# Optical Thomson Scattering: Background and Blanking

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This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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# Optical Thomson Scattering (OTS) team

- OTS Working Group
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  - Responsible Scientist – Steven Ross
  - Responsible Individual – Philip Datte
  - Mechanical Design – Justin Galbraith/ Michael Vitalich
  - Electrical Design – Ben Hatch/Warren Massey/Gene Vergel de Dios/Ray Iaea
  - Optical Design – Stacie Manuel/Bill Molander
  - Software – Kelly Burns/Barry Fishler
  - Additional Support – Steven Yang/Mike Rayce

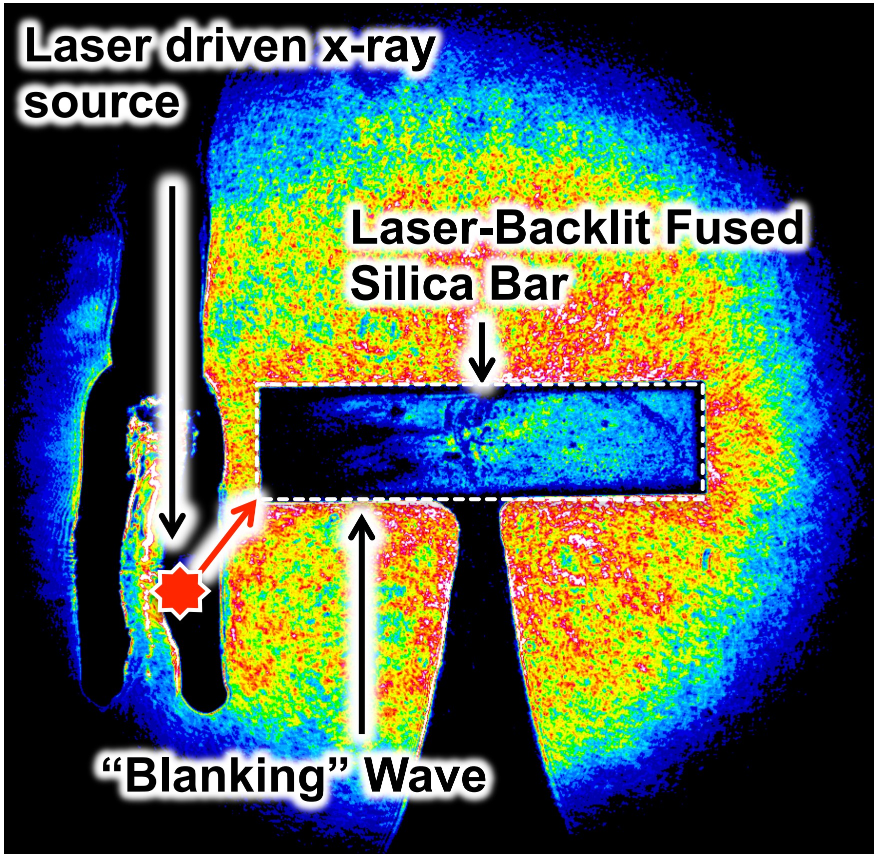
# Overview

## Background noise assessment:

- Quantify plasma **emission**:
  - Bremsstrahlung self-emission
  - Thomson scattering of the 3ω drive beams
- Quantify **optical collection** of self emission:
  - How much of the emitted radiation is transported to the spectrometer

## “Blanking” assessment:

- **X-ray flux** can cause the blast-window to become opaque or **“Blank”**
- Need to **quantify** blanking:
  - how much radiation is seen?
  - how much flux can window tolerate?
  - Can we shield?



# Background Noise Assessment

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# Background Assessment – Mathematical Framework

- Plasma is characterized by **Spectral Intensity** $I_{e,\Omega,\lambda}$. This is defined in terms of the radiant flux density $\Phi_e$.
  - **Power** per unit **volume** ($V$), **solid angle** ($\Omega$) and **wavelength** ($\lambda$)

$$I_{e,\Omega,\lambda} = \frac{\partial^2 \Phi_e}{\partial\Omega\partial\lambda}$$

- Optical emission from the plasma can be estimated based on **bremsstrahlung**:

$$I_{B,\Omega,\lambda} = \frac{2.09\times10^{-36} g Z^2}{4\pi}\left(\frac{n_e n_i}{\lambda^2 T_e^{1/2}}\right) e^{\frac{-1.24\times10^{-4}}{\lambda T_e}}$$

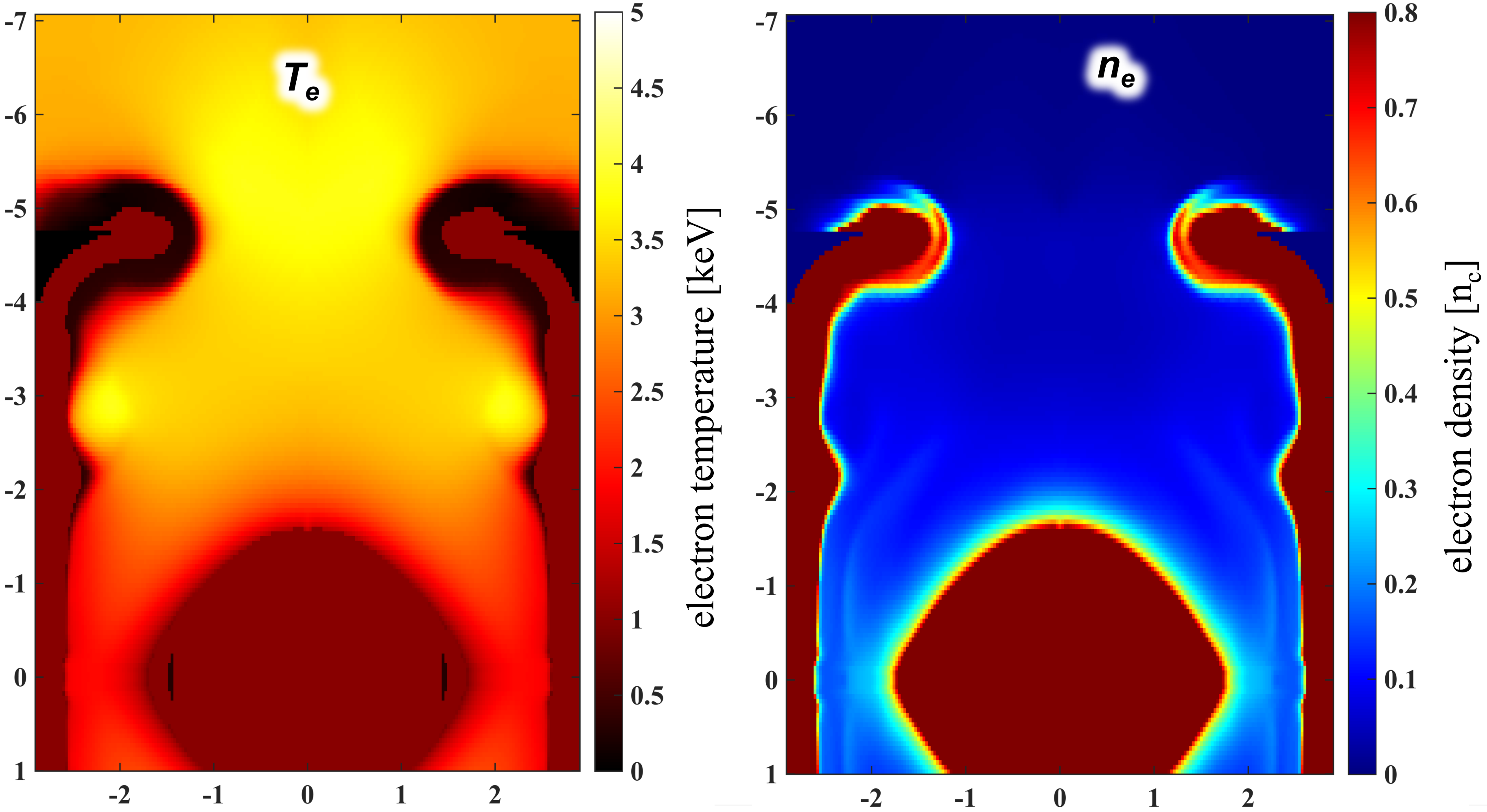
*Sheffield et al. (2010) - Plasma Scattering of Electromagnetic Radiation*

- We also need to assess the contributions from the **Thomson scattered drive beams** – more complicated!

$$I_{e,\Omega,\lambda} = I_{B,\Omega,\lambda} + I_{D,\Omega,\lambda}$$

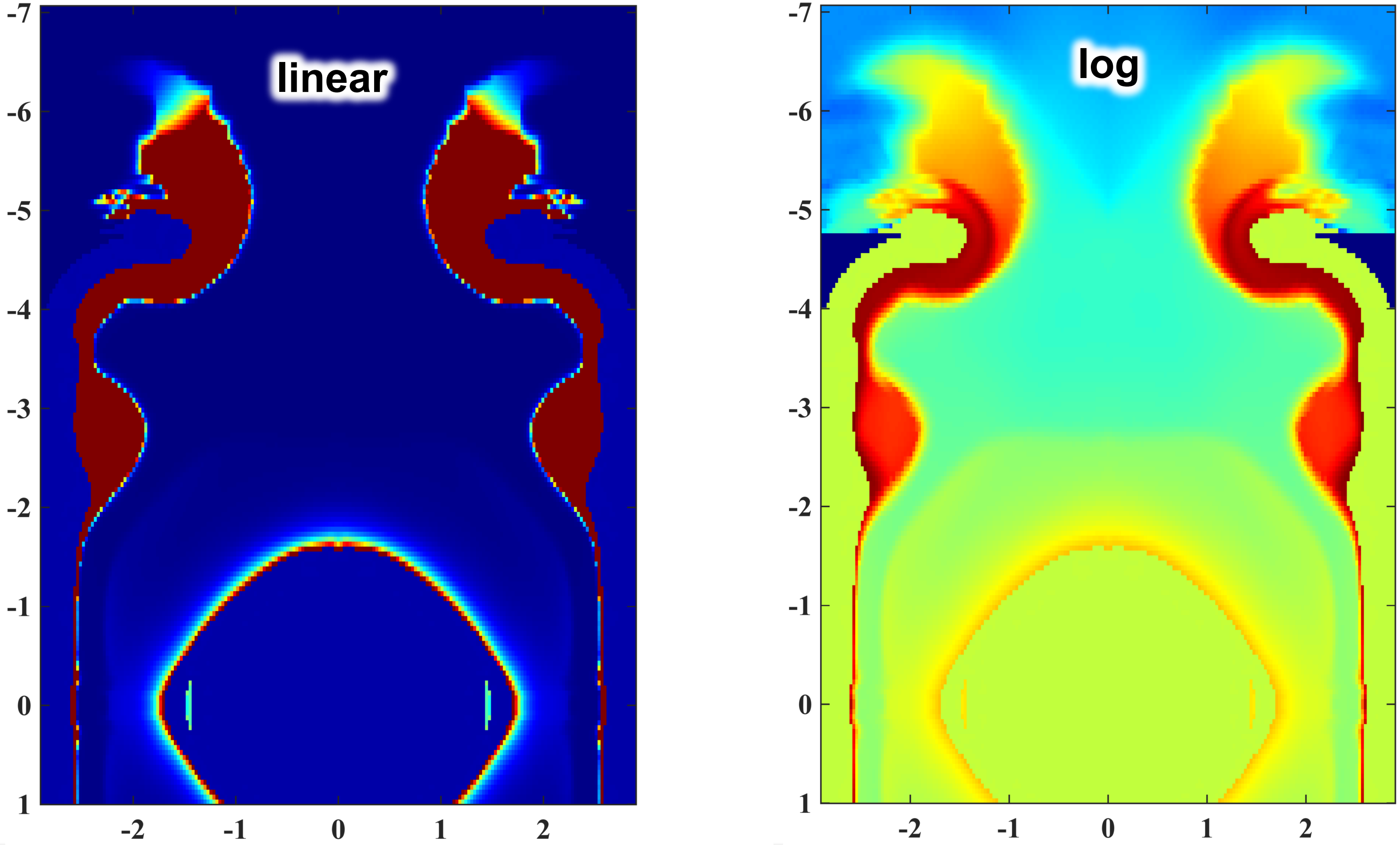
# Inverse Bremsstrahlung

Maps of **plasma conditions** obtained from simulation of a standard 4-shock hohlraum :



# Inverse bremsstrahlung

The **bremsstrahlung emission** map can then be calculated (log plot!):



# Thomson scattering of drive beams

- The calculation is **simplest** for collection **along the hohlraum axis**

- Each **Quad** is treated as a **single scattering geometry**

- the problem reduces to **4 scattering geometries**

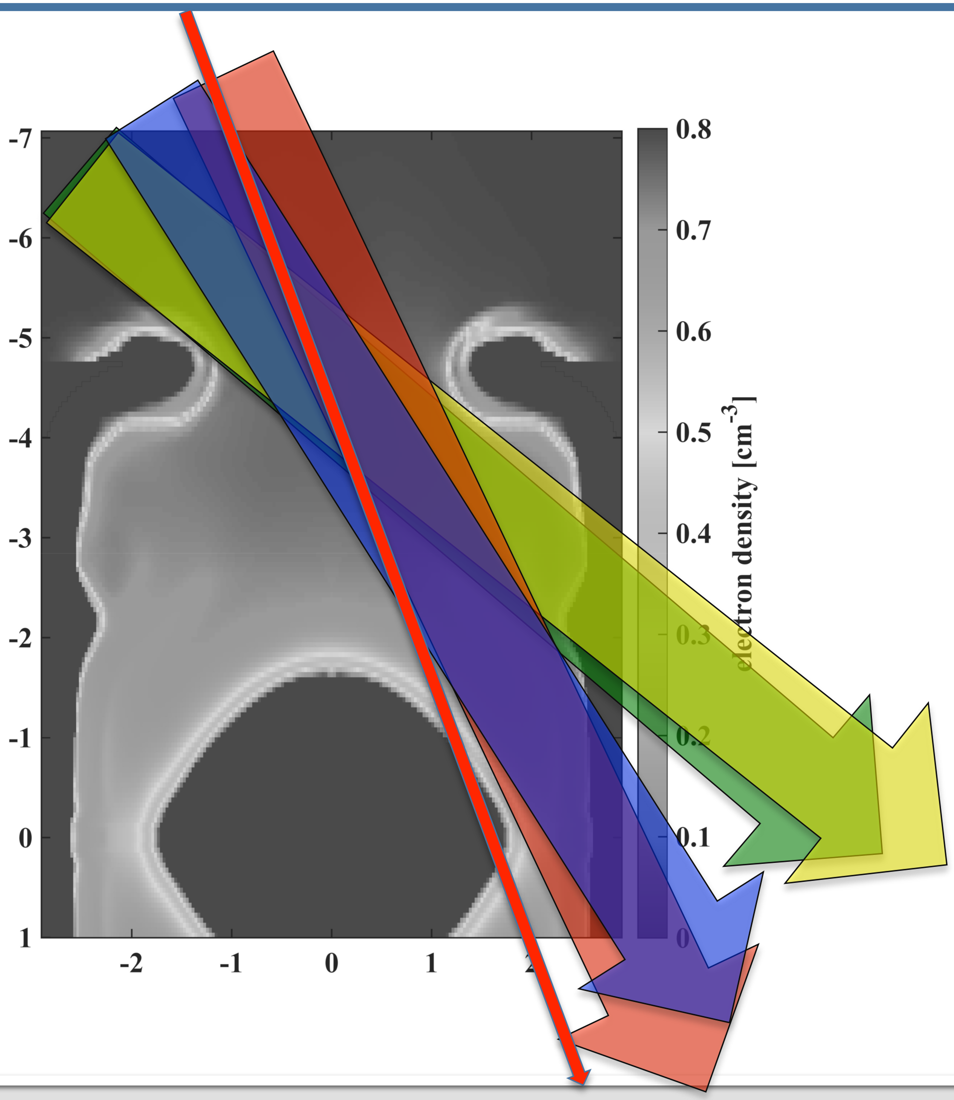
- Thomson scattering power is calculated using following equations:

$$I_{D,\Omega,\lambda} = \sum_{beams} \frac{P_i r_e^2 n_e}{2\pi}\left(1+\frac{2\omega}{\omega_i}\right) S(\omega,\vec{k}) \;;$$

$$\vec{k} = \vec{k}_s - \vec{k}_i; \quad \omega = \omega_s - \omega_i; \quad \omega_i = \frac{2\pi c}{\lambda_i}; \quad \omega_s = \frac{2\pi c}{\lambda}$$

$$S(\omega,k) = \frac{2\pi}{k}\left[\left|1-\frac{\chi_e}{\epsilon}\right|^2 f_{e0}(\omega,k) + \bar{Z}\left|\frac{\chi_e}{\epsilon}\right|^2 f_{i0}(\omega,k)\right]$$

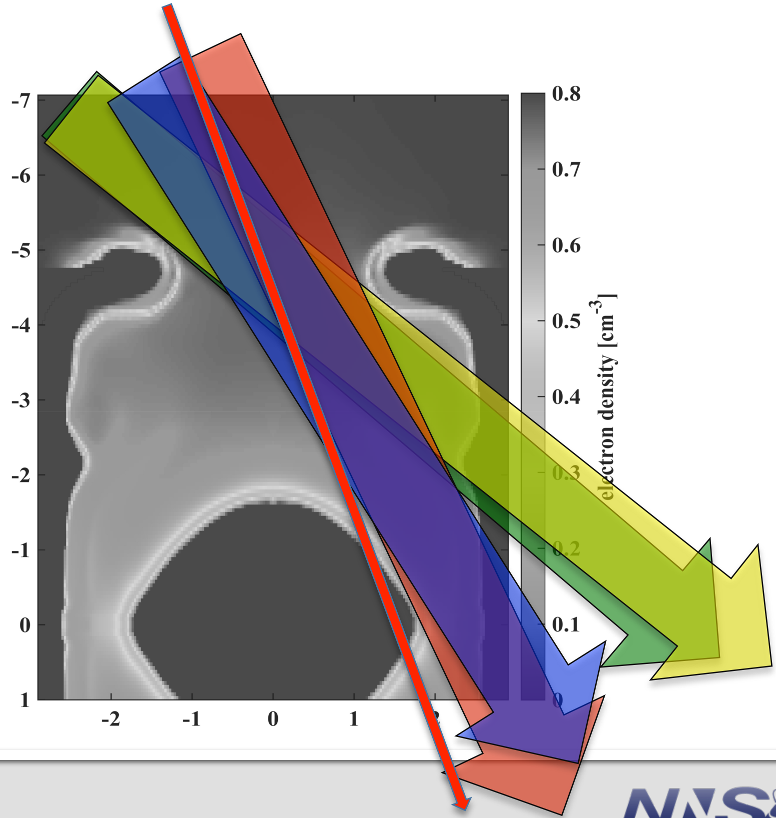
- Other collection geometries could be harder to model but not intractable.



# We can calculate:

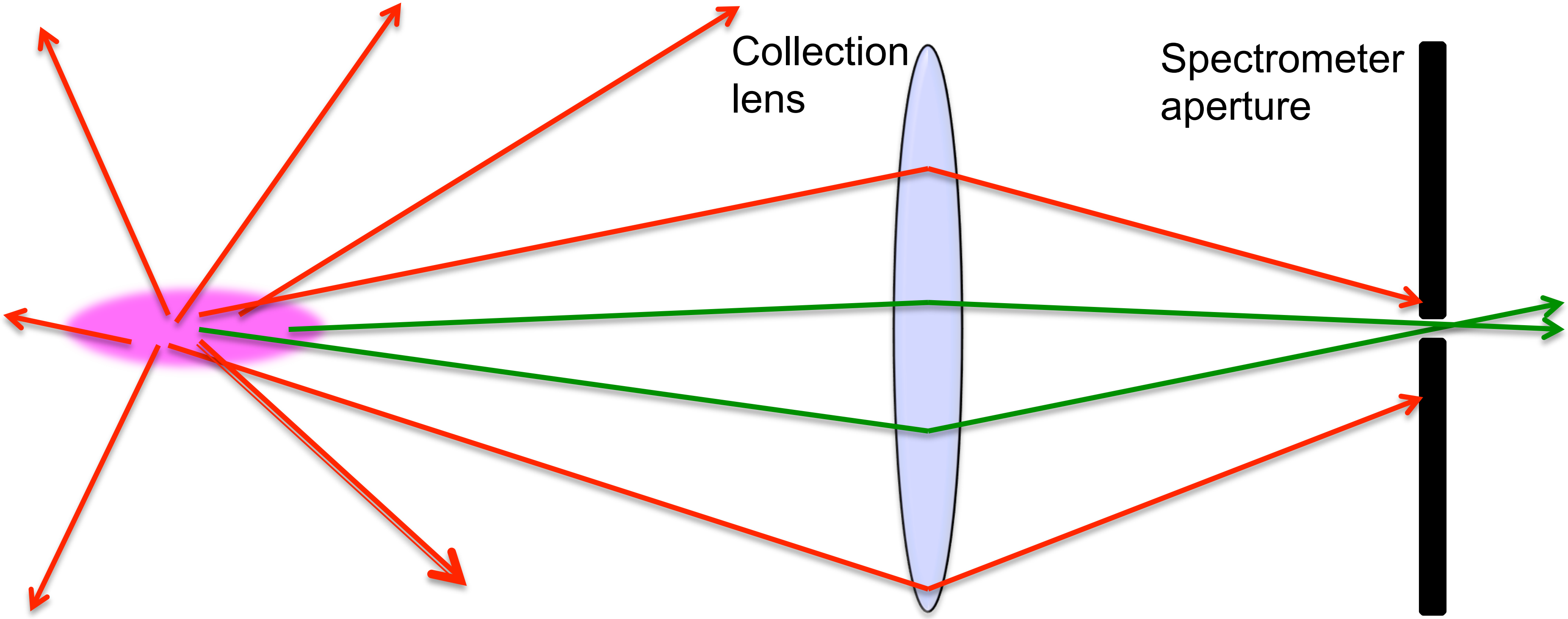
- Thomson **Spectral intensity** due to the **probe** beam: $I_{S,\Omega,\lambda}$
- Thomson **Spectral intensity** due to the **drive** beams: $I_{D,\Omega,\lambda}$
- Background **Bremsstrahlung** emission: $I_{B,\Omega,\lambda}$

But what does the spectrometer see?



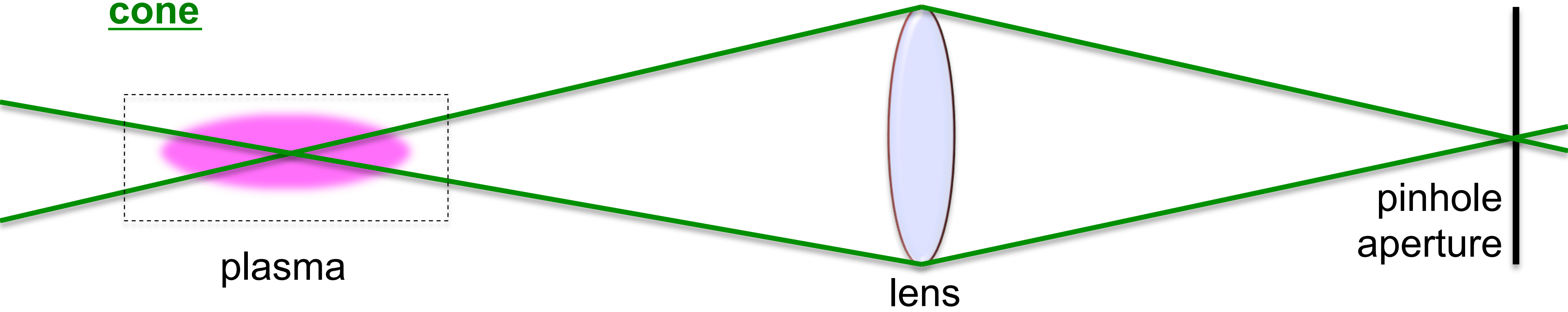
# Optical collection:

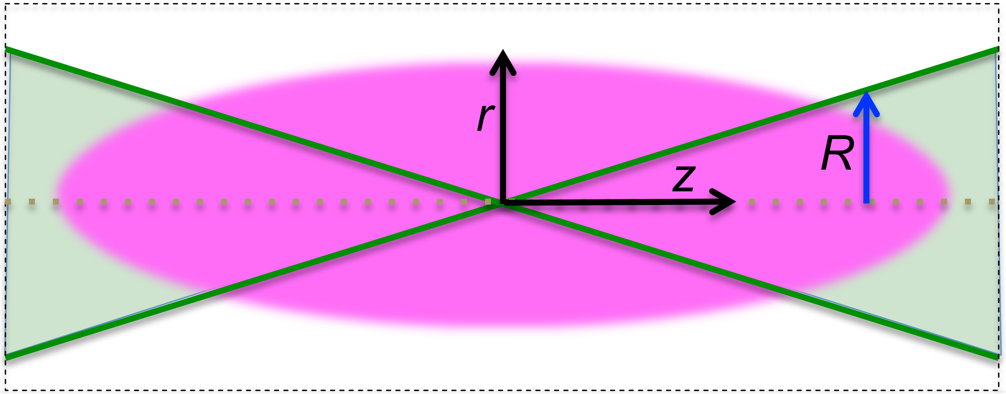
- Only **small fraction** of emitted or scattered radiation is **collected** by the **lens**
- Much of this is **discarded** by the **spectrometer aperture**
- These **spatial variations** in collection efficiency can be **quantified**



# Optical collection (simplified…):

- Simplification – for **lens aperture >> pinhole**
- The collection is treated by **limiting** range of **integrals** of $I_{e,\Omega,\lambda}$ over $dV$ and $d\Omega$
- **Lens + pinhole aperture** will only collects light from the **volume** within the **F-cone**





- The **radius** of the collection cone is:

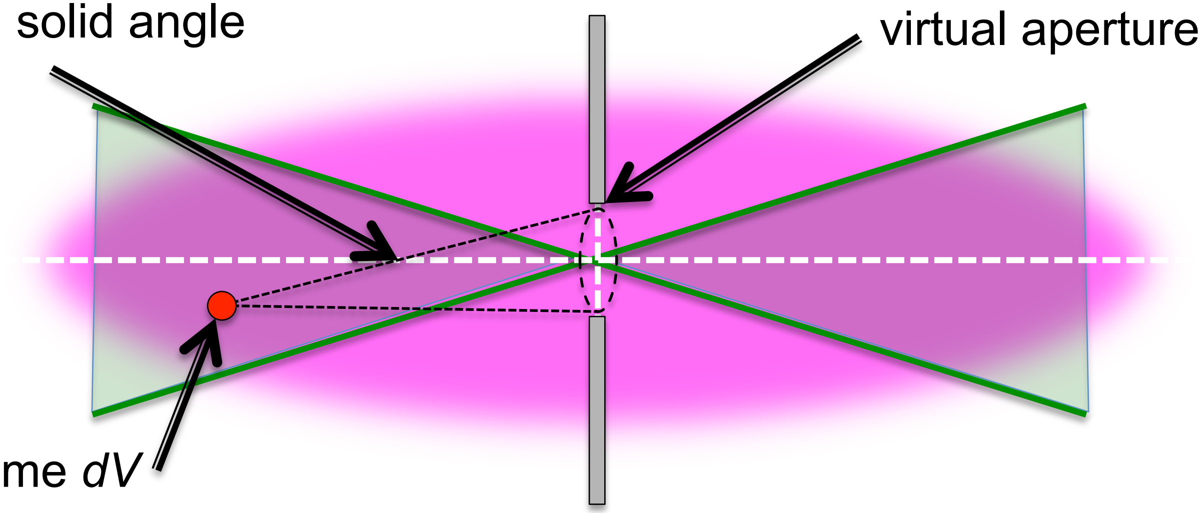
$$R = \frac{z}{2F}$$

- Used to **limit** the **volume** of emission **integration**

# Optical collection (simplified…):

- Within collection cone, the **pinhole limits** the **solid angle** of emission collected

- Project **Virtual Aperture** – the aperture imaged into the plasma:



accepted solid angle cone $\Omega_A$

virtual aperture area $A_f$

source volume $dV$

$$\int_{\Omega_A} d\Omega = \iint_{A_f} \frac{dA(r,z)}{(r^2+z^2)} \approx \frac{A_f}{z^2} \quad (z \gg r)$$

# Final calculations for background

- These limits are used to **calculate** the **power** delivered **through** the **aperture**:
- **Integrate** 3D emission map **over collection** to find the **power**, ***P_λ***

$$P_\lambda = \int_{V_c} \int_{\Omega_A} I_{e,\Omega,\lambda} d\Omega\, dV = 2\pi \int_{-\infty}^{\infty} \int_{0}^{\frac{z}{2F}} I_{e,\Omega,\lambda} \frac{A_f}{z^2} r dr\, dz$$

- **Assumption:** Plasma emission is function of ***z* only**:

$$P_\lambda = \frac{\pi A_f}{8F^2} \int_{-\infty}^{\infty} I_{e,\Omega,\lambda} dz$$

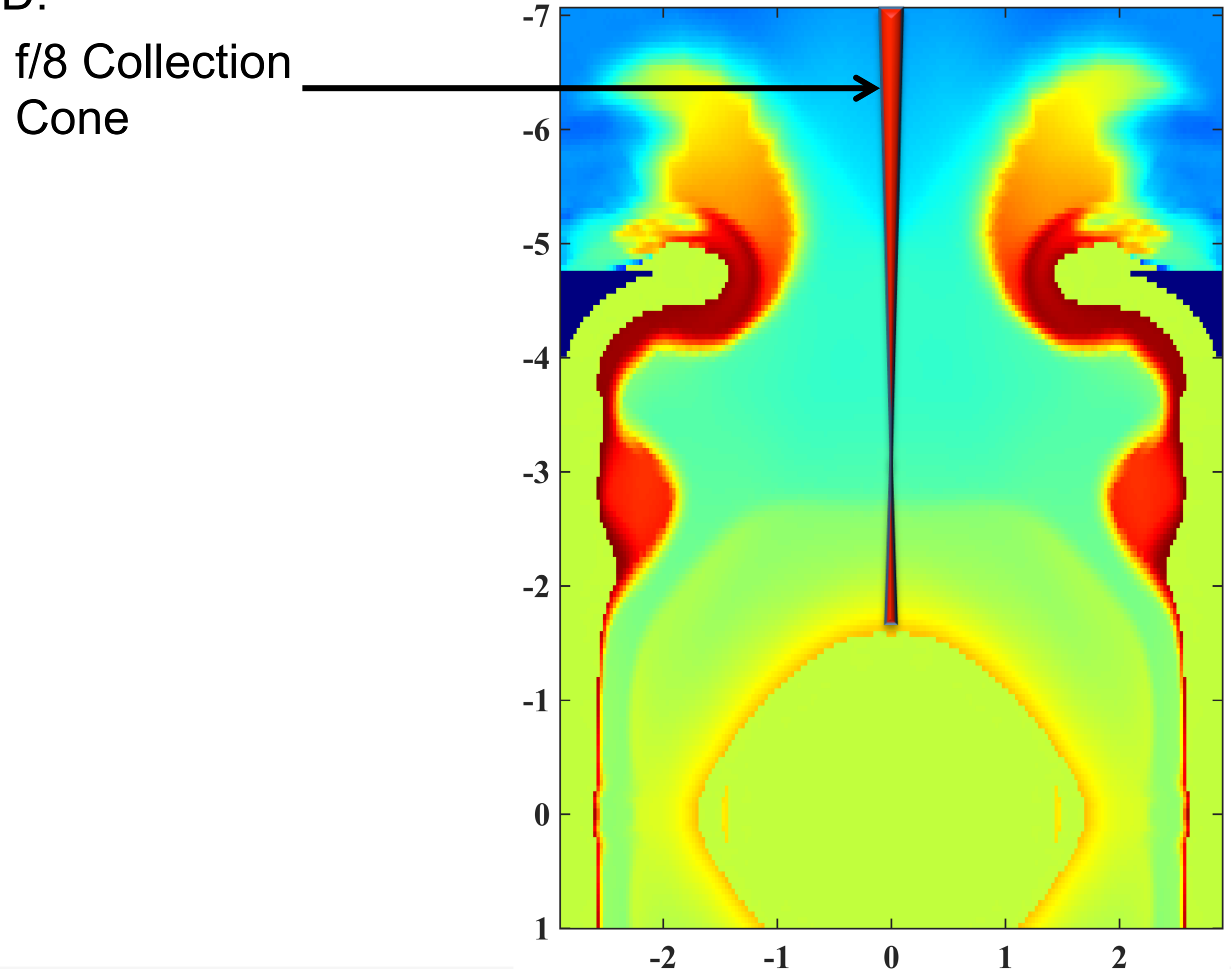
  - This assumption is pretty reasonable given that the collection system is f/8. Collection is thus only along a relatively narrow column

- **Assumption:** Plasma emission is **uniform** from plasma of **length *L***:

$$P_\lambda = \frac{\pi A_f L}{8F^2} I_{e,\Omega,\lambda}$$

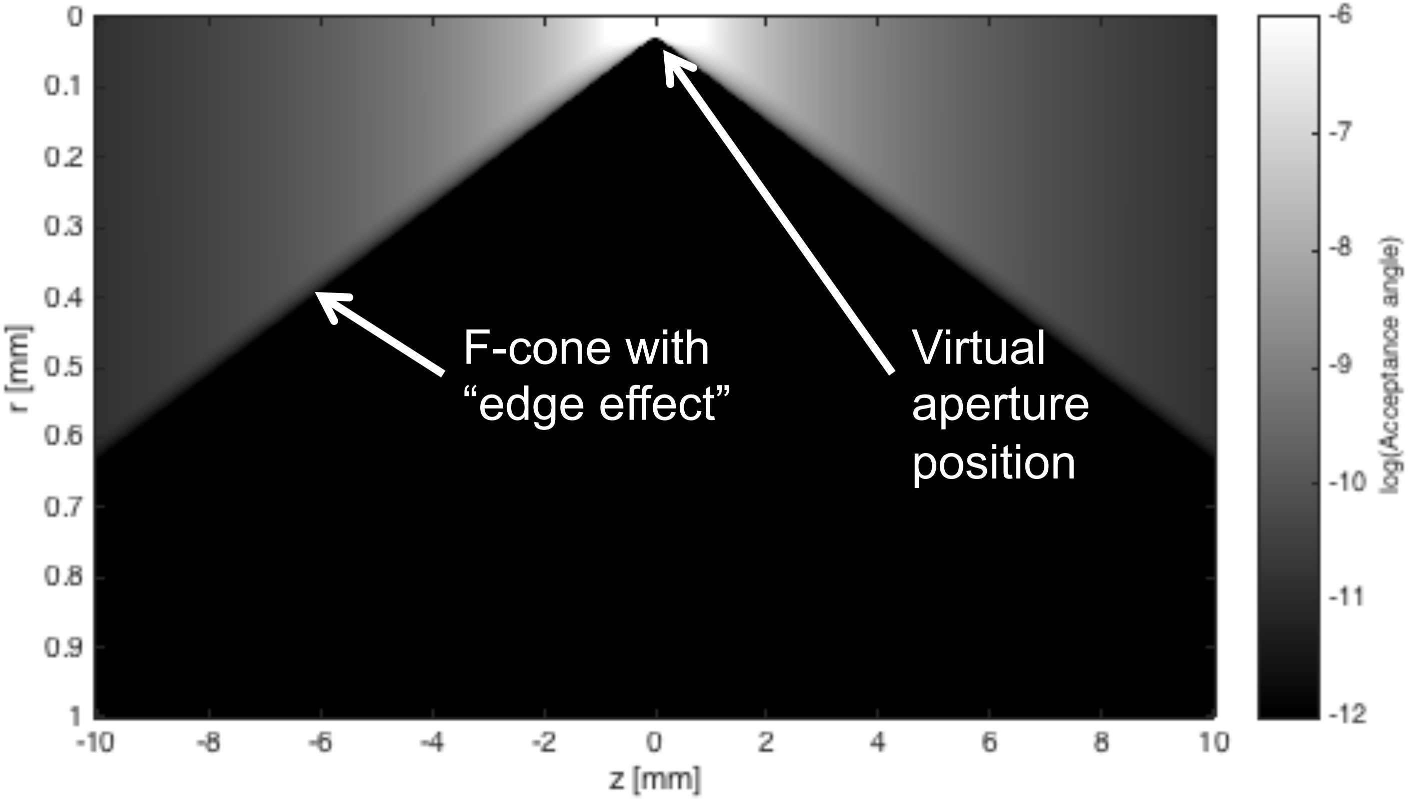
# Inverse bremsstrahlung

The **F-cone** is very narrow inside the Hohlraum – can be reasonably treated as 1D:



# More detailed calculations…

Virtual aperture point-projected onto the lens and overlap calculated



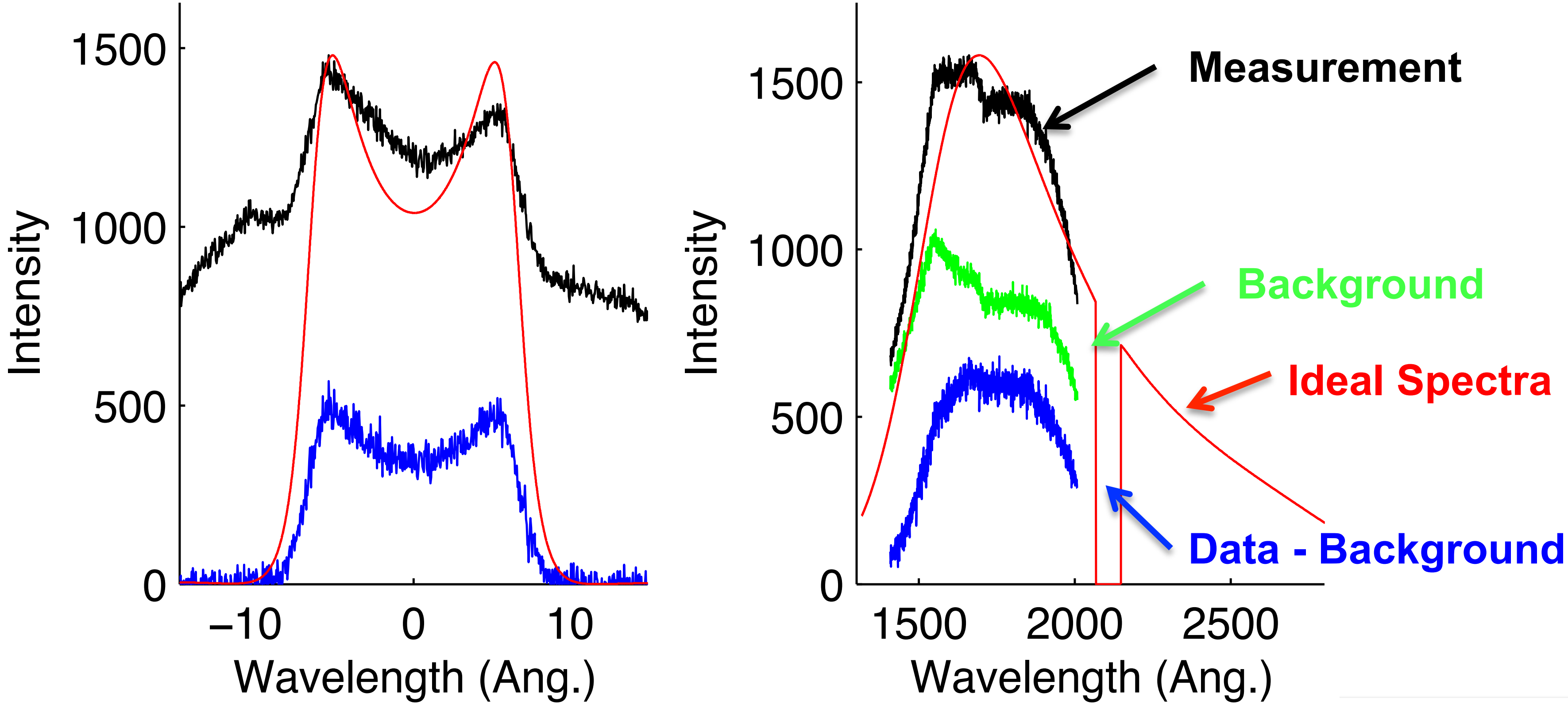
F-cone with “edge effect”

Virtual aperture position

- **Edge effects** occur over the **scale-size** of the **aperture**.
- These have **no effect** on the **“total collection”**

# Self Emission calculation results

- Self-emission background calculated from emission map shown earlier
- **Signal to background of 0.8** is expected for a **10 J** probe
- **Ion feature is resolvable** – especially if background is known
- **Electron feature** measurement is extremely **challenging** due to **shape sensitivity**



# Thomson Scattering of Drive calculation results

- **Nominal 10 J Probe**

- **Ion feature** should be easily **analyzable**

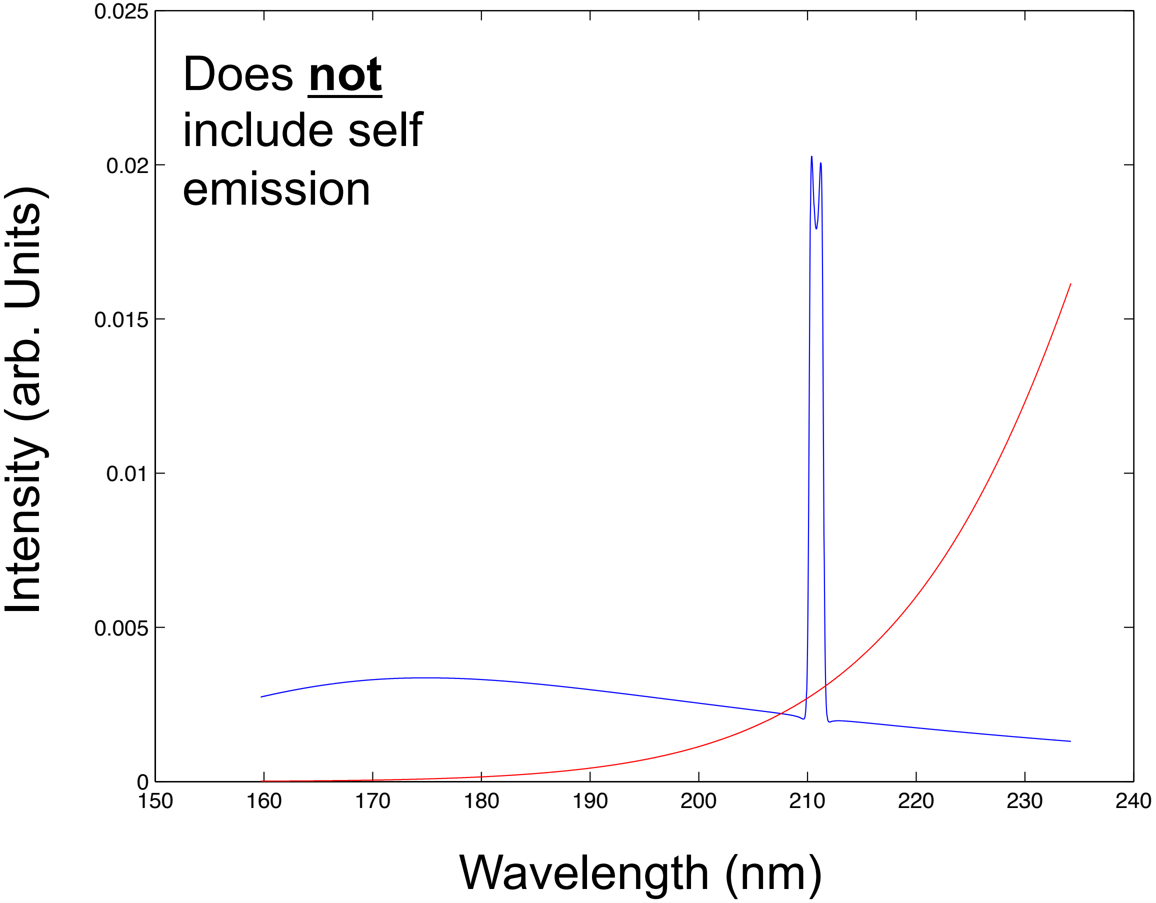
- **3ω** scattering can be **subtracted** either through **background shot** or **constrained calculation**

- **Background** on the **blue-side** of the **electron feature** should be reasonably **small**

- **Effect** looks much **smaller** than **self-emission**

5ω TS Signal

3ω TS Signal from drive beams



# X-ray Induced Blanking Assessment

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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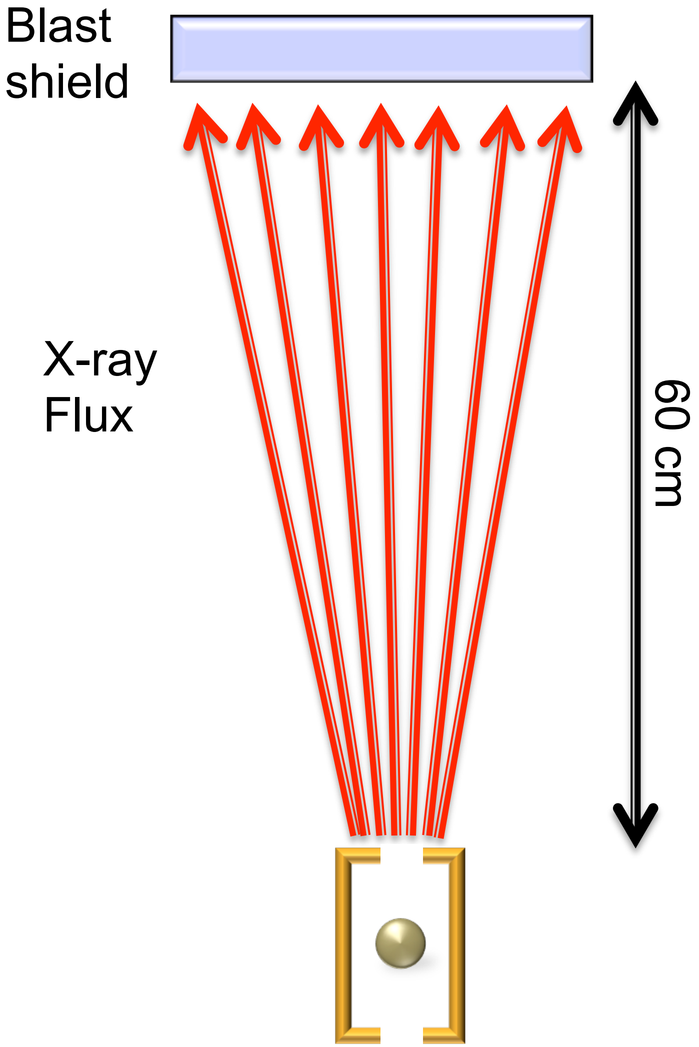
# Blanking Assessment: The Problem

- Optically **transparent materials become opaque** when subjected to sufficient radiation

- The limits of **acceptable** radiation **dose** are **poorly understood**

- We **need** to know:
  - **Dose limit** for glass before “blanking”
  - **Expected X-ray dose**

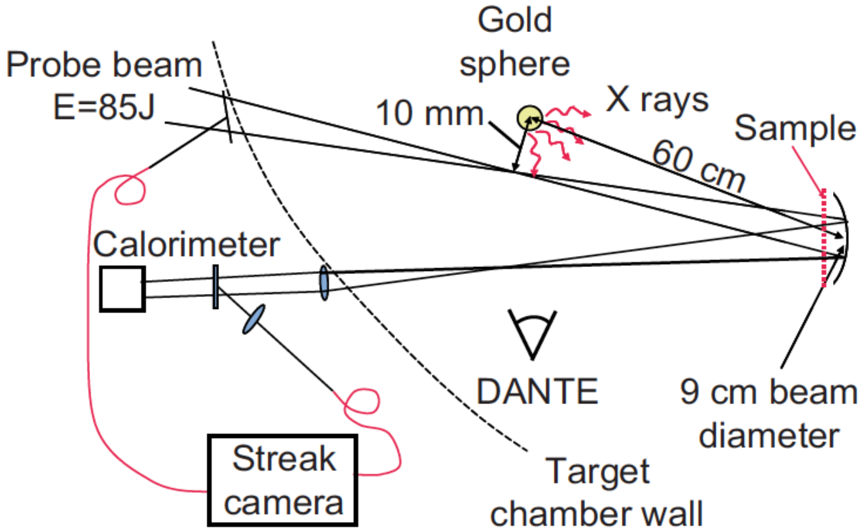
- **Experimental verification** that OTS will not blank before measurement is **essential**

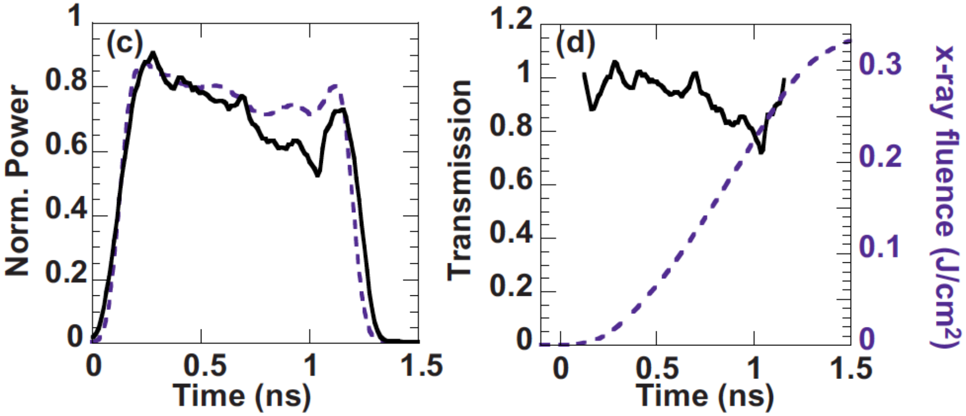


# Previous Blanking Measurement

*London et. al. Rev. Sci. Instrum. 79, 10F549*

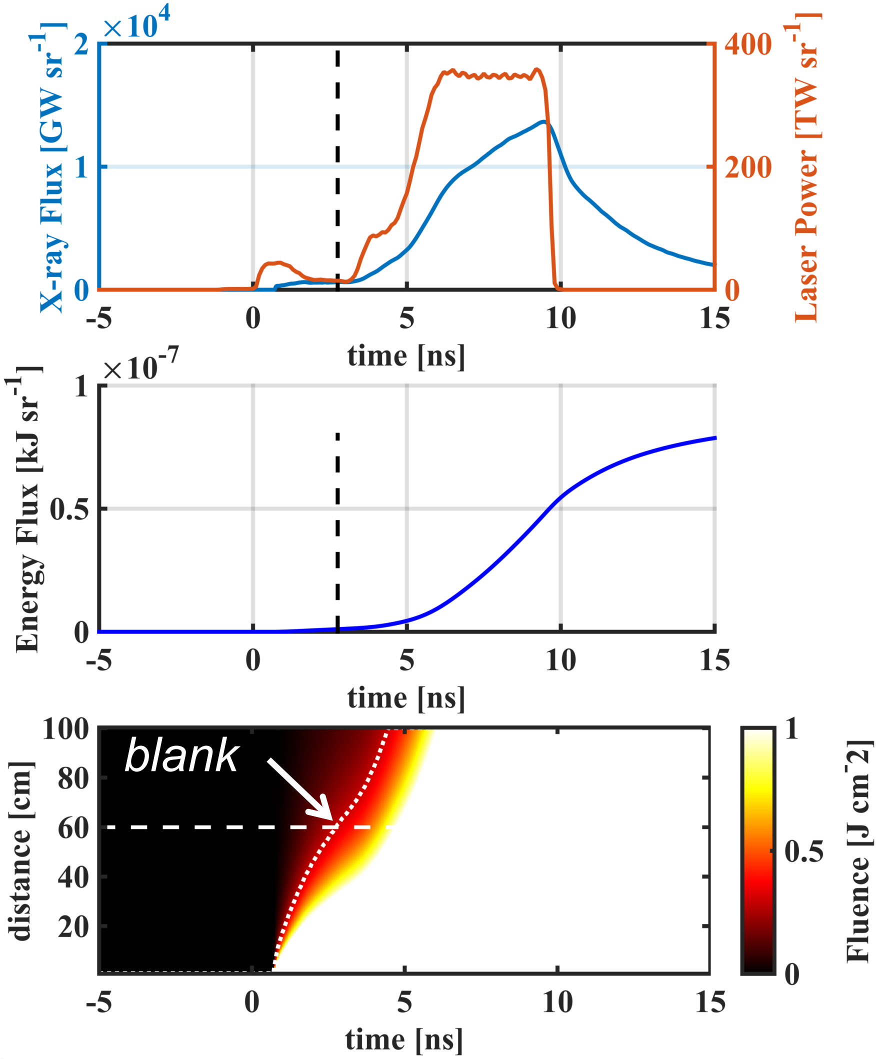
- Measurements of **fused silica transmission** under **x-ray** exposure at **OMEGA**
- X-rays produced by laser heating a **gold sphere**
- Results show ~ **80%** transmission at ~ **0.3 Jcm$^{-2}$** x-ray fluence





# Scaling to the NIF

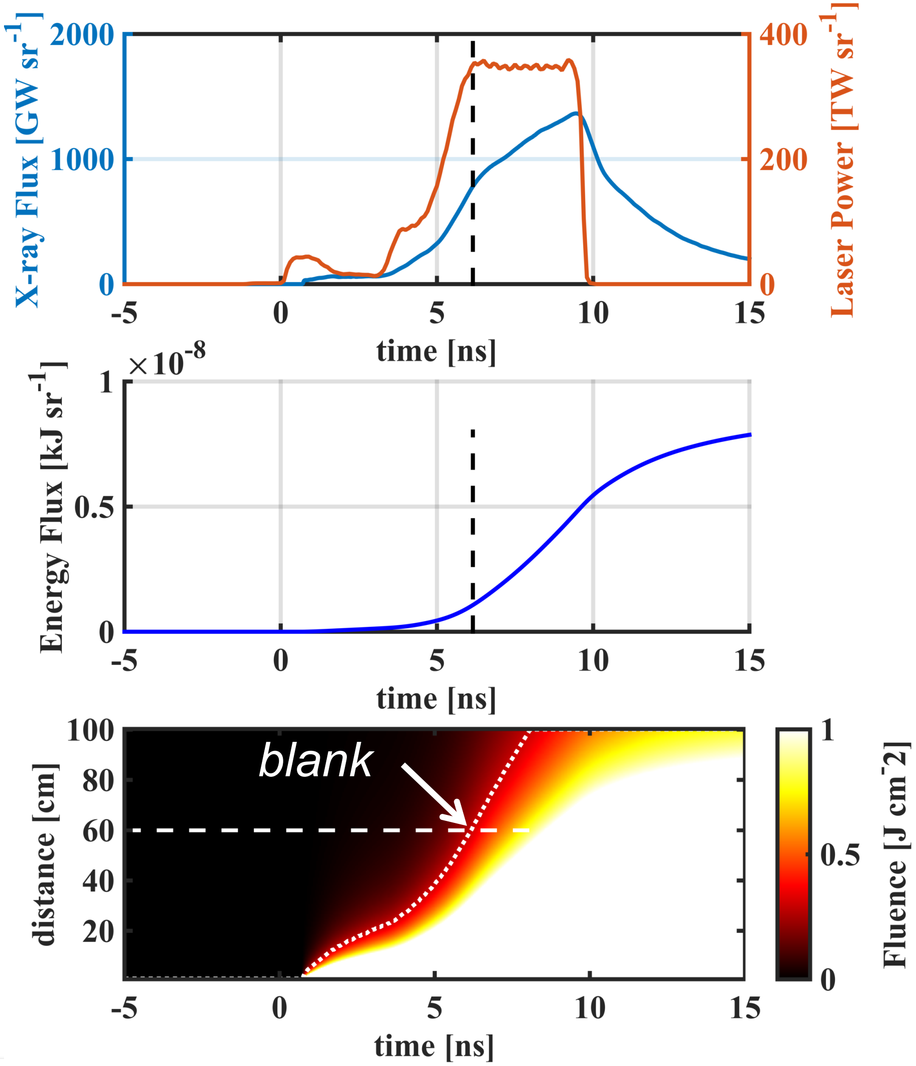
- Estimate based on a nominal hohlraum shot
- Worst Case Scenario
- Calculated from **X-ray flux** measured by **Dante**
- **Dose limit** for “blanking” (0.3 J cm$^{-2}$) reached at **2 ns** from drive-start
- Experiment wont work like this…



# Reduce flux by 10…

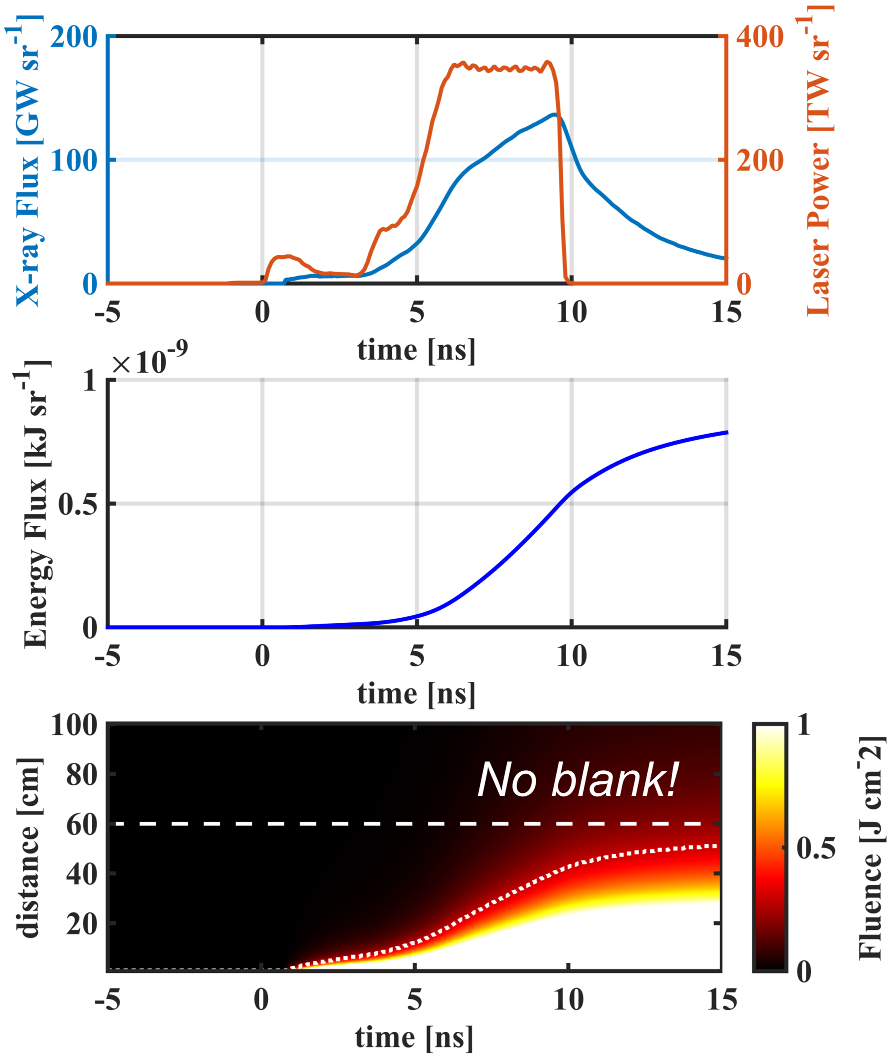
- Extends blanking time to start of main pulse

- Not good enough….



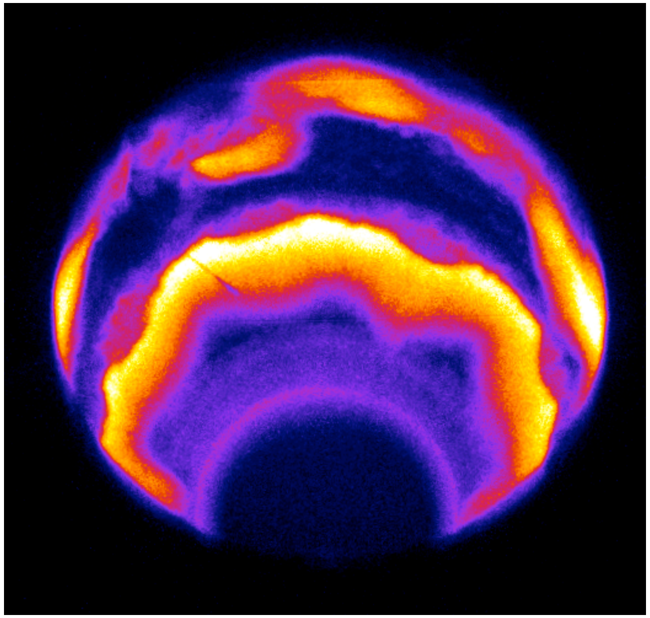
# Reduce flux by 100!

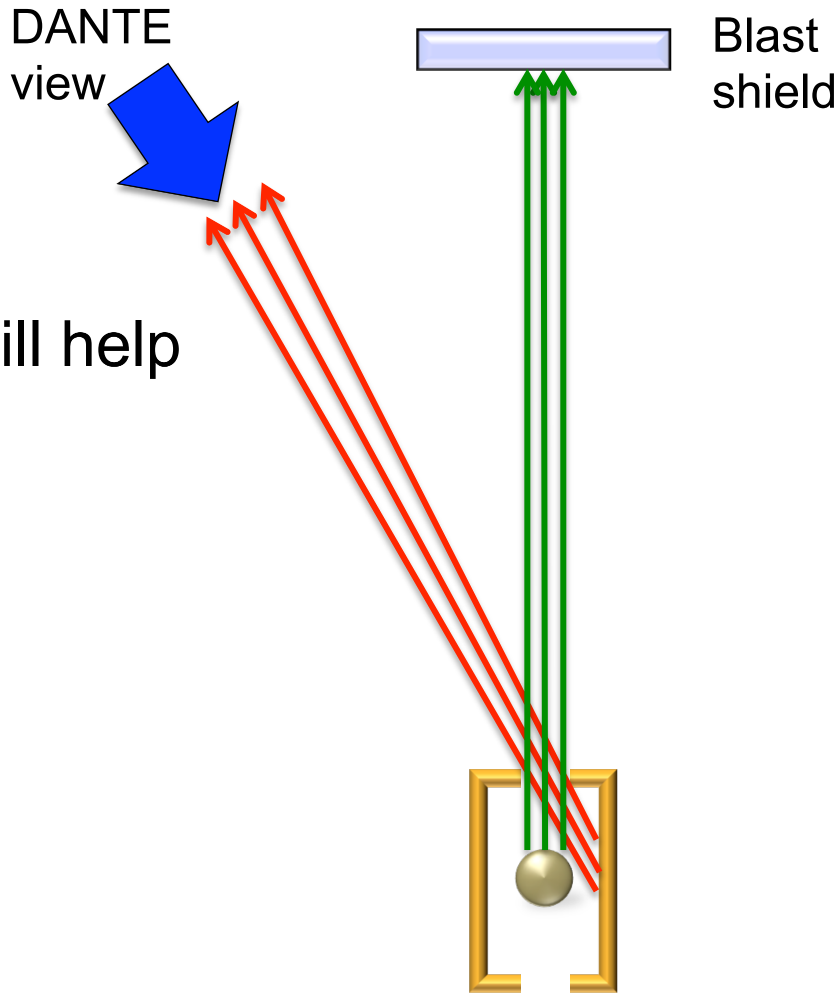
- **Window doesn't blank!**
- Not clear this is possible…



# Reducing the Dose – Line of Sight

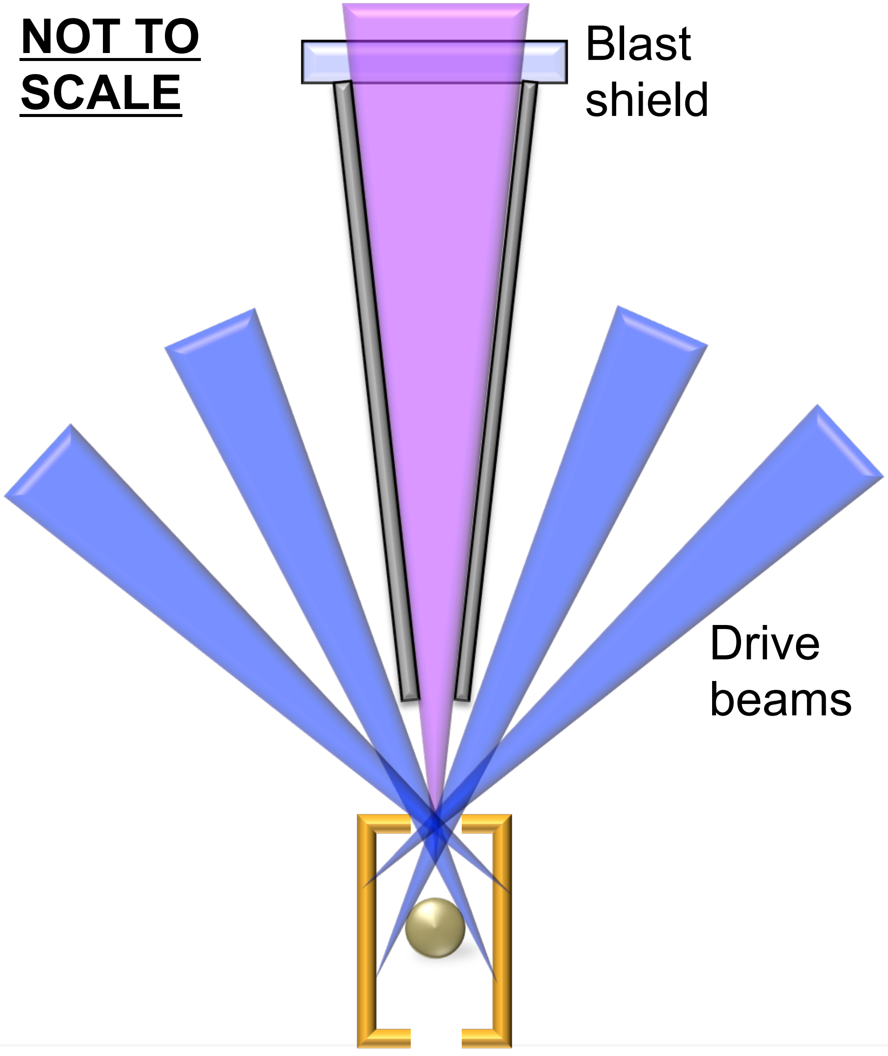
- **DANTE** sees the **hohlraum wall**
- The **blast shield** will **not**
- Need to **quantify** how much this will help





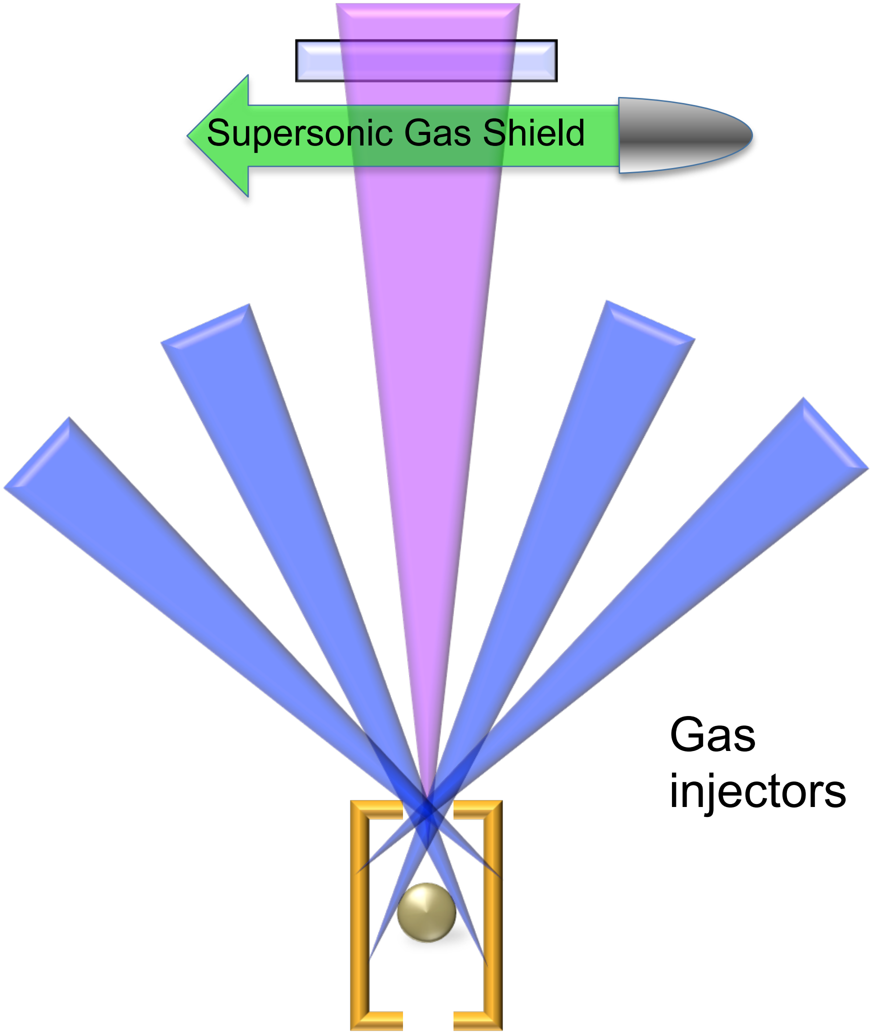
# Reducing the Dose – Solid Shielding

- Shielding is **difficult**
- In order to shield without reducing the collection cone shield must be **very close to target**
- Drive beams will get in the way



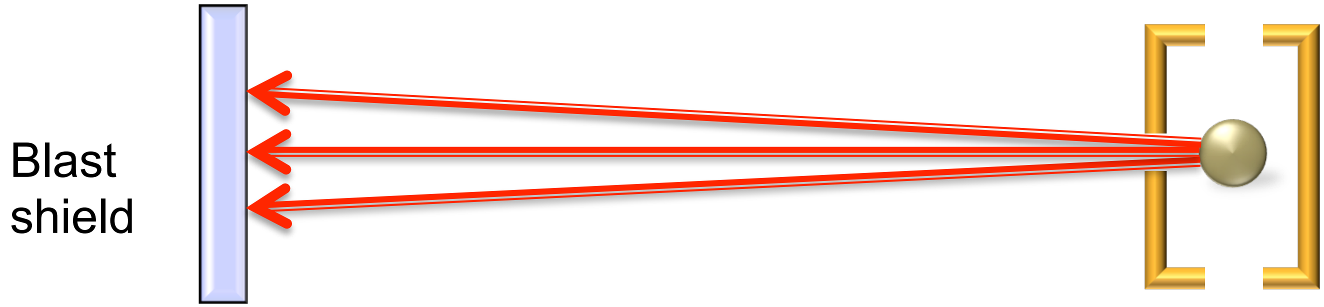
# Reducing the Dose – Gas Shield

- **X-ray Gas shield** injected before shot
- **Attenuates X-rays** but not **dense enough to block optical** propagation
- Rely on supersonic gas **expansion time** to protect hohlraum from gas



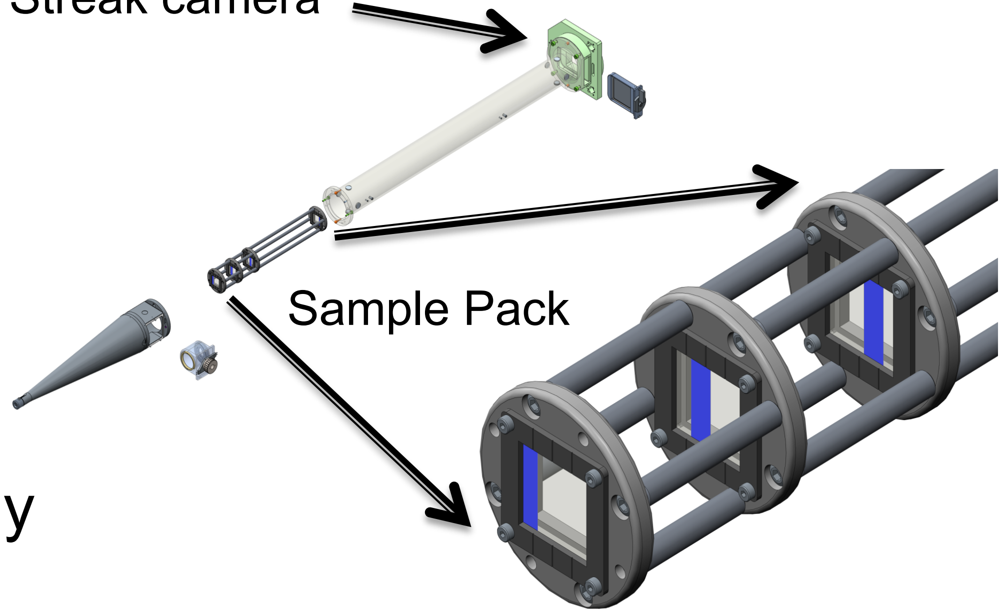
# Reducing the Dose – Change Configuration

- Alternatively can move to a **equatorial** measurement
- **Reduced x-ray flux** due to **smaller diagnostic hole**
- No Gold wall view
- Not our ideal choice – surrogacy issues, hole closure etc.
- Again, **need to quantify difference in Flux**



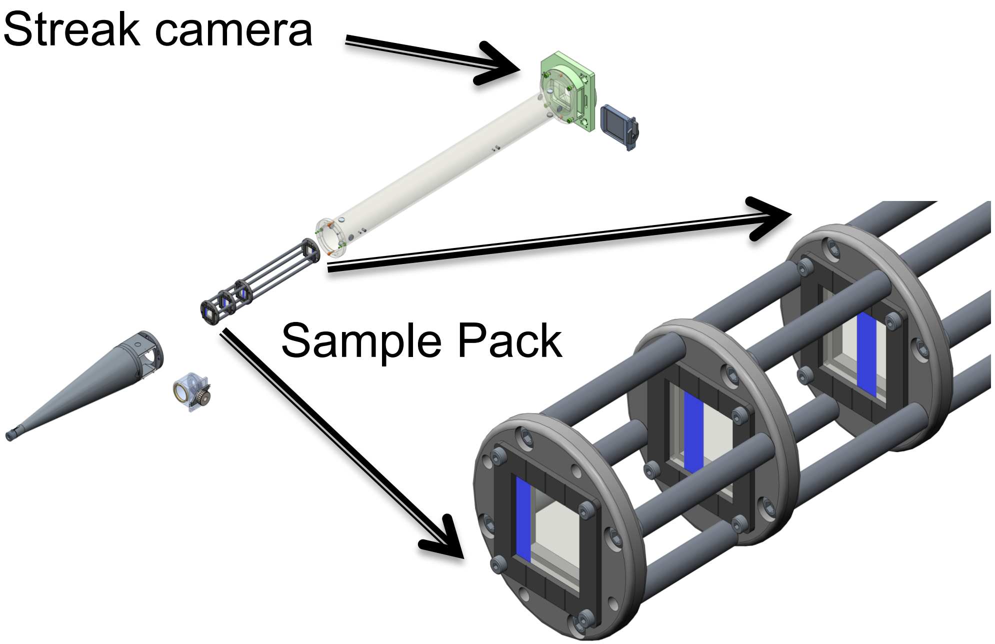
# Experimental Planning

- Need to **understand blanking** effects in a **variety of materials**
  - —MgF
  - —CaF
  - —LiF
  - —AlO
- Ideally:
  - —**OMEGA**
    - test materials positively measure blanking
  - —1-2 **NIF** shots
    - Cross Calibration



# NIF Shot Concept

- Use Polar DIM
- Place glass samples over a **range of distances** from the Hohlraum
- Distances control the **X-ray Fluence** seen by each glass sample
- **Record** Hohlraum **self emission** on **Streak Camera**
- Should observe glass **blanking in sequence**



# Summary

- Two Background effects:
  - **Self Emission**
  - **Drive Thomson Scattering**
- We **know how to assess** these – initial results suggest this problem is **manageable**
- **Blanking** is caused by x-ray irradiation of the blast shield
- This problem looks more **challenging**
- We need more data:
  - **Blanking limits** for different glasses
  - **X-ray flux measurements** along relevant lines of sight