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Energetic Ion Loss Attending Early Neutral Beam Injection in NSTX

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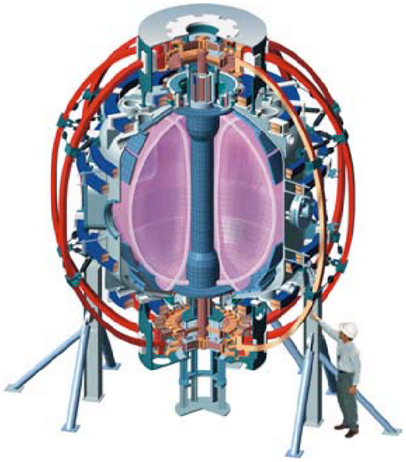

NSTX Physics Meeting
February 14, 2005

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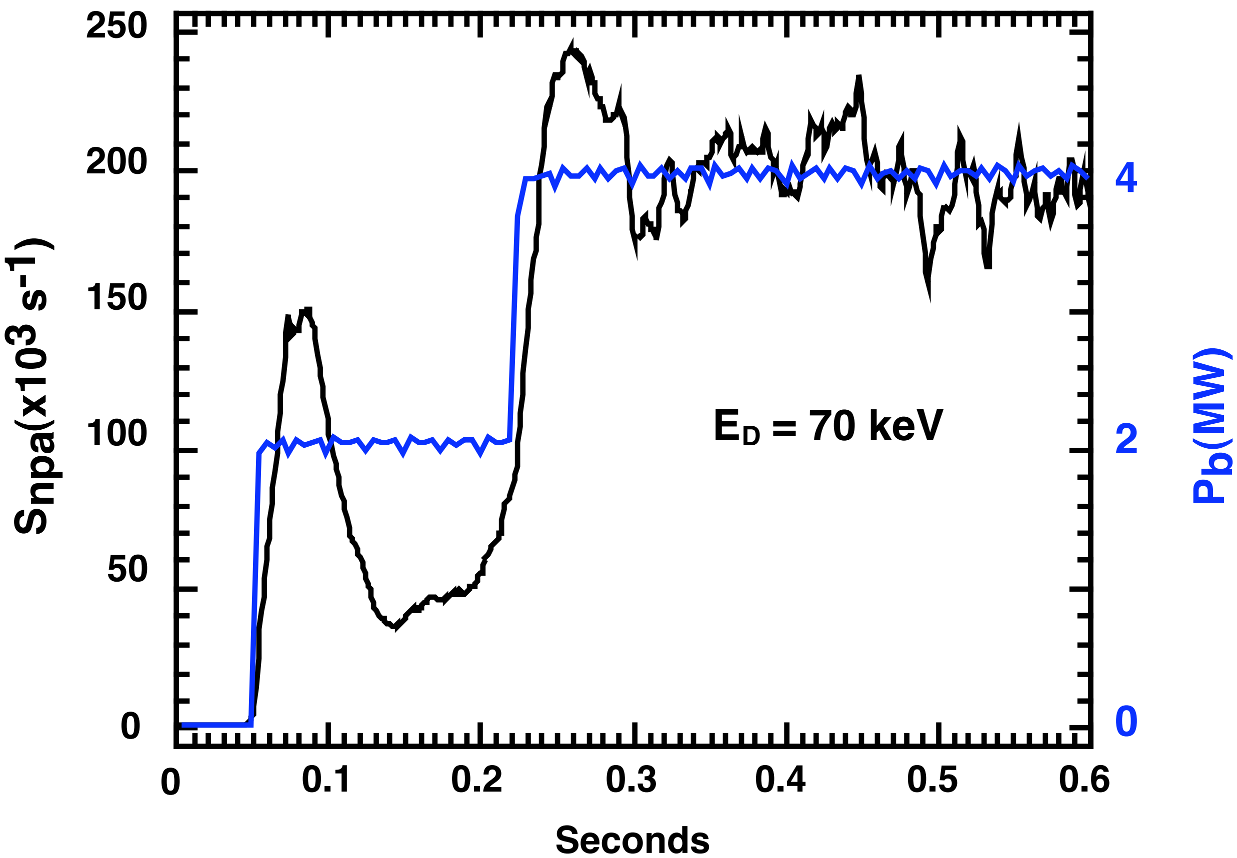
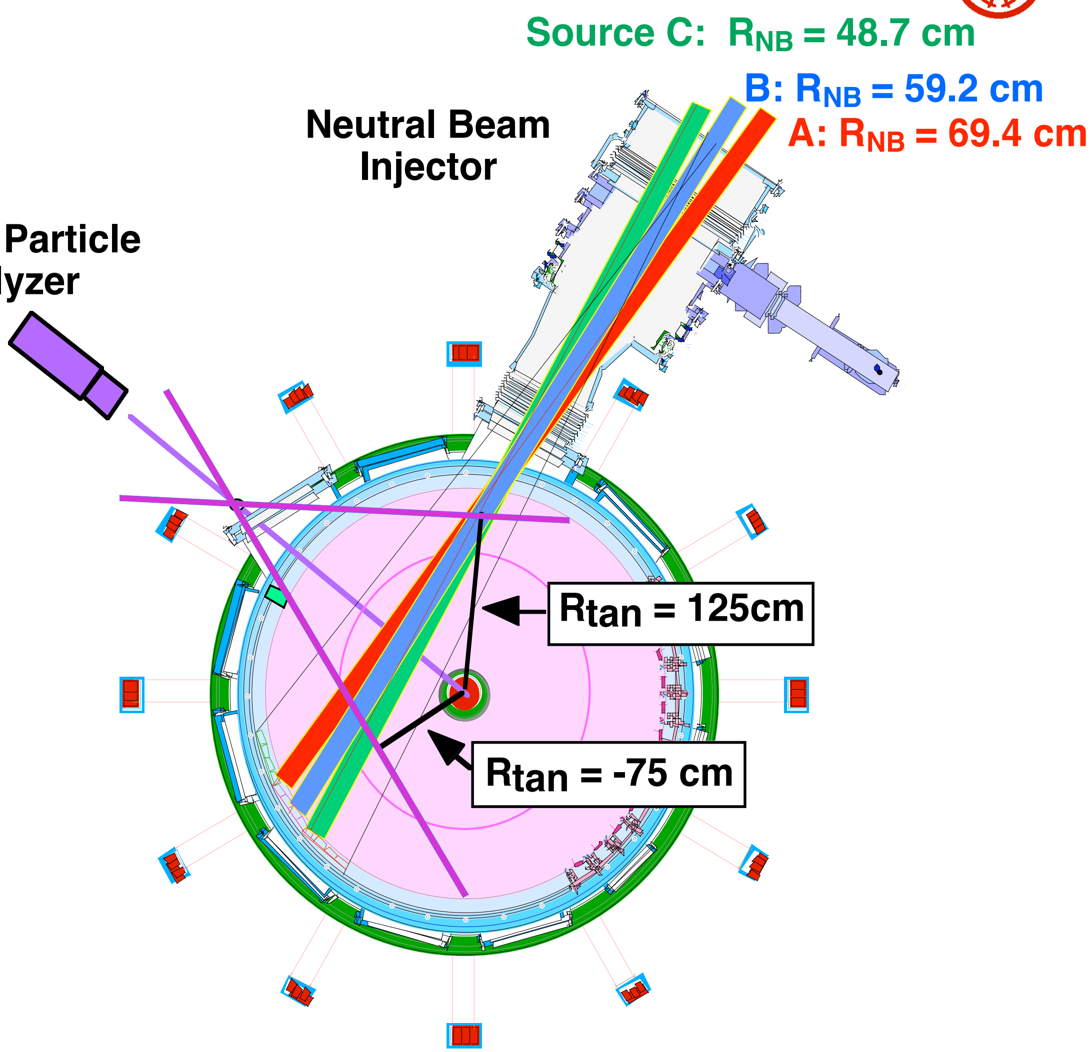
The NPA Energetic Ion Signal Indicates Significant Ion Loss for Early NB Injection



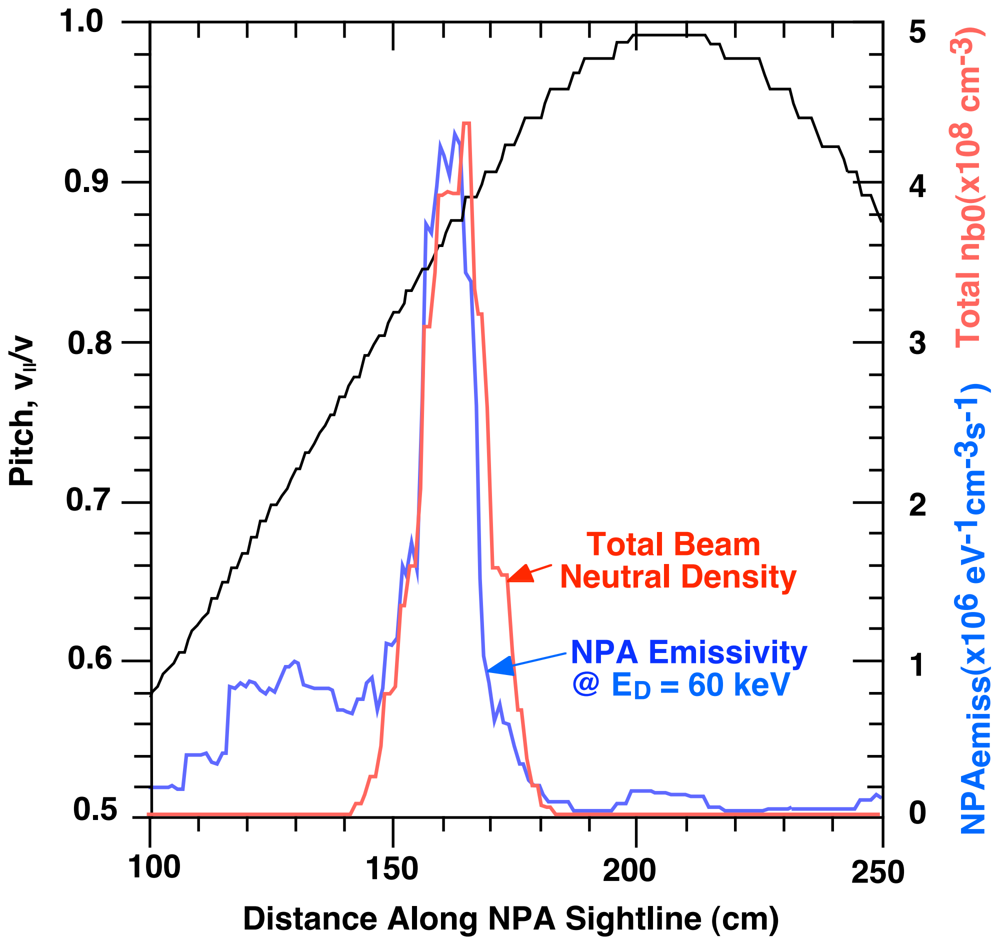
- A large drop in the NPA signal (~65%) occurs shortly after NB turn-on.
- This is not a detector saturation effect, since even higher signal levels are sustained after turn-on of the 2nd NB.

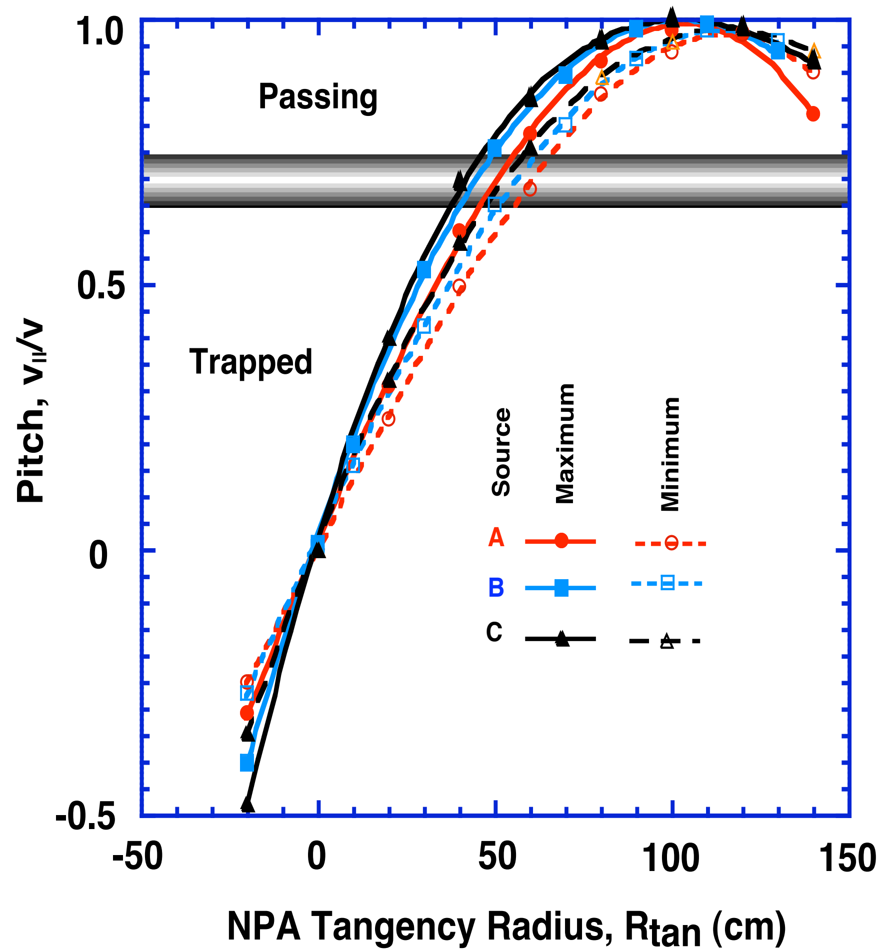
Layout of the EIIB NPA on NSTX



- Positive (negative) NPA R_{tan} sightlines view co-going (counter-going) ions.

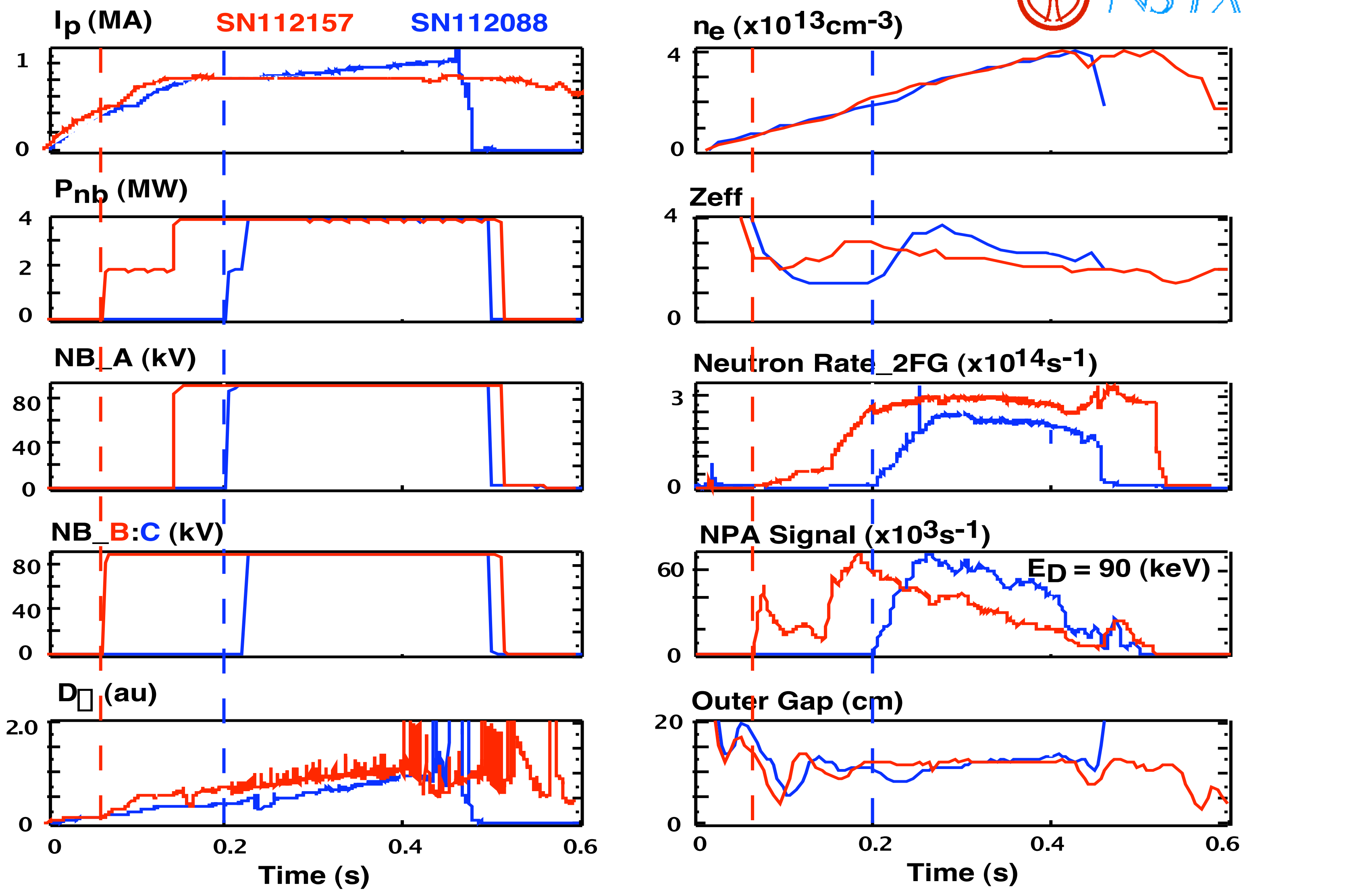
The Line-integral NPA Signal is Localized to the Sightline/NB Intersection Region





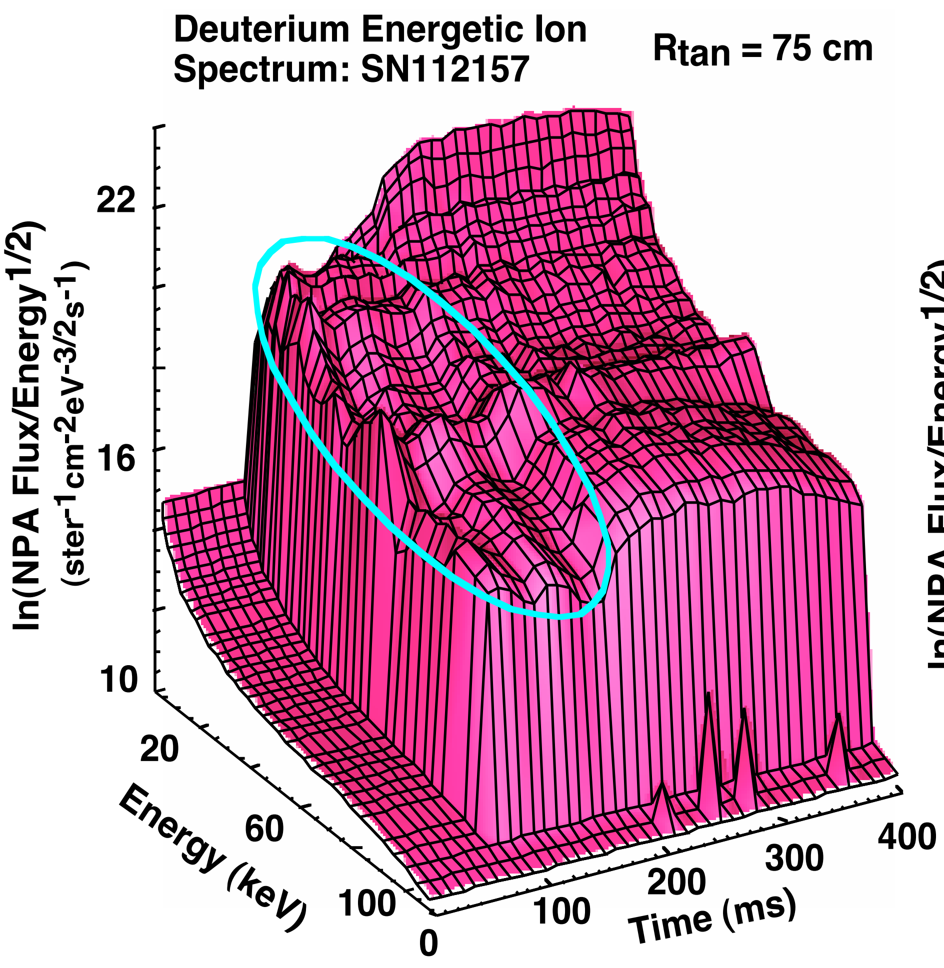
- The ion pitch viewed by the NPA depends on the sightline R_{tan}.

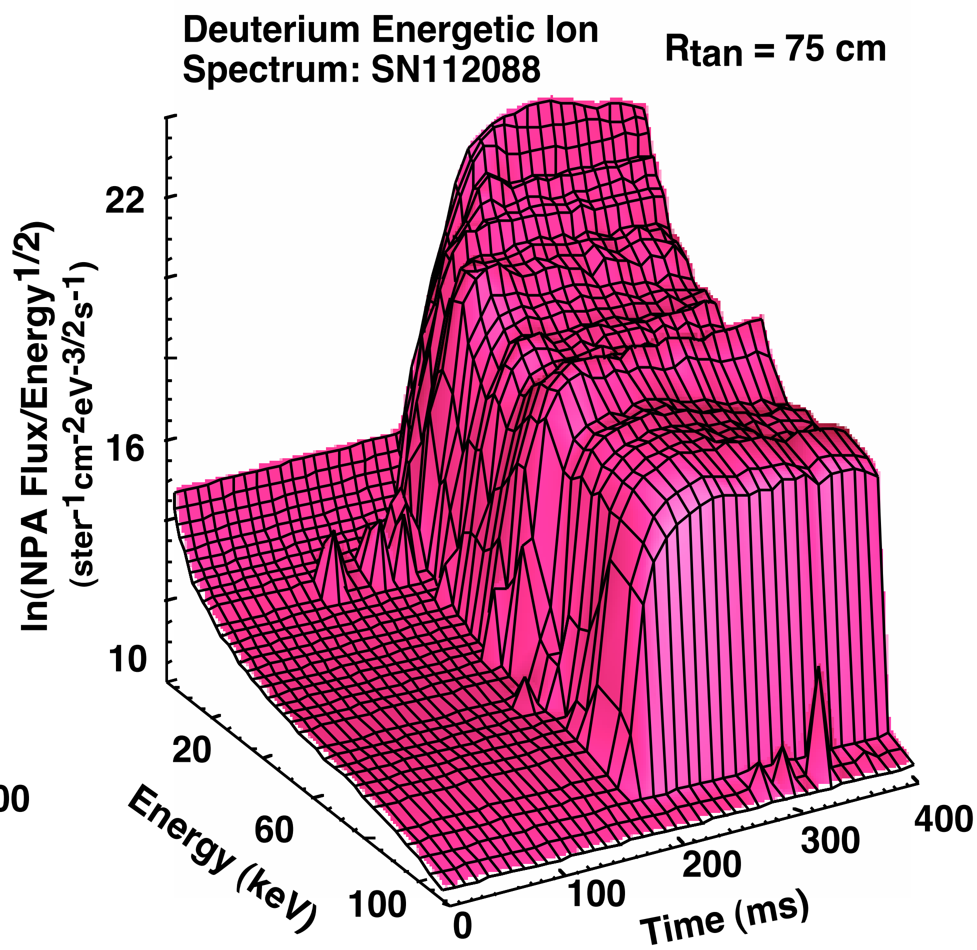
Comparison of Early and Late NB Turn-0n



- The NPA signal exhibits energetic ion loss only for early NB injection at low I_p.

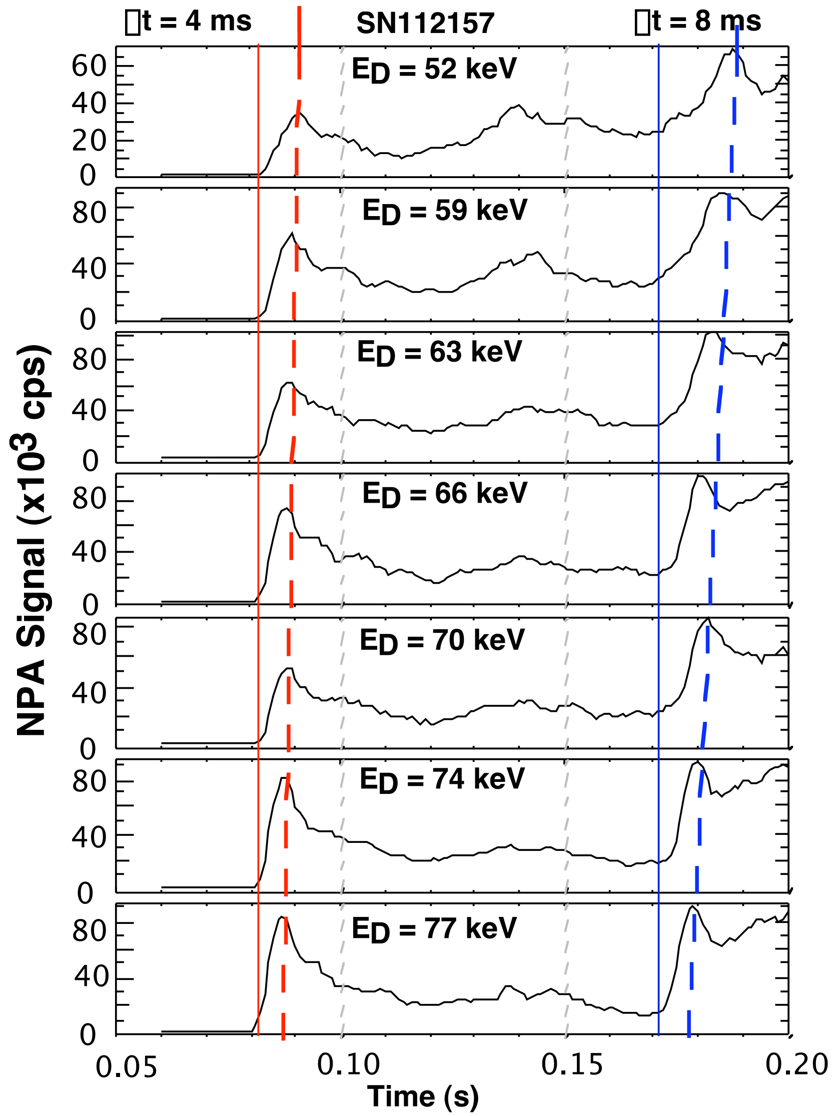
Comparison of NB Spectra w/wo Turn-on Loss





- Loss of E, E/2, E/3 NB components propagates to all energies (encircled).

S_{NPA} Exhibits Slowing-down Characteristics



- **Slowing-down time:**

$$\tau_{se} = 6.27 \times 10^{14} \frac{A_b T_e^{3/2}}{Z_b^2 n_e \ln \Lambda_e}$$

- **At:**

  t_1 = 0.08 s, Te ~ 200 eV, n_e ~ 1.2x10^{19}m^{-3}
  t_2 = 0.17 s, Te ~ 600 eV, n_e ~ 2.1x10^{19}m^{-3}.

- **The calculated ratio of slowing-down times,**

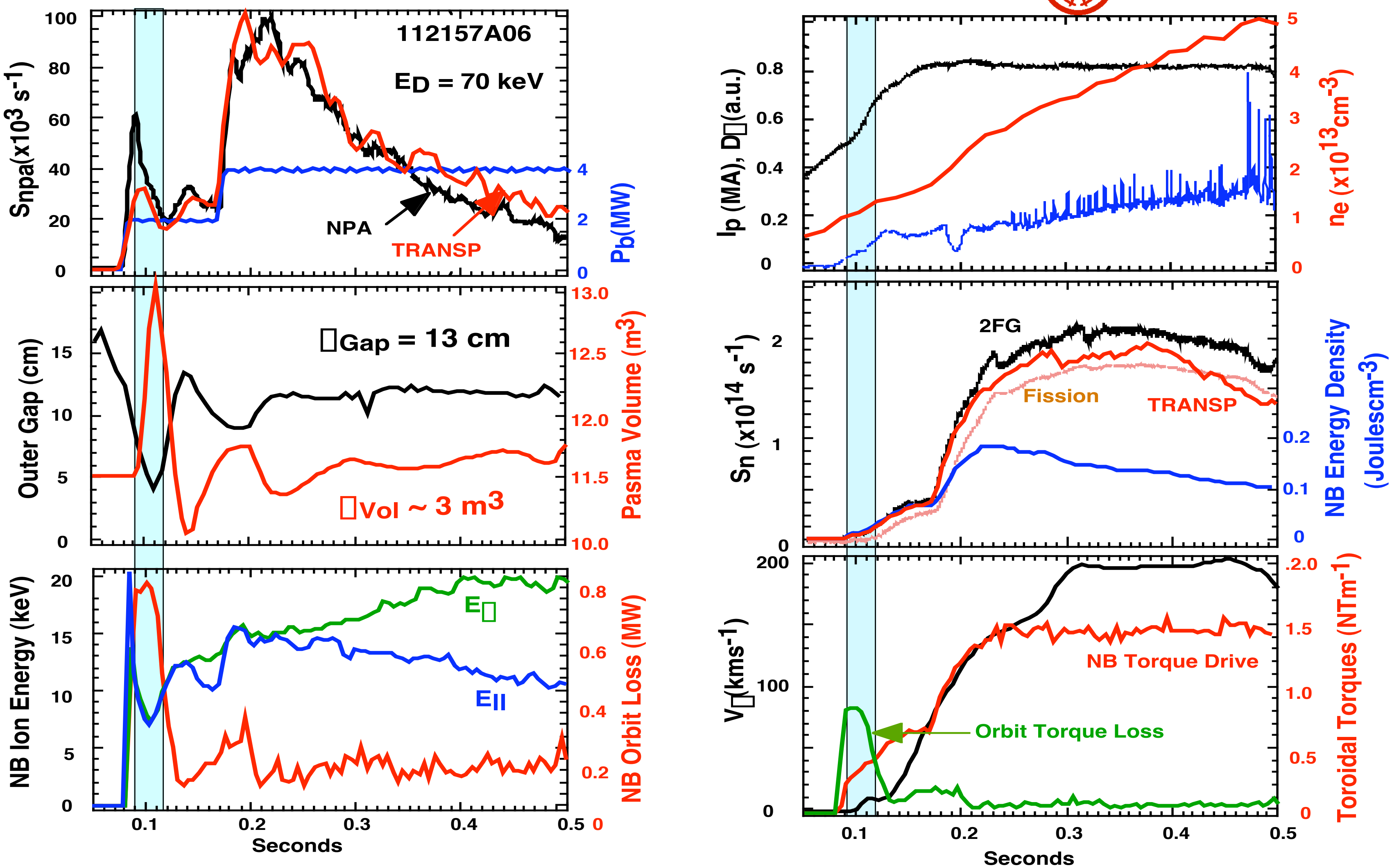
  τ_1 / τ_2 ~ 28 ms/58 ms ~ 0.48

agrees reasonably well with the measured value of 0.5 (measured over only a portion of the energy slowing-down range).

- **This provides supporting evidence that the NPA signal is "real" (e.g. not a detector saturation effect).**

NB Turn-on Loss Correlates with Outer Gap Excursion

- B_T = 4.4 kG, Sources B @ 88 keV, A @ 92 keV



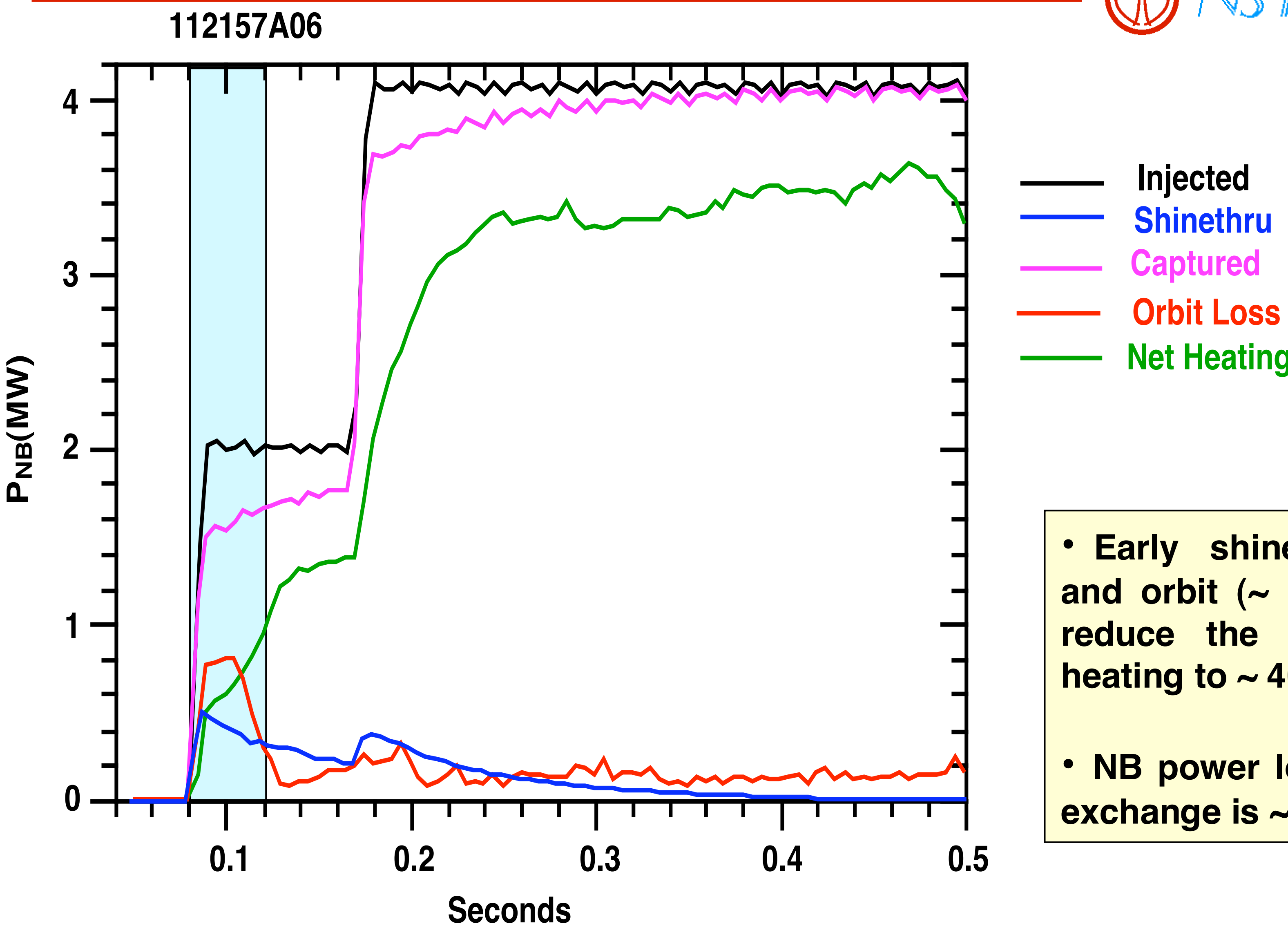
- Note: the NPA views the residual confined ion distribution, not the orbit loss ions .

Neutral Beam Power Inventory

PPPL PRINCETON PLASMA PHYSICS LABORATORY

- B_T = 4.4 kG, Sources B @ 88 keV, A @ 92 keV

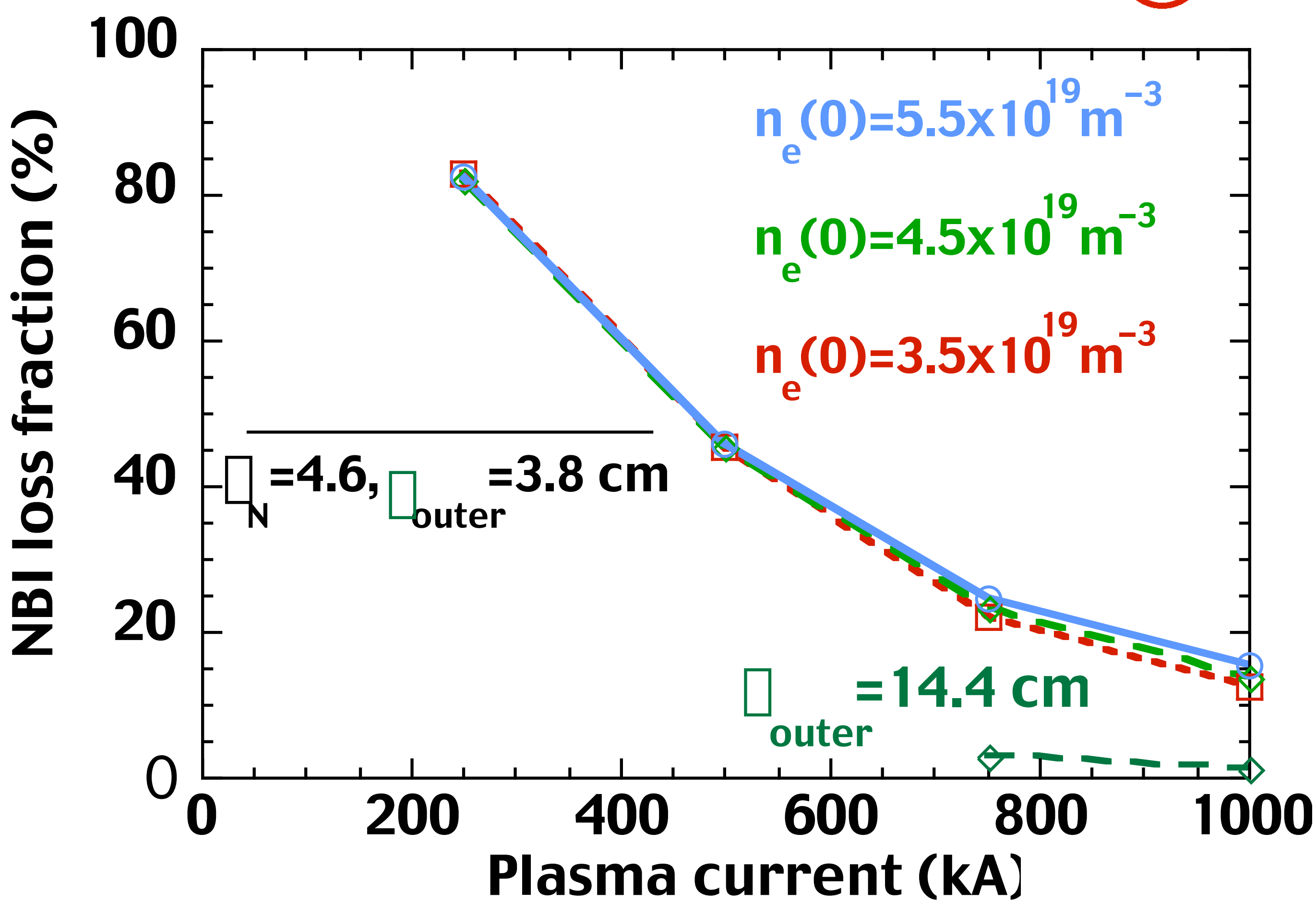
NSTX



- Early shinethru (~ 20%) and orbit (~ 40 %) losses reduce the effective NB heating to ~ 40 % of P_{inj}.

- NB power lost to charge exchange is ~ 70 kW.

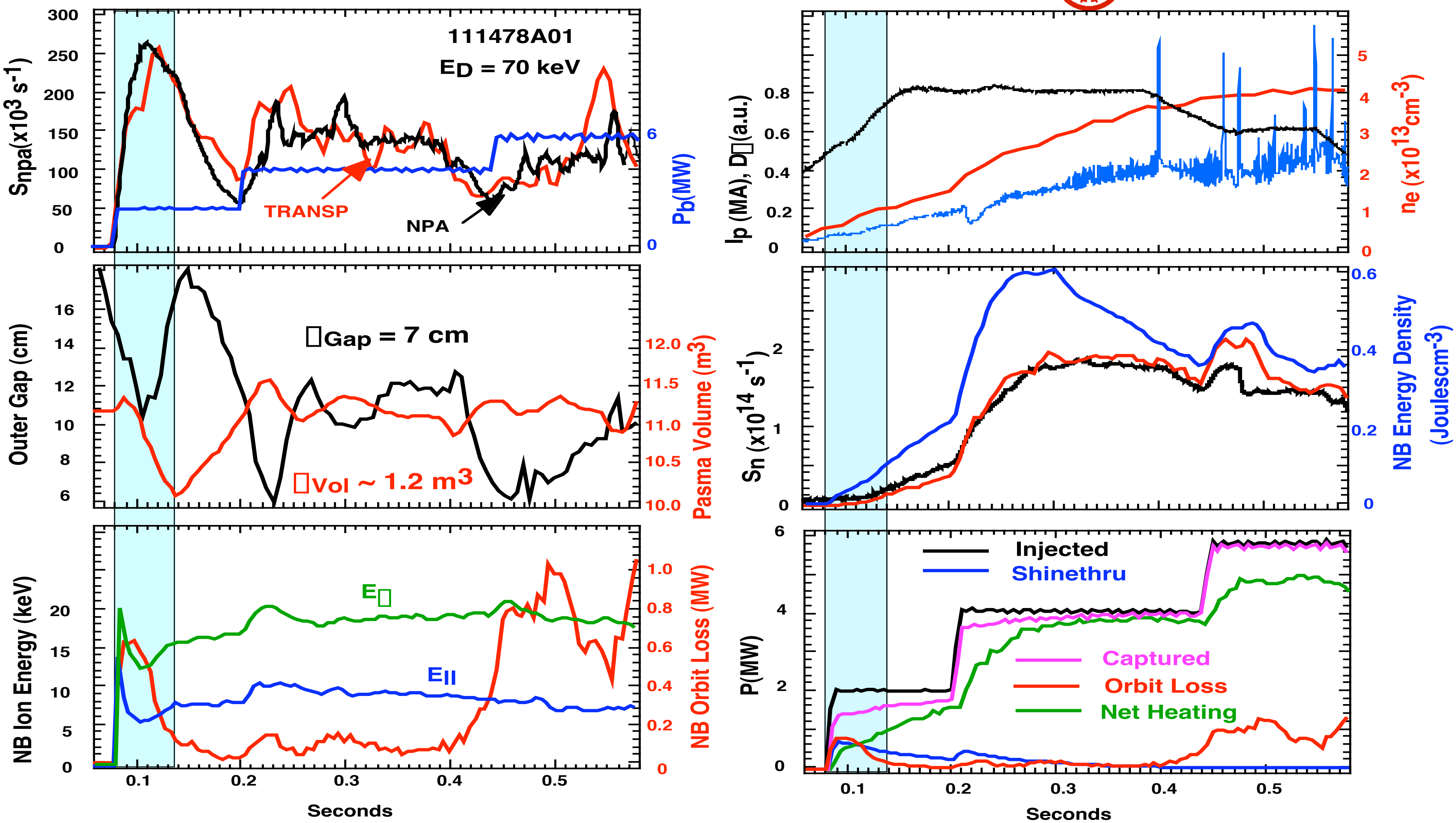
Calculated NB Power Loss vs I_p



- NB loss increases strongly with decreasing I_p and outer gap, δ_{outer}.

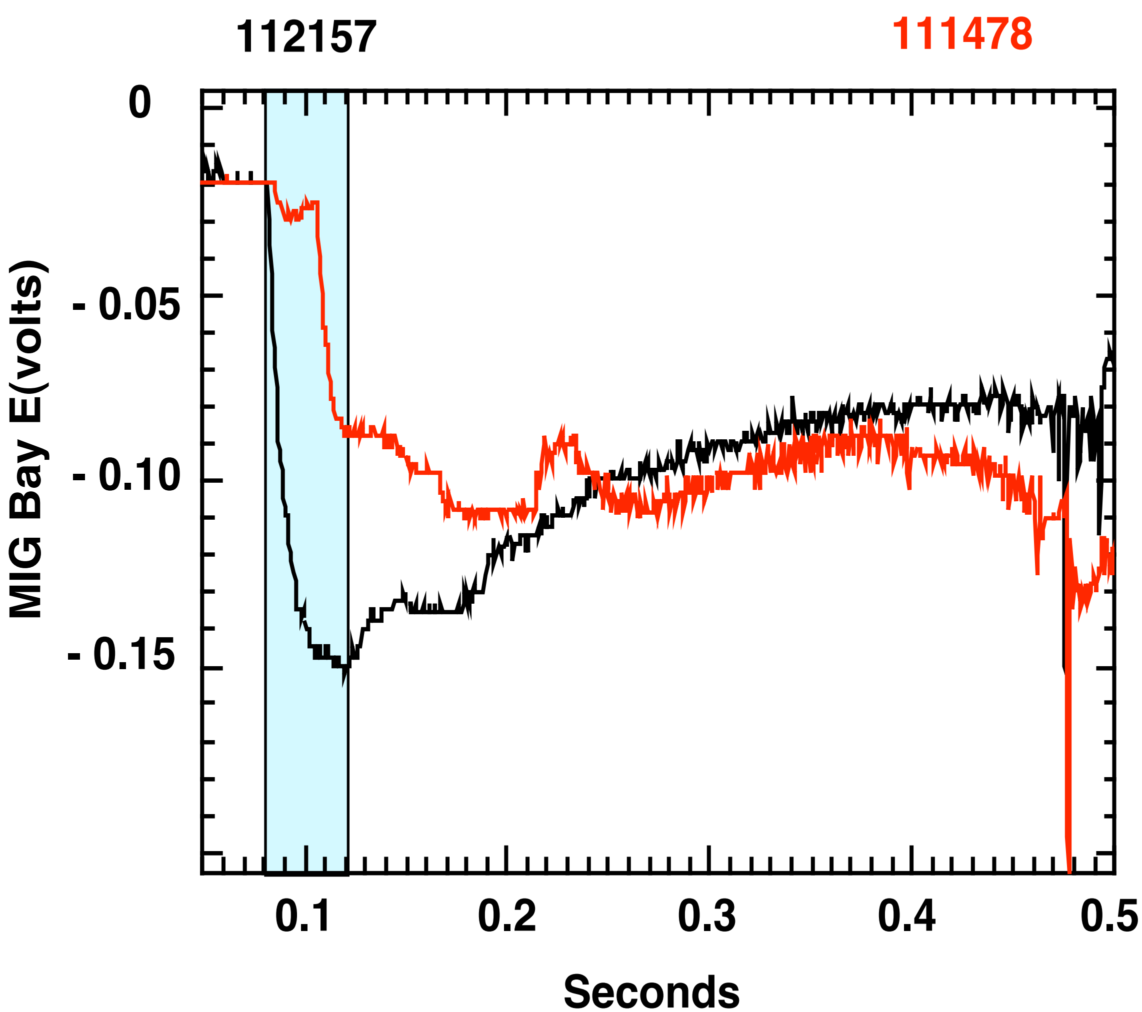
Ion Loss with “Smaller” Outer Gap Excursion

- B_T = 4.4 kG, Sources B:A:C @ 88:88:83 keV



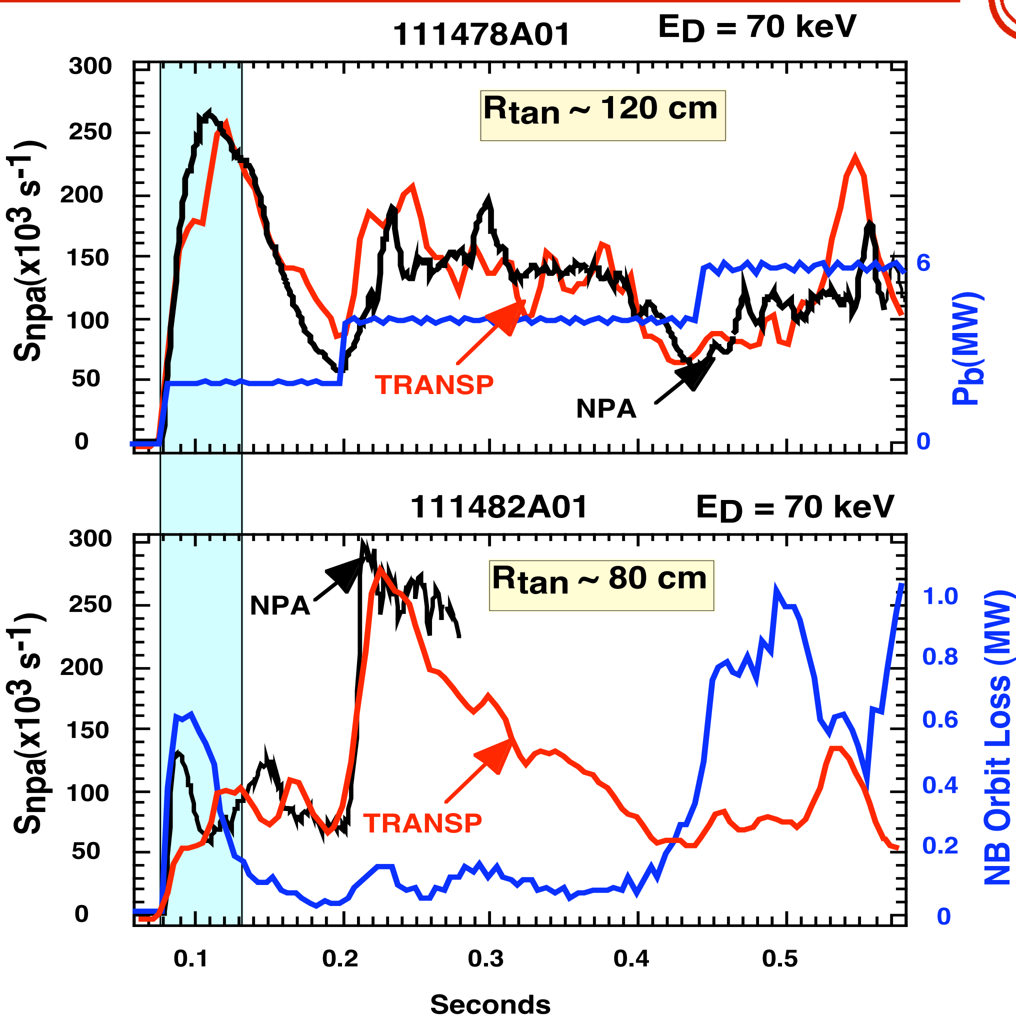
- **Better gap control reduces the NB turn-on orbit loss by ~ 20%.**

Gas Fuelling Variations Complicate Assessment of NB Turn-on Loss



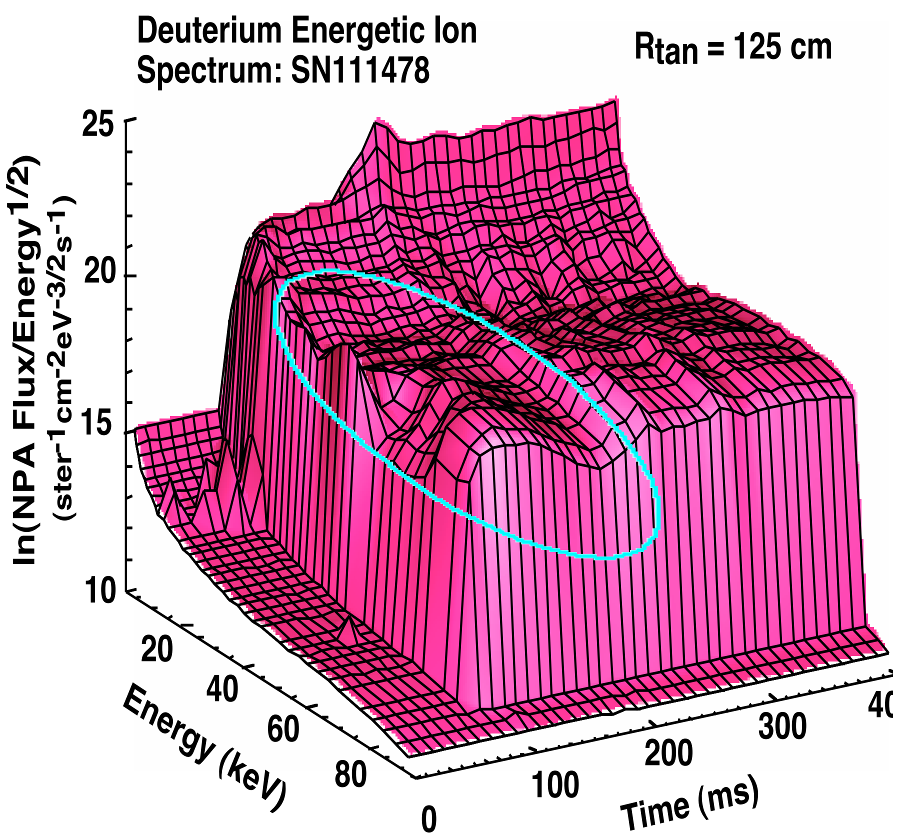
- The "larger" loss case (112157) has enhanced gas fuelling compared with the "lower " loss case.
- Increased gas puffing increases the edge n_o and thus the charge exchange signal.

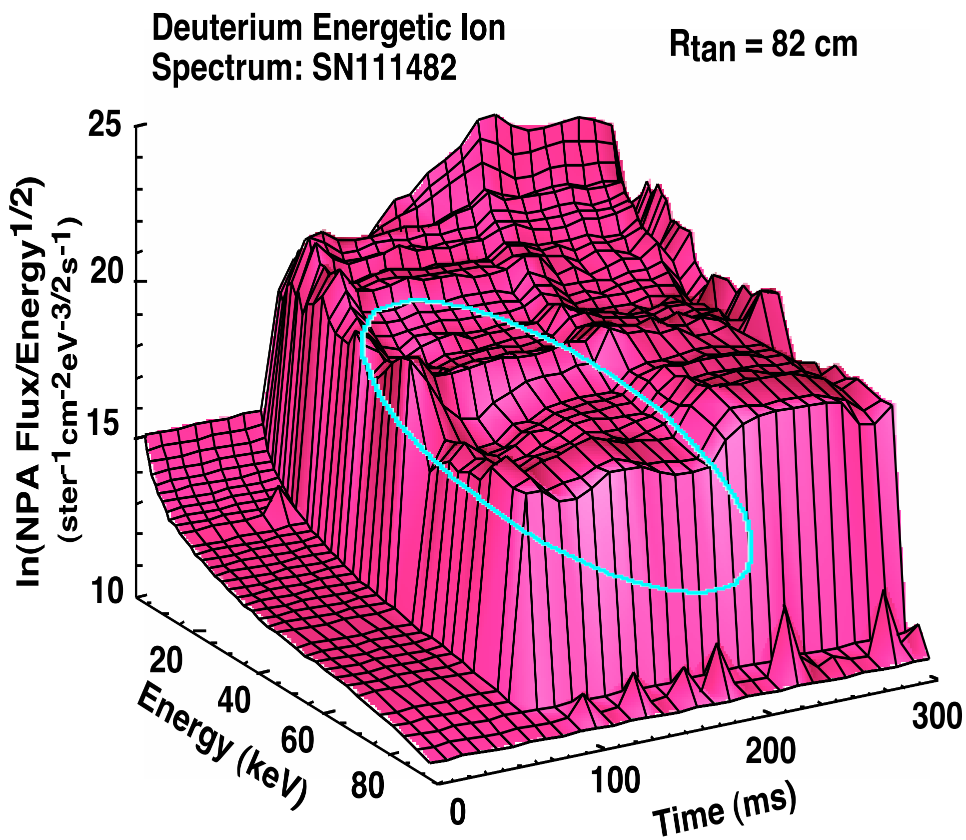
Observed and Simulated Ion Losses Depend on NPA R_{tan}



- **Both the observed and simulated NPA signal amplitudes are reduced at smaller NPA R_{tan}.**

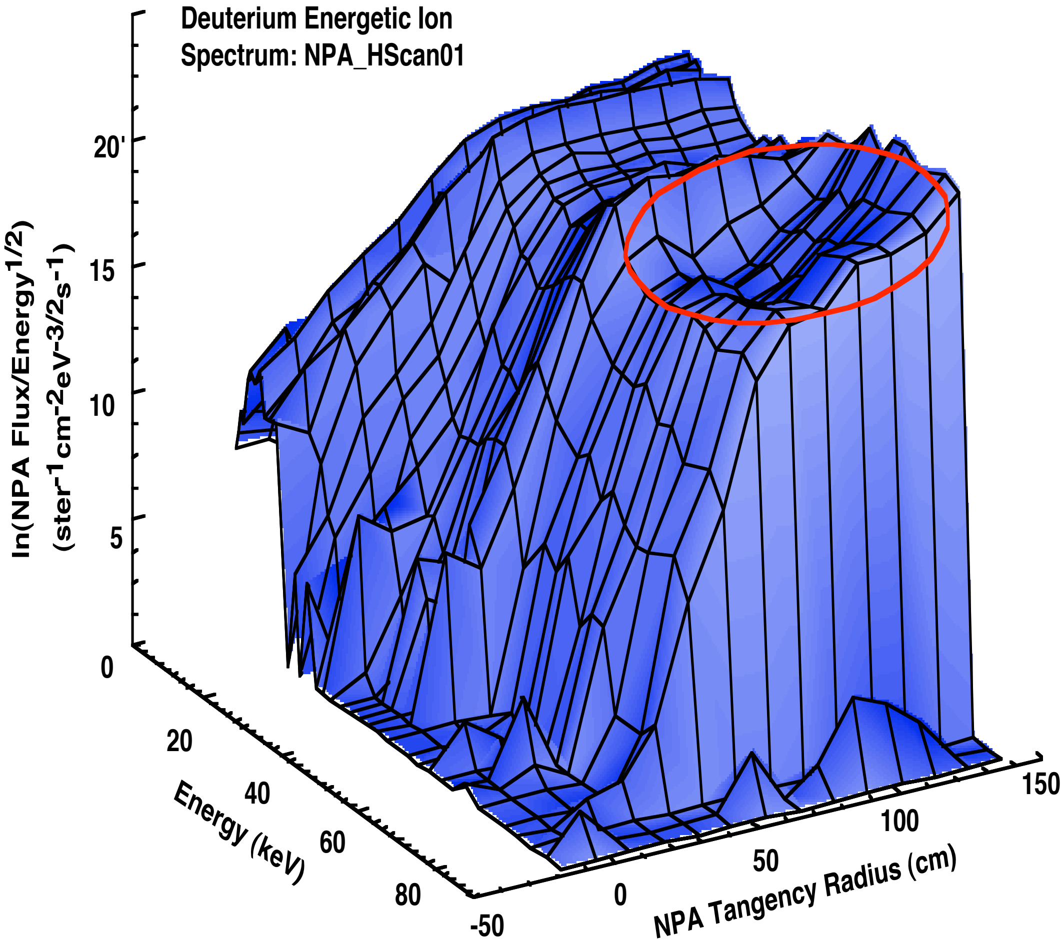
Observed NB Turn-on Ion Loss Depends on NPA R_{tan}





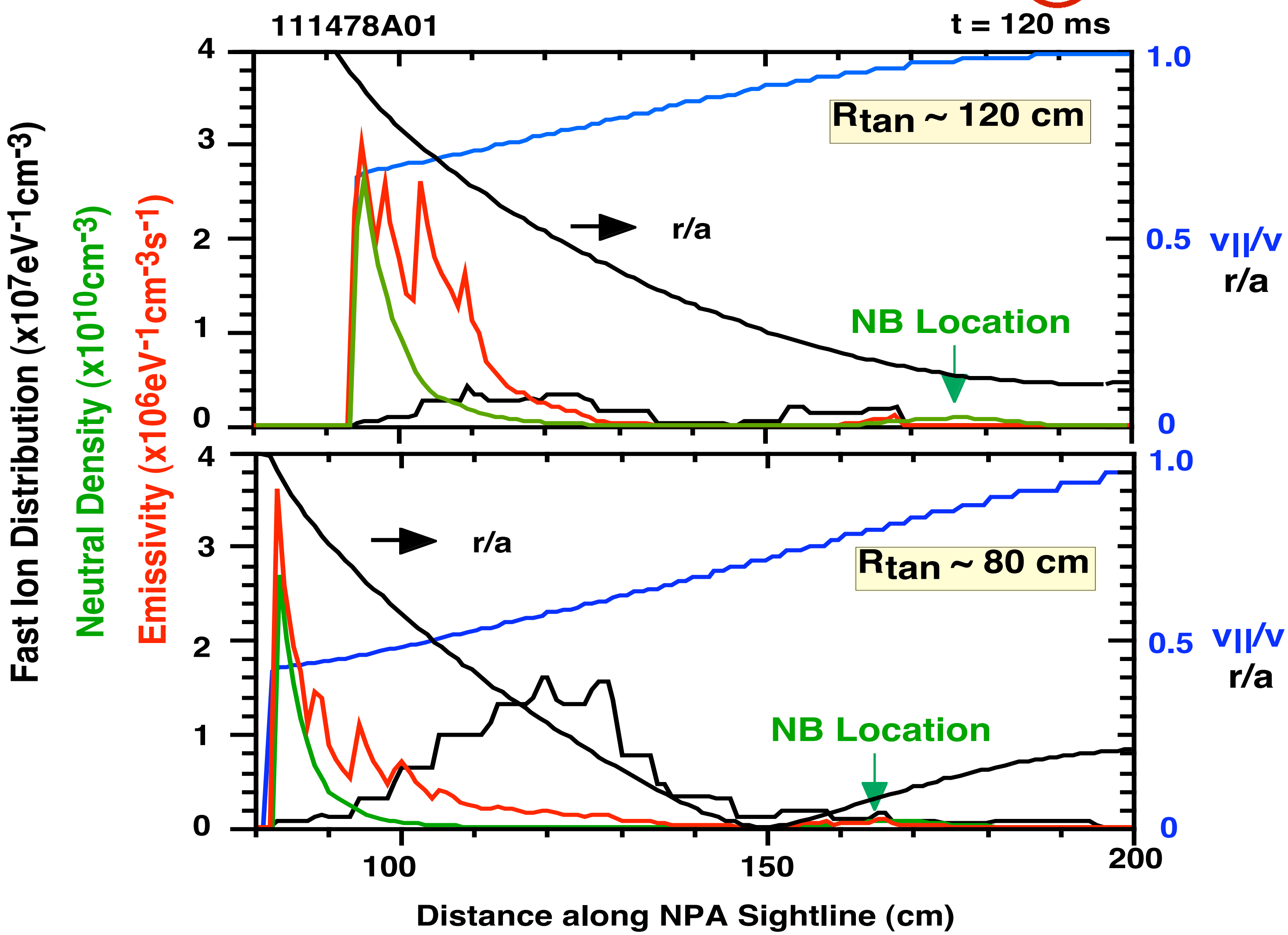
- NB Turn-on ion loss occurs over an extended energy range, but the greatest loss is observed for E>E/2.

Preliminary Evidence for Spatial (or Pitch) Localization of NB Turn-on Ion Loss: t = 120 ms



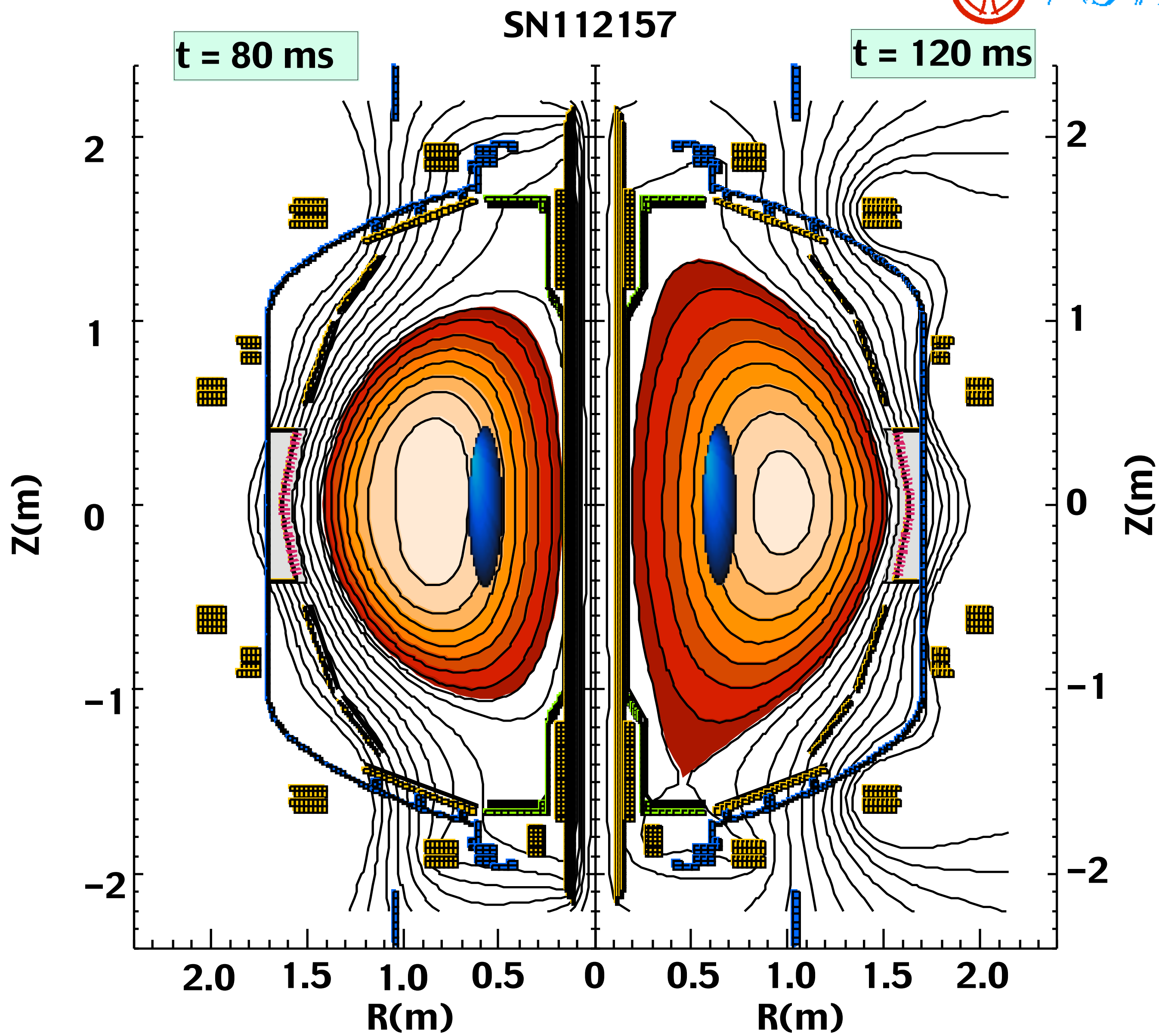
- NB turn-on ion loss in the region $E > E_b/2$ appears to be localized in the spatial range $60 < R_{tan}(\mathrm{cm}) < 115$ (encircled region).

Source of NPA Signal (Emissivity) at NB Turn-0n: E_D = 60 keV

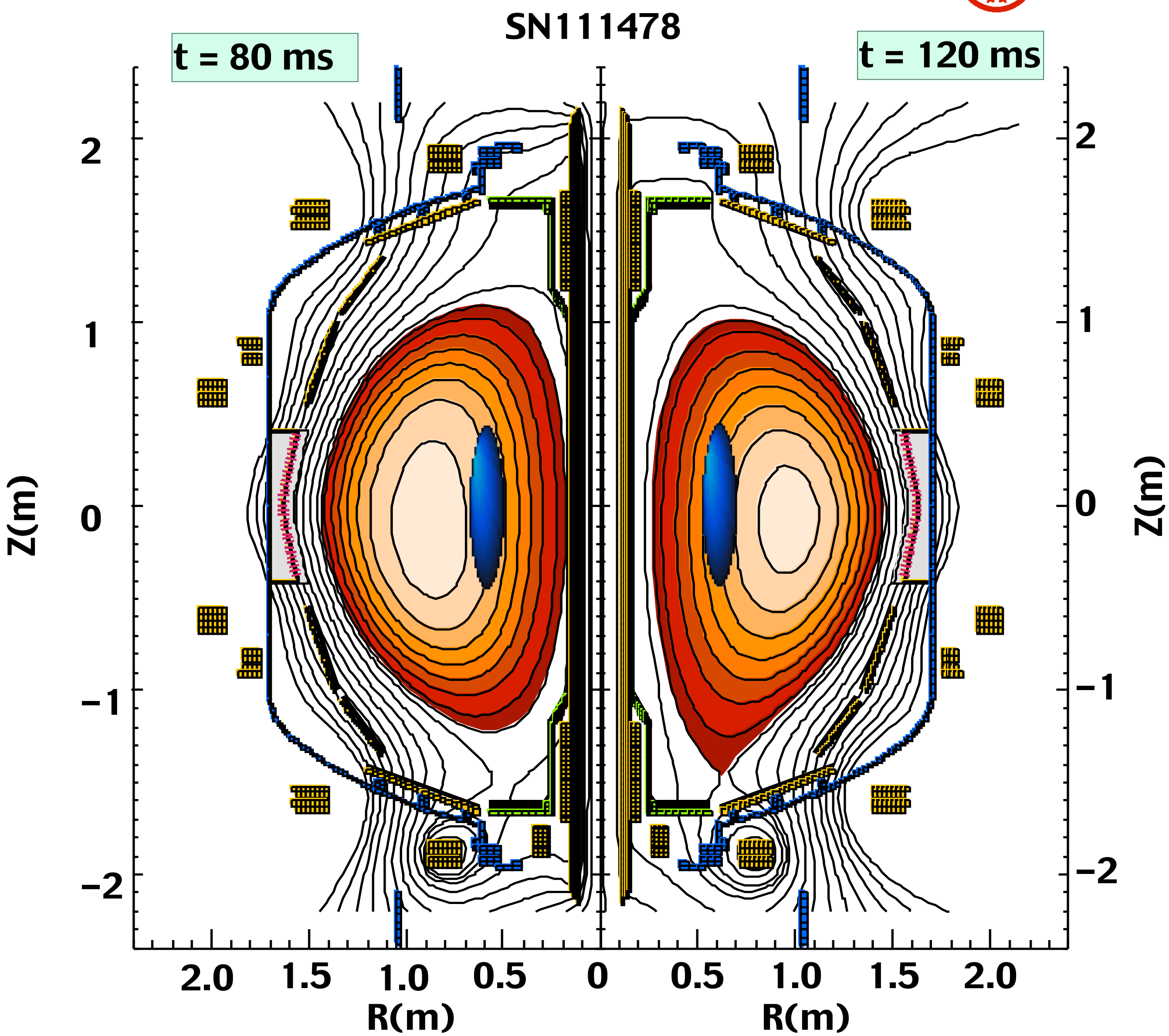


- The NPA signal near NB turn-on is edge-weighted and samples trapped ions.

EFIT Equilibria near NB Turn-on: SN112157 and Source B Footprint



EFIT Equilibria near NB Turn-on: SN111478 and Source B Footprint



Comparison of NB Turn-on Conditions
t = 100 ± 20 ms, Source B @ 88 keV, P_{NB} = 2 MW

	112157	111478	111482
I_p(kA)	460 - 500 - 700	480 - 525 - 650	470 - 540 - 670
Ne(x10^{13}cm^{-3})	0.84 - 1.15 - 1.40	0.67 - 0.87 - 1.07	0.77 - 0.87 - 1.07
Outer gap(cm)	13.2 - 6.3 - 10.2	12.4 - 11.0 - 13.0	13.4 - 11.7 - 12.1
Mean $\square_{gap}$(cm)	10.8	1.7	1.05
P_{NB} Loss(MW)	0.77	0.65	*0.65*
S_{nps} Loss(%)	75	0	50
NPA R_{tan}(cm)	75	125	82

- An inherent ion loss occurs due to NB injection at low I_p.
- A large gap excursion aggravates this loss (compare 112157 & 111482).

Summary

• Of the NB power injected during early turn-on, ~ 20% is lost to shine-through and ~ 40% is lost to bad orbits leaving a net heating of ~ 40% of P_{inj}.

• Most of the orbit loss (~ 75%) is inherent due to injection at low I_p but poor gap control can aggravate the loss (~ 25%).

• The orbit loss is dominated by trapped ions.

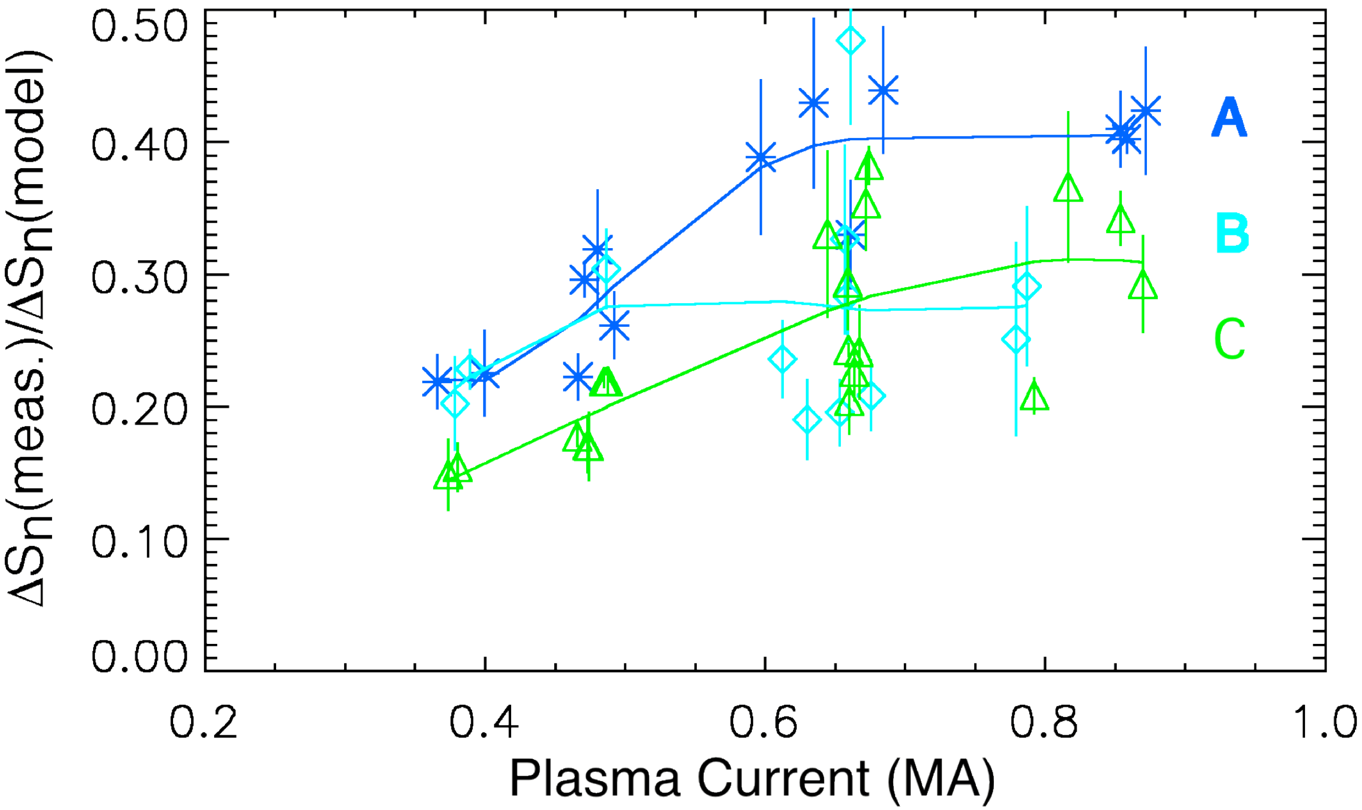
• The goal of inhibiting current penetration is compromised not only by the the loss of NB heating, but also by impurity influx driven by the power losses.

• Turn-on losses might be mitigated by:

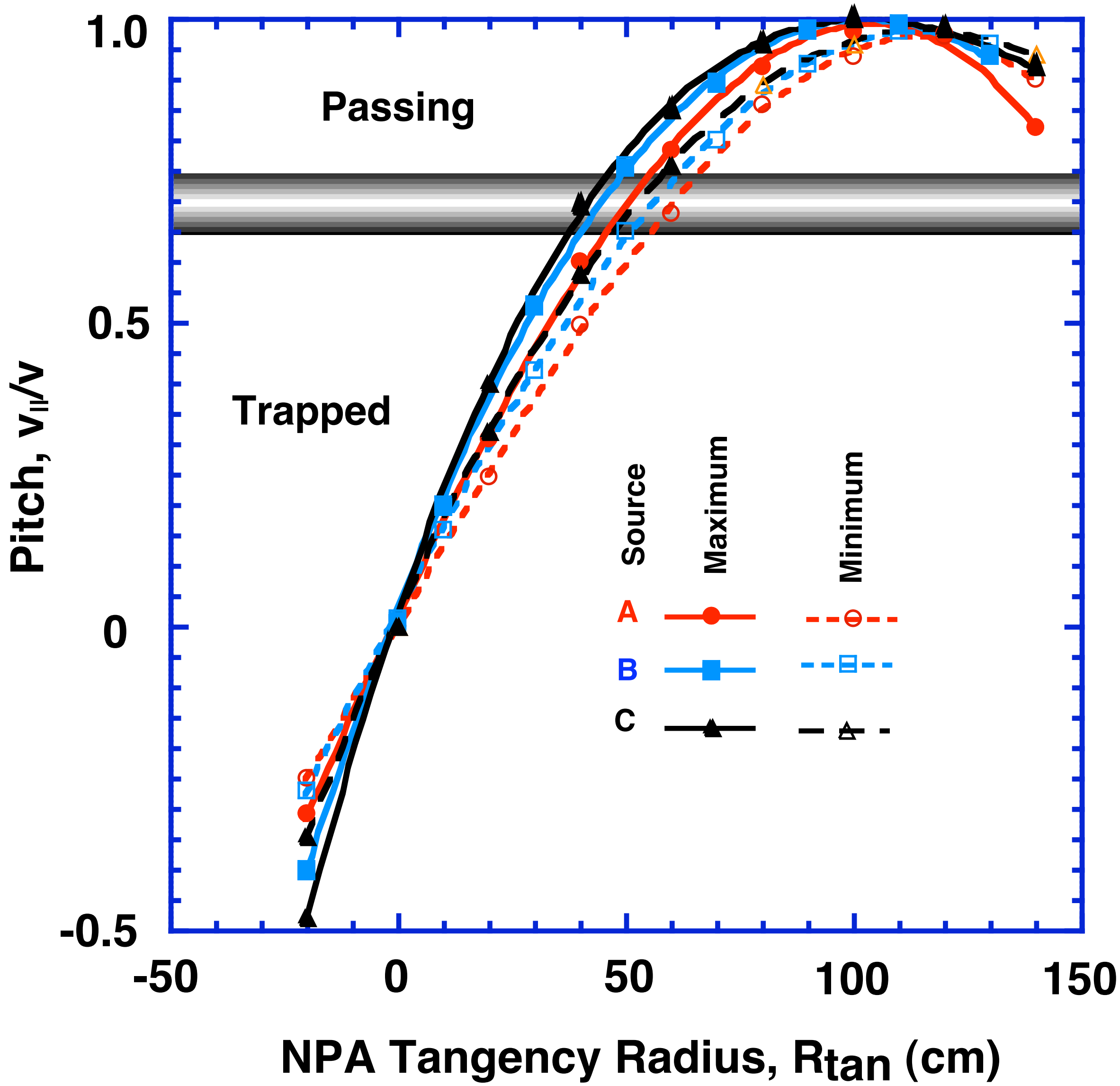
- using Source A instead of Source B to reduce the trapped ion fraction,
- optimizing the beam injection energy (MSE issue),
- improving gap control.

Backup Stuff

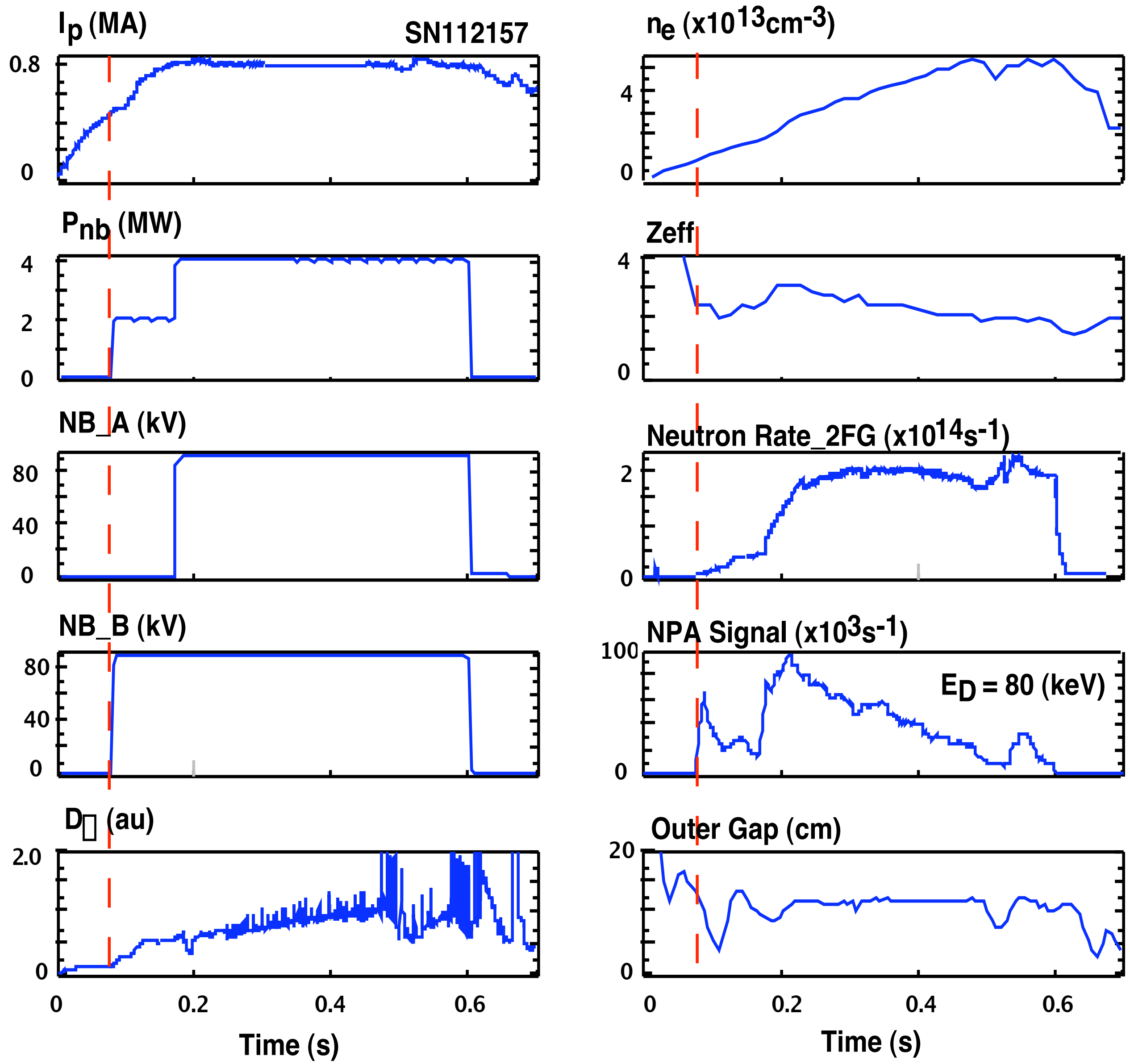
Increasing I_p & NB R_{tan} Improves Beam Ion Confinement



- **Source A (R_{tan}=0.7 m) better than C (0.5 m).**
- **Confinement best for I_p>600 kA.**

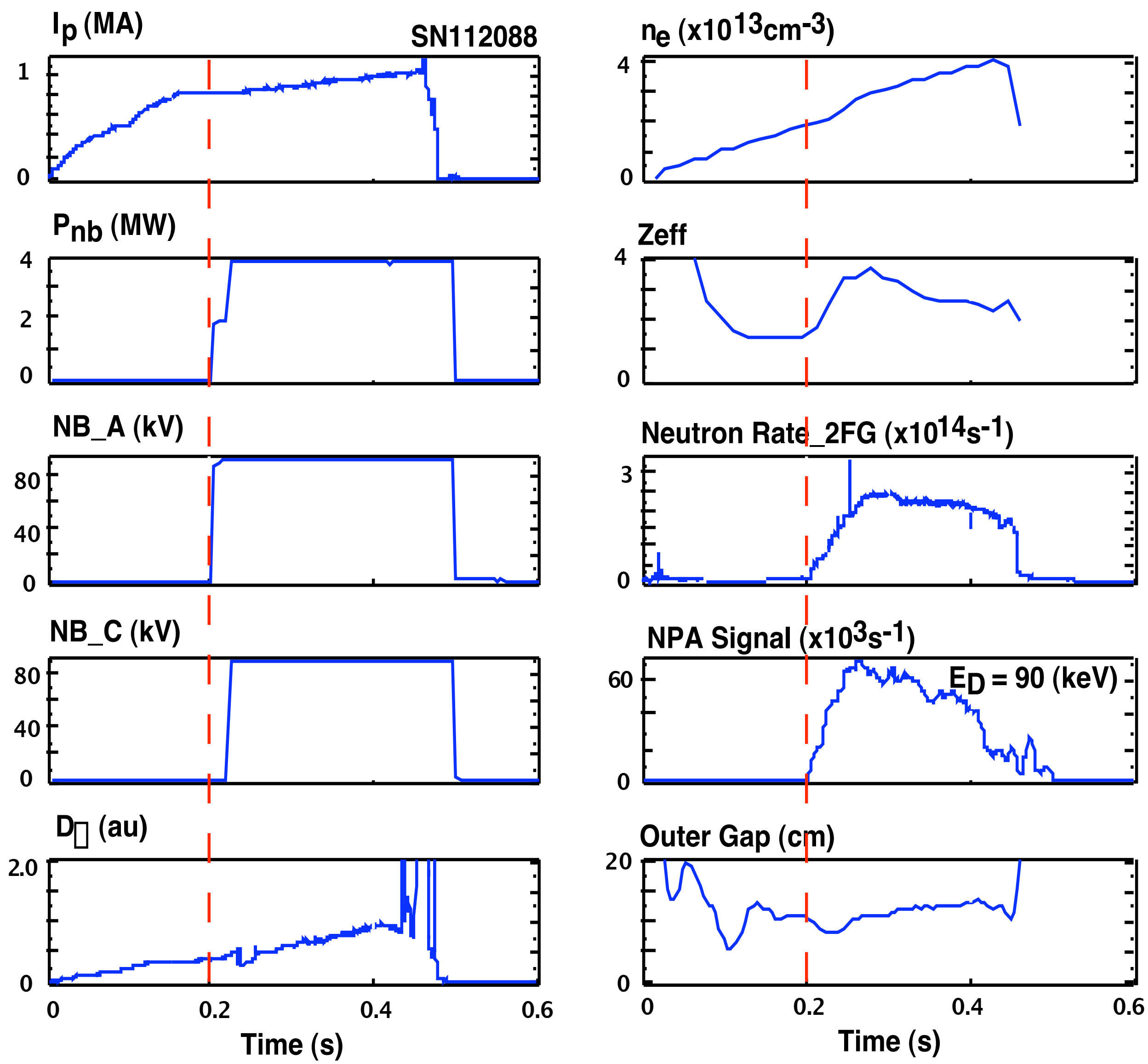

Passing
Trapped
Pitch, v||/v
NPA Tangency Radius, Rtan (cm)
Source
Maximum
Minimum
A
B
C
1.0
0.5
0
-0.5
-50
0
50
100
150

NB Turn-0n Energetic Ion Loss Scenario

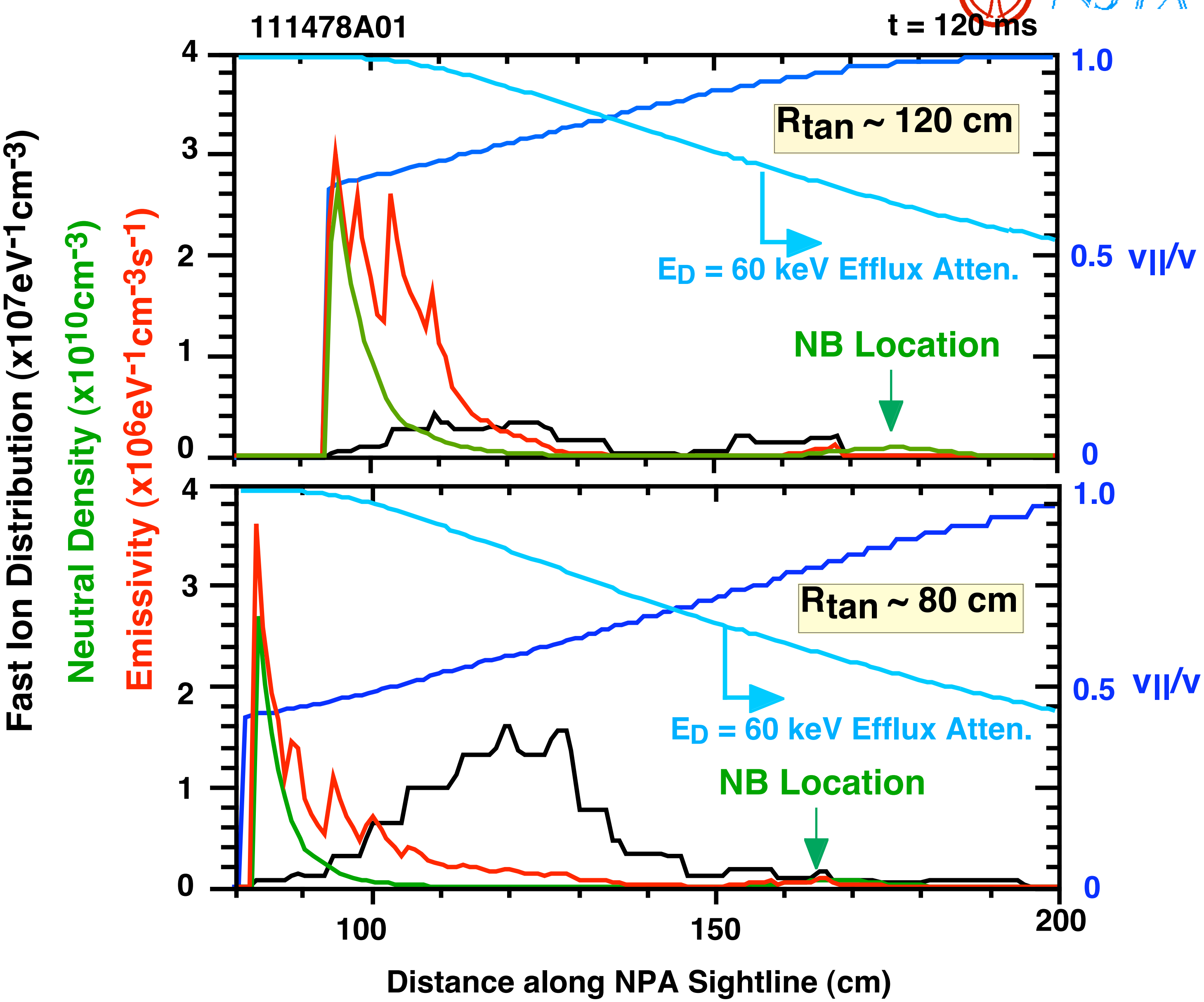


- NBI initiated at t = 0.08 s using Source B with P_b = 2 MW at E = 88 keV $n_e \sim 0.9 \times 10^{13}$ cm^{-3}.
- H-mode onset does not occur until t ~ 0.2 s, after turn-on of the second NB.
- Since n_e is low, high NB shine through, low neutron yield and low NPA signal attenuation are expected.
- An abrupt loss in the NPA energetic ion signal follows initial NB injection.
- Premise: poor gap control during I_p ramp up is a key factor in this ion loss.

A Contrasting Scenario: Late NB Turn-on



- NBI initiated at t = 0.2 s using Source A with P_b = 2 MW at E = 92 keV and n_e ~ $1.8x10^{13}$ cm^{-3}.
- H-mode onset does not occur until t ~ 0.23 s, after turn-on of the second NB.
- Neutron yield and NPA signal rise linearly after NB turn-on: i.e. no energetic ion loss signature.
- Good gap control at NB turn-on.


111478A01
t = 120 ms
Rtan ~ 120 cm
ED = 60 keV Efflux Atten.
NB Location
Rtan ~ 80 cm
ED = 60 keV Efflux Atten.
NB Location
Fast Ion Distribution (x10^7eV^-1cm^-3)
Neutral Density (x10^10cm^-3)
Emissivity (x10^6eV^-1cm^-3s^-1)
v||/v
0.5
1.0
0
4
3
2
1
0
100
150
200
Distance along NPA Sightline (cm)

Layout of the EIIB and Solid State NPAs on NSTX