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Laser-Plasma Interaction Experiments with Single and Multiple NIF Beams

D. J. Strozzi, J. D. Moody, H. F. Robey, L. Divol, P. Michel, R. L. Berger, E. A. Williams, D. E. Hinkel

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LPI experiments with single and multiple NIF beams

Anomalous Absorption Conference
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Lawrence Livermore National Lab

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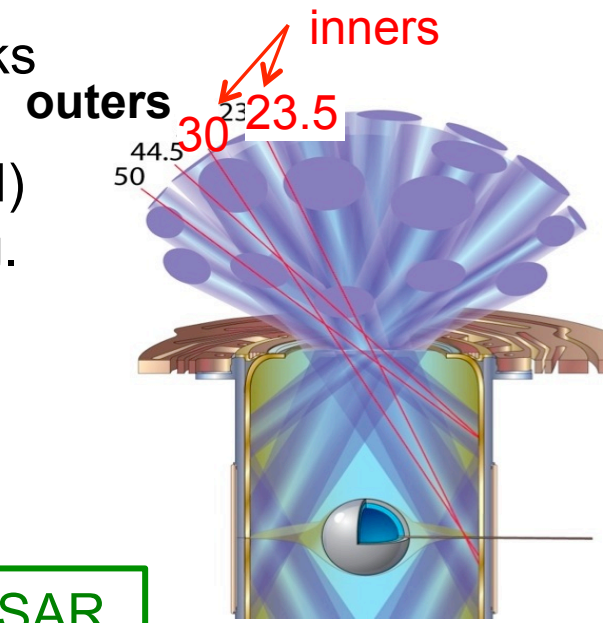
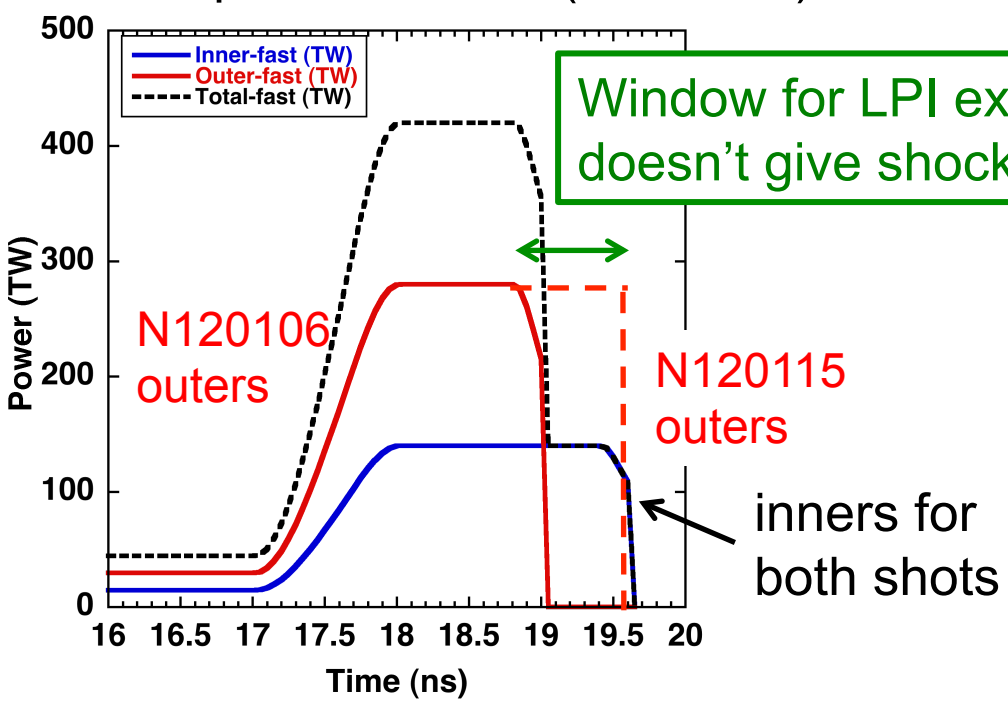
N120106 and N120115: "keyhole" shots isolate effect of outer cones on inners

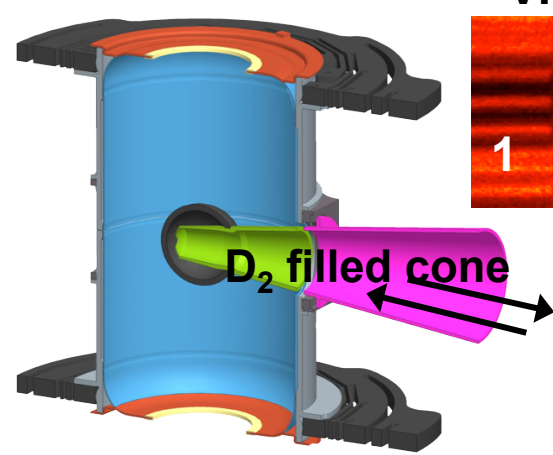
- "Keyhole" targets: VISAR detector: tune first 3 shocks
- "Fast rise" (~1 ns) from third to fourth shocks
- Gold hohlraum with "large" laser entrance hole (LEH)
- 3 laser colors: λ_{30}-λ_{out} = 6.6 Ang., λ_{23}-λ_{30} = 1.5 Ang.
- Same energy, except outers extended in N120115
- Very low inner-cone SBS



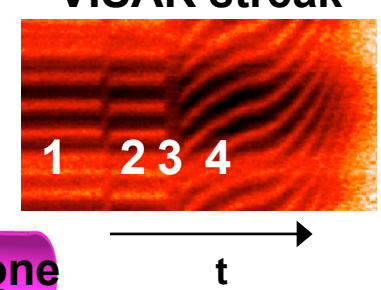
Fourth pulse fast-rise (N120106)



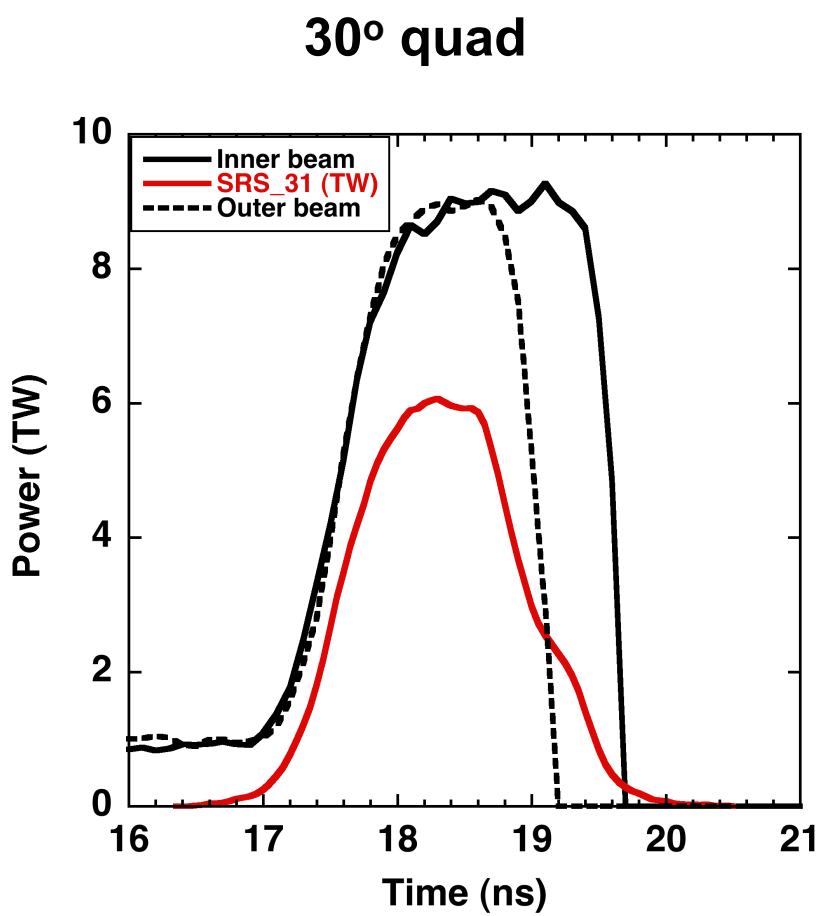
Window for LPI experiments! VISAR doesn't give shock data this late

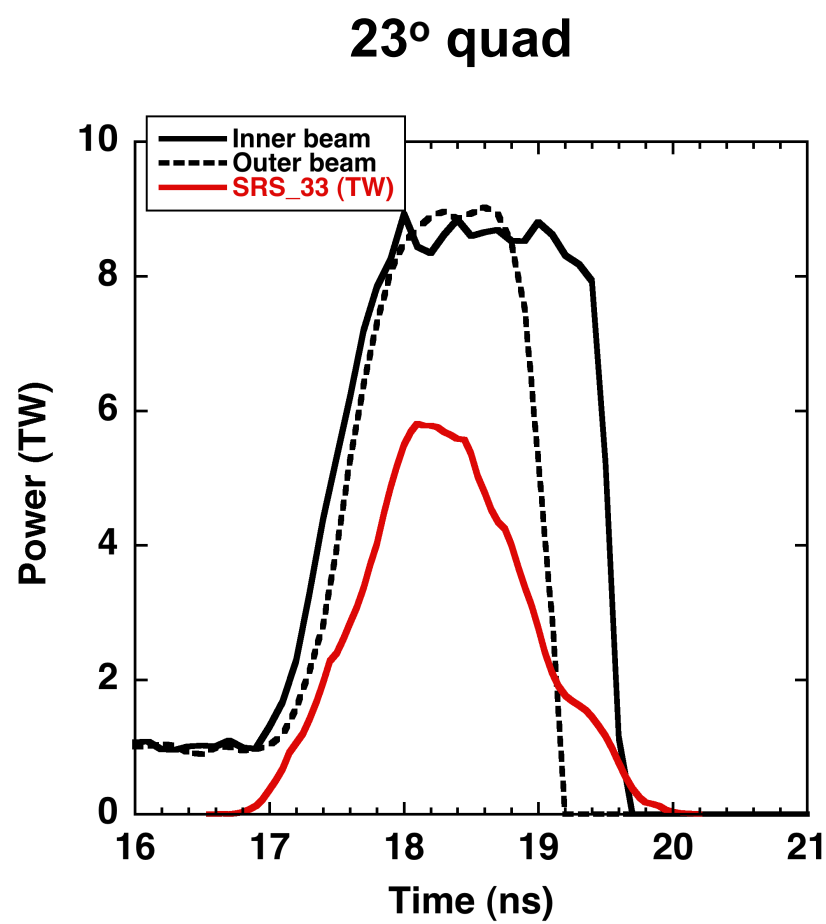


May 2011
VISAR streak

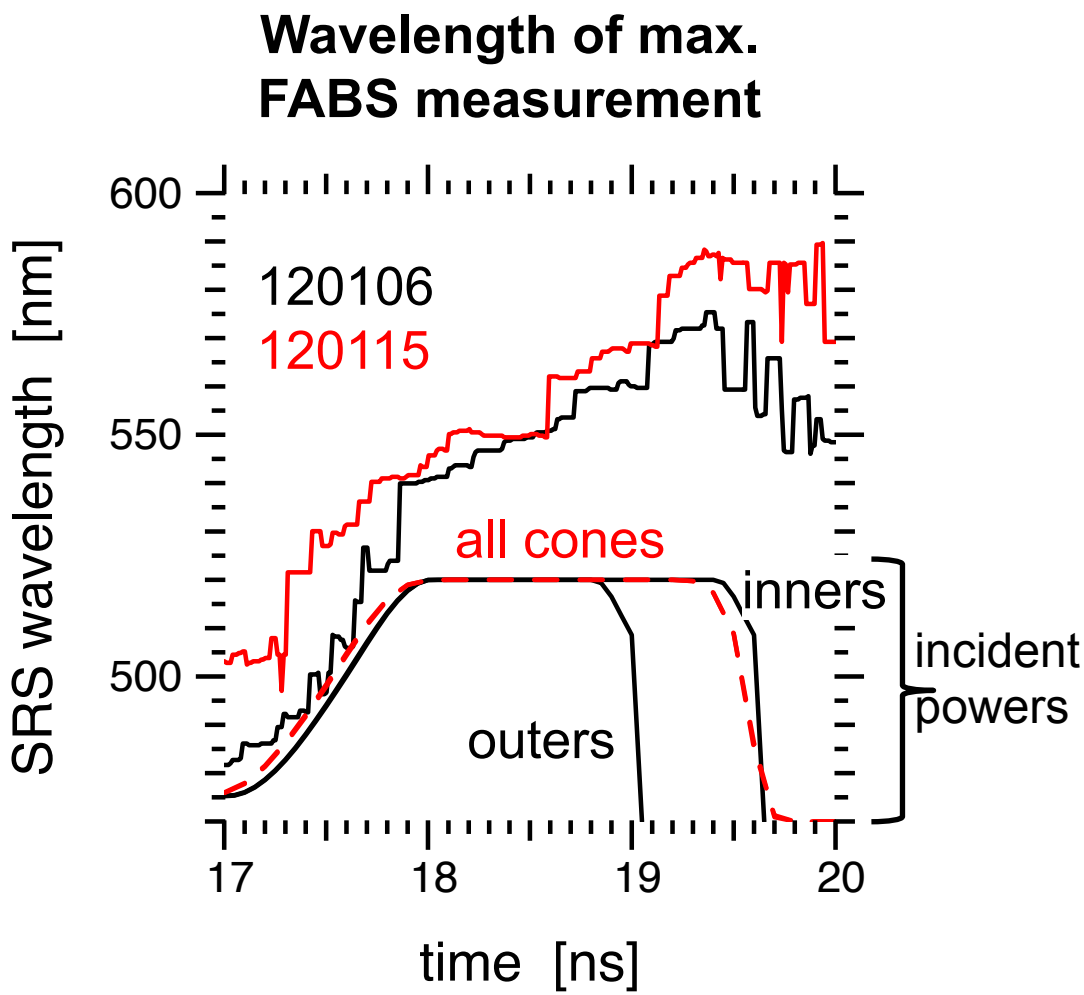


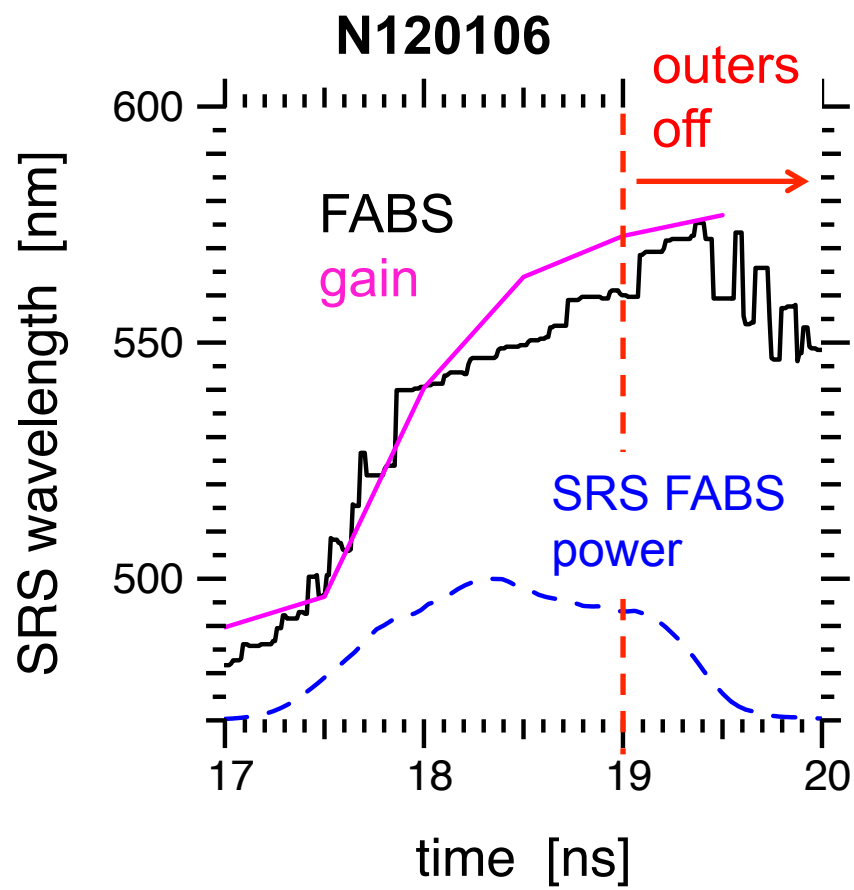
N120106: SRS on both inner cones drops when outers turn off





SRS spectrum on 30° cone evolves similarly if outers truncated or not; gain spectrum within ~10 nm

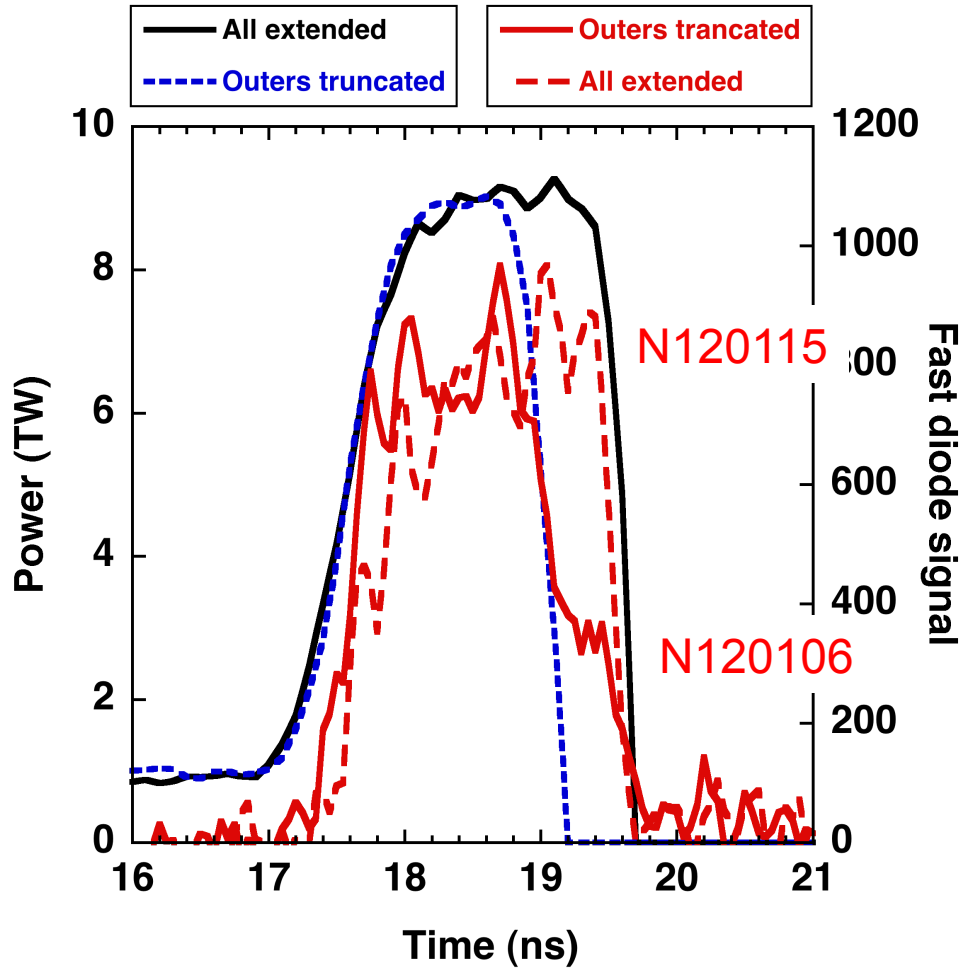




Gain spectrum from Hydra rad-hydro by H. Robey with high-flux model; low-flux model gives 20-30 nm longer wavelength

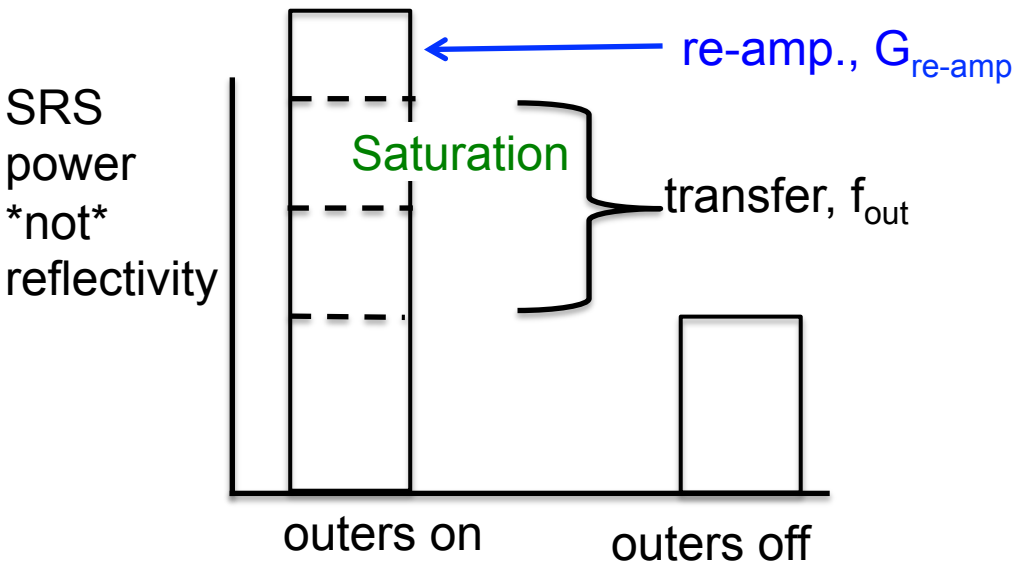
N1201{06, 15}: SRS power when outers are off is 40% of value with outers on

SRS data for 30° cone

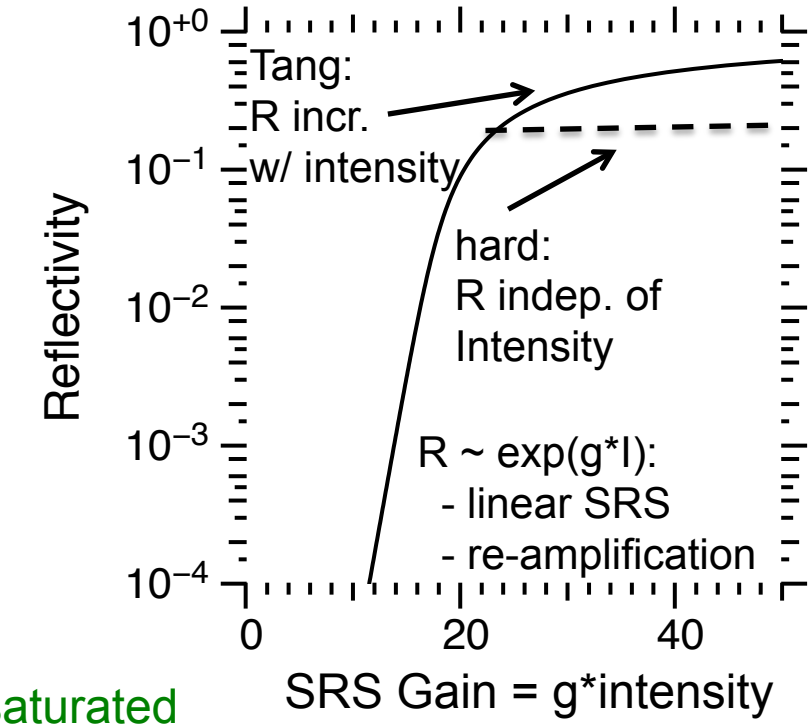


30° cone SRS power: N120106 (outers off) / N120115 (outers on): **0.4**

Inner SRS drops when outers off: no power transfer, no re-amplification, less saturation



Linear gain; Tang vs. hard saturation



When outers off:

Decreases because transfer stops

Decreases if Tang (not hard) saturated

Decreases because re-amplification stops

$$P_{30}^{SRS} = P_{30}^{inc} \cdot R(g * I_{30}) \cdot R_{\text{re-amp}}$$

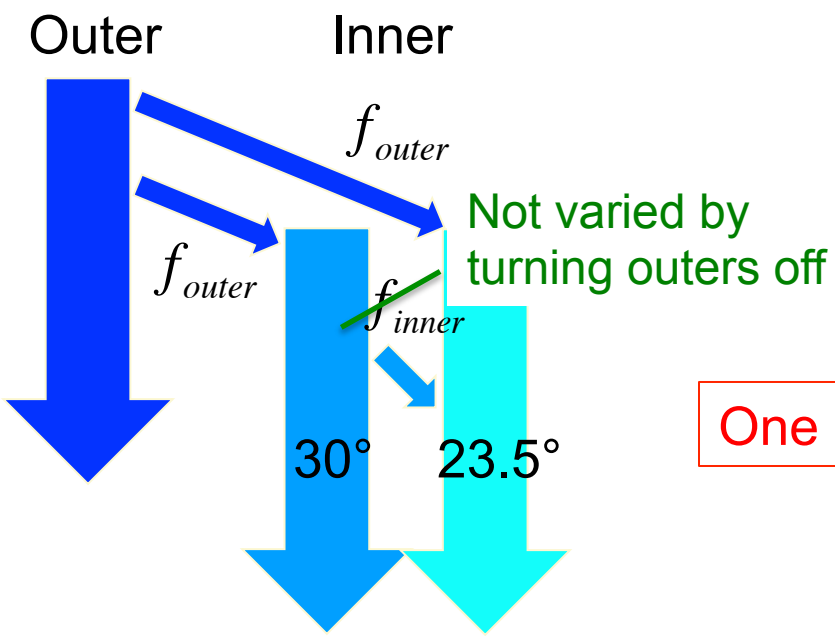
$$P_{30} = P_{30}^{inc} + \frac{1}{2} f_{out} P_{out}^{inc}$$

$$R_{\text{re-amp}} = \exp[G_{\text{re-amp}}]$$

Two unknowns: f_{out}, $G_{re\text{-}amp}$

SRS light from one beam amplified when crossing another beam [P. Michel et al.]

One-parameter model for cross-beam energy transfer from outer to inner cones



$$P_{23,30} = P^{inc}_{23,30} + \tfrac{1}{2}\Delta P_{out}$$

$$\Delta P_{out} = \text{total power xfer from outer to inner cones}$$

One unknown

$$= \boxed{f_{out}} P^{inc}_{out}$$

$$P^{inc}_{out} = P^{inc}_{44} + P^{inc}_{50} \approx 4 P^{inc}_{30}$$

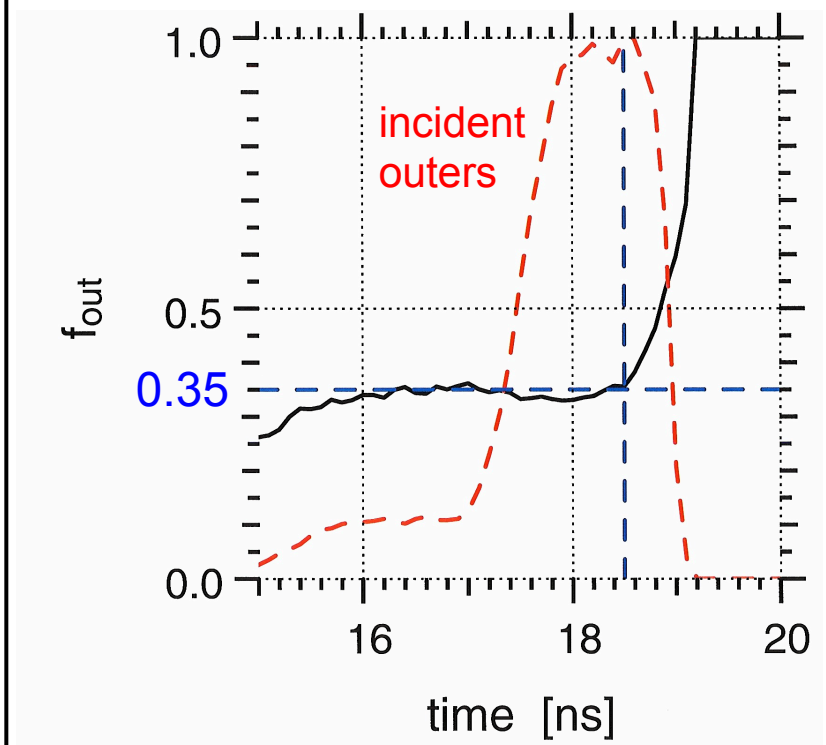
$$P_{23,30} = P^{inc}_{23,30}(1 + 2 f_{out})$$

f_{out} = fraction of outer-cone power transferred to inner cones

We neglect spatial non-uniformity in transfer, which should be looked at (R. L. Berger)

Measured ratio of SRS powers relates transfer and re-amplification

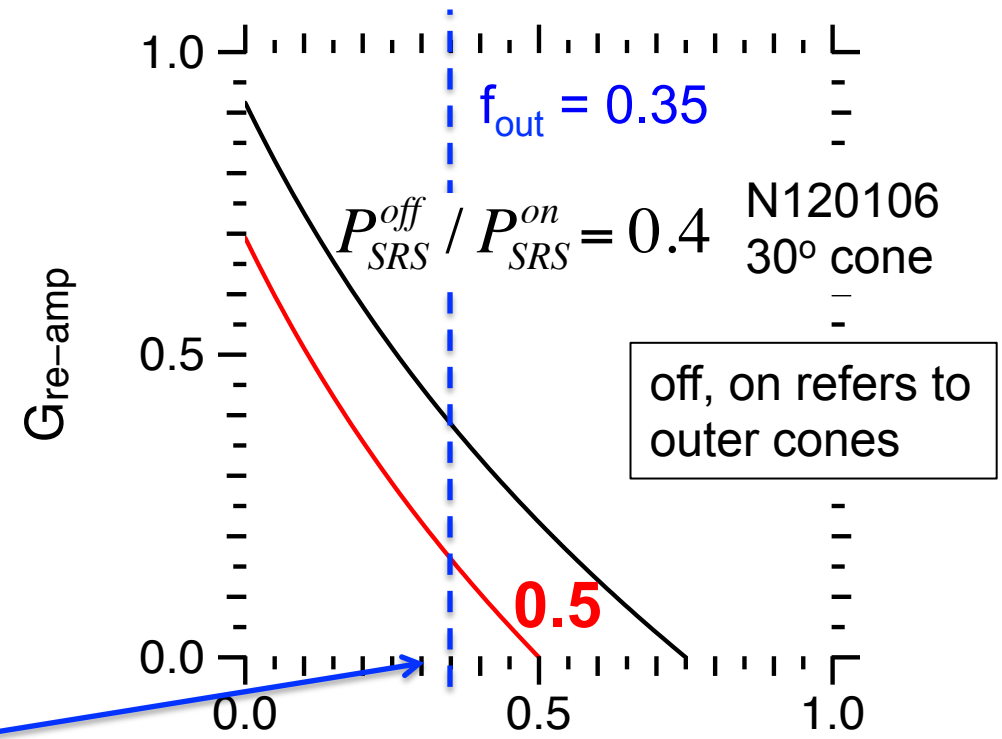
Power transfer from H. Robey's post-shot Hydra of N120106



$$\frac{P_{SRS}^{on}}{P_{SRS}^{off}} = \rho \cdot (1 + 2 f_{out}) \exp G_{\text{re-amp}}$$

$$\rho = \frac{R(g * I_{30}^{on})}{R(g * I_{30}^{off})} \rightarrow 1$$

hard saturation: maximizes $G_{\text{re-amp}}$



- f_{out} ~ 0.35 agrees w/ capsule symmetry data (R. Town)
- Hydra's f_{out} passes basic check: inconsistent w/ SRS drop if f_{out} > $G_{\text{re-amp}}$ = 0 values

f_{out} = frac. of outer power xferred

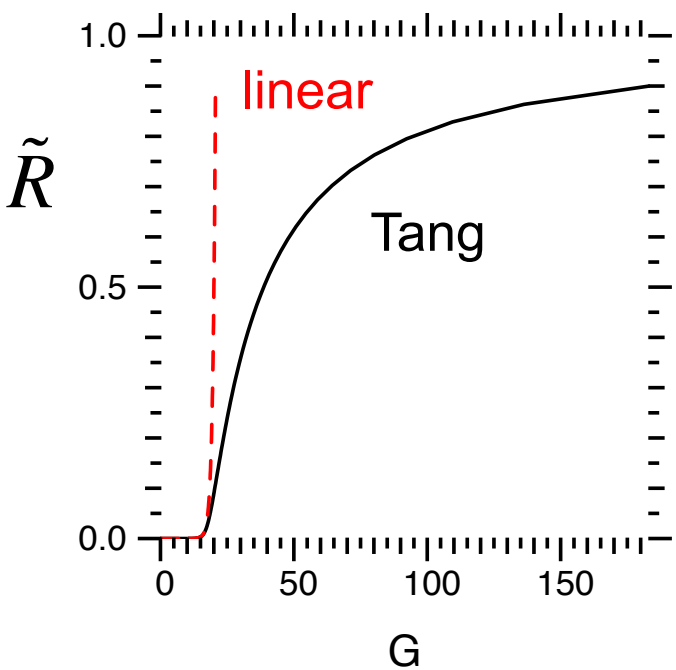
Allow for saturation to vary with intensity

- $G_{re\text{-}amp}$=0: SRS changes only due to power transfer; $G_{re\text{-}amp}$>0 lowers A, raises G
- Neglect change in g = role of plasma conditions in gain
  — measured spectra similar for N120106 and N120115

$$A \equiv e^{-G_{\text{re-amp}}} \frac{P_{SRS}^{on}}{P_{SRS}^{off}} = \rho\left(1+2f_{out}\right) = \alpha(f_{out}, G)$$

$$\rho = \frac{R(P_{30}^{on})}{R(P_{30}^{off})} = \frac{R(G\cdot(1+2f_{out}))}{R(G)}$$

$$G \equiv gI_{30}^{inc}$$



Tang formula: coupled-mode eqs. w/ pump depletion

$$\tilde{R}\left(1-\tilde{R}+\tilde{s}\right) = \tilde{s}\exp\left[G\left(1-\tilde{R}\right)\right]$$

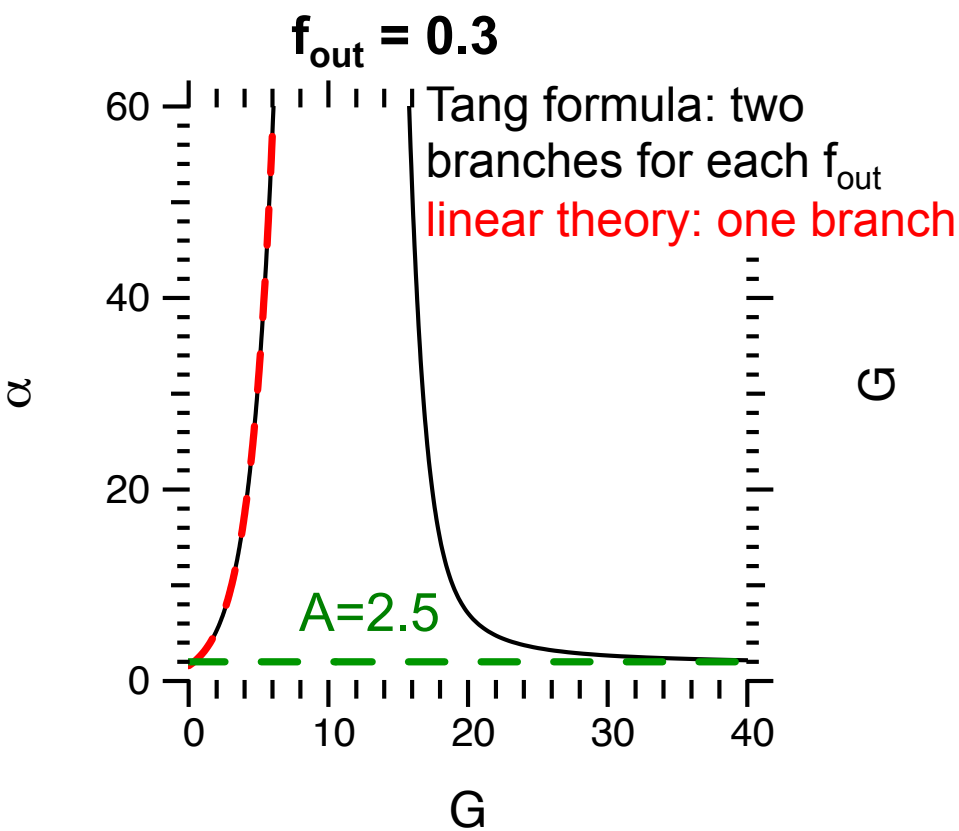
$$\tilde{R} = \frac{\omega_0}{\omega_1}R \qquad \tilde{s} = \frac{\omega_0}{\omega_1}\frac{I_{1\text{seed}}}{I_0} \rightarrow 10^{-9}$$

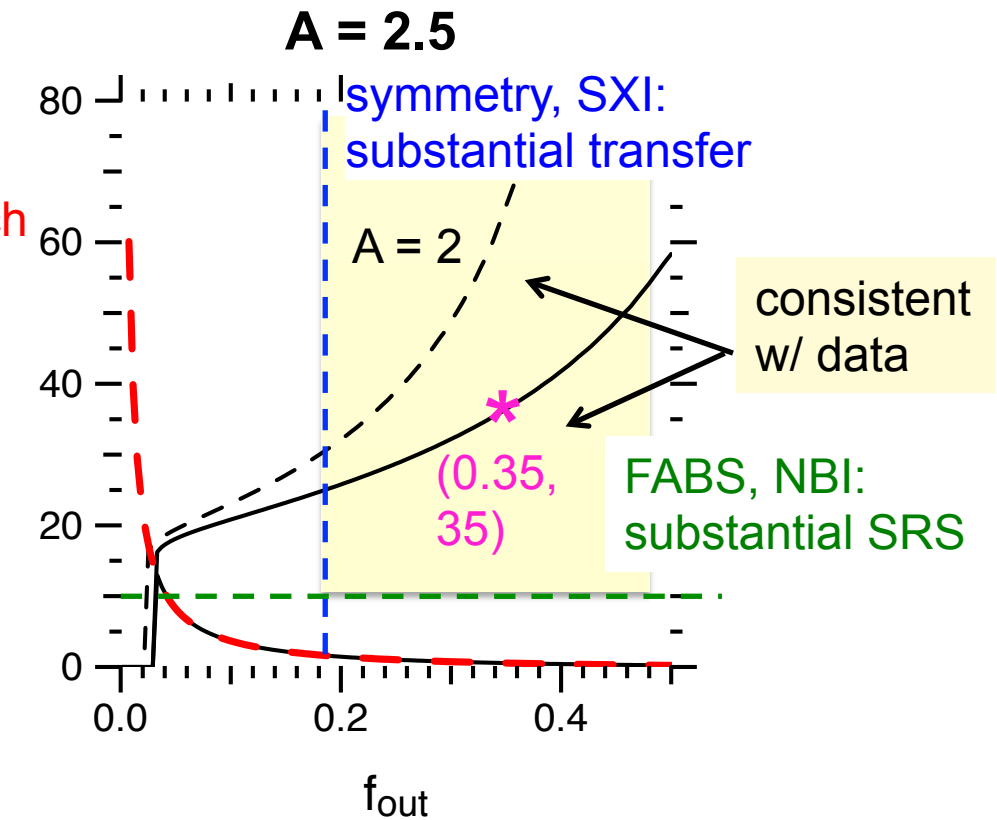
Manley-Rowe

linear theory

$$R = s\exp G; \quad G = \frac{1}{2f}\ln\left[\frac{A}{1+2f}\right]$$

Inner-cone SRS is strongly saturated





- Small drop in SRS for large transfer:
  - Linear branch requires small gain, not consistent w/ large SRS
  - Consistent w/ large gain on strongly-saturated, pump-depleted Tang branch
- Estimating G and f_{out}:
  - N120106: SRS power ~ 28% incident when outers off; wavelength = 570 nm
  - No re-absorption of scattered light: R_{tilde} = 0.45, G = 35 -> f_{out} = 0.33 – near sims!
  - R_{off} / R_{on} = 0.45 / 0.67 = 0.67; I*dR/dI = 0.2

Conclusions for N120106 and N120115: effect of outer cones on inners

- Inner cone SRS power approximately **doubled** by presence of outer cones
- Hydra modeling, and symmetry scaling with $\Delta\lambda$, suggest 35% of outer beam power transferred at time outers shut off
- Measured SRS decrease consistent with this 35% transfer, and with modest outer-inner re-amplification gain exponent of at most 0.15 - 0.4
- Saturation: neglecting re-amp. (which *minimizes* saturated gain): {large SRS, large transfer, and small SRS drop when outers} imply SRS is strongly saturated, not in linear regime

March keyholes: one inner cone extended – "single-quad" LPI experiments!

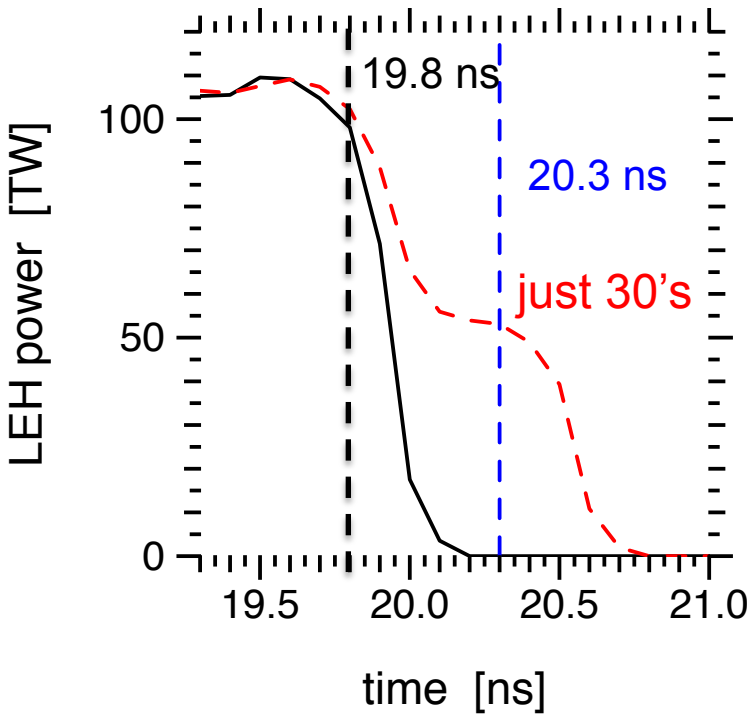
- But in a rapidly evolving, maybe azimuthally-asymmetric, hohlraum…
- Slow (3 ns) rise of fourth pulse
- "small" LEH
- 3-color scheme: $\lambda_{30} - \lambda_{out}$ = 7.3 Ang.; $\lambda_{23} - \lambda_{30}$ = 1.2 Ang.
- Single-quad expt. if no re-amplification of one inner quad by others on same cone
  - — Power transfer excluded by azimuthal symmetry

shot	hohlraum	peak power [TW]	extended cone
N120229	DU	420	30
N120303	DU	420	23
N120304	Au	420	30
N120305	DU	320	30

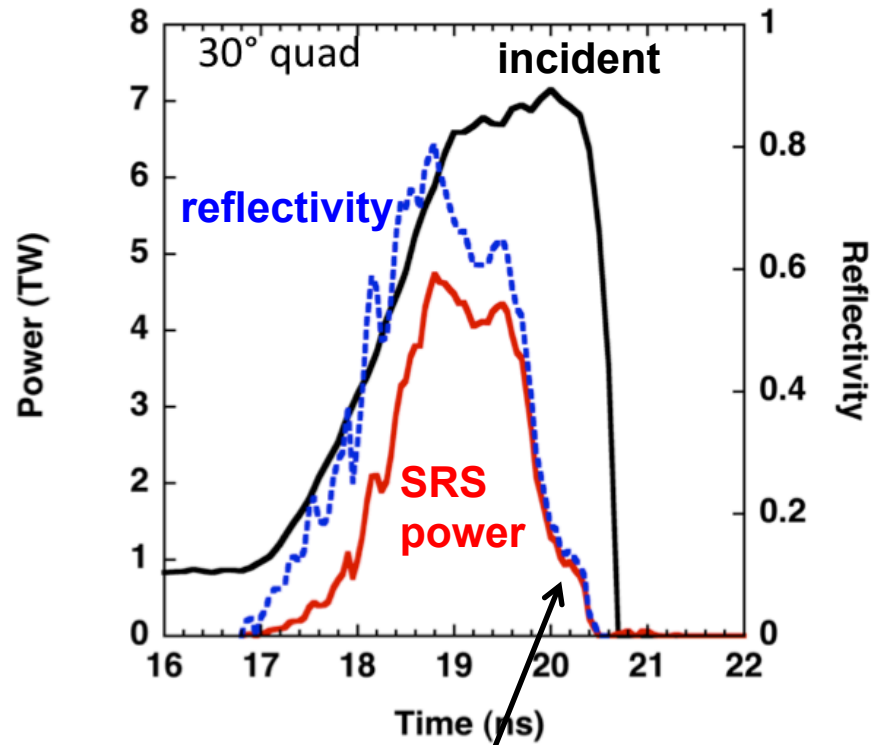
← shot we study

N120305: “single-quad” 30° cone SRS ~ 15-20%

Incident powers



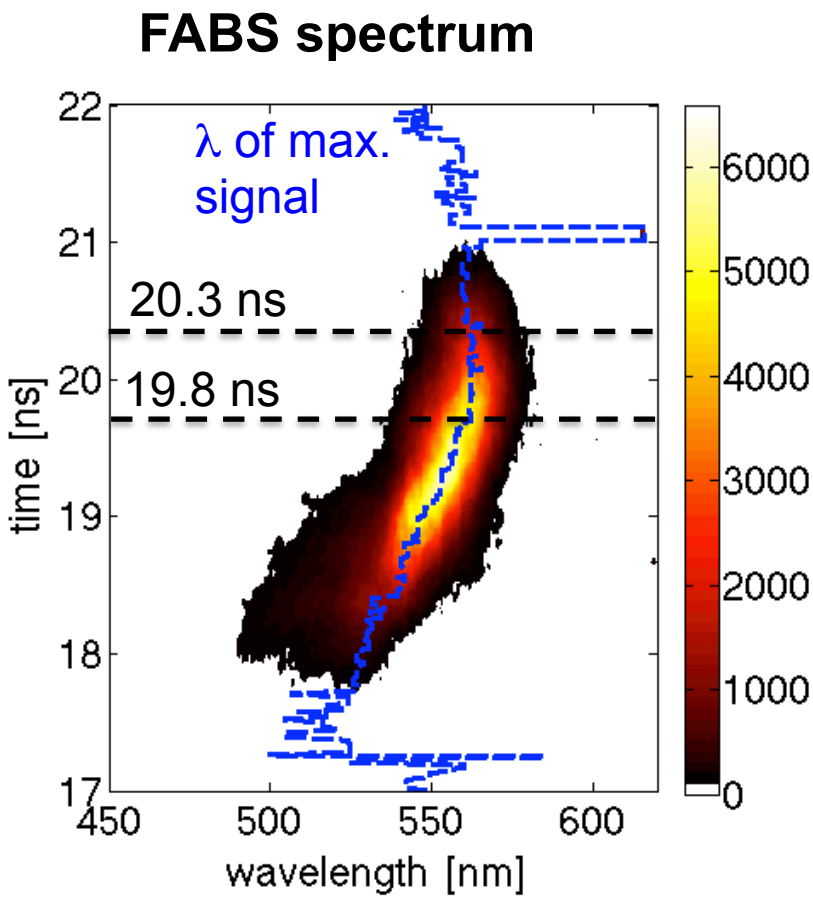
SRS from deconvolved NBI movie

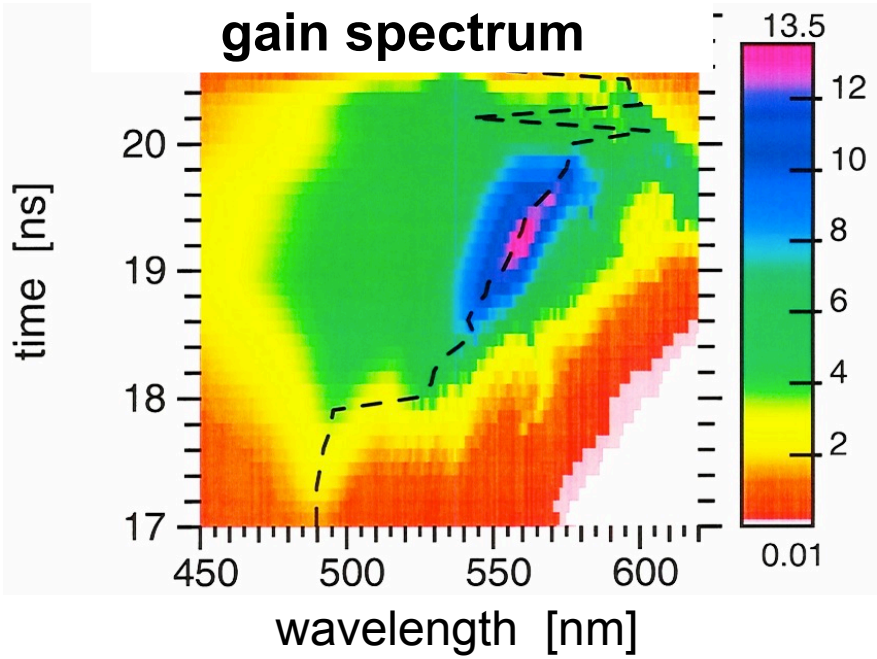


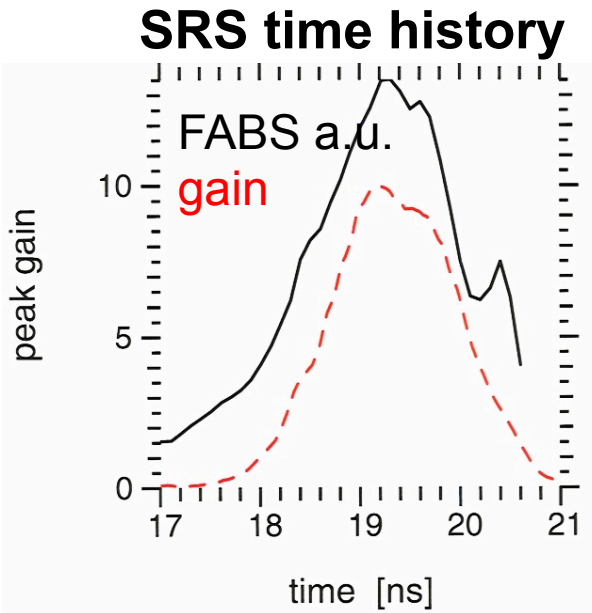
plateau when just 30’s on; ~15-20% SRS reflectivity depending on shot

SRS power starts dropping <u>before</u> other cones turned off – complicates analysis

N120305: SRS spectrum on 30° cone

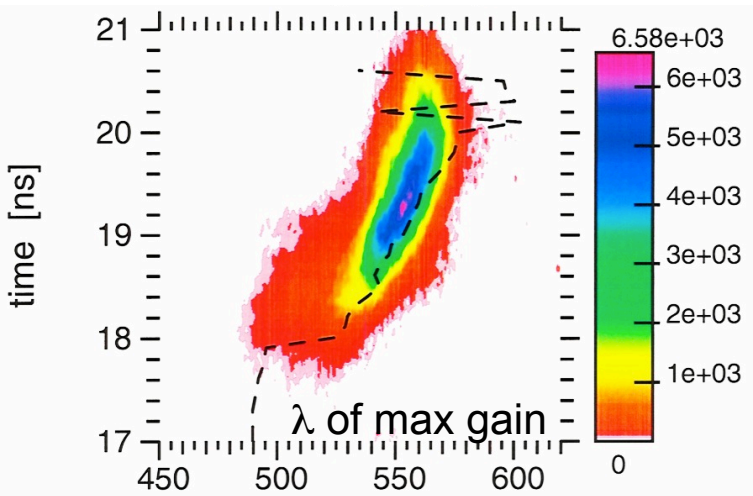




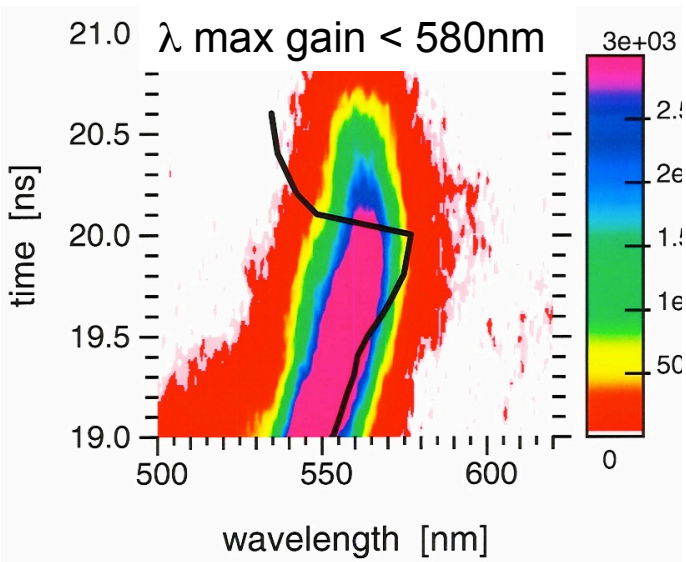


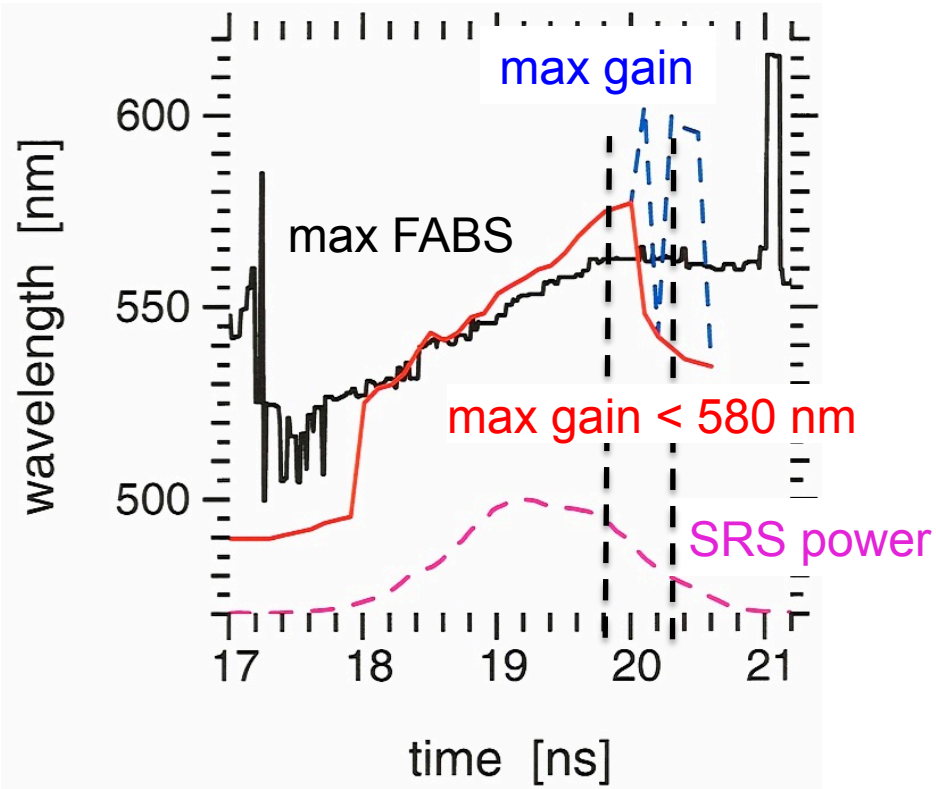
N120305: 30° cone SRS: FABS and linear gain agree when all cones on, differ when just cone 30 on

FABS spectrum



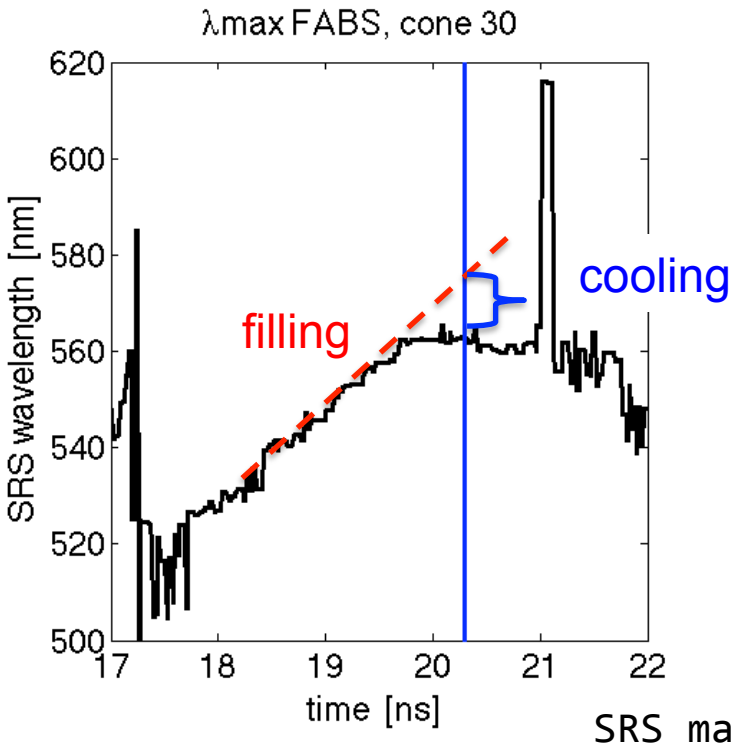
zoomed late, and capped





Multi-quad effects not essential to match spectrum

N120305: 30° cone SRS FABS spectrum: filling and cooling rates



SRS matching conditions: λ, T_e -> n_e

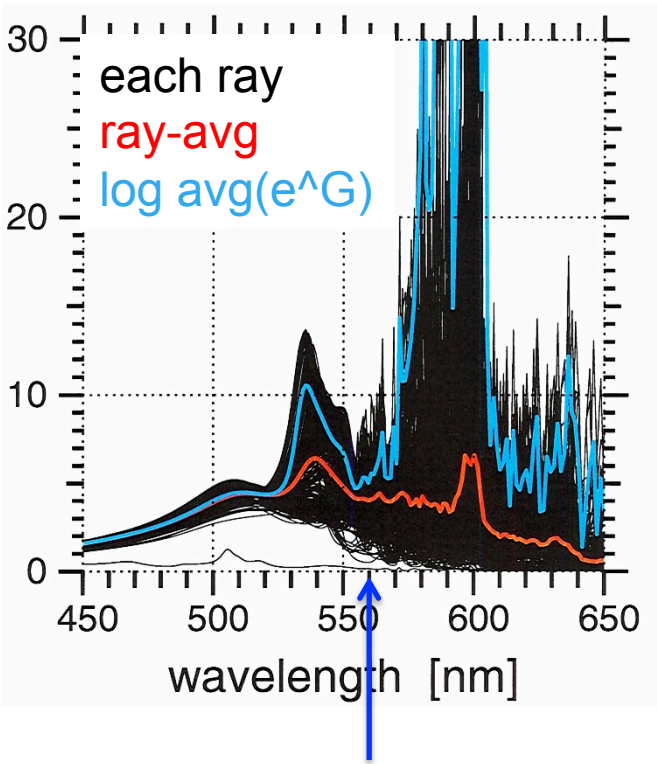
t [ns]	λ [nm]	n_e/n_{cr} [1.5 keV]	n_e/n_{cr} [3 keV]
19	545	0.102	0.069
19.5	558	0.115	0.082

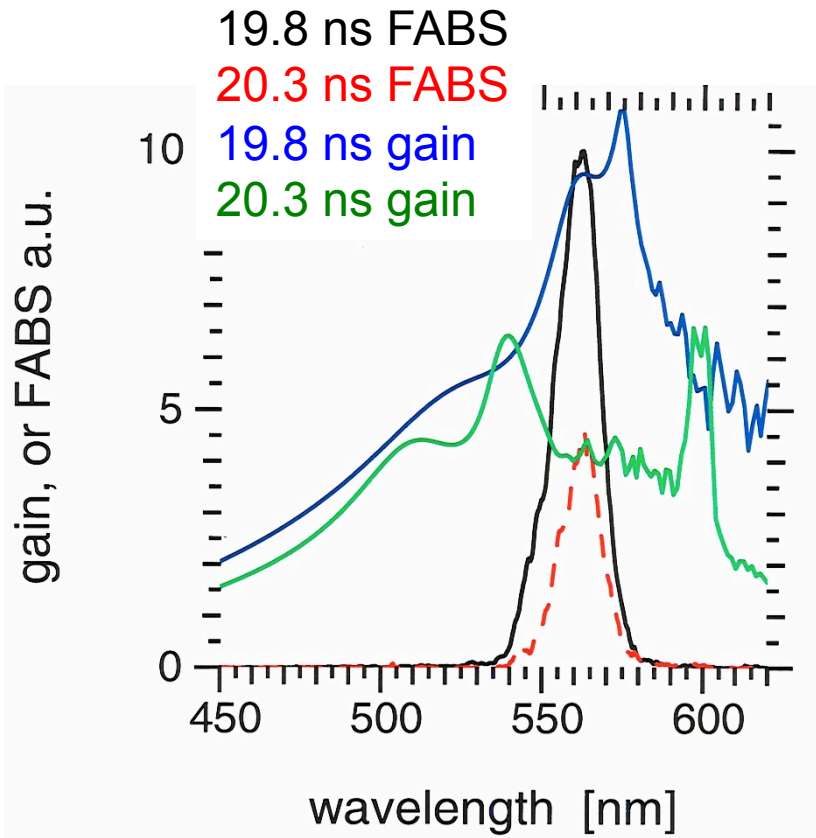
fill rate: $dn_e/dt = 0.026\ n_{cr}/ns$ for 1.5 or 3 keV!

cooling rate: $0.1n_{cr}$ and 2.3 keV match with 560 nm. To keep wavelength constant, $dn_e/dt = 0.026$ is balanced by $dT_e/dt = -1.1$ keV/ns

N120305: 30° cone SRS: what happens when other cones turn off

SRS gain, t = 20.3 ns





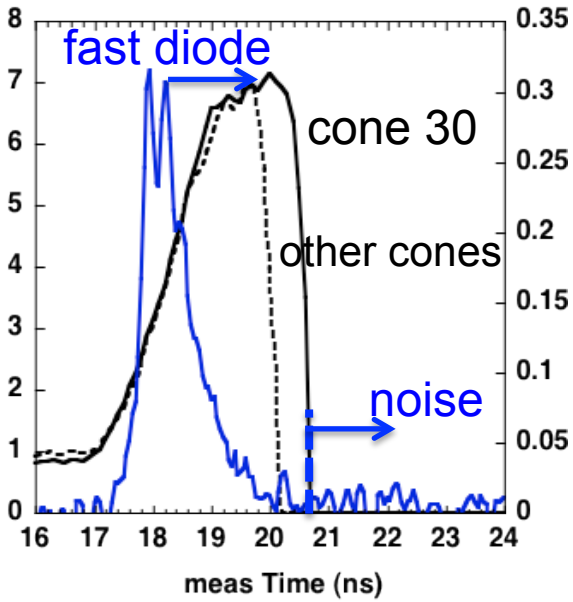
- FABS wavelength of 560 nm in "dead zone" of gain spectrum:
  - LPI physics (speckles, inflation) not likely to fix that
  - Plasma conditions likely wrong

Why gains blueshifted at late time?

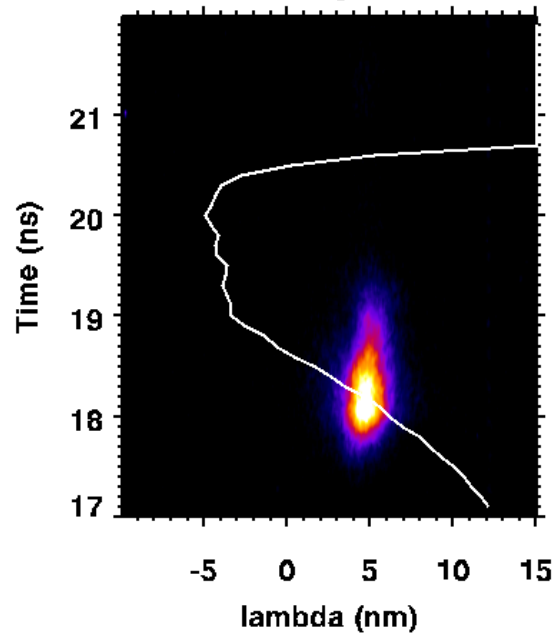
- Azimuthal non-uniformity:
  - Plasma really hotter in beams?
- Rad-hydro codes have trouble when laser turned off?

N120305: SBS on 30° cone: gains ~ 1.5 Ang. redshifted vs. measurement

SBS power [TW]



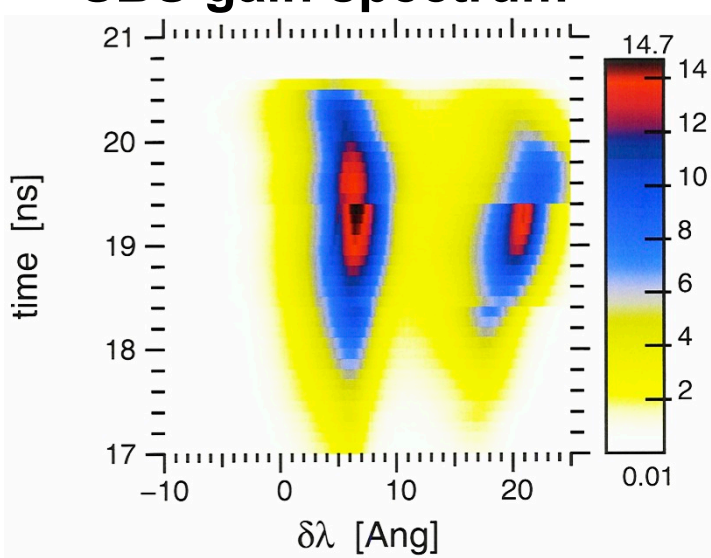
FABS SBS spectrum

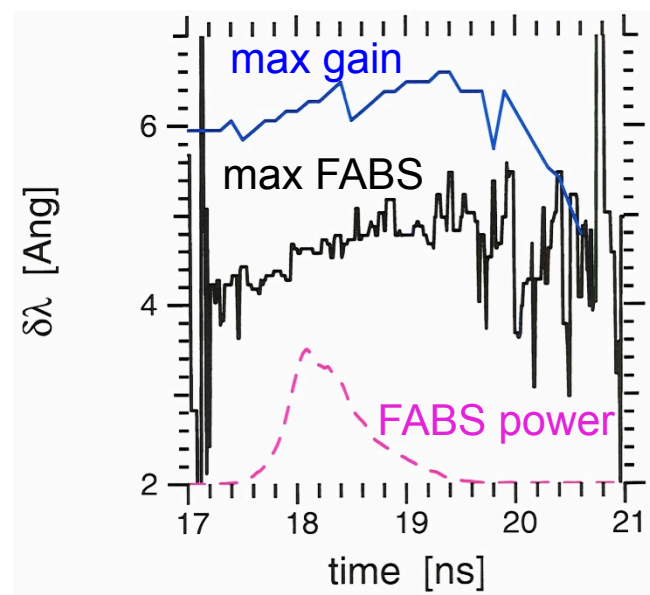


Time-dependent n_e[1] may explain redshift [R. L. Berger]

[1]T. Dewandre, J. R. Albritton, E. A. Williams, Phys. Fluids 1981

SBS gain spectrum

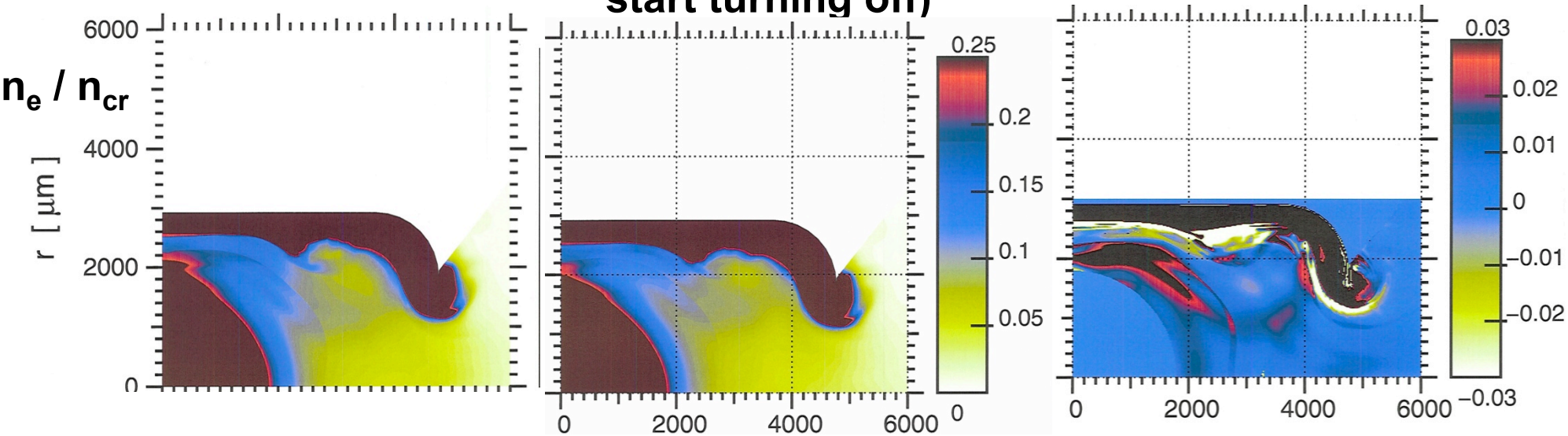




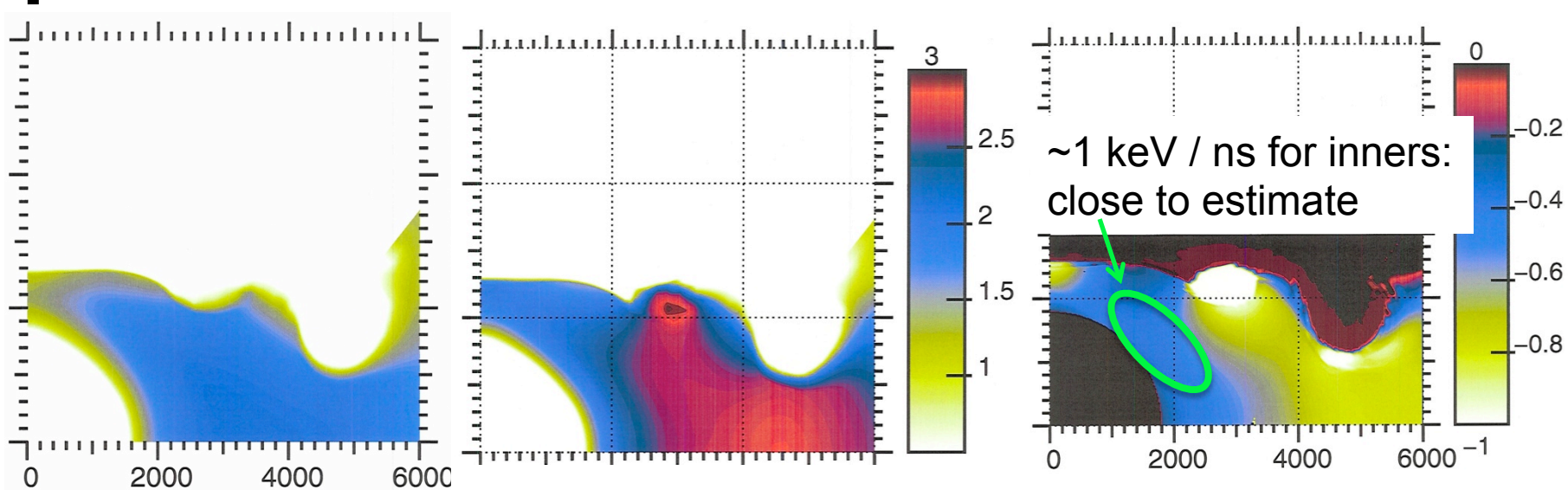
N120305: plasma maps from H. Robey's R-Z post-shot Hydra runs

20.3 ns (just 30's on) - 19.8 ns (other cones start turning off) = difference

n_e / n_{cr}



T_e [keV]



Conclusions on March 2012 keyholes

- Measured single-quad inner-cone SRS ~ 15-20%
- When all cones on, single-quad gain spectrum close to data
  — multi-quad effects not essential
- Gain spectrum changes more when just 30's are on than data –
  — rad-hydro plasma conditions likely wrong, perhaps due to degraded drive
- SBS gain spectrum ~ 1.5 Ang. redshifted vs. data
  — time-dependent density may explain