Status of the PROTO-SPHERA Proposal

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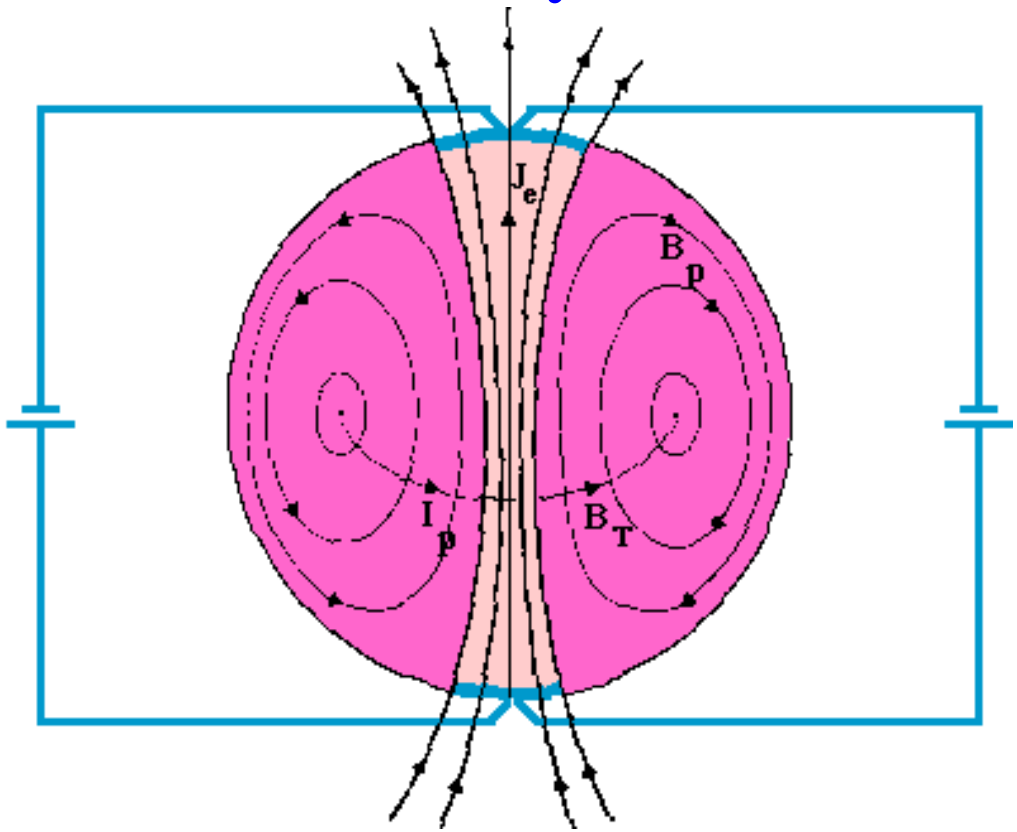
Outline of the Talk

1) **PROTO-SPHERA purpose & aims**
2) **PROTO-PINCH Experiment: results**
3) **Frascati Panel question & answer**
4) **Multi-Pinch Experiment**
5) **Conclusions**

Purpose

PROTO-SPHERA

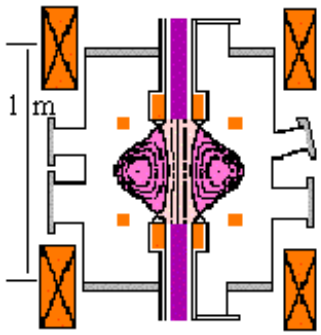
(Spherical Plasma for Helicity Relaxation Assessment)



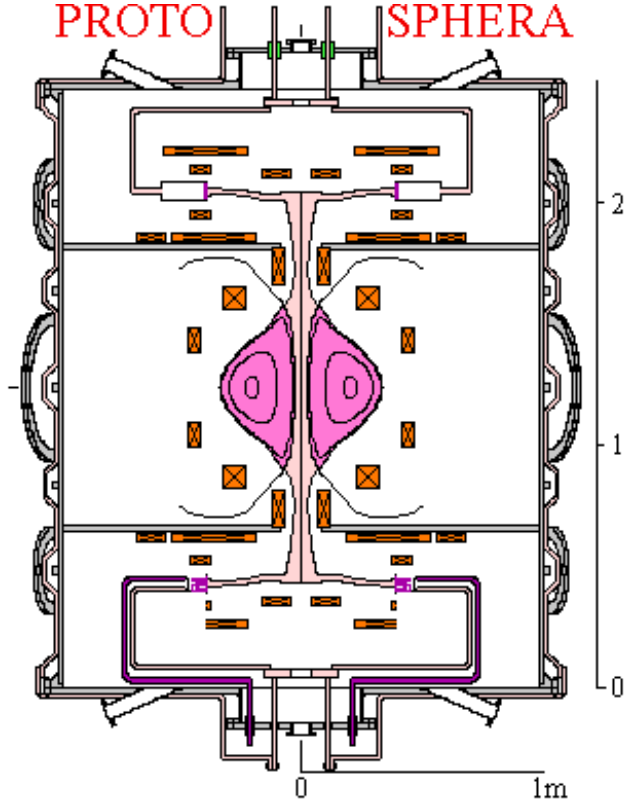
Aims at producing a spherical torus (ST)
with a screw pinch (SP) replacing the centerpost

Physics Design

TS-3



PROTO SPHERA

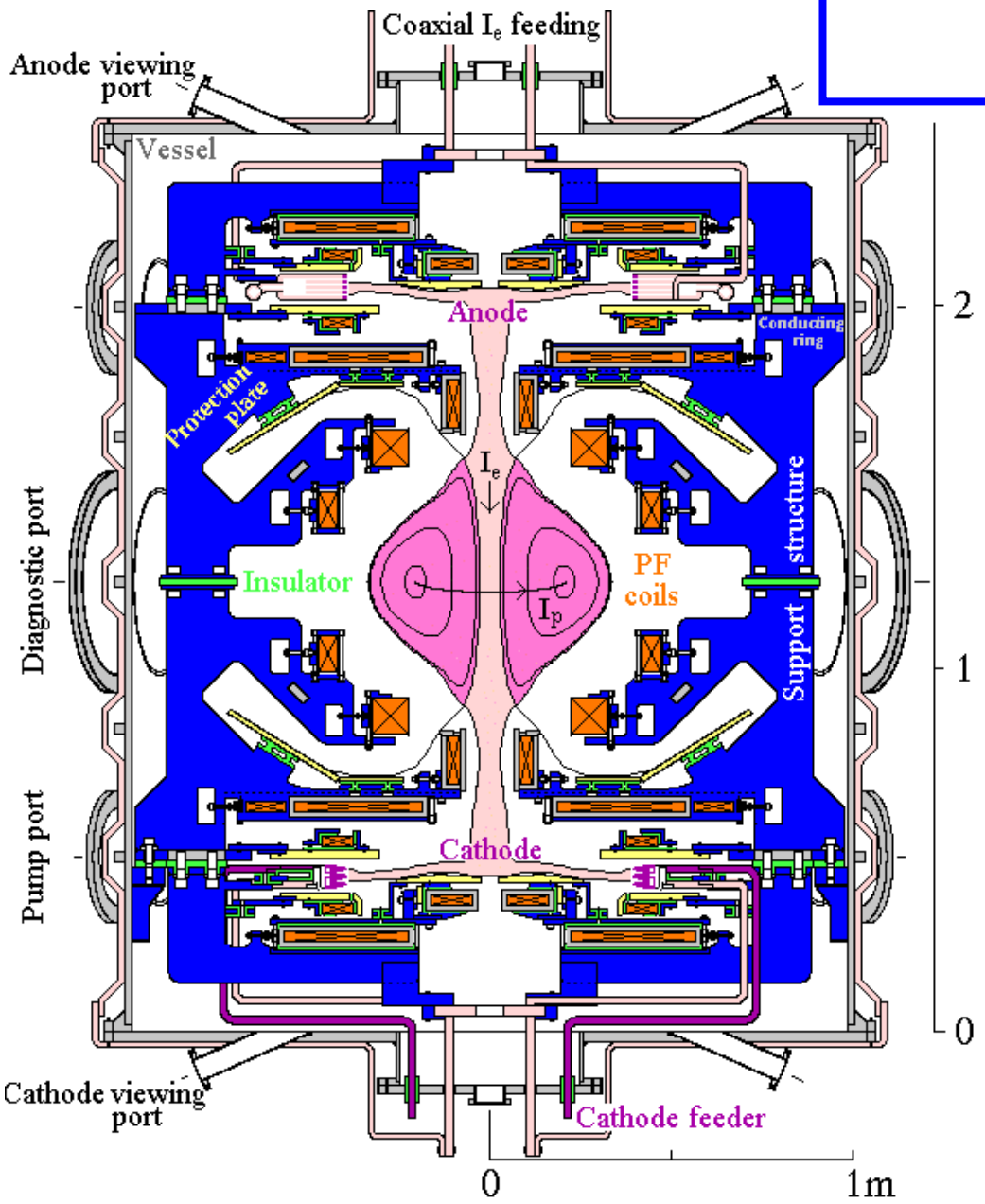


$I_e, I_p = 40, 50$ kA	pinch, ST currents	$I_e, I_p = 60, 240$ kA
$A = 1.6$	aspect ratio	$A \leq 1.3$
$\tau_{pulse} = 80\ \mu s \sim 110\ \tau_A$	pulse duration	$\tau_{pulse} \geq 70$ ms$\sim 1\ \tau_R$

PROTO-SPHERA aims at sustaining the plasma for more than

$\tau_R = \mu_0 a^2/\eta$ (resistive time)

Physics & Engineering Design



ST diameter =0.7m

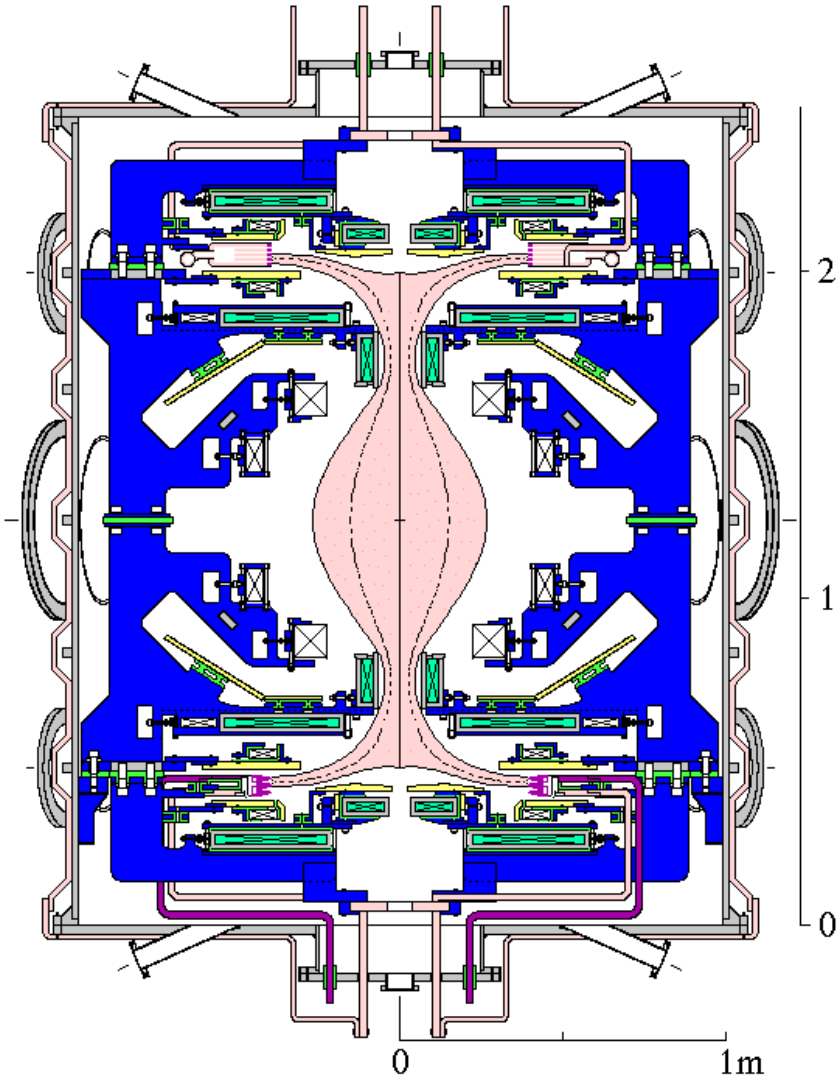
Toroidal plasma current I_p=240kA

Aspect ratio A=1.2, Elongation κ=2.35

Pinch current I_e=60 kA

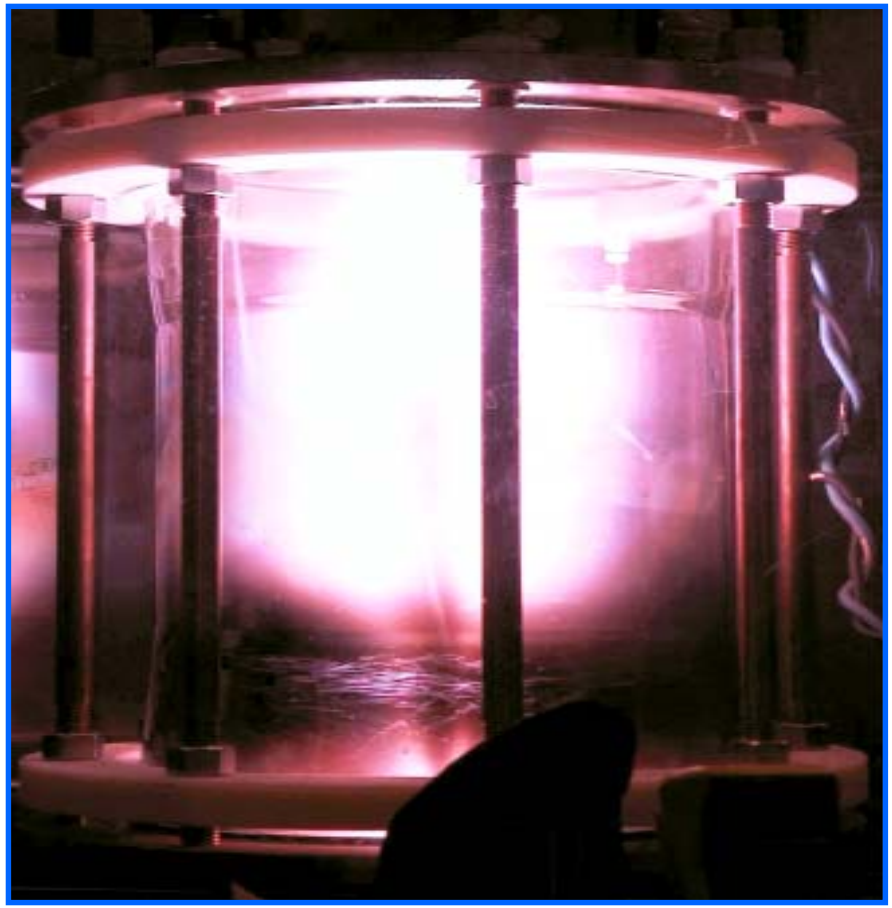
Engineering design complete (geometry, stresses and temperatures)

Main Breakdown features



- Screw pinch (SP) formed by a hot cathode breakdown
- Filling pressure $p_H \sim 10^{-3} \div 10^{-2}$ mbar
- Cathode filaments heated to 2600 °C
- $V_e \sim 100$ V applied on the anode
- Electrode arc current limited to $I_e \sim 8.5$ kA

PROTO-PINCH Testbench



- Test of **PROTO-SPHERA Cathode& Anode**
- Arc **breakdown** in configuration similar to ProtoSphera

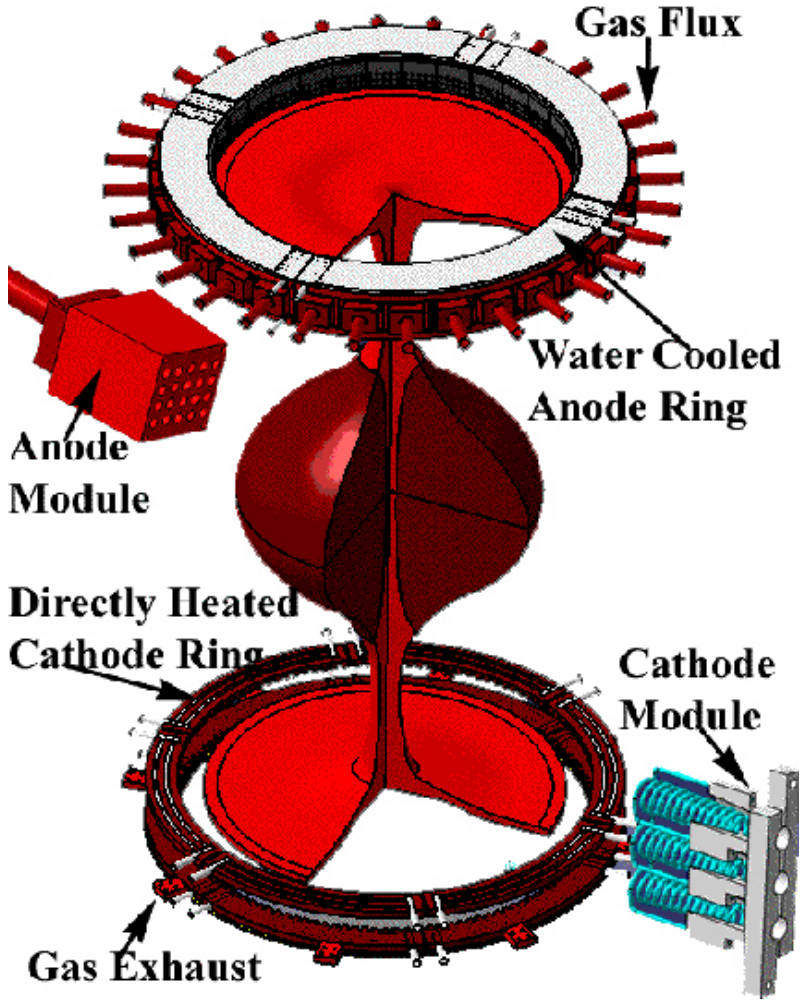
PROTO-PINCH Results

- Arc **breakdown** V= 80-120 V
- Stable arc $I_e \leq 1$ kA
- Capability to fulfill **PROTO-SPHERA** requirements:

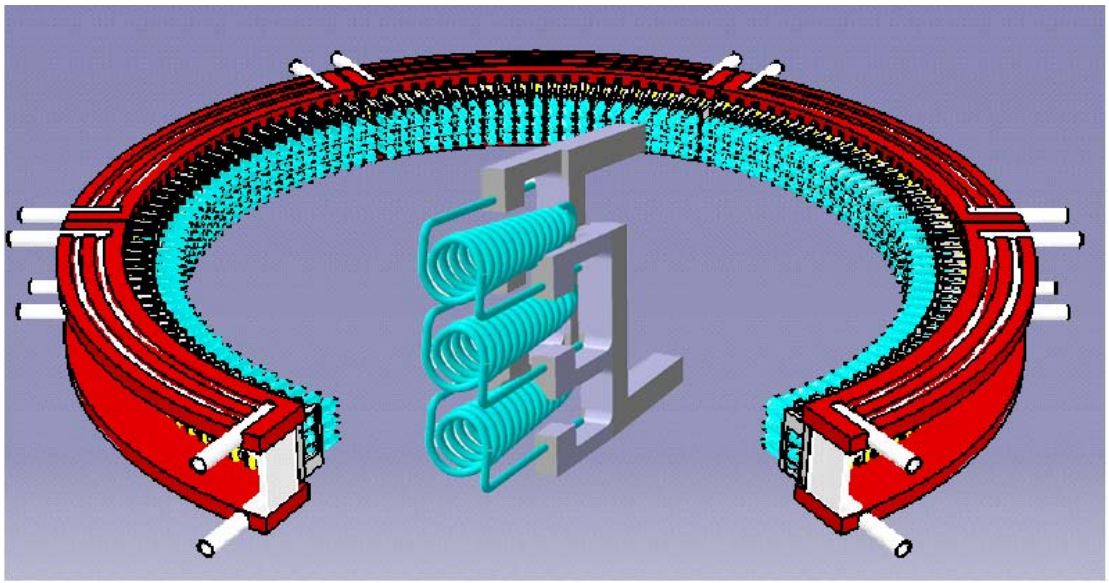
Arc Current, up to 60 kA

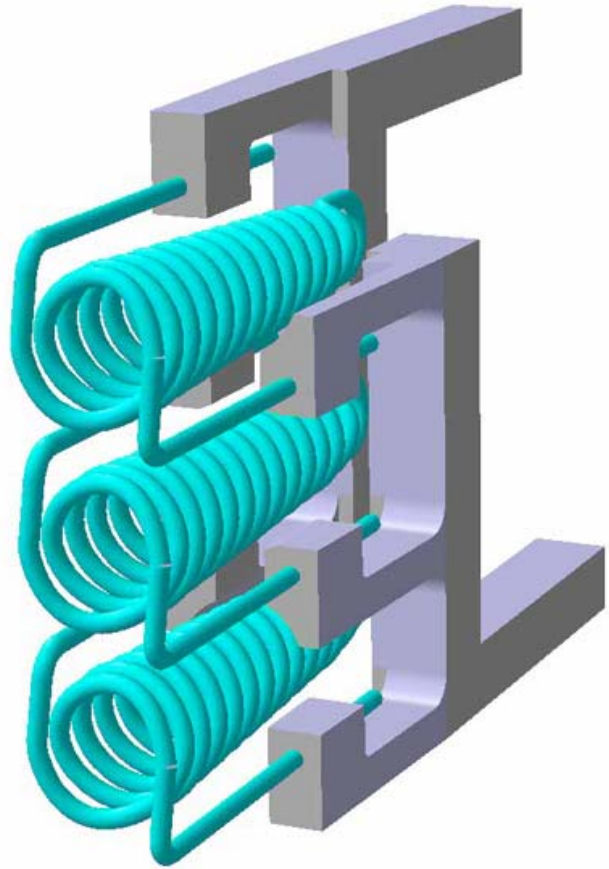
Electron Emissivity (1 MA/m^2)

Arc Power handling capability up to 9.0 MW



Cathode – Extrapolation to PROTO-SPHERA



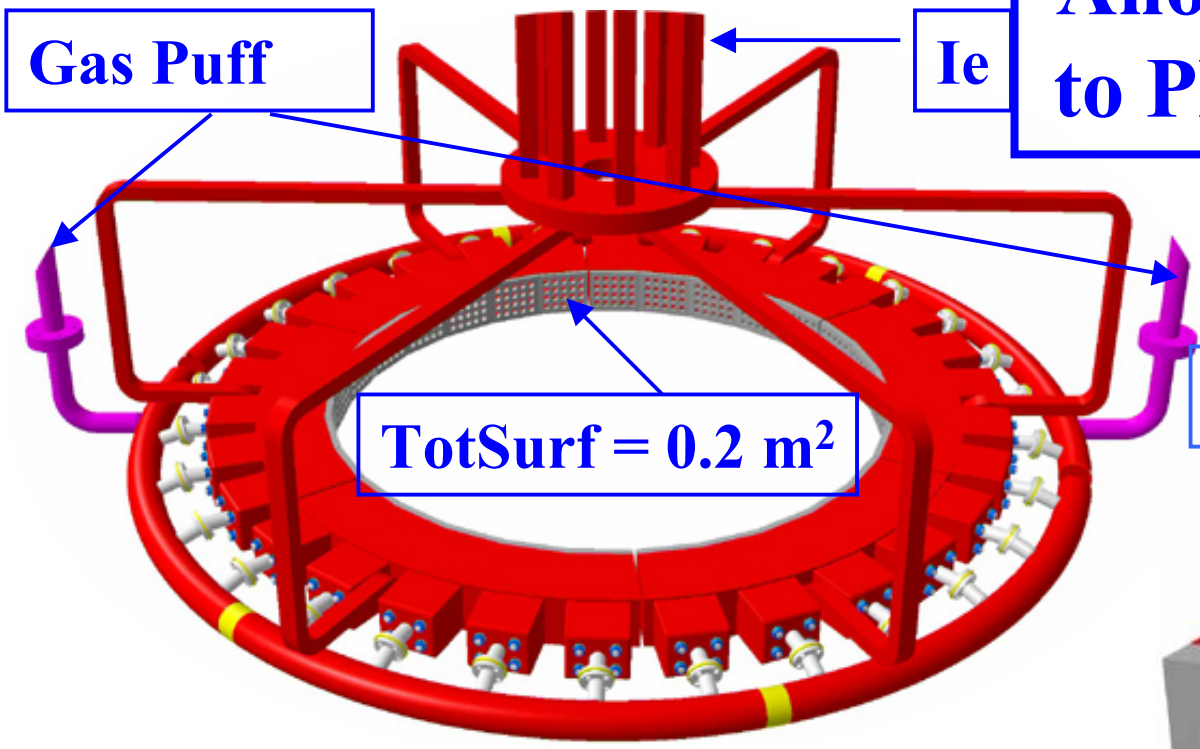


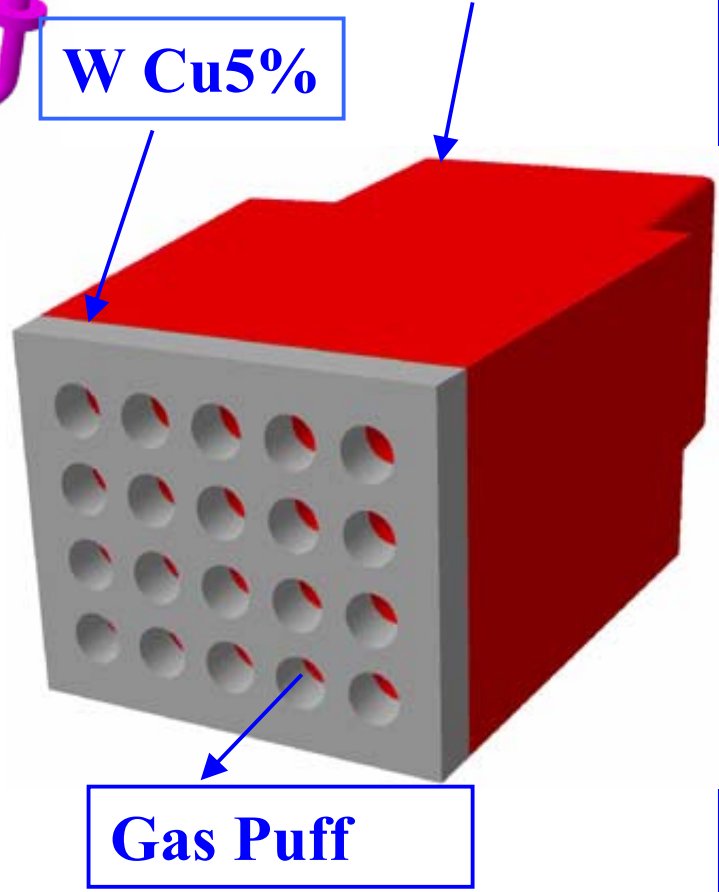
Cathode Emissivity

- Coil Material : **Pure W**
- Wire **Diameter = 2 mm**
- **Total Coils Number = 378**
- **Single Coil emission = 167 A**
- Tot126 **module** 3 x 167.5 A ≈ **63 KA**
- Current Density ≈ **1 MA/m²**

Conical Wire
Terminal & Clamp

Anode Extrapolation to PROTO-SPHERA





Anode Power Handling Capability:

$PROTO\text{-}SPHERA_{Tested}$ = 9 MW

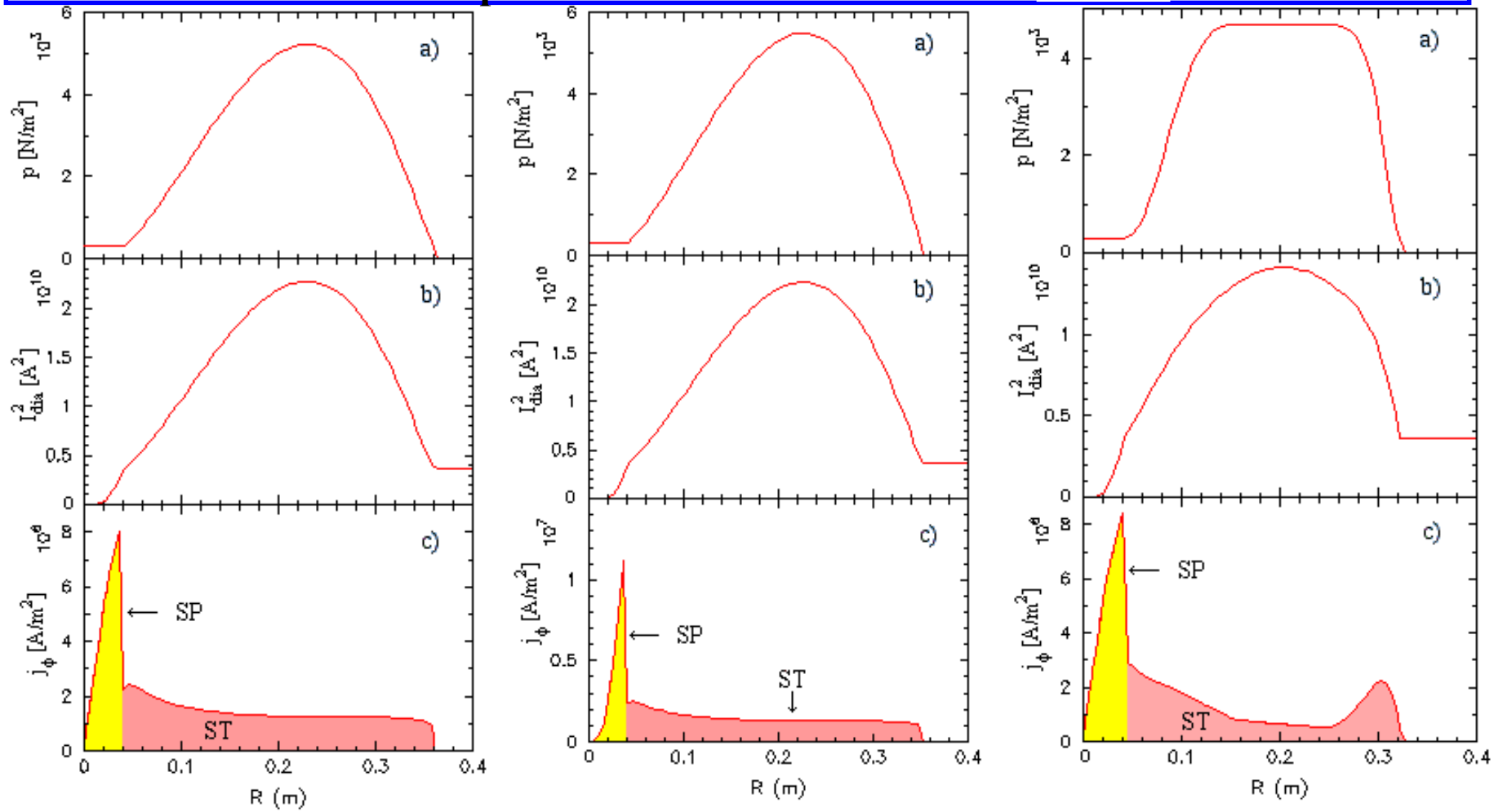
$PROTO\text{-}SPHERA_{Max}$ = 6.0 MW

Panel Questions & Answers

Results of the PROTO-SPHERA Panel held in Frascati on March 2002

- Interesting Concept Exploration Experiment, adeguate size & useful contribution to magnetic fusion programs.
- Is the physics basis for undertaking an experiment as proposed with PROTO-SPHERA adeguate?
  YES, BUT We recommend that a wider range of operation scenarios of μ and pressure profiles be analysed... (equilibria & stability, including n=0)
- Are the PROTO-PINCH electrode experiments a sufficient technical basis for a reliable electrode operation in PROTO-SPHERA?
  YES, BUT… are not yet adequate for reliable multi-electrode operation...

Equilibria: I_p=180 kA, I_e= 60 kA, β_p^{ST} = 0.22



Reference Equilibrium $I^2_{SP} \propto \psi^2$ $P_{ST} \propto I^2_{ST} \propto \psi^{1.1}$

$I^2_{SP} \propto \psi^\alpha$ $P_{ST} \propto I^2_{ST} \propto \psi^{1.1}$ α=3.0

h=0.9 and ε=0.5

All Equilibria has been obtained with the same coils set

PROTO-SPHERA Stability Results

- n=1,2,3 investigated for all equilibria
- Main constraint I_{ST}/I_e ,

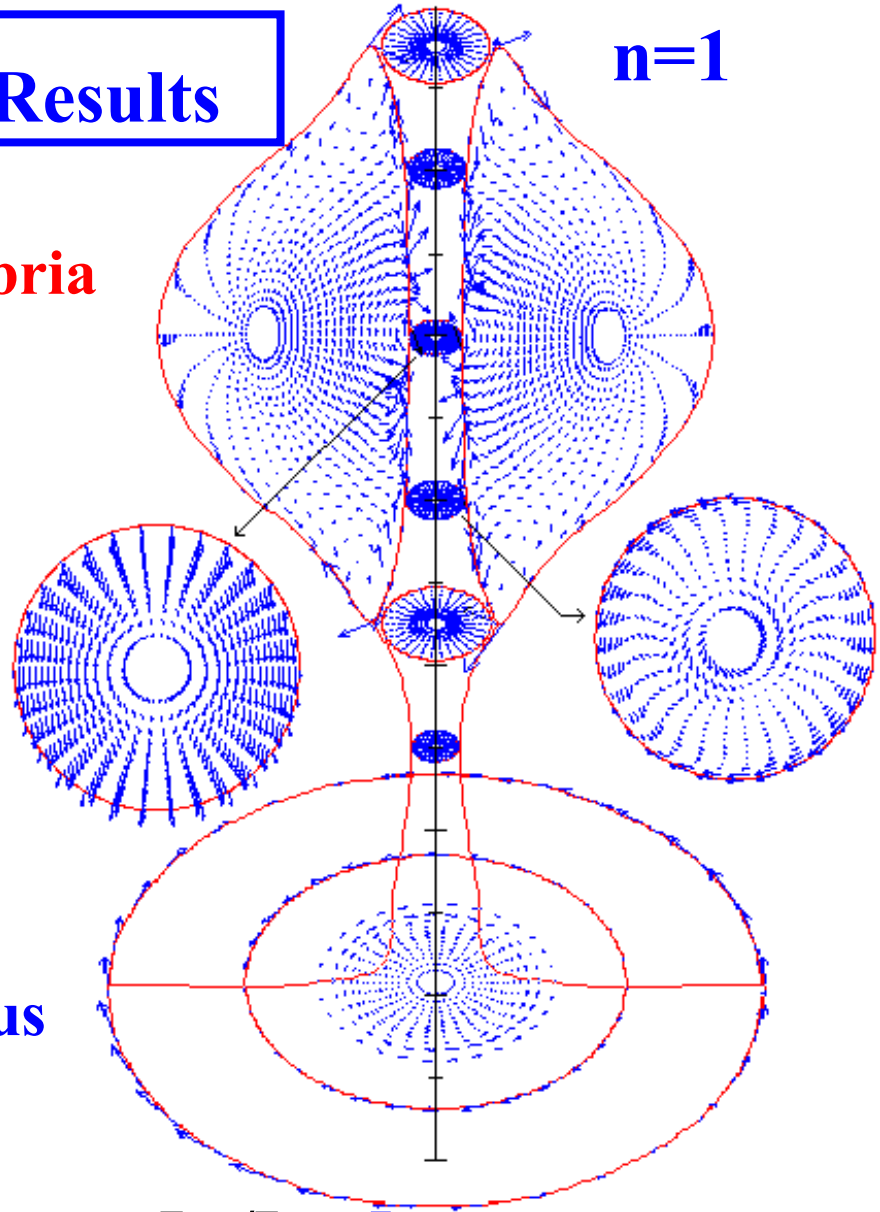
- $\beta = 21 \div 26\%$, $I_{ST}/I_e = 0.5 - 1$
- $\beta = 14 \div 15\%$, $I_{ST}/I_e = 4$

With $\beta_{T0} = 2\mu_0 \langle p \rangle_{vol} / \langle B_{T0}^2 \rangle_{vol}$

- $\beta_{T0} = 28 \div 29\%$, $I_{ST}/I_e = 0.5 - 1$
- $\beta_{T0} = 72 \div 84\%$, $I_{ST}/I_e = 4$

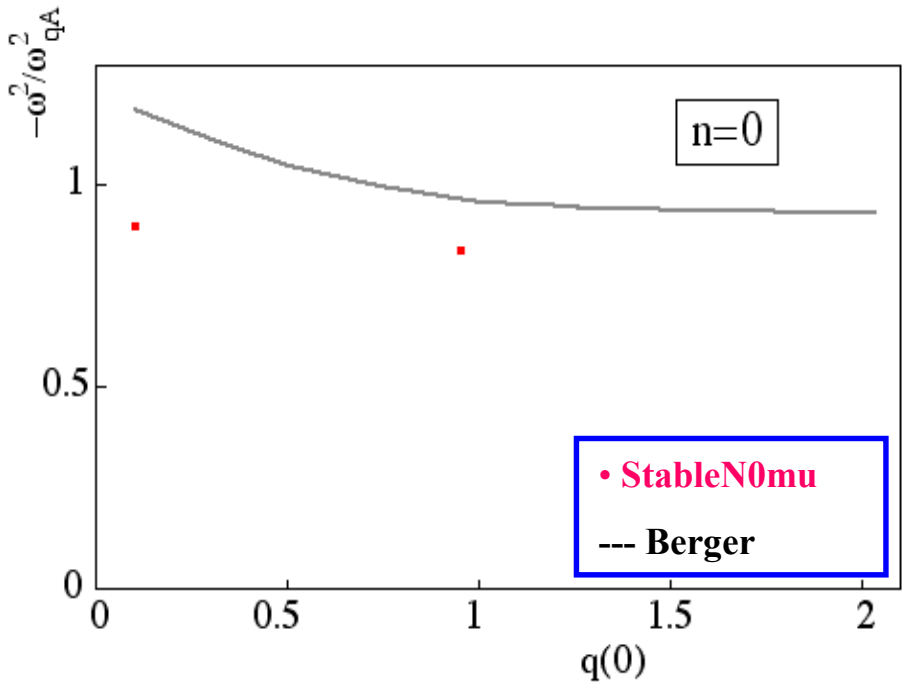
The dominant instabilities are :

- up to $I_{ST}/I_e \approx 3$ The Spherical Torus instabilities
- $I_{ST}/I_e > 3$ the Screw Pinch kink instabilities

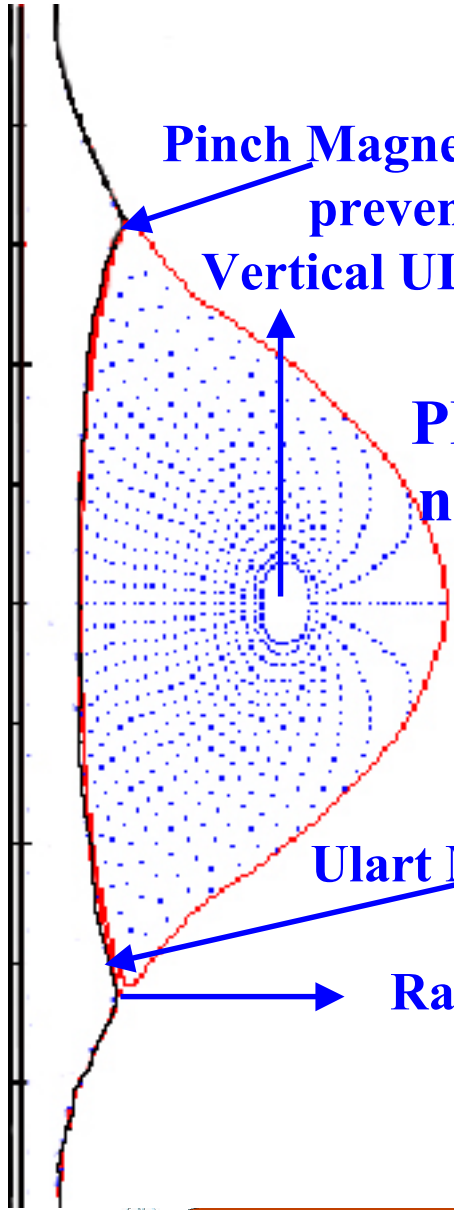


$I_{ST}/I_e = 5$ and $\beta \approx 15\%$
Unstable

Results STABLEN0mu Code: n=0



Comparison of the instabilities growth rate for free boundary codes
Mode numbers n=0, m=[-15,+15].

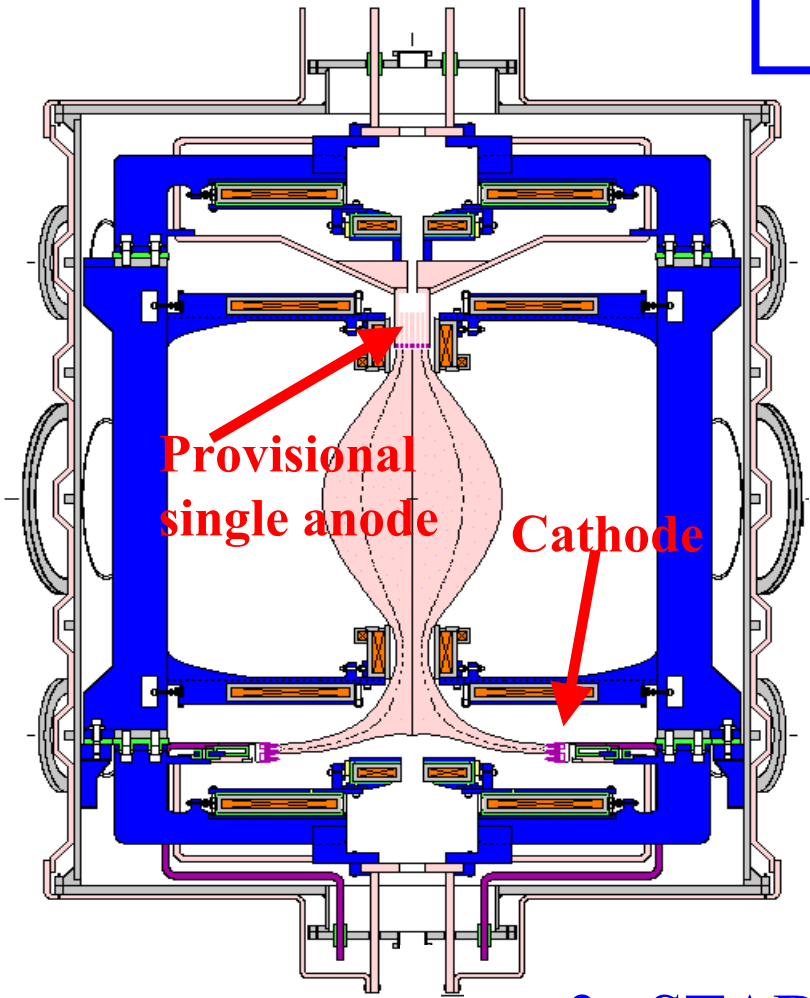


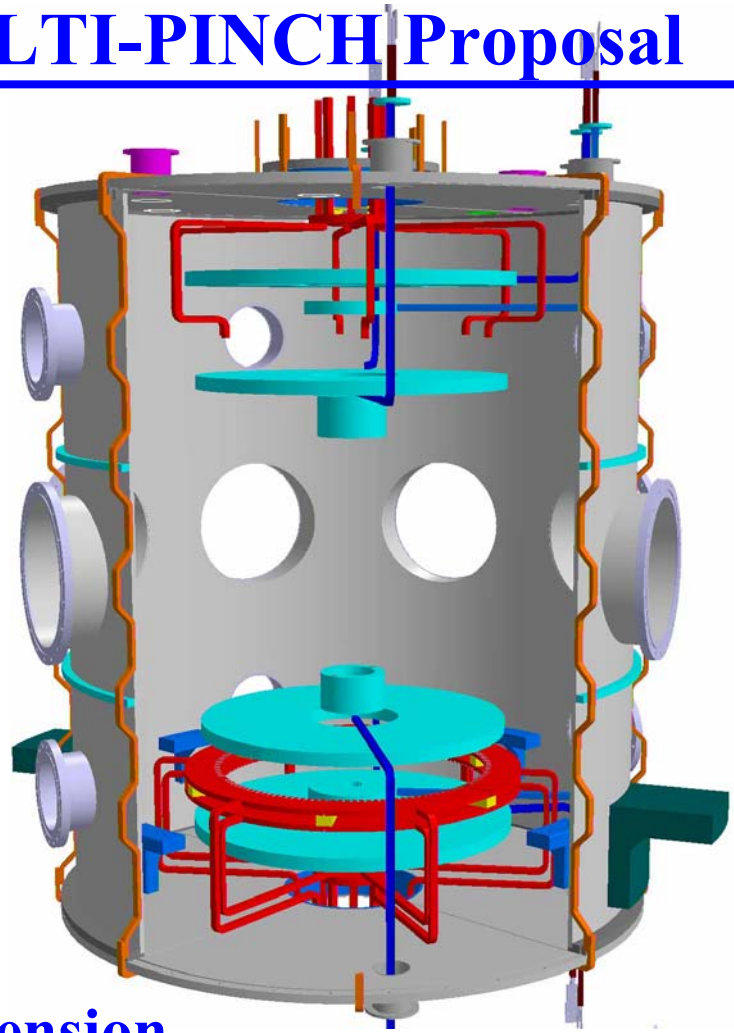
Pinch Magnetic Structure prevents n=0 Vertical ULART Drift

PROTO-SPHERA n=0 stable for any scenarios up to R/a = 1.2 κ < 4

Ulart Magnetic Structure prevents Radial Pinch Drift

MULTI-PINCH Proposal



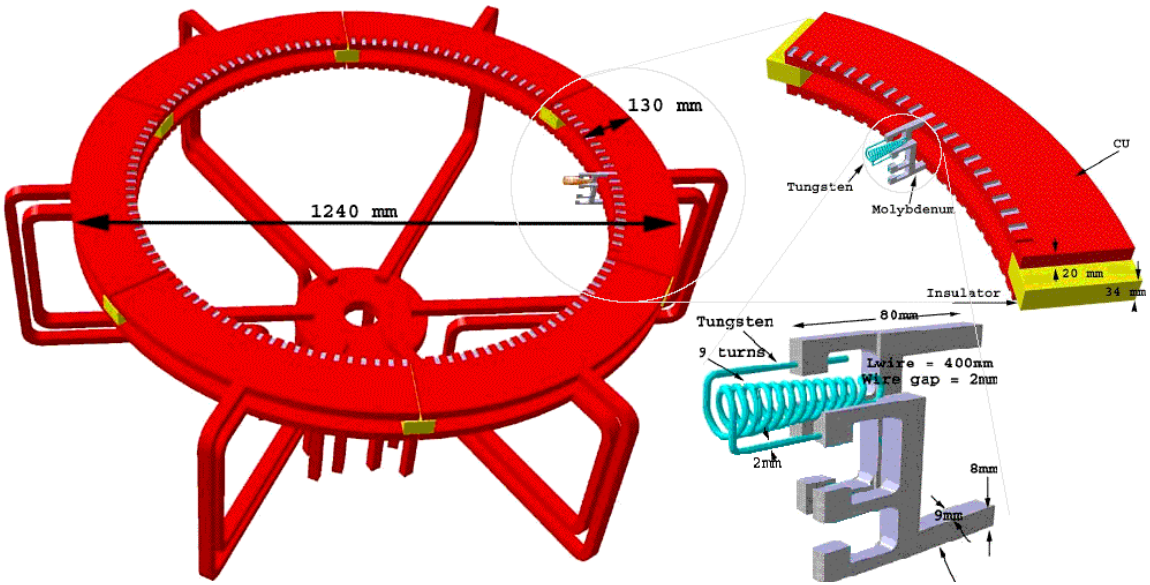


- ~ START Dimension.

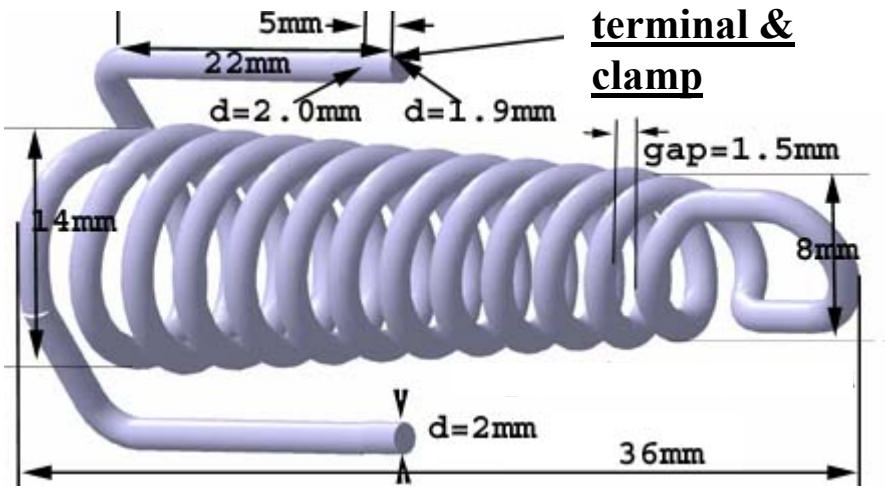
- Provisional simplified PF coils system with constant current:
Fed with 600 A, 120 V (recycled) vs. 1.9 kA, 350 V.

- Does not need cooling.

Multi-Pinch Cathode



Wire Length = 400 mm



Conical terminal & clamp

- The multi-pinch test is proposed with a limited number of cathode coils (18 vs. 378)
- Coils will drive a total limited current (2.7 kA vs. 60 kA) inside the pinch, simplifying the power supply for the multi-pinch.
- Each coil will be capable of delivering the design current (150 A).

Conclusions

Answers to the Questions raised by Panel:

- **...We recommend that a wider range of operation scenarios of μ and pressure profiles...**
- **An exhaustive range of scenarios with several μ and pressure profiles, equilibria & stability, has been investigated**
- **The PROTO-PINCH electrode experiments provide sufficient technical basis for designing the electrodes themselves in PROTO-SPHERA, but are not yet adequate for reliable multi-electrode operation**
- **The answer is the proposed MULTI-PINCH Experiment**
- **Depending on boundary conditions,**
  we plan to start the MULTI-PINCH experiment next year