MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

Radiation analysis of the SPI experiments performed at ASDEX Upgrade

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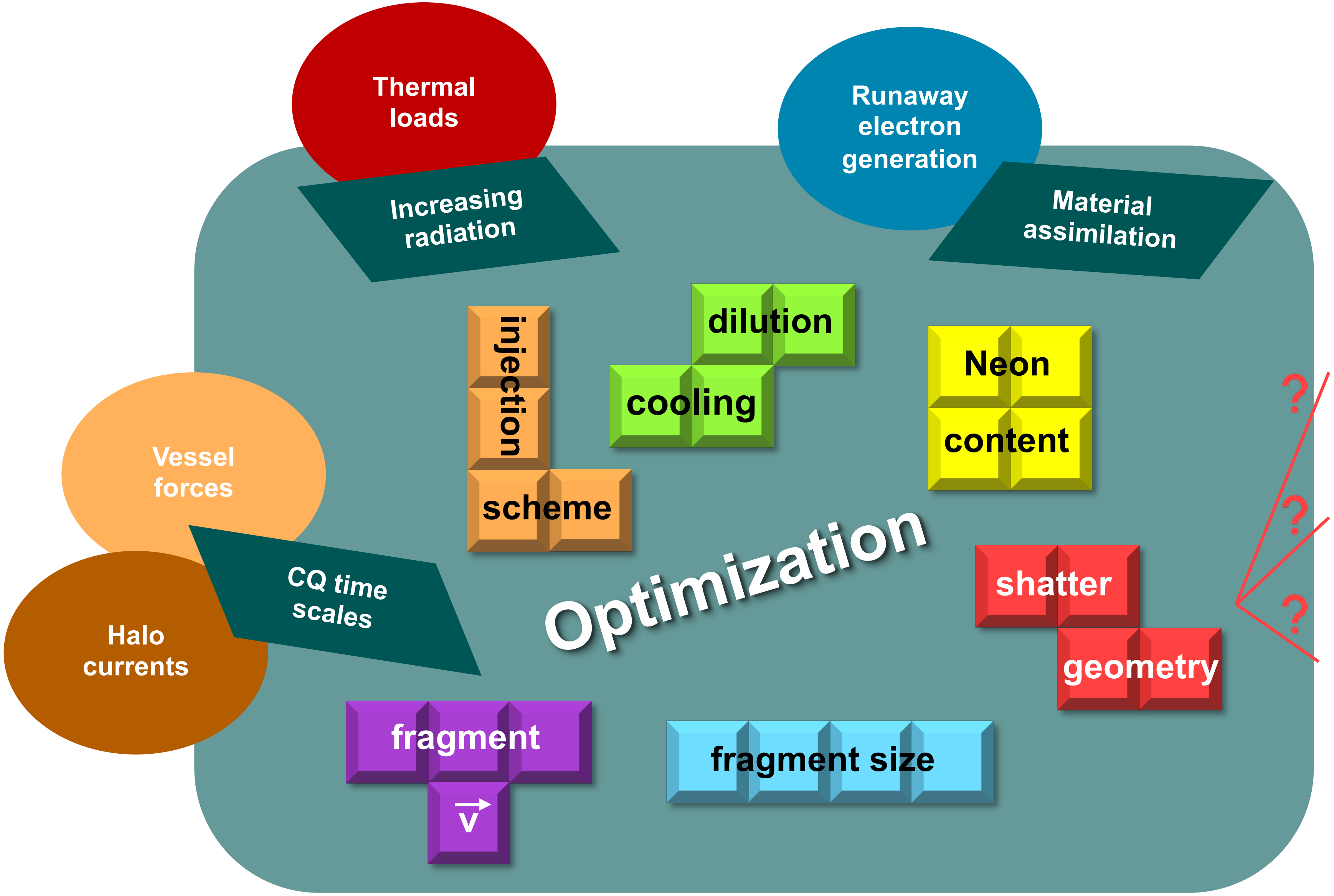
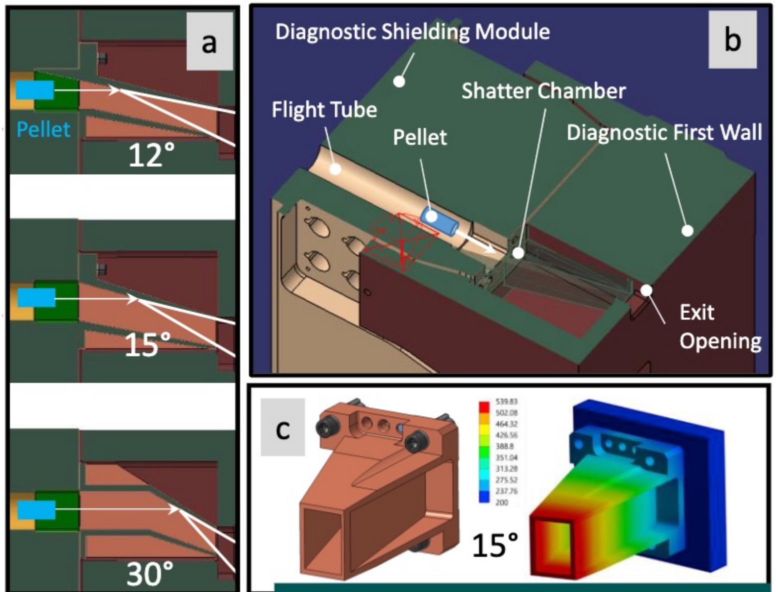
[5]Institute of Plasma Physics of the CAS, Prague, Czech Republic

Outline

- Motivation
- How does the ASDEX Upgrade shattered pellet injection (SPI) system work?
- What is special about the ASDEX Upgrade SPI?
- Radiation asymmetries and connection to CQ convexity
- Radiated energy fractions
- Summary

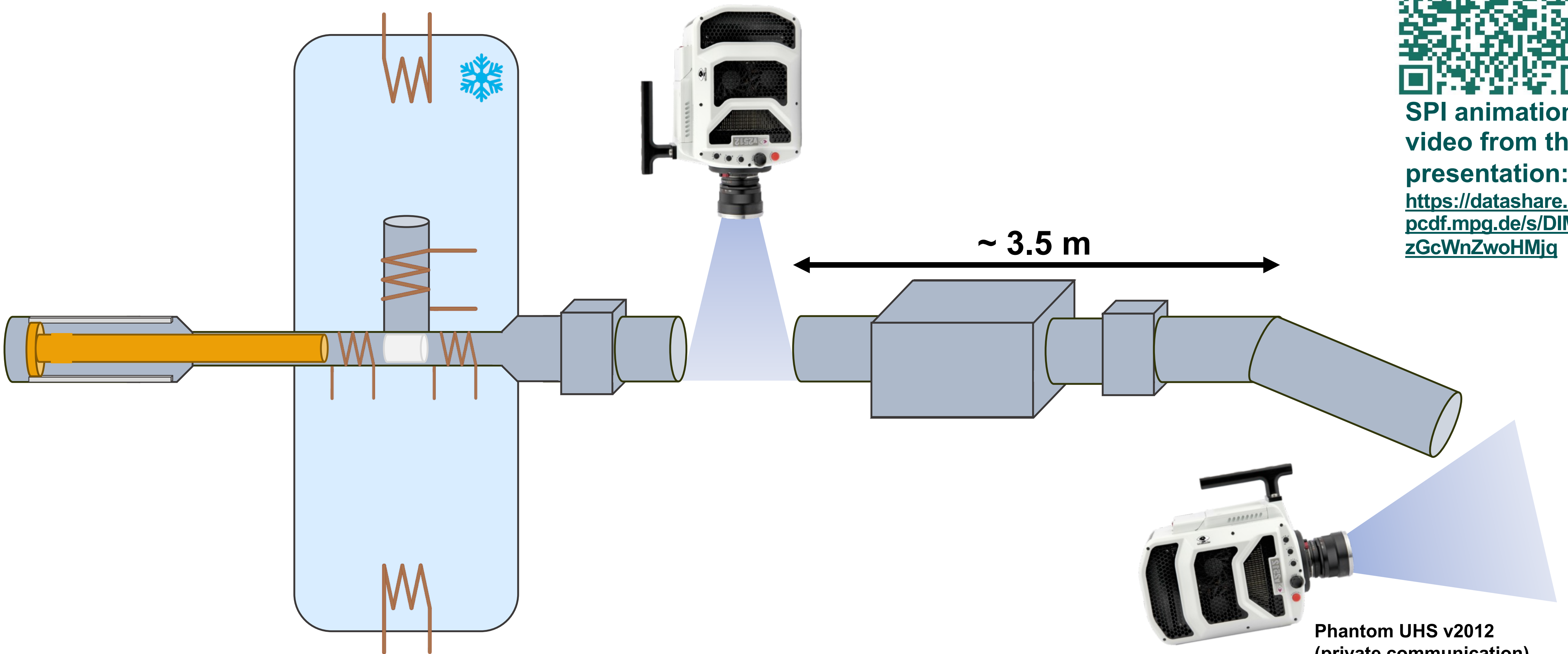
Motivation behind SPI experiments at AUG





Courtesy ITER DMS Team

How does the AUG SPI system work?

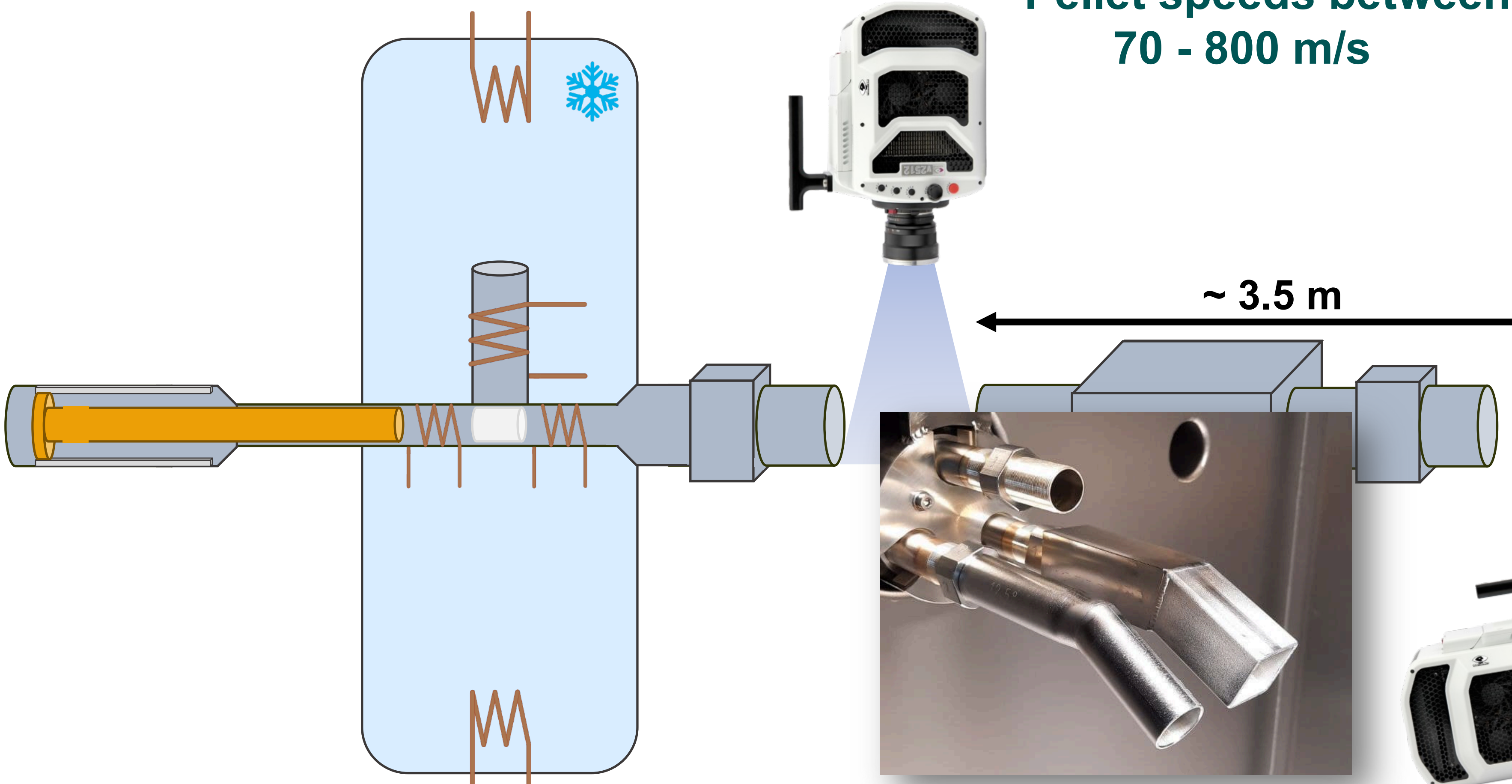


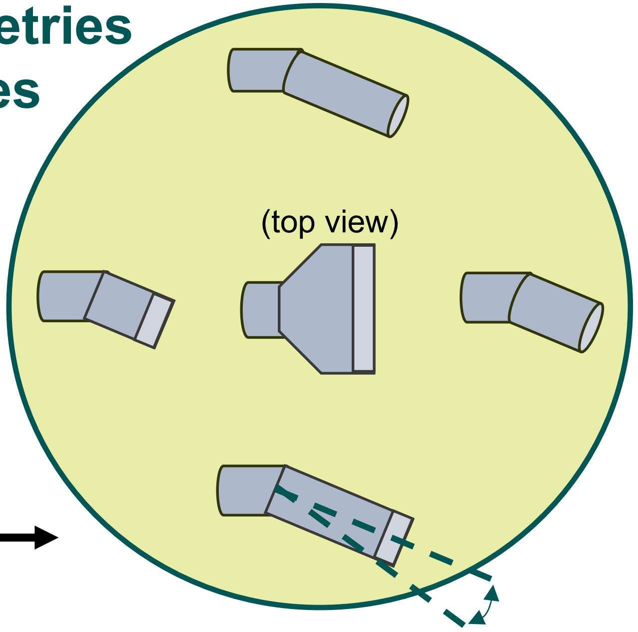
SPI animation video from the presentation:
https://datashare.mpcdf.mpg.de/s/DIMzGcWnZwoHMjq

Phantom UHS v2012 (private communication)
https://www.phantomhighspeed.com/

What is special about the SPI system at AUG?

- 10 different shatter head geometries
  - 12.5°, 15°, 25° and 30° angles
    - Pellet speeds between 70 - 800 m/s





Phantom UHS v2012
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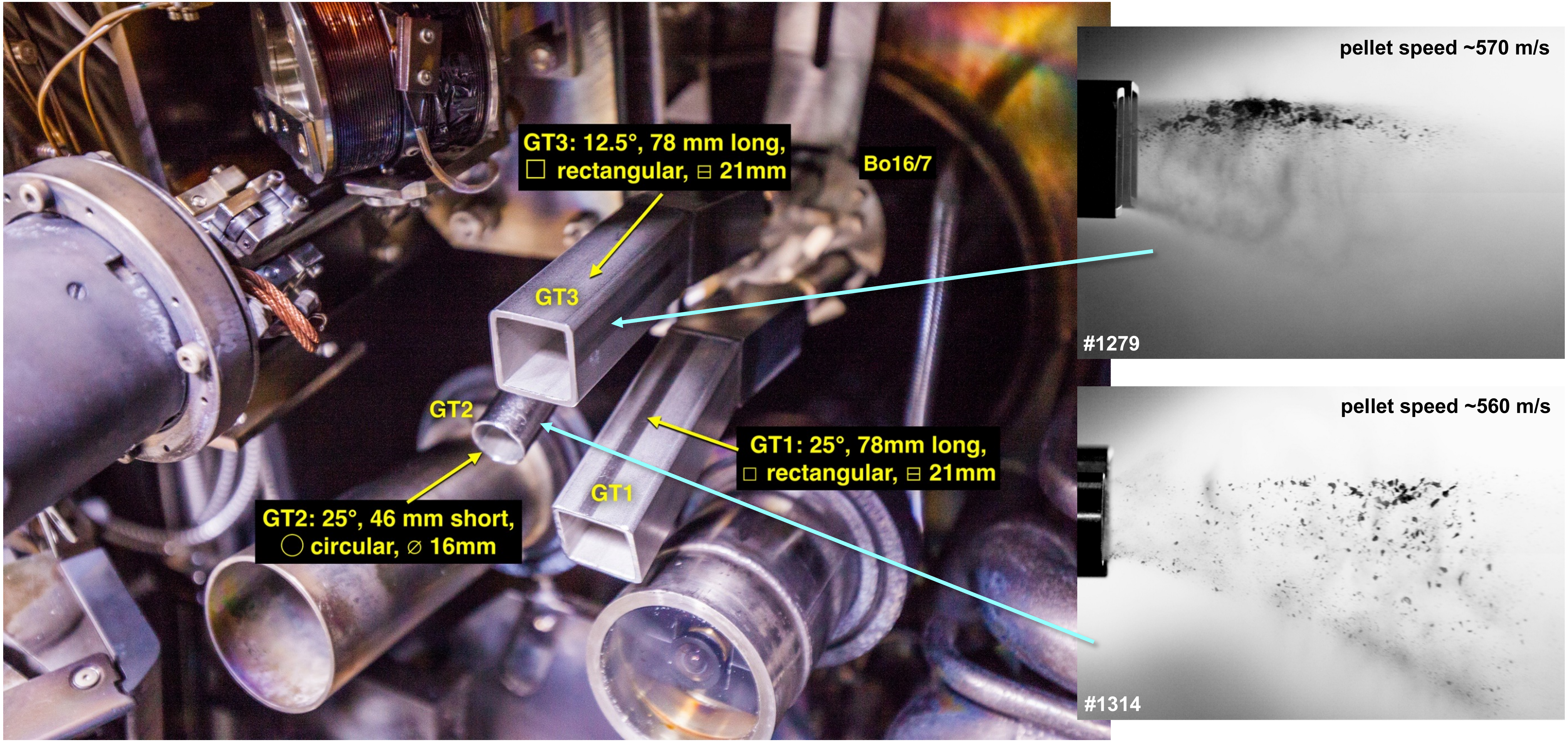
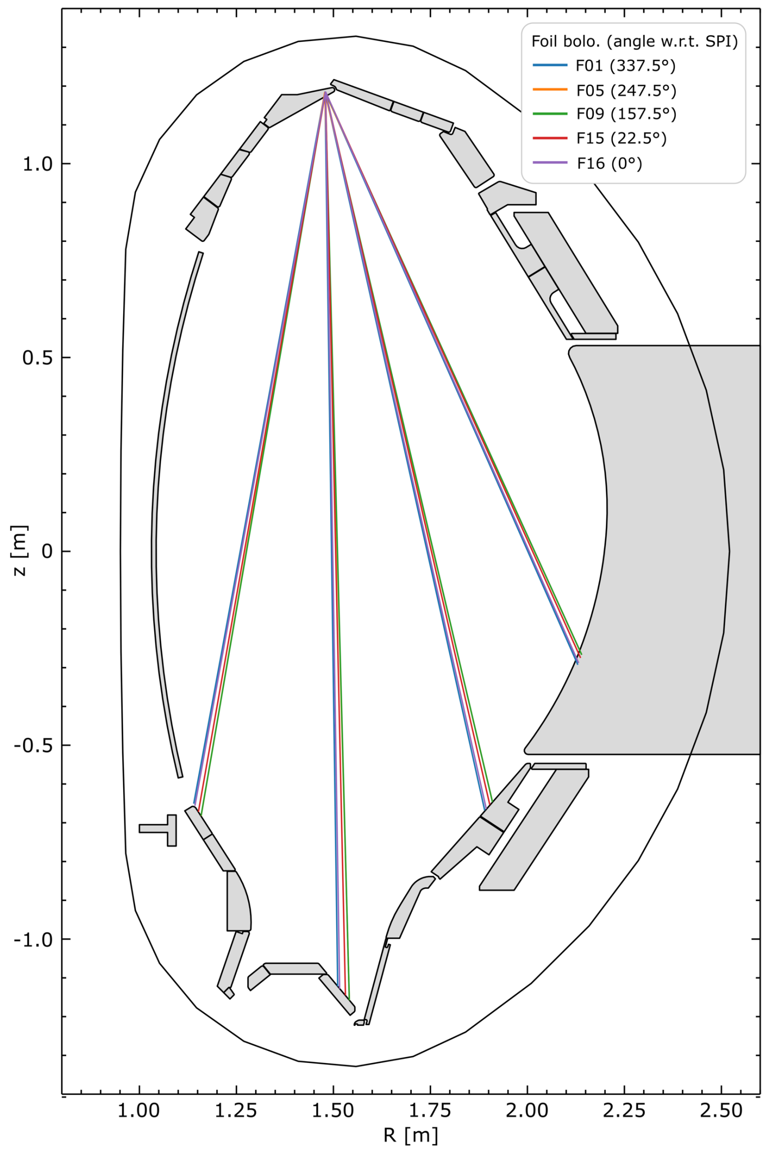
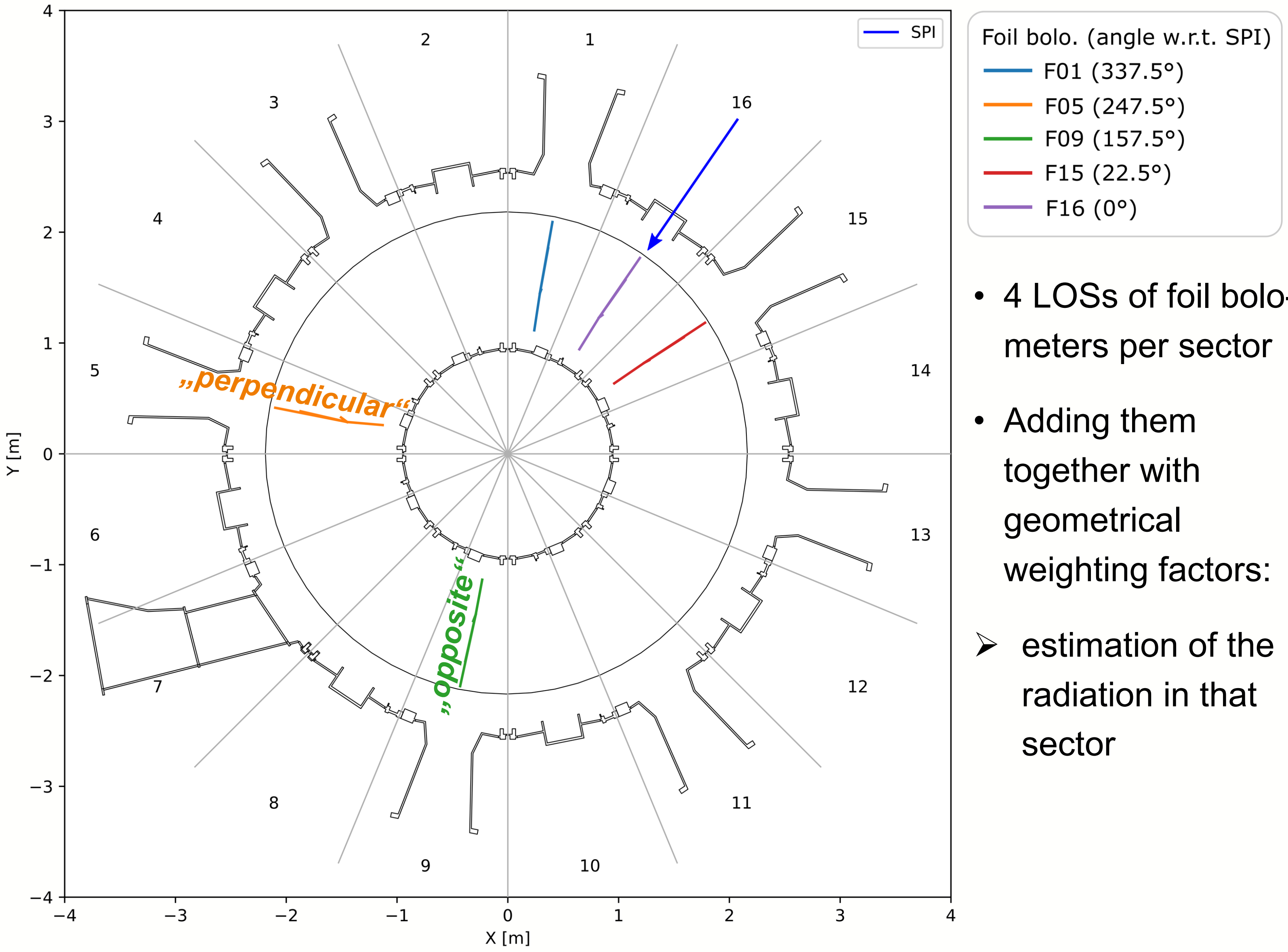
Current setup installed at ASDEX Upgrade



Radiation asymmetries

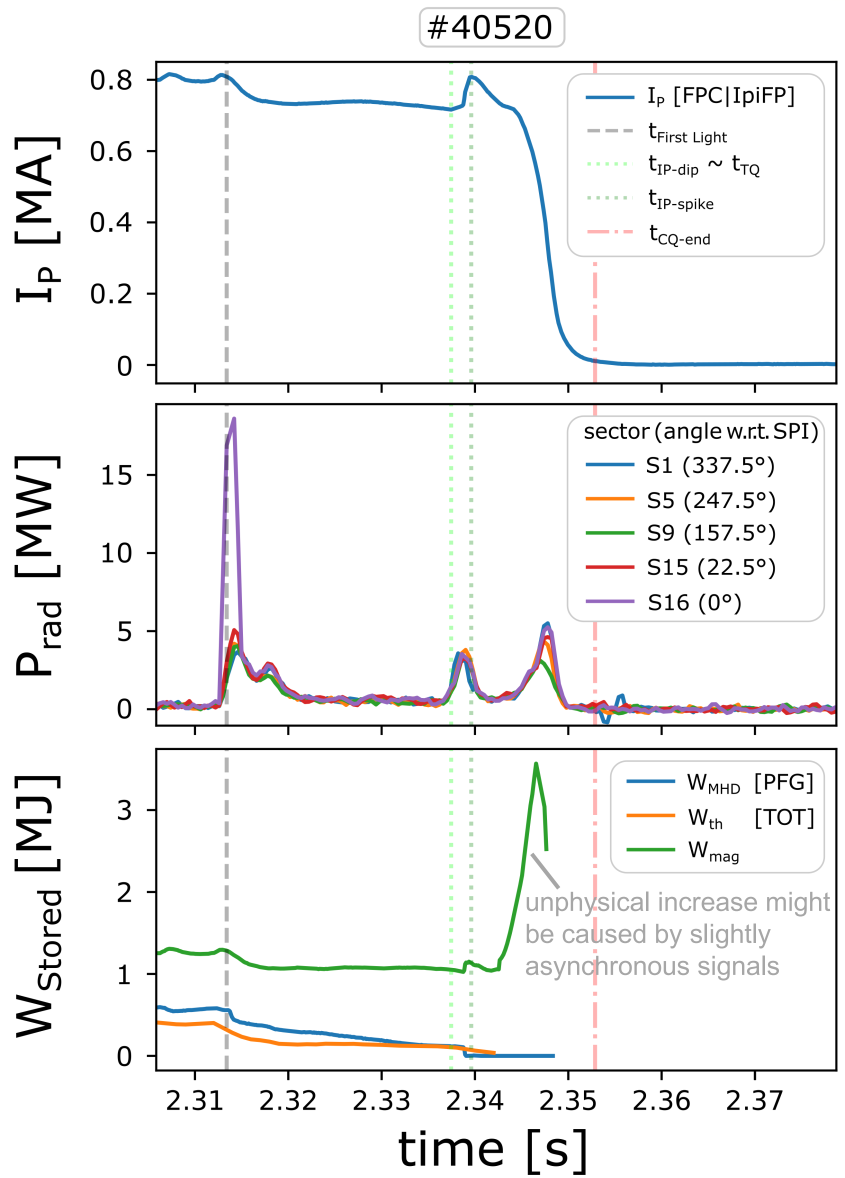
Upgrade to the AUG radiation measurements

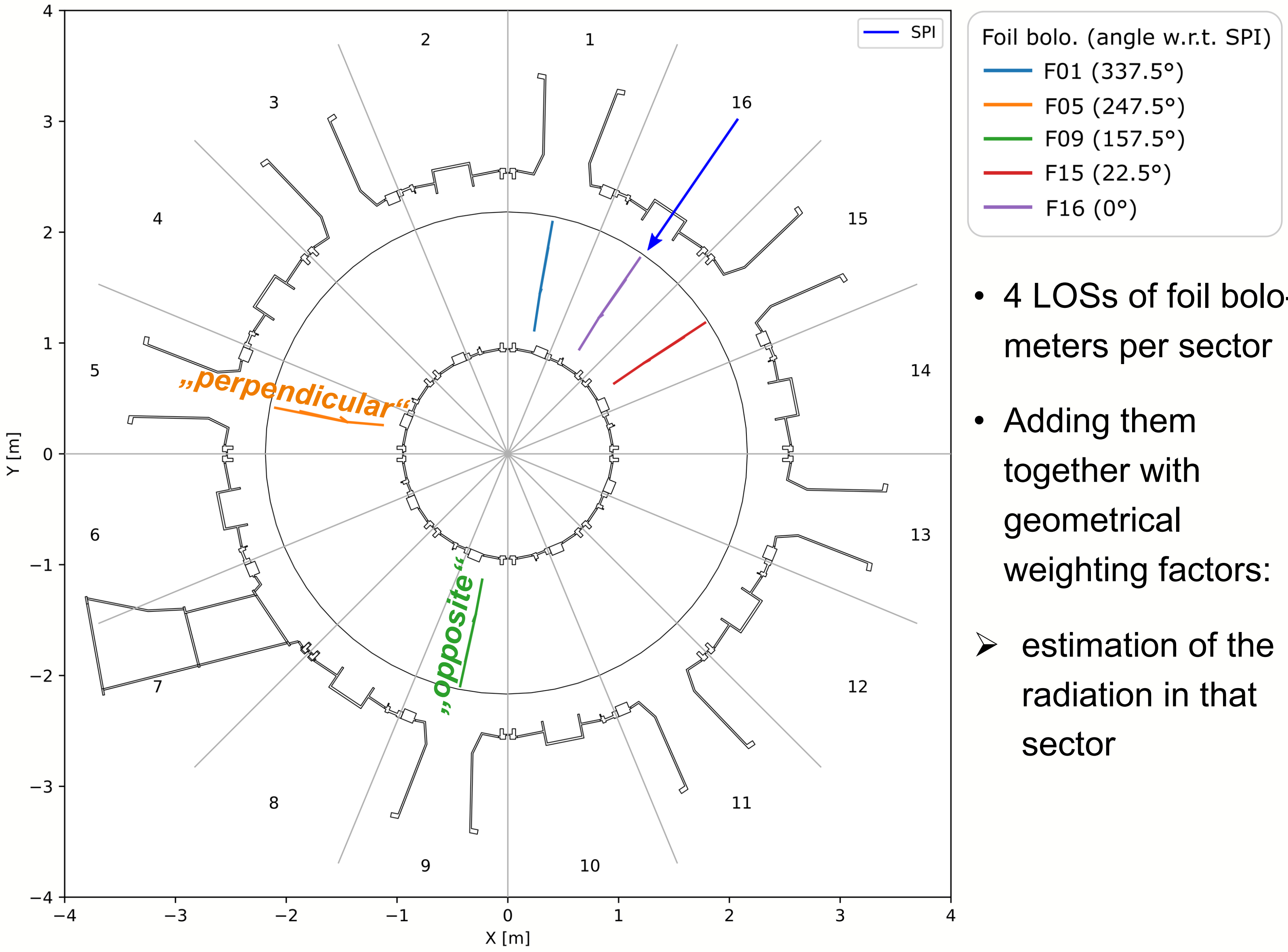




- 4 LOSs of foil bolo-meters per sector
- Adding them together with geometrical weighting factors:
  - ➢ estimation of the radiation in that sector

Radiation asymmetries





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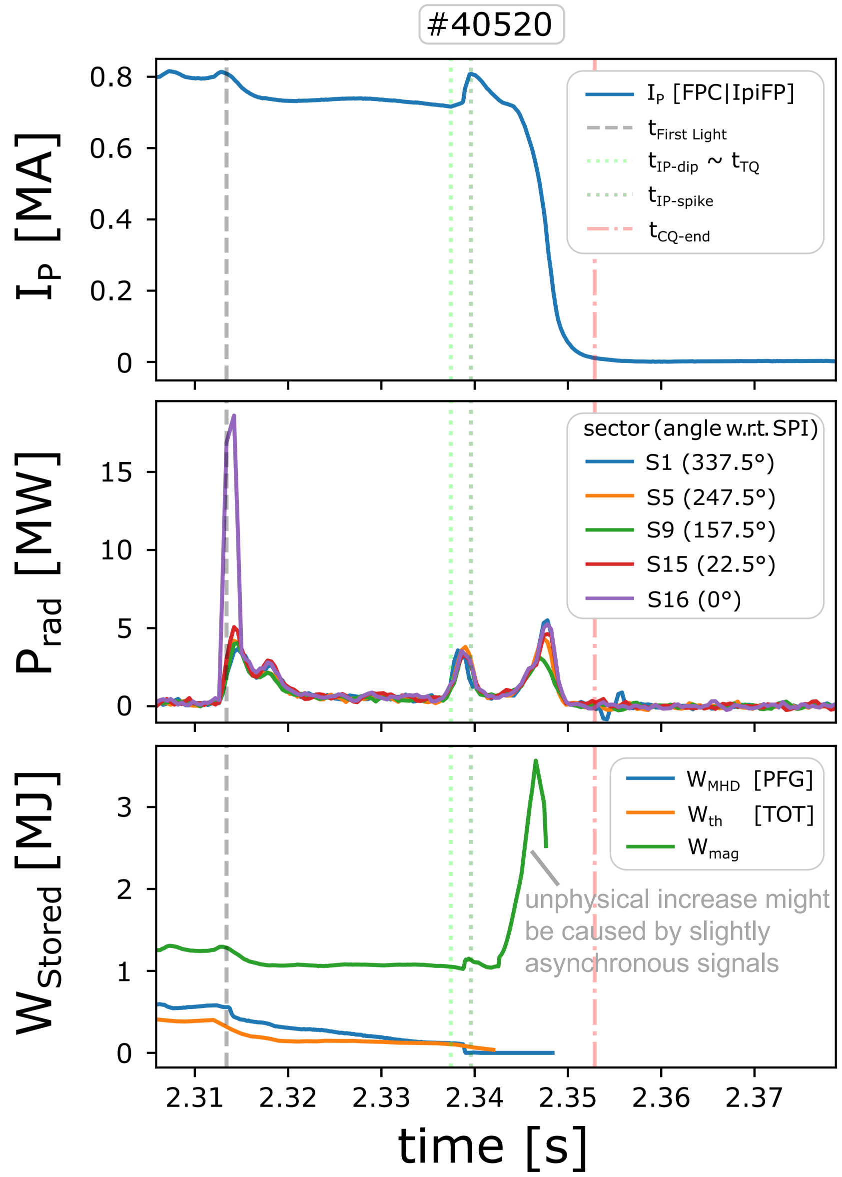
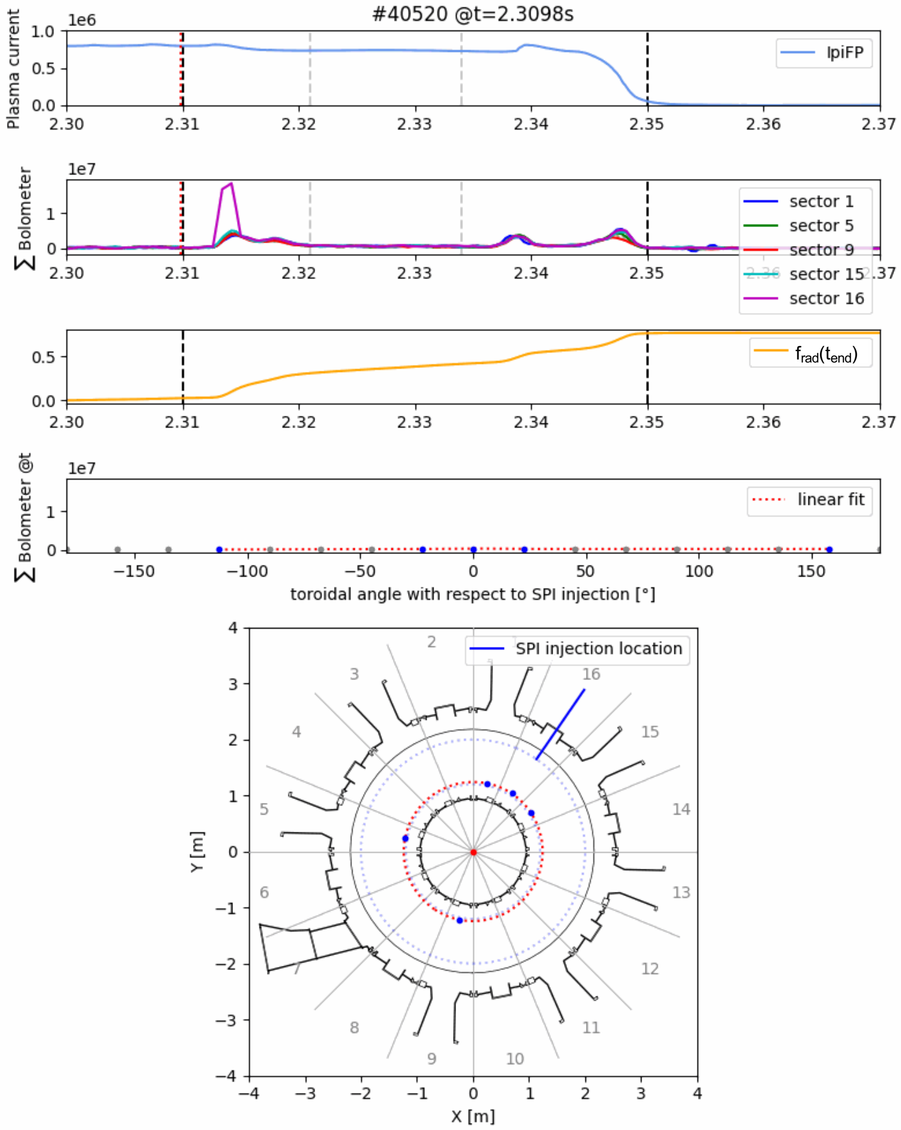
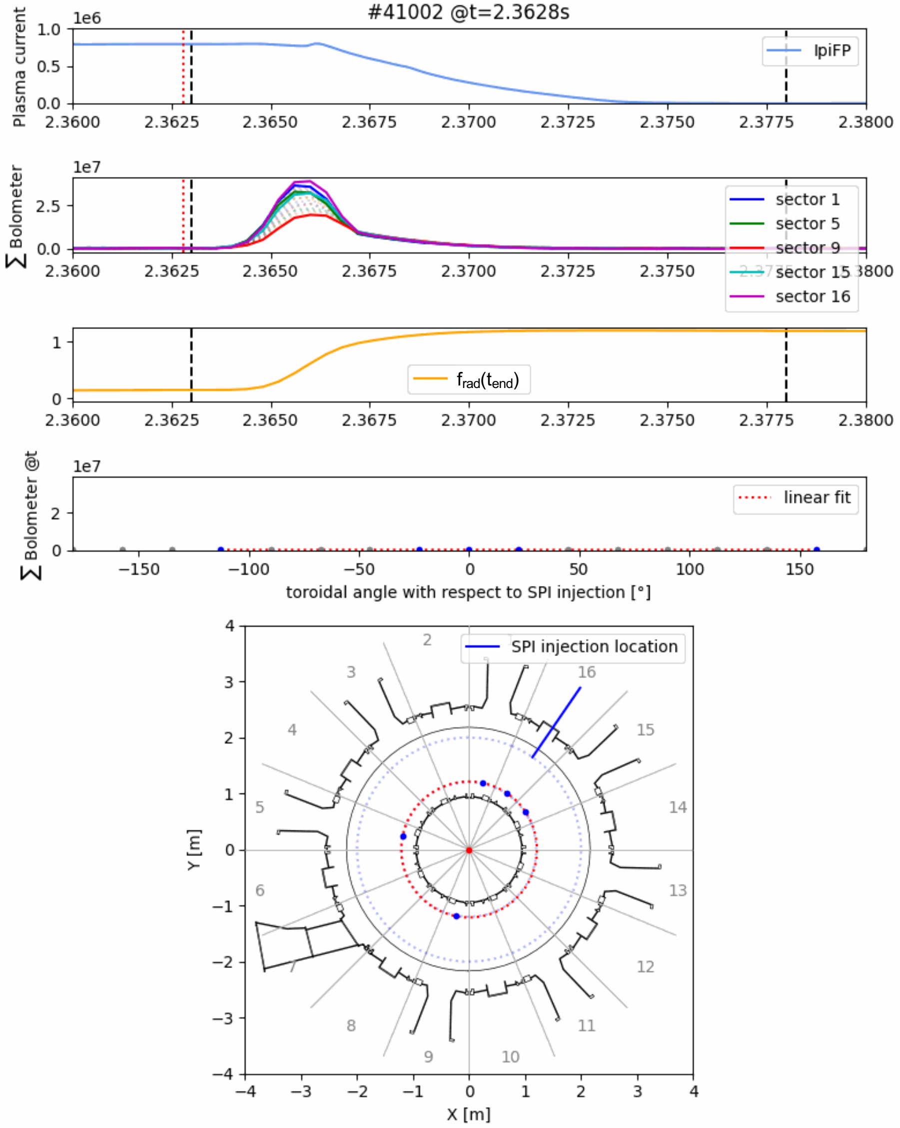


1.25% Ne, 4mm, 12.5° square, ~660 m/s



Radiation asymmetries

1.25% Ne, 8mm, 12.5° square, ~240 m/s



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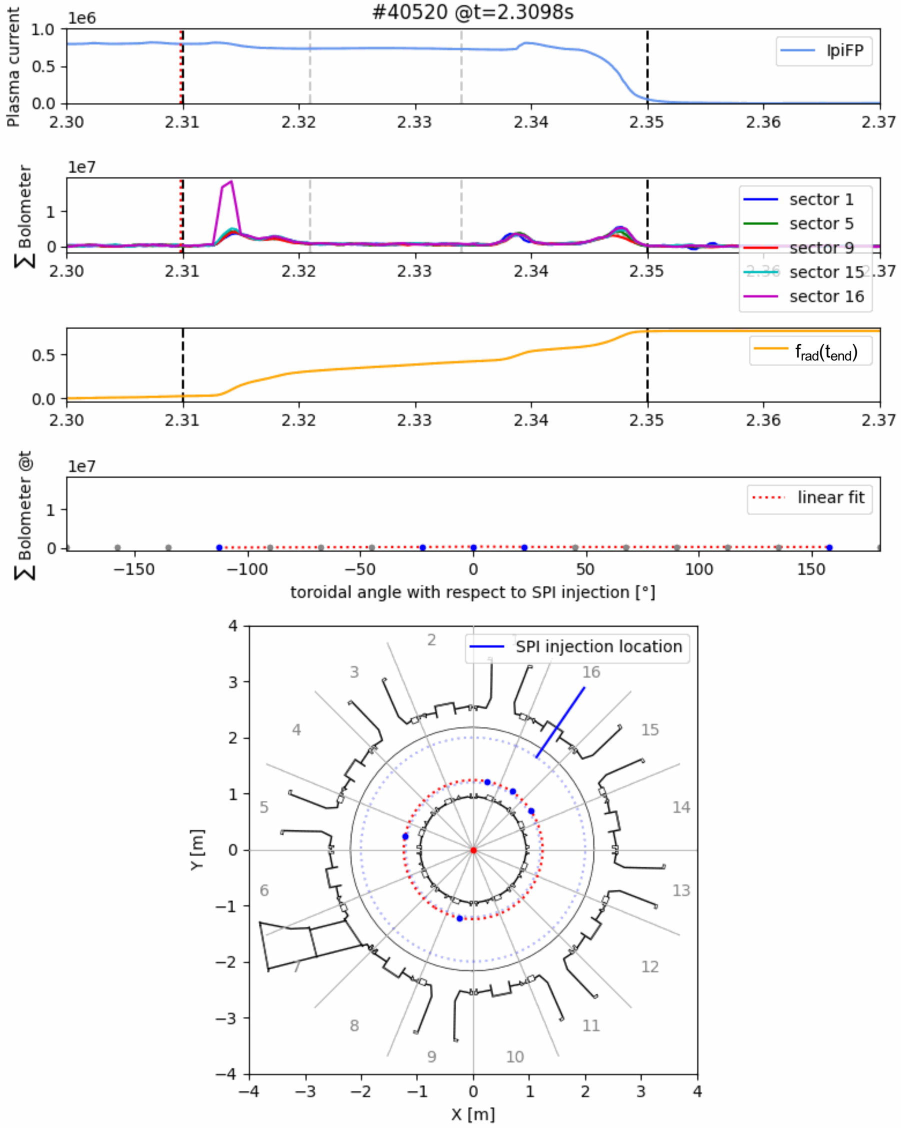
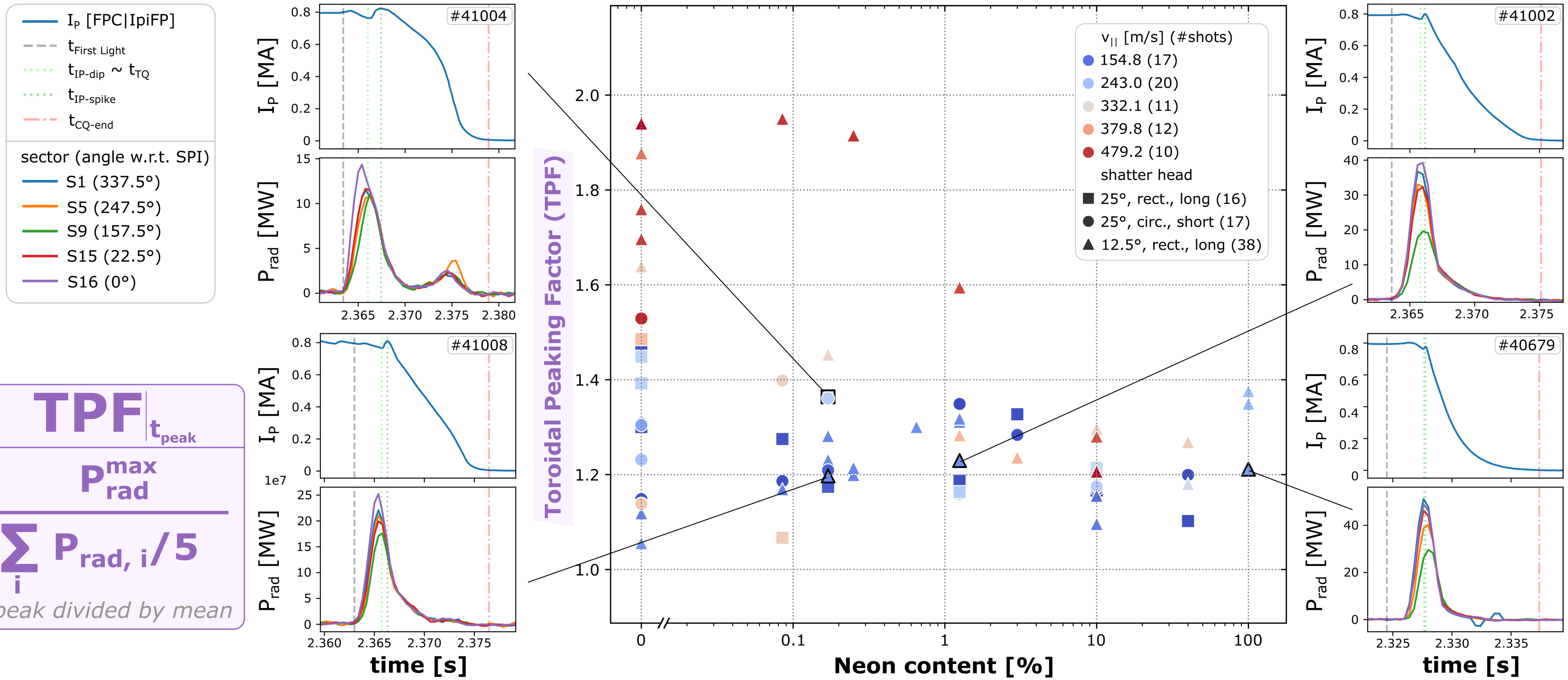


Toroidal Peaking Factor (TPF)

subset: 8mm, full-length, single injections into 1.8T std. H-modes



$$\left.\mathrm{TPF}\right|_{t_{peak}} = \frac{P_{rad}^{max}}{\sum_i P_{rad,\,i}/5}$$

peak divided by mean

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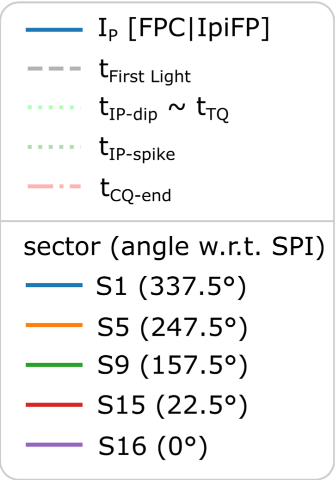

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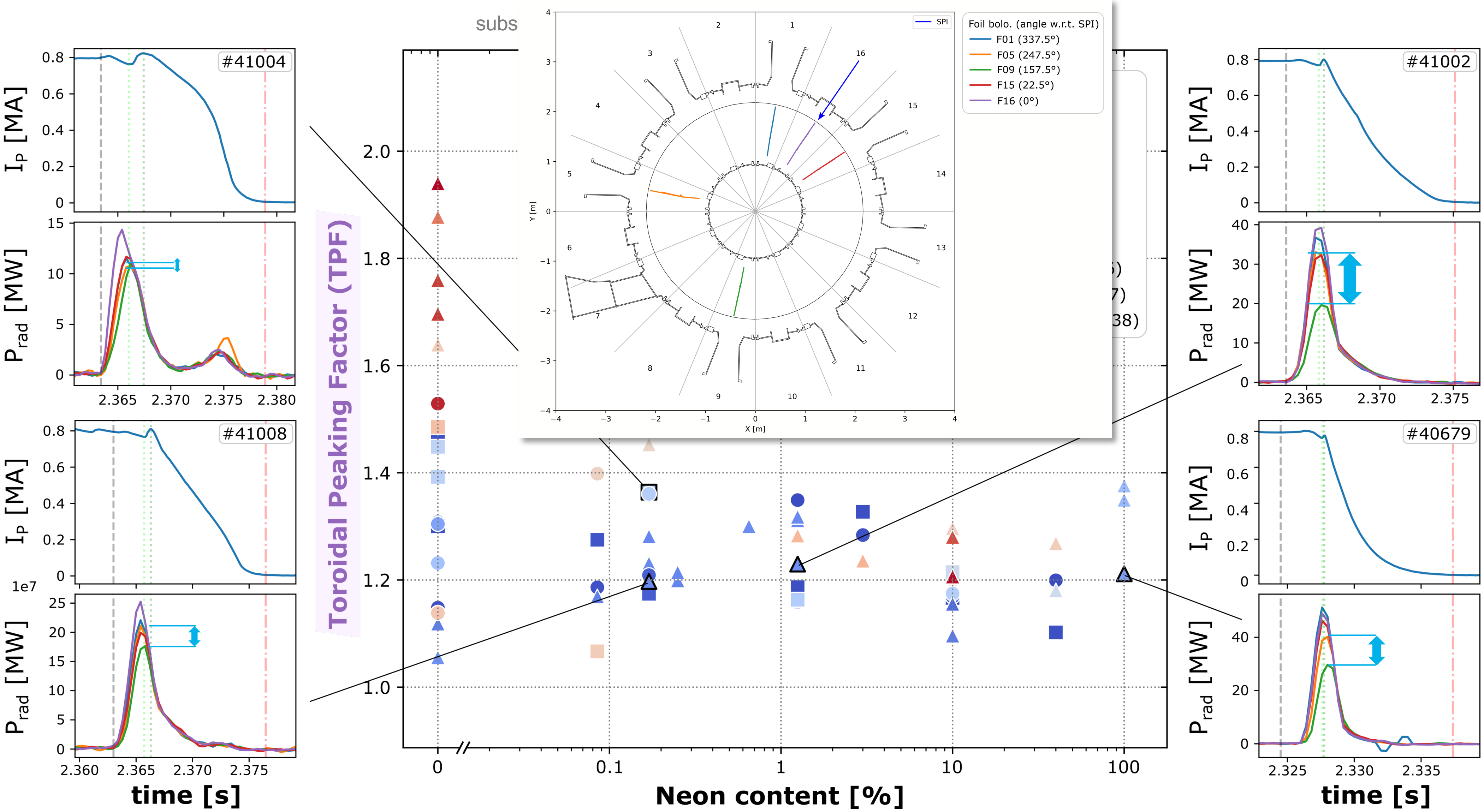
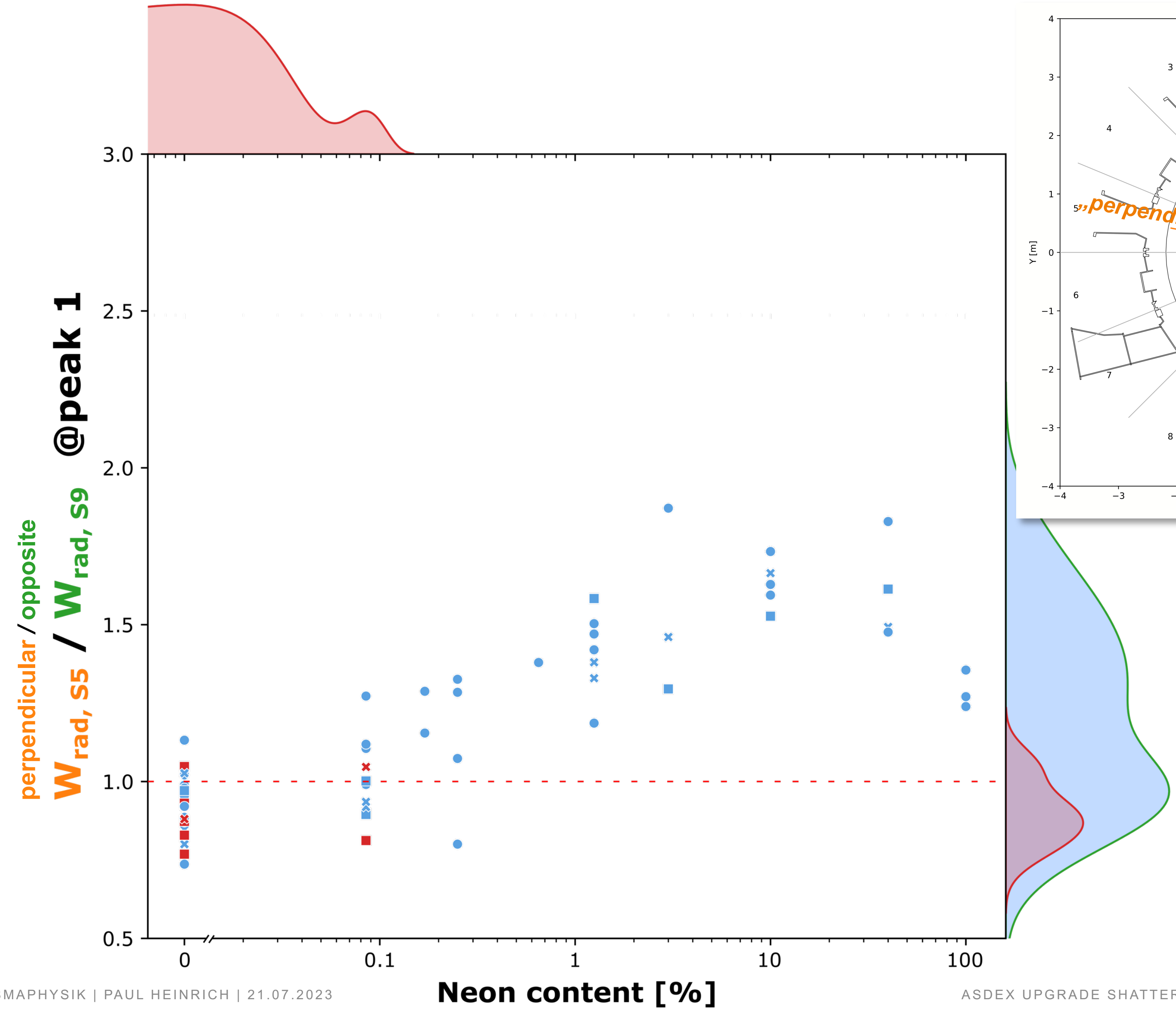
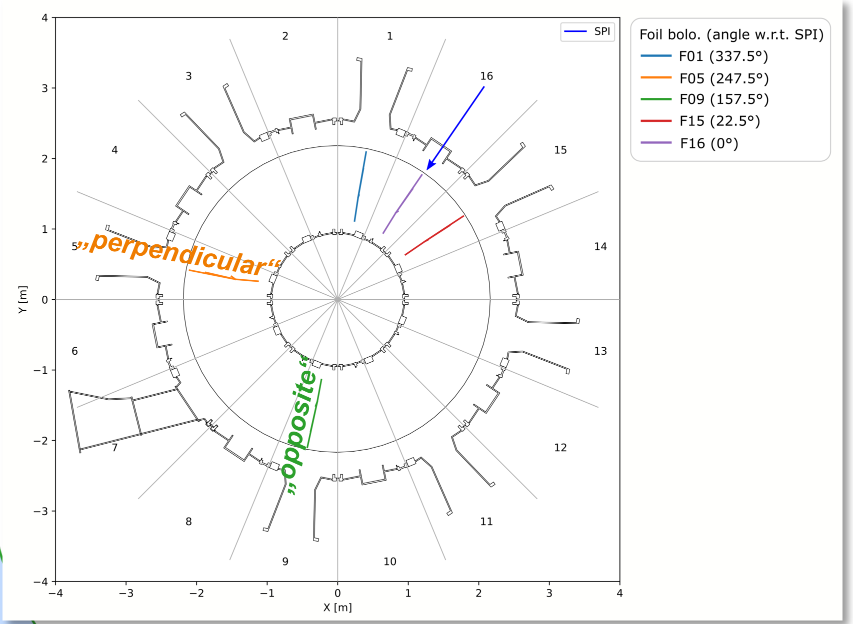


Convexity of the current quench (CQ)





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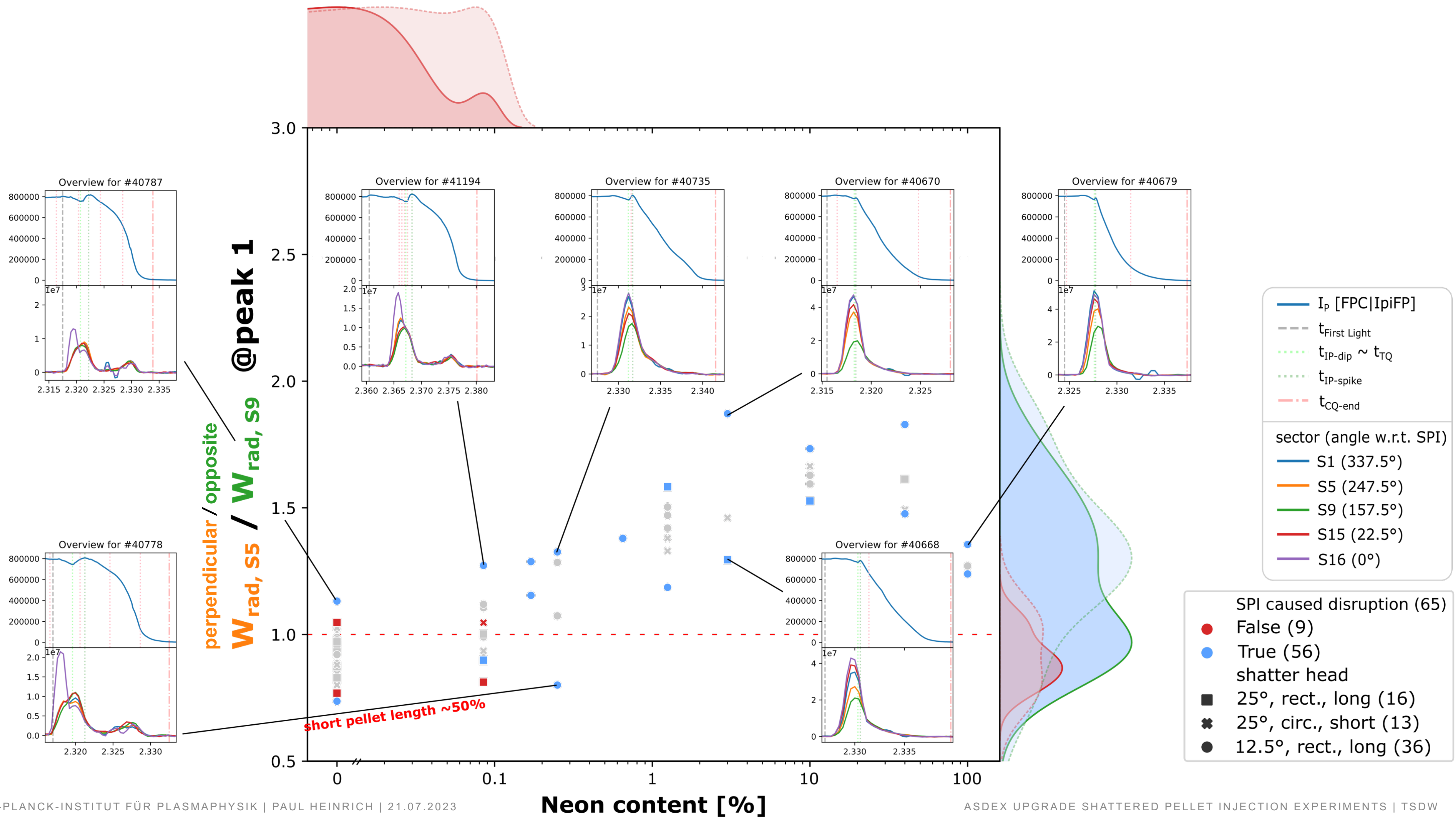
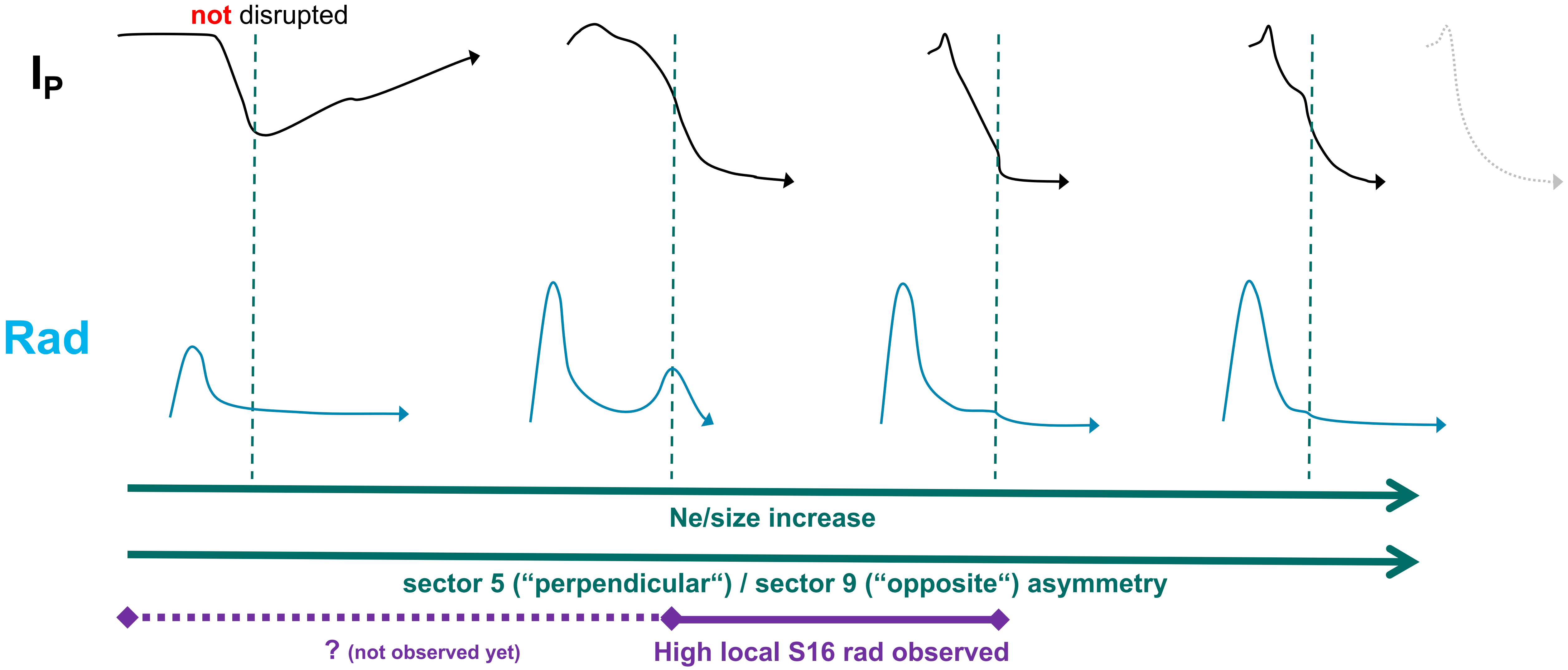


Disruption evolution



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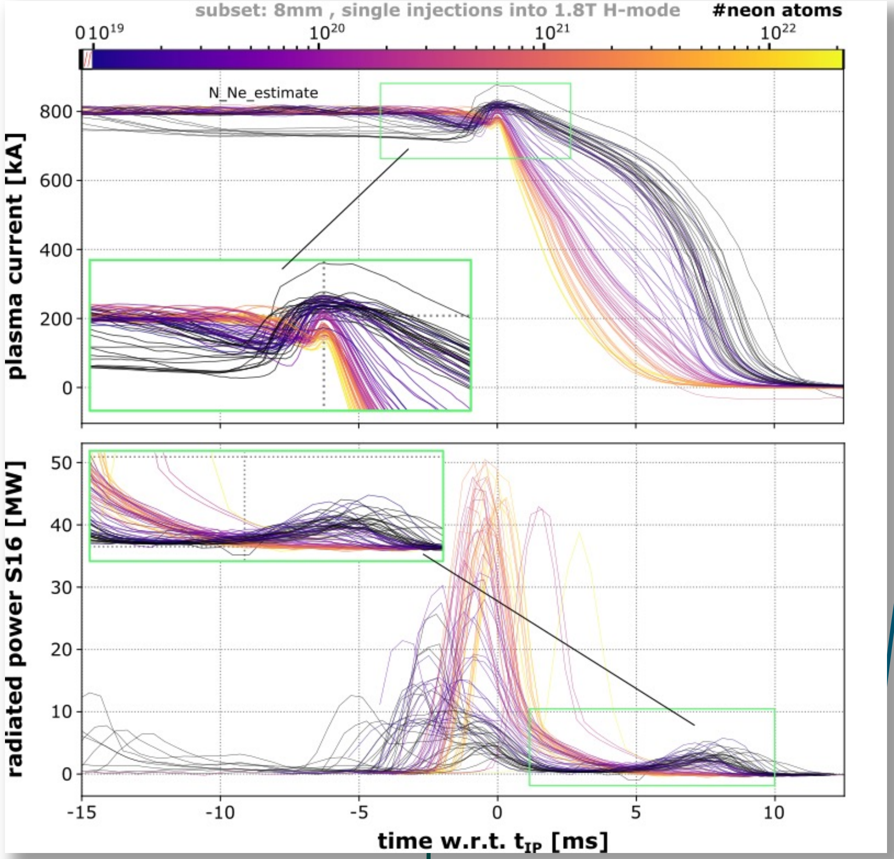
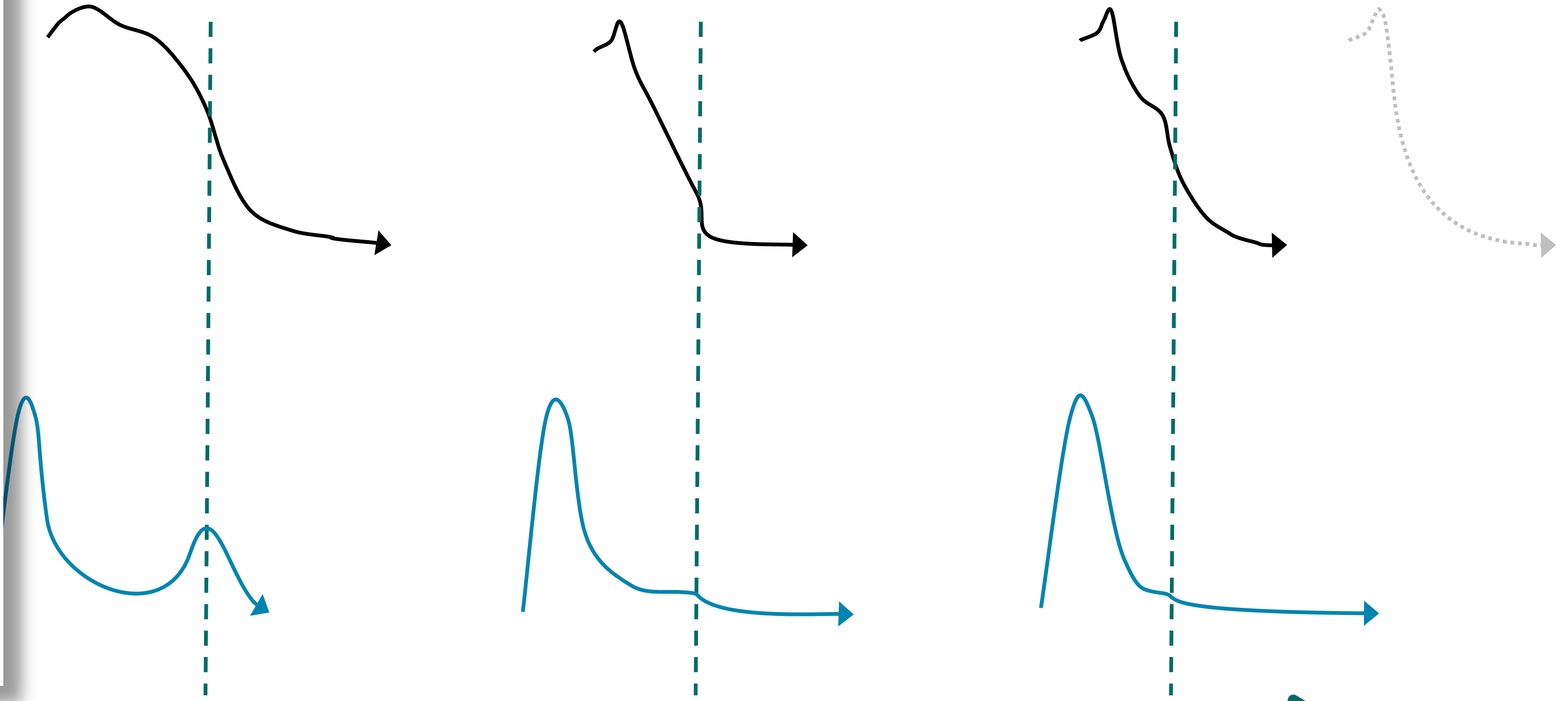




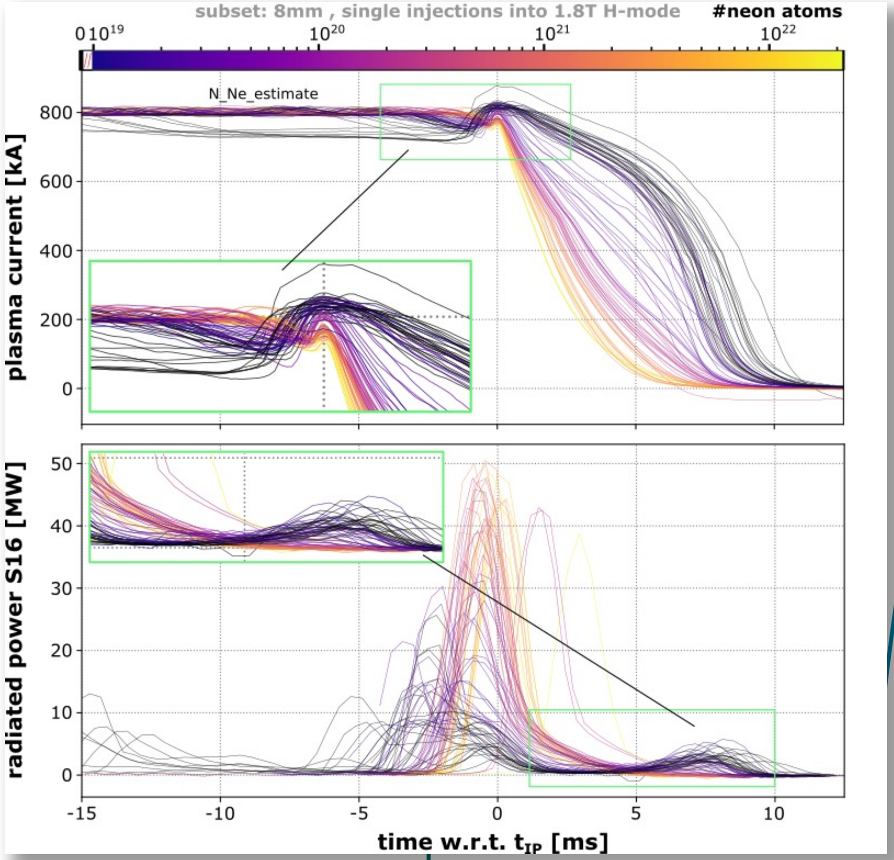
Ne/size increase

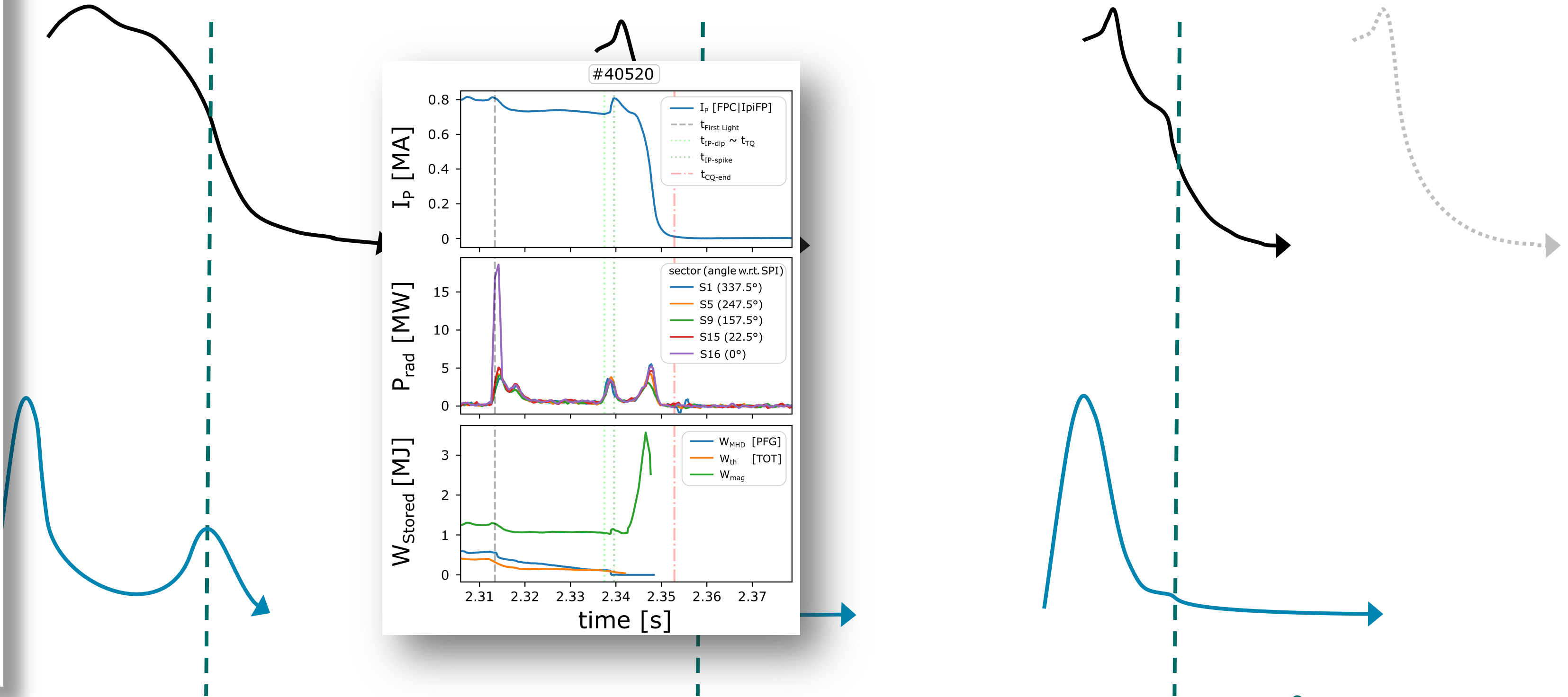
sector 5 (“perpendicular“) / sector 9 (“opposite“) asymmetry

? (not observed yet)

High local S16 rad observed

Disruption evolution





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High local S16 rad observed

Radiated energy fraction · f_{rad}

Radiated energy fraction (f_{rad})

energy stored inside the plasma

$W_{mag} + W_{th}$

W_{mag} | W_{th}

$W_{coupled}$ | W_{rad} | W_{cond}

energy coupled into the structure (e.g. coils, vessel)

energy radiated (derived by foil bolometers)

energy conducted to the PFCs (mainly divertor)

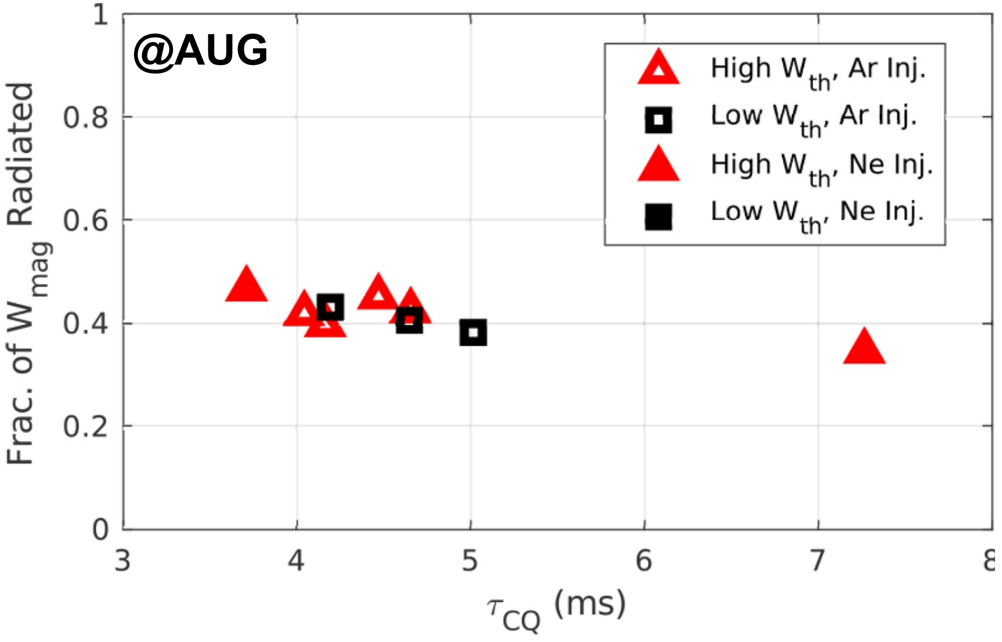
$$W_{mag} + W_{th} + W_{ext.\ heat.} = W_{rad} + W_{coupled} + W_{cond} + W_{RE}$$

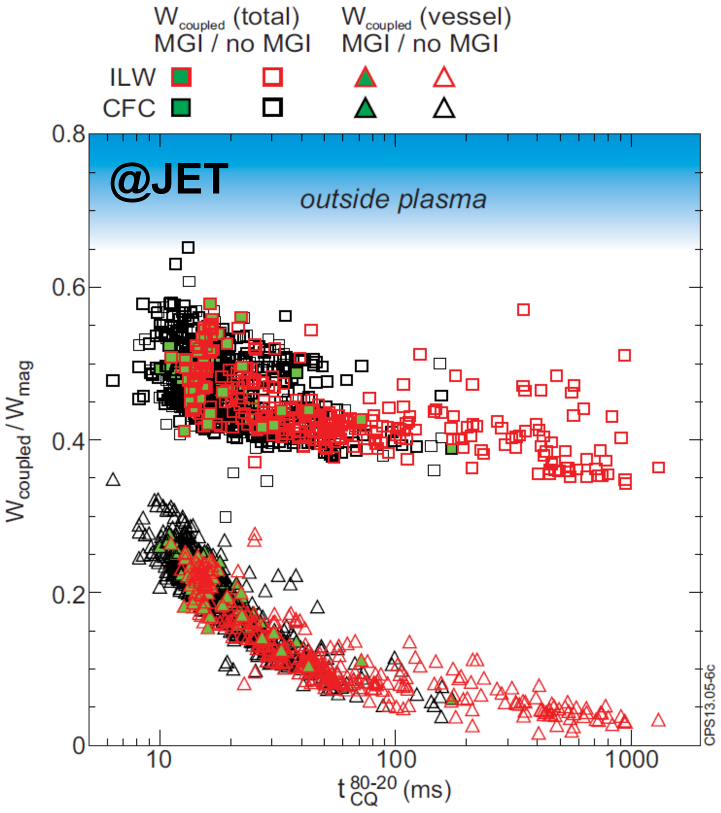
Lehnen et. al., Nucl. Fusion 53 (2013) 093007

Radiated energy fraction (f_{rad})

$$f_{rad} = \frac{W_{rad}}{W_{mag} + W_{th} + W_{ext.\,heat.} - W_{coupled}}$$

Sheikh et. al. Nucl. Fusion 60 (2020) 126029





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current estimate
$W_{coupled} = 0.5 \cdot W_{mag}$

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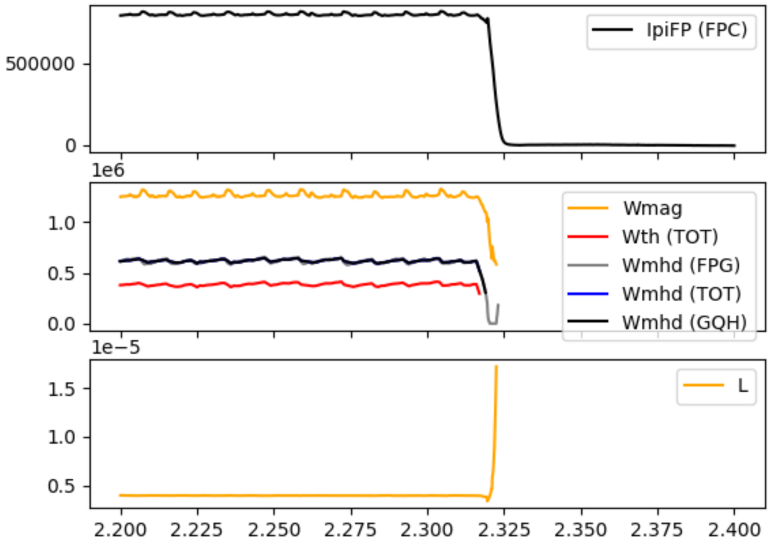

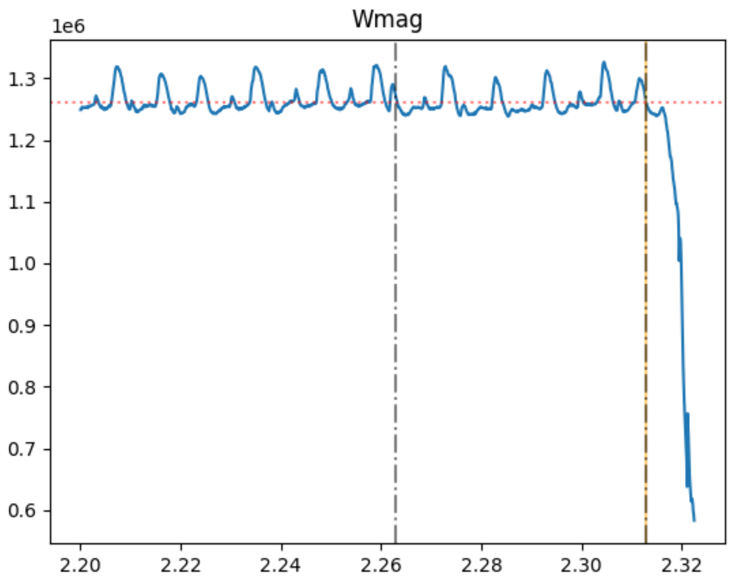

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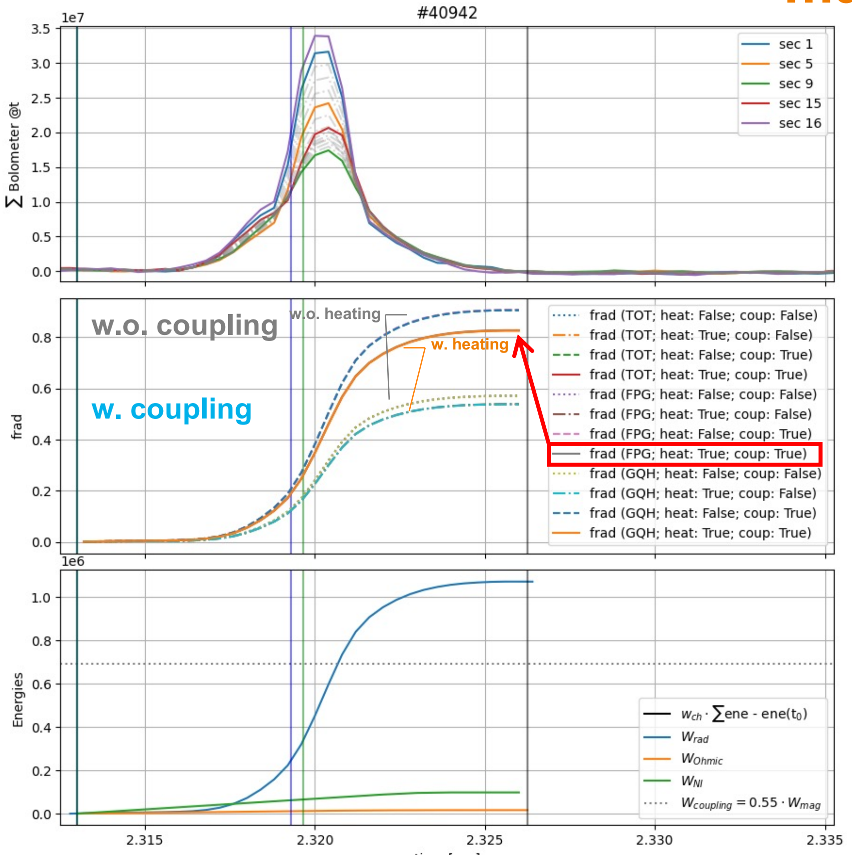

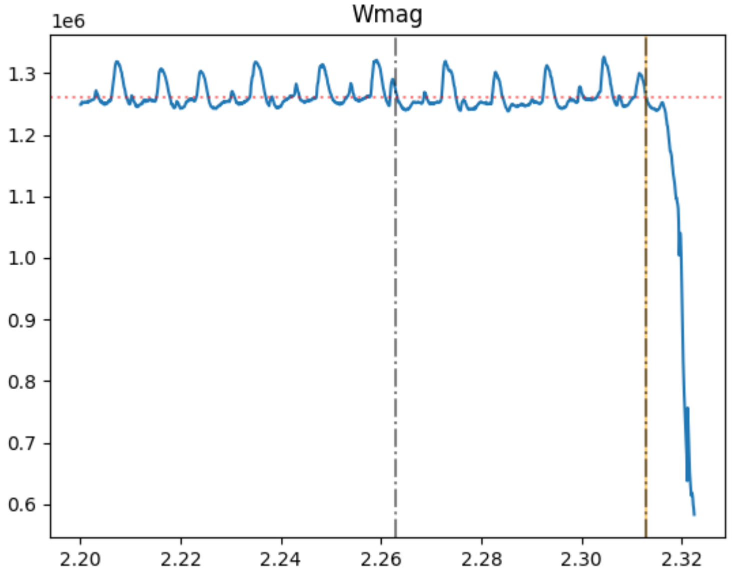

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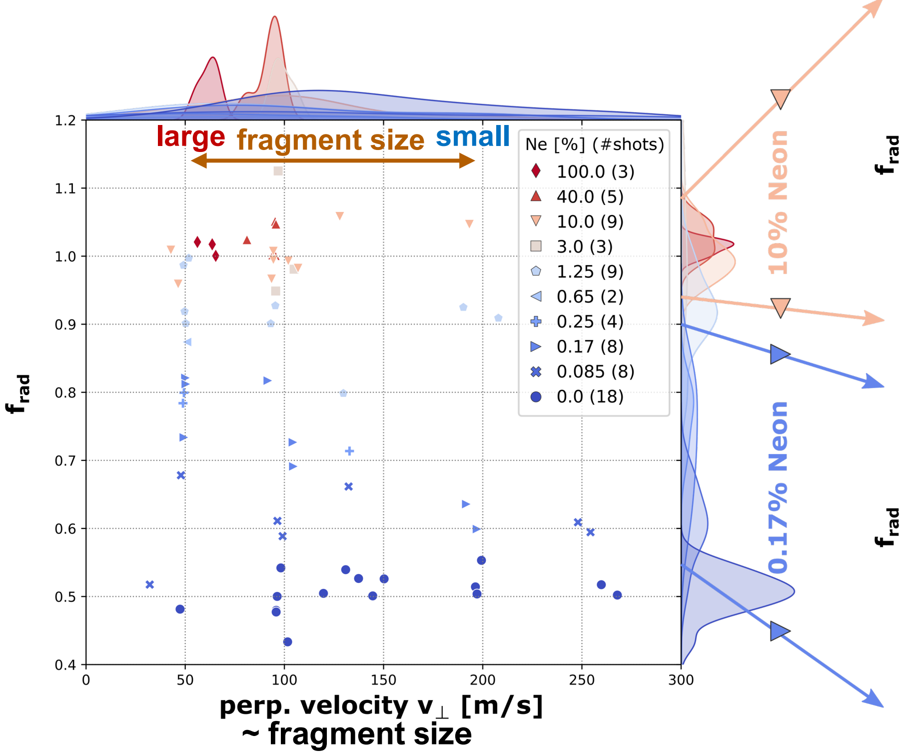
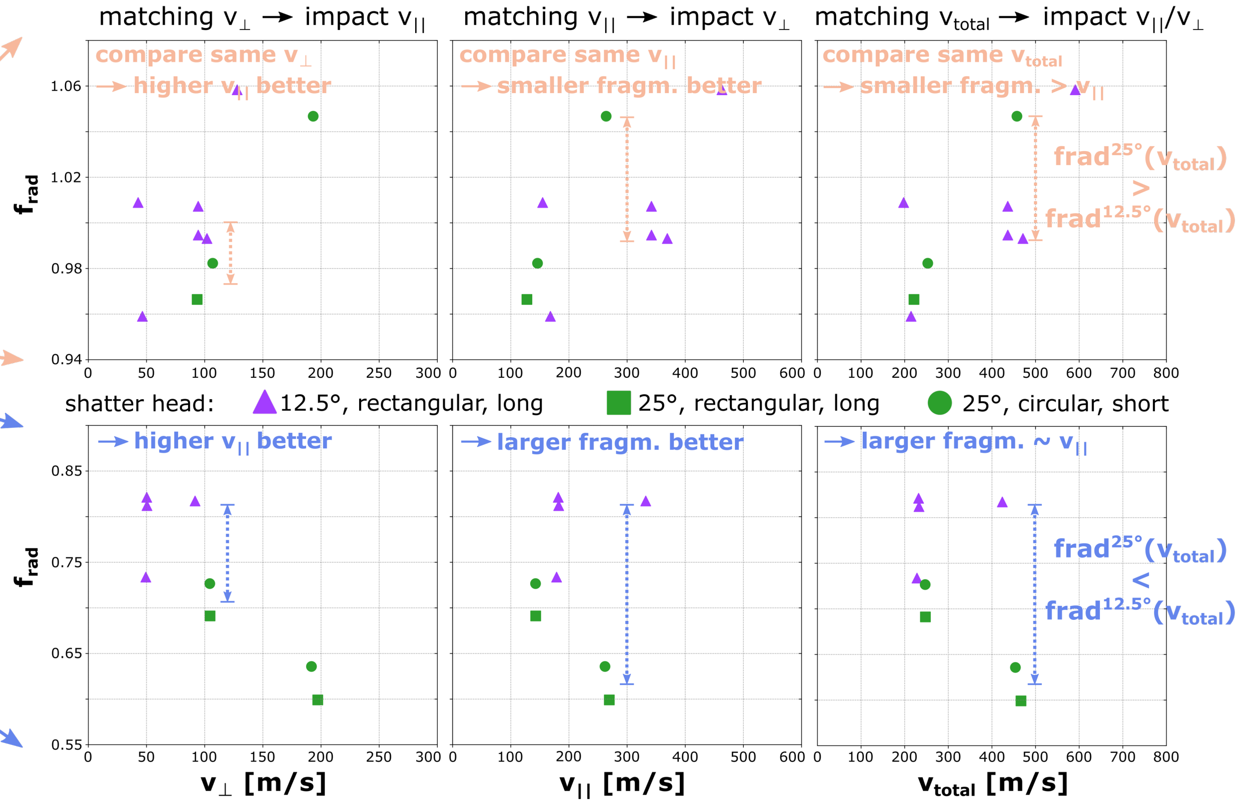




- f_{rad} depends strongly on the neon content and weakly on the shattering parameters (velocity & shatter head geometry)
- Increased $v_{||}$ seems beneficial; no general trend for optimal fragment size observed

effect on f_{rad}

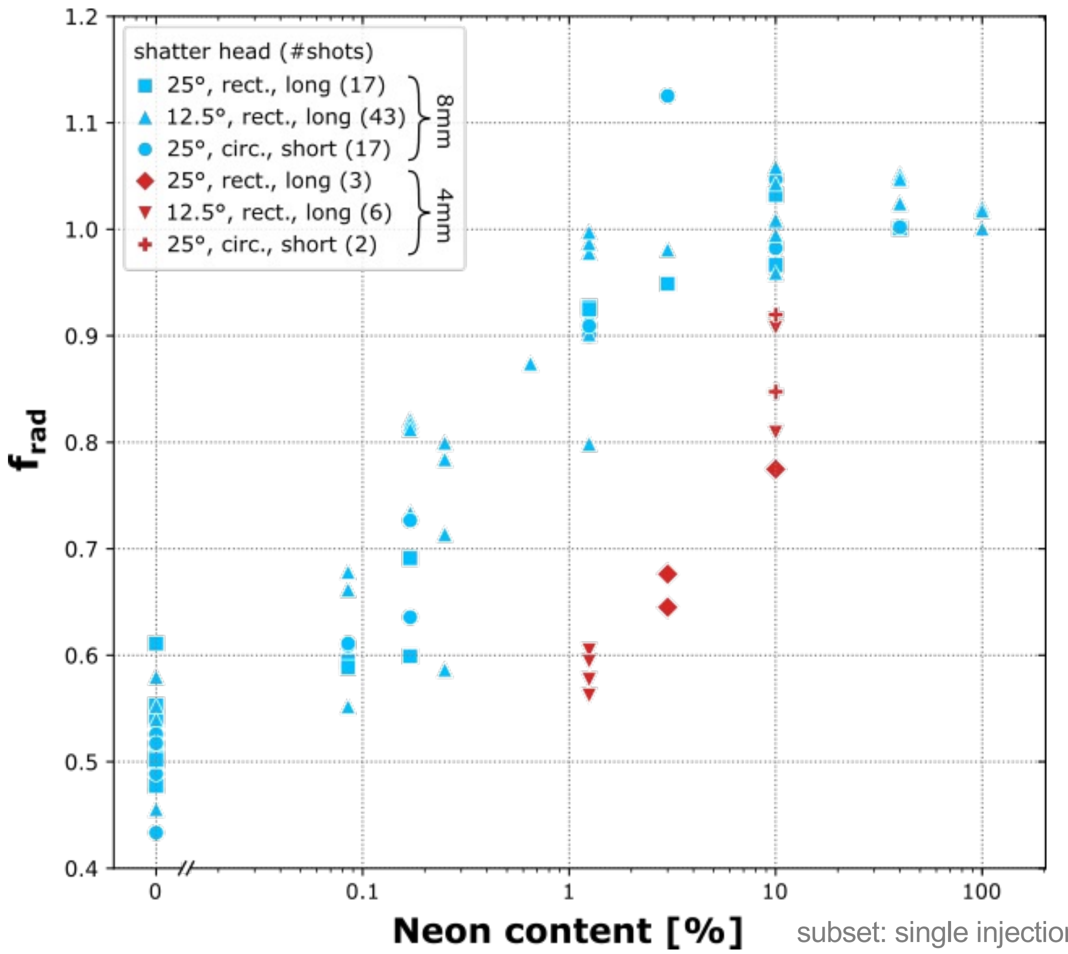
Ne %	40%	10%	1.25%	0.17%	0.085%	0%
v||	high	high	*	high	high	*
frag. size	-	small	*	large	large	*
angle	-	large	*	shallow	shallow	*

- not enough data

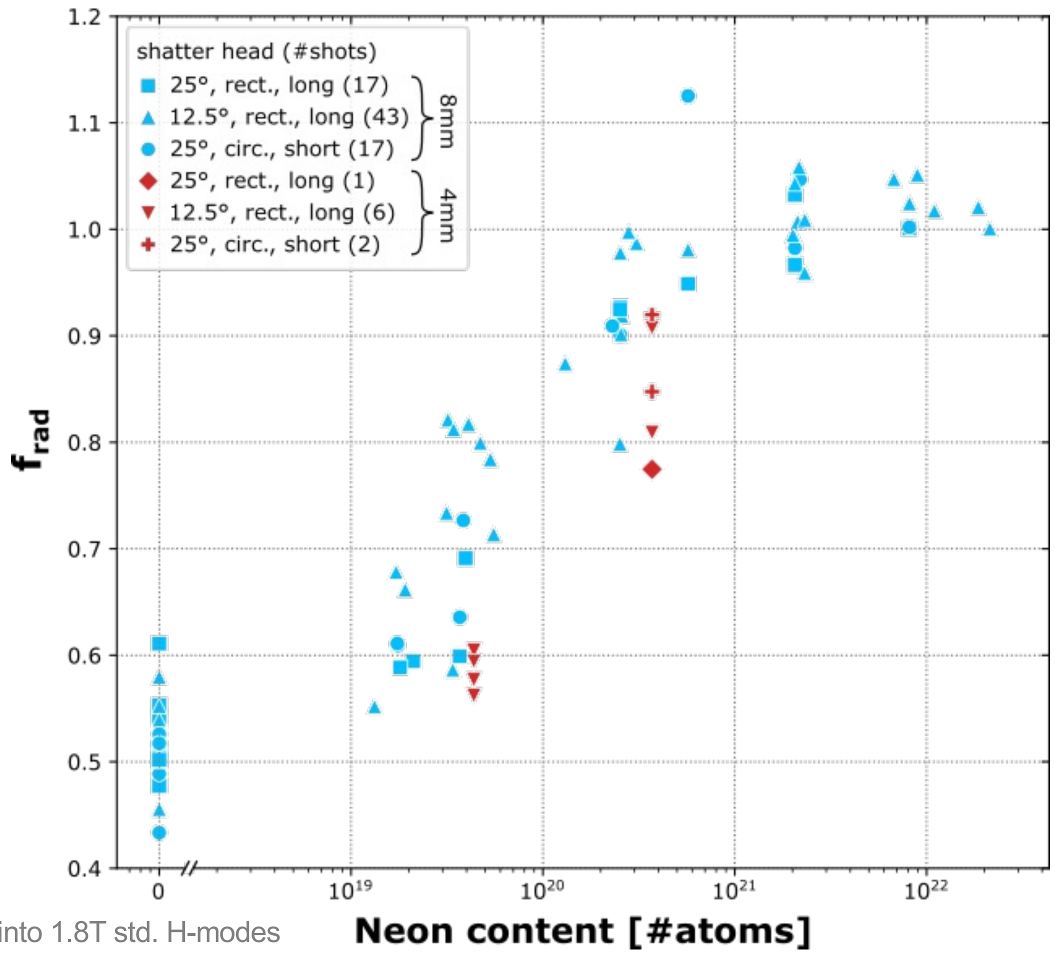
* unclear trend

frad - radiation saturation level

- The curve saturates around 10% neon (8mm) or 10^{21} neon atoms
- Radiated energy fraction dominated by the impact of the amount of neon



subset: single injections into 1.8T std. H-modes



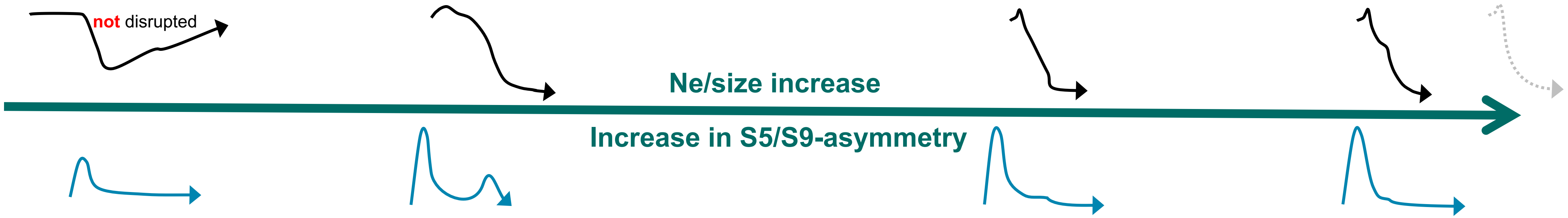
Summary

- **Highly flexible Shattered Pellet Injection (SPI) system installed at ASDEX Upgrade**
- **In total ~240 discharges executed with a good system reliability**
- **Up to 4 radiation peaks visible in the foil bolometers:**

  ↘ *Shard arrival · Mixing? · TQ/IP-spike · ~50% CQ*

SPI animation!

- **Highest Toroidal Peaking Factor (TPF) observed for low Neon quantities (< 1% Neon)**



- **With increasing Neon quantity: increasing S5/S9-asymmetry & convex → concave CQ**
- **Radiated energy fraction (f_{rad}) increases with parallel velocity and neon quantity;**

  no **visible trend for fragment size and shatter geometry**