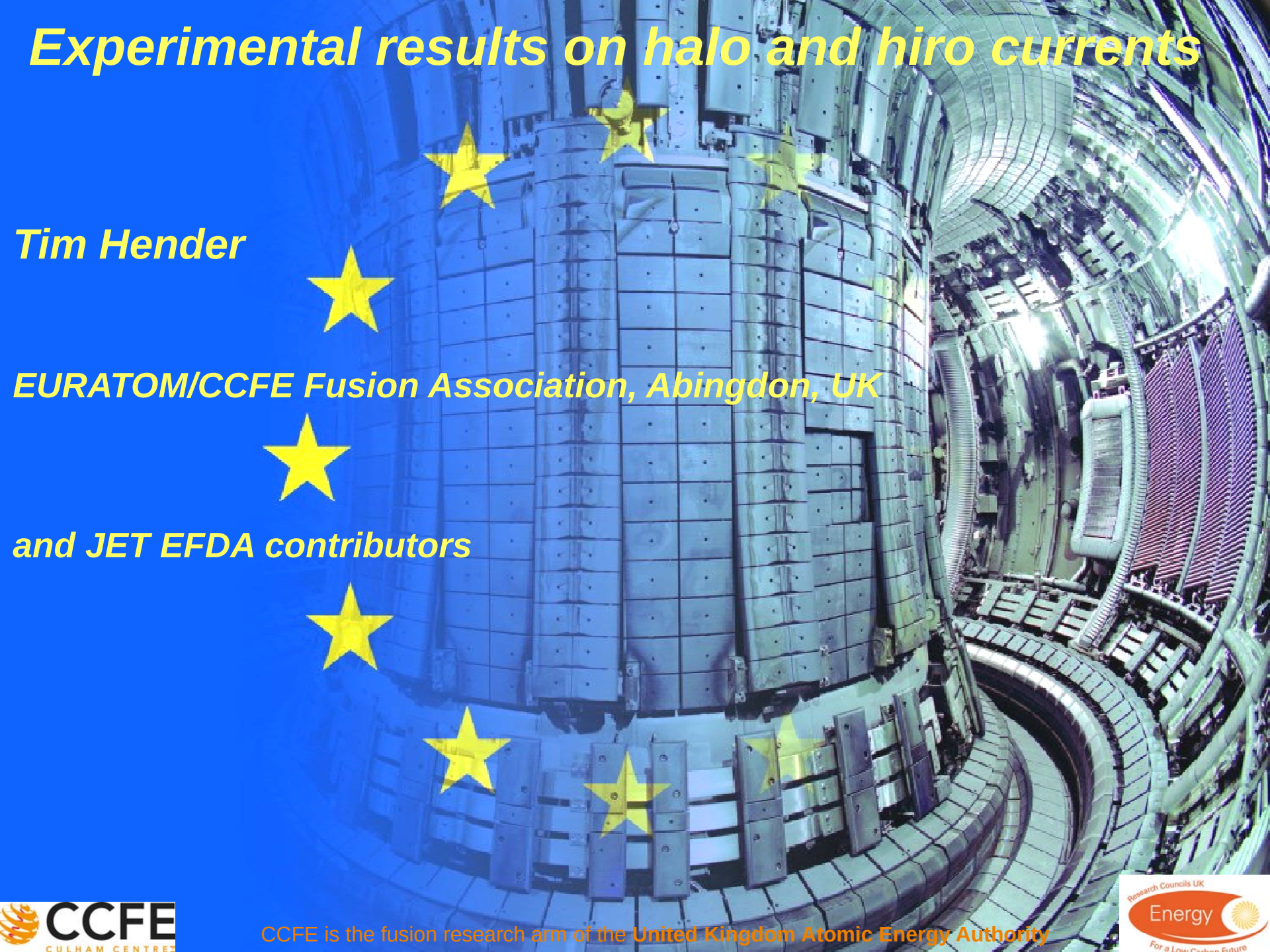
Experimental results on halo and hiro currents

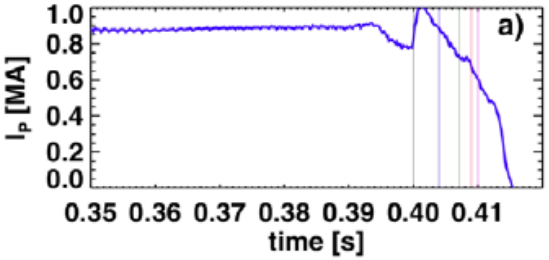
Tim Hender

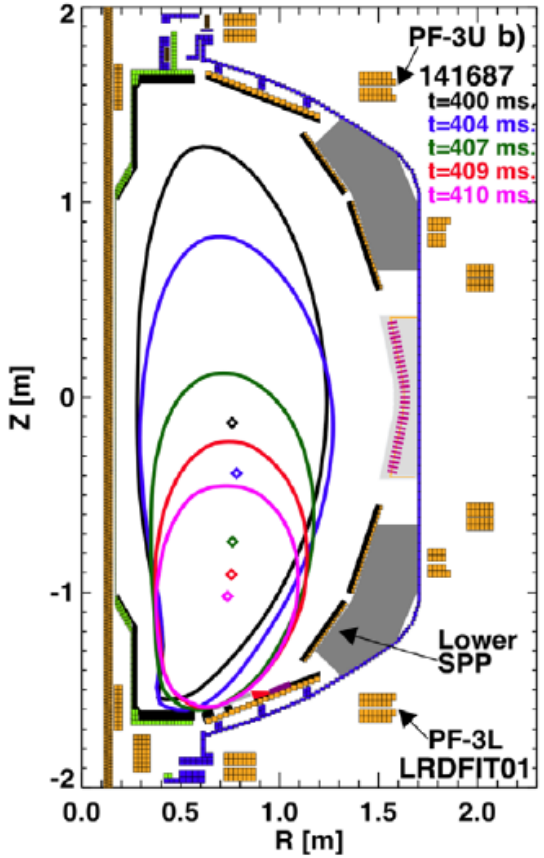
EURATOM/CCFE Fusion Association, Abingdon, UK

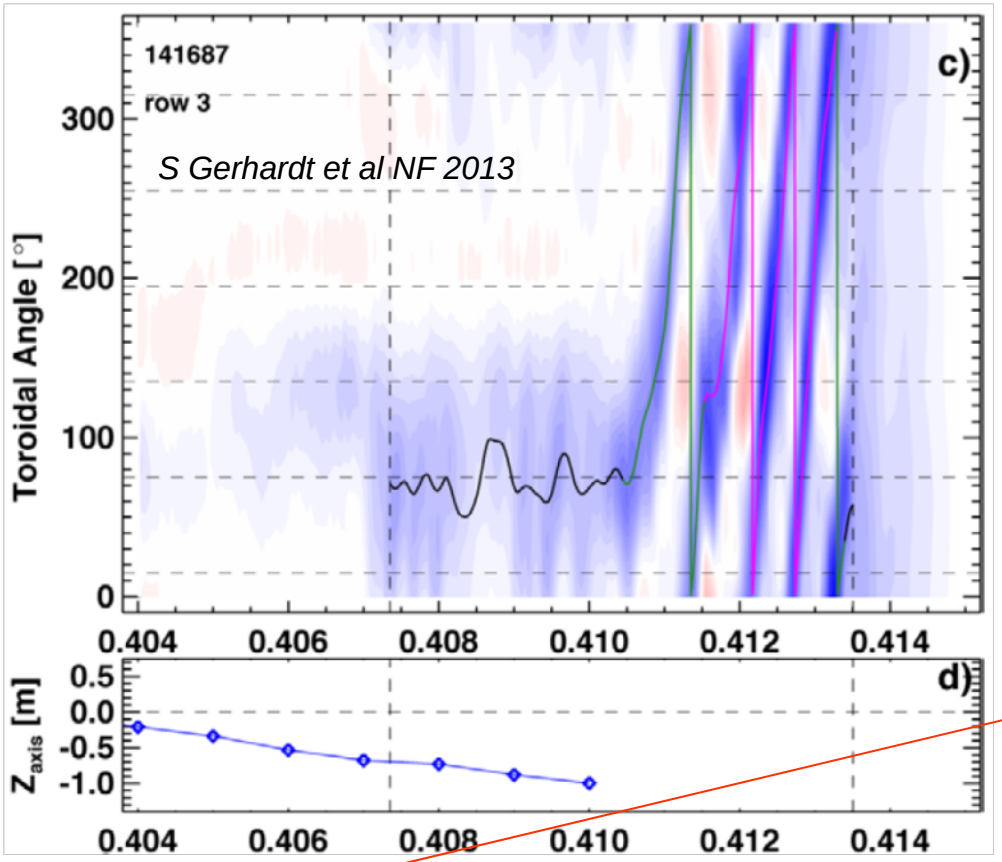
and JET EFDA contributors

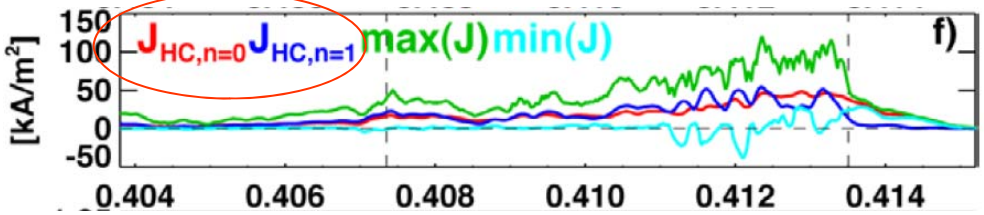


Halo currents*





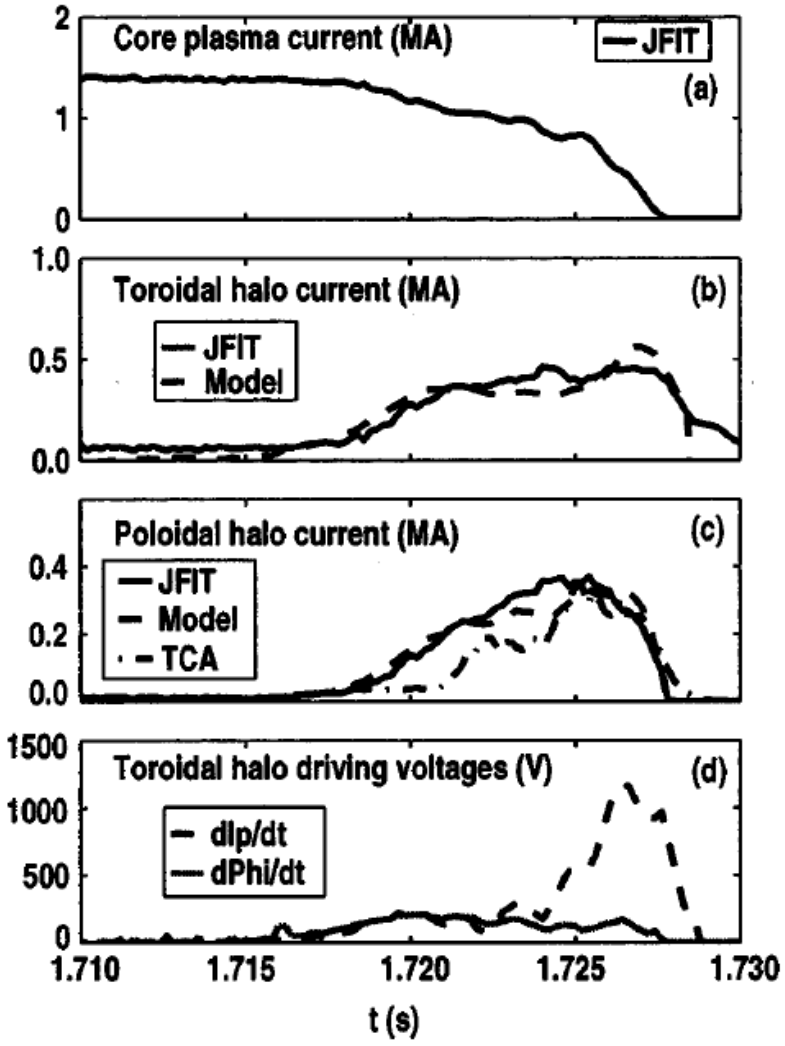




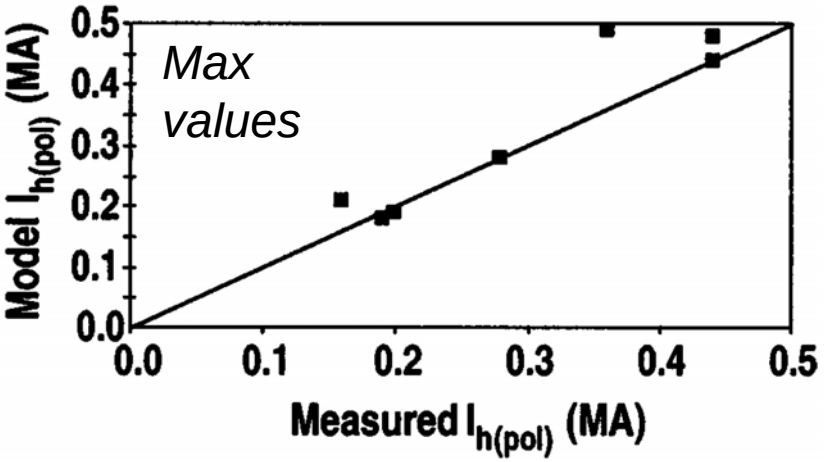
Halo's have can have a non-symmetric component

**I will call any current with part of its path in plasma edge and part in vessel a halo current*

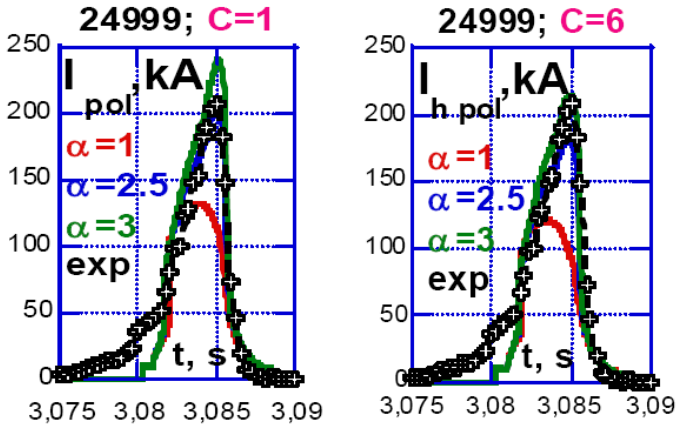
Symmetric Halo Current well understood



D Humphreys et al PoP 1999



- Treats the core and halo current regions as coupled circuits



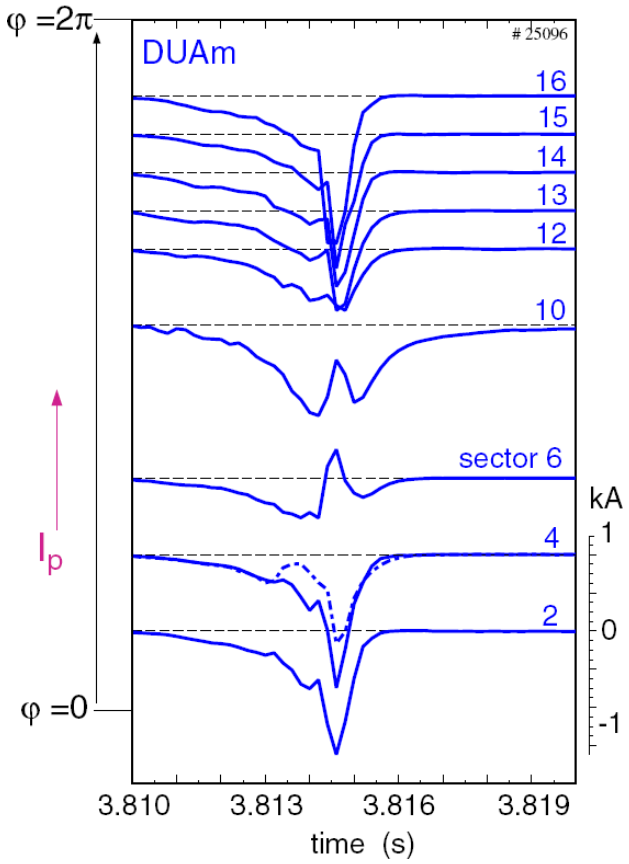
DINA model: *Lukash et al EPS 2010*

- Also halo modelling with TSC

Concentrate on non-symmetric halos

3 ways to measure asymmetric halos (all involve measuring at several toroidal locations)

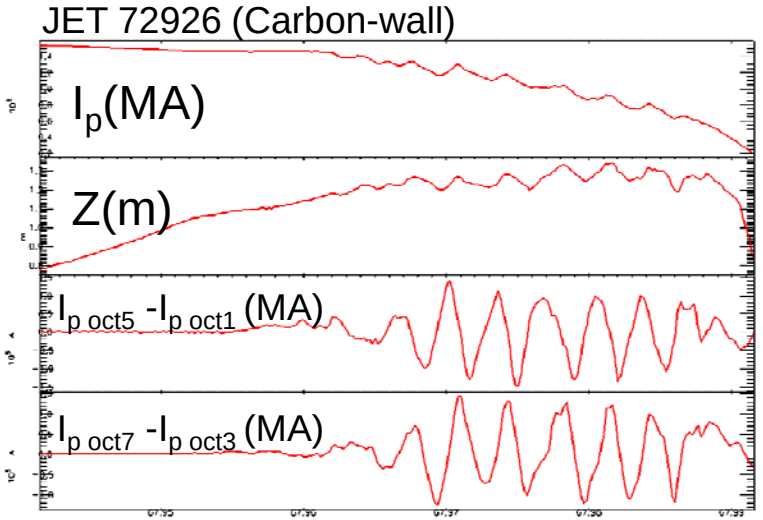
Tile shunt measurements



AUG: Pautasso NF 2011

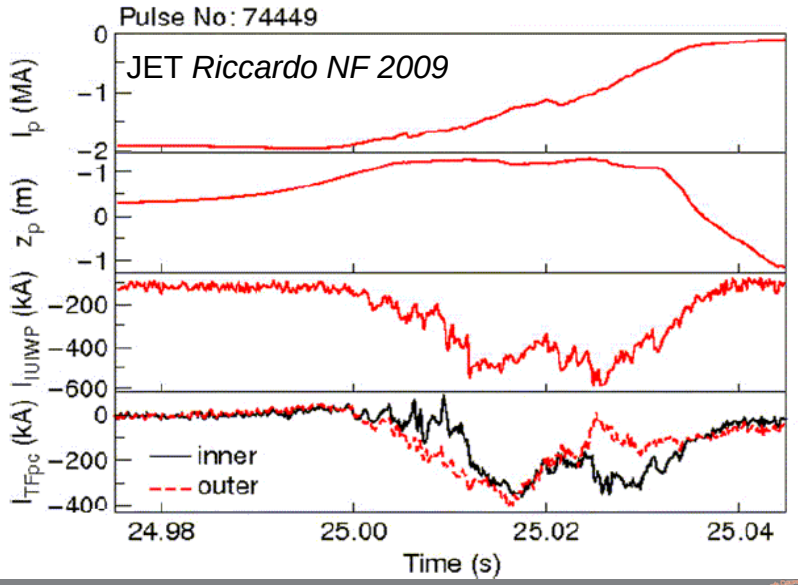
I_p measurements

Measures toroidal halo current (only done on JET)



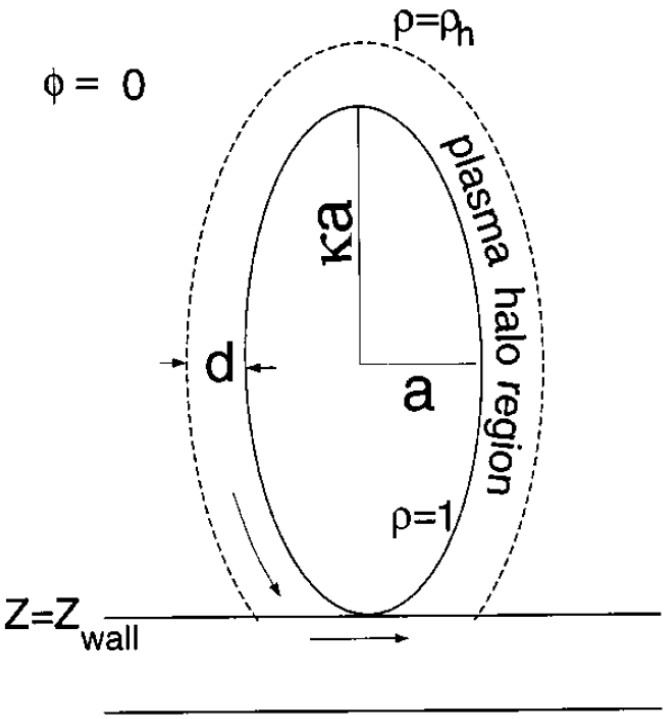
Change in B_t

Measures Poloidal Currents flowing for $R<R_{Btcoil}$



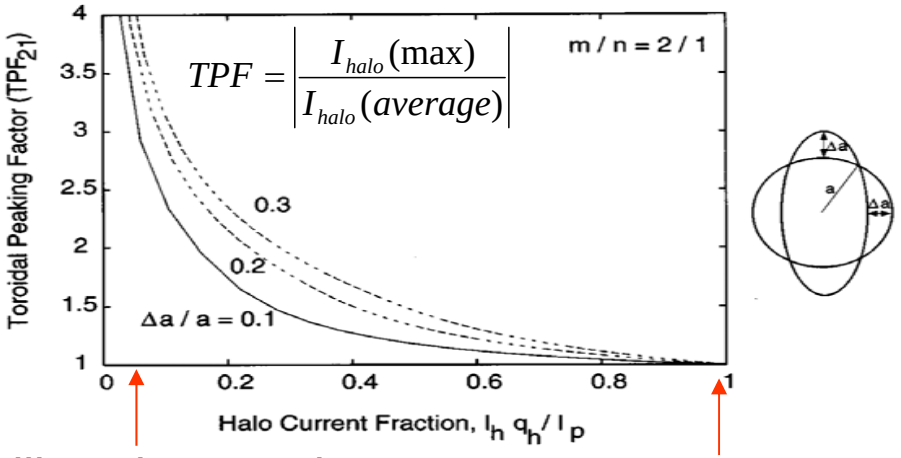
Halo Current Asymmetries - theory

At q_a=2 m=2,n=1 kink distortion:-



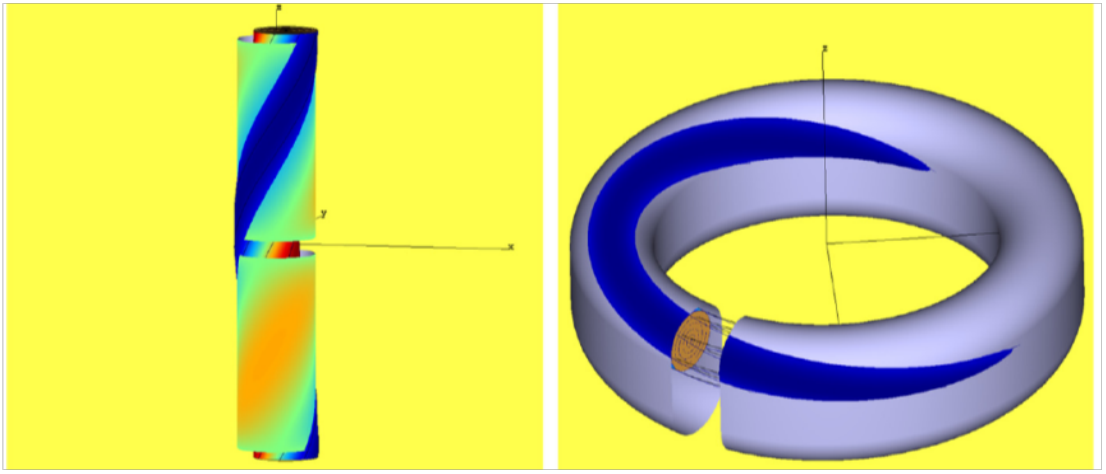
NB Helically rotating elliptic distortion

Pomphrey et al, Nucl Fus 1998



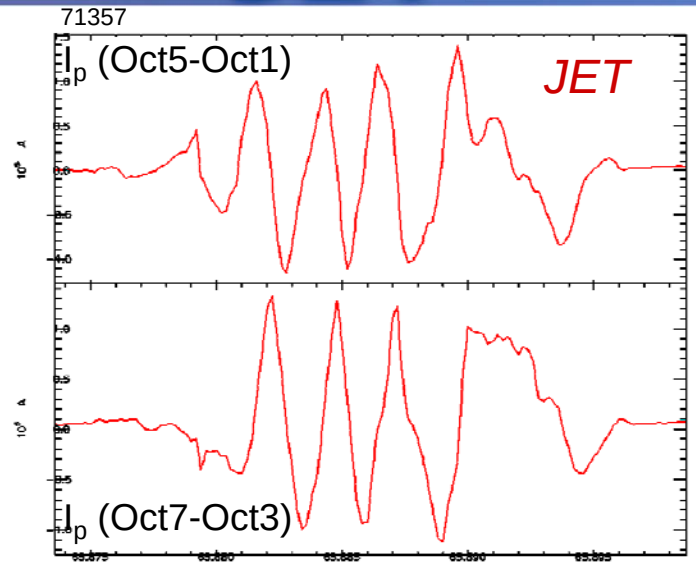
Ellipse just touches at ϕ=0 & 180° $\Rightarrow I_{halo}(av)=0$

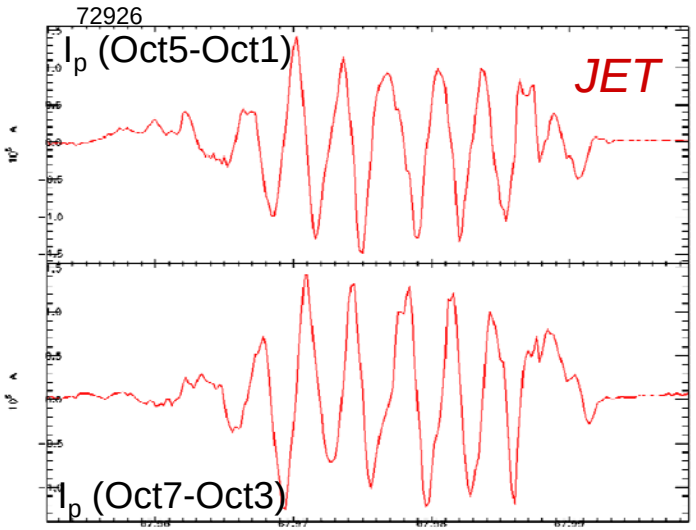
d>>a all current in halo

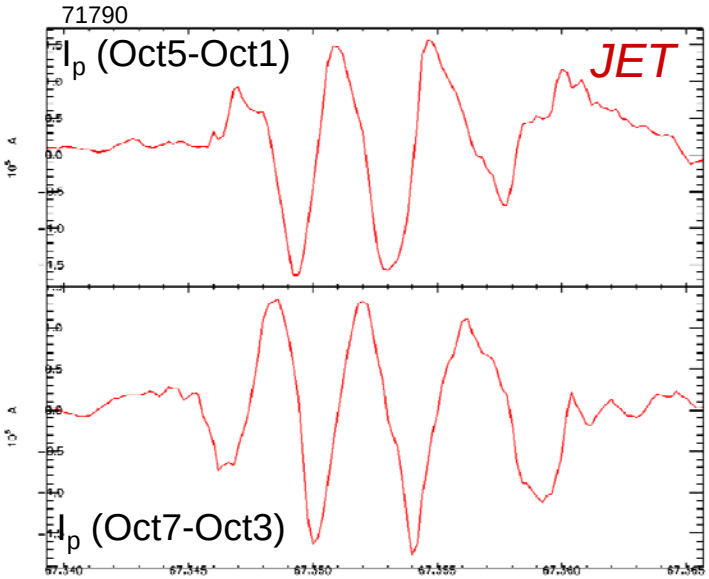


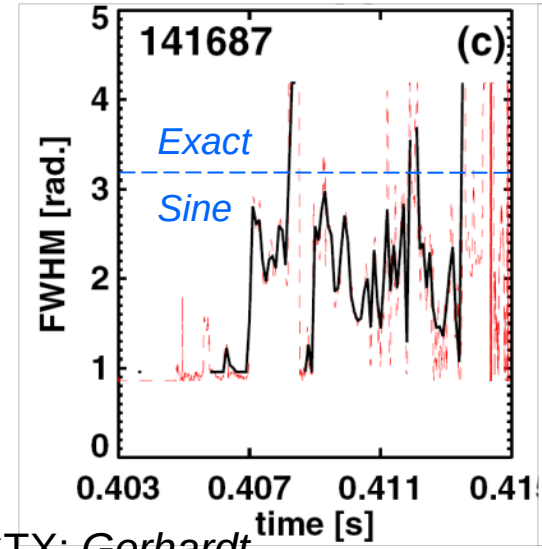
Kink mode – hiro current model Zakharov et al PoP 2008

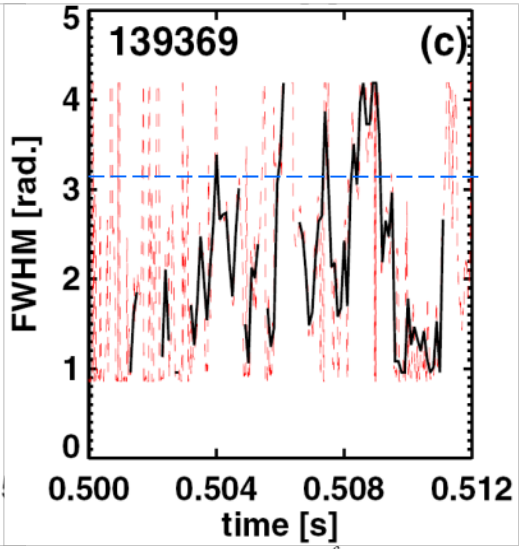
Halo asymmetries - sinusoidal?







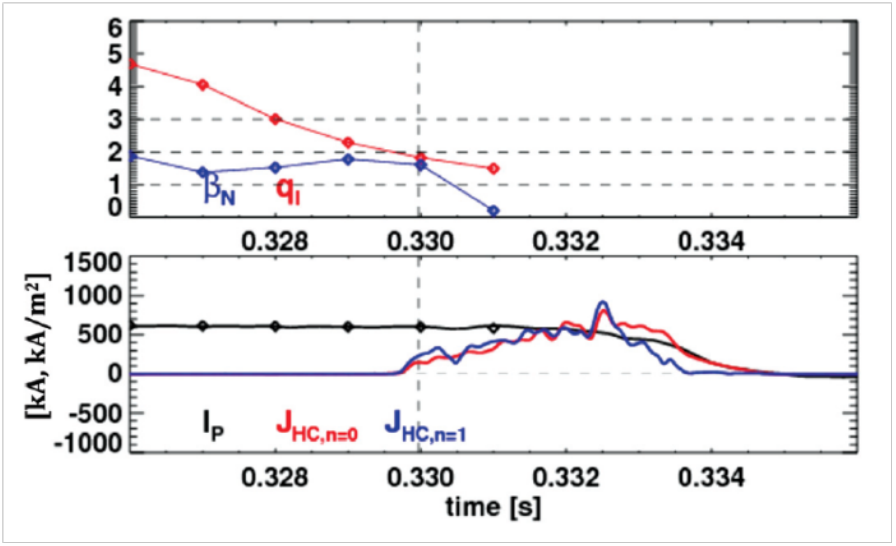




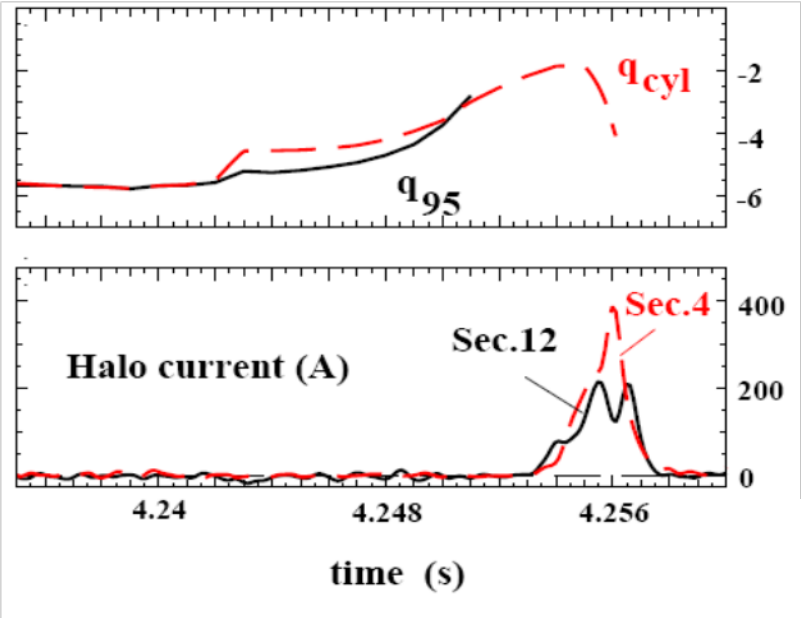
NSTX: *Gerhardt et al NF 2012*

$$J(\phi,t) = f_0 + f_1 \frac{(1+\cos(\phi - f_2 - f_3 t))^{f_4}}{2^{f_4}}$$

q=? at start halo asymmetry

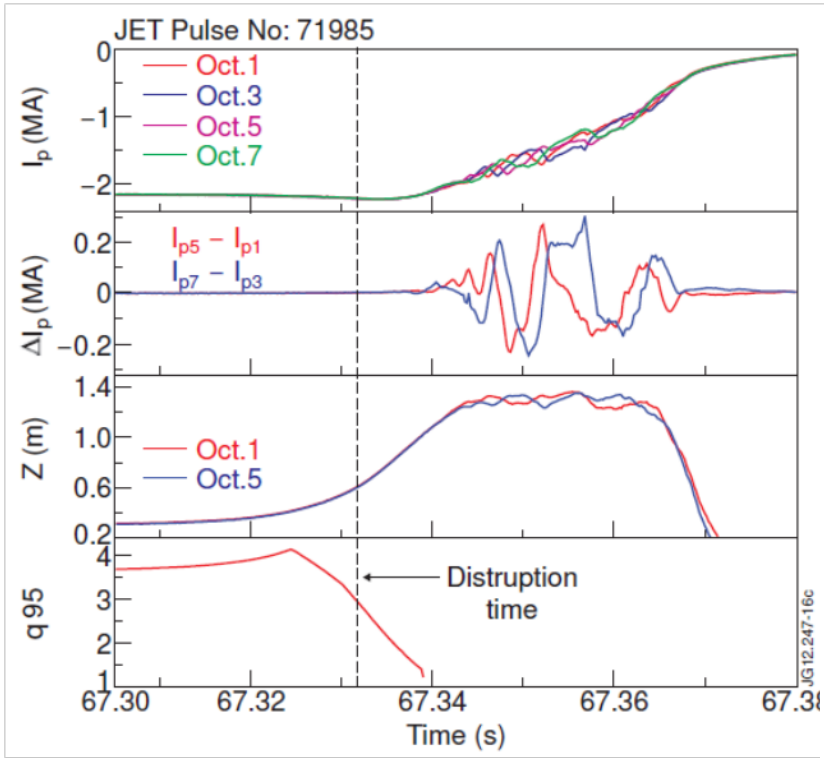


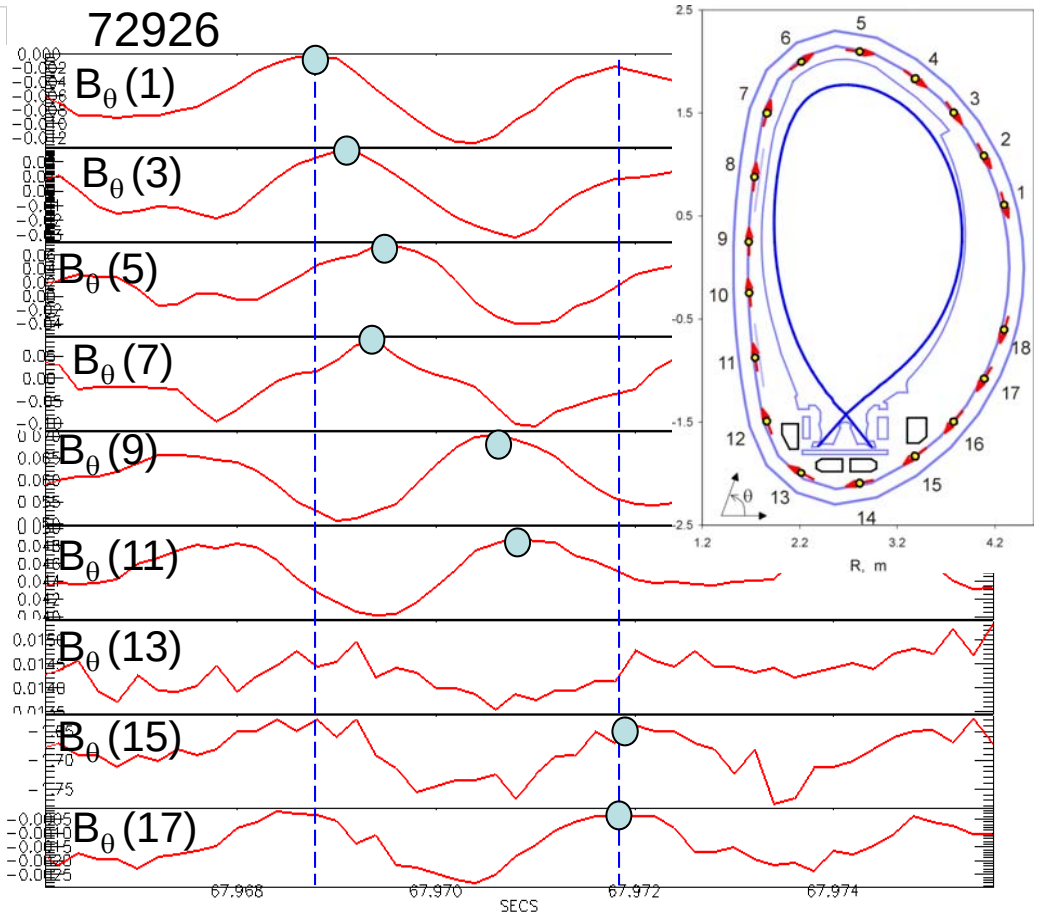
NSTX: Boozer PoP 2012



AUG: Pautasso IAEA 2004

q=? at start halo asymmetry

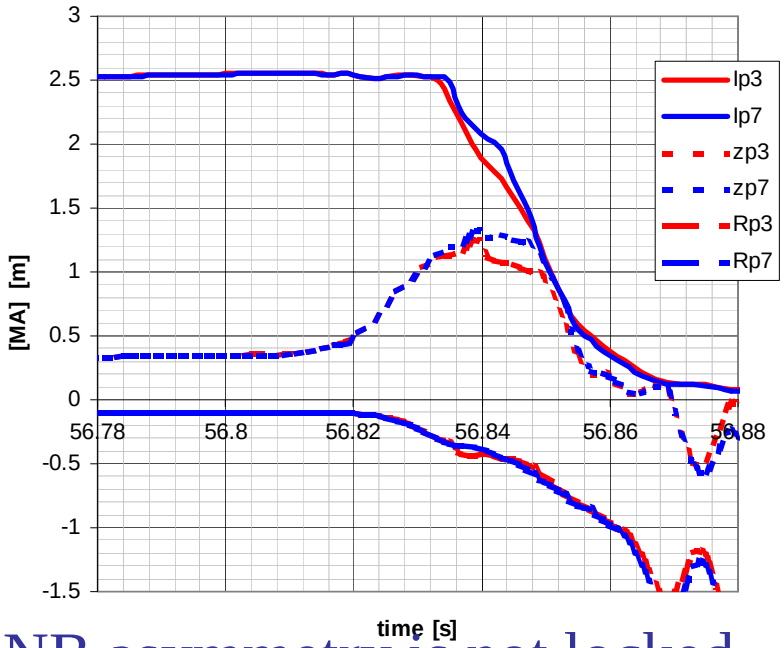




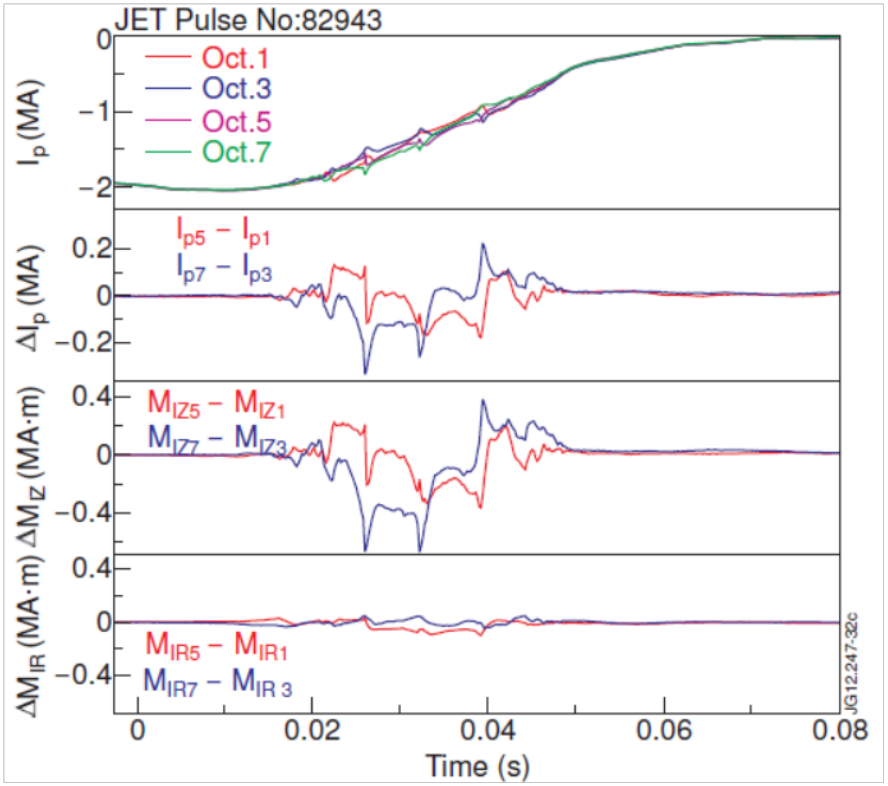
JET seems to be q=1 – consistent m=n=1 observed kink

Is it a kink mode?

- JET disruption measurements on opposite sides of torus (Octant 3 & 7) ⇒ tilt not kink (*Riccardo et al, Nucl Fus 2000)*



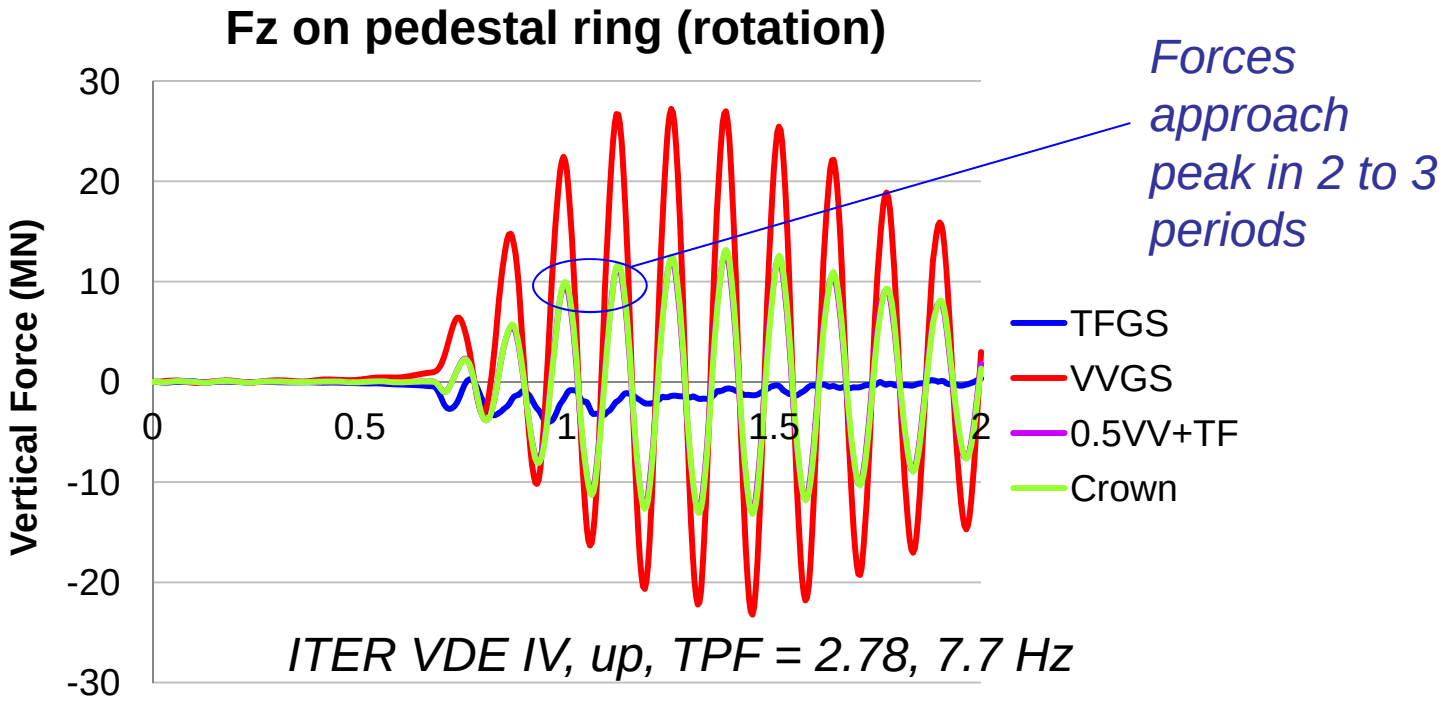
NB asymmetry is not locked so not just due to observation location



- Are the surface currents (hiro currents) affecting the measurements?

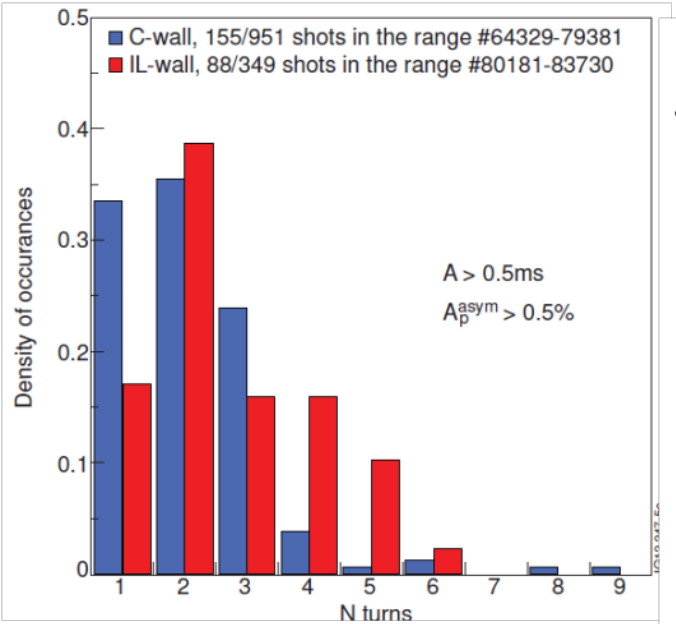
Halo asymmetry rotation

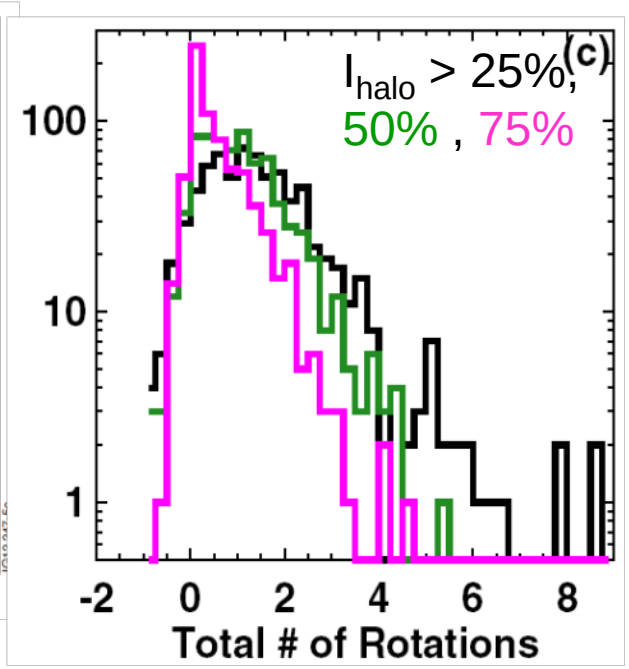
Possibility for dynamic amplification if near a resonant frequency (e.g. of the vacuum vessel):-

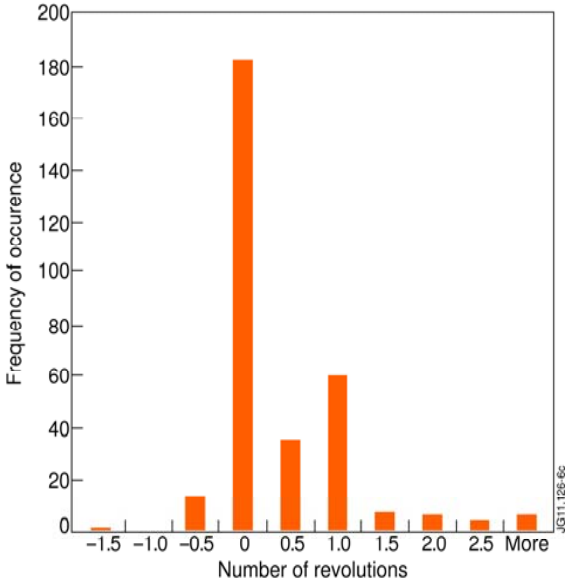


G. Sannazzaro and T Schioler
ITER Organisation

Halo asymmetry rotation







JET:-

Rotation mainly counter-Ip

NSTX:-

Rotation mainly counter-Ip

From Gerhardt et al NF 2013

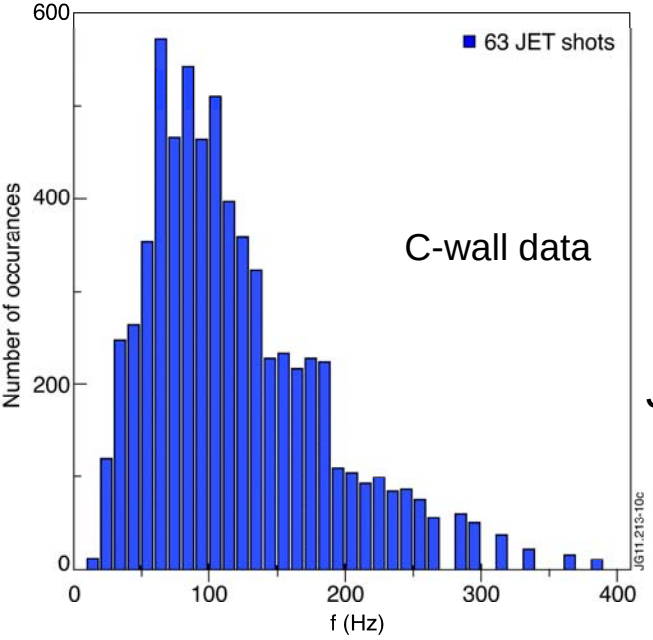
DIII-D:-

Rotation mainly locked (but co-Ip most commonly if does rotate)

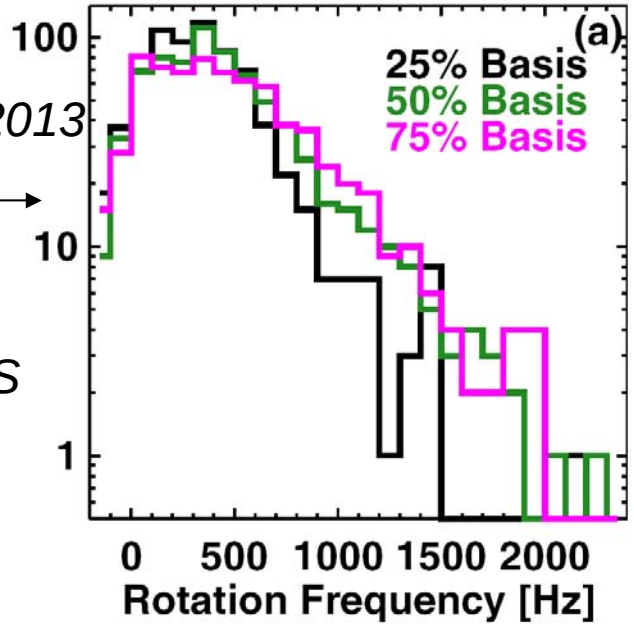
From ITPA WG6 report figure by N Eidietis

- In AUG the rotation is most commonly counter-Ip
- C-Mod published examples (*Granetz NF1996*) are counter-I_P

Halo rotation frequency smaller in bigger machines?

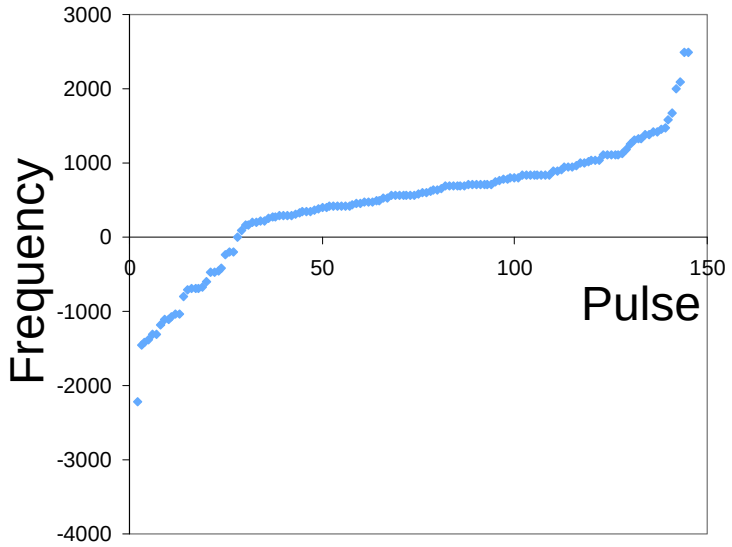


NSTX: S Gerhardt, NF 2013



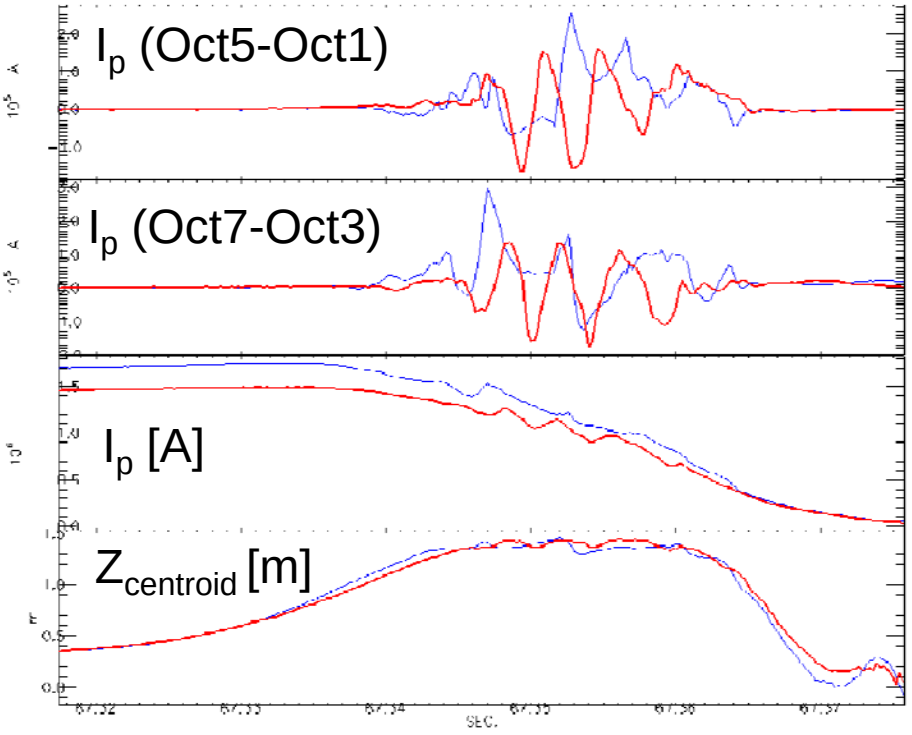
JET: S Gerasimov, 2012 EPS

DIII-D: N Eidietis
WG6 report

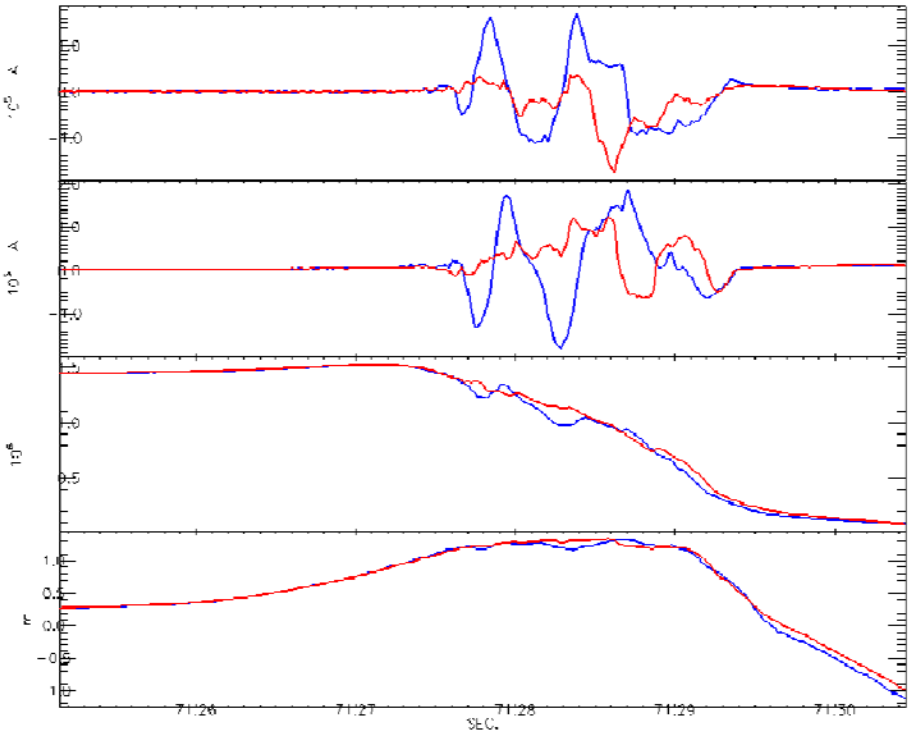


No obvious pattern for why some shots have substantial halo rotation

71790, 71791

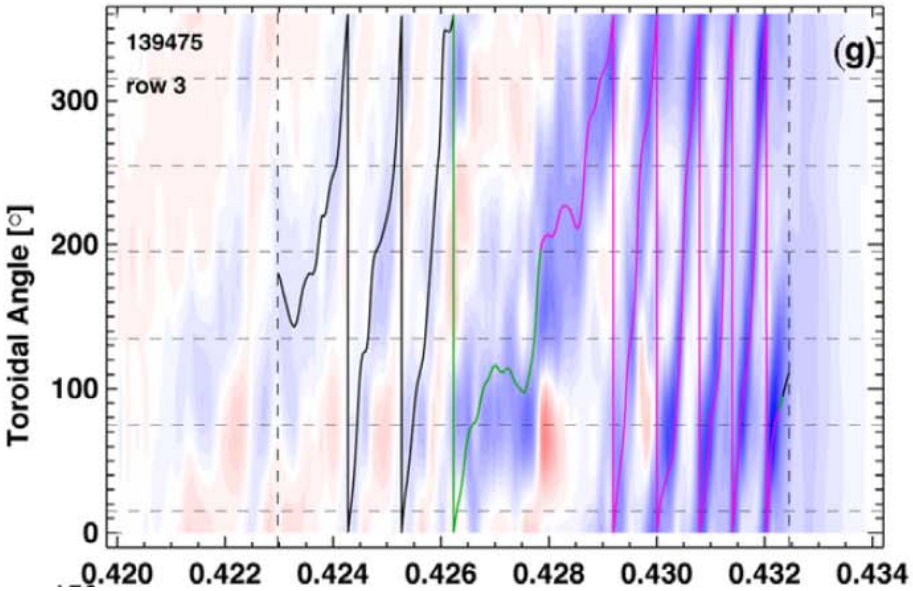


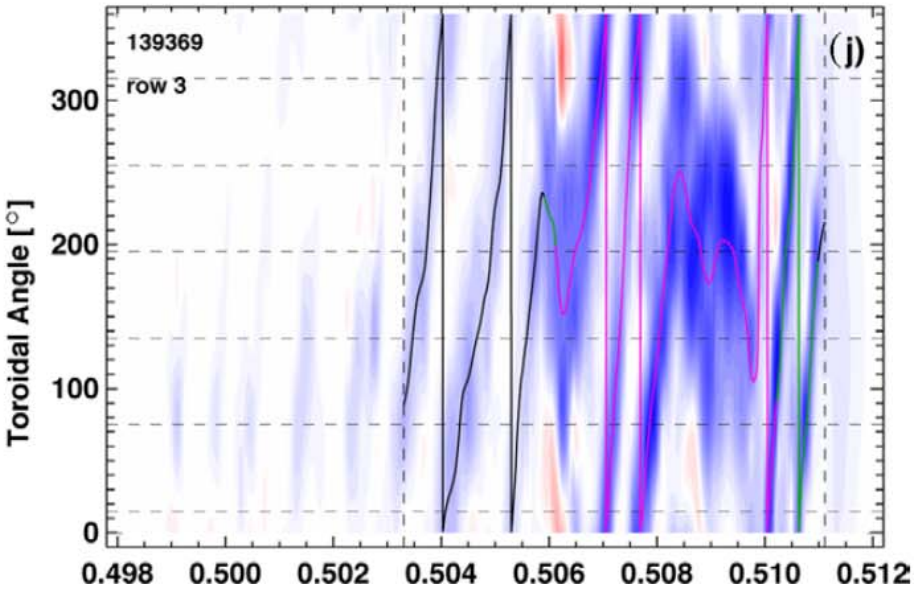
70237, 70238



Neighbouring similar shots have very different halo rotation

NSTX a lot of variability in halo rotation



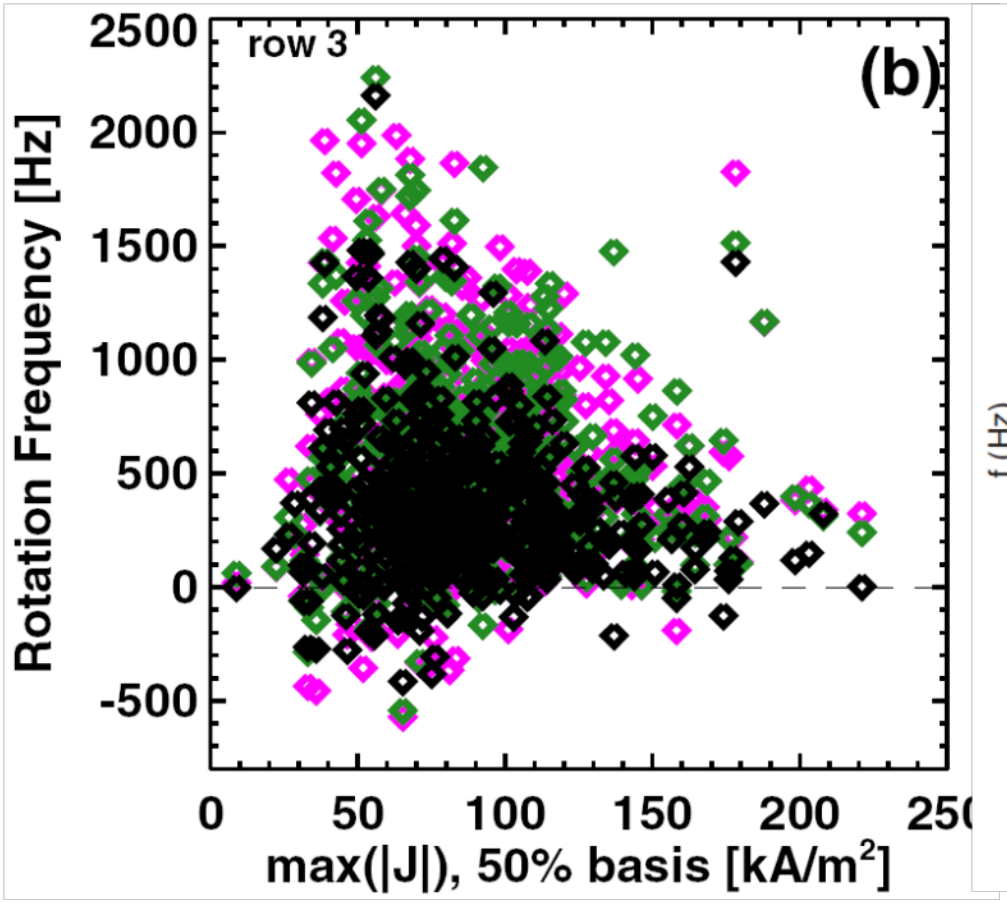


NSTX: S Gerhardt, NF 2013

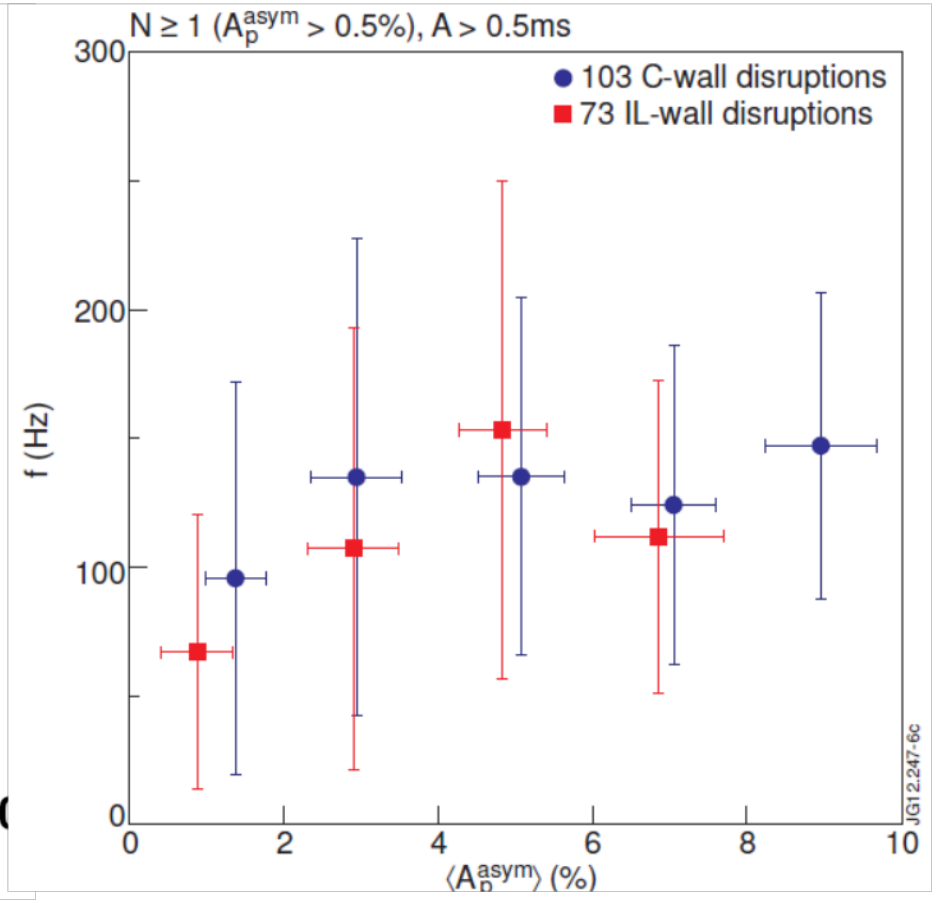
⇒ Modelling halo rotation will be challenging

Why don't larger halo asymmetries lock?

Or do they:-



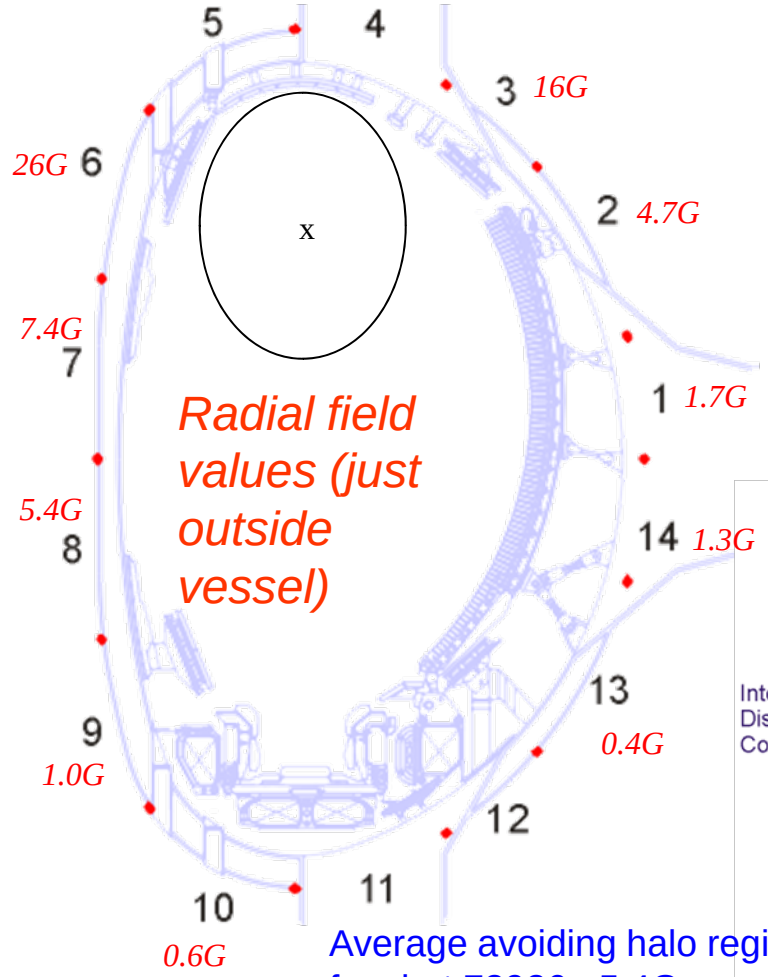
NSTX: S Gerhardt, NF 2013



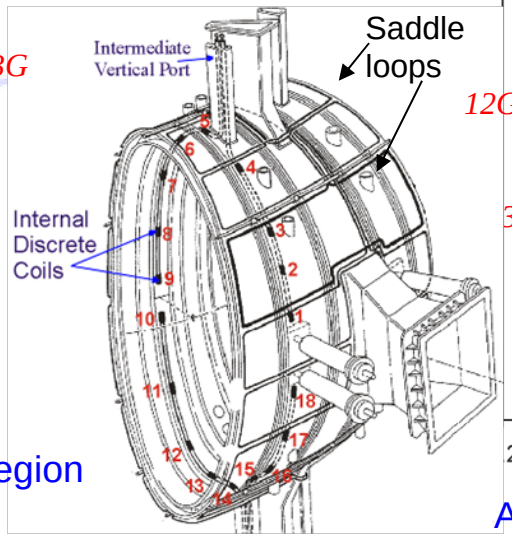
JET: Gerasimov EPS 2012

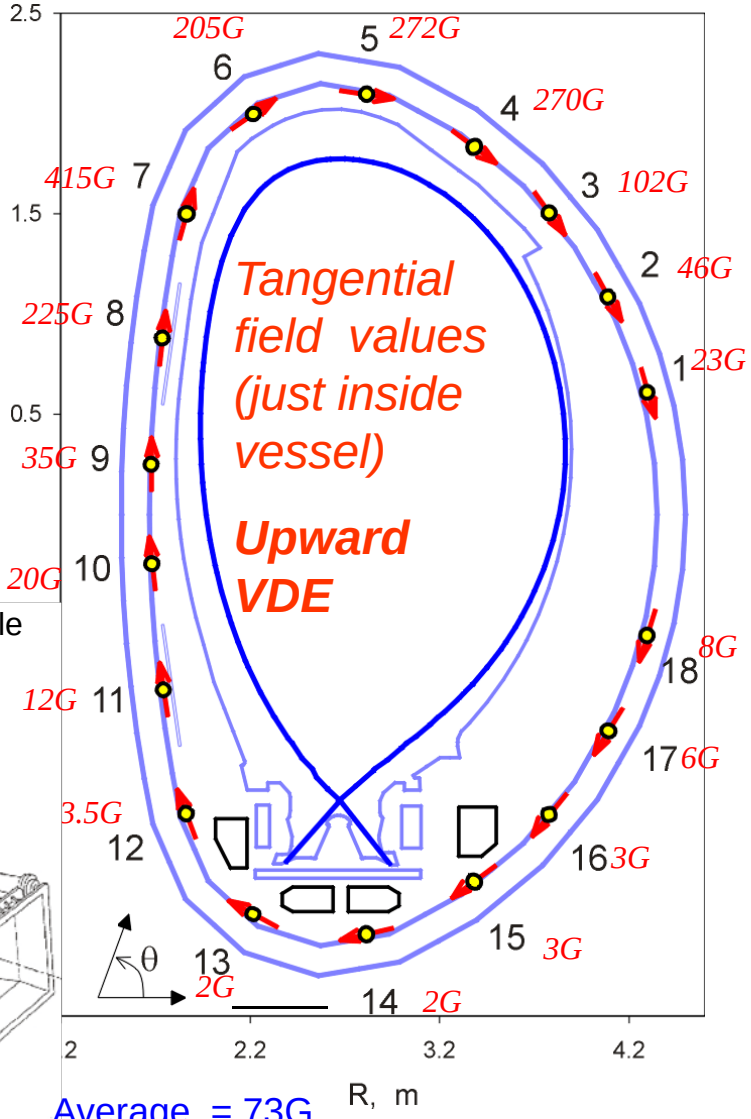
Why don't larger halo asymmetries lock?

$$Toroidal\ Force = \frac{4\pi^2 r_w^2}{\mu_0}\frac{n}{m}\frac{\omega\tau_w}{m}\frac{B_\vartheta^2(wall)}{1+(\omega\tau_w/m)^2}$$



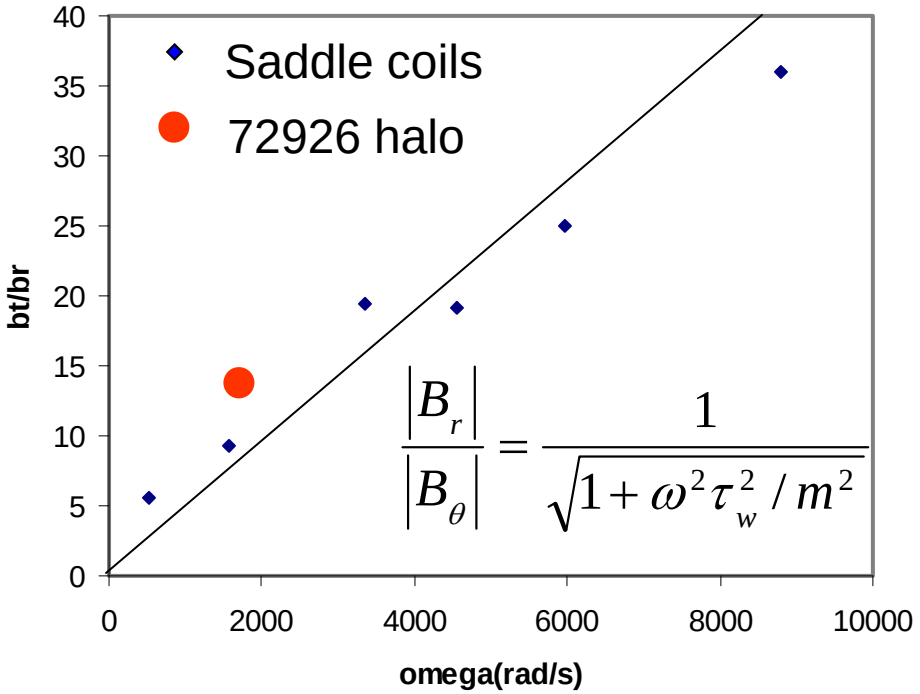
Average avoiding halo region for shot 72926= 5.4G

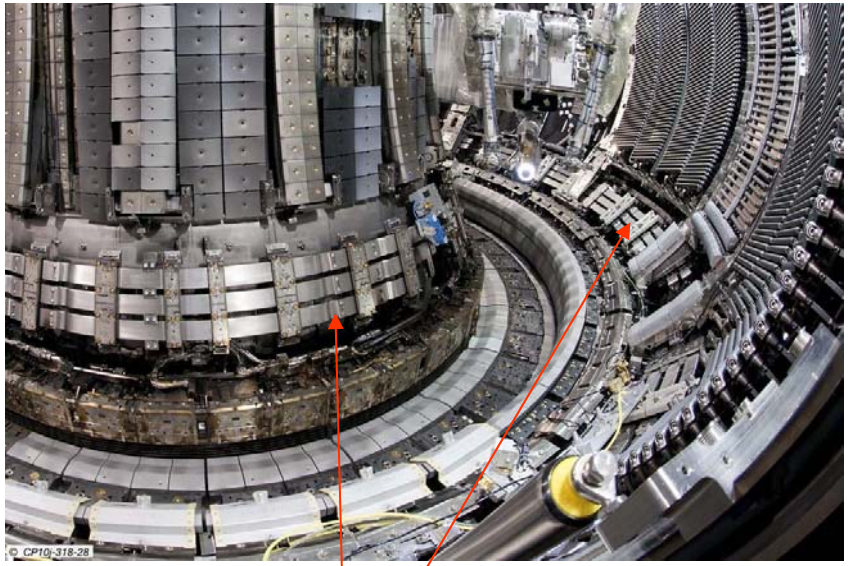




Average = 73G

Why don't larger halo asymmetries lock?





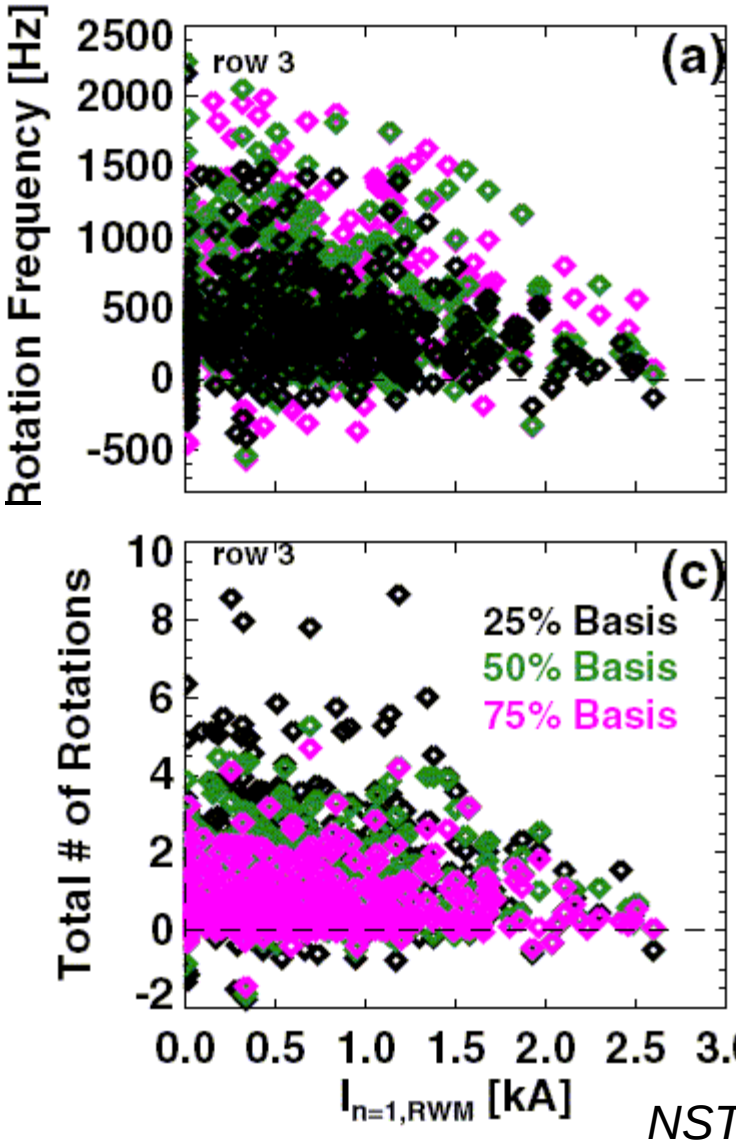
Internal saddle coils

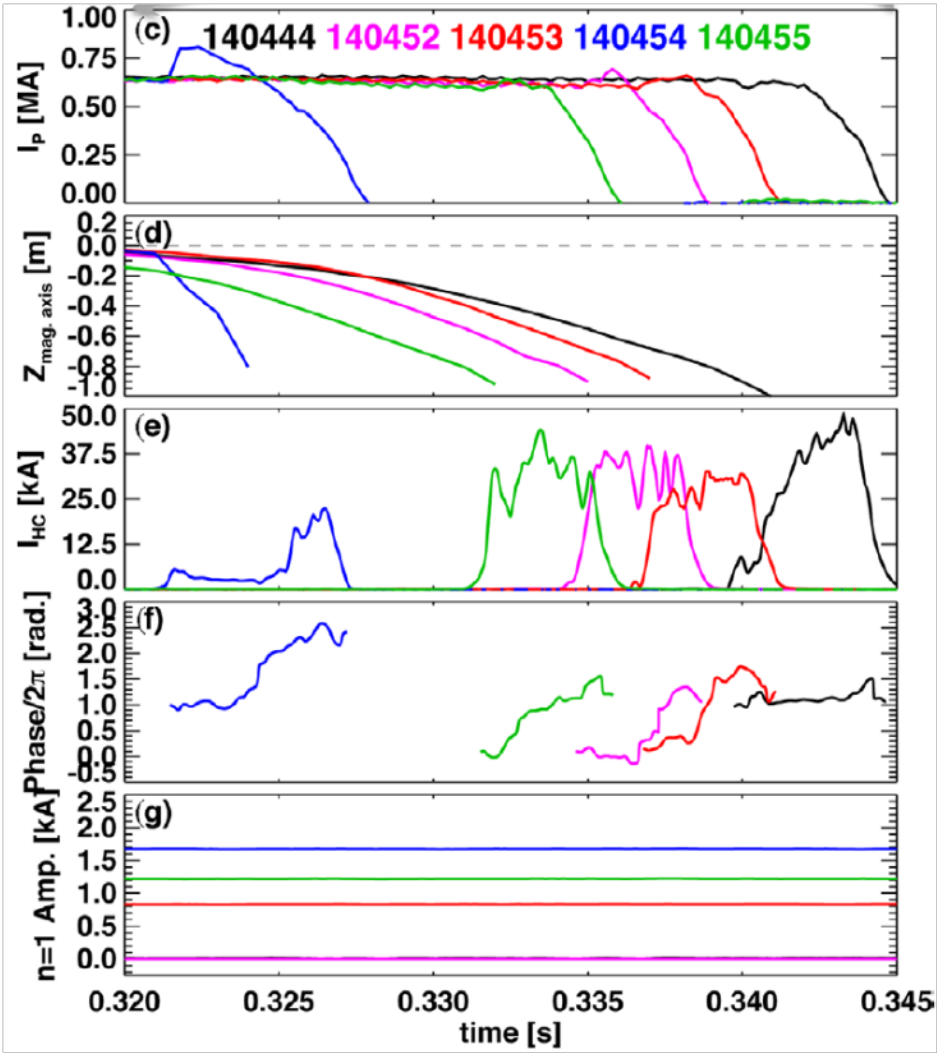
(after disconnection)

- $\Rightarrow \omega\tau_w/m$=13 for shot 72926 and B_θ=7.3x10^{-3}T (NB. maximum force at $\omega\tau_w/m$=2)
- $\Rightarrow$Toroidal Force ~ 200N
- Mass plasma O(10^{-5}) kg

Can we affect halo rotation with RMPs?

- Many periods of rotation seem to be inhibited, but why isn't locking force very strong?

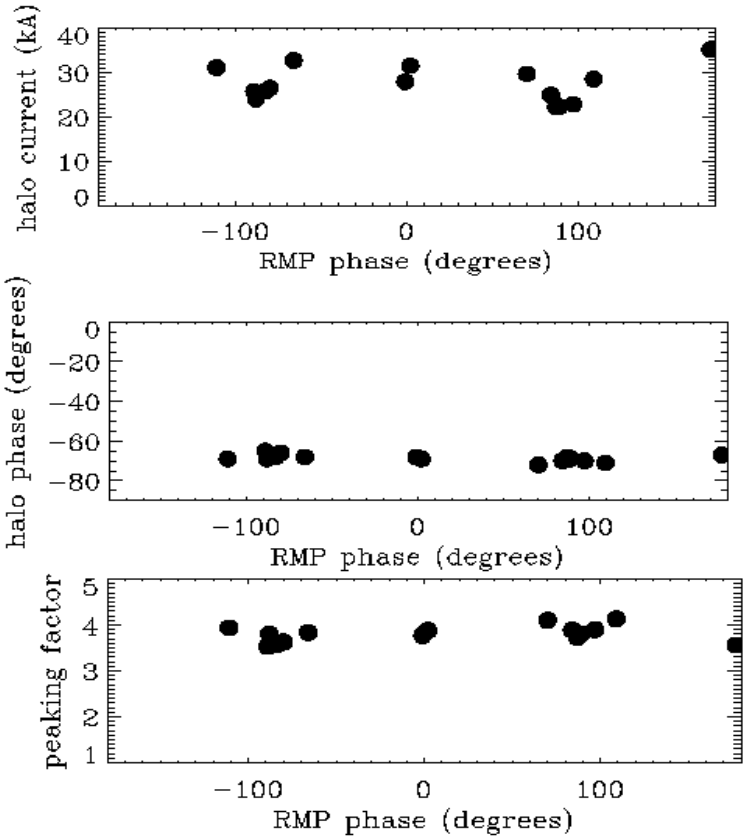




NSTX: S Gerhardt, NF 2013

Can we affect halo rotation with RMPs?

- In COMPASS-D halo peaking locked in phase, unaffected by applied (2,1) Resonant Magnetic Perturbation (RMP)



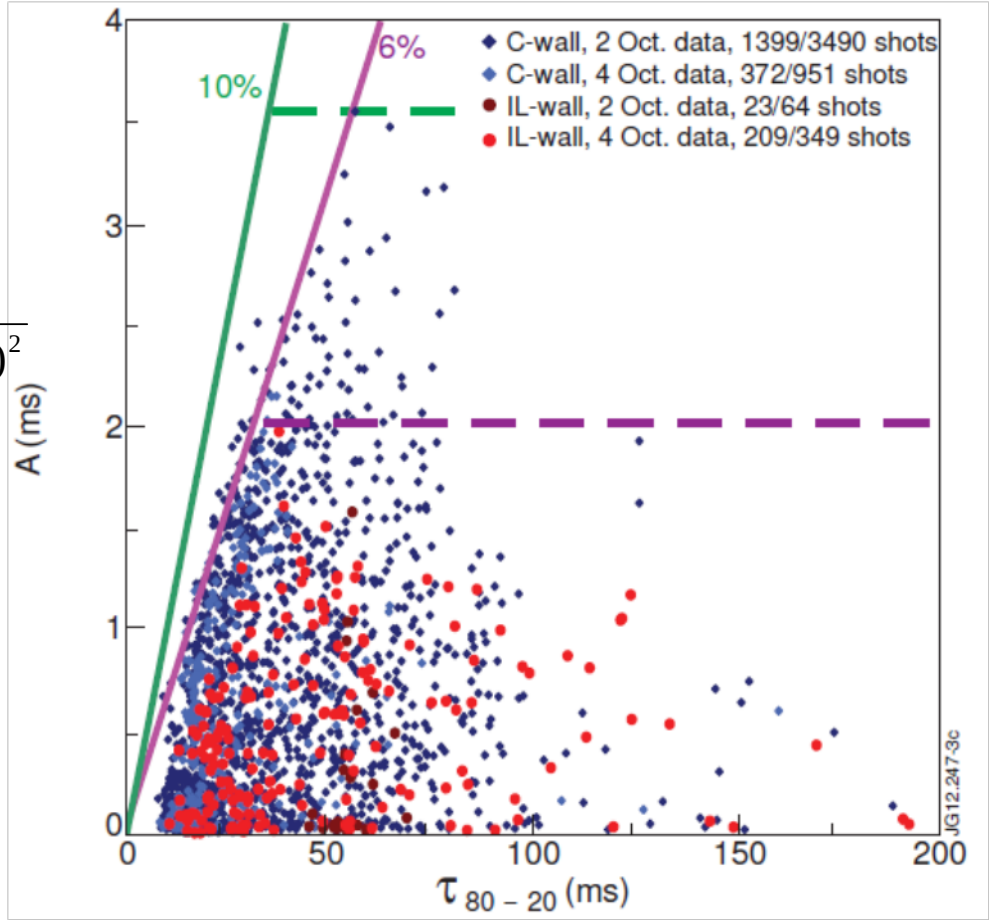
Knight et al, NF 2000

Effect of the halo asymmetry is due impulse force

$$A_{4\,oct} = \frac{1}{I_p^{dis}} \int I_p^{asym} dt \sim \frac{F_{impulse}}{aB_t I_p}$$

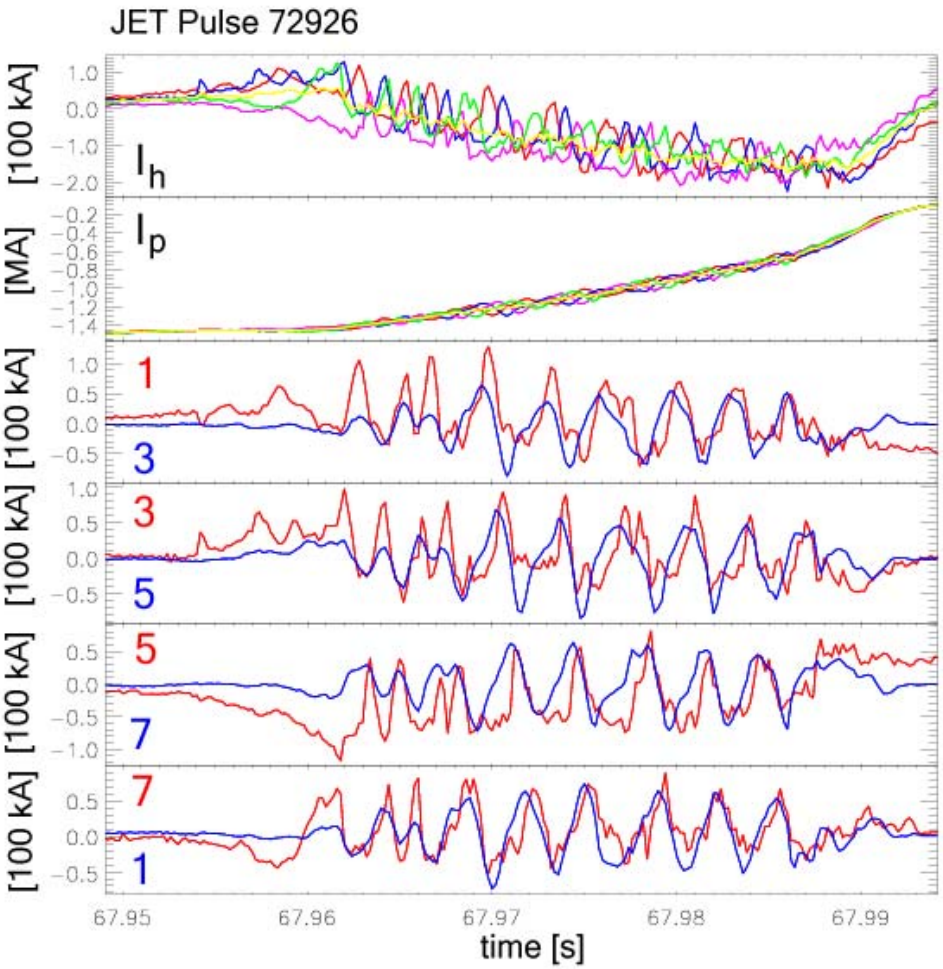
Pre-disrupt I_p

$$I_p^{asym} = \sqrt{(I_7 - I_3)^2 + (I_1 - I_5)^2}$$



- How to scale the impulse time with machine size?

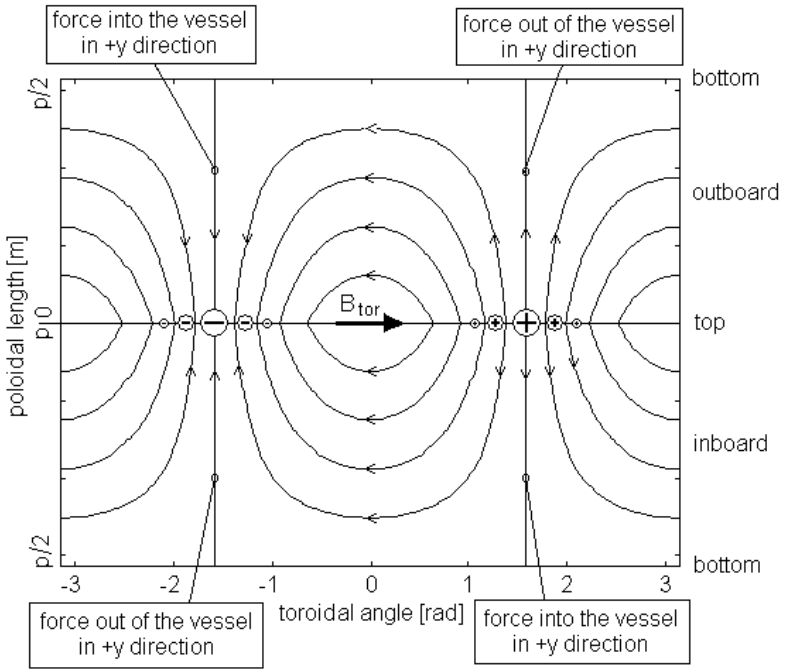
Relationship of poloidal and toroidal halo current



- Important to understand for ITER modelling

I_p Asymmetries – sink and source model

- Phenomenological model, but agrees with experimental observations (V Riccardo et al NF 2000):-



Plasma vertical position	$Z_p=Z_0+\delta Z_p \cos\varphi$
Plasma current	$I_p=I_0+\delta I_p \cos\varphi$
VV source/sink current density [A/m]	$j_v=\delta I_p/R \sin\varphi$

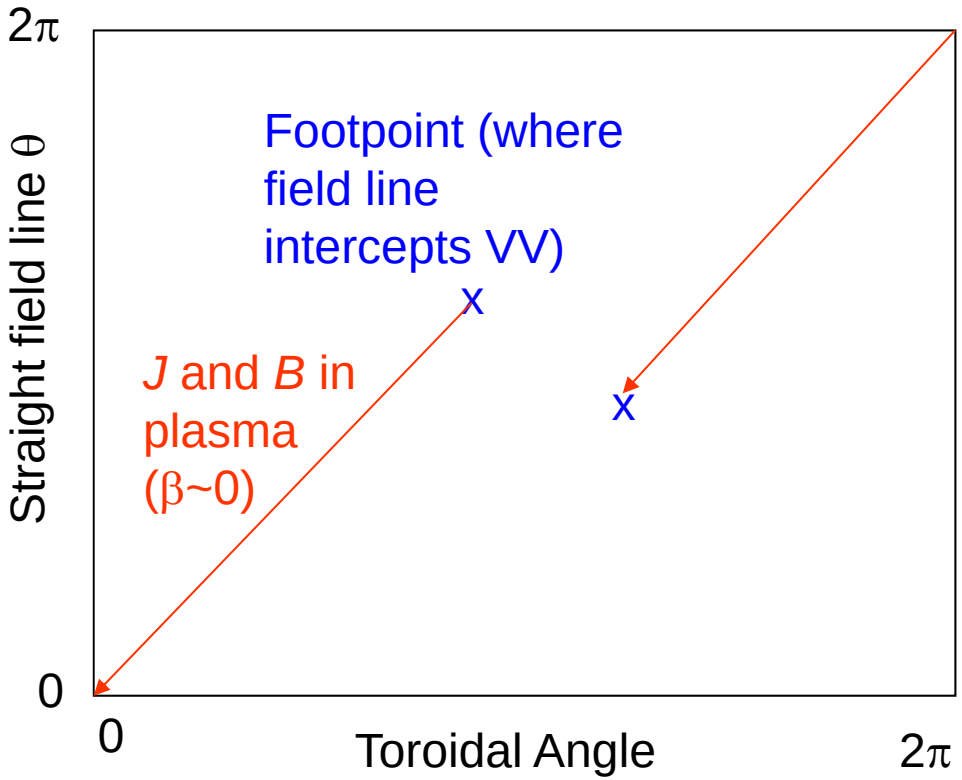
Vessel currents:- $j_\varphi=-\delta I_p/p \cos\varphi$

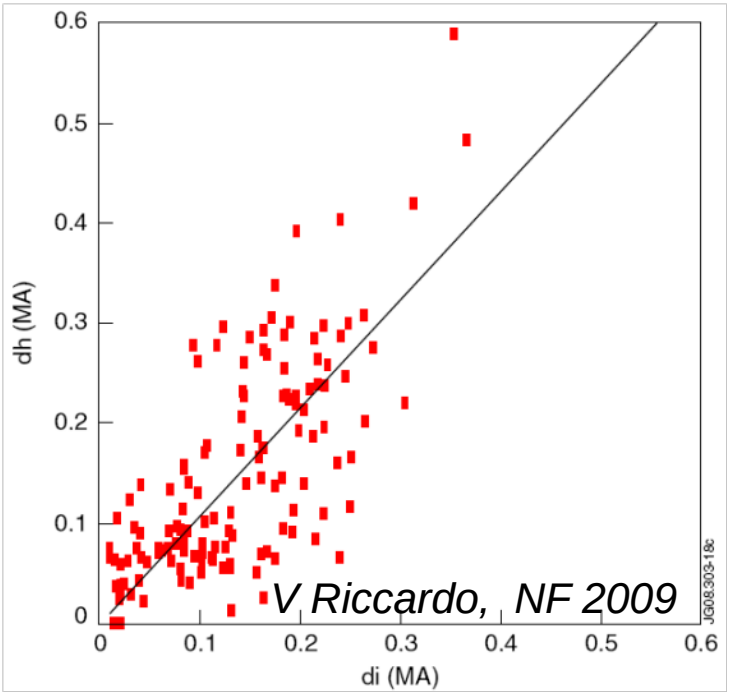
Poloidal extent

$j_s=(\delta I_p/2R)(p-2s)/p \sin\varphi$

- This model gives the observed phase relation of toroidal and poloidal halos (but there is no true poloidal halo current)

Relationship of poloidal and toroidal halo current





- In general there will be a poloidal halo current component
- Variability of poloidal and toroidal halo current as plasma (and footpoints) move

Summary – modelling issues

Asymmetry amplitude:-

- Magnitude of I_p asymmetry <~10%
- How to scale duration with machine size?
- Can a wall touching model account for observed dominantly sinusoidal asymmetry waveforms?
- Is there a difference between q=1 and 2 kinks on halo asymmetry behaviour?

Asymmetry rotation:-

- What drives the rotation mainly in counter-Ip direction
- Variability
- Why don't wall image currents cause locking?
- Effect of RMPs

Relationship of toroidal and poloidal halo current