# Main Chamber Plasma-Wall Interaction Studies in DIII-D in Support of ITER

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With:

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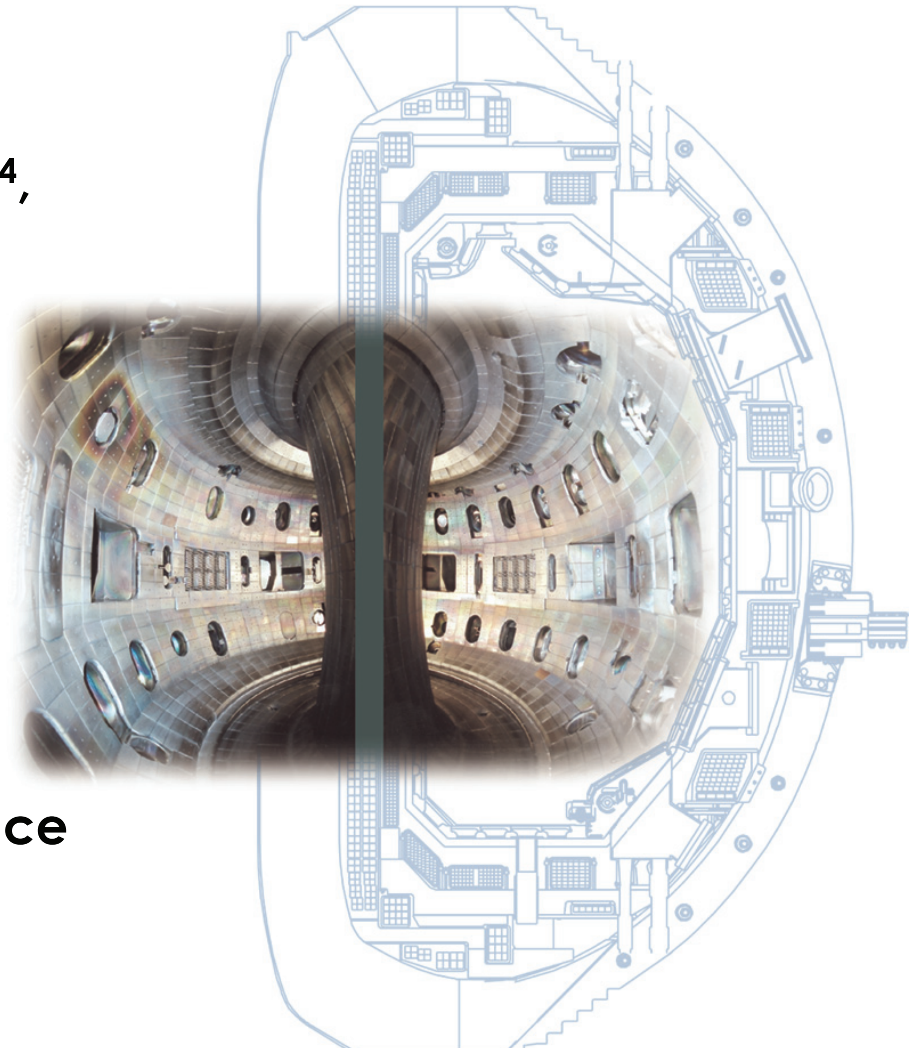

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# Why are We Interested in Plasma Interaction on the ITER First Wall?

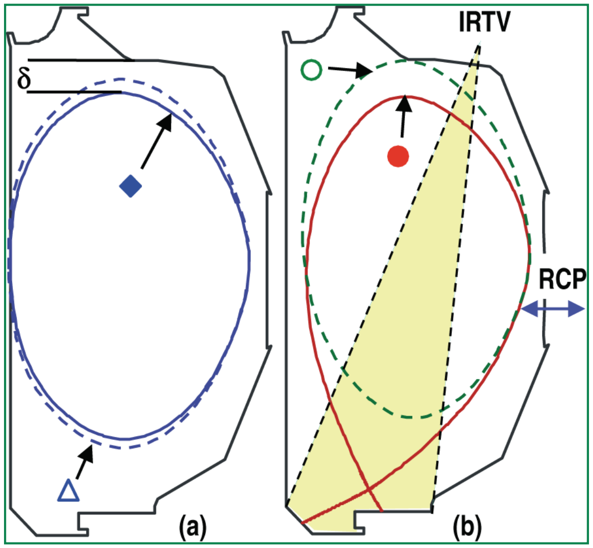
- **ITER will startup on limiters**
  - The ITER startup will use inside or outside limiters in L mode but the scaling predictions of power decay lengths are based on extrapolation from the diverted plasma database. The power deposition distribution will depend on the power flux density scrape-off length
- **Power deposition expected outside the main divertor**
  - ITER will use unbalanced double-null configurations with a secondary divertor at the top. Thermal and particle loads during and between ELMs need to be better known in secondary divertors and will help verify ITER design models
- **DIII-D can contribute**
  - DIII-D, with good diagnostics, excellent shape control,  and a flat lower divertor target geometry provides an excellent platform to study these issues

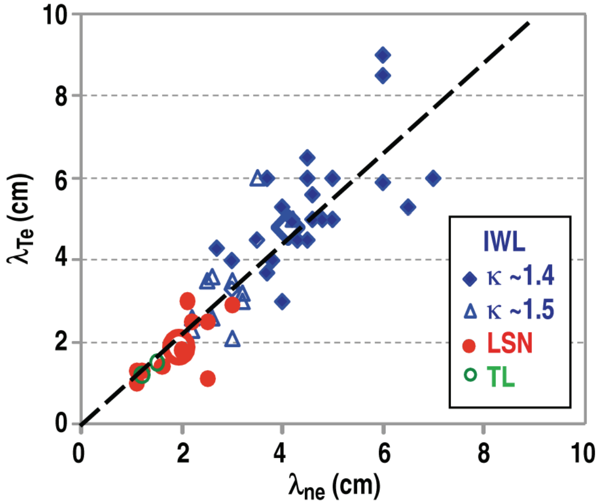
# SOL Power Decay was Measured by Probes and IRTV

- **Poloidal cross sections of the magnetic configurations used in the SOL width study include:**
  - Inner wall limited (IWL)
  - Toroidally limited (TL) and
  - Lower single null (LSN) diverted
- **Density and temperature SOL widths were measured with the midplane reciprocating probe and power decay lengths were calculated from:**

$$1/\lambda_q = 1/\lambda_n + 3/2\lambda_T$$

- **Density and temperature decay lengths were correlated and IWL widths were 2.5X the LSN widths as expected for ITER**

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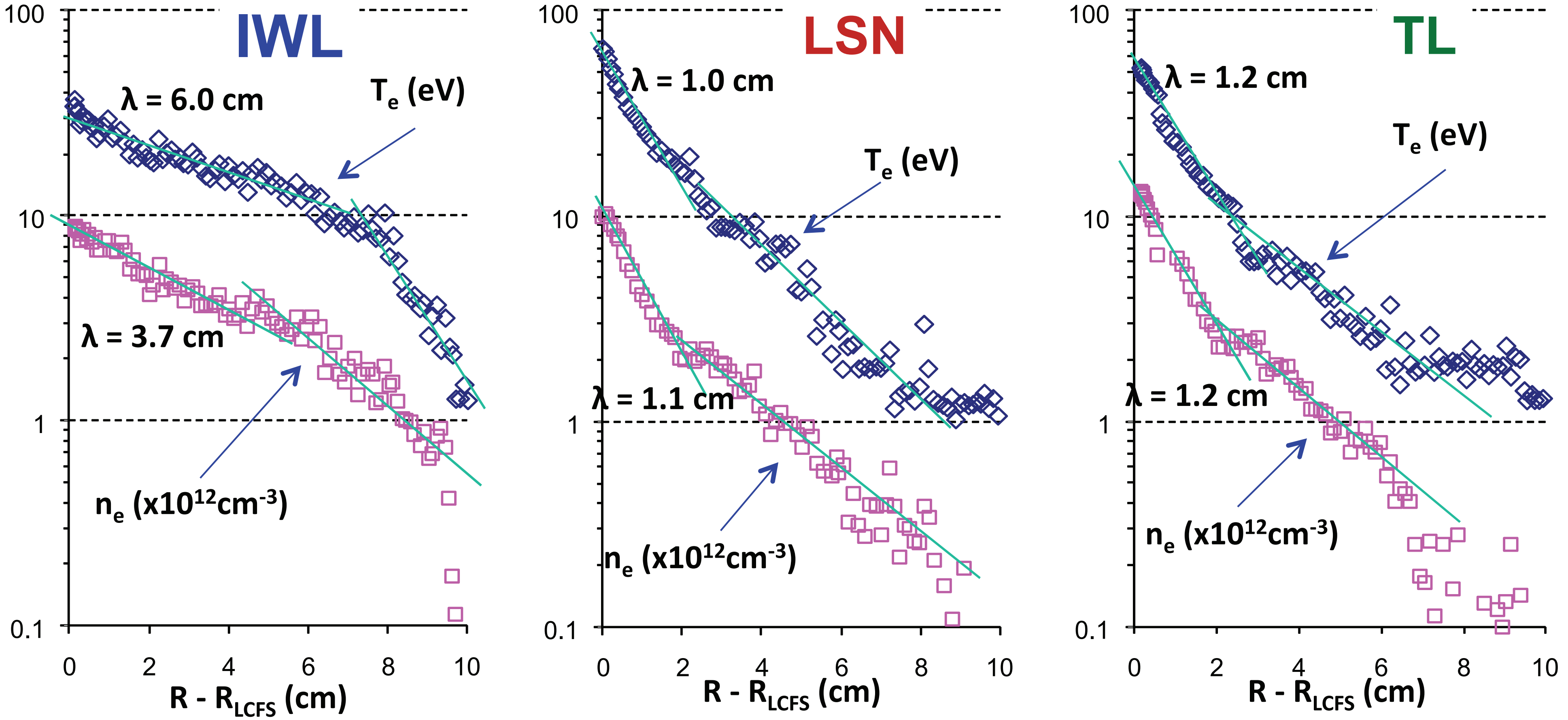
# SOL $n_e$ and $T_e$ e-folding Lengths Nearest to the Last Closed Flux Surface are Used for the Scaling




**Shot # 136490**
**$I_p$ = 0.88 MA**
**$n_e$ = 2.37x10$^{13}$cm$^{-3}$**
**$P_{SOL}$ = 0.4 MW**

**Shot # 136585**
**$I_p$ = 0.88 MA**
**$n_e$ = 1.76x10$^{13}$cm$^{-3}$**
**$P_{SOL}$ = 0.23 MW**

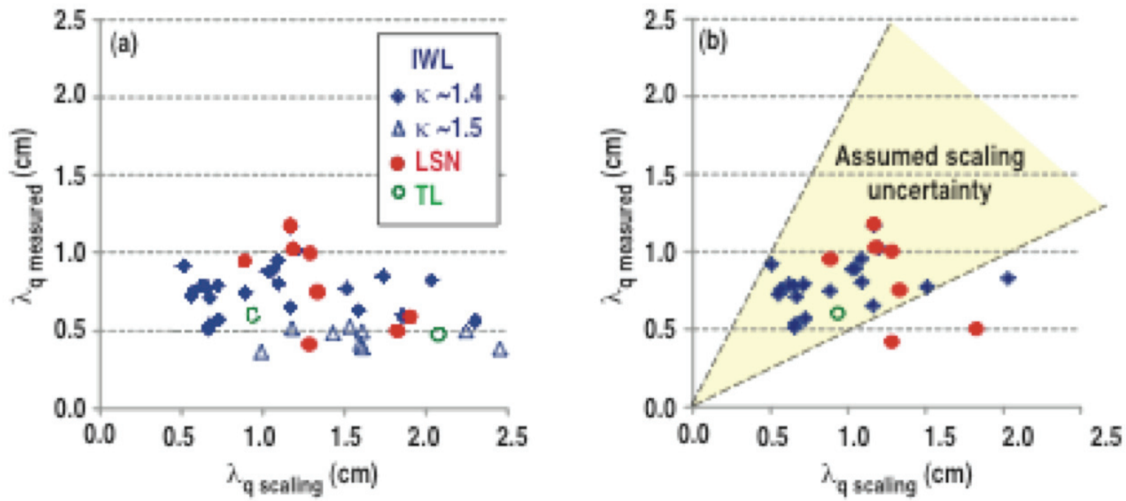
**Shot # 136595**
**$I_p$ = 0.87 MA**
**$n_e$ = 2.16x10$^{13}$cm$^{-3}$**
**$P_{SOL}$ = 0.23 MW**

# Power Flux Decay Measurements do not Correlate With the Expected Scaling

- From the ITER thermal load specification, the SOL power flux scaling, $\lambda_q$ is expected to be:

$$\lambda_q = (1+/-\ 1/3)\ 3.6\ 10^{-4}\ R(m)^2\ P_{div}(MW)^{-0.8}\ x q_{95}\ x\ ne(10^{19}m^{-3}) x Zeff^{\ 0.6}$$

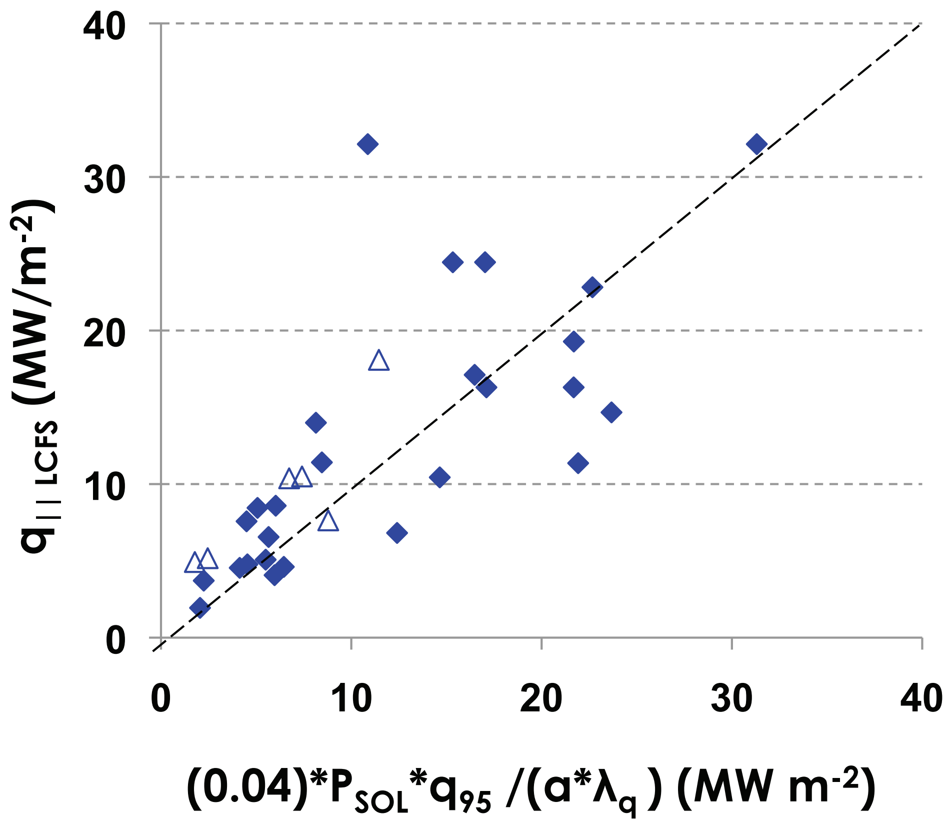
- The reciprocating probe measurements do not correlate with the plasma parameter scaling trends but most measurements are nevertheless within a factor of 2 of the absolute magnitude of the scaling prediction



# $\lambda_q$ in IWL is Consistent With Simple SOL Power Balance

- From a simple SOL power balance we can expect:

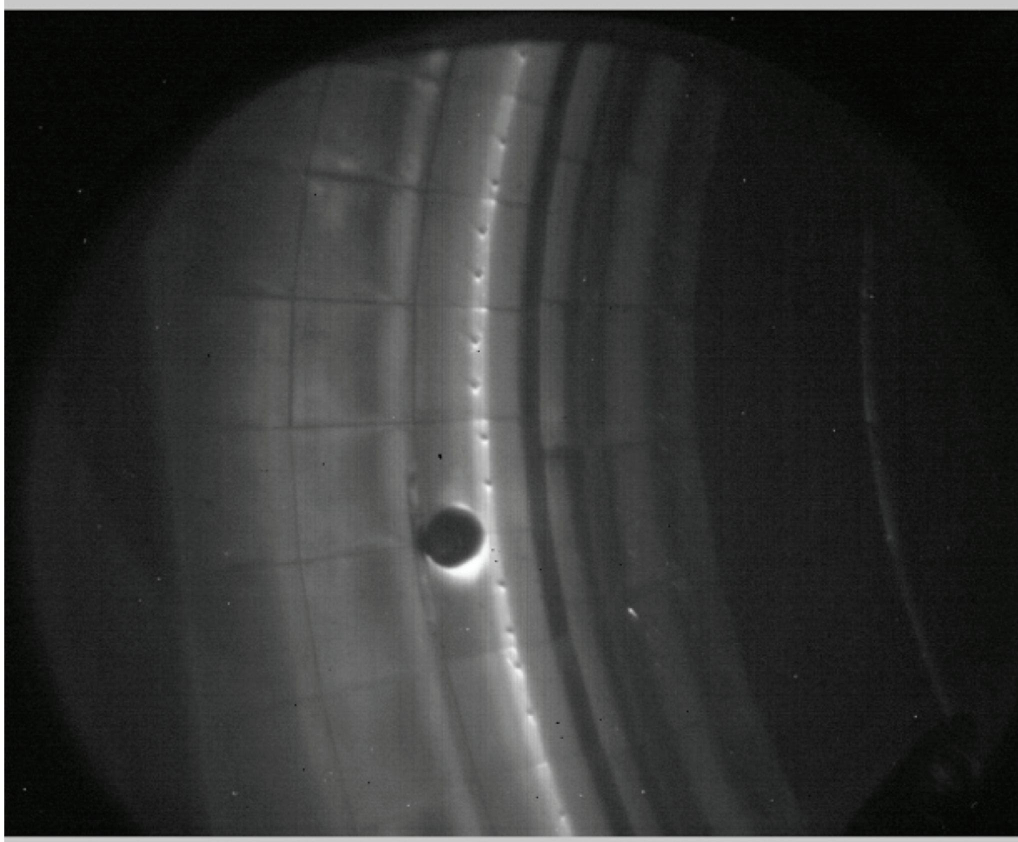
$$q_{\mathrm{LCFS}} = \frac{P_{SOL}}{A_{q\|}^{SOL}} = \frac{P_{SOL}}{4\pi R\lambda_q (B_\theta / B_\phi)} \propto \frac{P_{SOL} q_{95}}{a\lambda_q}$$



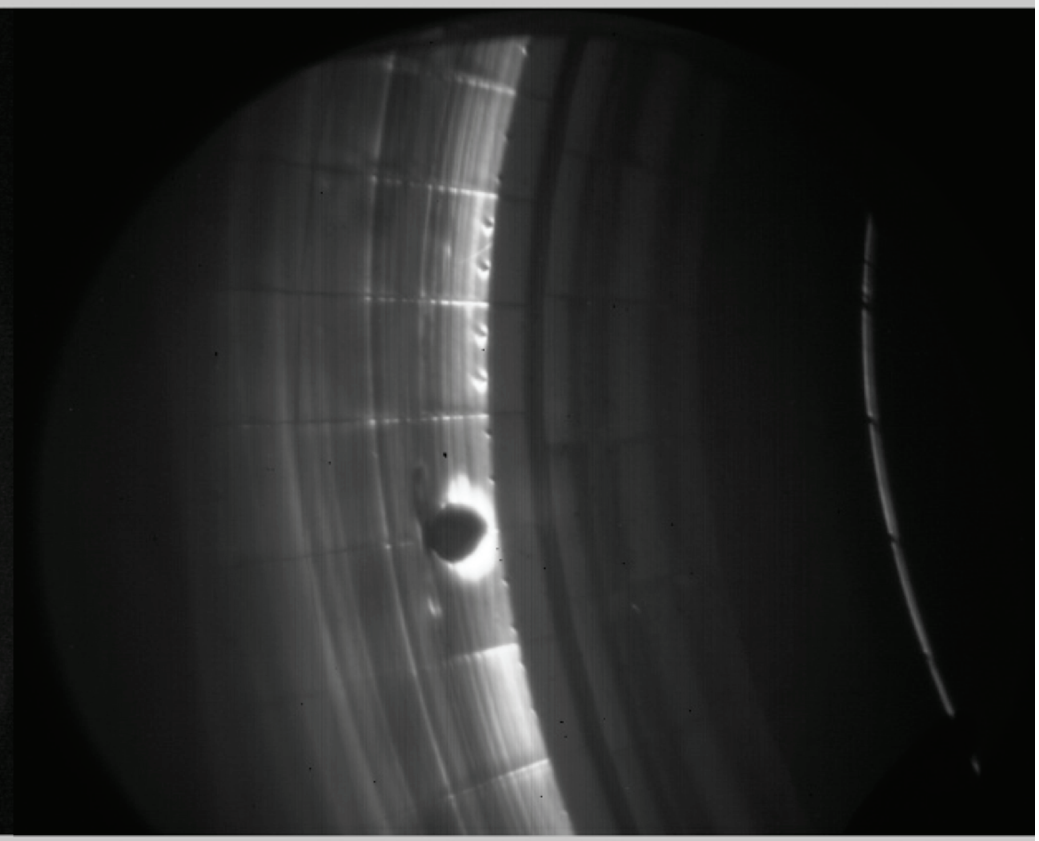

The dependence is fairly close to linear

# Fast IRTV Images Show Structure During an ELM

Secondary divertor IRTV images of flat lower divertor targets before and during an ELM



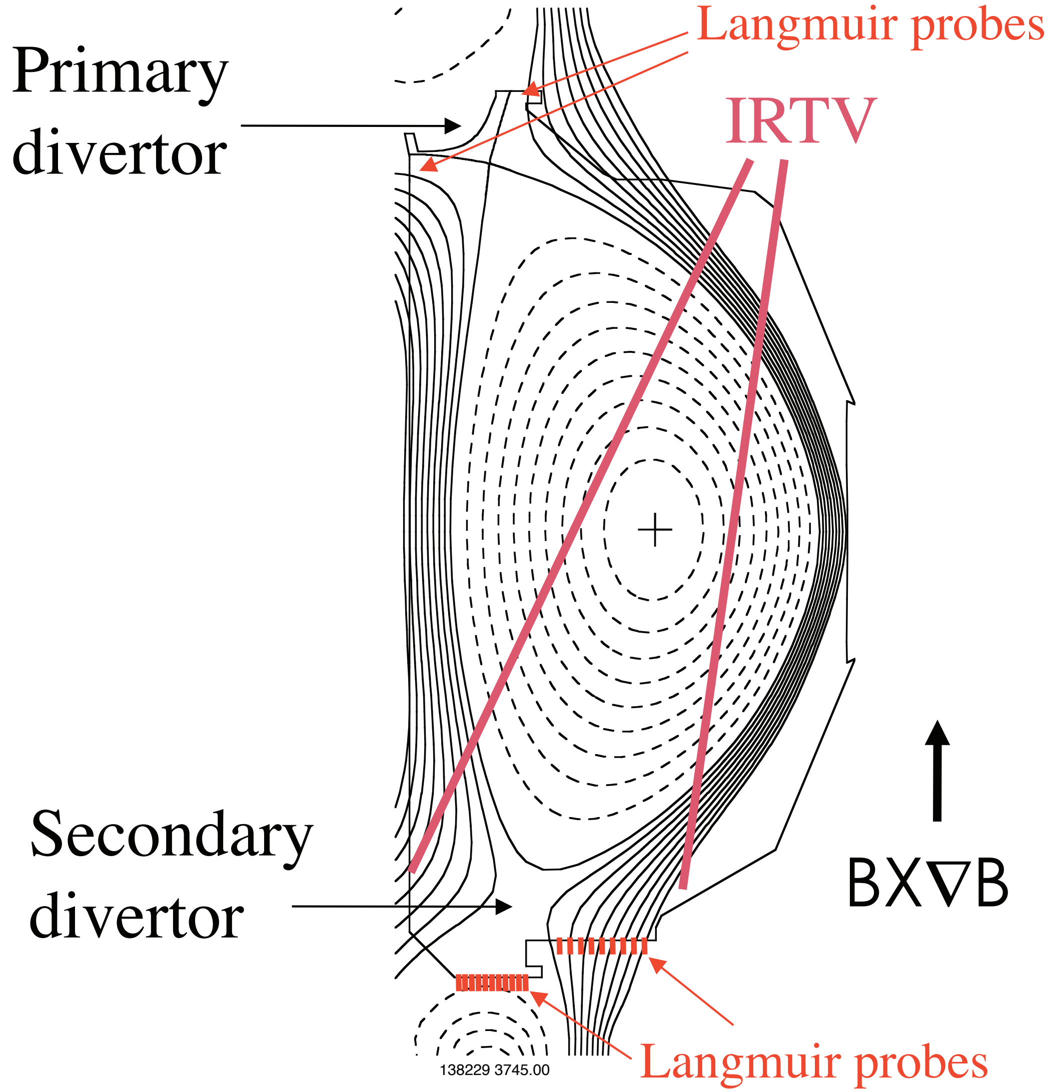
Before ELM



During ELM

# Upper Primary Divertor with Ion Grad B Drift Up was Used to Study an ITER-like Secondary Divertor

- **Fast IRTV looks down onto the lower secondary divertor tiles at 60 degrees**
- **Langmuir probes are embedded in the target plate tiles in both divertors**
- **Fast thermocouples are 1 cm below the surface in the lower divertor tiles**
- **The magnetic balance shown is scaled from ITER shape**

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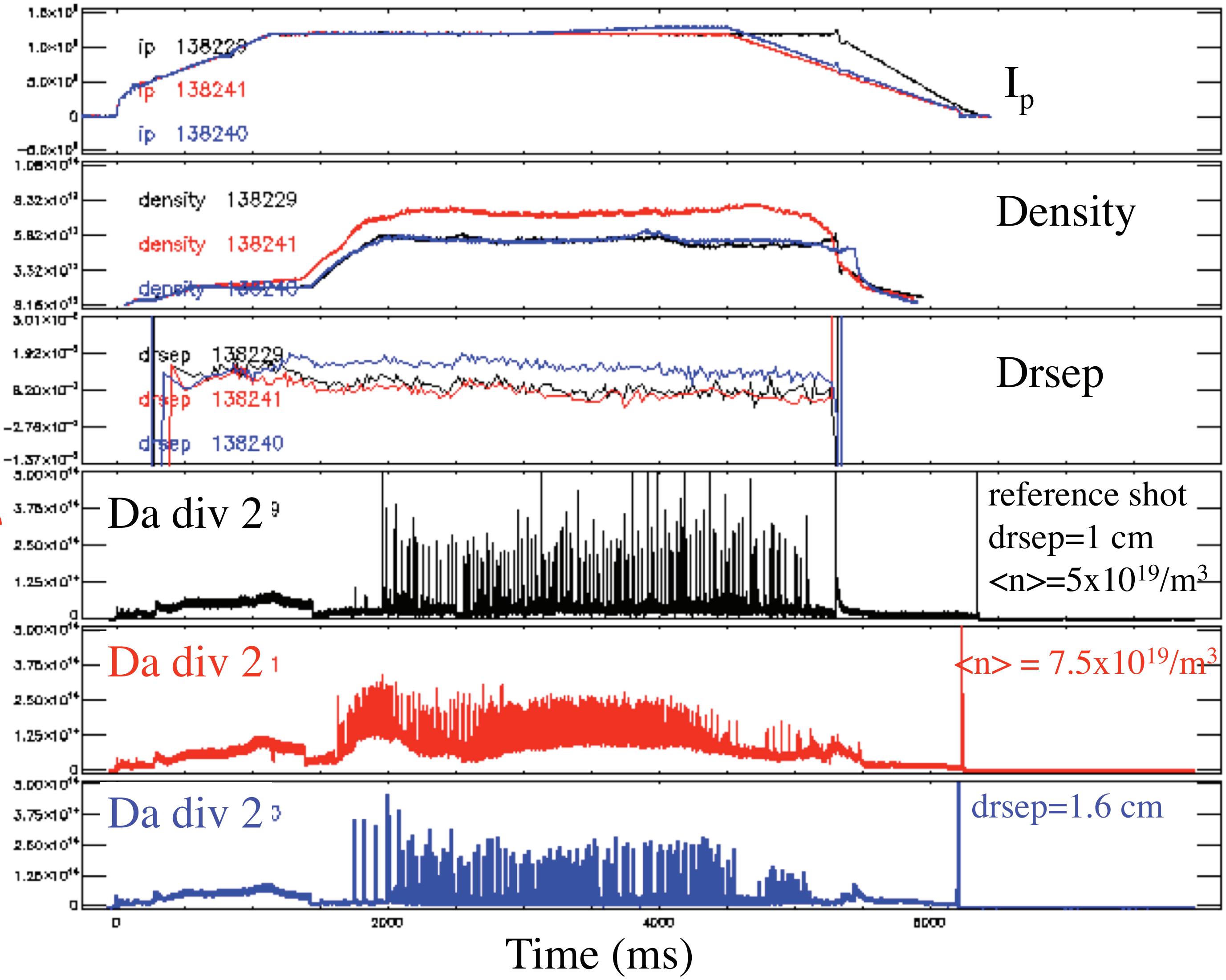
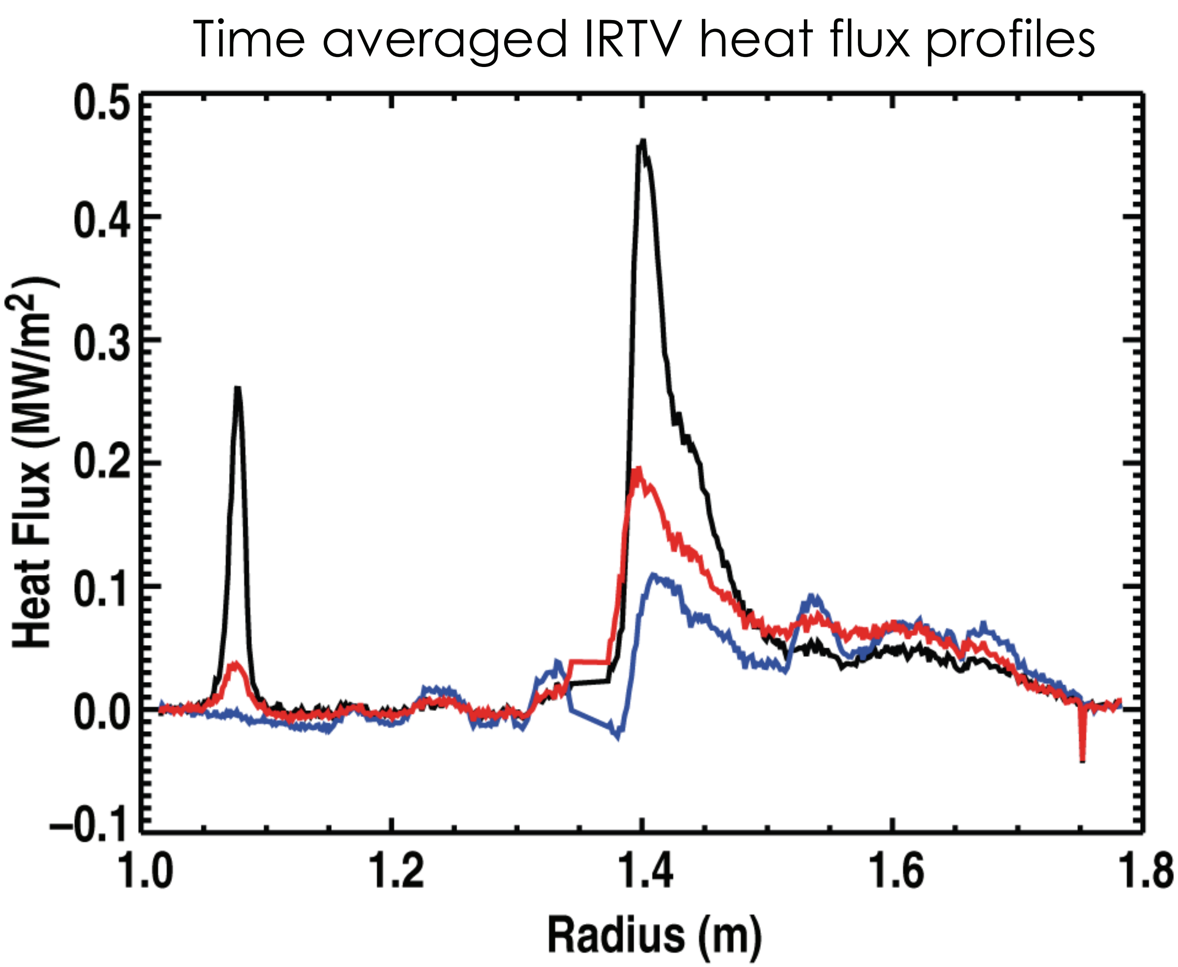
# Density and Magnetic Balance Effects on the Secondary Divertor Were Studied

- **Reference shot**
  - Type 1 ELMing H mode
- **Density and drsep were scanned with other parameters fixed**
- **Higher density (red) makes smaller more rapid ELMs, higher div 2 recycling**
- **Magnetic shift up (higher drsep) reduces the div 2 interaction (blue)**



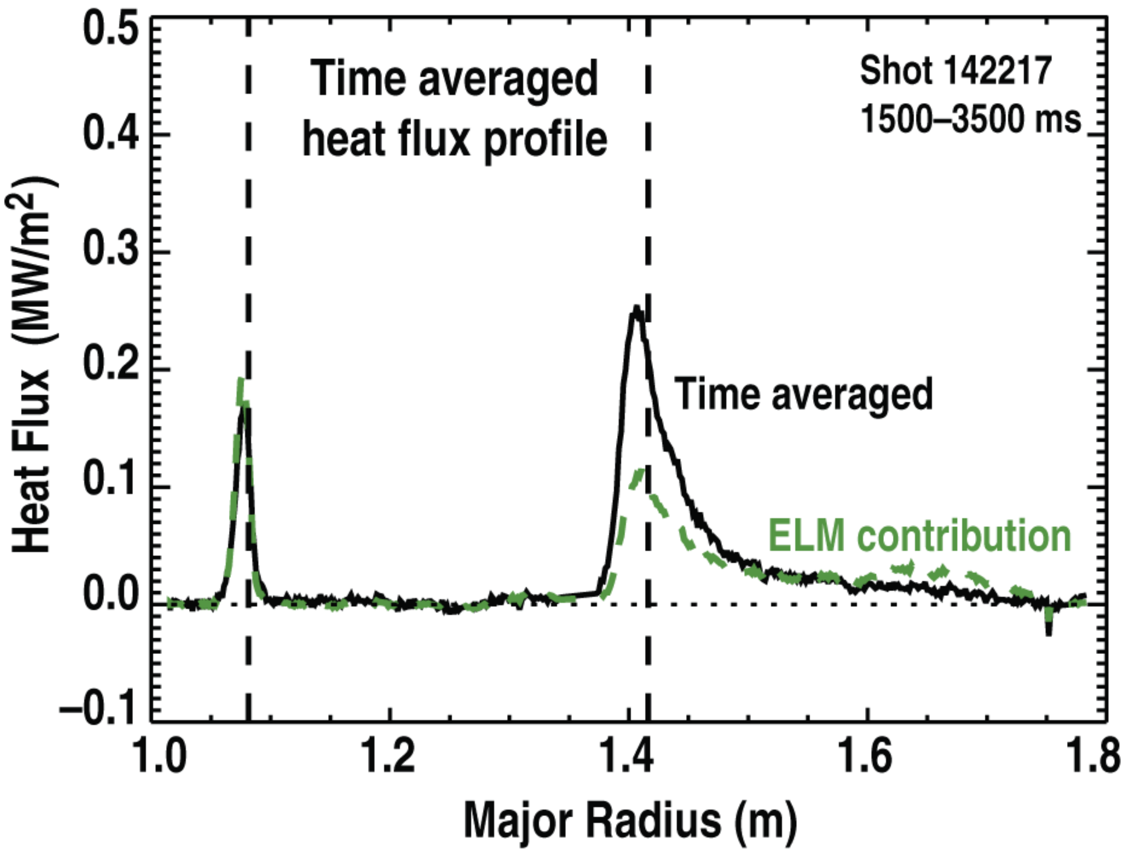
# Secondary Divertor Time-averaged Heat Flux Profiles Depend on Magnetic Balance and drsep

- **The time averaged heat flux in the secondary divertor is**
  - Peaked at the strike point with typical initial spatial decay
  - Shows the effect of magnetic balance on the heat flux(blue)
  - Shows the effect of increased density on the heat flux profile (red)



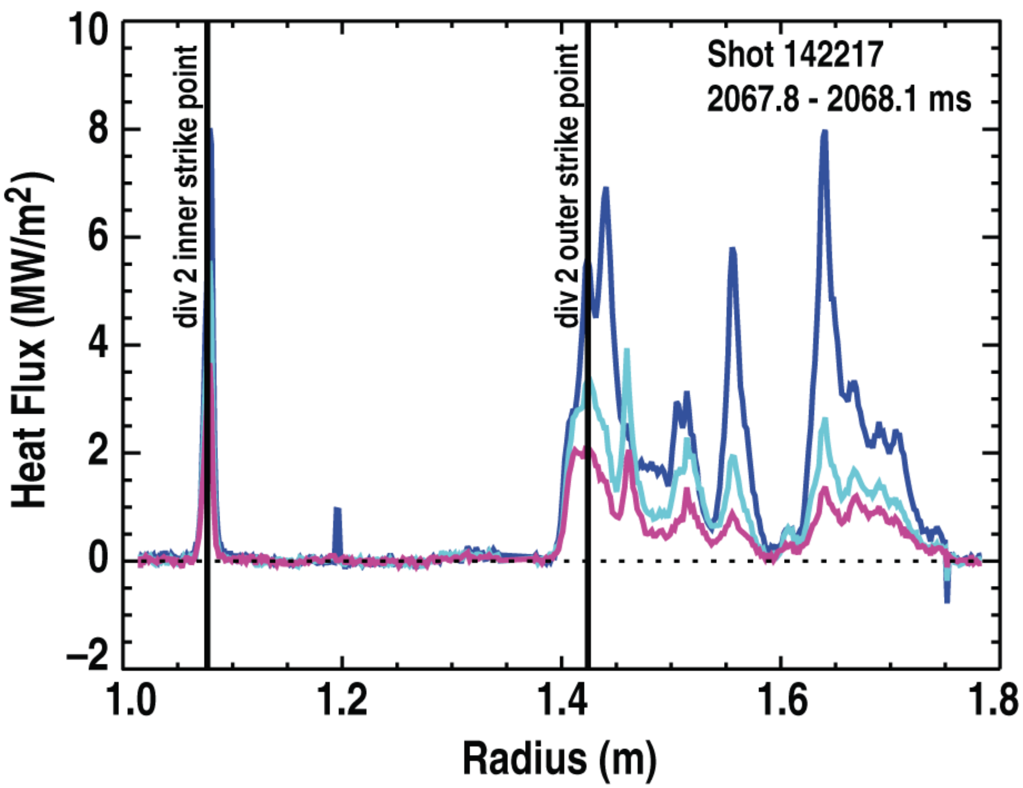
# Secondary Divertor Heat Flux Profiles Show Exponential Decay and Broader ELM Footprint

- This time averaged heat flux profile with background subtracted has been averaged over 2 seconds
- The ELM footprint shows a peak near the secondary divertor strike point but is broader than the averaged profile
- The time averaged heat flux profile at the inner strike point is largely due to ELMs



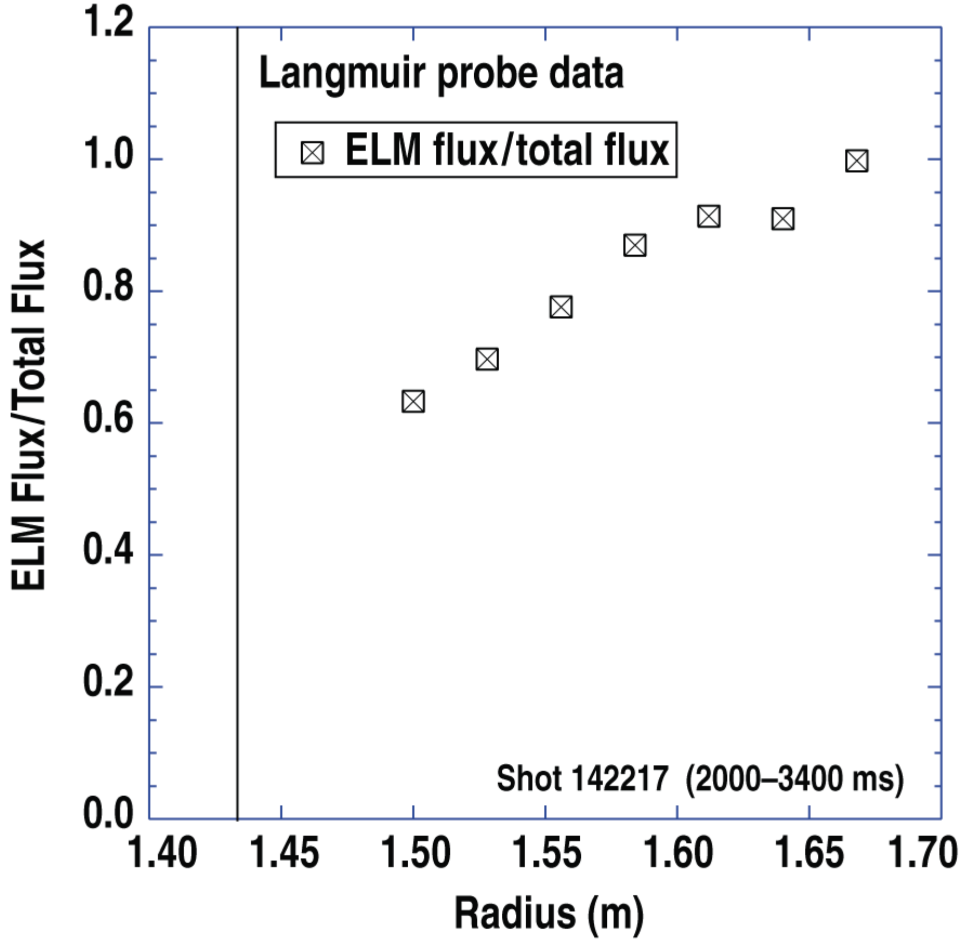
# ELM Heat Flux is Large and Erratically Distributed

- The ELM heat flux footprint is shown for three times during the ELM
- The shape is variable and could be affected by reflections and thin deposited layers especially at the far SOL
- The amount of heat flux at the inner strike point is larger than expected for the secondary divertor but moves with the strike point and is too fast to be affected by camera motion



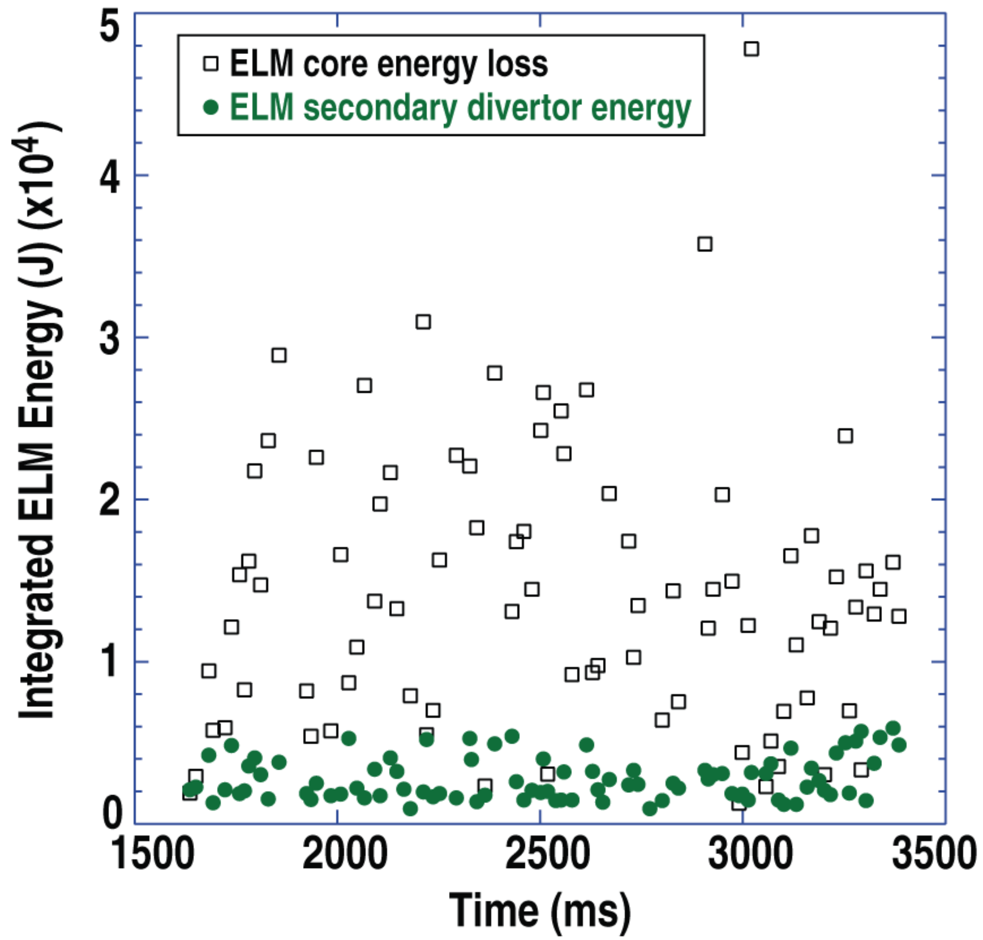
# Particle Flux Profiles Also Show a Broader ELM Footprint

- The plot at right shows the ratio of ELM particle flux to total particle flux averaged over 1400 ms
- The fraction of particle flux in the far SOL is all due to ELMs
- This shows that the ELM particle flux footprint is broader than the steady state profile



# Core ELM Energy Loss From EFIT is Compared to Secondary Divertor Integrated ELM Energy from IRTV

- Core ELM energy loss (boxes) is calculated from fast EFIT equilibrium using fast magnetic probe signals
- Secondary Divertor ELM energy deposition (green dots) is calculated from integrating the IRTV heat flux profiles (12 kHz) over the ELM time and assume toroidal symmetry

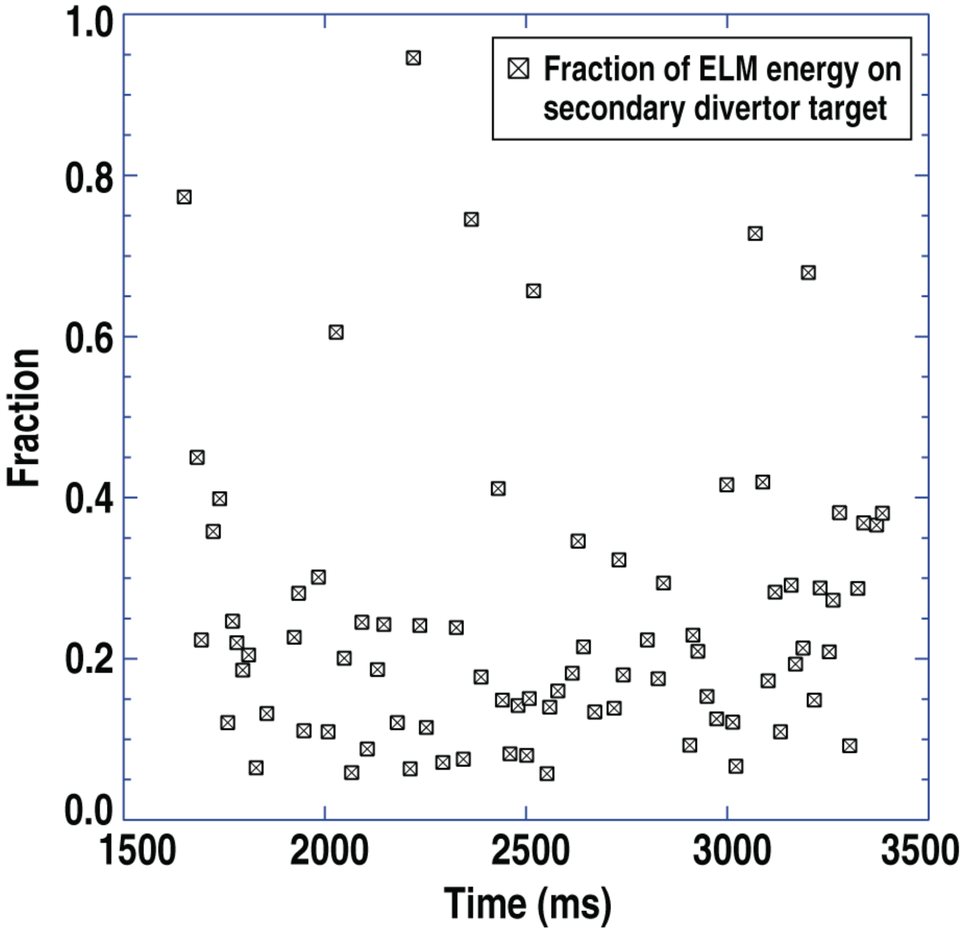


# About 20 % of the Core ELM Energy Loss is Deposited in the Secondary Divertor for this Plasma Shape

- The plotted points are the fraction of the core energy loss that arrives in the secondary divertor

- The median value of the points in the graph is about 20%

- The scatter is the points is largely due to uncertainties in the core energy loss for the smaller ELMs



# Summary

- **SOL power decay widths in L mode limiter plasmas**
  - IWL cases ~ 2.5 X diverted LSN (as assumed for ITER)
  - No correlation with scaling trend of plasma parameters but results constitute indirect confirmation of $R^2$ dependence of scaling
  - Results consistent with simple SOL power balance

- **Secondary divertor**
  - Heat flux profiles were broader and more uneven than expected
  - Multi peaked ELM footprints were seen
  - 20% of core ELM ΔE was measured at the secondary divertor target plate
  - More heat flux than expected at the secondary divertor inner strike point
  - Density and drsep scans demonstrated that
    - Higher density REDUCES ELM size and secondary divertor ΔE
    - Higher drsep REDUCES heat flux and ELM interactions