Modeling Beam Ion Relaxation with application to DIII-D

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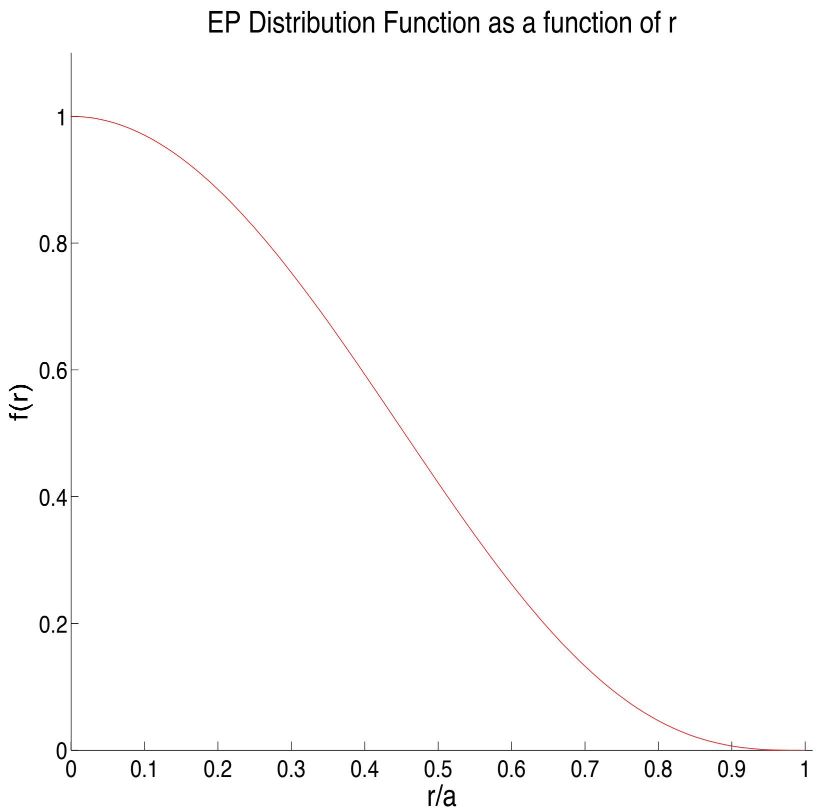
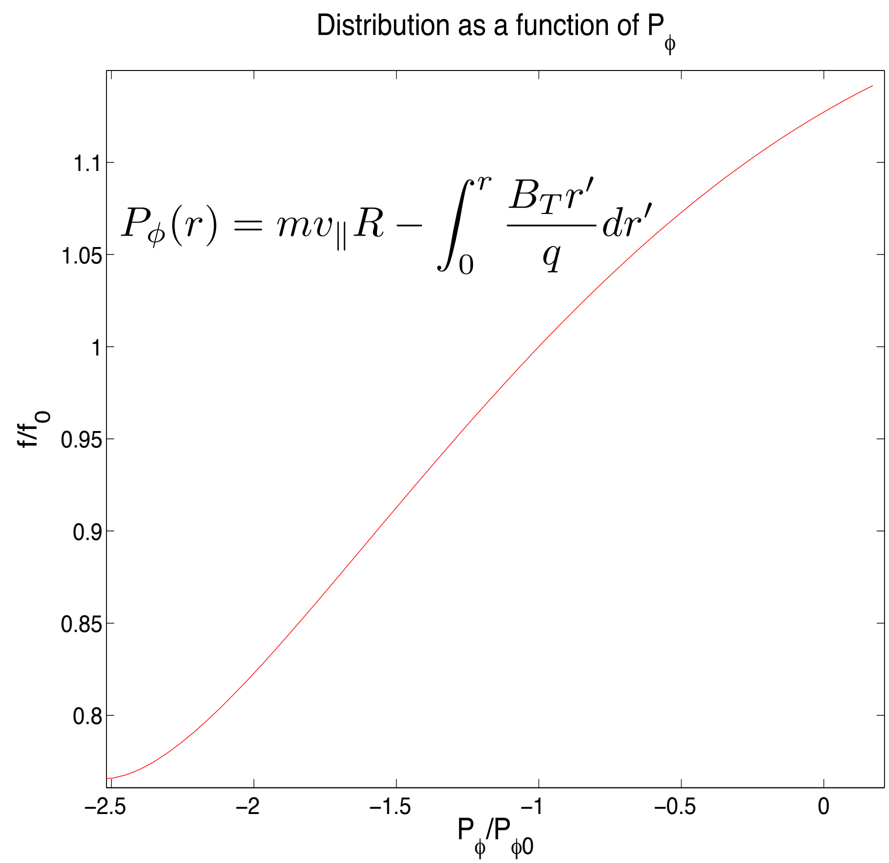
TAE Induced Losses of EP



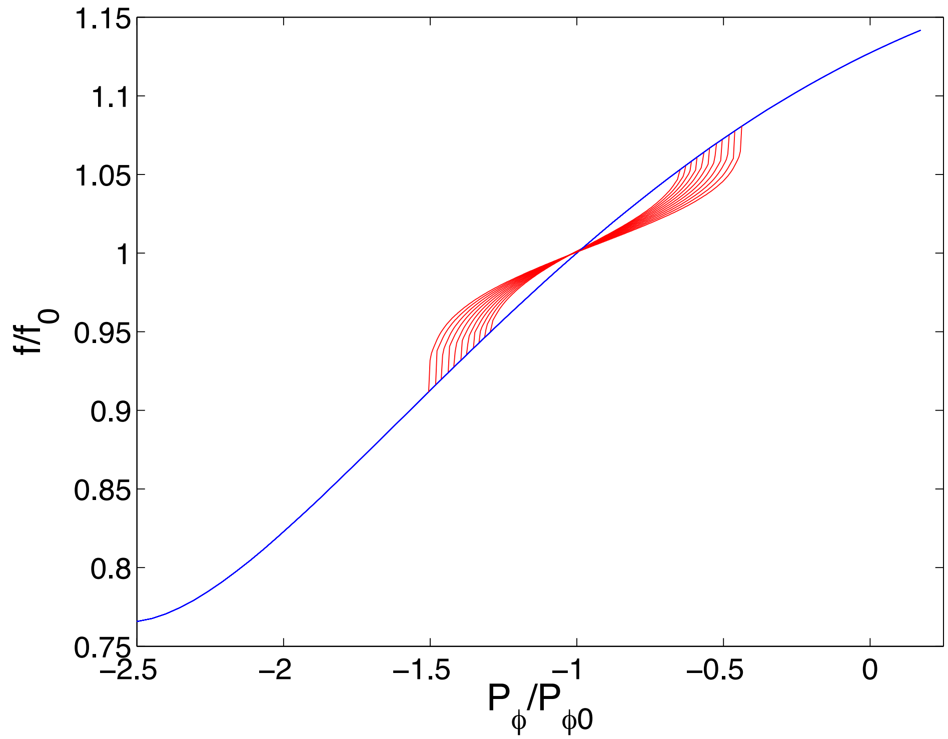


$$\gamma_{grth} \propto \omega \frac{\partial f}{\partial E} + n \frac{\partial f}{\partial P_\phi}$$

QL model

$$
\begin{cases}
\dfrac{\partial f}{\partial t} = \sum_k \dfrac{\partial}{\partial P_\phi} D_k(P_\phi) \dfrac{\partial}{\partial P_\phi} f + S \\
\quad \text{where } D(P_\phi) \propto W_k \delta(\Omega_k) \\
\dfrac{\partial W_k}{\partial t} = 2\gamma W_k \\
\quad \text{where } \gamma = \gamma_{grth} - \gamma_{dmp} \\
\quad \gamma_{grth} = \gamma' \dfrac{\partial \beta}{\partial r} \\
\Omega_k = \omega - n\hat{\omega}_\phi + (m+p)\hat{\omega}_\theta
\end{cases}
$$

Illustration of self consistent QL relaxation



instability

$\gamma > 0 \qquad W_k \nearrow$

diffusion

$D_k \nearrow \qquad \dfrac{\partial \beta}{\partial r} \searrow$

Saturation at marginal stability

$\gamma_{grth} \searrow \; \gamma_{grth} \to \gamma_{dmp} \quad \gamma = 0$

Reduced QL model

Using analytic expressions for finding the qualitative dependencies of the growth and damping rates on energetic particle's β

$$\gamma_{grth} = \gamma' \frac{\partial \beta}{\partial r}$$

γ' depends on:
- the mode number, n
- relative mode widths to particle orbit
- Plasma parameters
- Isotropy

The mode that are most unstable form a plateau[1] in n number where

$$\frac{r^2 \omega_c}{R q^2 v_A} \approx n_{min} < n < n_{max} \approx \frac{r \omega_c}{q^2 v_A}$$

Which is used to compute the critical conditions on the slope of the pressure profiles at each radial position r_0.

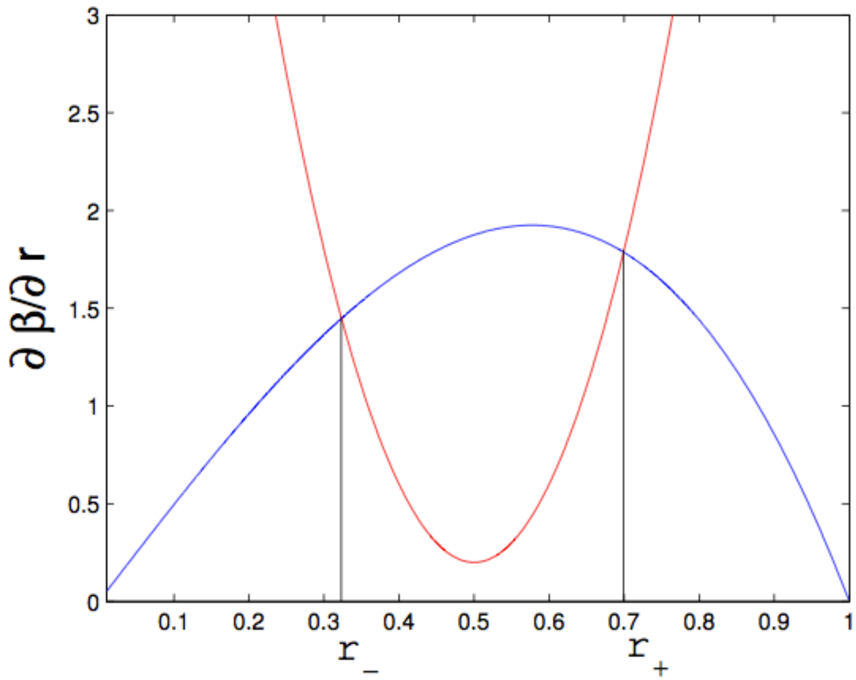
$$\gamma_{grth} = \gamma_{dmp} \qquad \text{i.e} \qquad \frac{\partial \beta_{crt}}{\partial r} = -\frac{\gamma_{dmp}}{\gamma'}$$

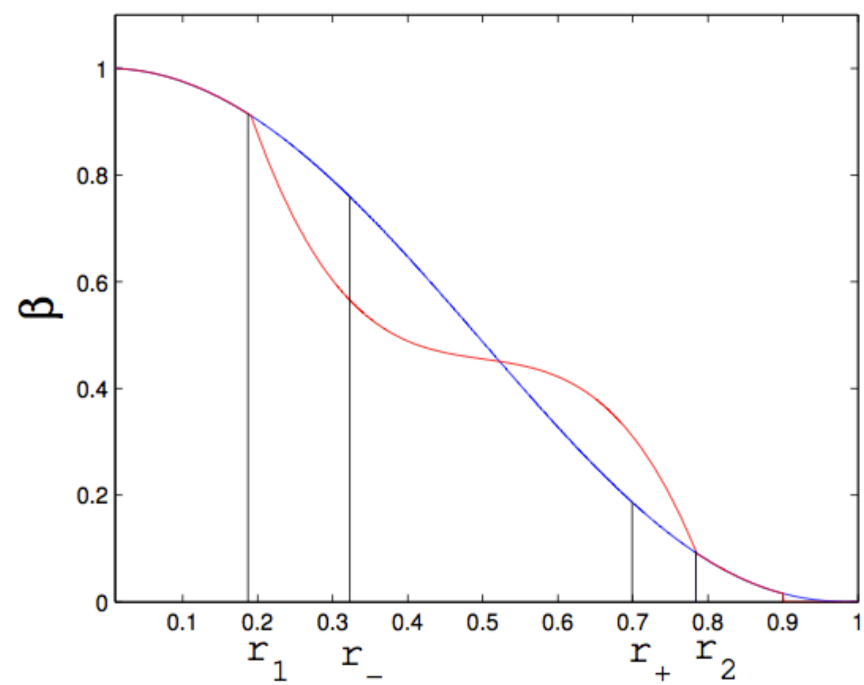
Kolesnichenko's rough estimate for the percentage of particles that are resonant is η

$$\beta = \begin{cases} \beta(r) \\ \eta \beta_{rlx}(r) + (1-\eta)\beta(r) \\ \beta(r) \end{cases}$$

[1]Fu, Phys. Fluids B 4 (1992) 3722;

Integrating relaxed profiles.





With the constraints:

continuity

$$\beta(r_1) = \beta_{rlx}(r_1)$$
$$\beta(r_2) = \beta_{rlx}(r_2)$$

Particle conservation

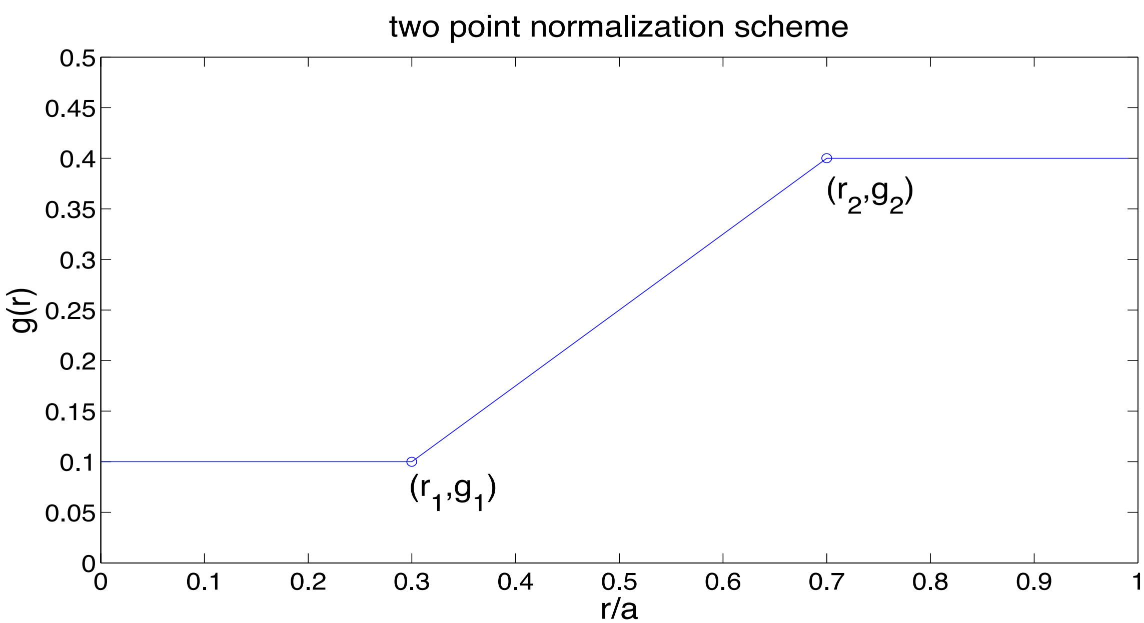
$$\int_{r_1}^{r_2} \beta = \int_{r_1}^{r_2} \beta_{rlx}$$

NOVA and NOVA-K

To apply 1.5D on experimental results, NOVA and NOVA-K are used to give quantitative accuracy to the analytically computed profiles.

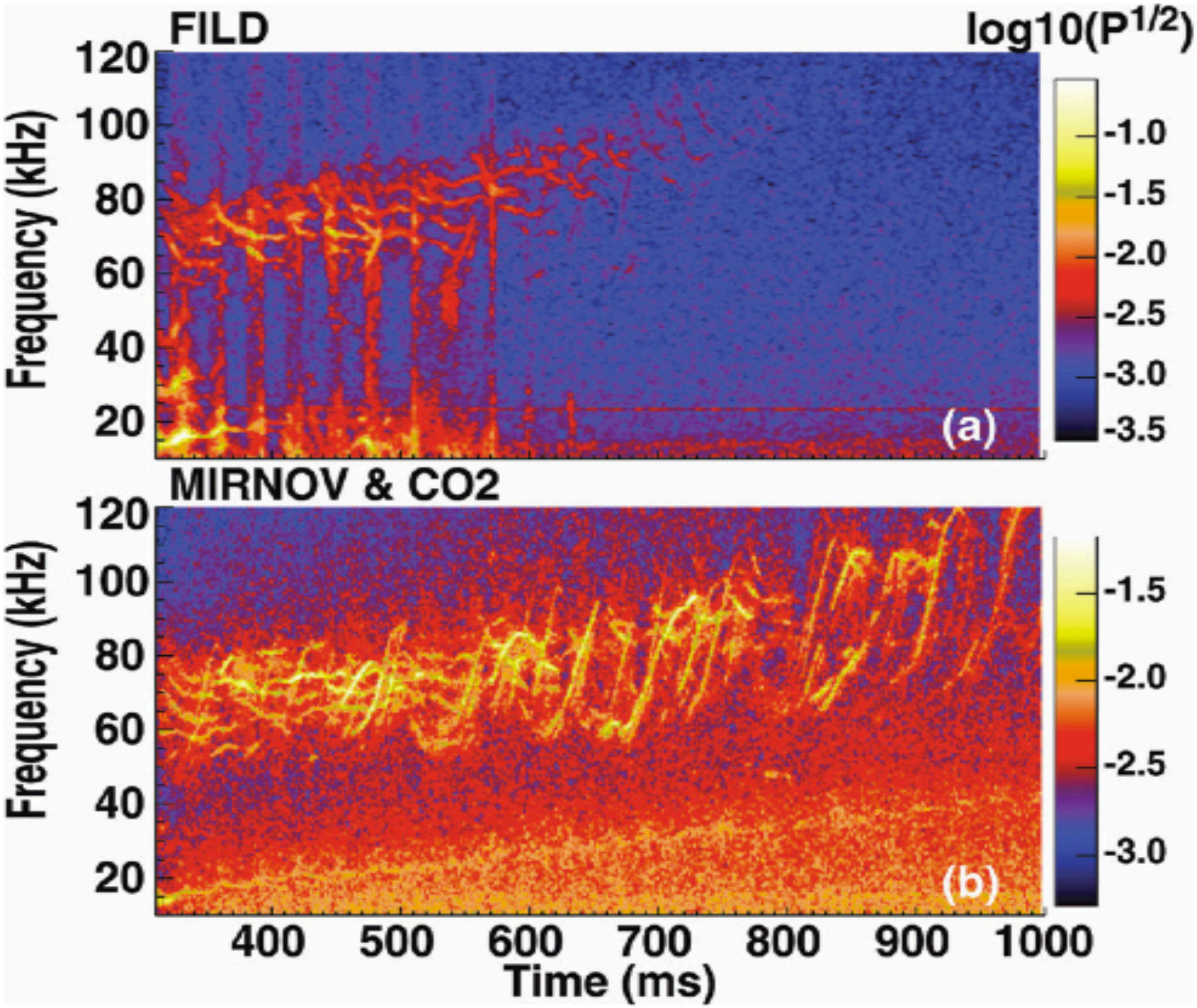
We find the two most localized modes from NOVA for a given n close to the expected values at the plateau.

We calculate the damping and maximum growth rate at the two locations, r1 and r2, to which the analytic rates are calibrated to by multiplying them by the following factor, g(r) .

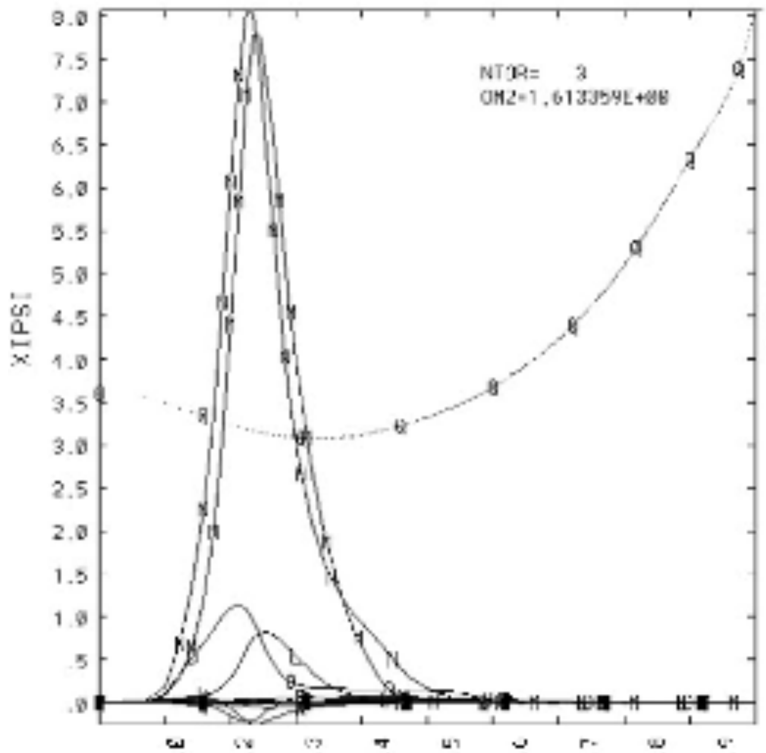


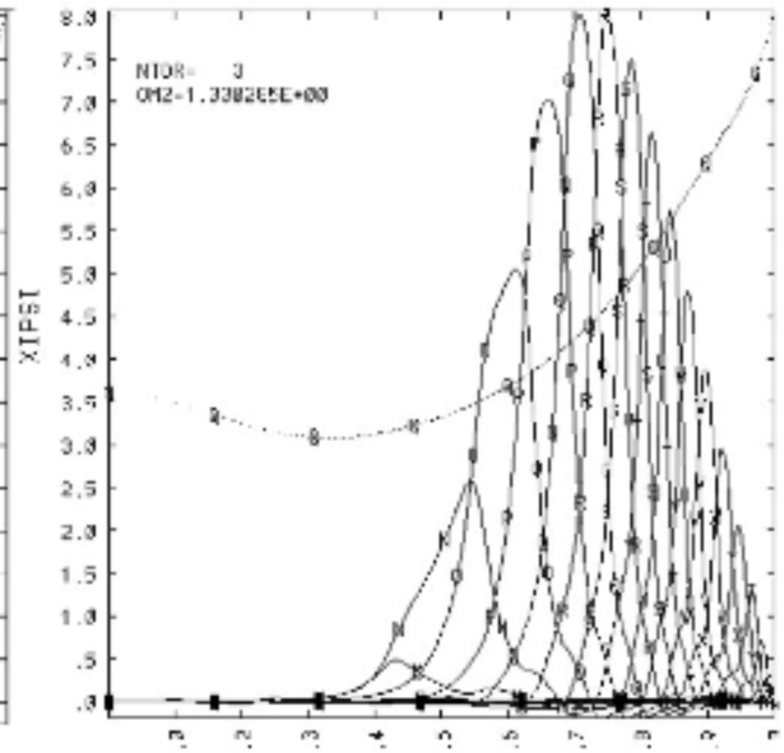
$$g_{1,2} = \frac{\gamma_{NOVA}(r_{1,2})}{\gamma_{analytic}(r_{1,2})}$$

DIII-D beam losses and TAE activity



NOVA Computed rates of discharge #142111

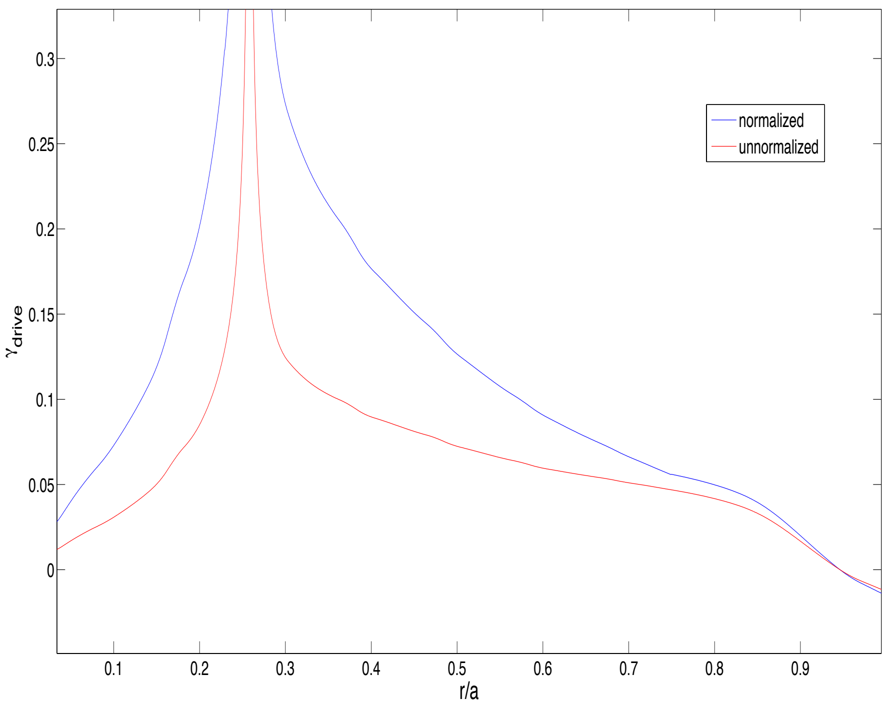


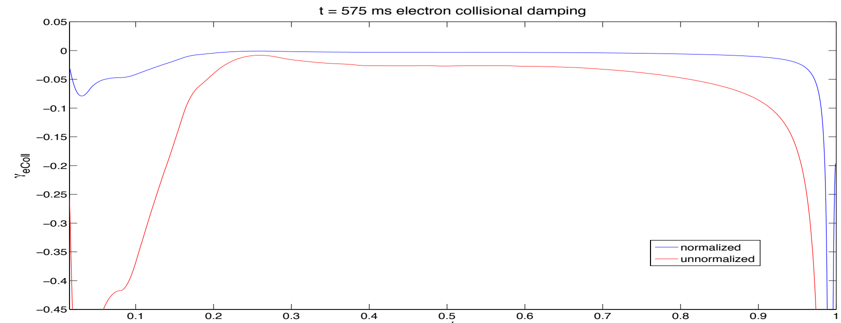


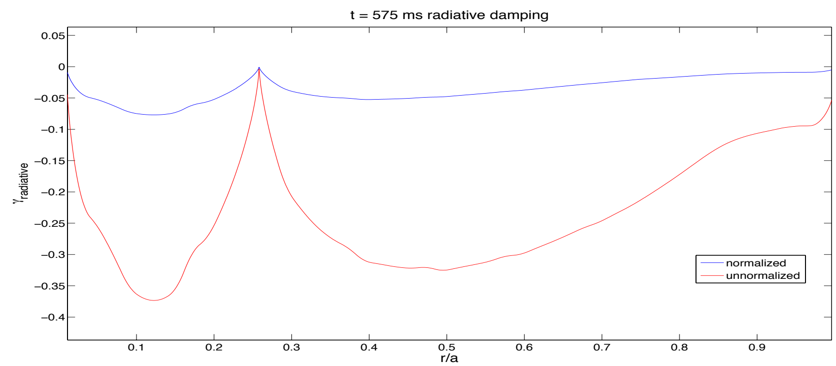
For $t = 575$

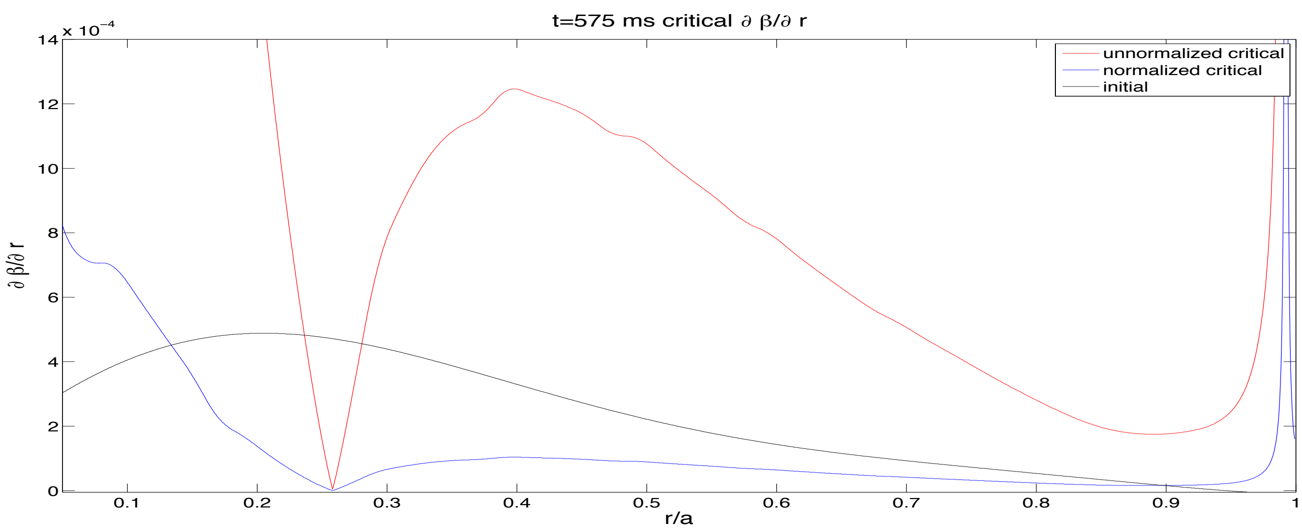
Mode Location	$\gamma_{growth}(\%)$	$\gamma_{eColl}(\%)$	$\gamma_{rad}(\%)$
$r/a = 0.23$	30	0.17	3.4
$r/a = 0.73$	5.7	0.49	2.0

Normalized rates for t=575 ms

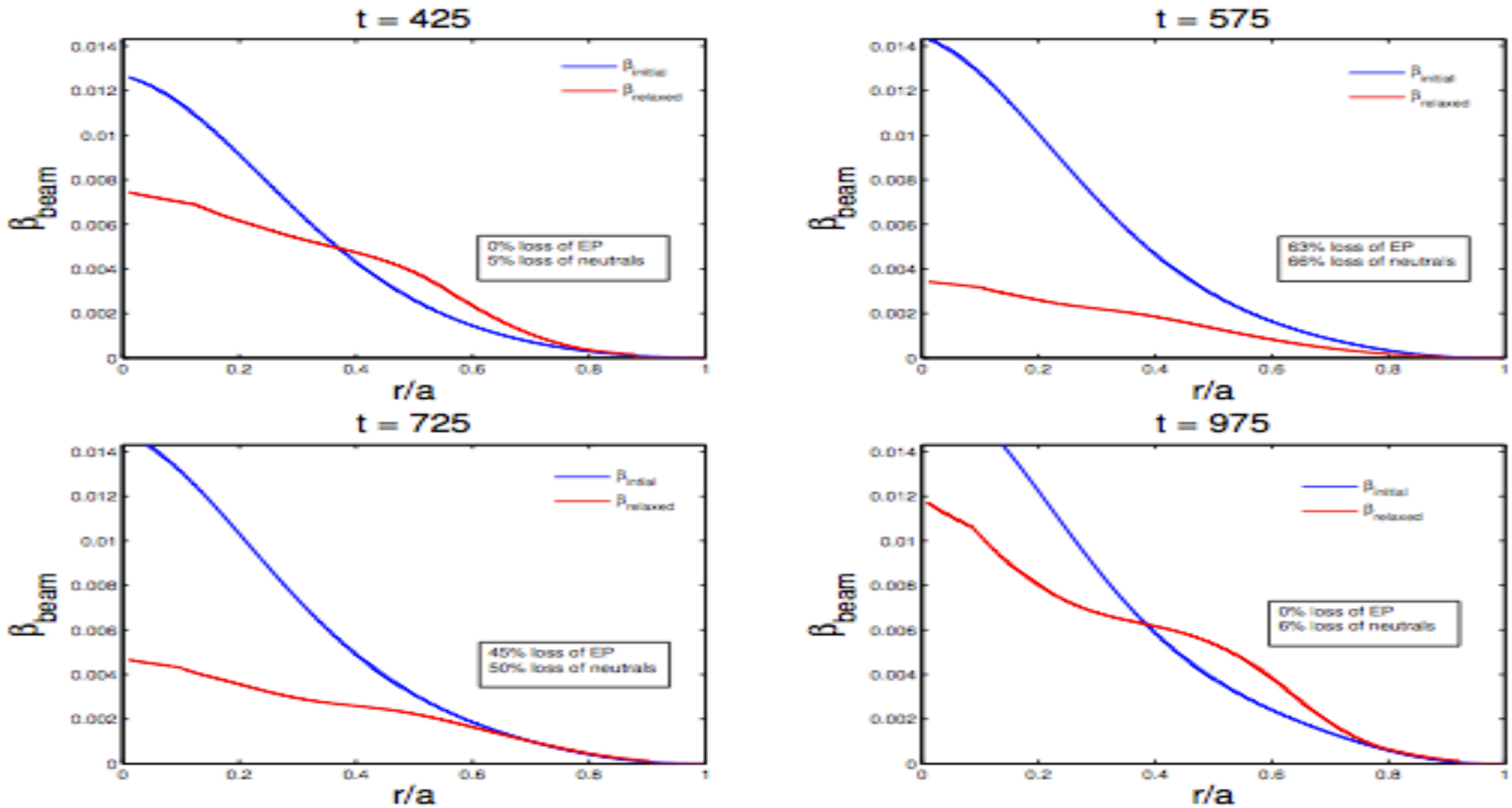




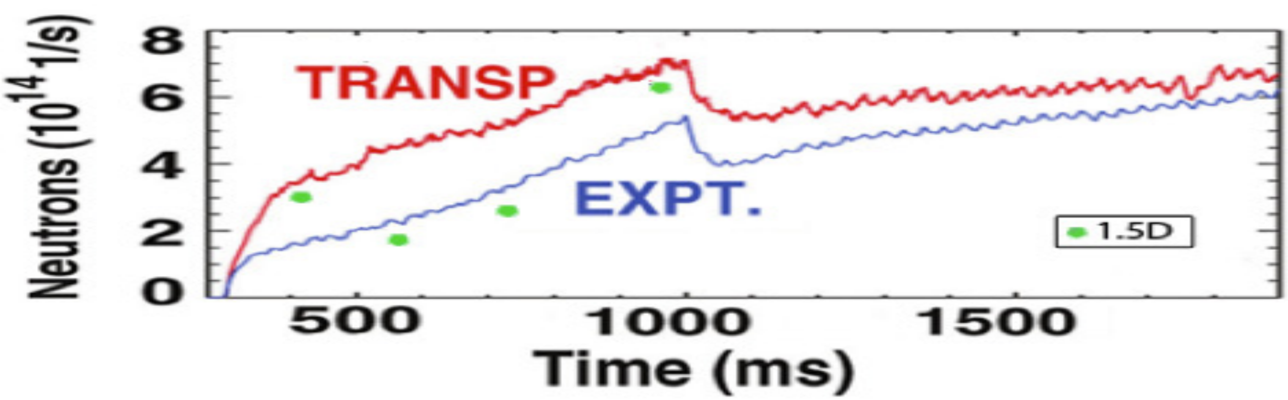




1.5D results



t = 425
0% loss of EP
5% loss of neutrals
t = 575
63% loss of EP
66% loss of neutrals
t = 725
45% loss of EP
50% loss of neutrals
t = 975
0% loss of EP
6% loss of neutrals
$\beta_{initial}$
$\beta_{relaxed}$
β_{beam}
r/a



TRANSP
EXPT.
1.5D
Neutrons (10^{14} 1/s)
Time (ms)