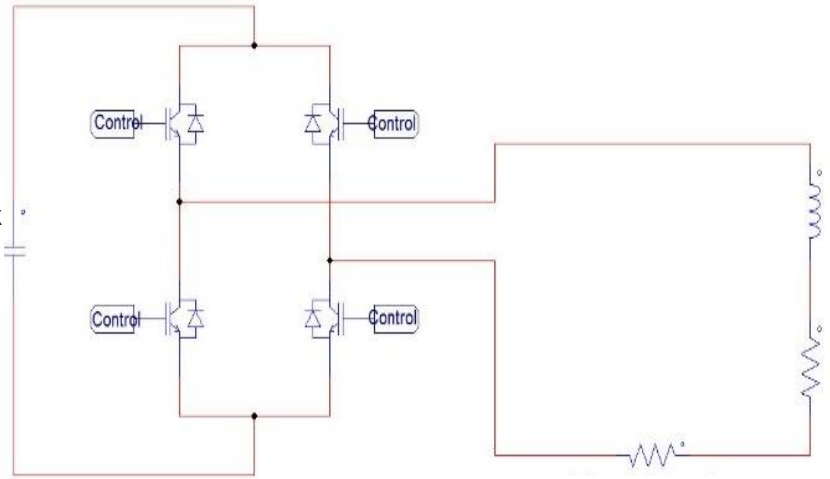
MEDUSA-CR Power Supplies



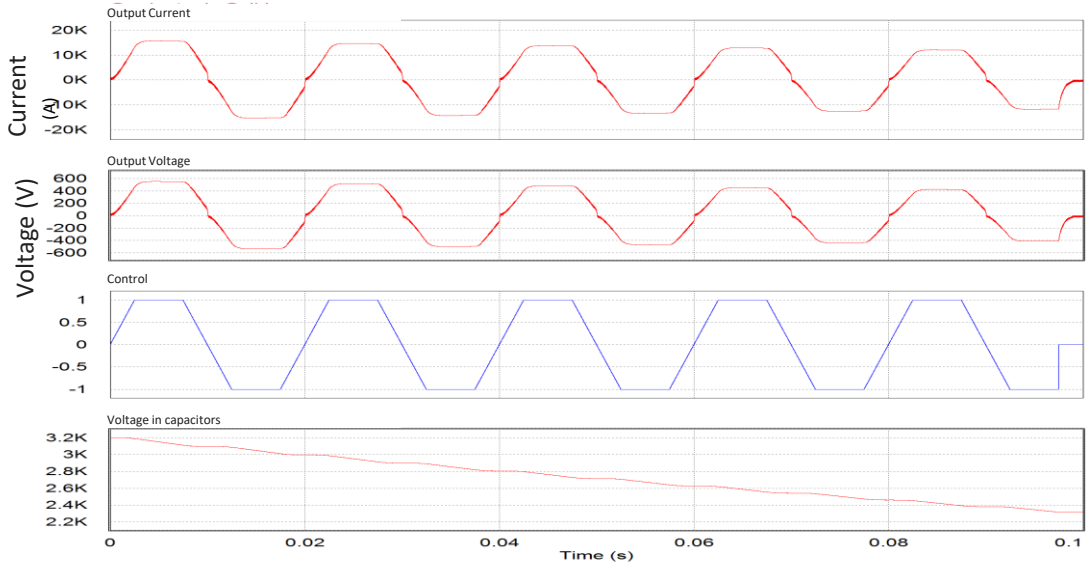
Charge system of capacitors and isolation of the discharge network

Coil	Voltage	Capacitance	Number of capacitors	Number of banks
Ohmic (OH)	350V	12F	1200	12
Toroidal Field(TF)	350V	9F	900	18

MEDUSA-CR Power Supplies



Current control system of the coils and current form

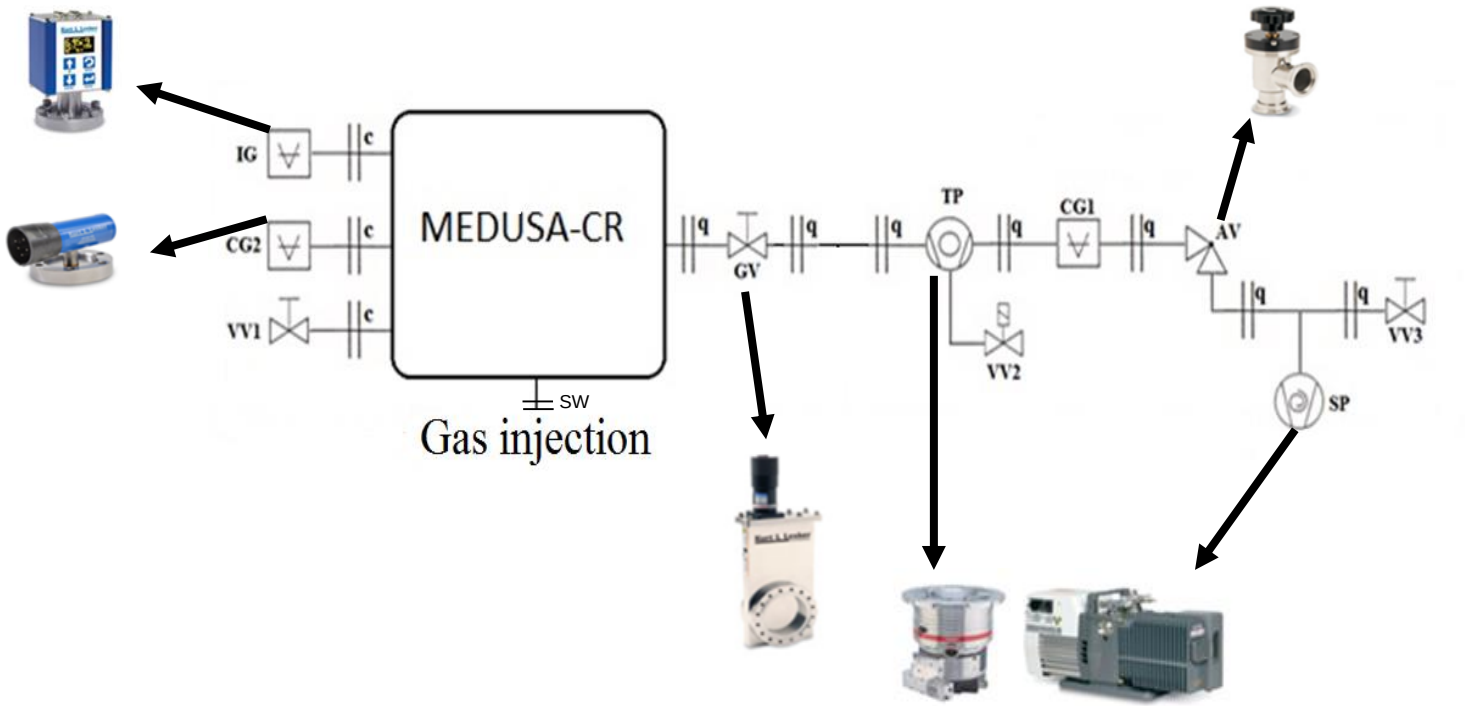


Power Feedthroughs??

Looking for

MEDUSA-CR Vacuum pumping system

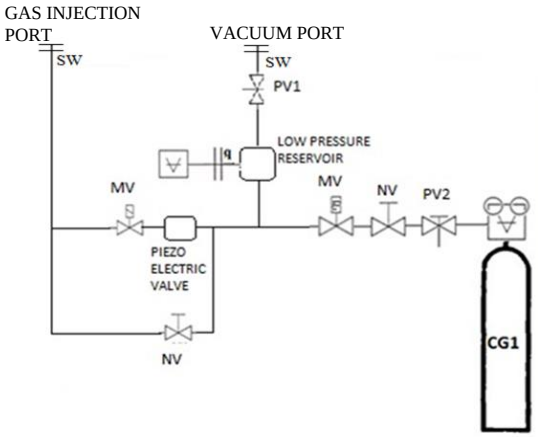
- Minimum pump pressure: **10^{-10} Torr**
- 1 mechanical pump (**10^{-4} Torr**), and 1 turbo-molcular pump (**10^{-10} Torr**)
- Additional equipment: RS485 communication, **vacuum convectron**, **ion gauge sensors** and **RGA** (Residual Gas Analyzers)



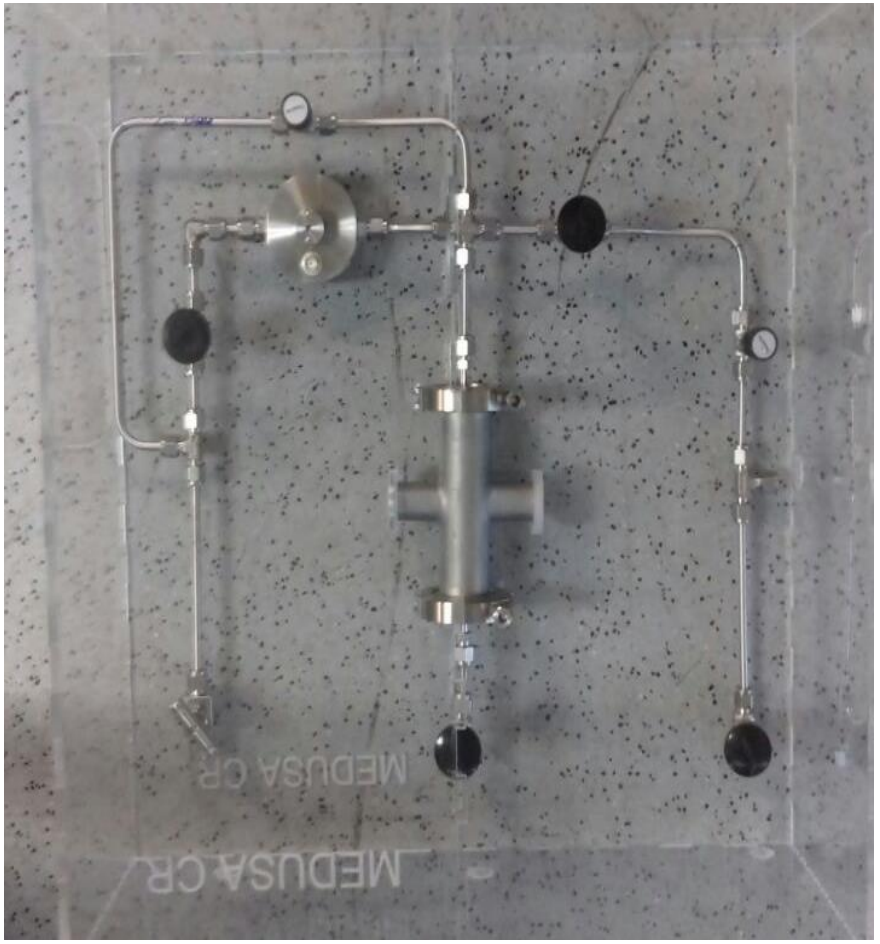
Illustrated Parts of vacuum system

MEDUSA-CR Gas injection system

Gas injection system



Specification table	
Resevoir	
Needle valve	
Meetering valve	
Mini Plug	
Piezoeletric valve	
Manometer	
Pressure gauge	



MEDUSA-CR Gas Injection and Vacuum System

MEDUSA-CR Diagnostics

DAY ONE

Magnetic : Rogowski Coils and Plasma Current (I_p)

Electric : Validation of all Existing 12 flux loops : 2 for Loop Voltage (V_ℓ)

Monitors for Gas Detection : RGA (residual Gas Analyser)

Monitors for Radiation Detection : Hα, I_{HXR} , C-III (≈ 48eV), O-VI (≈138eV)

MEDIUM TERM

Interferometer: Line Integrated Density, Michelson Scheme, 1mm (n_c=9x$10^{20}$$m^{-3}$)

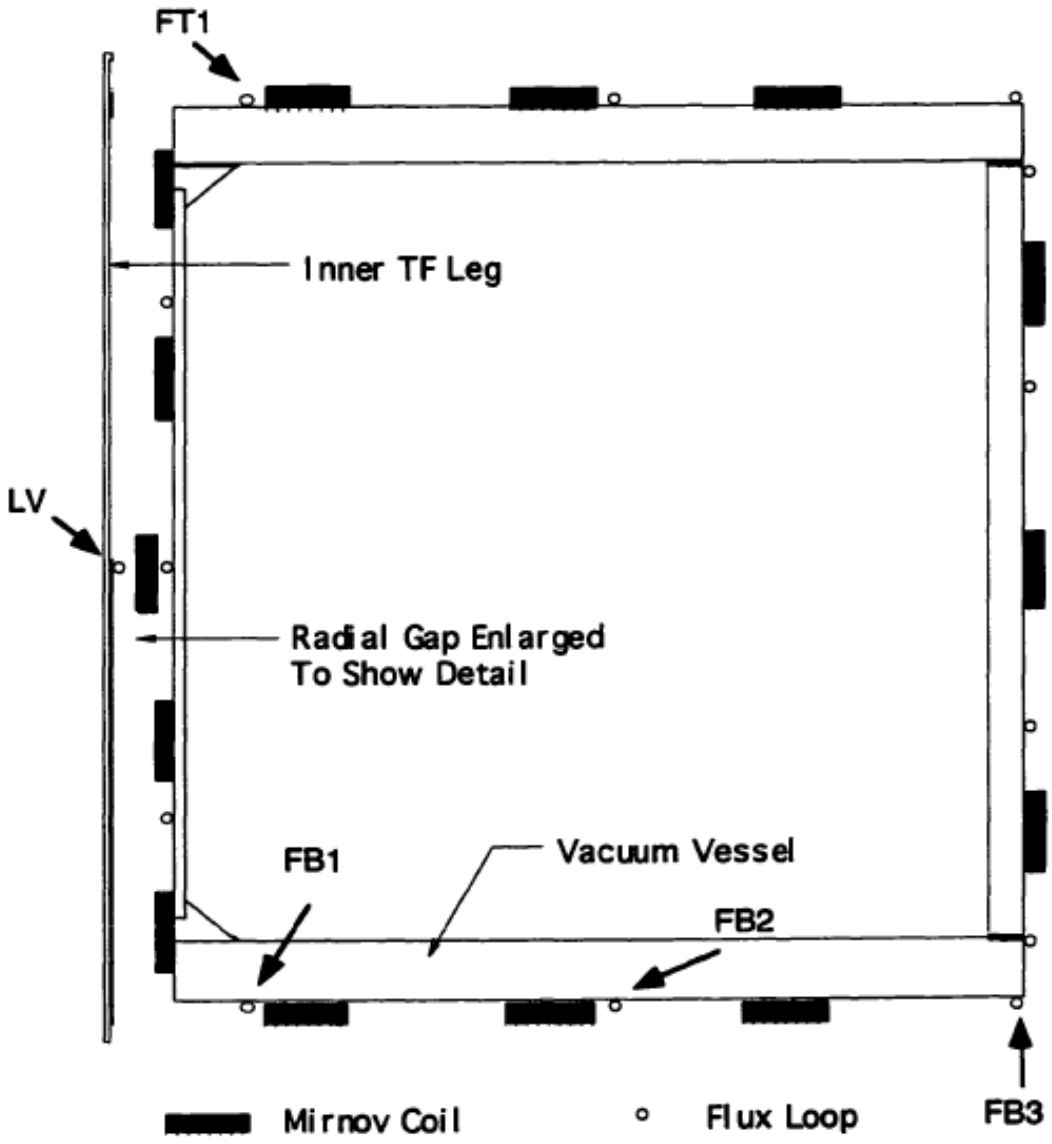
Magnetic : Flux Loops for Tokamac 2.0 and FIESTA Equilibrium Reconstruction codes
Horizontal and Vertical Position Control

Validate the existing 14 Mirnov Coils (θ) and expand to φ direction

Magnetic Probe Array (Hall Probe) for Equilibrium Reconstruction

Triple Langmuir Probe: 4-PIN scheme, 4mm inter pin space Ø=0.5mm, 2mm length, with rotating axis, i.e., a similar design of the one used at TCABR (e.g. C. Ribeiro, APS 2010)

MEDUSA-CR external magnetics



1 Rogoswski Coil (Ip)

14 Flux loops

14 Mirnov coils

Positions of MEDUSA external magnetics

MEDUSA-CR Computer Facilities

The existing computer facilities are:

SOFTWARE

FIESTA code installed locally
EFIT code installed locally

COMSOL Multiphysics, Solid Works and Inventor Autodesk Softwares

HARDWARE

Hardware available at the National Laboratory of Advanced Computing in Costa Rica.
Specialized and up-to-date hardware, efficient applications and trained personnel to take advantage of all that technology

MEDUSA-CR Scientific Programme

One of the attractive features of MEDUSA is the glass vessel because this leads instant field penetration for any external coils.

The major topics for the scientific programme are:

- Comparative studies of equilibrium and stability between natural divertor D and bean-shaped ST plasmas [3].
- Study of an ergodic magnetic limiter [3,4,5].
- Alfvén wave heating and current drive.
- Transport.

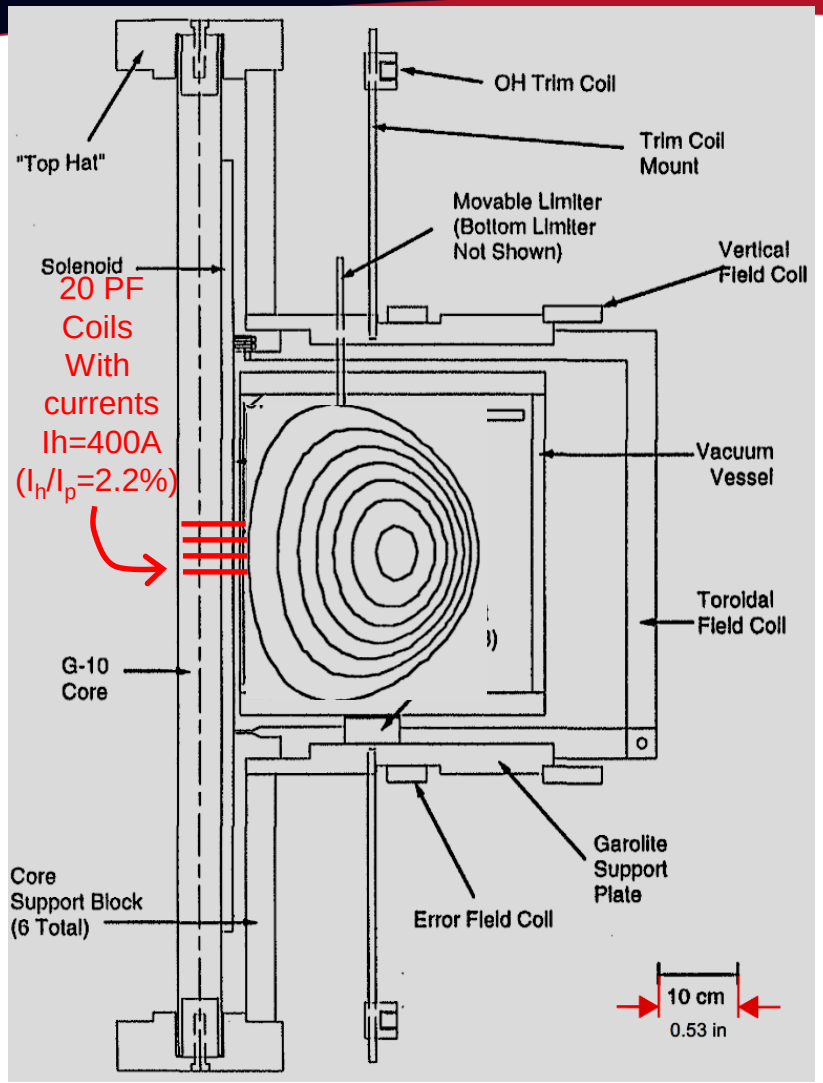
References:

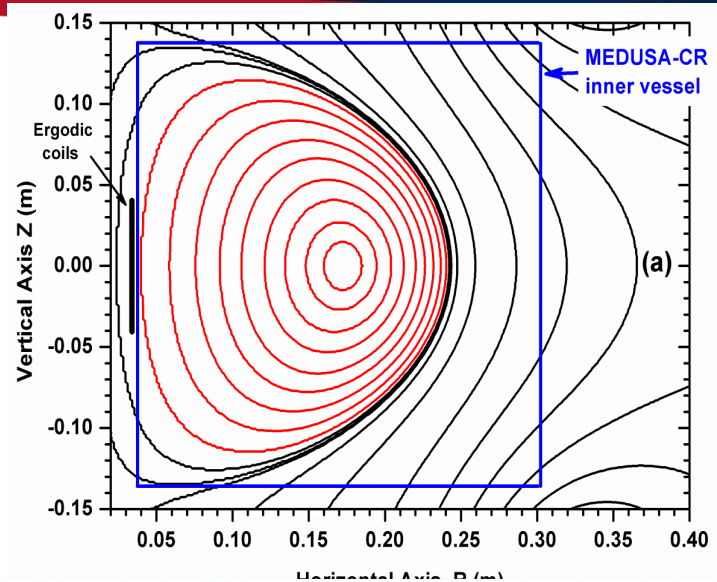
[3] C. Ribeiro et al., Proc. 25th Symposium on Fus. Eng., San Francisco, US, June 2013.

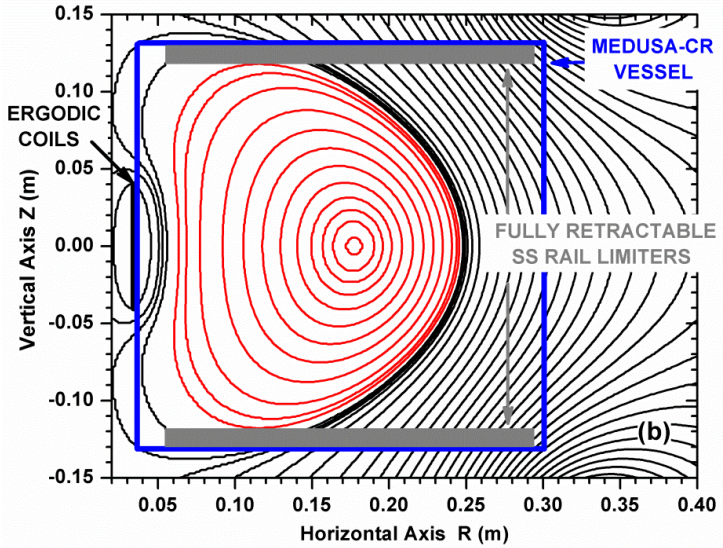
[4] C. Ribeiro et al., Proc. 39th EPS Conf. Contr. Fusion and Plasma Phys., vol. 36F, P1.091, Stockholm, Sweden, July 2012.

[5] J. J. E. Herrera-Velázquez, E. C. Alarcon, and C. Ribeiro, 24 th IAEA Fusion Energy Conference, TH-p2-28, San Diego, US, 8-12 October 2012.

Ergodic limiter





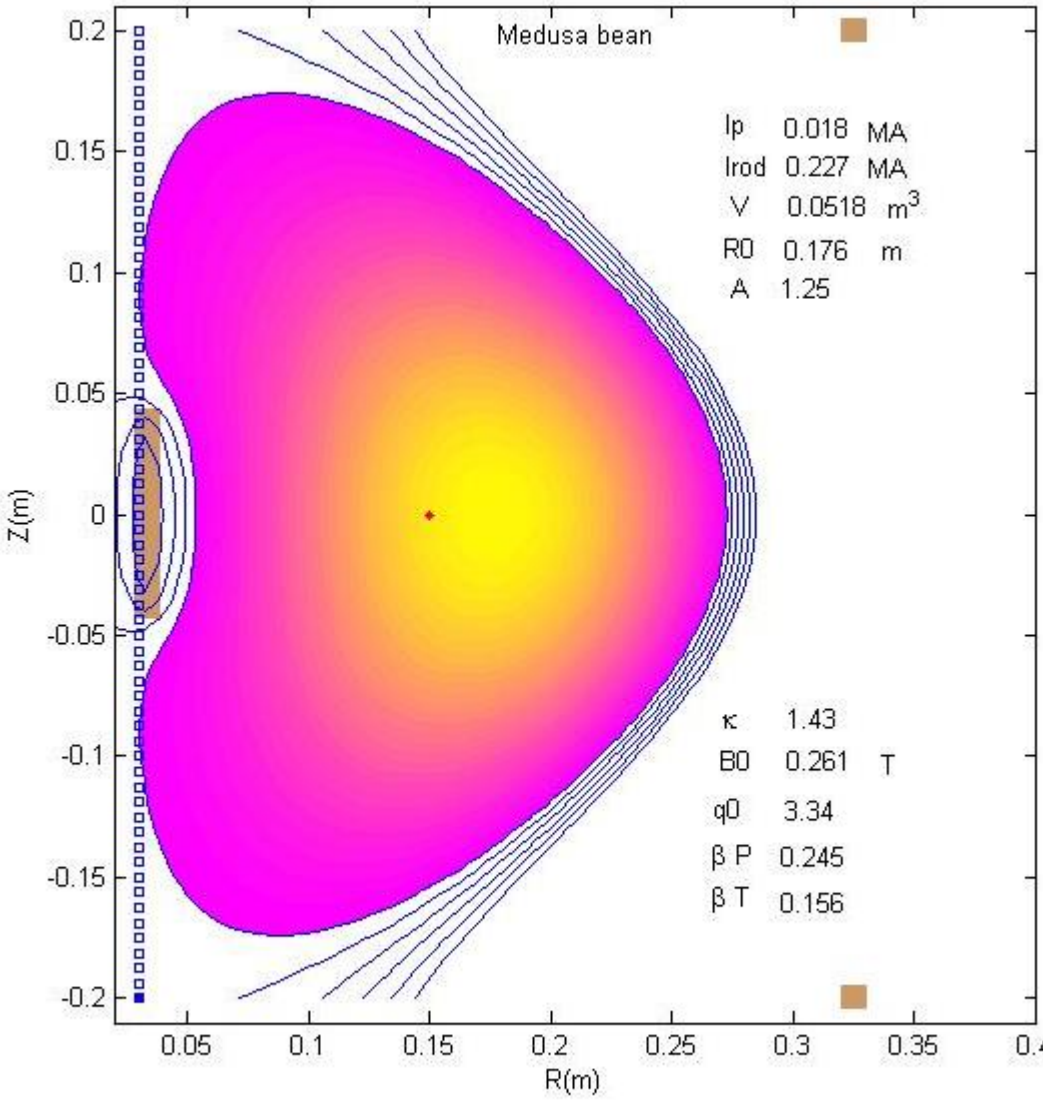


D-shape with low or highly triangularity and the novel bean-shaped ST equilibrium can be created via external inboard poloidal field coils.

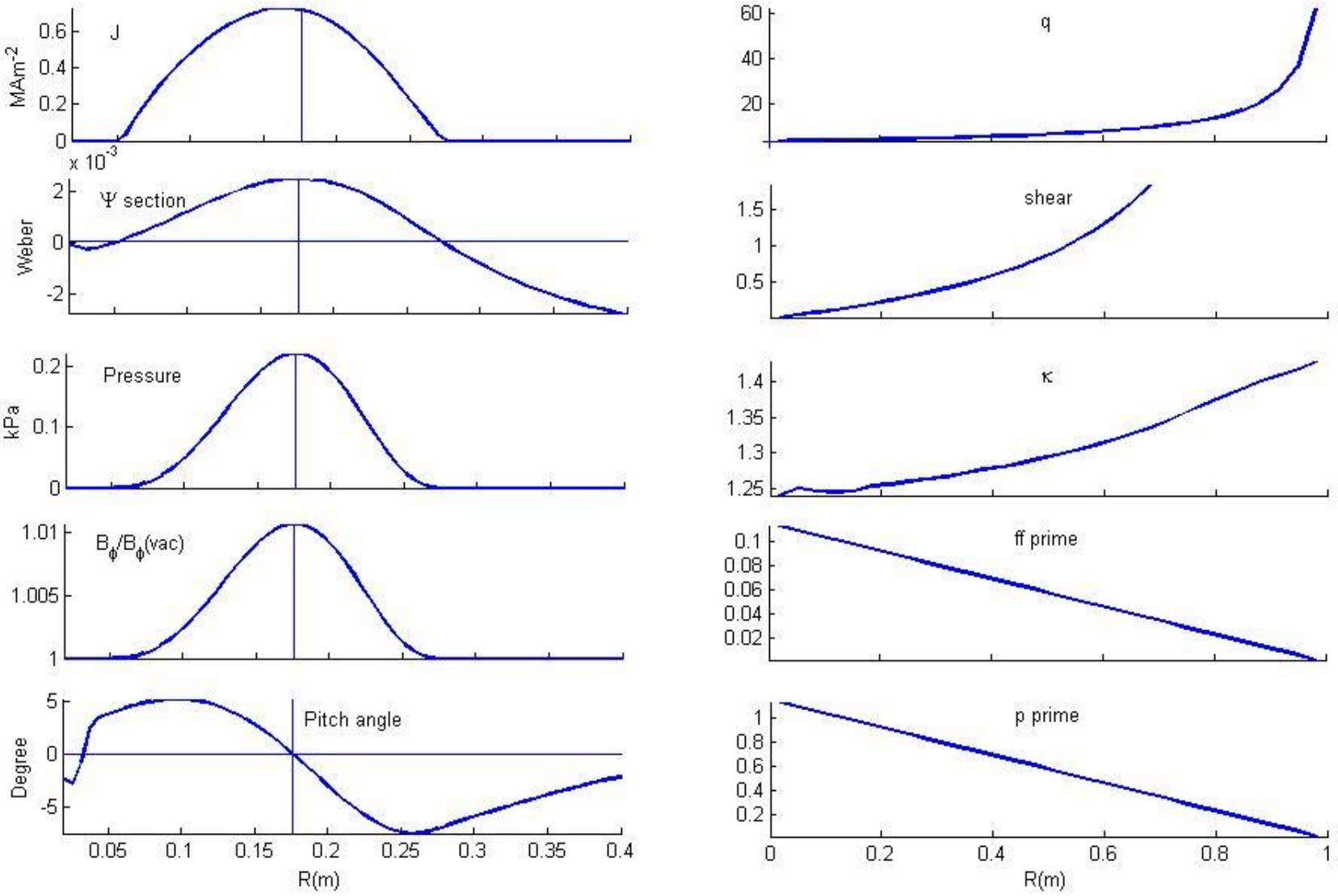
Simulations using FIESTA code

- FIESTA is a forward equilibrium solver developed by Geoffrey Cunningham from CCFE. The code was written in Matlab.

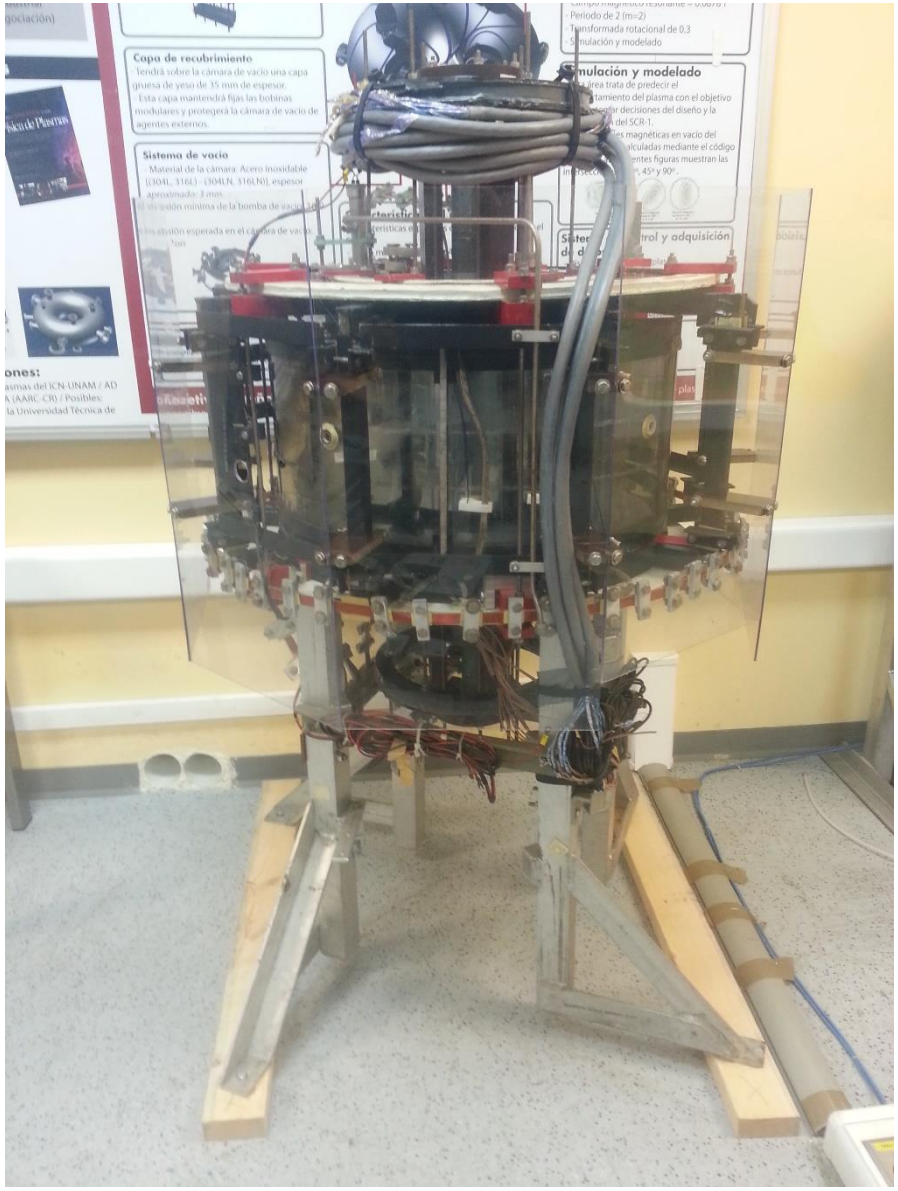
- The popular EFIT code is currently being installed locally for more precise/real simulations of Medusa-CR confinement behavior.

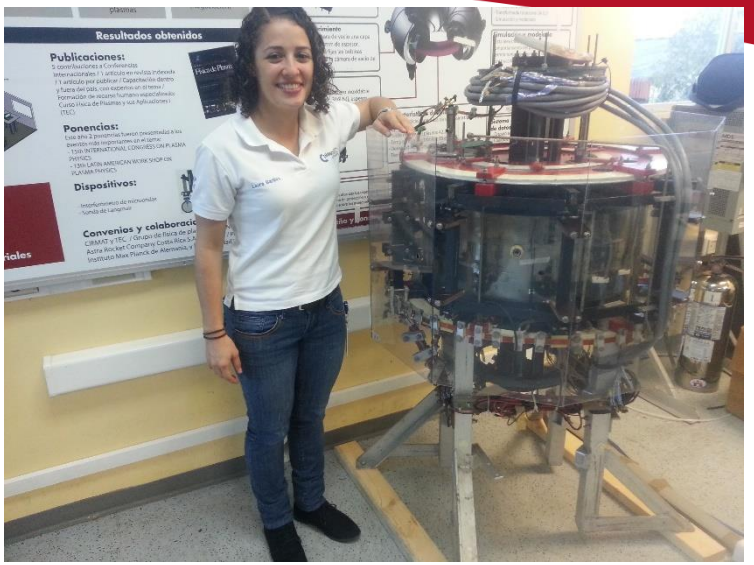


Simulations using FIESTA code



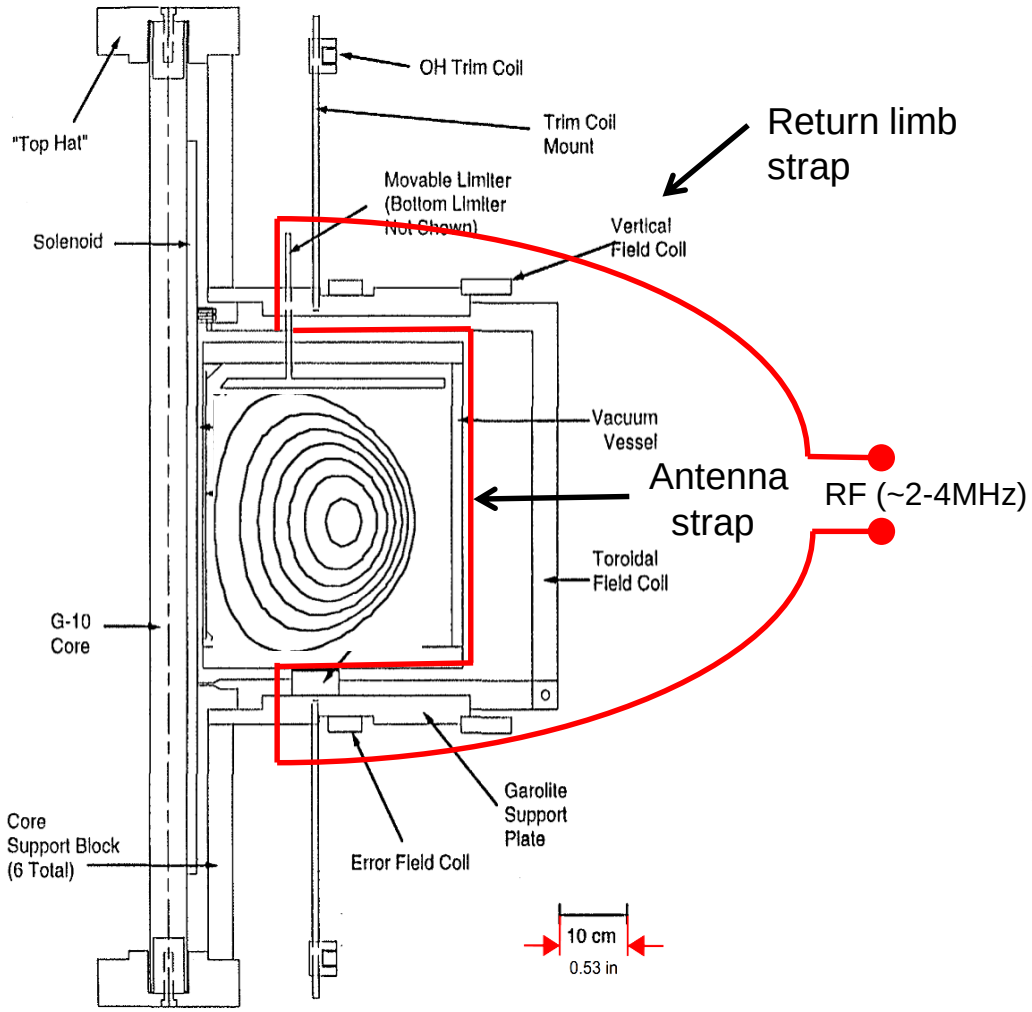
MEDUSA in Costa Rica





MEDUSA-CR (Dec 2014) as it is at Instituto Tecnológico de Costa Rica, Cartago, Costa Rica

3) Alfvén wave heating



No plasma shield is needed

We will adopt the folded antenna design with a return strap radius far from the plasma for optimizing the power deposition

Antenna positioned between two consecutive toroidal field coils

Use a single module external to the vessel

This unique scheme may clarify, once for all, whether sputtering and hydrogen release from the antenna/vessel play any role in the density rise observed in the previous experiments, where the antenna was an in-vessel system.

Preliminary design of the folded Alfvén Wave antenna coupled to MEDUSA-CR device

Publications and Conference Contributions MEDUSA-CR

CONFERENCE CONTRIBUTIONS

- J. Gonzalez, C. Ribeiro, J. Carvajal-Godínez, A. J. Balma, J. Mora, J.Asenjo, ***Control, Energy, Vacuum, Gas Fuelling and Safety Systems for the Spherical Tokamak MEDUSA-CR***, 15th Latin American Workshop on Plasma Physics (LAWPP), 27-31 January 2014, San José, Costa Rica.

- C. Ribeiro et al., ***Overview of the Spherical Tokamak MEDUSA-CR***, 15th Latin American Workshop on Plasma Physics (LAWPP), 27-31 January 2014, San José, Costa Rica, to be published at the American Institute of Physics (AIP), Conf. Proc.

- Ribeiro C., J. Gonzales, A. J. Balma, J. S. Arbustini, J. J. E. Herrera-Velazquez, E Chavez-Alarcon, ***Re-commissioning and Scientific Programme of the Spherical Tokamak MEDUSA-CR***, in 16th IAEA Technical Meeting on Research Using Small Fusion Devices (TM-RUSFD), San Jose, Costa Rica, 27-29 January 2014, to be published at the American Institute of Physics (AIP), Conf. Proc.

- Ribeiro C., J. J. E. Herrera, E. Chavez, ***Natural Divertor Spherical Tokamak Plasmas with Bean Shape and Ergodic Limiter***, 55rd American Physical Society Meeting, Plasma Physics Division, Denver, Colorado, US, 11-15 November 2013.

- J. Gonzalez, C. Ribeiro, et al., ***Energy, Vacuum, Gas Fuelling and Security Systems for the Spherical Tokamak MEDUSA-CR***, 55th Annual Meeting of the APS Division of Plasma Physics, November 11-15, Denver, Colorado, 2013.

- Ribeiro C., J. J. E. Herrera E. Chavez, and K. Tritz, ***Bean-shaped Spherical Tokamak Plasmas with an Ergodic Limiter***, 17th International Workshop on Spherical Torus (ISTWZO13), York, UK, 16-19 September, 2013.

- Ribeiro C., **V. I. Vargas**, J. J. E. Herrera, and Esteban Chaves, ***Equilibrium features of bean-shaped spherical tokamak plasmas with an ergodic limiter***, 25th Symposium on Fusion Engineering, San Francisco, 10-14 June 2013, DOI: 10.1109/SOFE.2013.6635429.

- Ribeiro C. et al., ***Re-commissioning the Spherical Tokamak MEDUSA in Costa Rica, Second Research Coordination Meeting of the Coordinated Research Project on Utilization of a Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research***, IAEA, Vienna, Austria, 19-23 March 2013.

- Ribeiro C. et al. ***The Spherical Tokamak MEDUSA for Costa Rica***, 54rd American Physical Society Meeting, Plasma Physics Division, Providence, Rhode Island, 29 October to 02 November 2012.

- J. Julio E. Herrera-Velazquez, Esteban Chéves Alarcén, and Celso Ribeiro, ***Use of the 3D-MAPTOR Code in the Study of Magnetic Surfaces Break-up due to External Non-Axisymmetric Coils***, 24th IAEA Fusion Energy Conference, TH-p2-28, San Diego, US, 8-12 October 2012.

PEER-REVIEWED ARTICLES

- Ribeiro C., J. J. E. Herrera, E. Chavez, ***Bean-Shaped Spherical Tokamak Equilibrium with Ergodic Limiter***, IEEE Transactions on Plasma Science, Vol. 42, Issue 3, Pages 585-589, 2014. **[En Scopus e ISI Thomson Reuters].**