COMPASS
INSTITUTE OF PLASMA PHYSICS ASCR

Edge Plasma Heat Flux Study in the COMPASS tokamak

***P. Vondracek*[1,2], *J. Horacek*[1], *R. Panek*[1], *R.A. Pitts*[3], *P. Stangeby*[4], *R. Goldston*[5], *M. Kocan*[3]**
R. Dejarnac[1], *M. Komm*[1]

[1]*Institute of Plasma Physics AS CR, v.v.i., Association EURATOM-IPP.CR, Prague, Czech Republic*
[2]*Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic*
[3]*ITER Organization, Route de Vinon sur Verdon, 13115 Saint Paul Lez Durance, France*
[4]*University of Toronto, Institute for Aerospace Studies, Toronto, Canada*
[5]*Princeton Plasma Physics Laboratory, Princeton, USA*

Outline:

- **Parallel Heat Flux** in SOL
- Motivation – **ITER start-up limiter shape** optimization
- Special HFS limiter experiments at COMPASS
  - **Funnel effect** study
  - **double-exponential SOL profile** investigation
  - limiter shape optimization
  - **Non-ambipolar flux** study
  - **Heuristic Drift** (HD) **model**

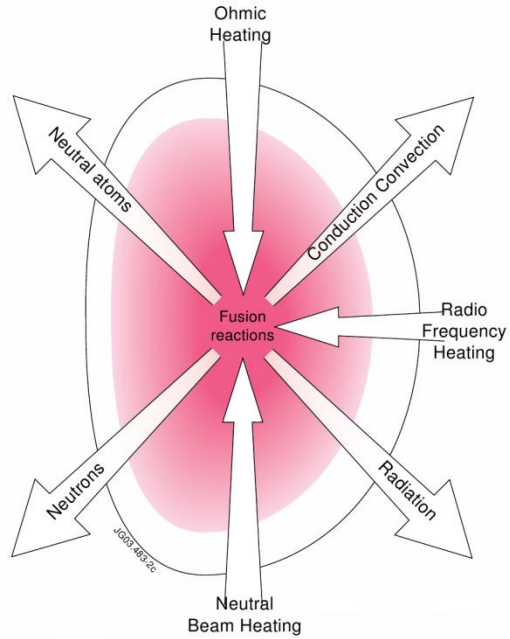
Parallel Heat Flux in SOL

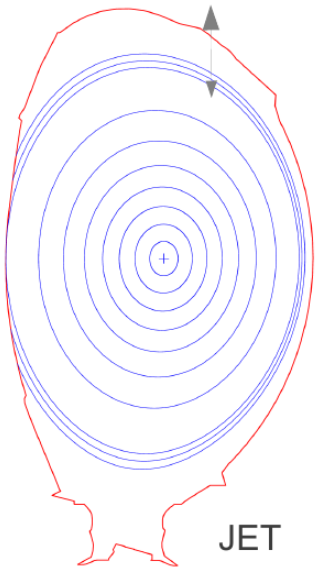
- Diffusion, convection and turbulent transport brings particles to the SOL

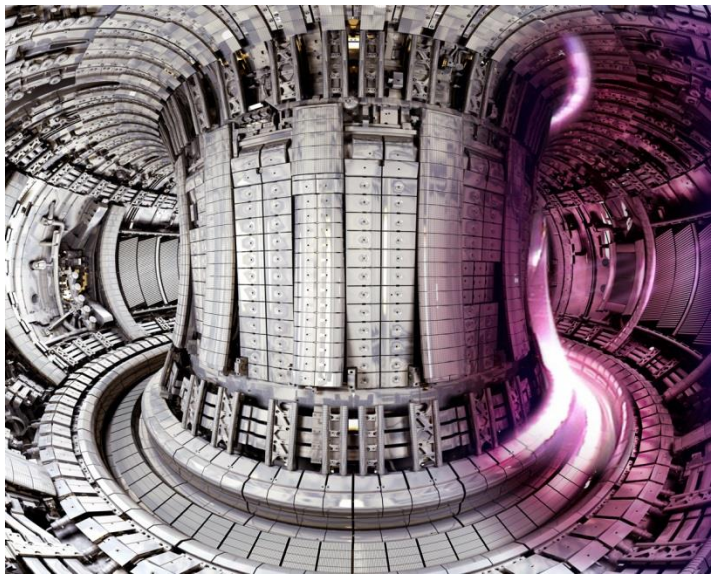
  => parallel heat flux with a **radial decay λ_q** occurs in the SOL

$$q_{\parallel}(r) = q_{\parallel 0}\exp\left(-r/\lambda_q\right) \qquad q_{\parallel 0} \approx \frac{P_{\mathrm{SOL}}\left(B/B_{\mathrm{p}}\right)}{4\pi R\lambda_q}$$

- Radial profile of the parallel heat flux determines **limiter heat load** distribution => $q_{\perp \mathrm{lim}} = q_{\parallel}\sin(\alpha)$



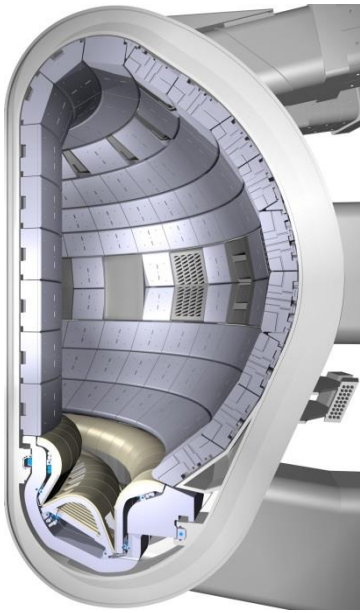




Motivation

ITER start-up limiter shape optimization

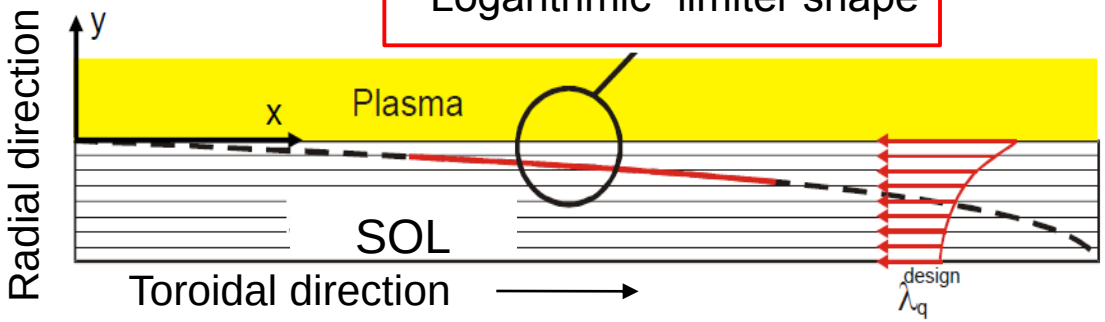
- HFS beryllium limiter tiles are foreseen to be used for plasma start-up in ITER
- **Tile shaping** should provide **uniform heat flux** distribution across the limiter surface
- **Exponential radial decay of parallel heat flux** in SOL is expected

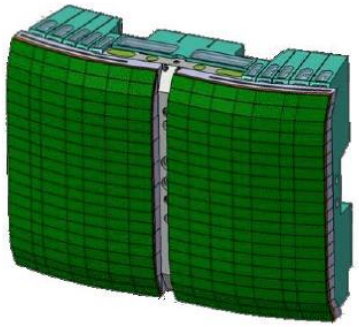


$$q_{\perp \mathrm{lim}} = q_{\parallel 0} \exp\left(-r/\lambda_q\right) \sin(\alpha)$$

$$y = -\lambda_q \ln\left(1 - \mathrm{C}x/\lambda_q\right)$$

"Logarithmic" limiter shape





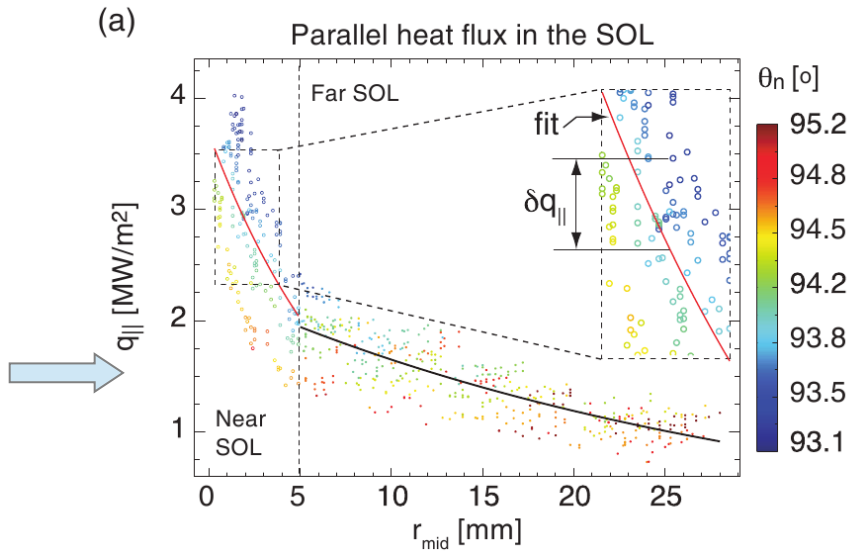
Motivation

Prediction of λ_q for ITER

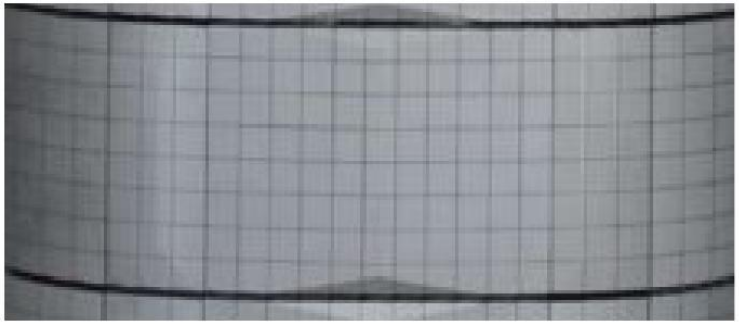
1) Current limiter design λ_q^{imp}**=50mm**

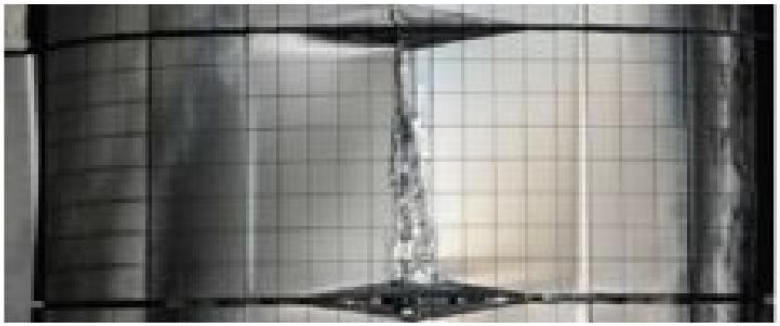
2) Multi-tokamak scaling λ_q^{omp}**~45mm**
(7.5MA scenario) [Horacek et al. 2013]

3) JET beryllium ITER-like limiter experiments
λ_q~couple mm
Near & far SOL feature observed [Arnoux 2012]



Unexpected heat flux observed
- limiter melted at the crown!!!





Funnel effect??? *Non-single exponential SOL profile???* *Non-ambipolar flux???*

ITER-like HFS limiter on COMPASS

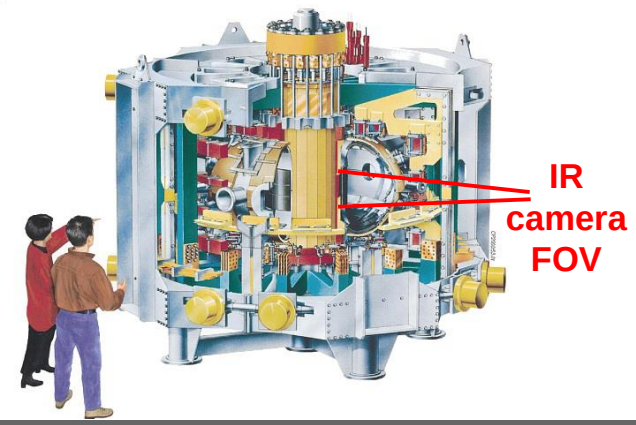
Series of dedicated experiments with **special limiters** at HFS

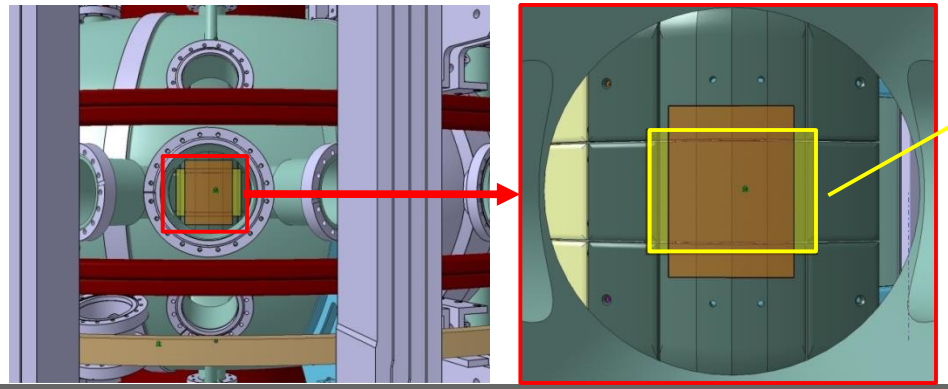
Main diagnostics:

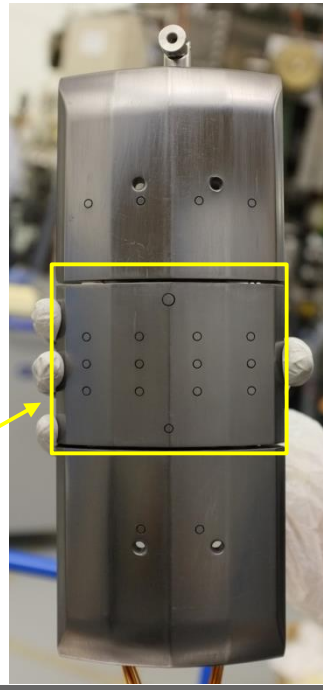
- Microbolometric **IR kamera** (120Hz, 160x120px, 1px~1mm)
  + **THEODOR code** for heat flux calculation
- Midplane **reciprocating probe manipulator**
- 20 embedded **HFS limiter probes**

Various I_p and B_T orientations

Radial position of the limiter was varied (ΔR = 12, 22, 40mm)







Funnel effect

Assumption:

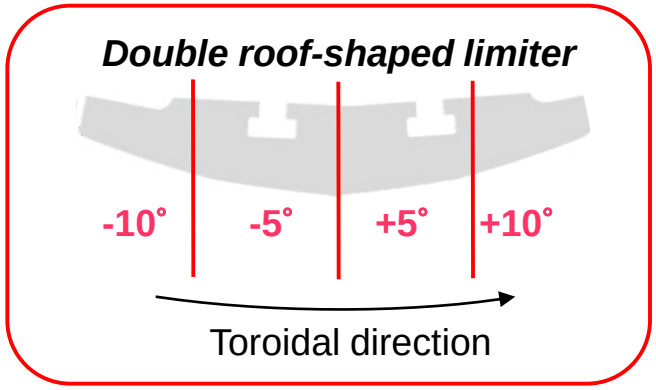
„Funnel effect“ is angle-dependent

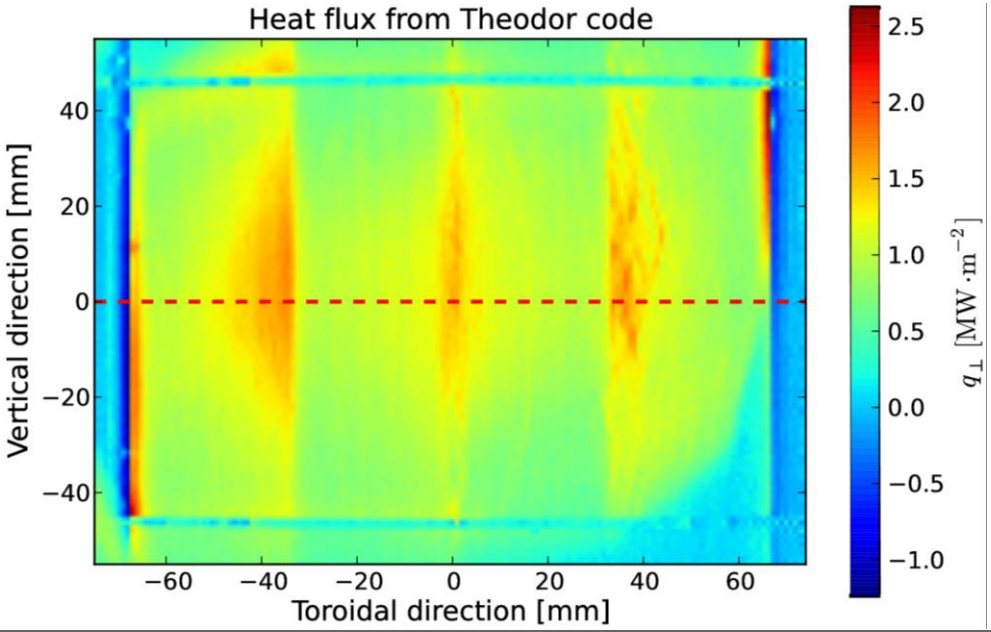
=> **additional heat flux to the 5° parts expected**

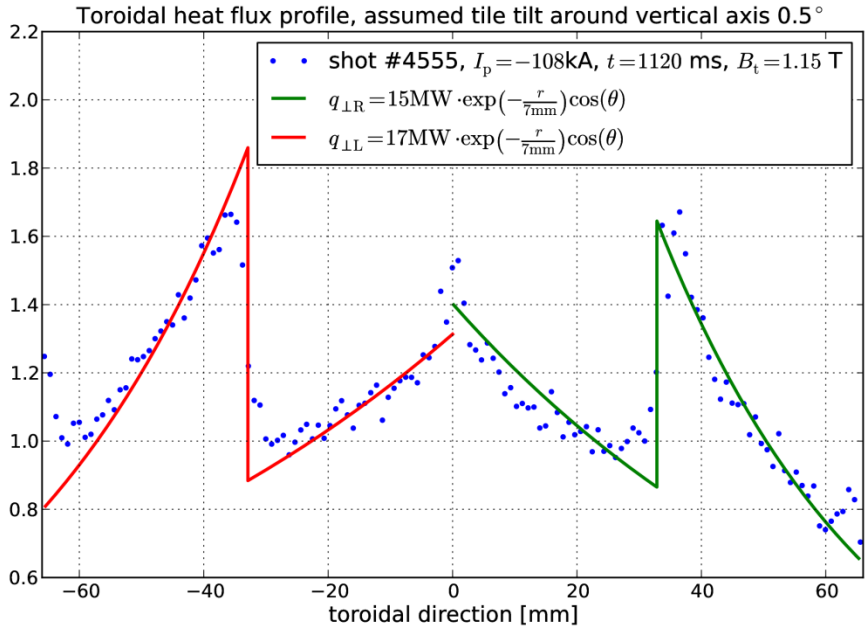
Result:

Heat flux purely parallel

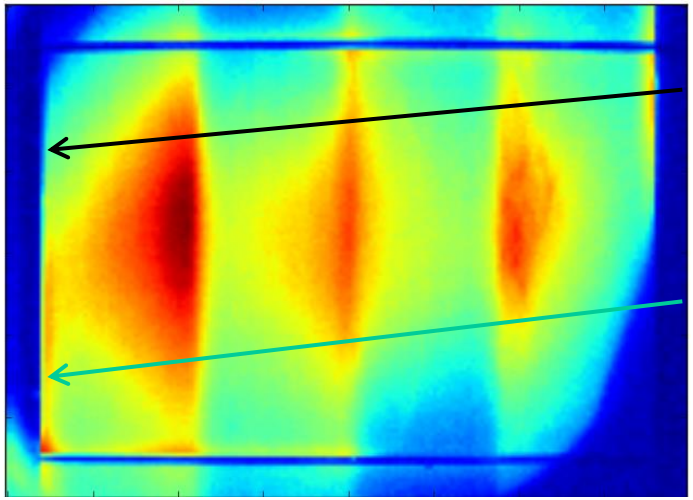
=> **no funnel effect evidence**



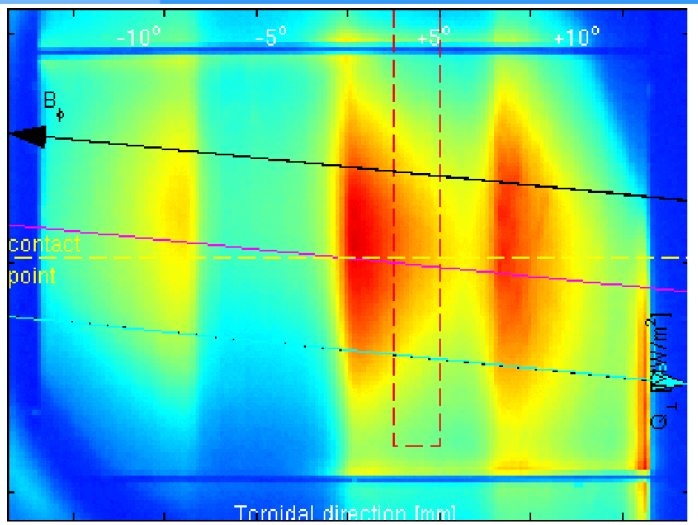




Heat flux asymmetry

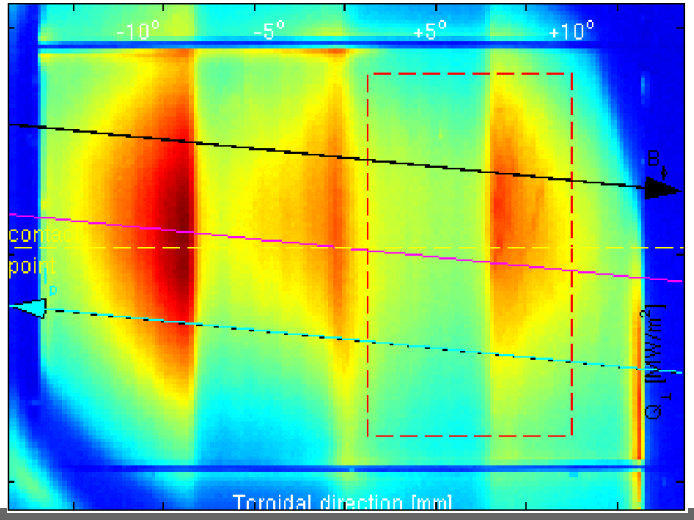


I_p<0

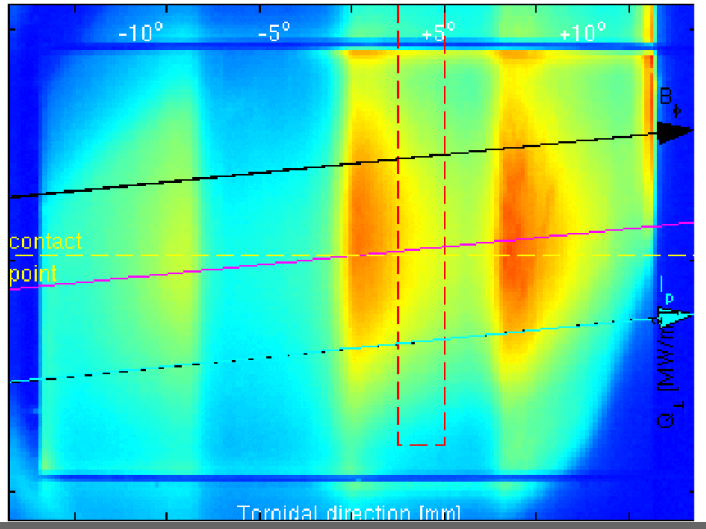


B_T<0

I_p>0



B_T>0



Near & Far SOL

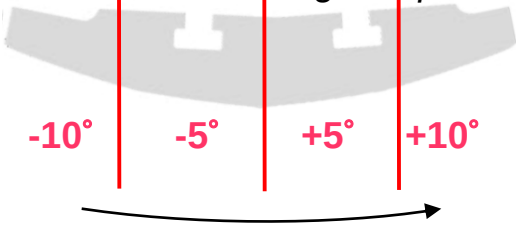
Double-exponential radial profile:

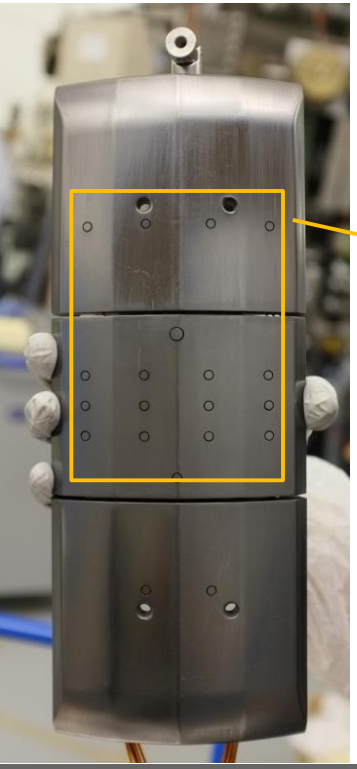
$$q_{\parallel}(\Delta r) = q_{\parallel 0,\mathrm{near}} \exp\left(-\Delta r/\lambda_{q,\mathrm{near}}\right) + q_{\parallel 0,\mathrm{far}} \exp\left(-\Delta r/\lambda_{q,\mathrm{far}}\right)$$

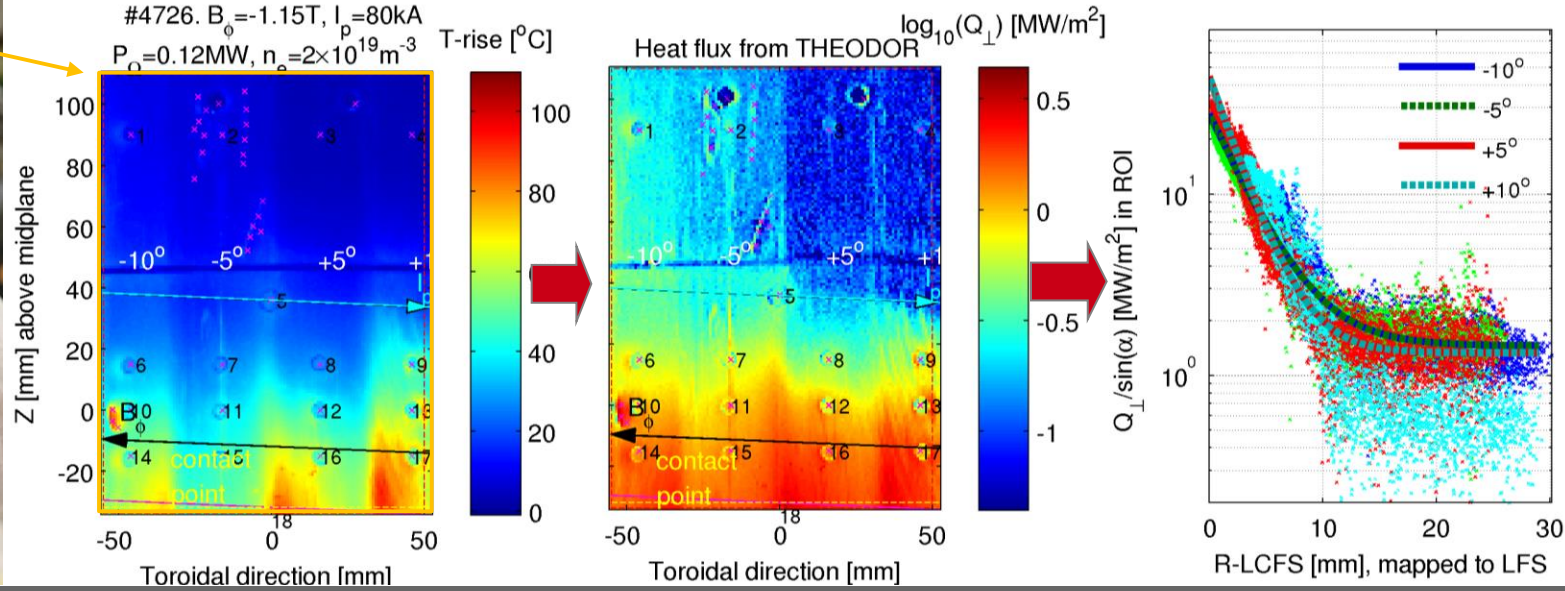
Double roof-shaped limiter

± 5˚tilting mechanism

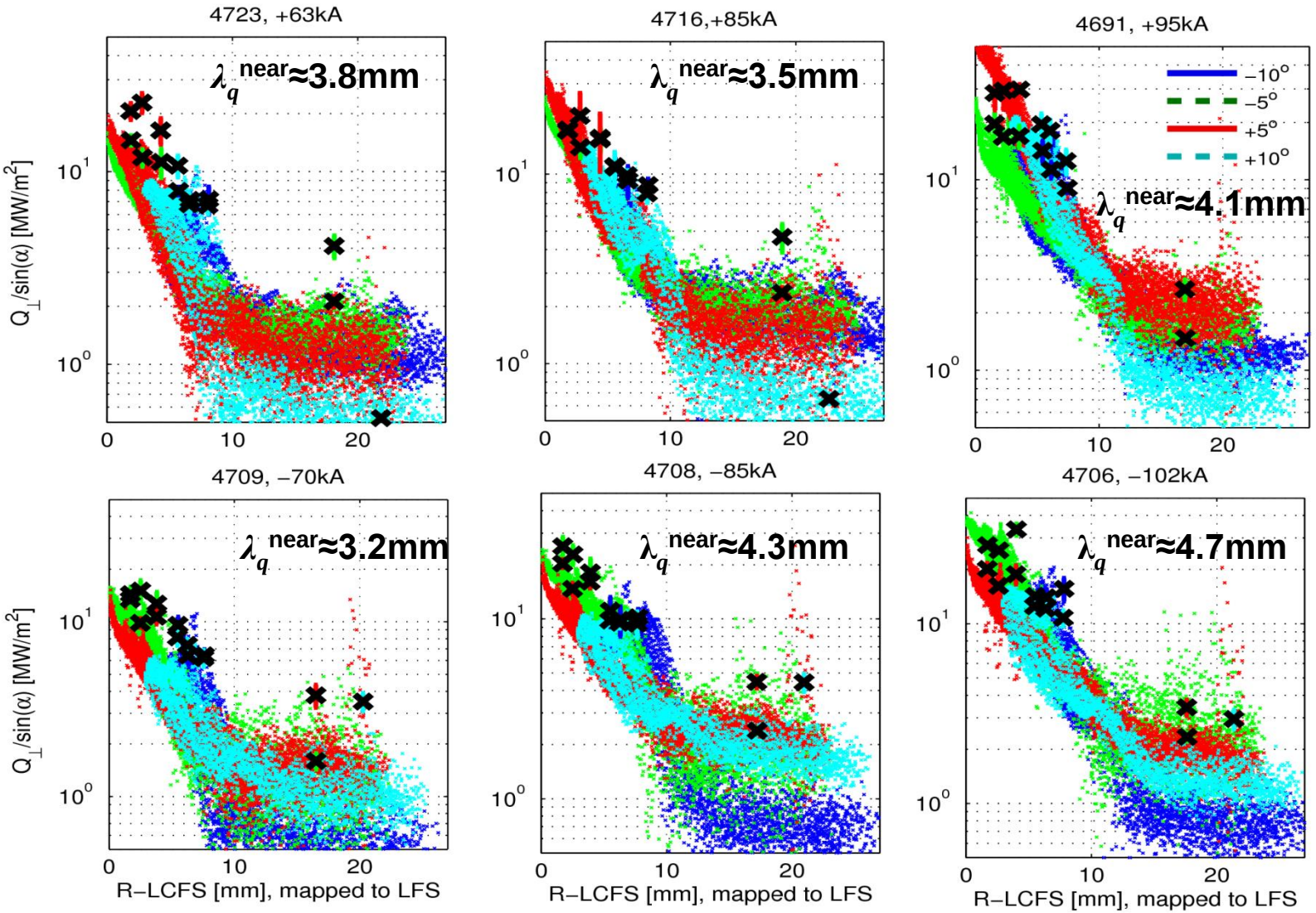
20 flush mounted langmuir probes



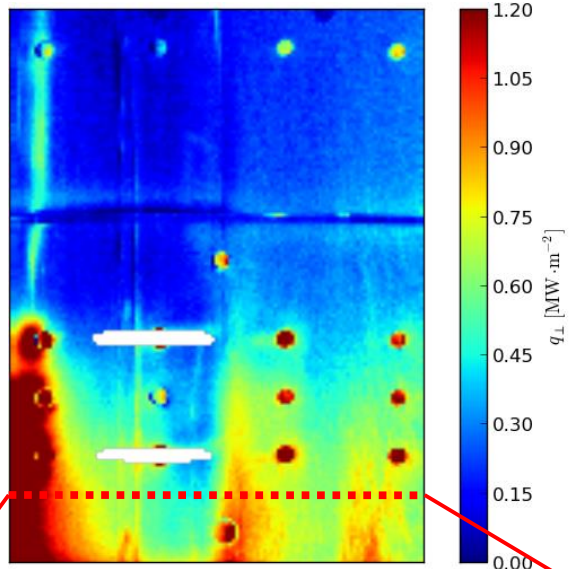


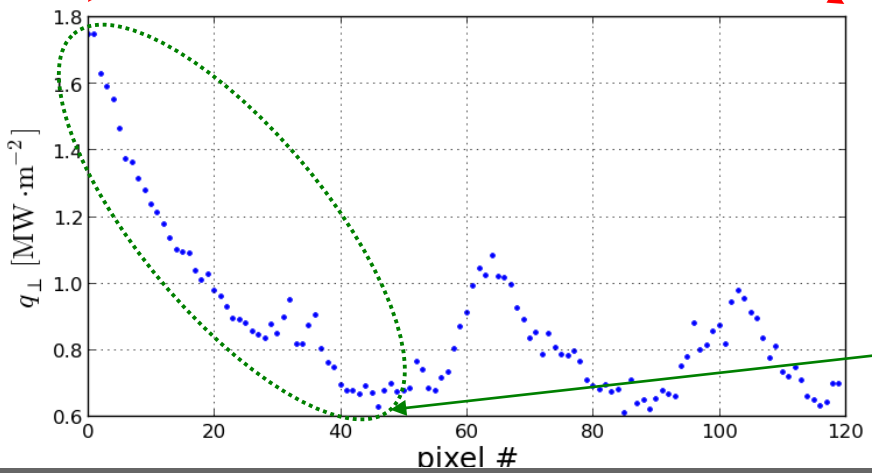


Near SOL λ_q plasma current scan



Shape optimization



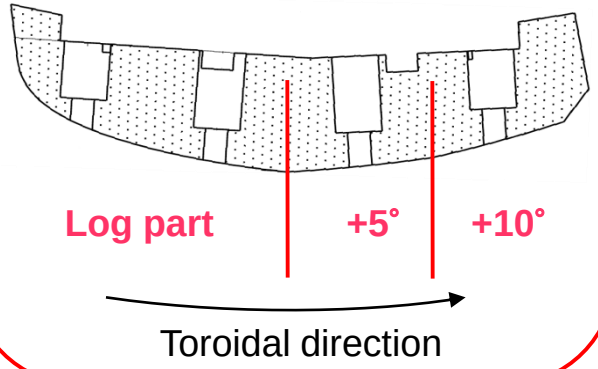


Combined double roof-shaped and logarithmic limiter

± 5˚tilting mechanism

4 flush-mounted langmuir probes

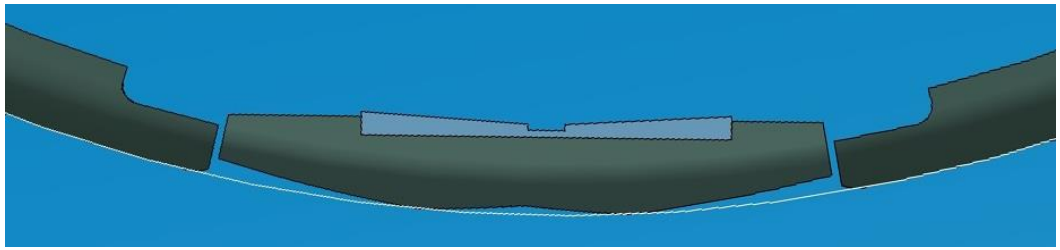
16 domed langmuir probes



Log part of the limiter optimized for λ_q^{omp}**=2.9mm**
=> heat flux should increase towards limiter edge for typical COMPASS shot

Recessed roof-shaped limiter

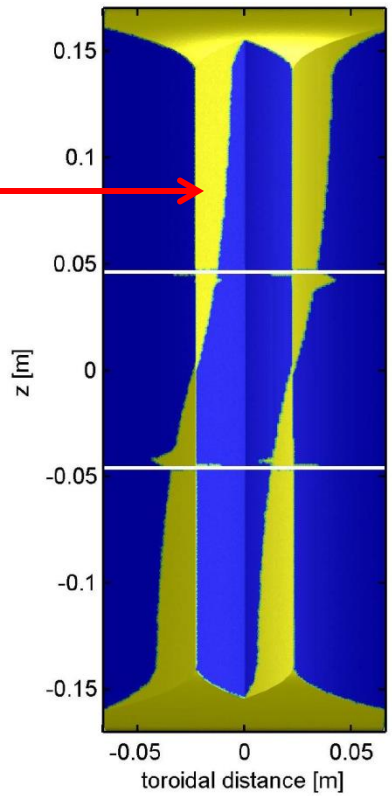
Plan for 01/2014

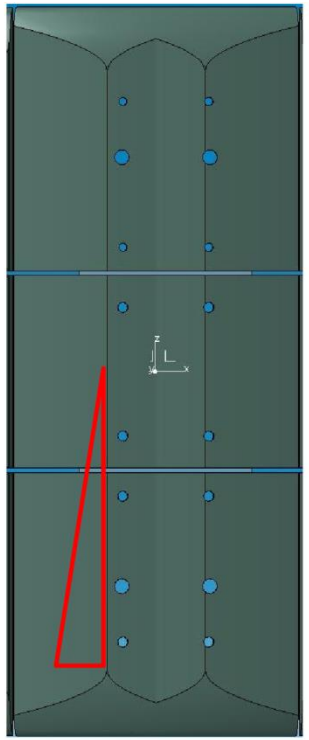


- Better approximation of the ITER continuous central column limiter
- Quite **small wetted area**

=> IR camera with a finer spatial resolution will be used

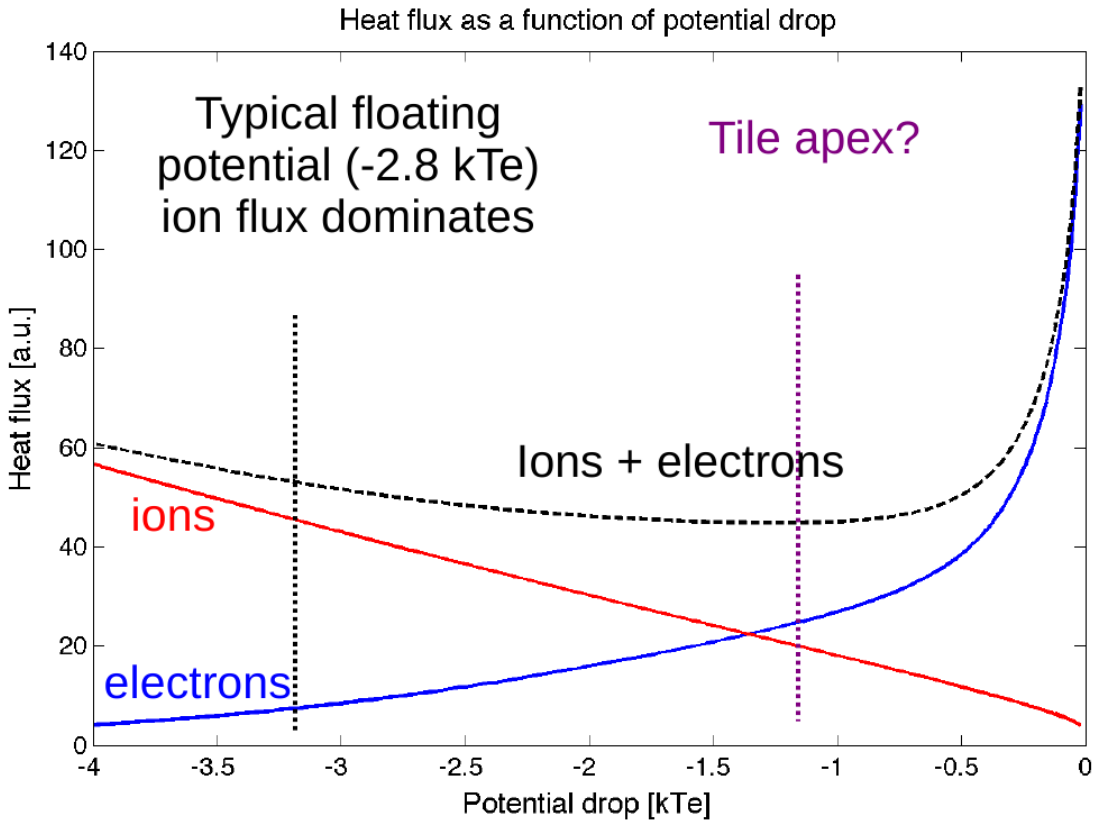
JADE MWIR camera
cooled InSb detector
320x256px. 170Hz 1px.~0,6mm
Larger FOV = wider radial profile





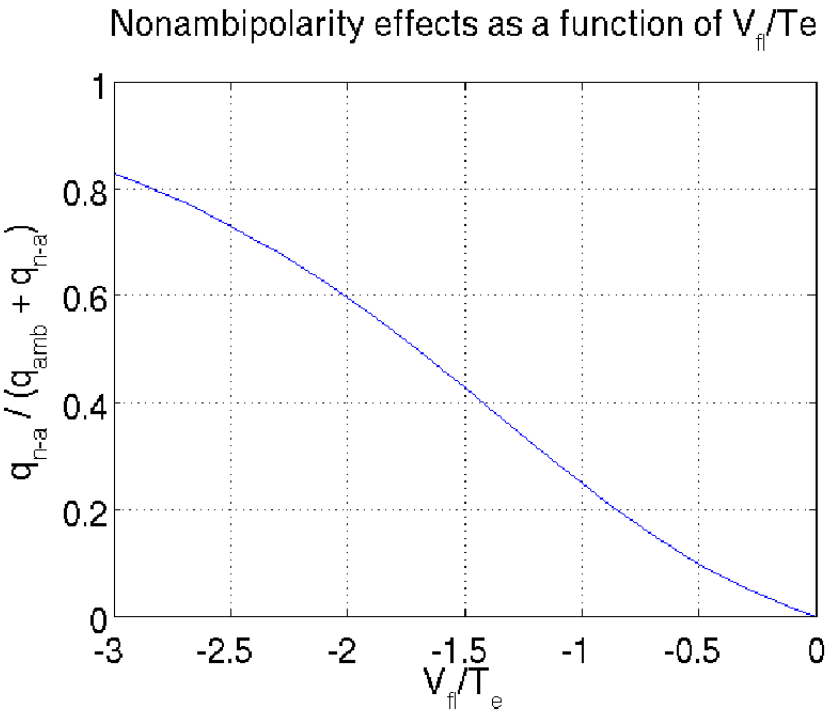
Non-ambipolar flux studies

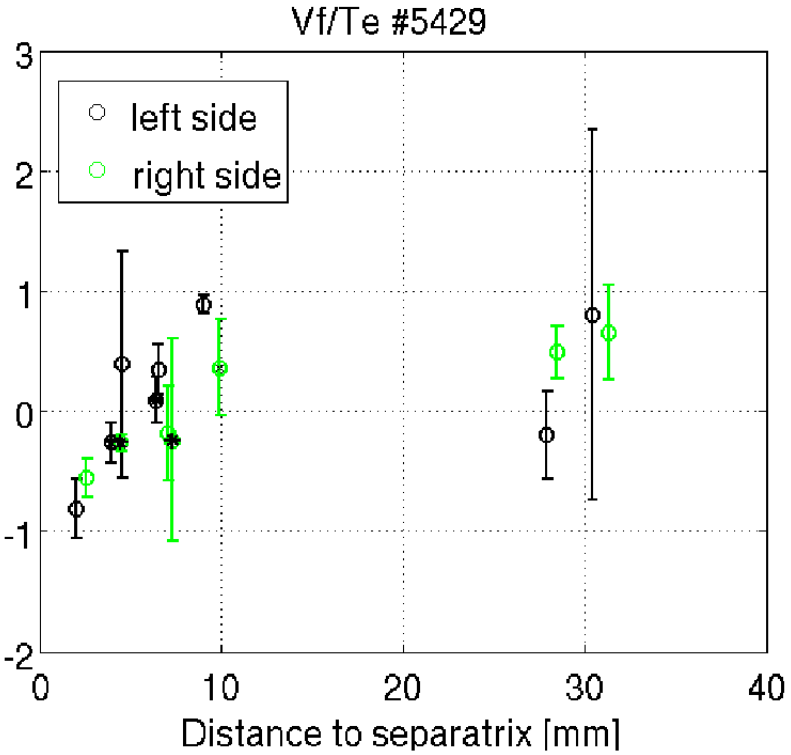
- Local heat flux exposed to the limiter depends on its potential compared to the plasma potential
- Heat flux can significantly vary as the plasma potential varies across the limiter surface



Non-ambipolar flux studies

Role of floating potential





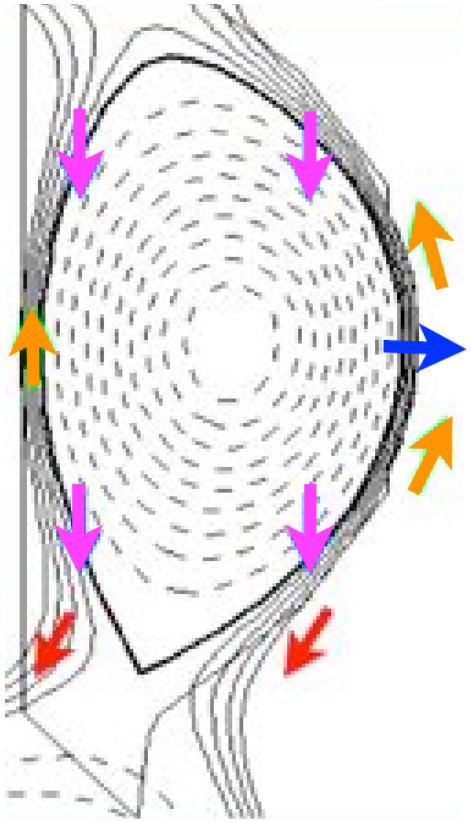
In order to have Δq comparable to q, we need $\mathbf{V_{fl}/T_e < -1.5}$

In experiment we generally see $V_{fl}/T_e > -1.0$

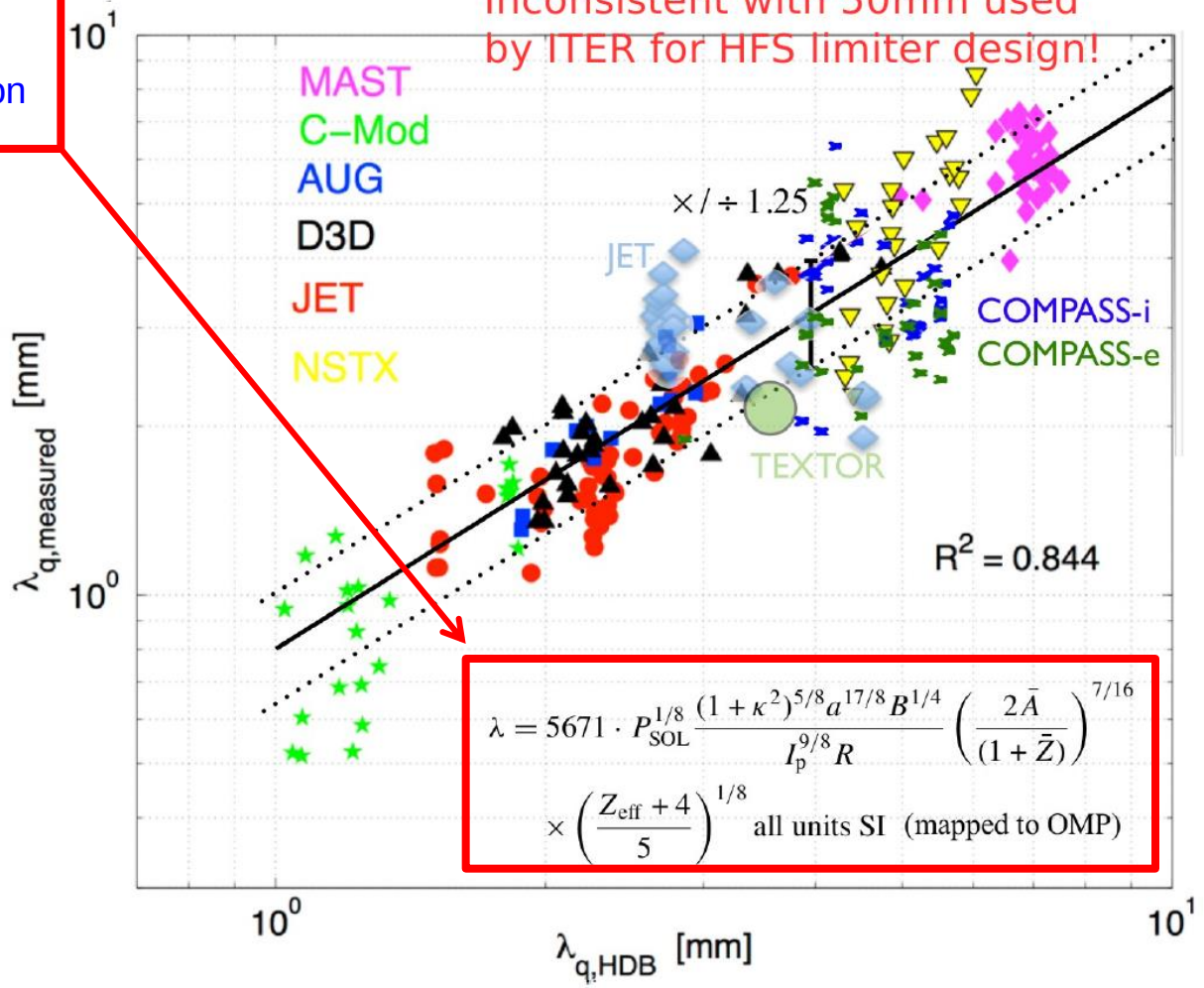
But still, non-ambipolarity may contribute ~ up to 30% in the near SOL

Heuristic drift model

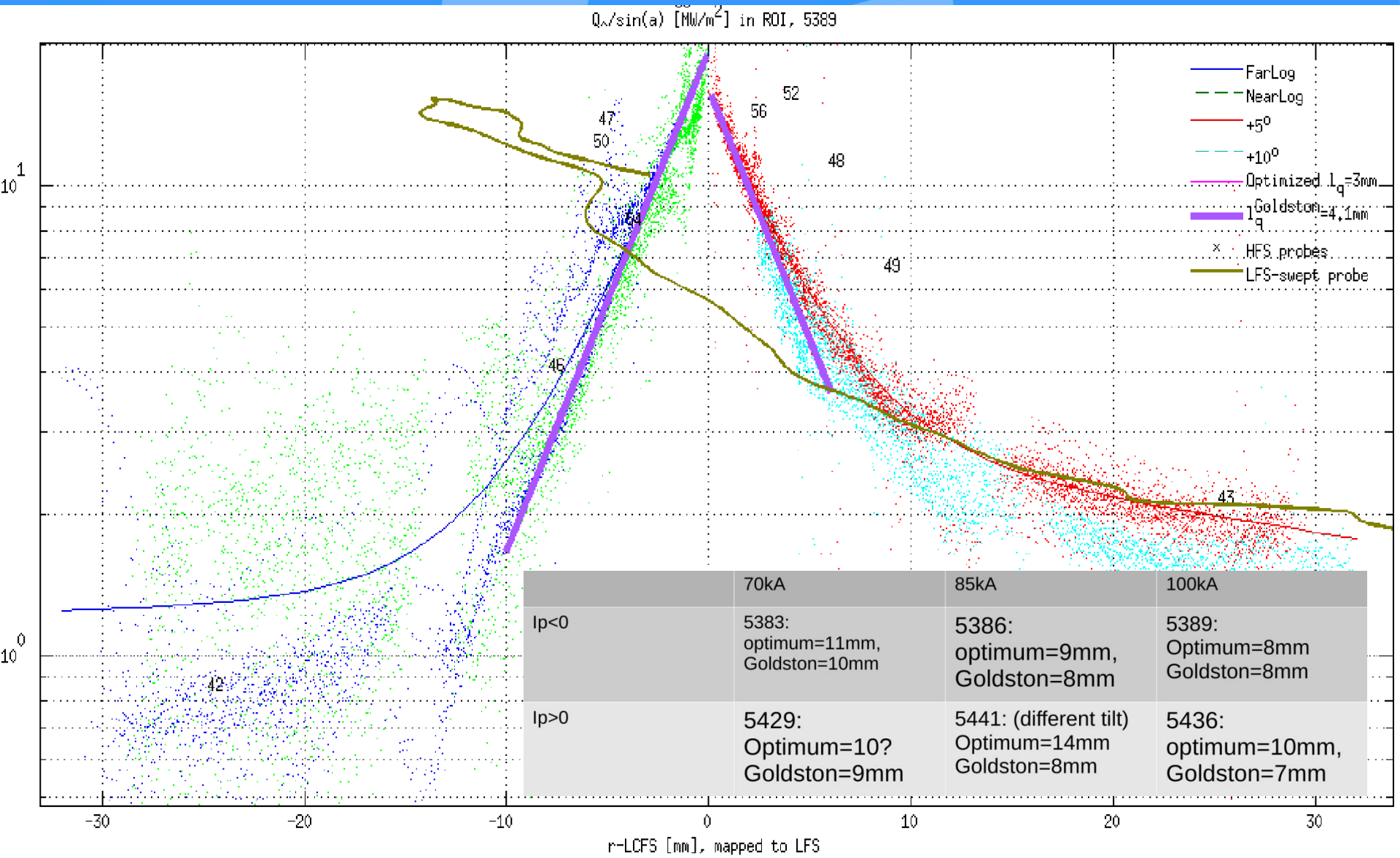
- Vertical drifts cross separatrix into SOL
- Parallel flows in SOL
- Pfirsch-Schlüter flow
- Anomalous electron thermal conduction



Inconsistent with 50mm used by ITER for HFS limiter design!



HD model & Experiment



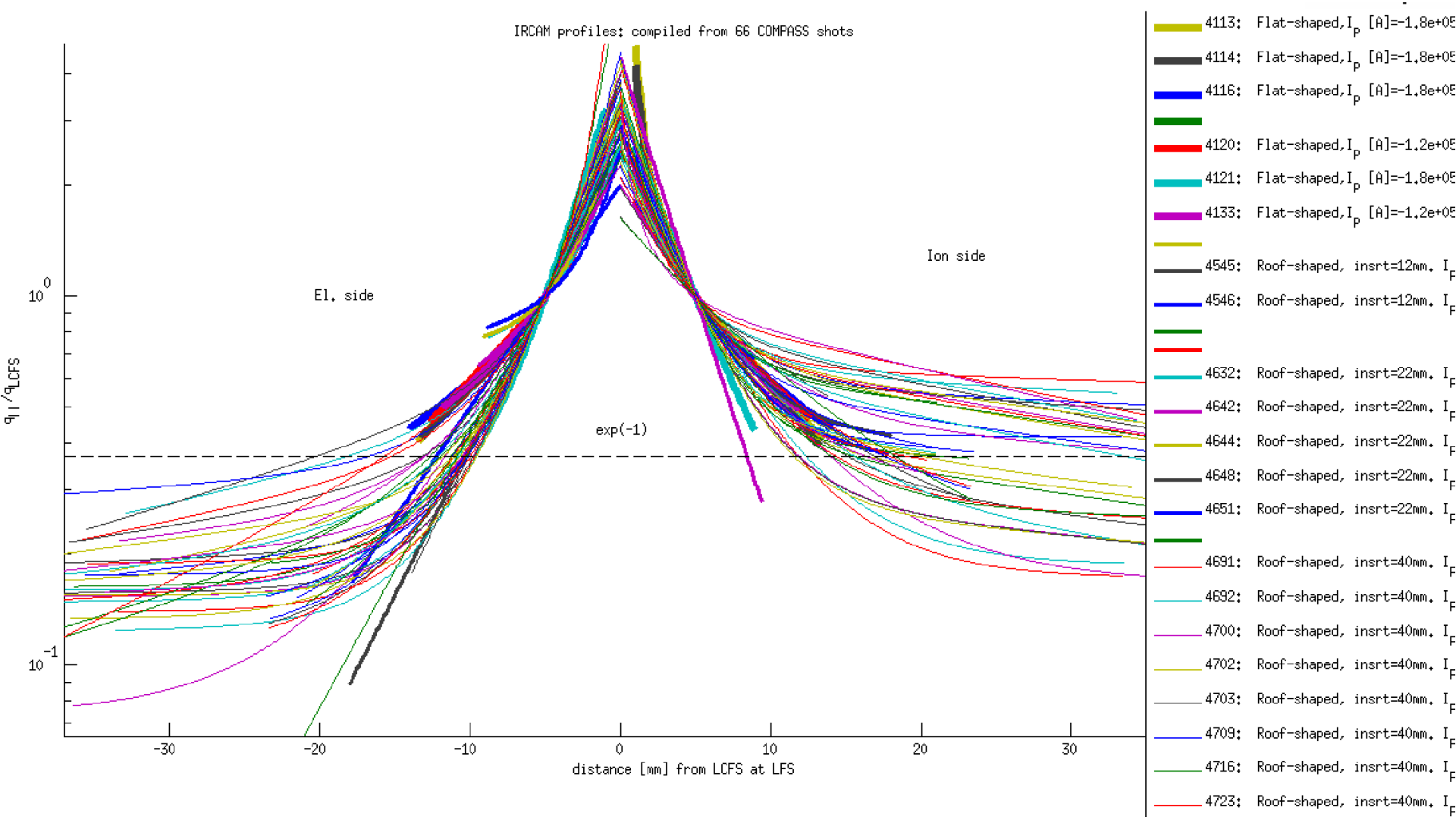
	70kA	85kA	100kA
Ip<0	5383: optimum=11mm, Goldston=10mm	5386: optimum=9mm, Goldston=8mm	5389: Optimum=8mm Goldston=8mm
Ip>0	5429: Optimum=10? Goldston=9mm	5441: (different tilt) Optimum=14mm Goldston=8mm	5436: optimum=10mm, Goldston=7mm

Conclusion

- COMPASS experiments indicated that ITER HFS limiter shape optimized for decay length measured at LFS might not be correct - we need more data analysis
- Further study of double-exponential heat flux SOL profile of plasma limited at HFS is needed.
- **λ_q scaling based on HFS data** (IR or probes) **is urgently needed!**
- **Local non-ambipolarity** of the parallel heat flux is not negligible but **quite weak** effect
- COMPASS data in **good correspondence with the HD model**
- **Recessed roof limiter experiment will be performed** to investigate influence of the non-continuous limiter

Thank You for your attention!

Different limiters comparison



Changes in heat flux due to non-ambipolarity affect both electrons and ion (from Rob Goldston's cookbook)

$$q_{e,n-a} = q_{\parallel,e}(V=0) - q_{\parallel,e}(V=V_{float}) = 2\,T_e\,j_{sat,i}\left(\exp\left(-V_{fl}/T_e\right)-1\right)$$

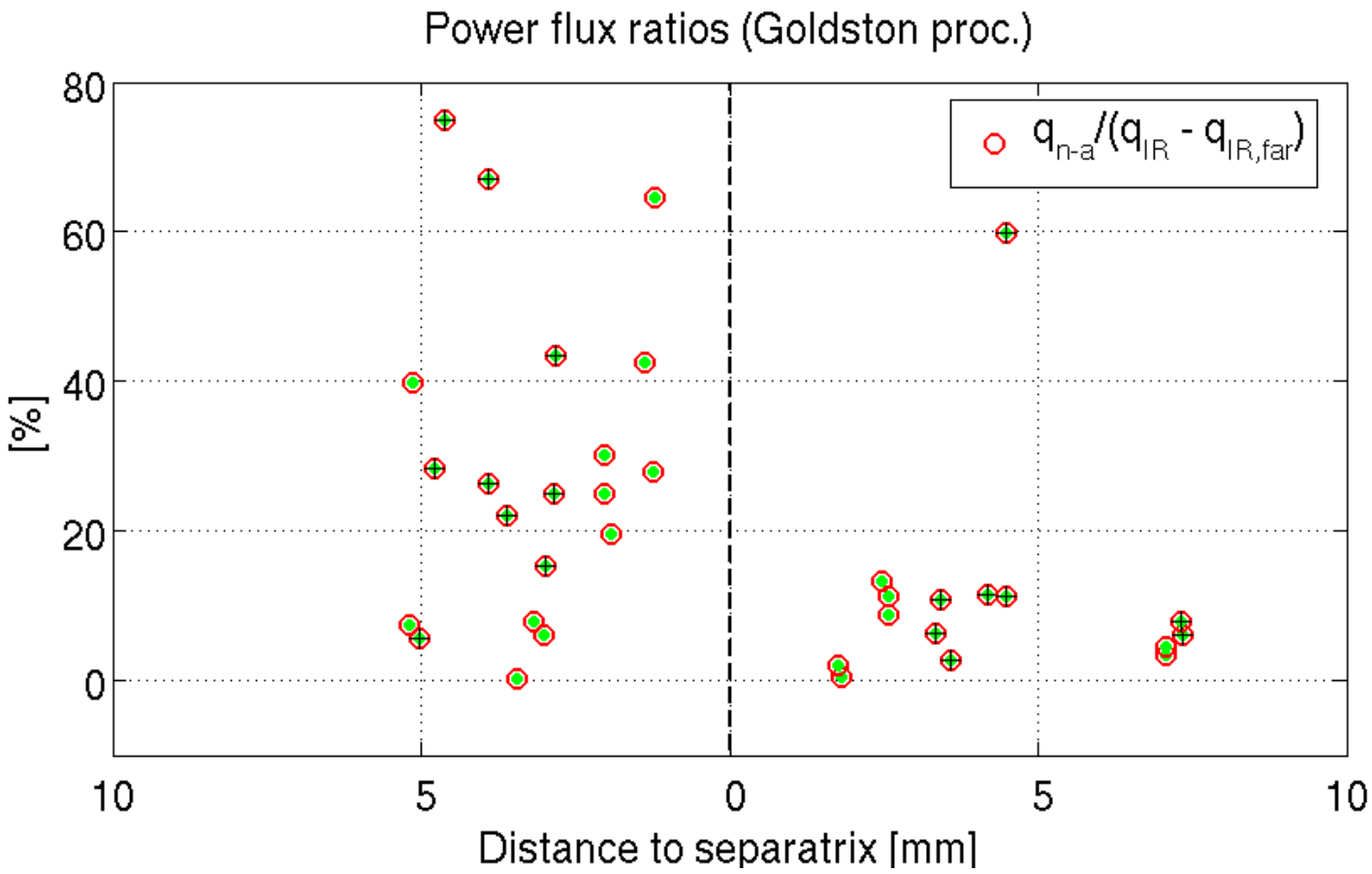
$$q_{i,n-a} = j_{sat,i}\,V_{fl}$$

$$q_{n-a} = q_{i,n-a} + q_{e,n-a} = 2\,T_e\,j_{sat,i}\left(\exp\left(-V_{fl}/T_e\right)-1+V_{fl}/2\mathrm{T}_e\right)$$

We may relate this increase of heat flux to simple estimate $q = 7.34 * T_e * j_{sat}$

$$\frac{q_{n-a}}{q_{amb}} = \frac{2}{7.34}\left(\exp\left(-x\right)-1+\frac{x}{2}\right);\; x = V_{fl}/T_e$$

The advantage of this approach is that we don't need to know j_{sat}, which may be difficult to obtain from IVs due to problems with saturation of the ion branch


Power flux ratios (Goldston proc.)
$q_{n-a}/(q_{IR} - q_{IR,far})$
80
60
40
20
0
[%]
10
5
0
5
10
Distance to separatrix [mm]