[KP1.45] Modeling of ICRF Experiments in C-Mod

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P.T. Bonoli (MIT-PSFC) and M. Brambilla (IPP-Garching)

ICRF Heating and current drive combined with lower hybrid (LH) current drive provide critical capabilities for the establishment of long duration high β_N AT discharges on C-Mod. In particular, ICRF minority ion core heating, off-axis mode conversion (MC) current drive, and potential flow shear driven by mode converted ion Bernstein waves (IBW) offer flexible profile control options. Though the TRANSP code is capable of analyzing minority heating experiments, the ICRF package must be extended to treat the IBW excited via mode conversion from fast waves. To this end, the TORIC full wave code which includes a quasi-localized treatment of the IBW is being installed in TRANSP. Benchmarking comparisons of TORIC against the METS integral 1D kinetic code will be discussed. Preliminary simulations of ICRF experiments in a variety of regimes obtained with the TRANSP / Toric package will be presented.

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Highlights of this poster

- A suite of ICRF modeling codes for C-Mod is described.

- The 1D METS code and the 2D TORIC code have been compared for the *D-H heating regime* over a wide range of H concentrations.
  - good agreement is found for both relative power splits and power deposition profiles;
  - mode conversion efficiency is sensitive to n_e and the minority H concentration, as expected from theory.

- METS and TORIC have been compared in the *D-^{3}He heating regime*
  - reasonable agreement is found for on-axis heating of ^{3}He.
  - differences are found for off-axis heating cases.

- Initial testing of the TRANSP /TORIC package is underway.

Hear talks this meeting by P.T. Bonoli et al [QI2.03] and G. Taylor et al [RO2.06] for further details and comparisons against experimental measurements

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A suite of codes can be used for modeling ICRF experiments on C-Mod

- **1D Single Pass Absorption Code - METS**
  - ➟ **provides estimates of absolute strength of absorption mechanisms**

- **2D Power Deposition Code - TORIC**
  - ➟ **provides direct wave power deposition profiles in poloidal cross section**

- **Time-dependent Transport Analysis - TRANSP**
  - ➟ **provides time-dependent power deposition profiles, including self-consistent evolution of rf-driven nonthermal distribution function(s)**

    - **SPRUCE module in TRANSP limited to minority and/or second harmonic majority heating regimes**

    - **installation of TORIC nearly complete for extension of modeling capabilitiy to mode-conversion heating regimes**

    - **2D bounce-averaged quasilinear Fokker-Planck package (FPP) used to model rf-driven nonthermal distributions**

M.I.T.

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Wave Absorption modeled in 1D with METS code

***METS* code** **solves for wave fields and absorption assuming:**

- **1D single-pass absorption formulation;**
- **all orders of $k_\perp \rho_i$ and of Bessel functions retained;**
- **all three components of E field retained;**
- **finite $k_{//}$ and k_y retained;**
- **toroidal upshift of $k_{//}$ retained**
- **option to include effects of parallel gradient**

METS developed by Mission Research Corporation and PPPL
D.N. Smithe et al, Radio Frequency Power in Plasmas (AIP,NY,1997) p367.

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Wave Absorption modeled in 2D with TORIC code

***TORIC* code** **solves for wave fields and absorption assuming:**

- **2D boundary value formulation;**
- **all three components of E field retained;**
- **poloidal and toroidal mode expansion utilized;**
- **toroidal upshift and B_p modification of $k_{//}$ retained;**
- **FLR expansion to second order in $k_\perp \rho_i$, with explicit solution for mode converted IBW retained to this order;**
- **Electron Landau damping of IBW formulated for $(k_\perp \rho_i)^2 >> 1$, following M. Brambilla, Nucl. Fusion 38 (1998) 1805.**

TORIC developed by M. Brambilla (IPP-Garching) and P.Bonoli (PSFC-MIT)

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METS and TORIC have been compared over a range of discharges with D-H heating

case \ param.	H concentration relative to n_e	electron density (10^{20} m^{-3})	temperature (keV)
A	2.5 %	3	3
B	11.5 %	3	1.8
C	14 %	3	2
D	19 %	3	1.8
E	28 %	2.6	1.5

B_{T0} ~ 5.46 T R_0 ~ 0.67 m a ~ 0.22 m f ~ 80 MHz

Nphi ~ 10 so $k_{//}@R_0$ ~ 14.93 m^{-1}

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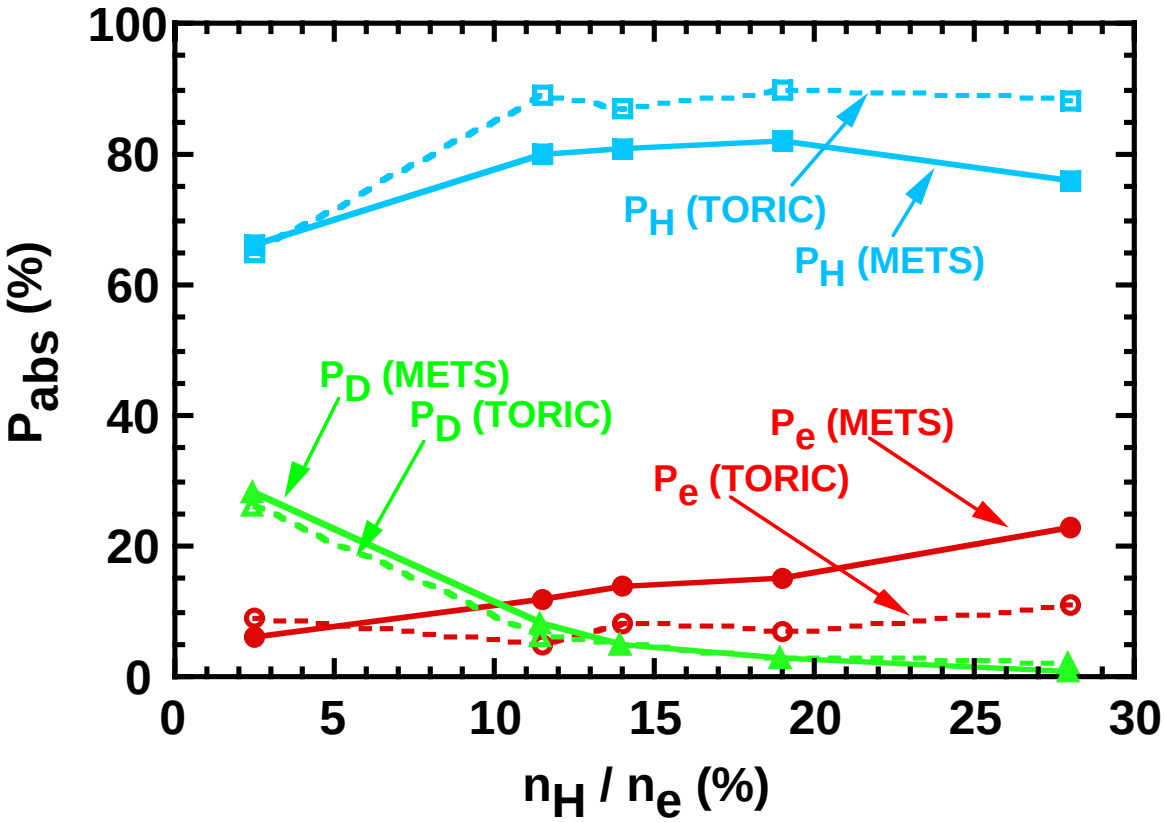
Good agreement on relative power absorption splits found between METS and TORIC



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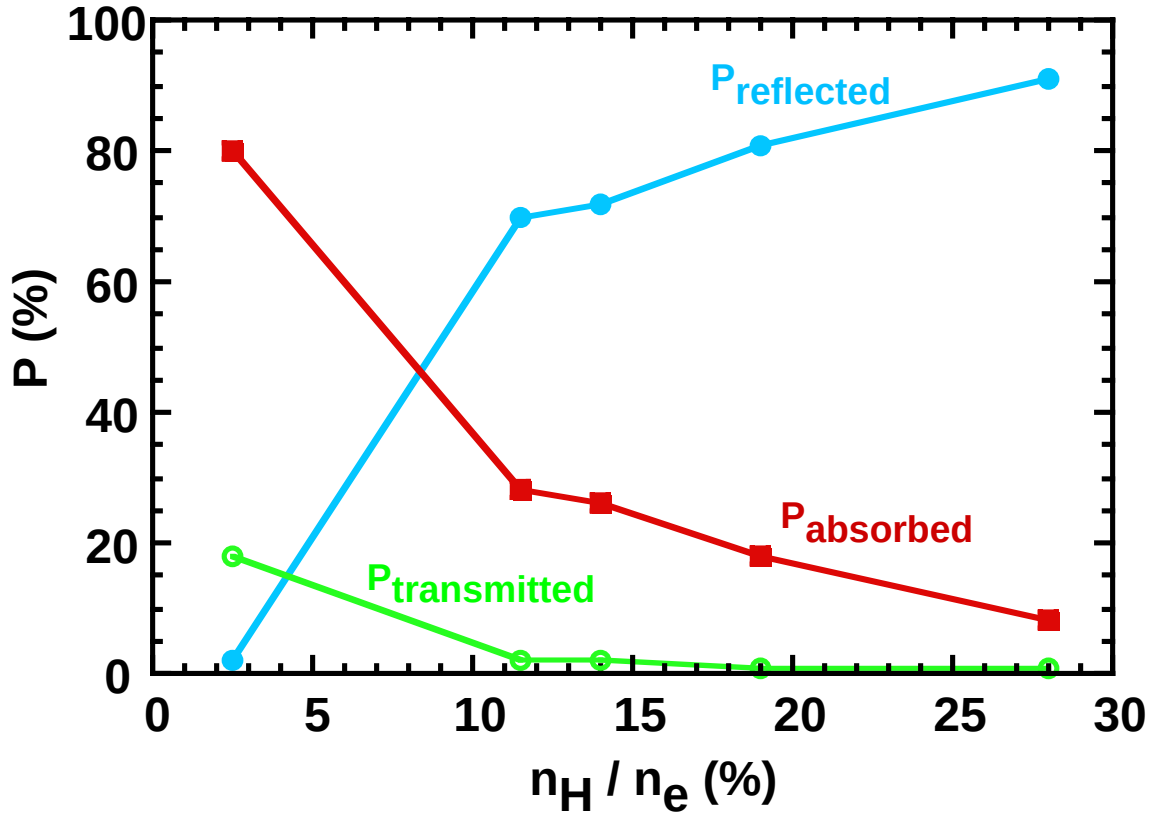
METS predicts that single pass absorption efficiency decreases as the H concentration increases



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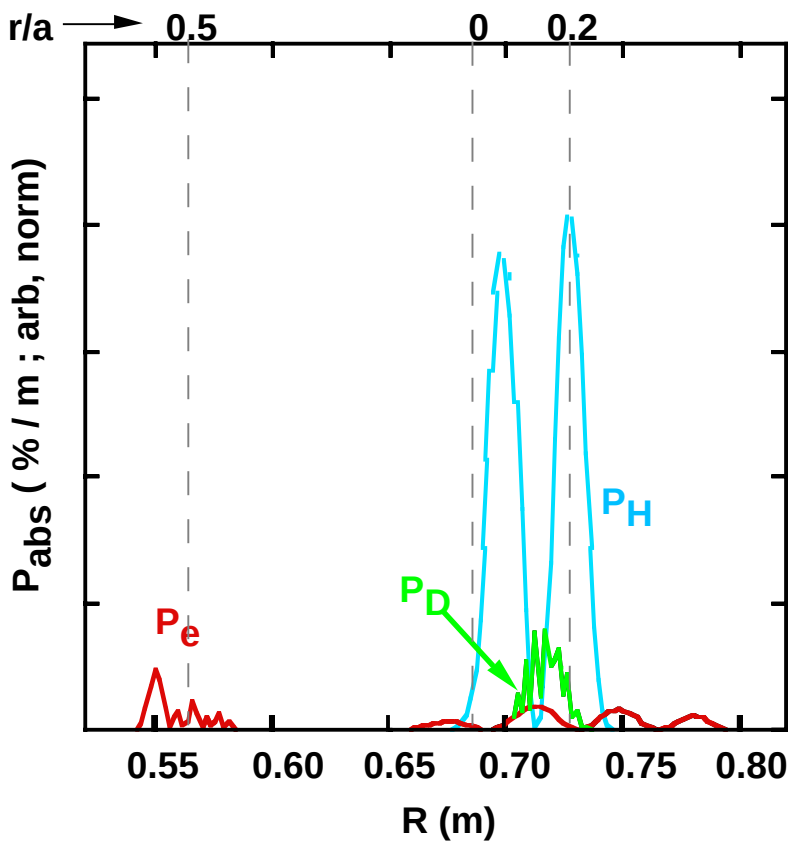
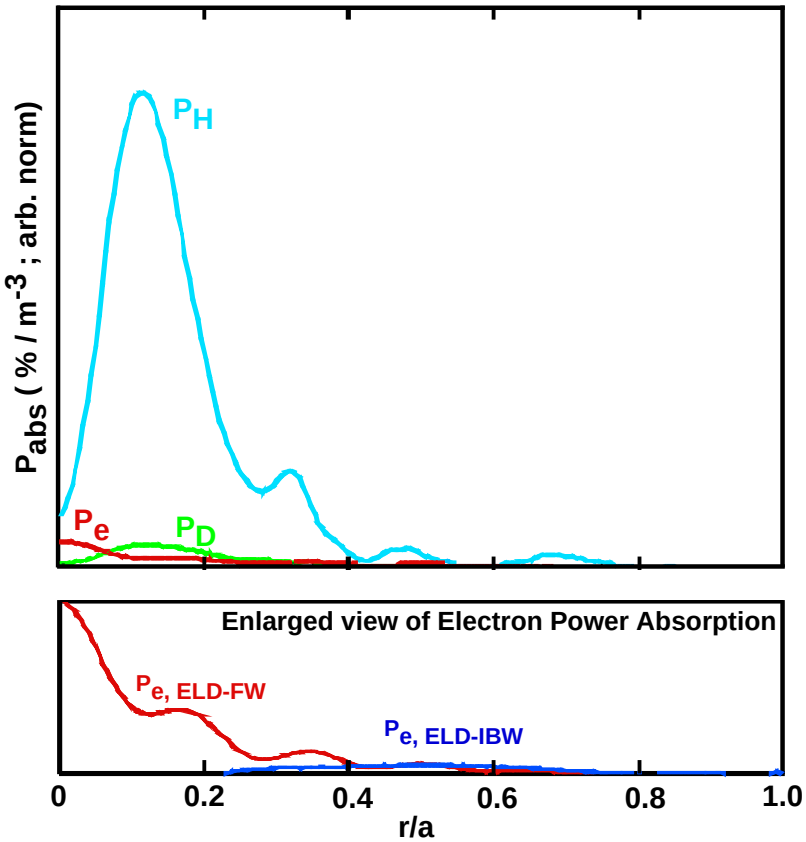
Qualitatively similar radial power deposition profiles predicted by METS and TORIC

METS midplane power deposition profile



TORIC radial power deposition profile



Case B $n_{e0} \sim 3e^{14}\ m^{-3}$ $\eta_H \sim 11.5\ \%$ $T_0 \sim 1.8$ keV

D - H heating @ 80 MHz and 5.46 T

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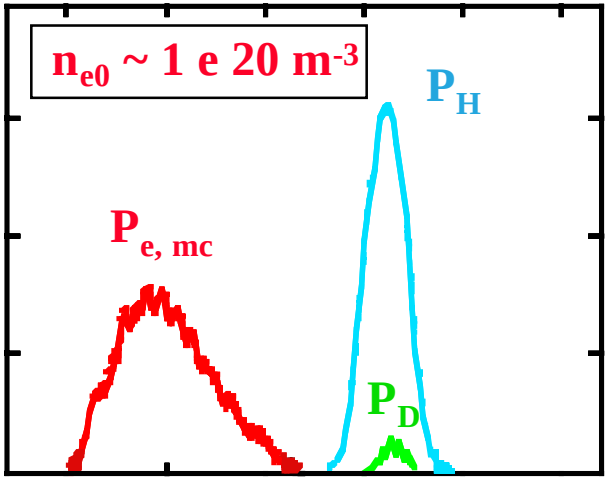
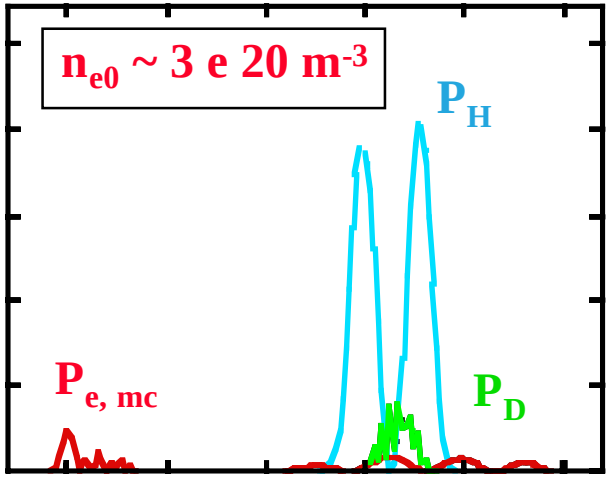
Mode conversion electron damping is predicted to increase for lower electron densities

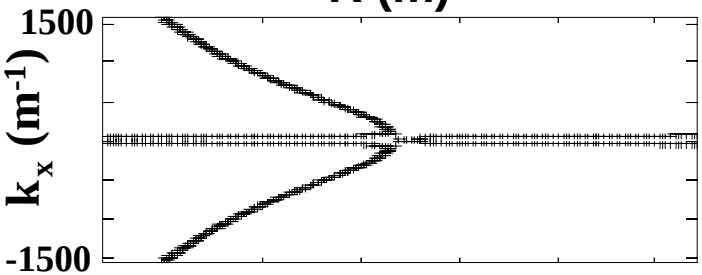
METS midplane power deposition profiles

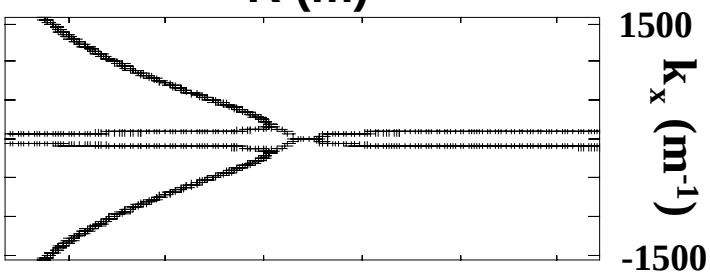
Single-pass
$P_e \sim 18\%$
$P_H \sim 16\%$
$P_D \sim 1\%$





Single-pass
$P_e \sim 4\%$
$P_H \sim 24\%$
$P_D \sim 2\%$





D - H heating @ 80 MHz and 5.46 T $\eta_H \sim 11.5\ \%$ $T_0 \sim 1.8$ keV

TORIC also predicts a factor of 4 increase in P_e due to enhanced mode conversion for these cases.

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METS and TORIC have been compared over a range of discharges with D - ^{3}He heating

Off-axis Heating with B_{t0} ~ 7.85 T

case \ param.	^{3}He concentration relative to n_e	electron density (10^{20} m^{-3})	T_{e0} / T_{i0} (keV)
A	9 %	2.2	3 / 2.26
B	17 %	2.4	3 / 2.21
C	24 %	2.4	2.7 / 1.8
On-axis Heating with B_{t0} ~ 7.9 T			
D	2 %	2.5	2.7 / 1.8

R_0 ~ 0.67 m a ~ 0.22 m f ~ 80 MHz Nphi ~ 10 so $k_{//}$ @R_0 ~ 14.93 m^{-1}

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METS and TORIC predict similar electron heating rates for on-axis heating in the D - ^{3}He regime

case \ P_{abs}	P_{3He} METS	P_{3He} TORIC	P_e METS	P_e TORIC	P_D METS	P_D TORIC
2% ^{3}He	94%	74%	6%	9%	0	16 %

Note:

- the METS single pass absorption coefficients have been scaled up to 100% total absorption;

- the D absorption in TORIC is believed to be due to poloidal mode resolution limits.

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Differences are found in the METS and TORIC results for off-axis heating in the D - ^{3}He regime

P_{abs} / η_{3He}	P_{3He} METS	P_{3He} TORIC	P_e METS	P_e TORIC	P_D METS	P_D TORIC
9 %	98 %	76 %	2 %	18 %	< 1%	6 %
17 %	10 %	54 %	90 %	41 %	< 1%	6 %
24 %	7 %	53 %	93 %	34 %	< 1%	13 %

Note that the METS single pass absorption rates have been scaled up to yield 100% total absorption.

The differences are believed to be caused by insufficient resolution of the large $k_\perp \rho_i$ IBW fields with the poloidal mode expansion method.

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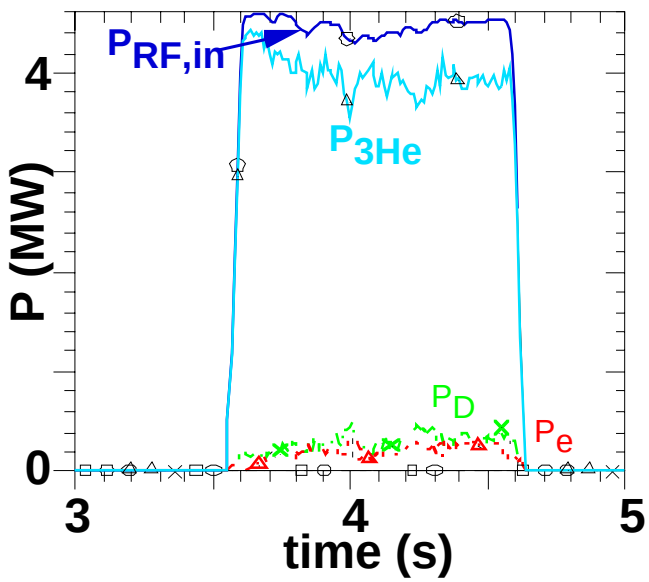
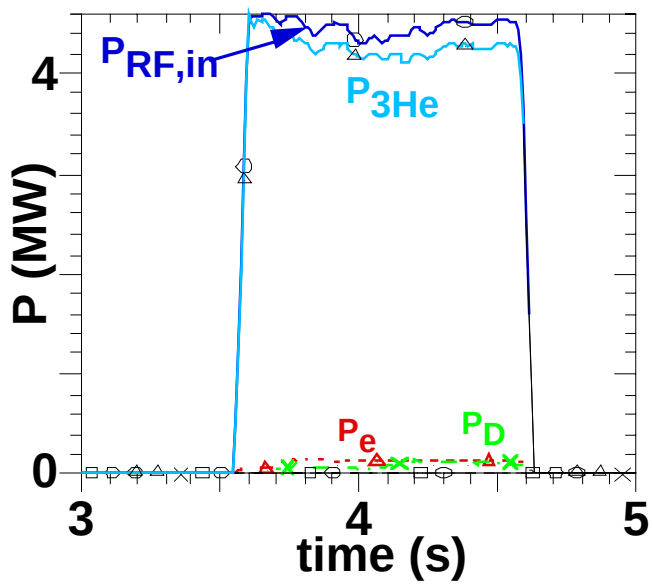
TORIC has been installed in the TRANSP code

Benchmarking comparisons between the TORIC and SPRUCE packages in TRANSP in low mode conversion regimes are underway.



TRANSP / SPRUCE



TRANSP / TORIC

For a D-^{3}He test case from TFTR with ~ 6% ^{3}He, the two codes yield similar volume-integrated power splits to the plasma species.

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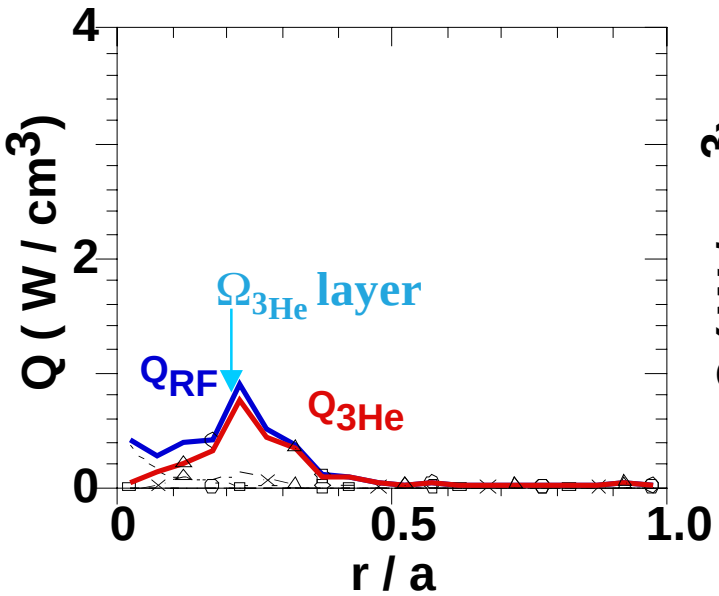
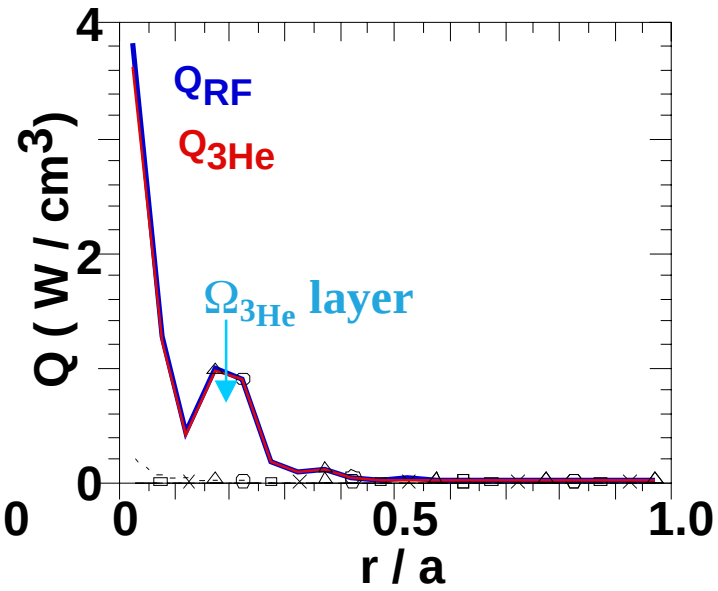
Initial tests of the TORIC / TRANSP package indicate some further development is needed



TRANSP / SPRUCE



TRANSP / TORIC

Some differences are found in the radial power deposition profile for the TFTR test case. The differences may be due to:

- coding errors in the interface between TORIC and TRANSP(e.g., mapping error,volume normalization error, etc.)
- model differences between the SPRUCE and TORIC packages even in the low mode conversion regime (e.g., recent improvements in the absorption model in TORIC need to be included in the TRANSP package).

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SUMMARY

•Good agreement is found between the 1D METS and 2D TORIC predictions for both relative power splits and power deposition profiles in D-H heating regimes;

•Mode conversion electron heating in D-H plasmas in CMod depends sensitively on the electron density, according to both METS and TORIC:

- •for $n_e \sim 1$ e 20 m^{-3}, significant MC electron heating is predicted
- •for $n_e \sim 3$ e 20 m^{-3}, MC electron heating is predicted to be small

•Reasonable agreement is found between METS and TORIC predictions in the D - ^{3}He regime for on-axis heating of ^{3}He.

•Differences between METS and TORIC in off-axis D - ^{3}He mode conversion regimes are believed to be due to poloidal resolution limits in TORIC for the large $k_\perp \rho_i$ IBW fields excited via mode conversion.

•TORIC has been installed in the TRANSP time-dependent transport analysis package and initial testing is underway.

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