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ASCOT modeling for the ITER FILD project

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Universidad de Sevilla

PSFT Plasma Science and Fusion Technology

20/03/2025   VTT – beyond the obvious

EUROfusion

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-Introduction
-Simulations/results
-Conclusions/outlook

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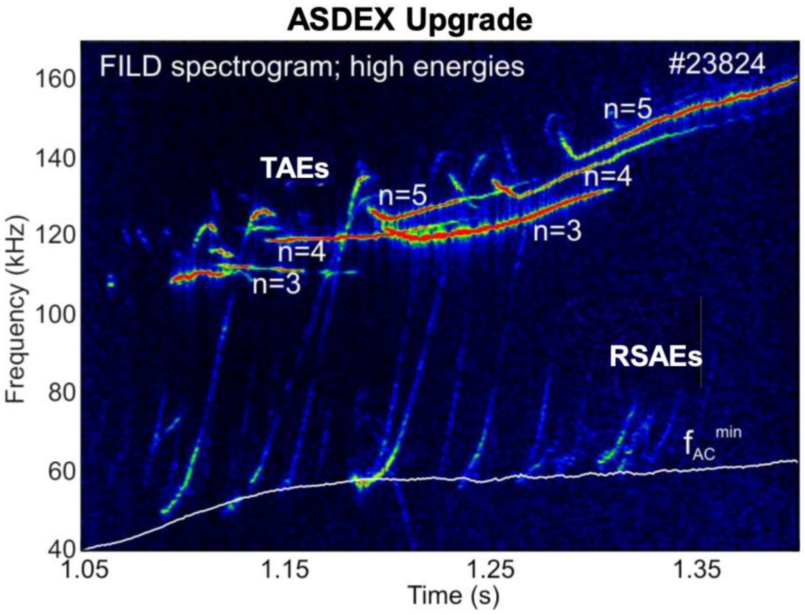
Good Alpha-Particle Confinement is Essential for ITER Success

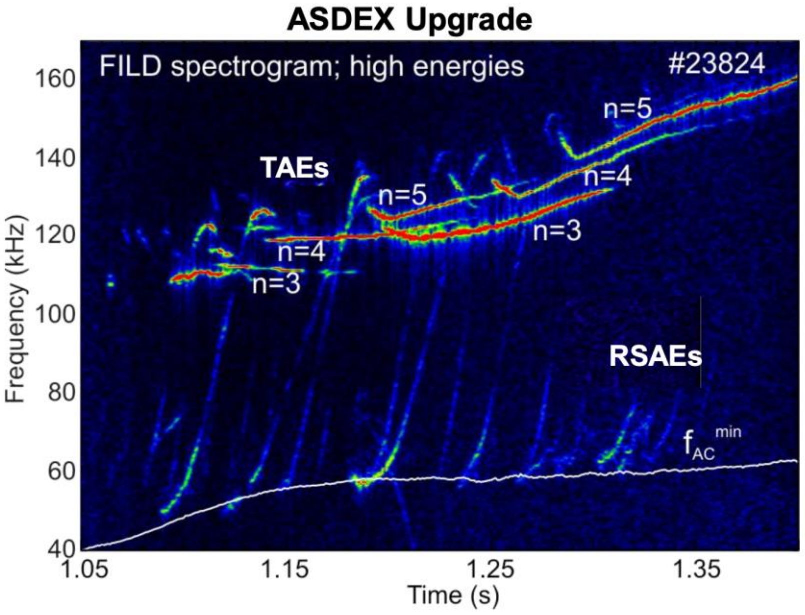
- ITER Mission Goals
  - ITER is designed to produce a plasma dominated by alpha-particle heating
  - Produce a significant fusion power amplification factor (Q>10) in long-pulse operation (300 – 500 s)
- Fast-ions have strong impact on
  - Fusion performance / NBI current drive
  - Device Integrity
- Fast-ions are subject to transport by
  - MHD fluctuations, e.g. Alfvén Eigenmodes, NTMs, fishbones…
  - Externally applied 3D fields



M. Garcia-Munoz et al, Phys. Rev. Lett. **104,** 185002 (2010)

Fast-ion diagnostics for ITER

- Confined ions
  - Neutron & gamma ray diagnostics
  - Collective Thompson Scattering (CTS)
  - Probe only limited phase-space -> tomography needed-> DTU!!!
- Lost ions
  - Infrared cameras (machine protection)
  - Fast-Ion Loss Detector (FILD) (physics)



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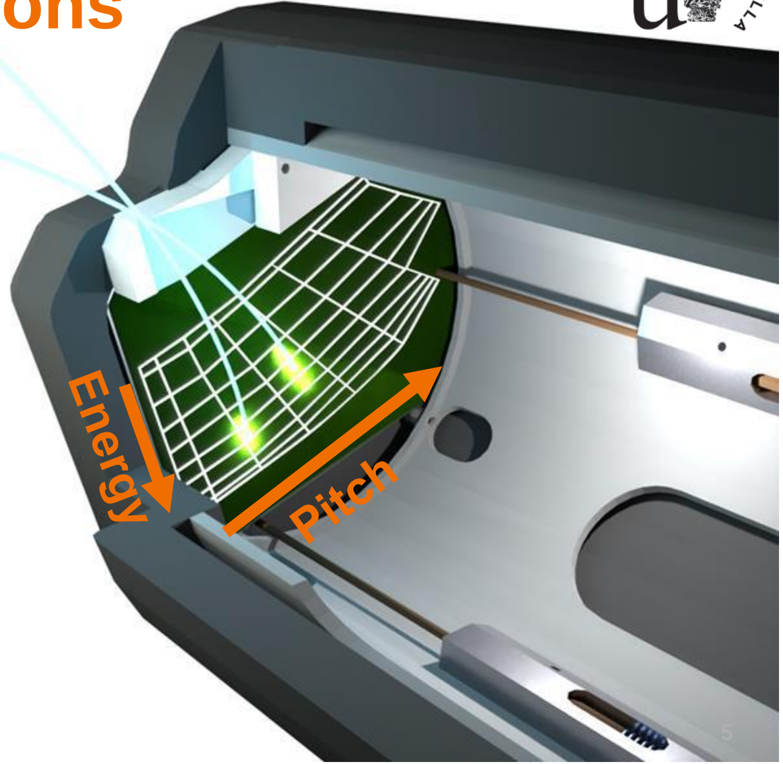
FILD Provides Full Information on Velocity-Space of Escaping Ions

- FILD provides local time-resolved energy and pitch angle measurements of escaping ions
- MHz temporal resolution enabled by fast scintillator decay time – *key for identifying coherent losses and impact of individual modes*
- Local velocity-space measurements like these help to isolate fundamental mechanisms
- Installed in virtually all fusion devices

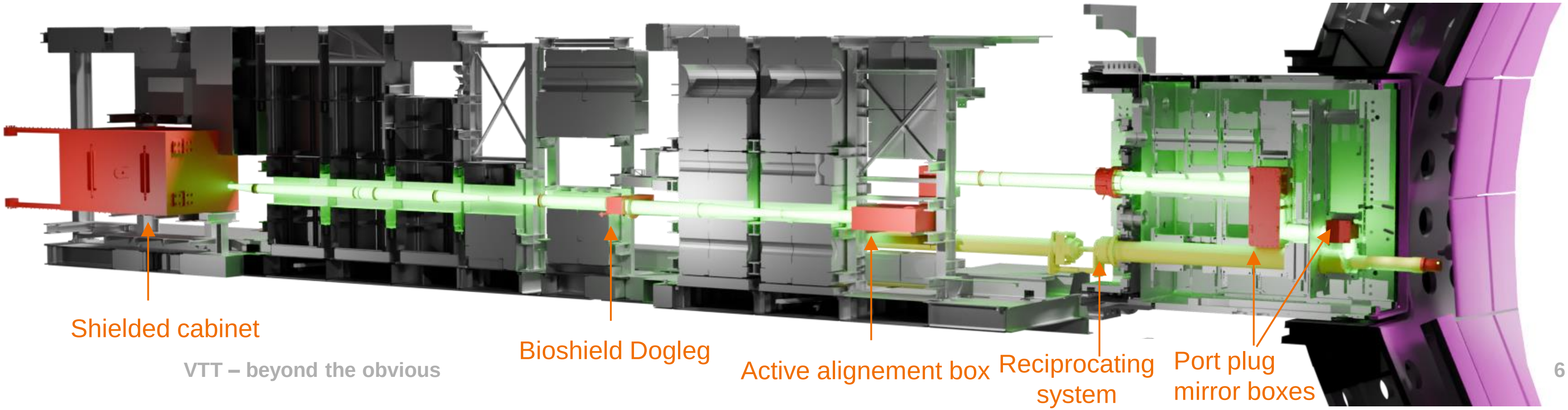


[1]S. J. Zweben, Rev. Sci. Instrum. **57**, 1774 (1986)
[2]M. Garcia-Munoz et al, Rev. Sci. Instrum. **80** 053003 (2009)

ASCOT Modelling Guides ITER FILD Design

- Exploratory simulations started back in 2016[1]
  - Fast-ion flux estimated using **vacuum approach**
  - Poloidal location of the probe, port space allocation
- Current design phase since ~2021
  - Re-visit ASCOT simulations, state-of-the-art modelling
  - Enough signal to noise ratio? Capable of measuring alphas and NBI losses?
- CDR successfully took place in February 2024 (no cat 1 chit)
- Some components to be delivered for SRO
- ASCOT+FILDSIM simulations are paramount to define light acquisition systems and heat-loads

[1]M. Garcia-Munoz et al, *Rev. Sci. Instrum*. **87**, 11D829 (2016)



ITER 15MA baseline H-mode + ASCOT

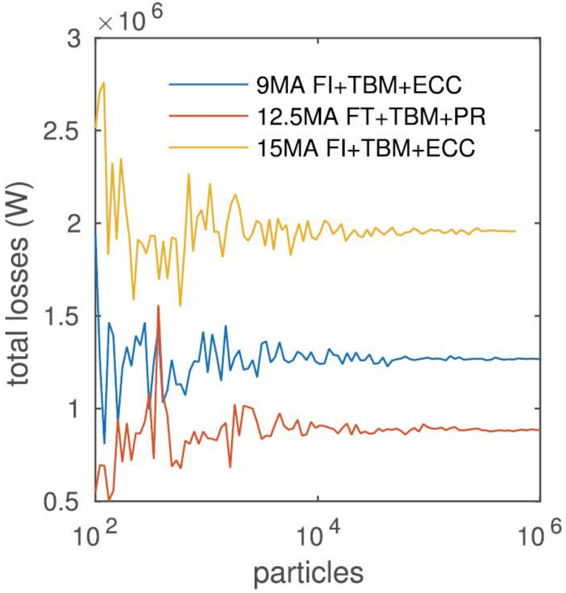
- All simulations are based on baseline scenario
  - ELM control coils (ECCs) will be applied
  - Toroidal n=3 mode, plasma response (MARS-F) [1]
  - TF ripple, ferritic inserts
  - Equilibrium and kinetic profiles from 1.5D transport runs [2]
  - Wall 3D geometry provided by IO
- ASCOT simulations
  - Monte Carlo orbit-following simulations in 3D geometry (wall + B-field)
  - 1-2M alpha markers using hybrid GC+GO until slow-down
  - Fluxes collected to FILD probe head
  - Beam ion simulations with lower resolution (10k-100k)

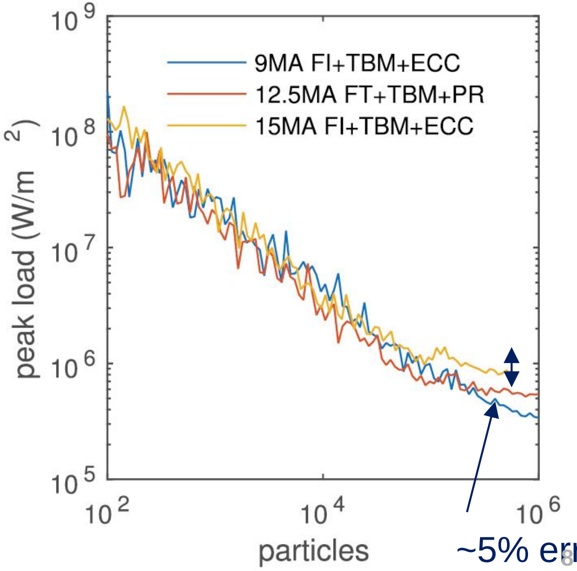
[1] L. Sanchis *et al* 2021 *Nucl. Fusion* **61** 046006
[2] T. Kurki-Suonio *et al* 2016 *Nucl. Fusion* **56** 112024

ITER 15MA baseline H-mode + ASCOT

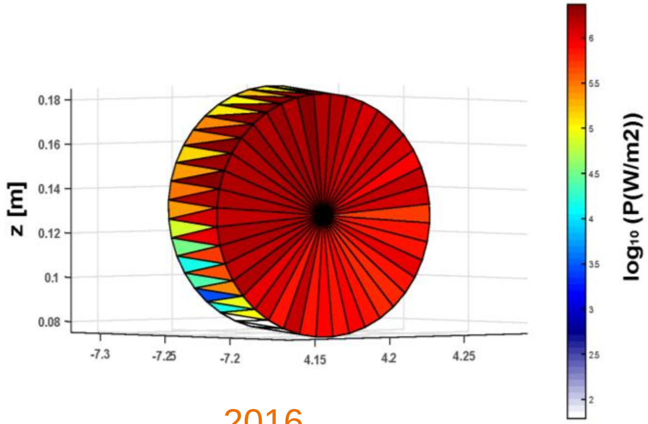
- ASCOT simulations
  - Typically 1-2M alpha particles simulated until slow-down

[1] T. Kurki-Suonio *et al* 2016 *Nucl. Fusion* **56** 112024

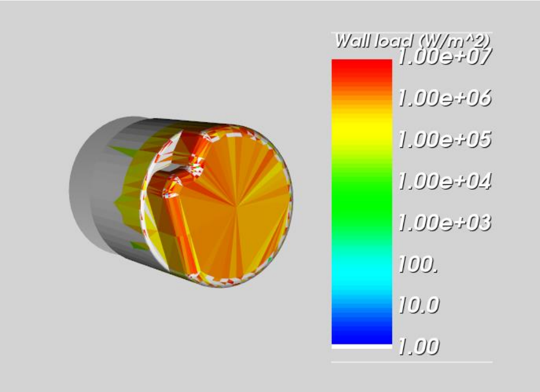




Significant improvements since 2016



2016



2022

- Simplistic probe head design
- Vacuum approx. n=4 **underestimated** the flux

- Detailed probe head design
- Plasma response n=3 included

(L. Sanchis *et al* 2021 *Nucl. Fusion* **61** 046006)

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A. Snicker et al.

Result 1: plasma response is of critical importance!

Power loads using: RMP (n=3), TF, FI (vacuum)

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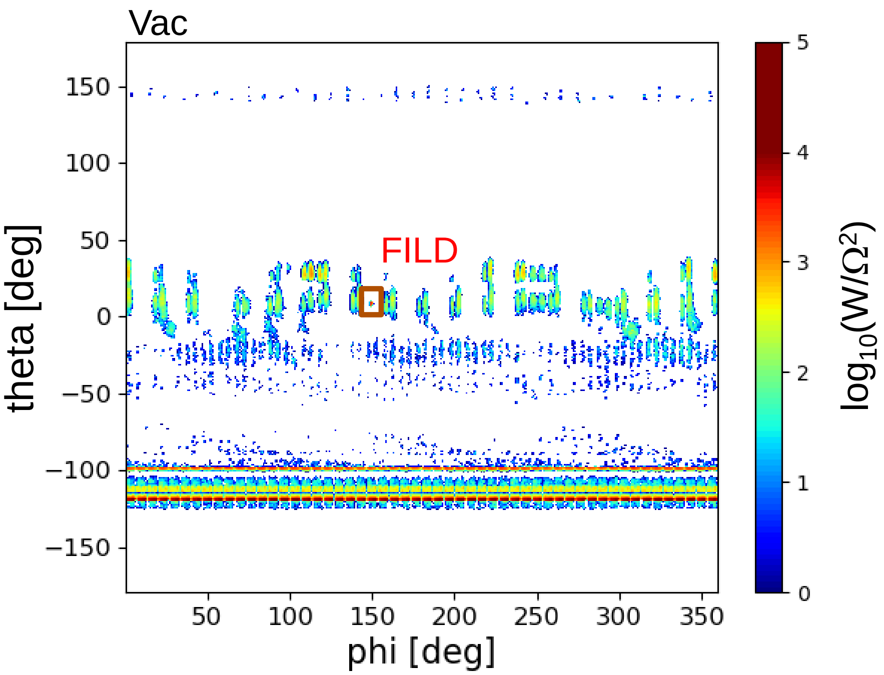
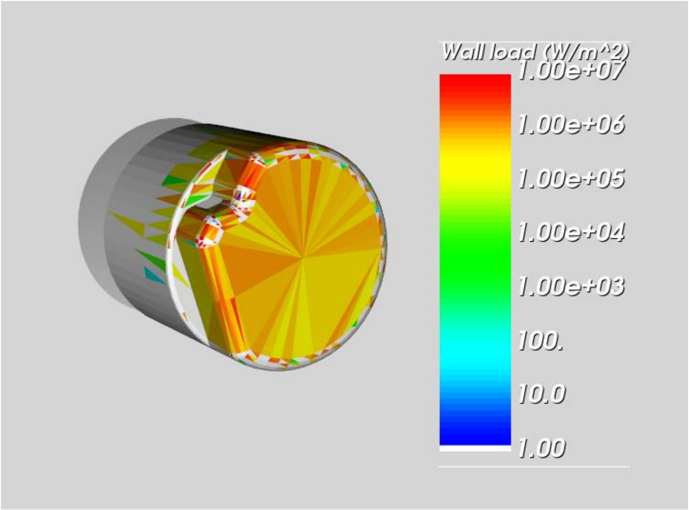
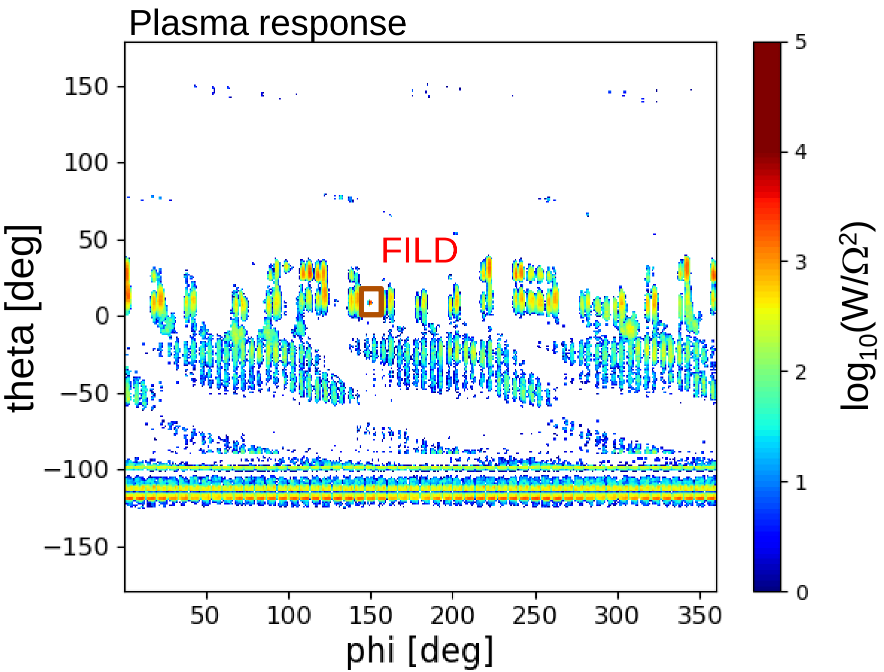


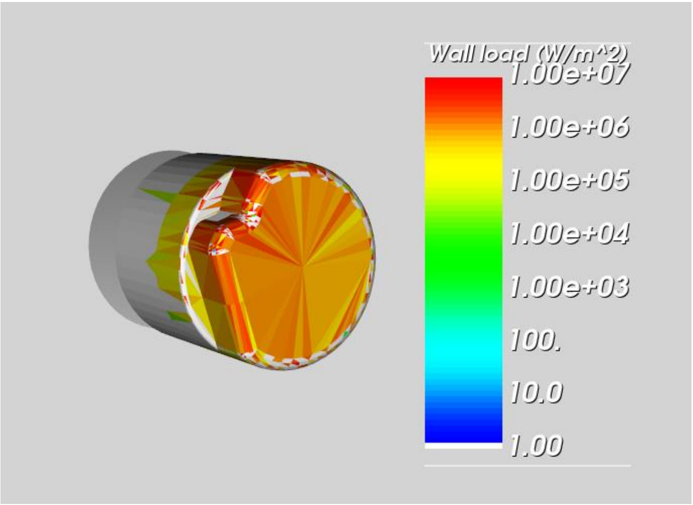


Total wall hits: 474421
FILD hits: 1741

Total losses: 4.20 MW
FILD losses: 8.38 kW

Power loads using: RMP (n=3), TF, FI (PR)

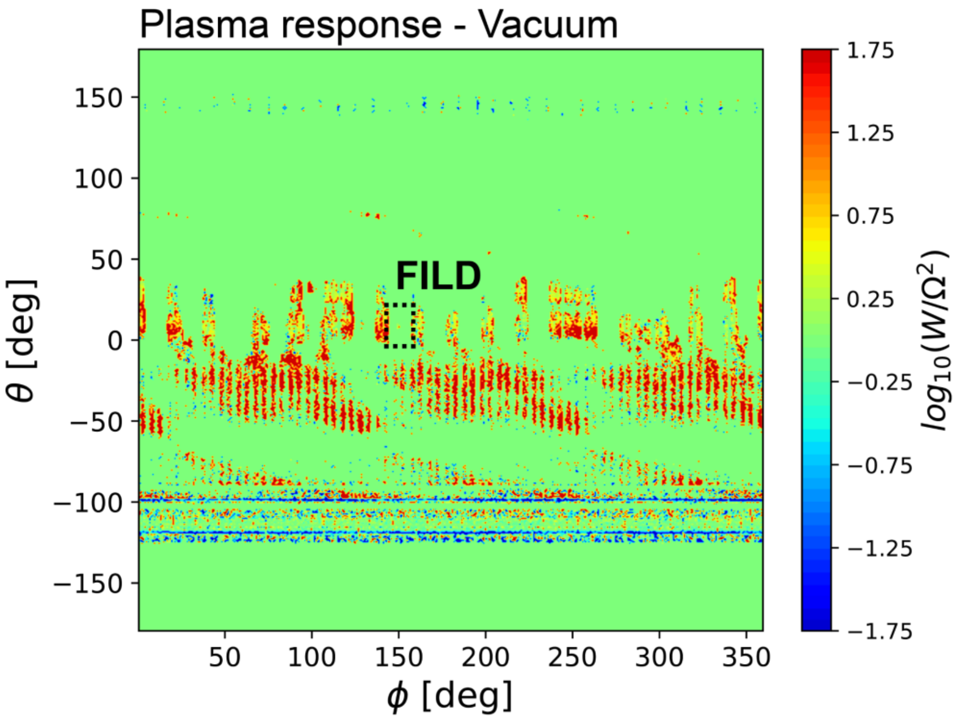


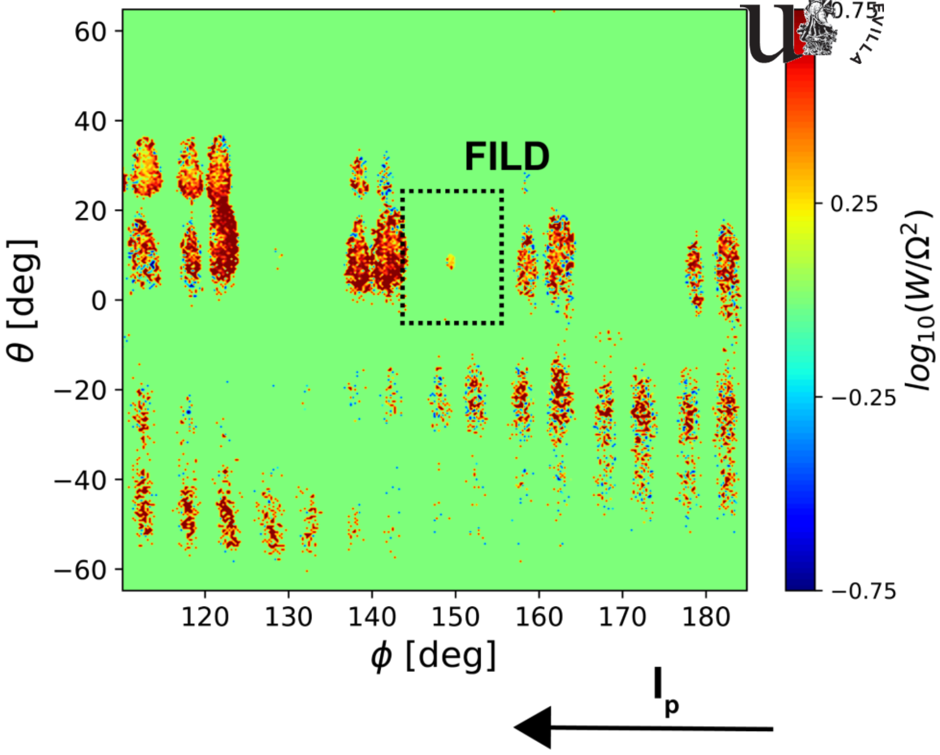


Total wall hits: 351099
FILD hits: 2318

Total losses: 1.89 MW
FILD losses: 15.2 kW

Plasma response shifts the patterns



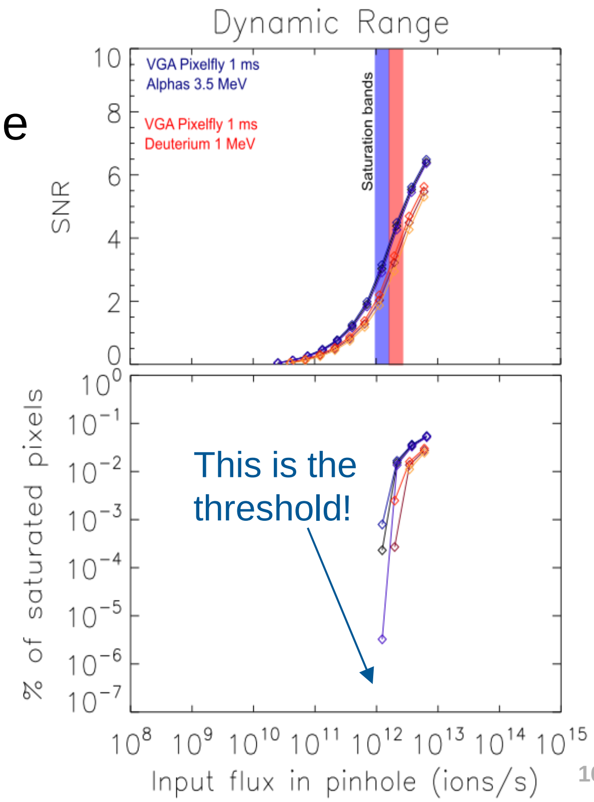


Result 2: ASCOT predicts measurable signal well over noise-level

Estimation of the signal to noise threshold

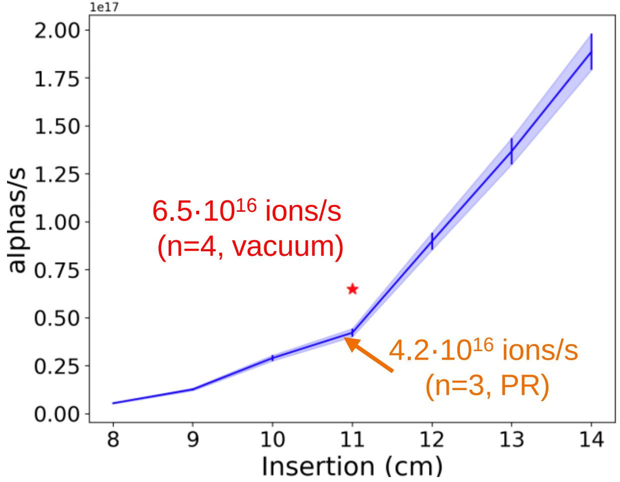
J. Galdon

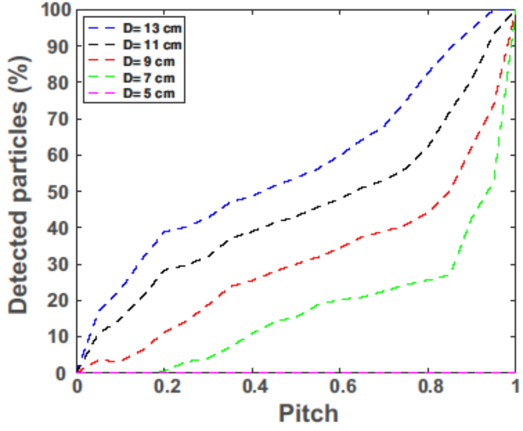
- FILDSIM: ~1e12 ions/s at the pinhole=noise
- ASCOT simulations to estimate signal at pinhole
  - Local estimate at the vicinity of the pinhole



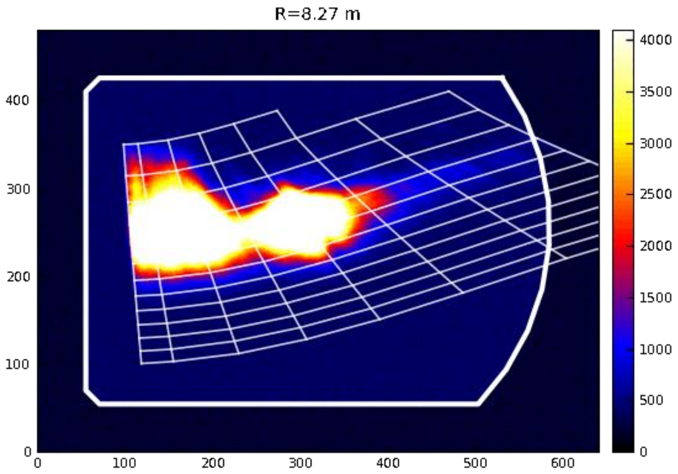
Probe Head Position Is Scanned To Determine Sensitivity of Results

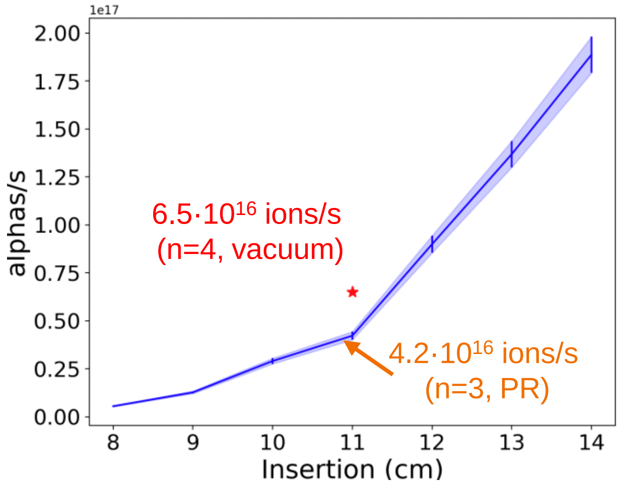
- Number of alpha particles reaching FILD comparable to case with n=4 RMPs (from 2016)
- Alpha particles reaching the probe head increase with insertion
- Backwards simulations predicted this insertion dependence, attributed to velocity-space coverage





Probe Head Position Is Scanned To Determine Sensitivity of Results

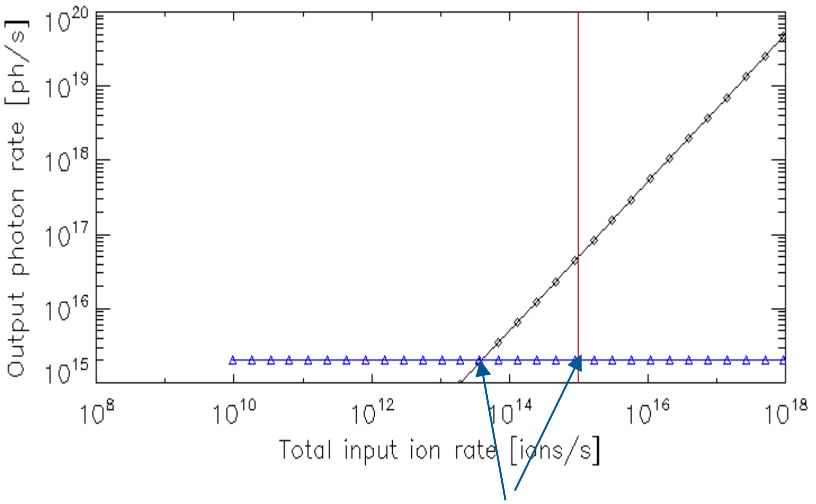




Result 3: Alphas should be measurable at early stage of ITER operation

Alphas should be measurable at very early stage (=at low alpha power)

- Scan the alpha power, compare alpha signal vs. noise
- Measurement threshold at 0.05*120MW~5MW!
- Assumption: background noise is kept constant…



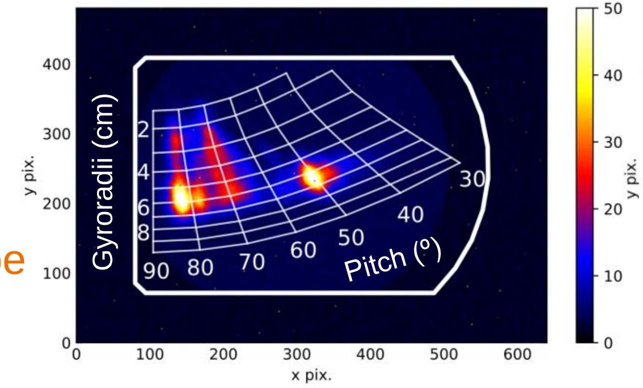
J. Galdon

Result 4: NBI losses could be separated from the alphas

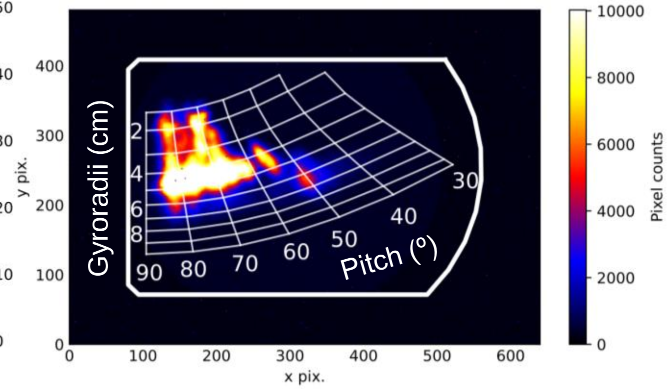
NBI signal is measurable

- Example here, “off-axis” beam configuration
- NBI+alpha velocity-space overlap
- Tomography methods could be used to separate the signal
- Is NBI signal more prone to rigid rotation of the ECCs?

Alphas only



Alphas+NBI off-axis

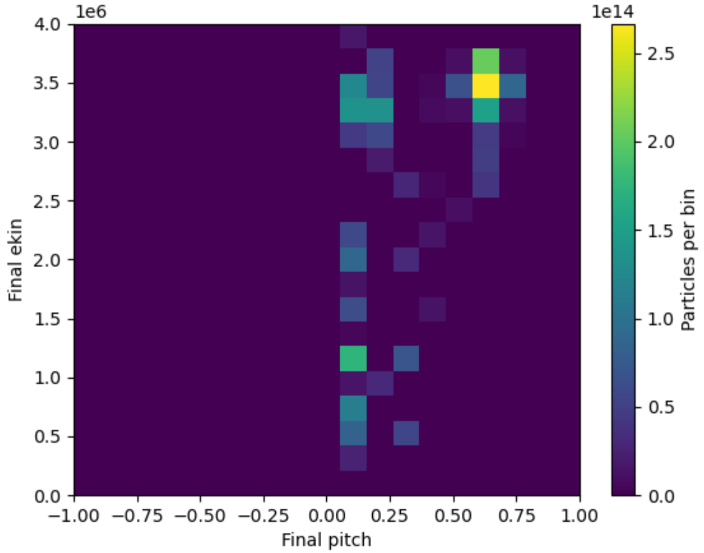


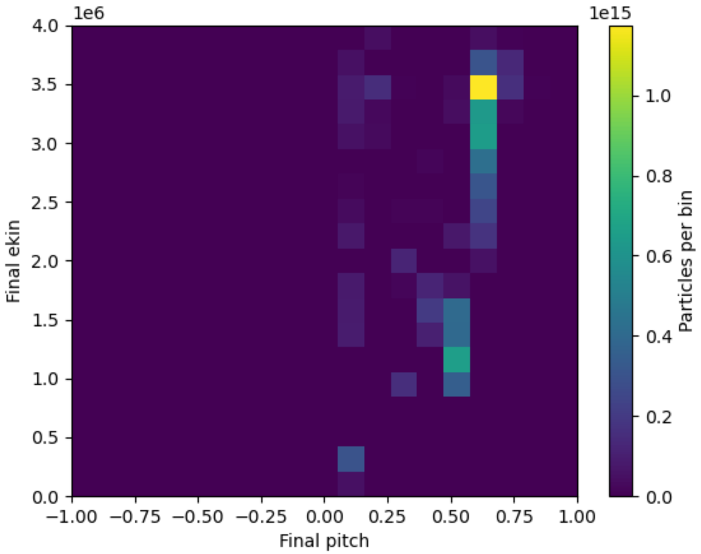
Note different colorbars!

Result 5: MHD will modify the fingerprints at FILD

(2,1) NTM affects velocity space of lost alphas

- (E,pitch) at FILD (left no NTM, right 15cm NTM)
- Additional spot at 1.5 MeV appearing
- FILDSIM tbd for synthetic image

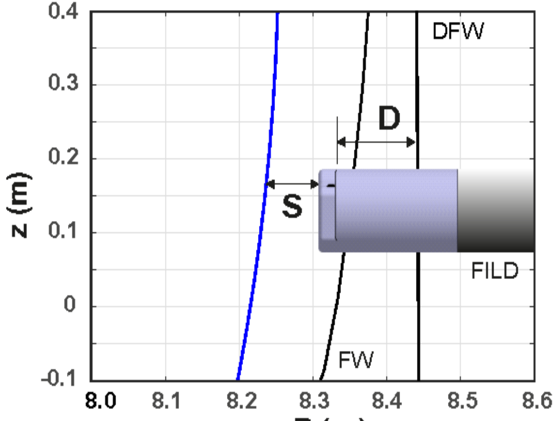


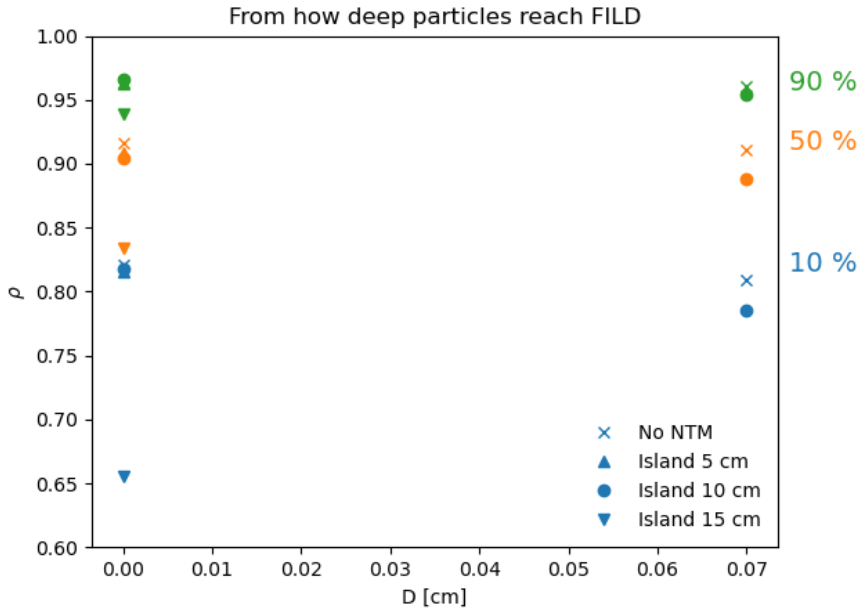


Result 6: FILD measures particles from rho~0.8-1.0

FILD measures losses from rho~0.8…1.0

- Origin of the lost alpha particles (blue 10%, orange 50% and green 90%)
- Influence of an (2,1) NTM is visible
- No strong dependency on the insertion depth (D)

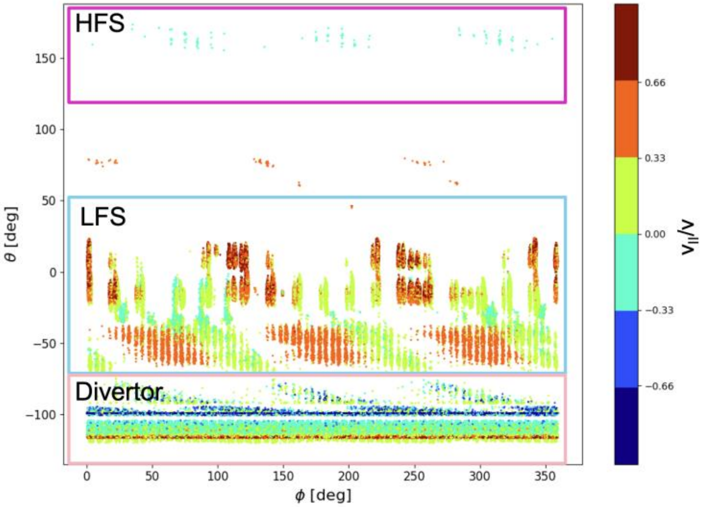


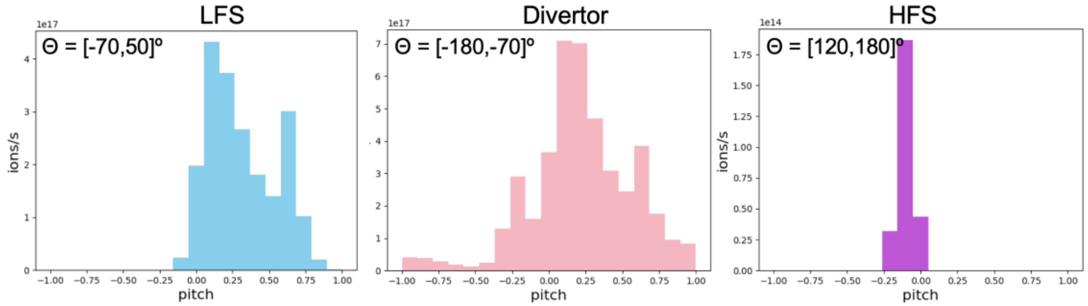


Result 7: FILD measures only co-going alphas

Due to geometric effects, only pitch>0 reach FILD location

- Pitch distribution of losses highly skewed towards pitch > 0
- On the LFS, only marginally negative pitches
- On HFS, only negative pitches but low flux
- Decision: Consolidated the single collimator design at ITER





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Summary and conclusions

- ASCOT (+FILDSIM) simulations presented for the ITER FILD
- Main results:
  - Importance of including the plasma response
  - Alpha particle signal overcomes the background noise
  - Fairly low level of alpha power should be measurable
  - Beam ions could be distinguished from alphas
  - MHD perturbations will influence the FILD signal (here NTMs)
- Next steps:
  - ASCOT vs. LOCUST comparison
  - Investigate other scenarios, update 15 MA H-mode (with W first wall)
  - Further MHD activity (TAEs)