QUEST計画への提案：高温超電導負三角度トカマクの提案

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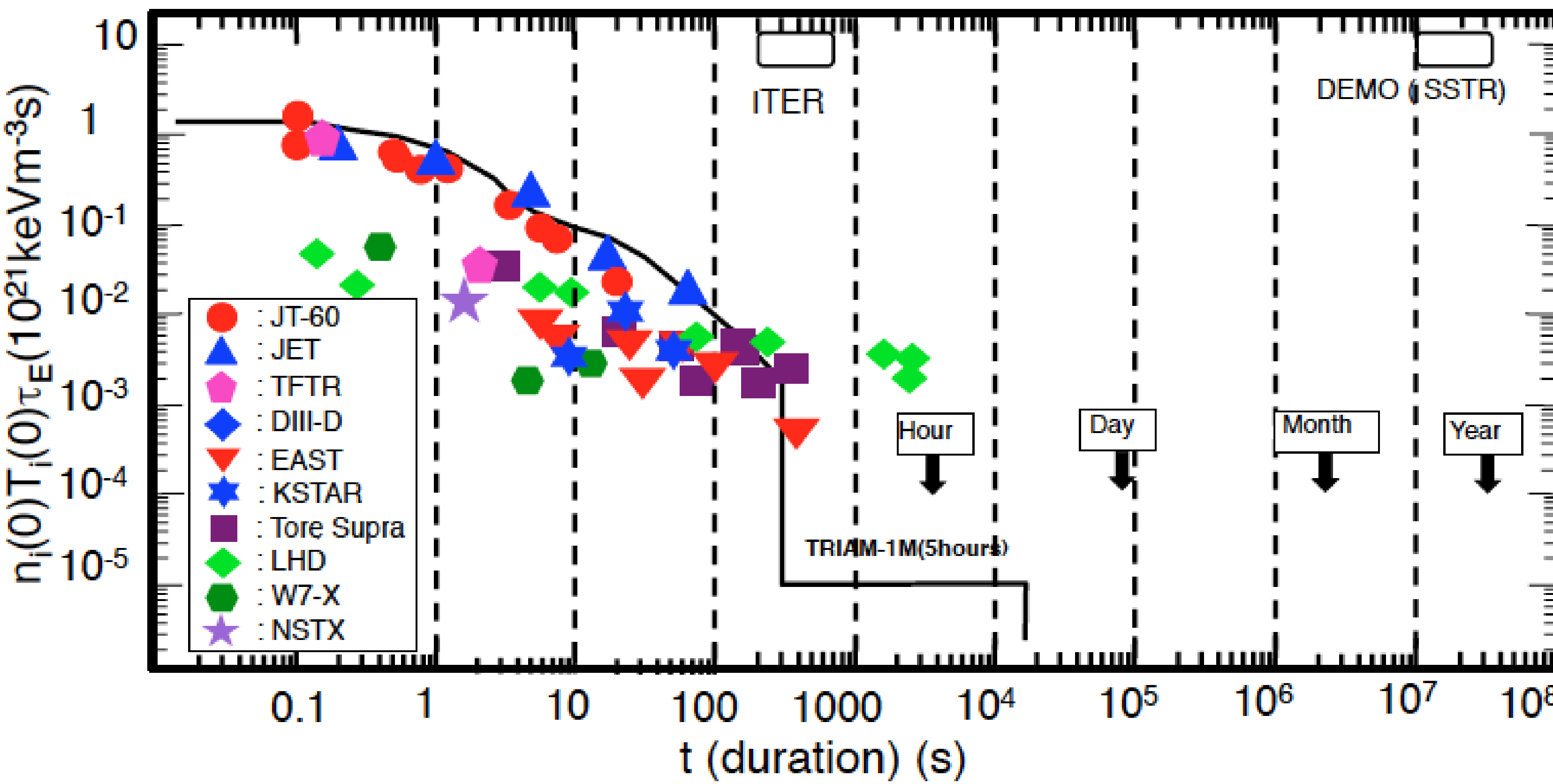
量研　菊池　満

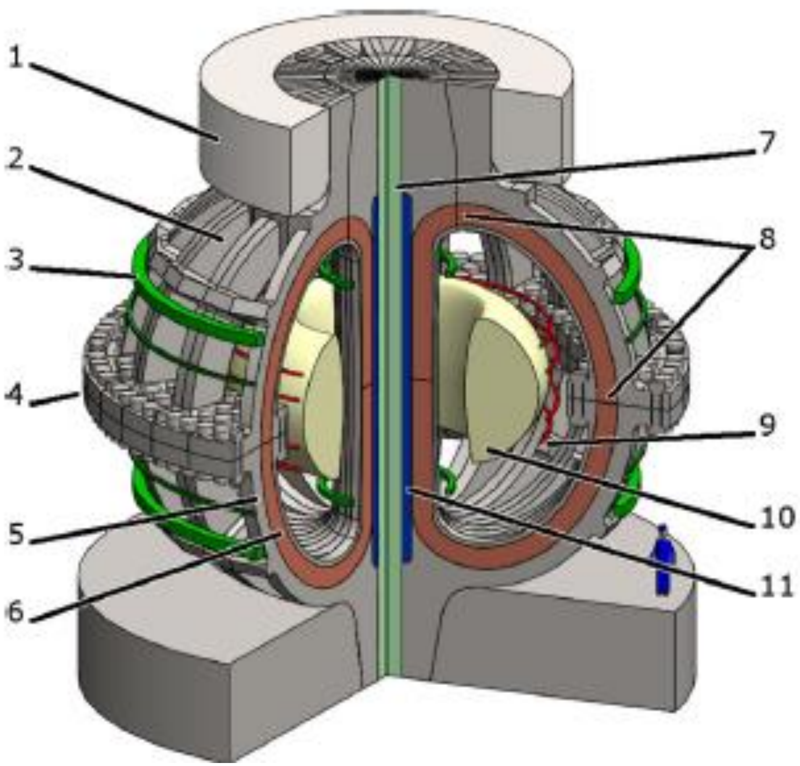
TRIAM

- TRIAM-1M はその超電導コイルを活用して長時間運転実証でonly oneの貢献をした。

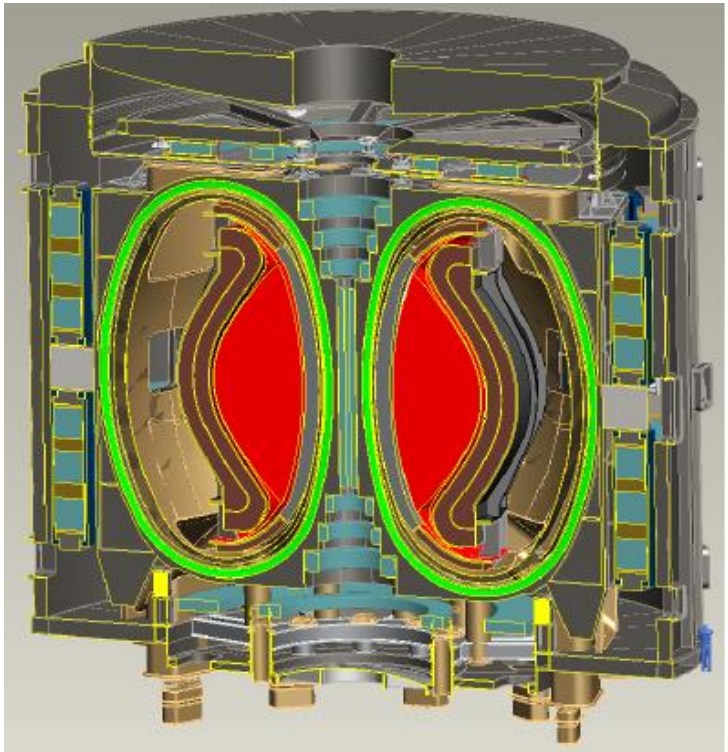


米国の動向

- MIT: 高温超電導を用いたコンパクトなPilot Plantの提案(ARC)
- PPPL:高温超電導を用いたST Pilot Plantの提案



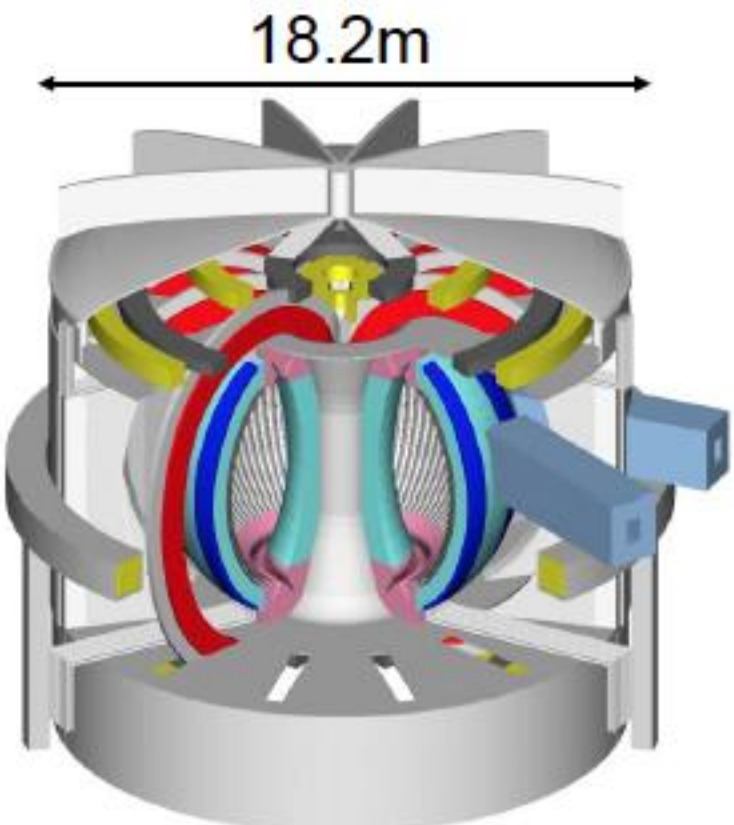
Volume=140m^3



Cryostat volume ~1/3 ITER

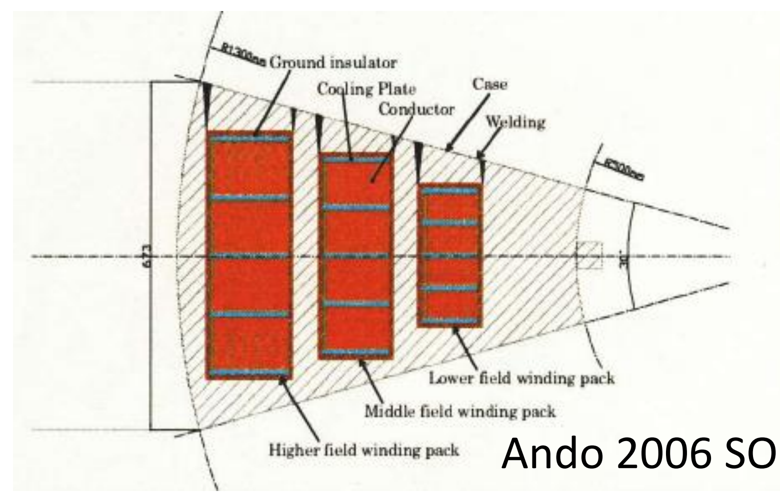
日本は高温超電導に強かった (VECTOR)

旧原研の西尾氏のVECTOR設計は、国内STコミュニティーでは崇められている。



Nishio, FEC 2004

	20 T conductor	13.4 T conductor	6.7 T conductor
Size including insulation (mm^2)	101x 6	81 x 6	51 x 8.4
Maximum magnetic field (T)	20	13.4	6.7
Nominal operating current (kA)	40	40	40
Operating temperature (K)	33	33	33
Width of Tape (mm)	101	81	51
Thickness of YBCO (mm)	0.04	0.04	0.04
Thickness of copper sheet (mm)	4	4	6.4
Critical current dennsity (A/mm^2)	11,000 at 20 T	14,000 at 13.4 T	22,000 at 6.7 T



Ando 2006 SOFE

HモードD型トカマク/STは解か？

- 熱：ELM熱流束、Goldston熱幅則。
- Hモードの粒子束は十分か？

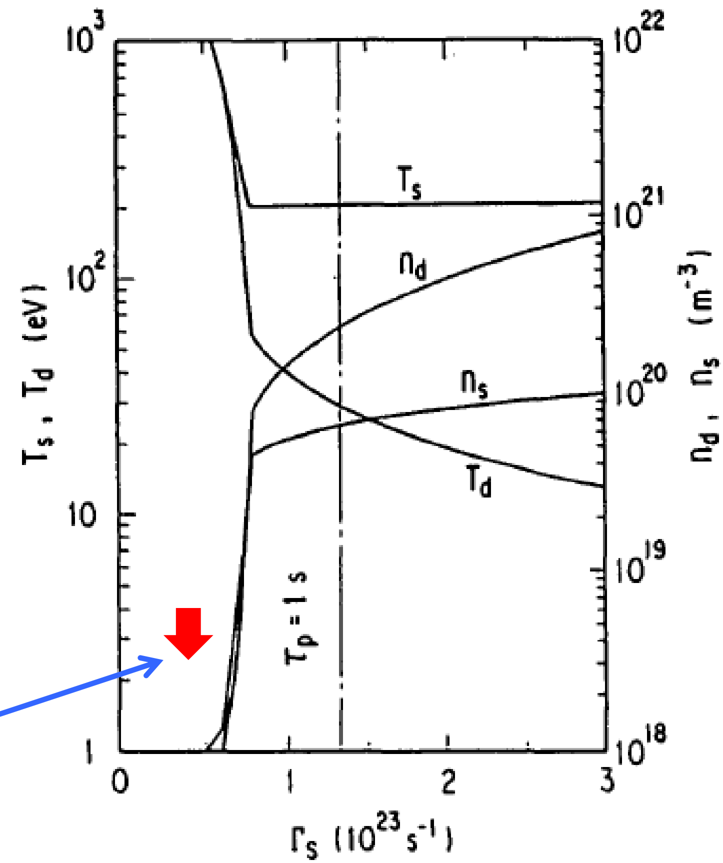
  M. Kikuchi, Energy 2013

  ：おそらく、足りない。

・全ての問題はHモードに由来する。

疑問1：QUESTはどんなプラズマを目指しているのか？

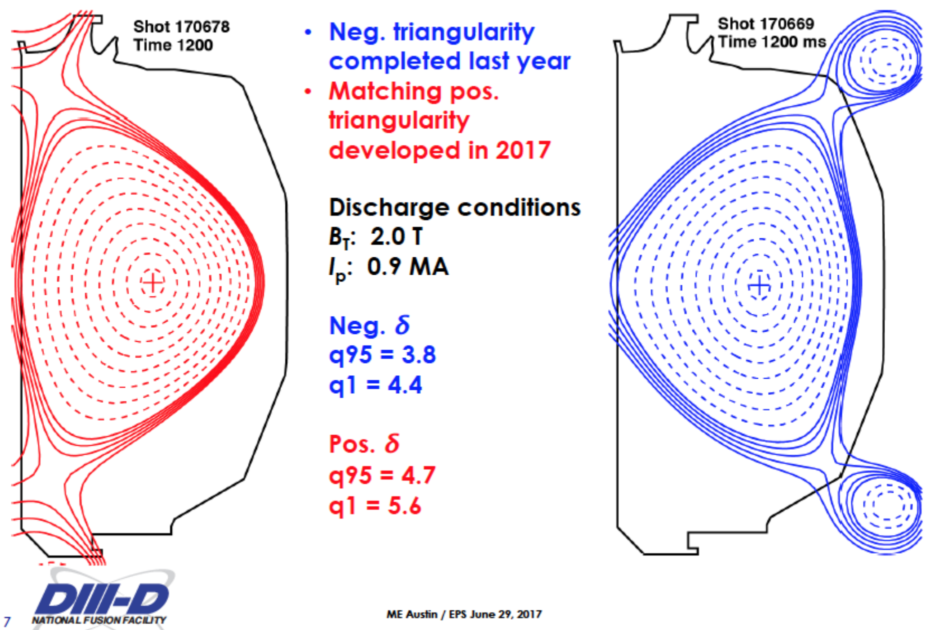
疑問2：QUESTはどう貢献するのか？



3.1 Particle out flux : If we use Goldston scaling of H-mode particle flux $\Gamma_H = 4\pi a n_{sep} T_{sep}/B$, we have $\Gamma_H = 2.8 \times 10^{22}/s$ for $a = 1.7m, n_{sep} = 7 \times 10^{19}/m^3, T_{sep} = 300eV, B = 7T$. This is order of magnitude smaller than the assumed value for SSTR.

Hモード以外の解はあるか？

Max Austin, EPS2017, APS2017 showed encouraging results.



δ>0 went into ELMing H-mode

δ<0 stayed at L-mode edge but has HH=1.2 confinement at β_N=2.6

参考論文4 M.E. Austin, A. Marinoni, et al., 59th APS-DPP Bulletin Bo4 2 "High confinement in negative triangularity discharges in DIII-D" :

BO4 2 High confinement in negative triangularity discharges in DIII-D* M.E. AUSTIN, *U. Texas* A. MARINONI, *MIT* M.L. WALKER, *Gen. Atomics* M.W. BROOKMAN, *U. Texas* J.S. DEGRASSIE, A.W. HYATT, C.C. PETTY, K.E. THOME, *Gen. Atomics* T.L. RHODES, C. SUNG, *UCLA* O. SAUTER, *SPC* Discharges with negative triangularity (δ) shape have been created in DIII-D with H-mode-like confinement (H_{98y2} = 1.2) and high normalized beta (β_N = 2.6) with L-mode-like edge pressure profiles and no ELMs. These inner-wall-limited plasmas with δ =−0.4 had the same global performance as a positive triangularity (δ =0.4) ELMing H-mode discharge with the same I_p, elongation and area. Preliminary fluctuation data shows negative δ plasmas have lower turbulence levels, typically reduced by 20%, in the outer region of the plasma, 0.7 $<r/a<$1.0, compared to equivalent positive δ discharges. Correspondingly, transport analysis indicates reduced ion and electron diffusivities for negative δ compared to the positive δ cases. Also, the positive triangularity discharges had 30-50% lower neutron rates as the identically heated negative triangularity ones, due primarily to impurity retention and deuterium dilution. These results show that negative triangularity is a viable candidate for reactor scenarios with its high confinement, ELM-mitigated characteristics plus a more economical and effective option for divertor placement.

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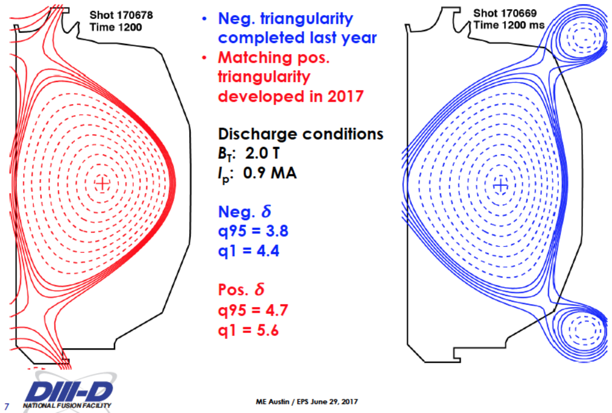
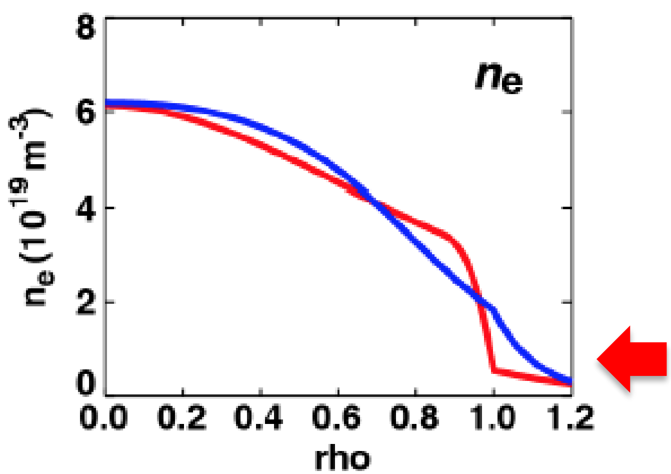
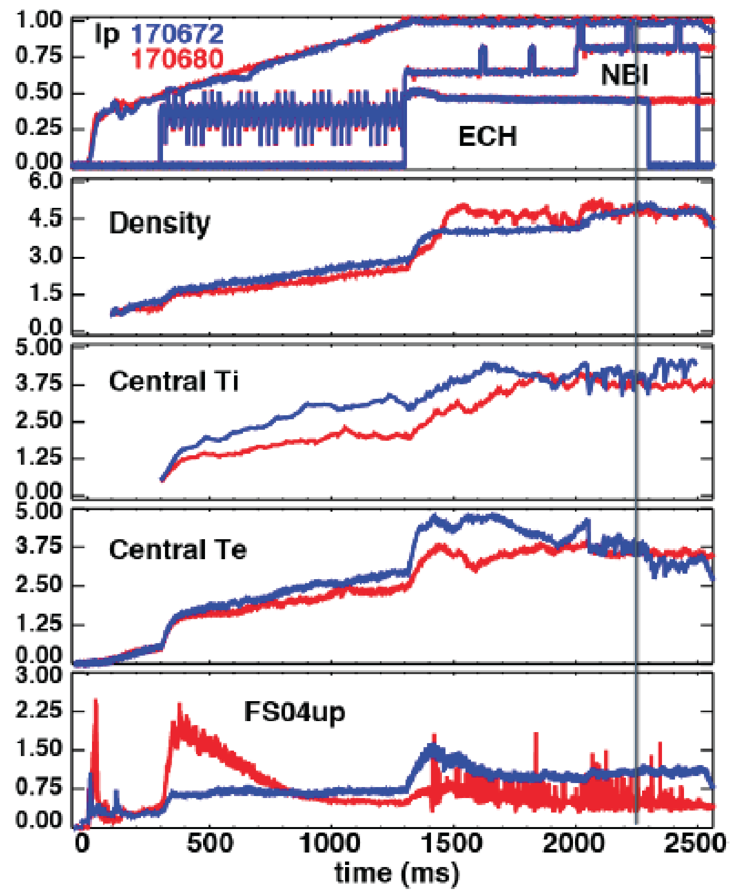






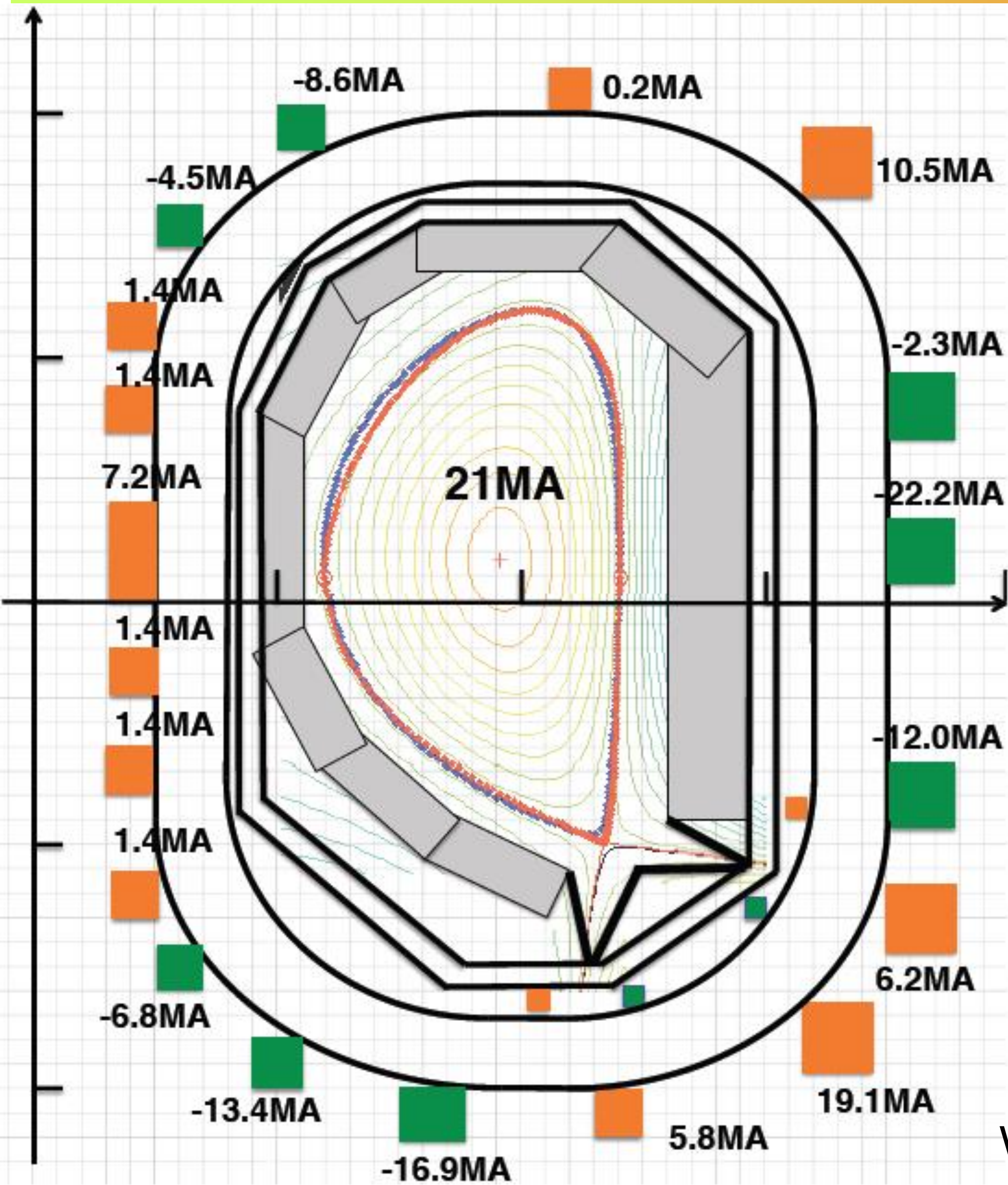
核融合炉は、高いSOL密度が必要。L->H 遷移によってSOL密度は大幅に減る。
Lモードエッジを持ち、ペデスタルに依存しない閉じ込めモードが必要。

負三角度核融合炉

M. Kikuchi, Energy (2013)
S. Medvedev, FEC 2014, FEC2016
M. Kikuchi, FEC2018

- ダイバータを外側に持ってきて、熱・粒子排気を容易にする。
- TCVとDIII-D実験はLモードエッジで高い閉じ込め性能。(ELM無し、熱幅は広い）
- 炉で必要なベータ値はβ_N=2.6でDIII-Dで実証済み。

2.1 Single null NTT configuration [Racetrack TF coils]



R_p=9m, a_p=3m, I_p=21MA, B_t=5.86T
q_{95}=3.0, κ_{95}=1.73, κ_x=1.8, δ_{Ux}=-0.4, δ_{Lx}=-0.9

Racetrack shaped TF coil is best suited for NTT configuration.
PF coil currents $\Sigma|I_{PF}|/I_p = 6.8$

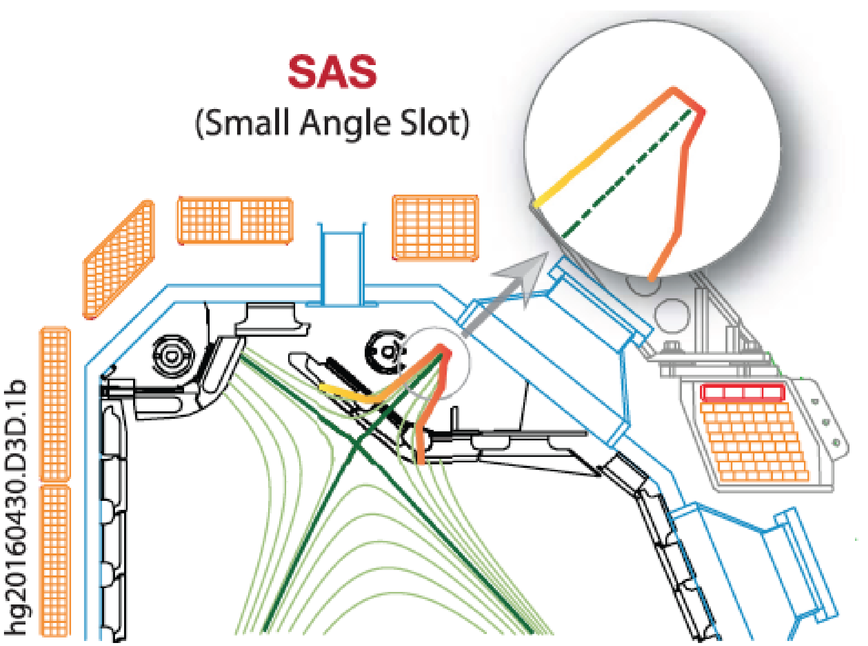
For single null NTT, vertical stability is fairly good. With a_w/a=1.3, the growth rate is ~14s^{-1}, similar to ITER value (6cm thick steel wall).
Beta limit (w/o wall) l_i=0.84

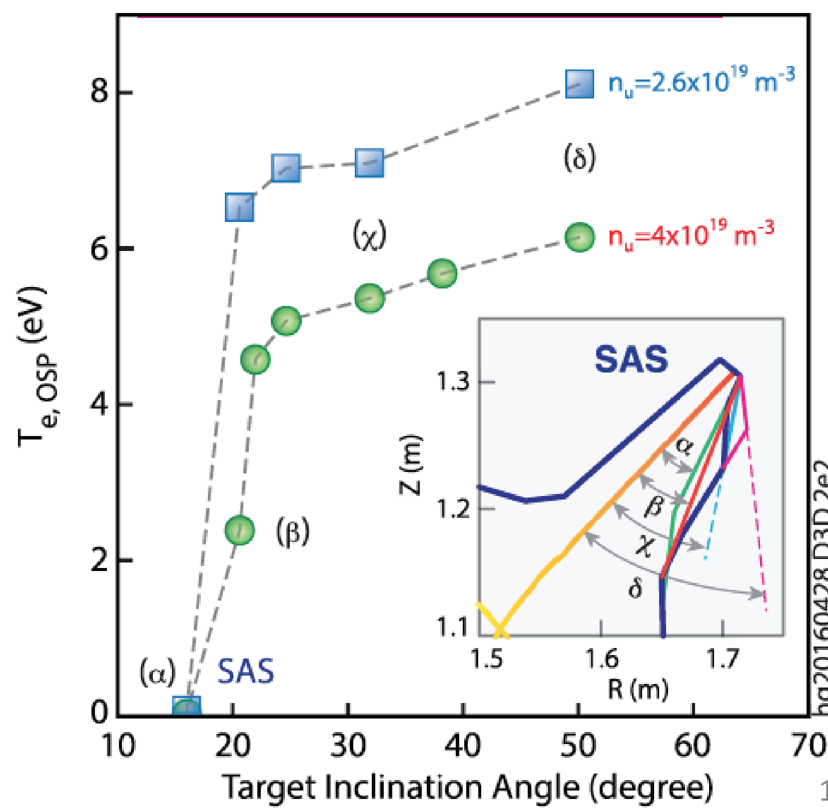
n = 1 betaN = 2.79
n = 2 betaN = 3.24
n = 3 betaN = 3.36
n = 4 betaN = 3.43
n = 5 betaN = 3.47
n = infty : betaN= 3.41

With a_w/a=1.3 wall, **β_N =3.3** n=1 stable

ダイバータ(SAS）

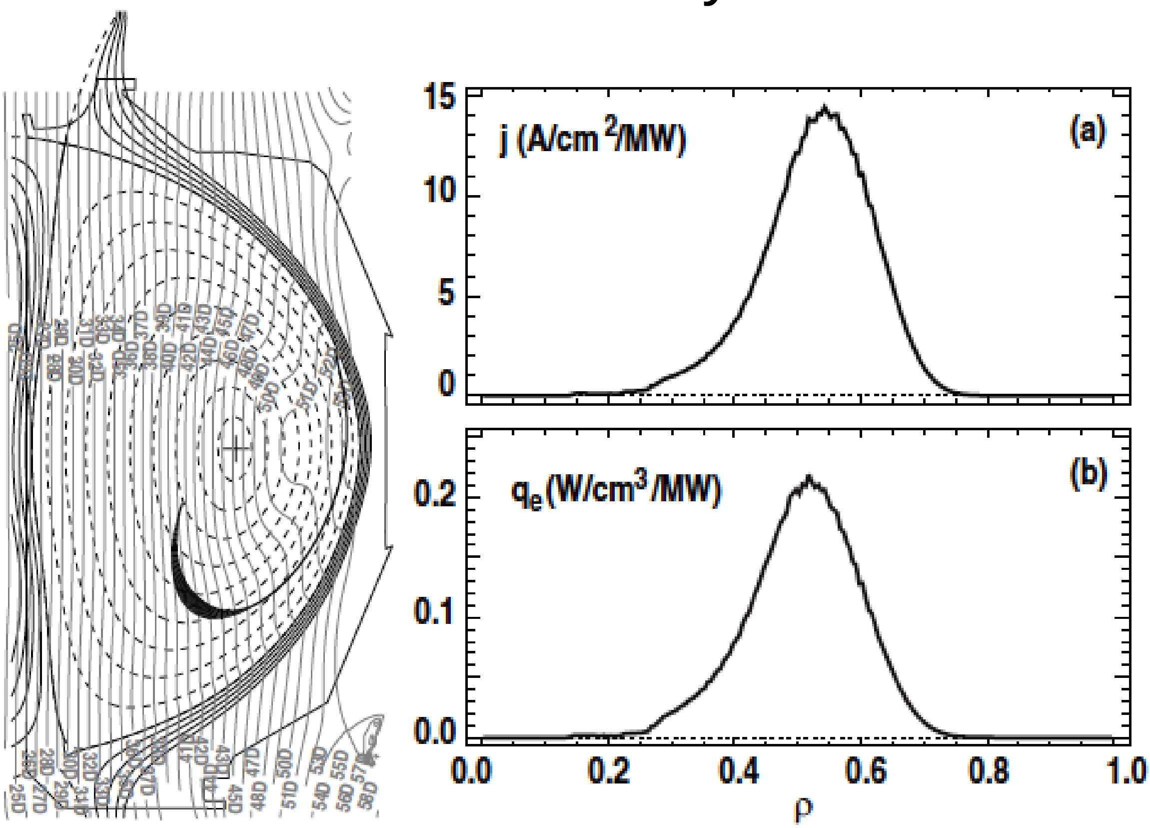
- **Guo, NF2017**
- **Small angle slot divertor**





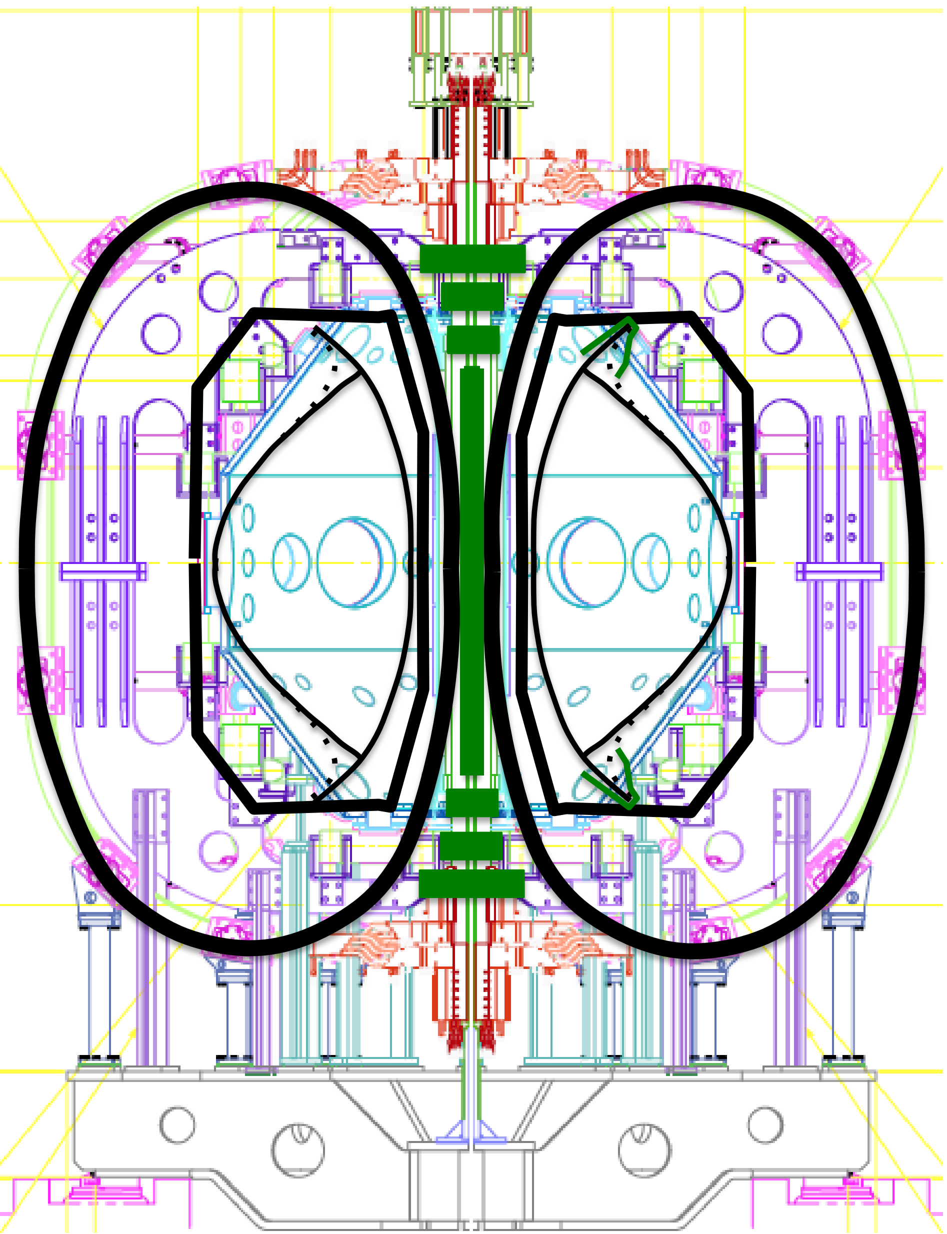
高周波電流駆動 (ヘリコン波）

- 高周波のfast wave / Helicon wave/ Whistler
- R. Prater, M. Porkolab, NF2014
- Robust to accessibility

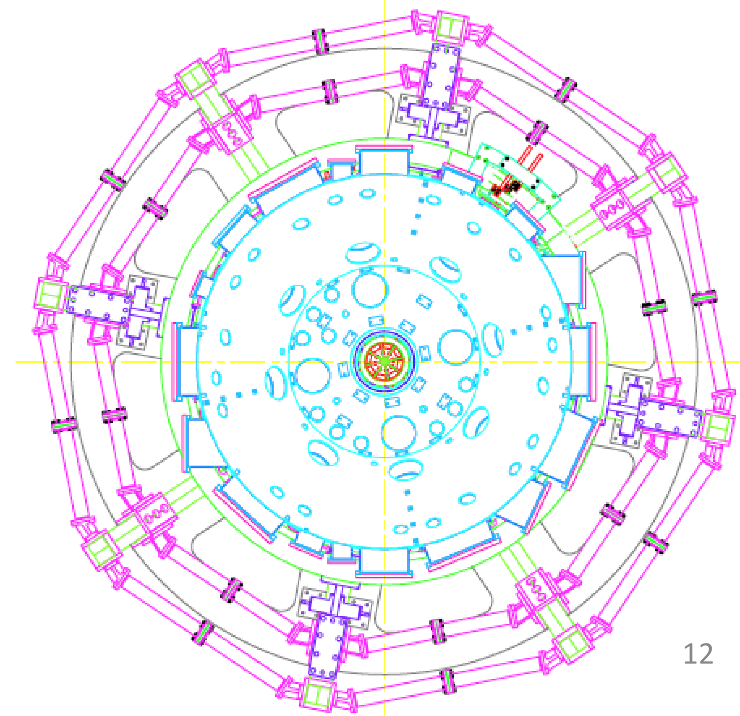


ARC: η_{CD}~4E^{19}A/W/m2
Inboard CD

QUEST (A->2)

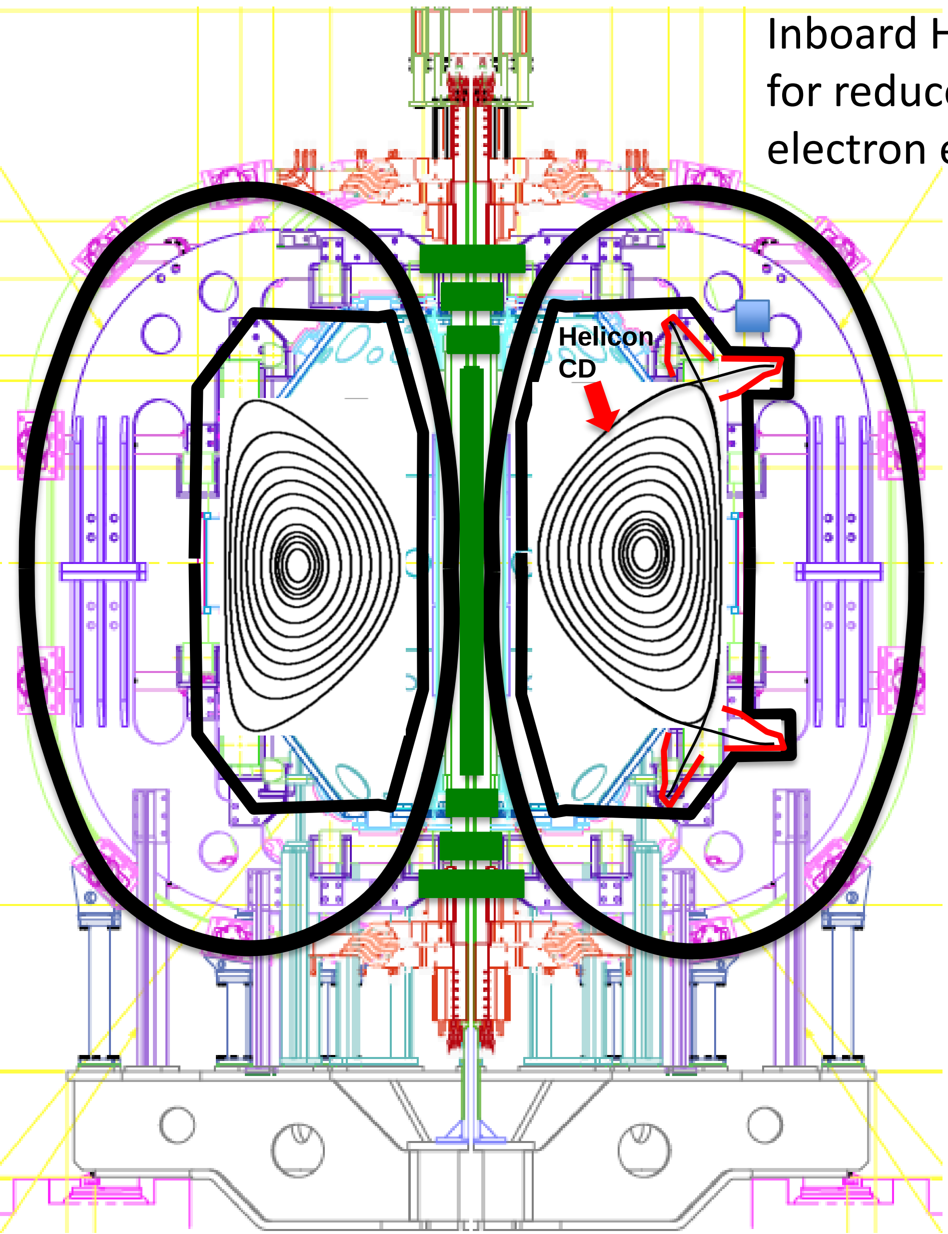


TFC -> HTC conductor 1.5T
VV -> Rectangular shaped



QUEST (A->2)

L-mode edge
HH=1.2
betaN=2.6
Inboard Helicon CD
for reduce trapped
electron effect



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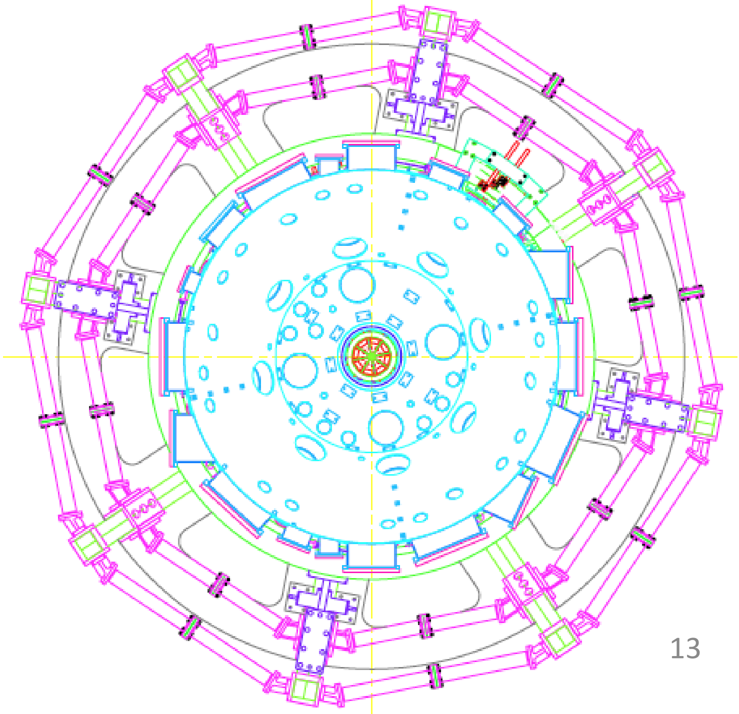

QUESTの将来計画

- どうすれば、QUESTは核融合開発に本質的な貢献ができるか？

1. TRIAMを上回る長時間運転。
2. Bt=0.25Tは低すぎる。-> 1テスラ以上。->高温超電導/NIFS