Spherical Torus with a Plasma Center Column (ST-PCC)

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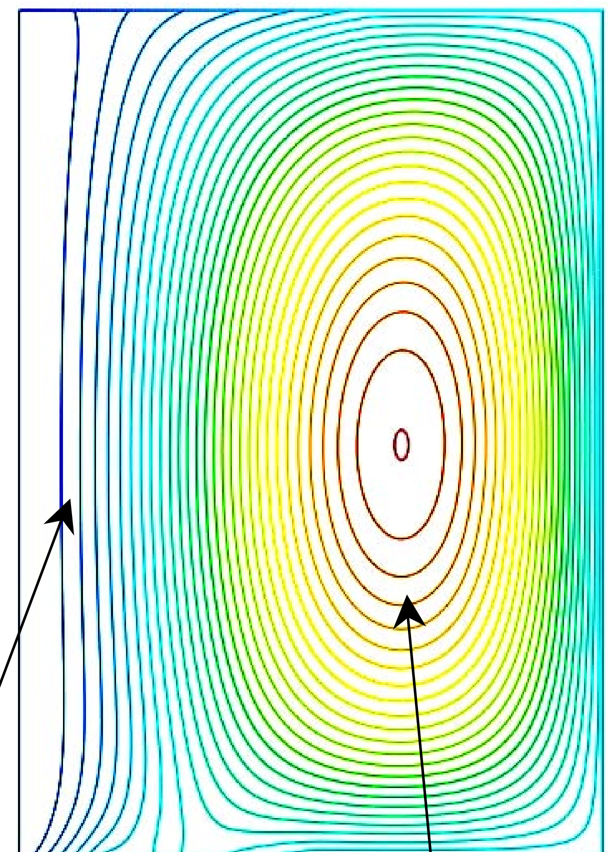
Self-organization could potentially give us a relaxed ST-PCC

Requirement	Design parameter
$\langle q \rangle > 1$	Elongation $e > 2$
Low aspect ratio (1.5–2)	Flux amplification (1–2.5)
Stability	$\lambda_{ST\text{-}PCC} < \lambda^{(n=1)}$ and $e < 3$

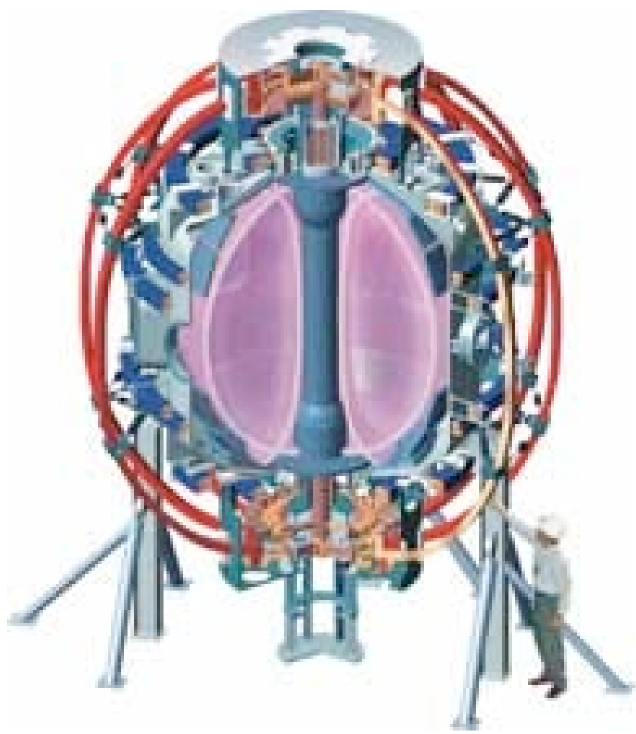
Relaxed ST-PCC:



Outline

- Why ST-PCC?
- Equilibrium/stability sets ST-PCC design space
- A possible Concept Exploration (CE) experiment

Spherical Torus (ST) has advantages and disadvantages as a fusion reactor



Advantages:

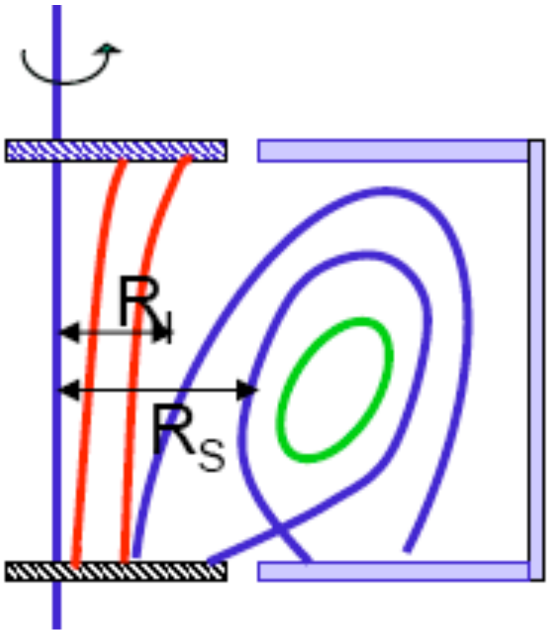
- Low aspect ratio → higher maximum stable $\langle\beta\rangle$
- Good natural elongation
- High bootstrap fraction

A weakness of ST concept:

- Space-constrained center column:
  - Carry inboard TF current
  - Prefer solenoid-free startup
  - Neutron-shielding needed in reactor
  - Center post maintenance/repair costly

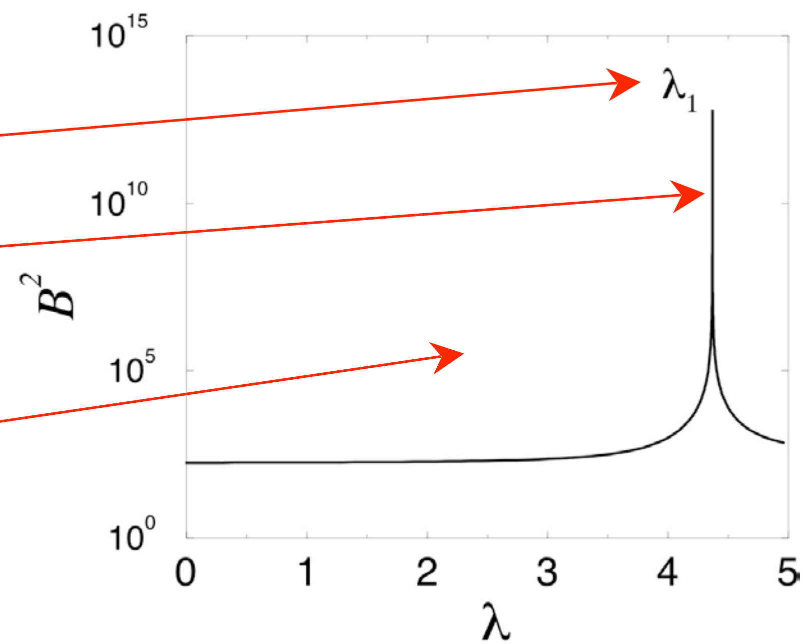
Plasma center column (PCC) confers many advantages to ST concept

- Eliminates material center post
- Efficient non-inductive formation scenario
- PCC carries inboard TF current
- (Hand off to rf/NBI for sustainment)



Taylor state provides baseline example for studying ST-PCC equilibrium & stability

- Axisymmetric, simply-connected, Taylor-relaxed: $\mathbf{B} = -\lambda\chi\nabla\phi + \nabla\phi \times \nabla\chi$
- Force-free Grad-Shafranov: $\Delta^*\chi + \lambda^2\chi = 0$, $\chi|_{\delta\Omega} = \chi_0$
- C-K mode bases: $\chi = \chi_v + \Sigma_i\alpha_i\chi_i$, $\chi_i|_{\delta\Omega} = 0$
- Solution: $\alpha_i = \lambda^2\langle\chi_v\chi_i\rangle/(\lambda_i^2 - \lambda^2)$
- Linear resonances at λ_i
- Classical Rosenbluth-Bussac (flipped) spheromak at λ_1
- Flux-core spheromak & ST-PCC exist below λ_1



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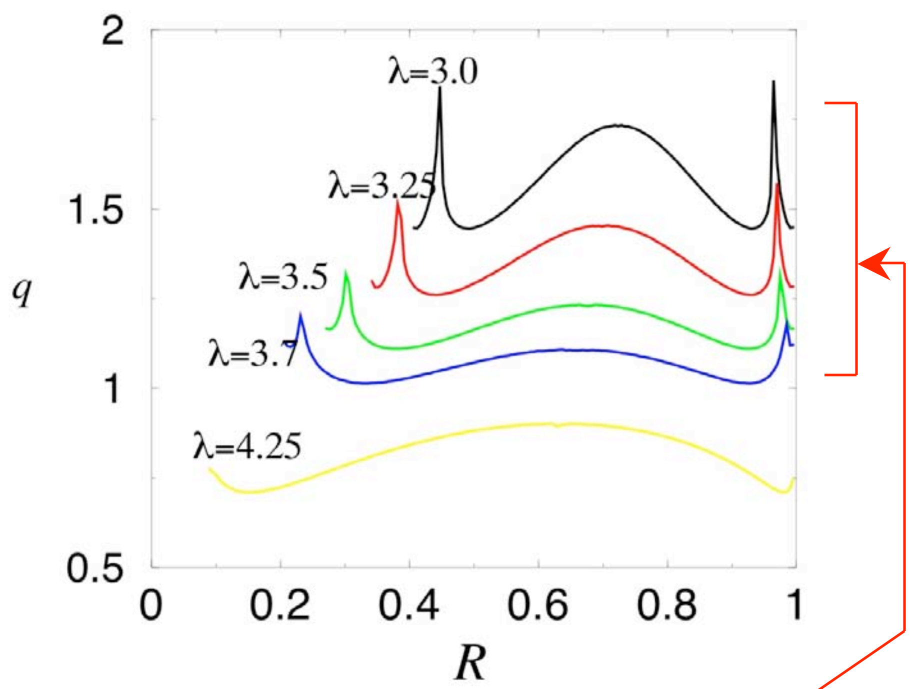
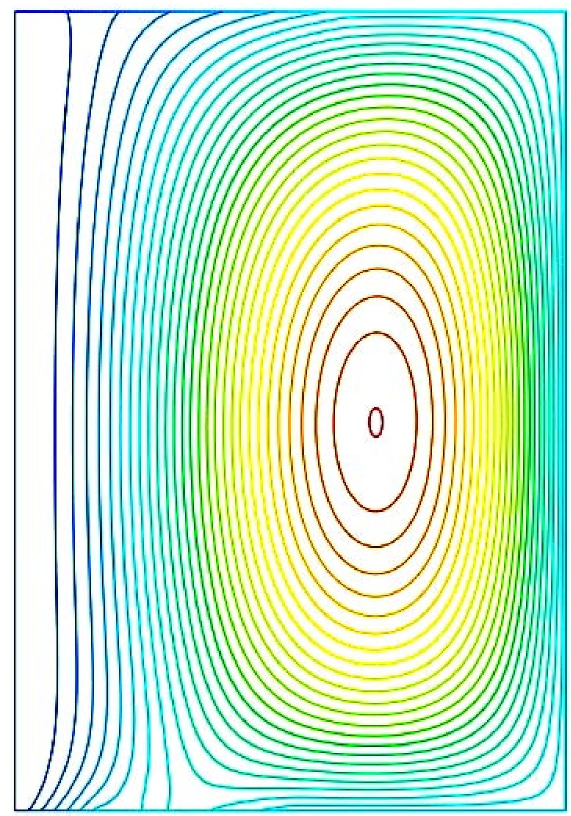
Tang & Boozer, PRL **94**, 225004 (2005).

Relaxed ST-PCC equilibria with *q* > 1 exist below first linear resonance



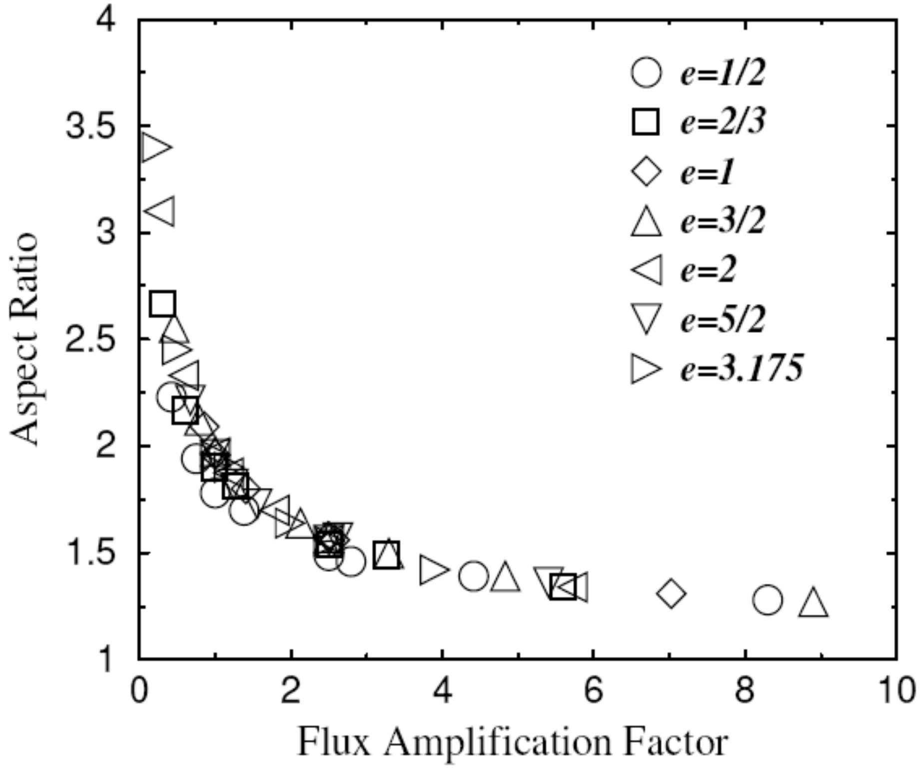
ST-PCC



Poloidal flux contours for λ=3.7;

B_{tor} produced by PCC current

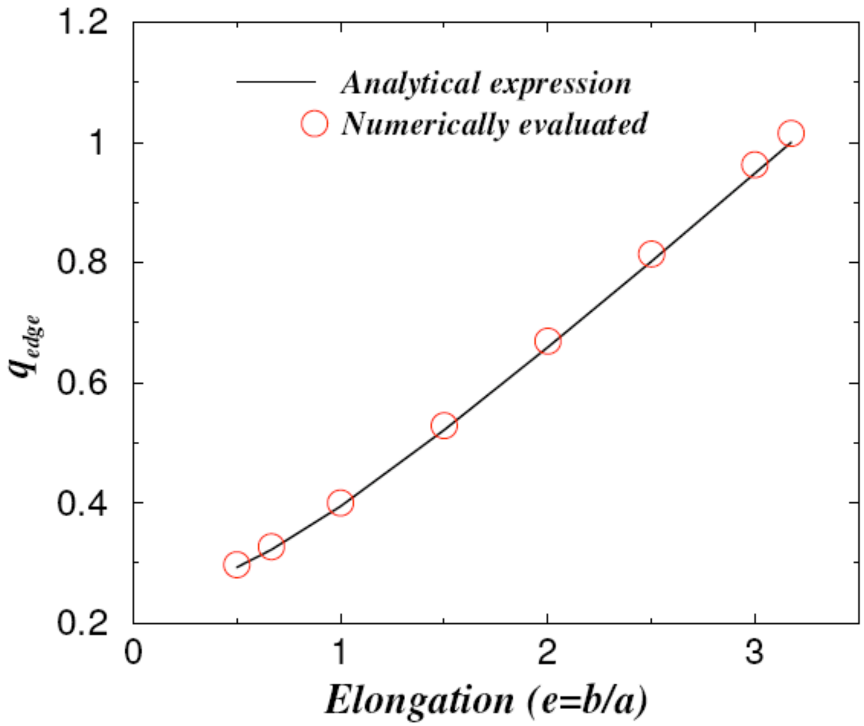
Flux amplification factor determines aspect ratio

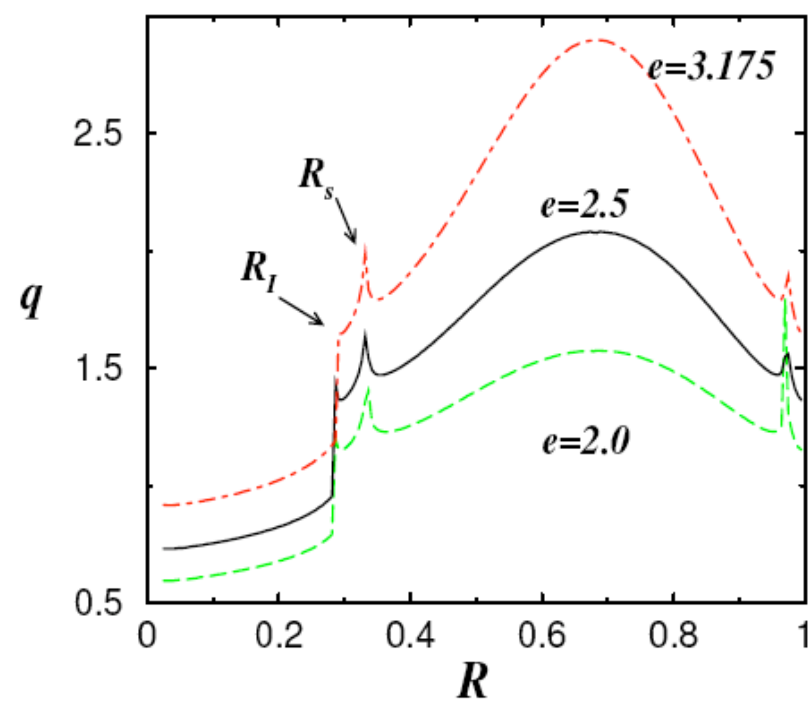


Aspect ratio of 1.5–2 achieved with flux amplification factor of 1–2.5

Tang & Boozer, submitted to PoP (2005).

Plasma elongation determines q profile

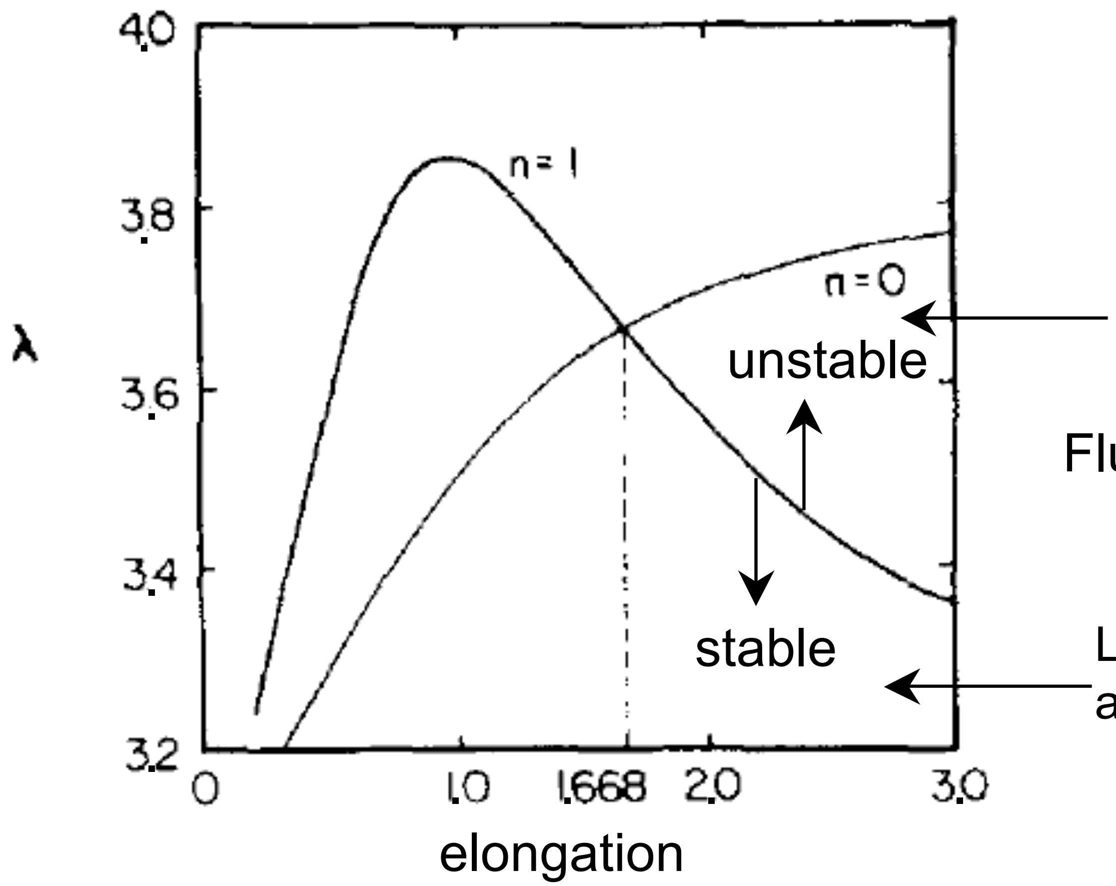




$\langle q \rangle$ > 1 for elongation > 2

Tang & Boozer, submitted to PoP (2005).

Ideal MHD stability of relaxed ST-PCC determined by chamber geometry



Flux amp. ~ $[\lambda_{(n=0)}^2 - \lambda^2]^{-1}$

Calculations from Bondeson et al. (1981)

Also Finn et al. (1981)

A narrow but promising window exists for ST-PCC

Requirement for ST-PCC	Impact on design
$\langle q \rangle > 1$	Need high elongation $e > 2$
Low aspect ratio 1.5–2	Flux amplification factor 1–2.5
TF field from PCC	High PCC current
Ideal MHD stability	$e < 3$, $\lambda_{ST\text{-}PCC} < \lambda^{(n=1)}$
Efficiency	High flux amplification (+subtle role of bias flux)

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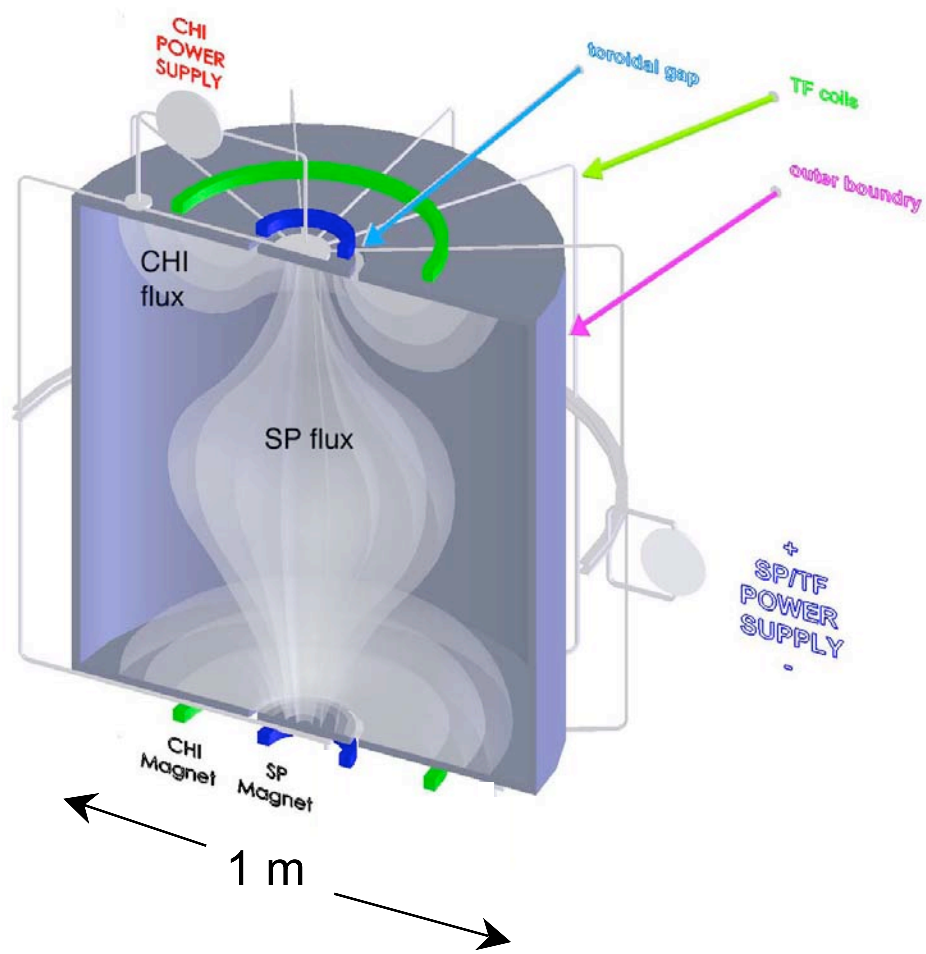
ST-PCC could be formed via driven relaxation of a screw pinch plasma & CHI

- 2 electrode sets (PCC, CHI)
- Bias vacuum flux
- Outer TF windings connect to PCC
- Drive kink instability of PCC and/or CHI flux to relax
- Then bring PCC current below kink threshold for TF



Research and technical objectives of a CE experiment

- Form ST-PCC via driven relaxation of PCC
- Experimentally characterize equilibrium/stability
  - Finite β, partially relaxed
  - Resistive modes
- PCC/TF electrodes must sustain large current
- PCC power handling, dissipation
- Ideas for how to scale-up to reactor

Synergy with other ICC efforts
(e.g., SSPX, HIT, Caltech, SSX, TCS)

Comparison with Italian ProtoSphera effort

	ProtoSphera	ST-PCC
Class/size	Proof of principle (old START chamber)	Concept exploration
Electrodes	Emissive (reactor relevant)	Non-emissive arc discharge (test physics)
Equilibrium	Less relaxed	More relaxed
Formation	Kink, induction (PF swing) and compression (to raise *q*)	Driven relaxation of PCC + CHI
Initial sustainment	Ohmic and helicity injection	CHI

Summary

- ST-PCC confers many advantages to ST reactor concept
- Used Taylor relaxed plasmas to explore ST-PCC equilibria/stability:
  - Flux amplification factor 1–2.5
  - Aspect ratio 1.5–2
  - Elongation > 2 for $\langle q \rangle_{separatrix} > 1$
  - $\lambda < \lambda_1^{(n=1)}$ and $e < 3$ for ideal MHD stability
- CE experiment
  - Test ST-PCC formation via driven relaxation of screw pinch
  - Physics of partially relaxed driven plasmas