Modeling of NIF Laser-Plasma Interaction Experiments with Single and Multiple Beams

APS-DPP
1 November 2012

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

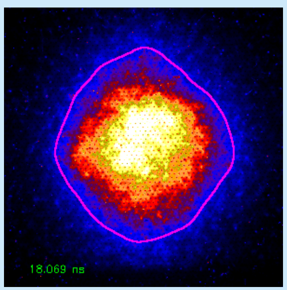
Tang reflectivity model gives transfer consistent with symmetry

- Done on recent keyhole shots – J. Moody, prior talk
- **Symmetry data:** transfer from outers increases inner beam power by ~70%
- **Single- vs. multi- beam shots:** direction of change in reflectivity is consistent with transfer to inners
- But magnitude of reflectivity change, with assumption of constant reflectivity, requires more transfer than symmetry data
- Reflectivity must increase with post-transfer power
- **Tang model**: reflectivity with pump depletion
  - **Inner-beam SRS:** 70% transfer – matches symmetry!
  - **Outer-beam SBS:** 66% transfer - matches symmetry AND inner SRS!!

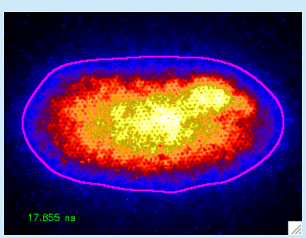
Cross-beam energy transfer affects backscatter

Inner-beam power increases by 70% to match shape of x-ray emission from imploded core

core x-ray emission

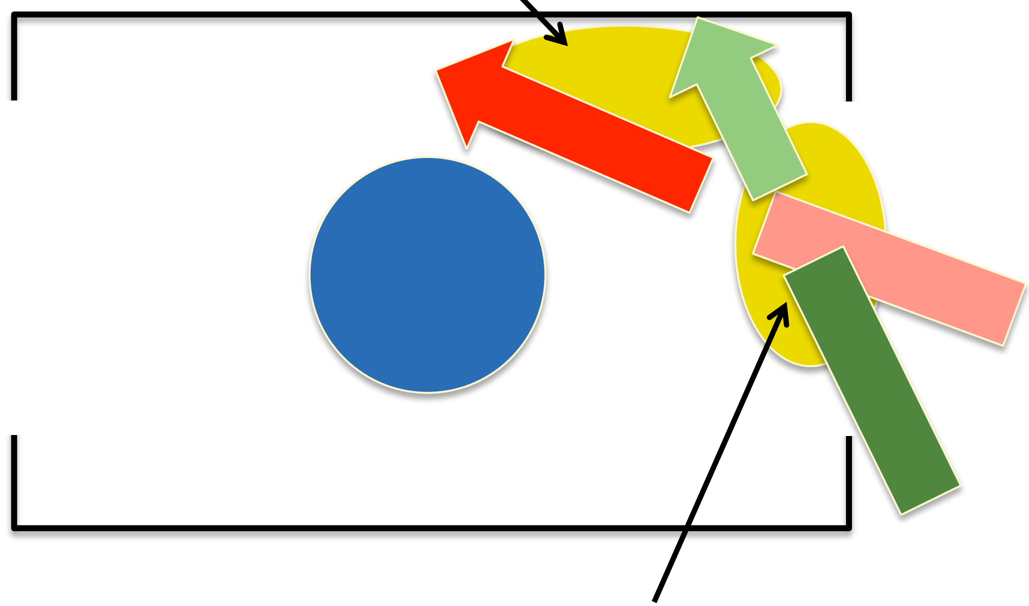


$\Delta\lambda = 5Å$



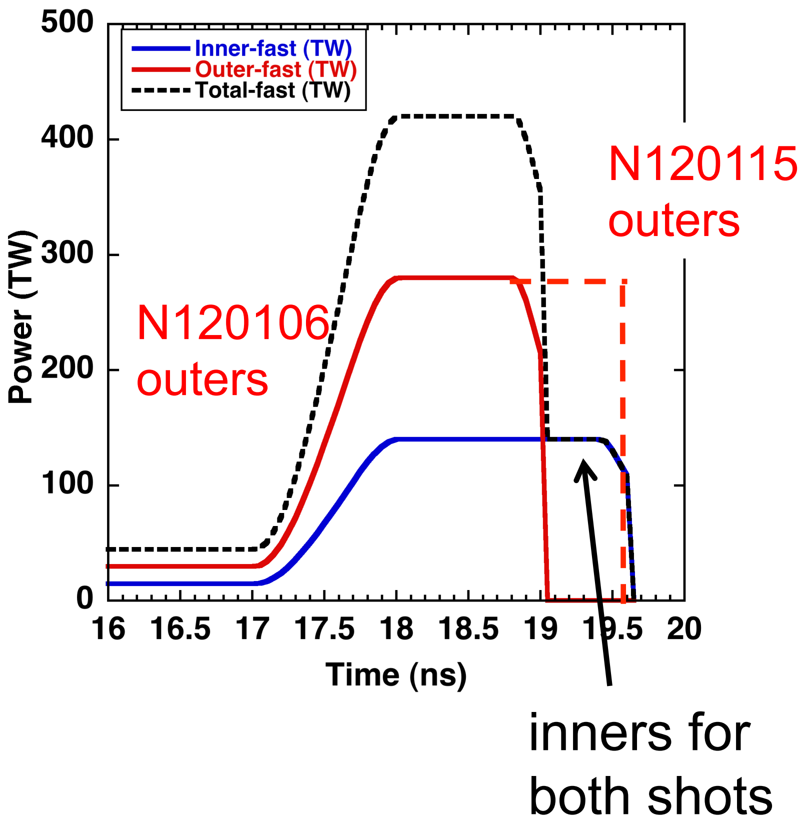
$\Delta\lambda = 1Å$

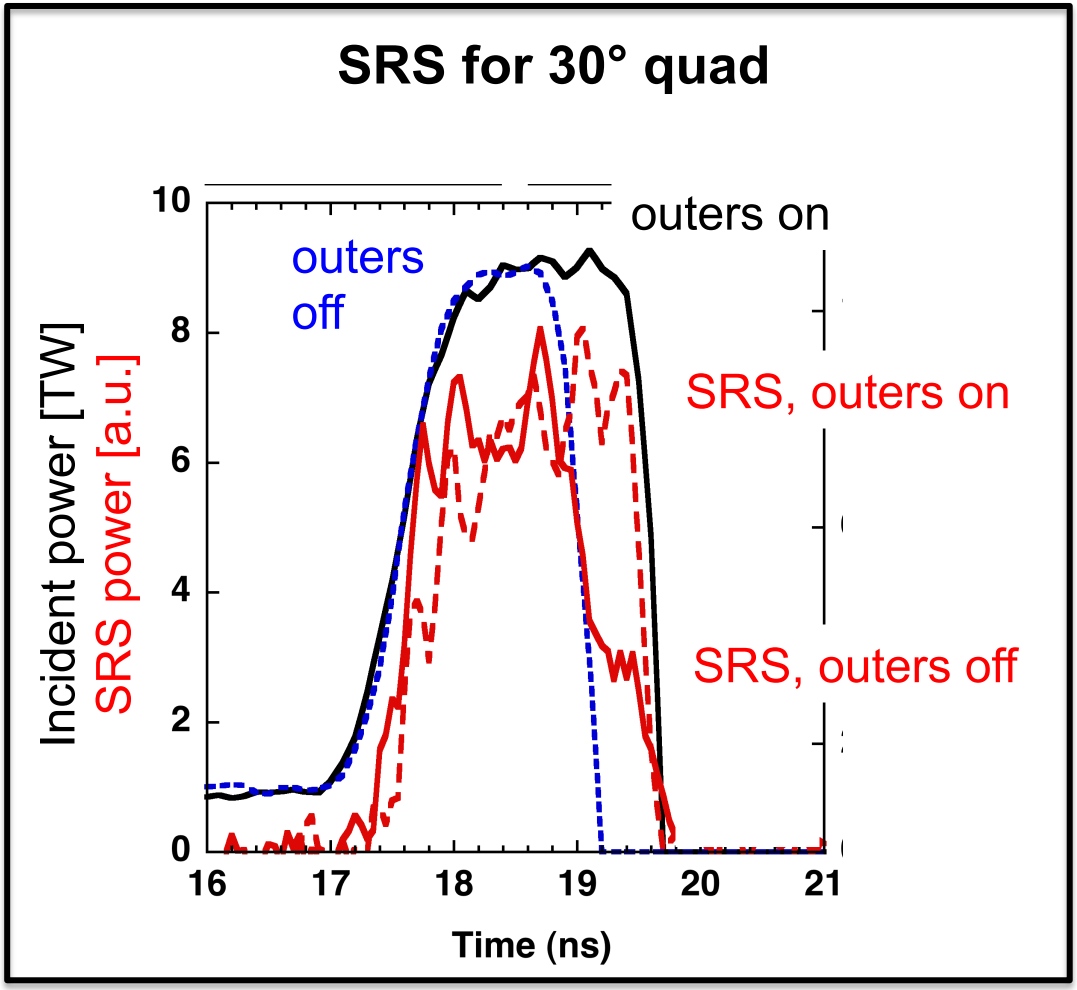
SRS, SBS develop after transfer



cross-beam energy transfer
inner wavelength > outer wavelength

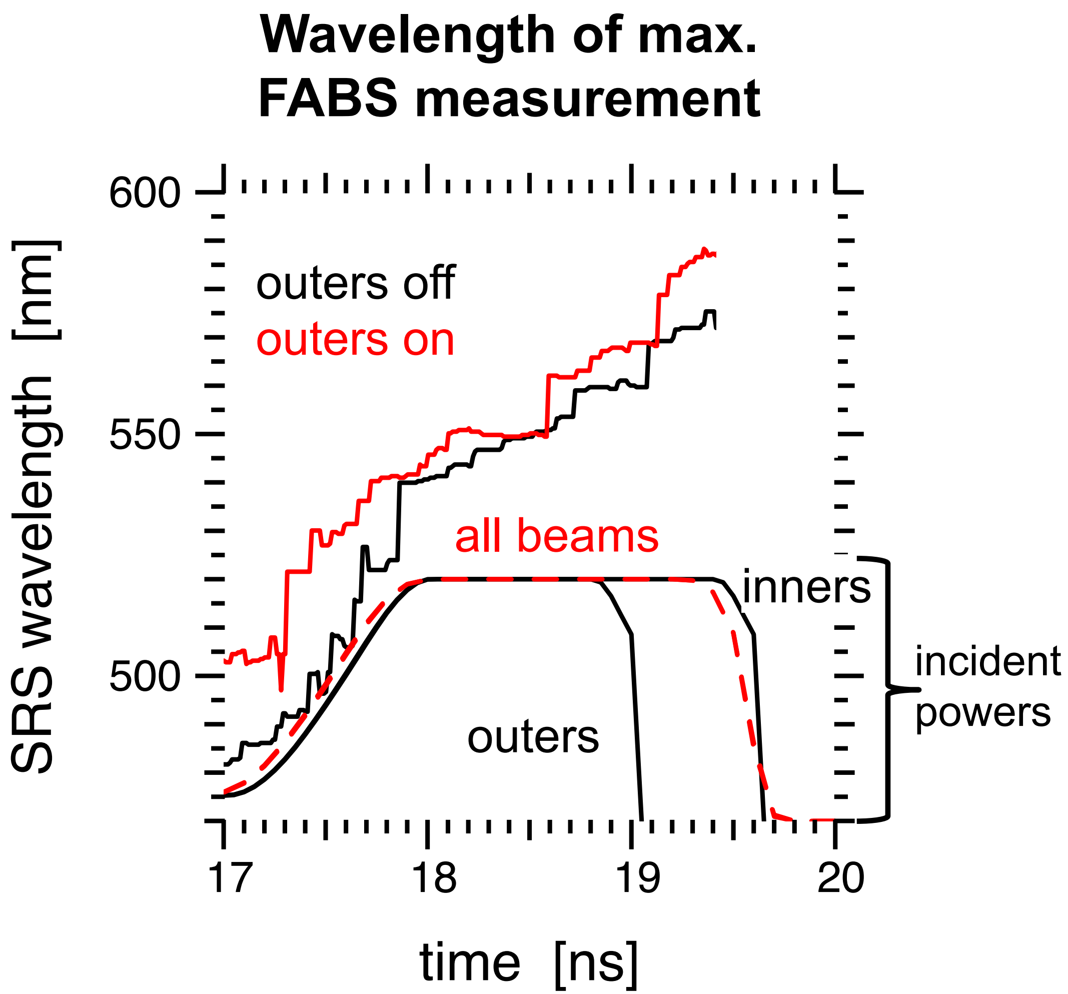
Inner beam SRS rises when outers turned on





P_{SRS} (outers off) = $0.28*P_{inc}$ = $0.4*P_{SRS}$ (outers on)

SRS spectrum on 30° beam similar with or without outers



Indicates plasma conditions are similar when outers turned off

Assuming constant reflectivity, inner-beam SRS is too large to be explained by transfer needed for symmetry

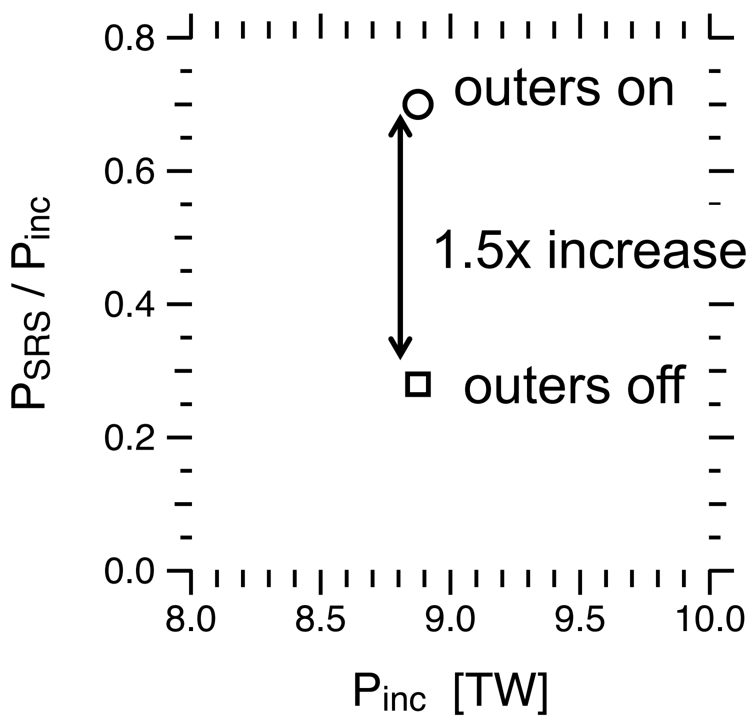
black = measured   red = inferred

$$P_{post} = P_{inc} * (1 + f_{in})$$

$$P_{SRS} = P_{post} * R(P_{post})$$

f_{in} = fractional increase of inner-beam power

- P_{SRS} with outer beams increases by 1.5x
- To get that with constant reflectivity requires $f_{in} = 1.5$
- That's > 2x the $f_{in} = 0.7$ from symmetry data

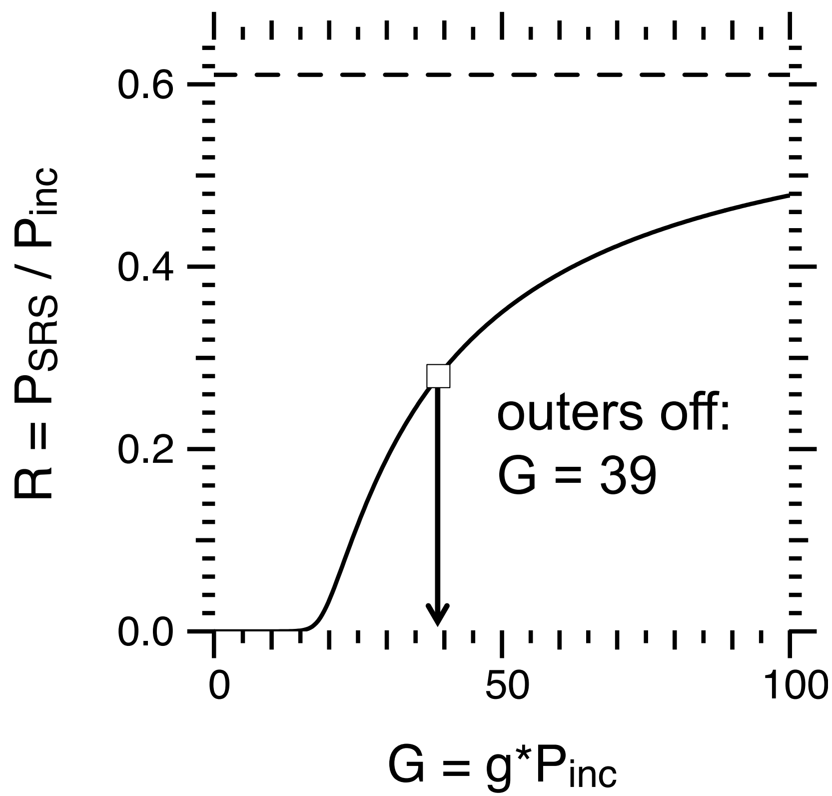


∴ Inner SRS reflectivity must increase w/ post-transfer power

Tang model of backscatter for inner-beam SRS

1. Single-beam gain set by expt. w/ outers off
2. Find transfer that gives measured P_{SRS} when outers on

Single-beam experiment



Tang formula with pump depletion

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

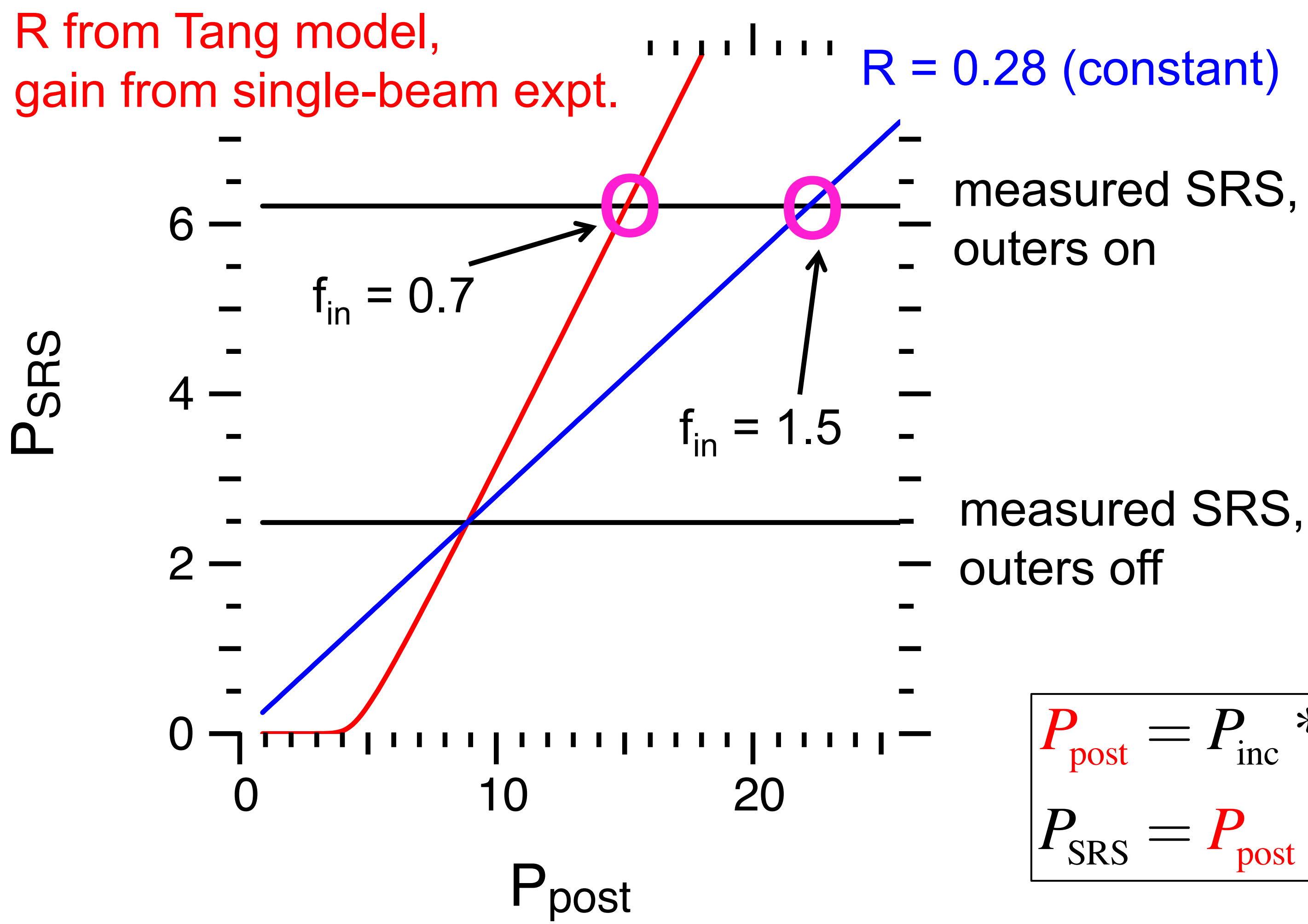
$$R=\frac{P_{BS}}{P_{post}} \qquad \tilde{R}=\frac{\omega_0}{\omega_1}R$$

$$\tilde{s}=\frac{\omega_0}{\omega_1}\frac{P_{seed}}{P_{post}}\sim 10^{-9}$$

$$G=g\bullet P_{post}$$

P_{inc} (measured) and P_{SRS} (measured) → g (inferred from Tang)

Tang model allows us to numerically solve for transfer that gives measured inner-beam SRS

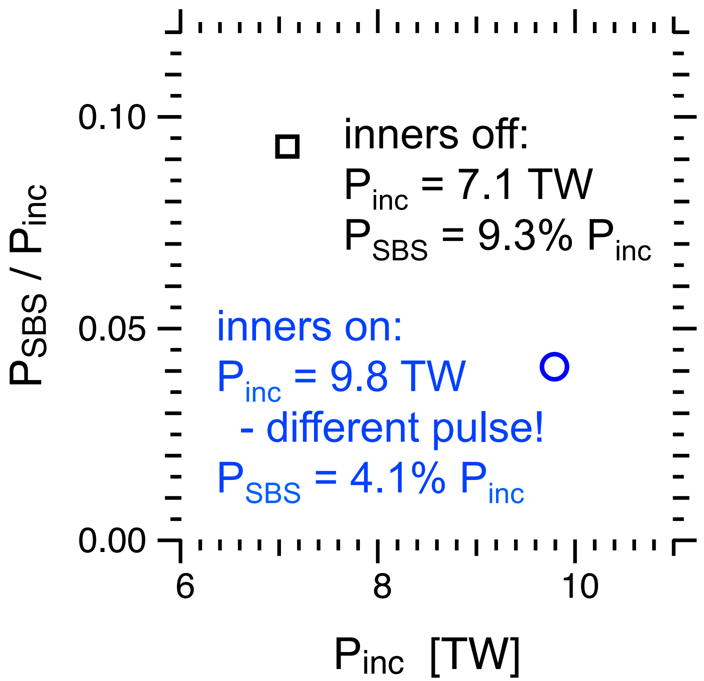


$$P_{post} = P_{inc} * (1 + f_{in})$$

$$P_{SRS} = P_{post} * R(P_{post})$$

Assuming Tang reflectivity, the SRS data give f_{in} = 0.7 – agrees with symmetry!

Outer-beam SBS increases significantly when inner beams turned off – no transfer to inners



$$P_{post} = P_{inc} * (1 + f_{in} / 2)$$

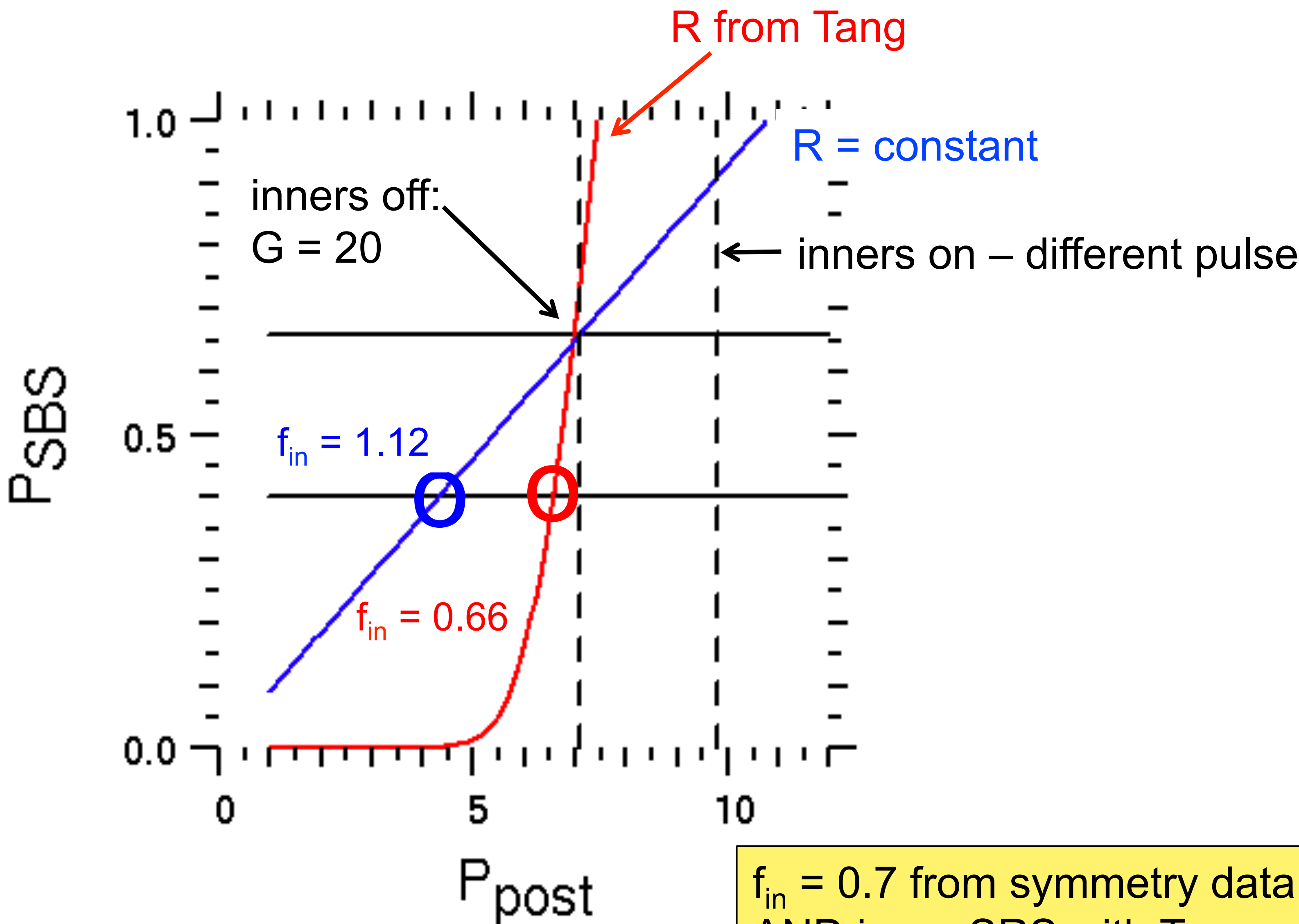
$$P_{SBS} = P_{post} * R(P_{post})$$

black = measured   blue = inferred

- P_{SBS} decreased by 0.61x when P_{inc} increased by 1.38x and inners turned on
  - Impossible without transfer to inners
- To get that with constant reflectivity requires f_{in} = 1.12
- Exceeds the f_{in} = 0.7 from symmetry data

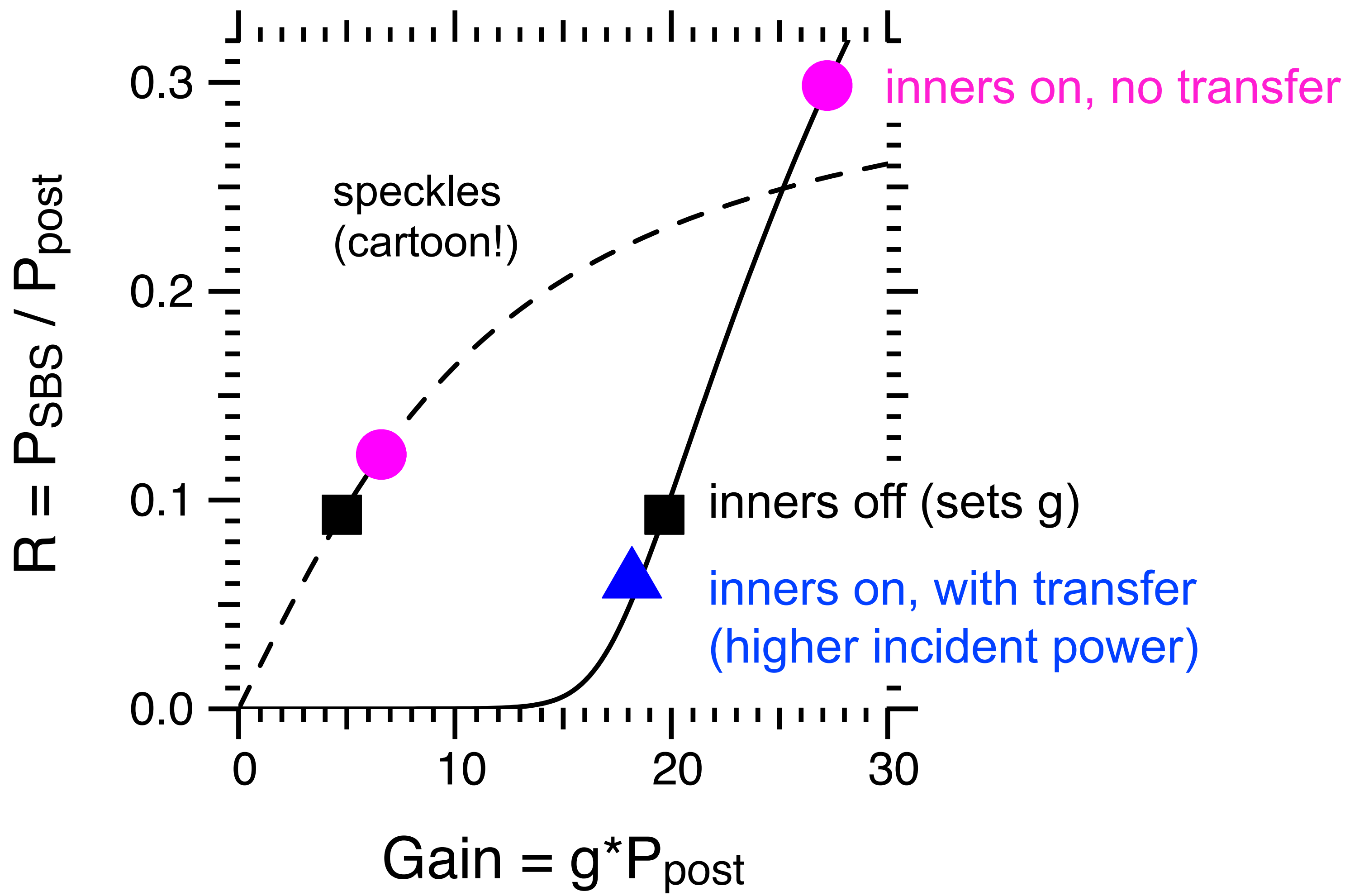
∴ Outer SBS reflectivity must increase w/ post-transfer power

Tang model for outer-beam SBS gives transfer consistent with symmetry AND inner-SRS result!



f_{in} = 0.7 from symmetry data AND inner-SRS with Tang

Tang model predicts strong power scaling of outer-beam SBS, speckles mitigate this



- Speckles reduce predicted increase: Tang curve, less steep, smaller gain
- We think outer-beam SBS comes from gold, can be reduced by adding boron

Tang model with gain from single-quad experiments gives transfer consistent w/ symmetry

$$P_{BS} = P_{post} * R(P_{post}) \qquad P_{post}^{in} = P_{inc}^{in} * (1 + f_{in}) \qquad P_{post}^{out} = P_{inc}^{out} * (1 - f_{in} / 2)$$

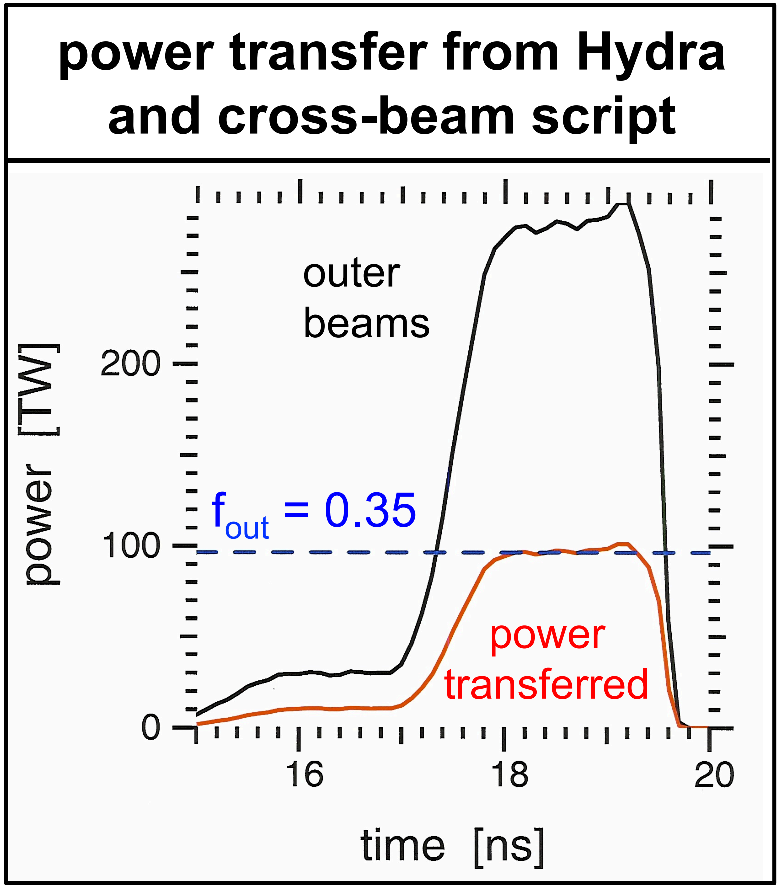
Symmetry data: f_{in} = 0.7

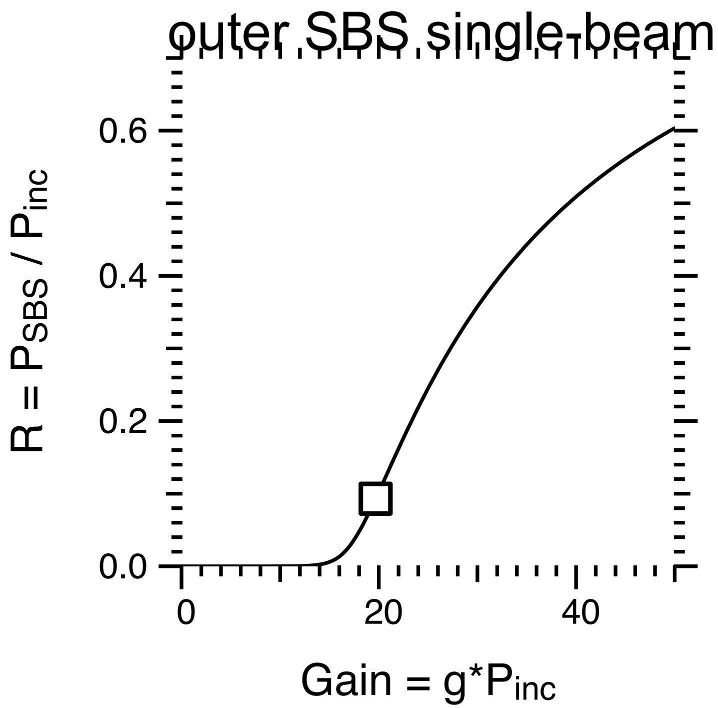
30° beam SRS	f_{in}	
hard saturation	1.5	too much transfer for symmetry
Tang model	0.7	predicts transfer that matches symmetry!

50° beam SBS	f_{in}	
hard saturation	1.12	too much transfer for symmetry
Tang model	0.66	matches symmetry AND inner-SRS Tang!

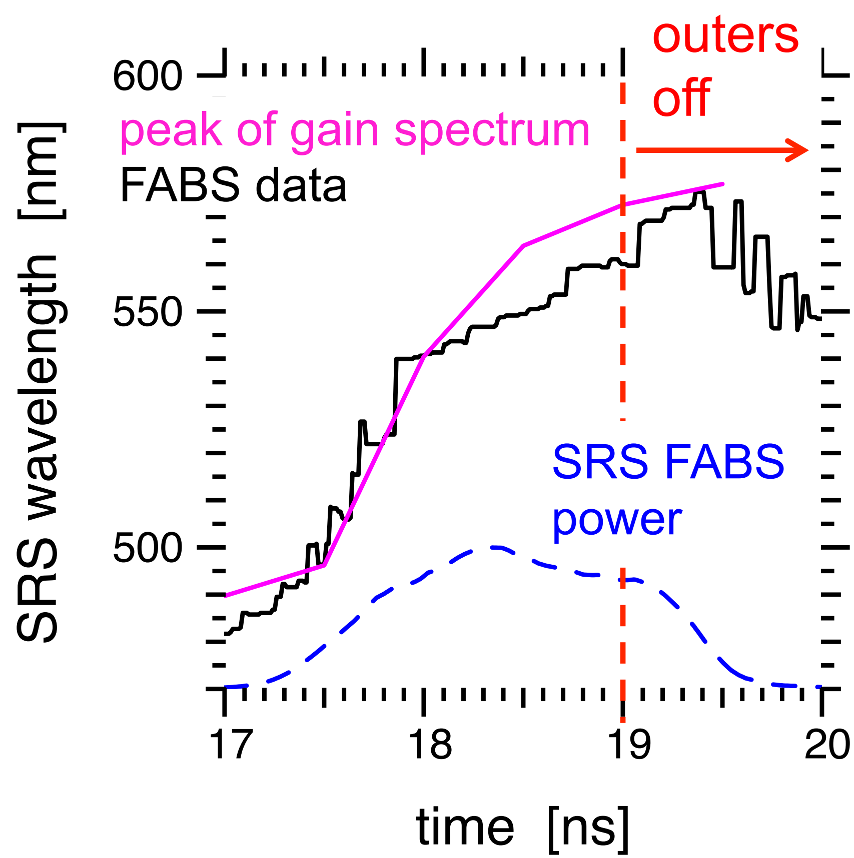
Outer-beam SBS in steeply-rising part of Tang curve – unlike inner SRS
Single-beam gains: outer SBS = 20 inner SRS = 39

BACKUP


power transfer from Hydra
and cross-beam script
outer
beams
power [TW]
200
100
0
f_{out} = 0.35
power
transferred
16
18
20
time [ns]



Shot with outers off



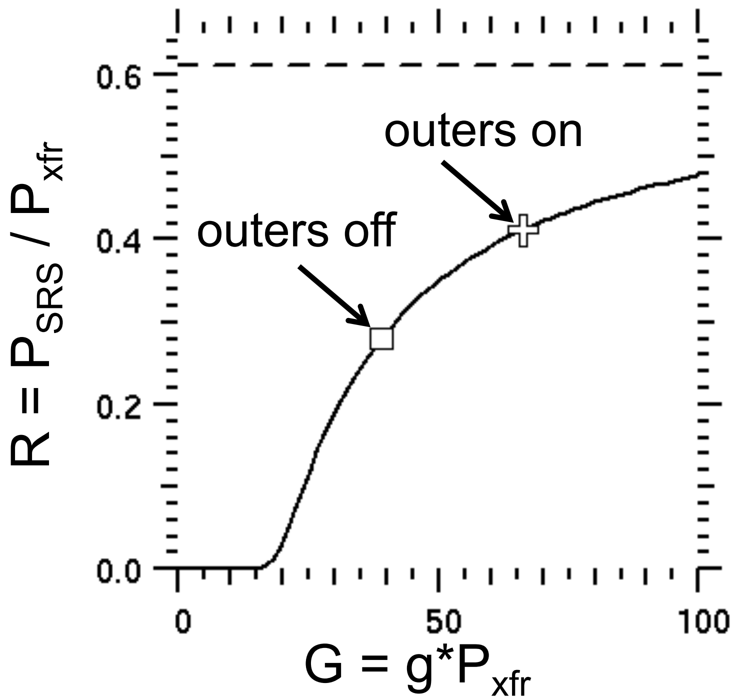
Tang model gives 30° beam SRS in fairly saturated regime

Procedure:

1. Single-beam gain set by expt. w/outers truncated
2. Solve for F_{xfr} to give measured P_{SRS} when outers on

$$P_{SRS} = P_{xfr} \bullet R(P_{xfr})$$

$$P_{xfr} = P_{inc} \bullet F_{xfr}$$



$$\frac{P_{SRS}(\text{outers on})}{P_{SRS}(\text{outers off})} = 2.5 \qquad \text{measured}$$

$$= F_{xfr} \bullet \frac{R^{on}(P_{xfr})}{R^{off}}$$

$$= 2.5 * 1 \qquad \text{hard saturation}$$

$$= 1.7 * 1.47 \qquad \text{Tang model}$$

transfer (1.7) — reflectivity increase (1.47)

- Symmetry → F_{xfr} = 1.7 ↔ 35% outer power transferred ($P_{out}^{inc} = 2P_{in}^{inc}$)
- Hard saturation (R constant): F_{xfr} = 2.5 - too big for symmetry
- Tang saturation (R varies w/ P_{xfr}): F_{xfr} = 1.7, agrees w/ symmetry!

Modest re-amplification of inner SRS by outers consistent with symmetry and constant reflectivity

hard saturation: R = constant
maximize transfer and re-amp.

$$P_{SRS} = P_{inc} \bullet F_{xfr} \bullet R \bullet \exp[G_{re-amp}]$$