Bremsstrahlung Measurements of the Properties of Laser-Generated Hot Electrons for Fast Ignition

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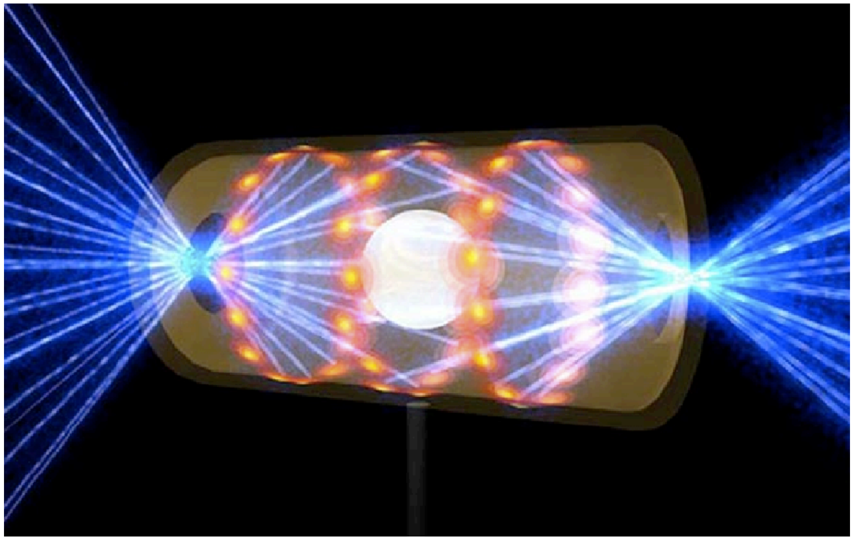
Fast Ignition is an ICF scheme with the potential for producing the high gains necessary for IFE

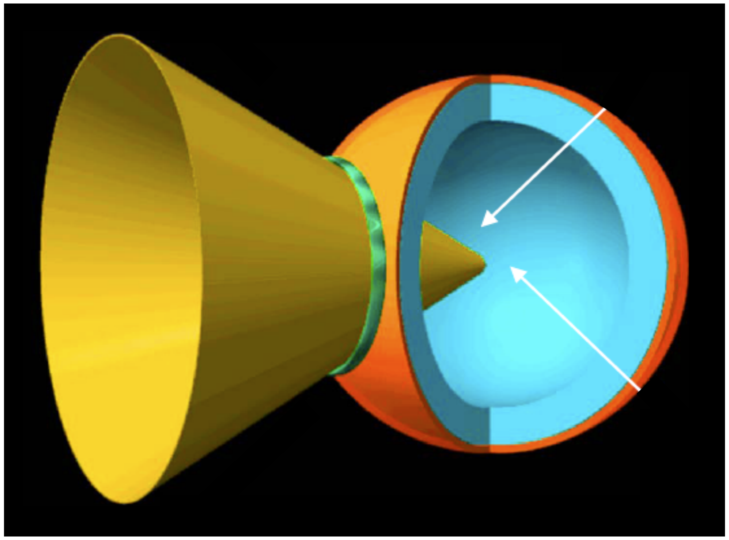
Central Hot Spot Ignition



1.3 MJ drive (compression & heating)

- Nanosecond lasers compress capsule and heat the low density center
- Coupled Compression and Ignition
- Primary Risk Factor: hydro instabilities resulting in shell breakup or quenching of the hot spot

Fast Ignition

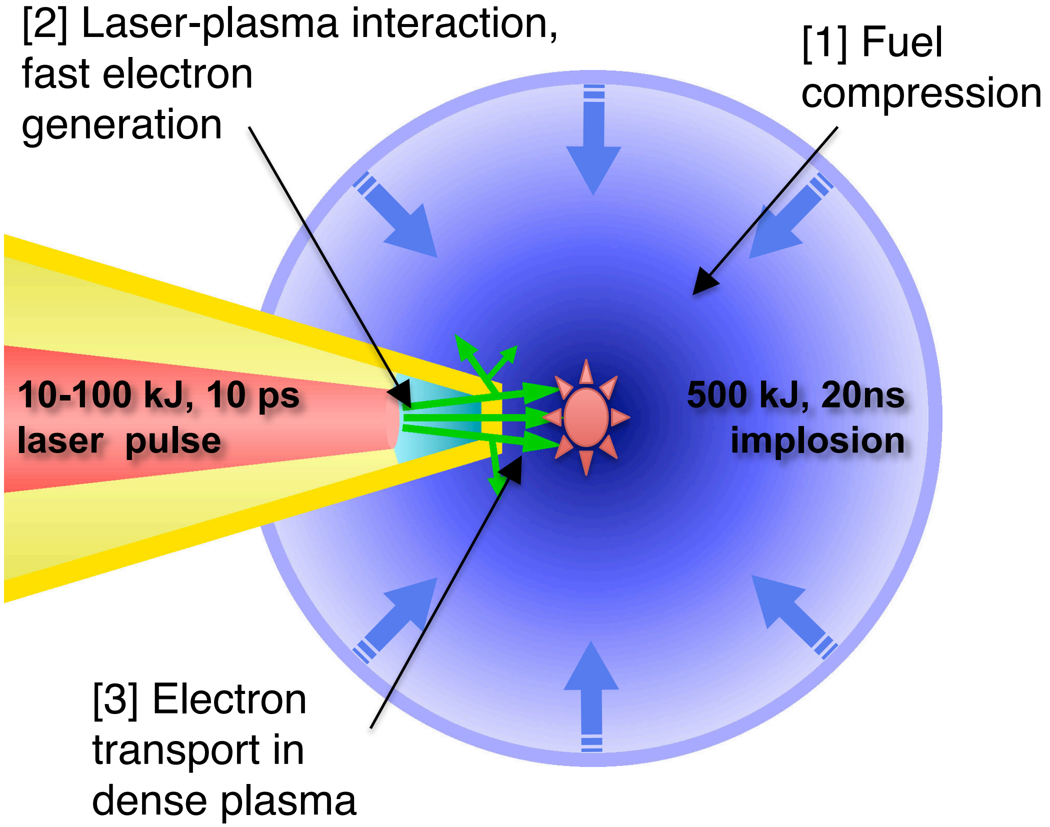


600 kJ drive (compression)
~100 kJ ignitor (heating)

- Capsule compressed by long pulse
- Short pulse laser heats hot spot
- Reduces hydro risk, higher gains, lower driver energies
- Primary Risk Factor: Coupling of the short pulse laser to the hot spot

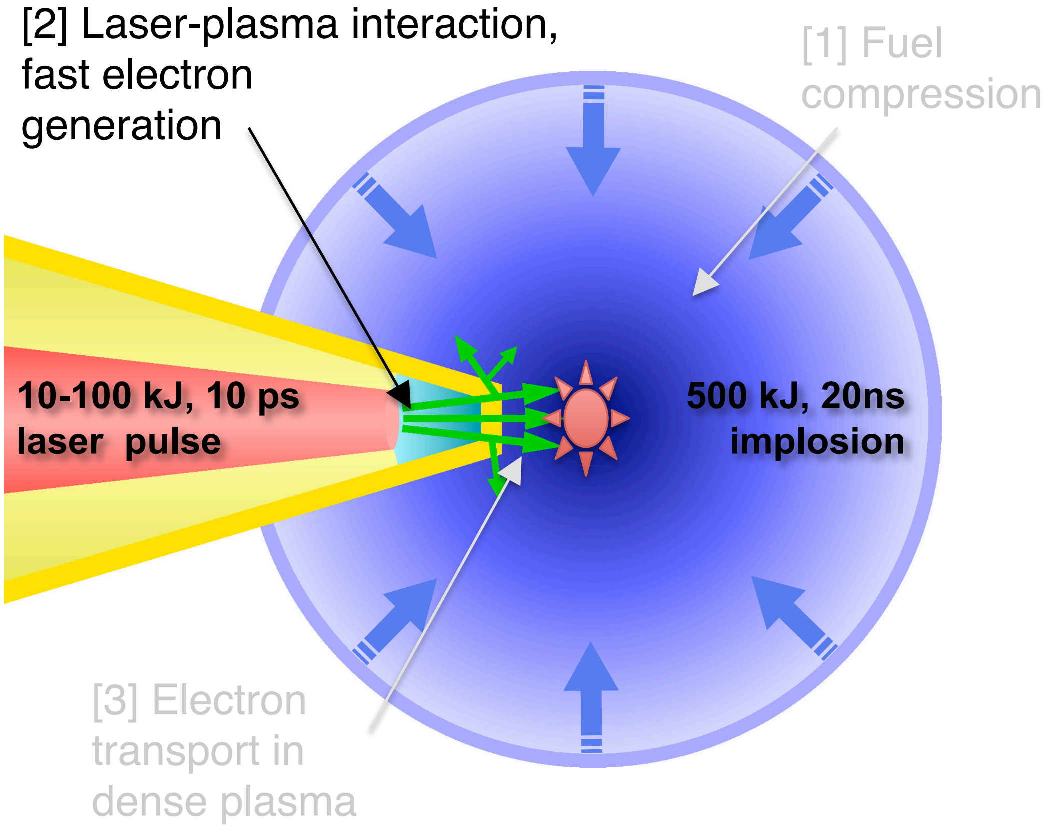
- **Fast Ignition can potentially reduce driver energy costs, relax uniformity and symmetry constraints, and produce higher ignition gains**

There are three principal design issues for electron cone-guided fast ignition



- Fast Ignition physics is extremely challenging as it encompasses ICF, relativistic laser interaction, particle beam transport in dense plasma – fundamental science of all intense laser interactions with high energy density plasma

There are three principal design issues for electron cone-guided fast ignition



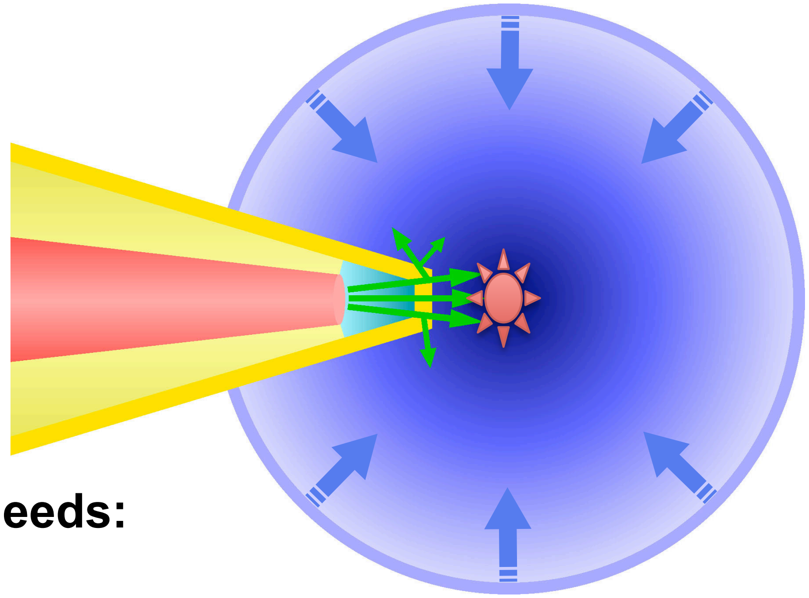
In FI the core is heated to 10 keV using an intense particle beam generated by an ultrahigh power laser

- Short-pulse laser must heat core to 10 KeV:

  Energy ~ 20 kJ

  Δz ~ 40 µm

  τ ~ 20 ps



For optimum coupling, the electron beam needs:

- High Conversion Efficiency of laser light to forward going fast electrons
- Electron spectrum maximizing 1-3 MeV electrons
  - Hot electron range to reach core and deposit energy in hot spot
- Divergence angle that is well collimated
  - Biggest factor in energy coupling to the core

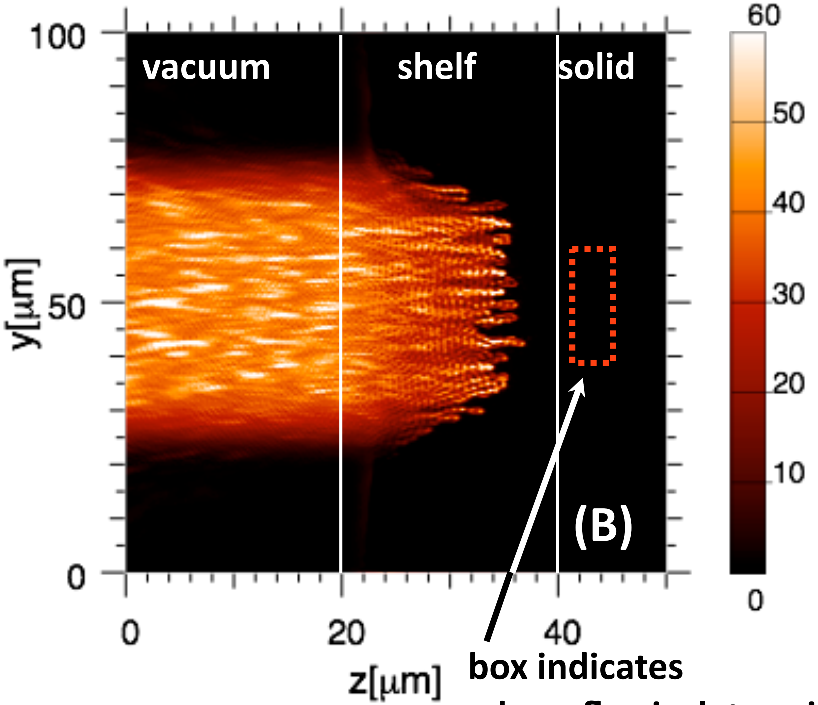
*S. Atzeni, POP 8, 3316 (1999)

PIC simulations suggest a 60% coupling into hot electrons with a wide divergence angle

- High-res explicit PIC, planar geometry, reduced spatial and temporal scales
- Intensity equivalent to 4.3kJ, 40µm diameter super-gaussian focal spot

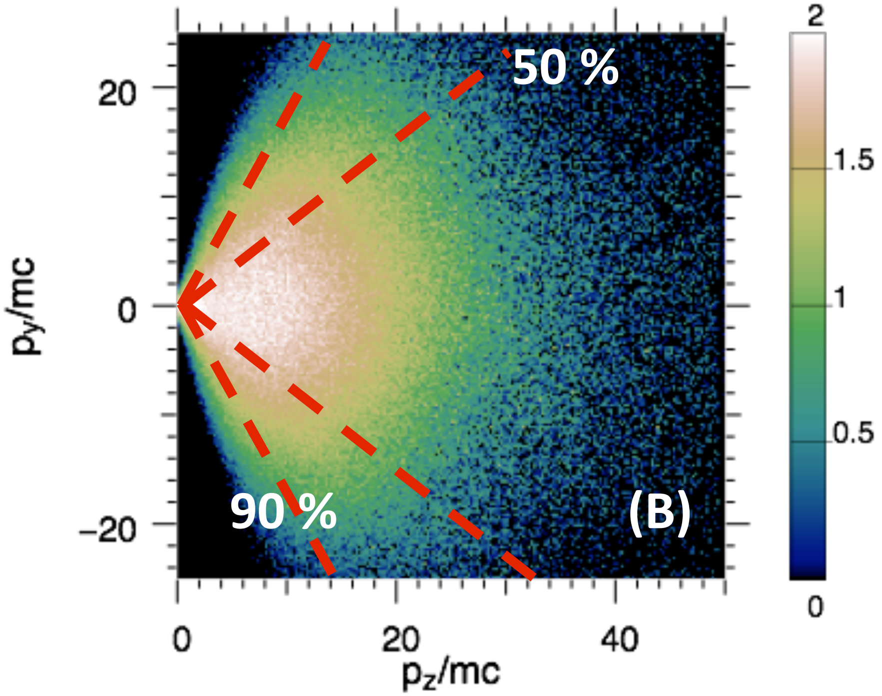
  (NIF ARC beam w/o abberations)

field energy density at 440.675 fs



box indicates where flux is determined

energy flux directionality at 450.449 fs

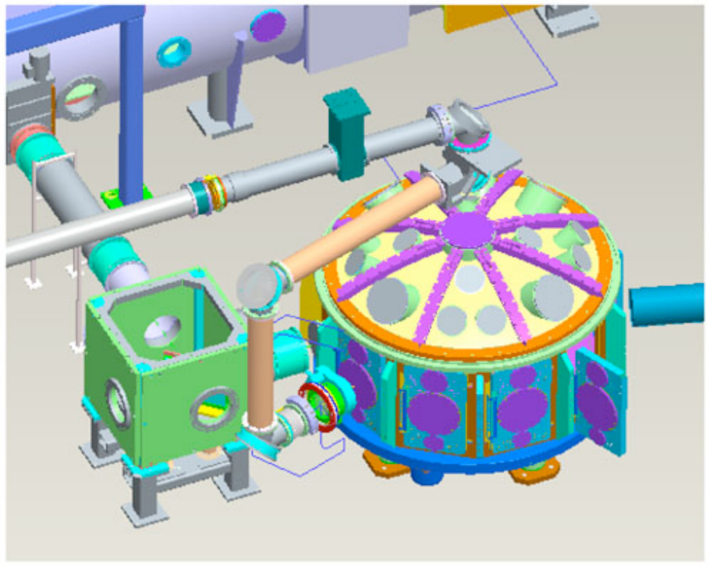


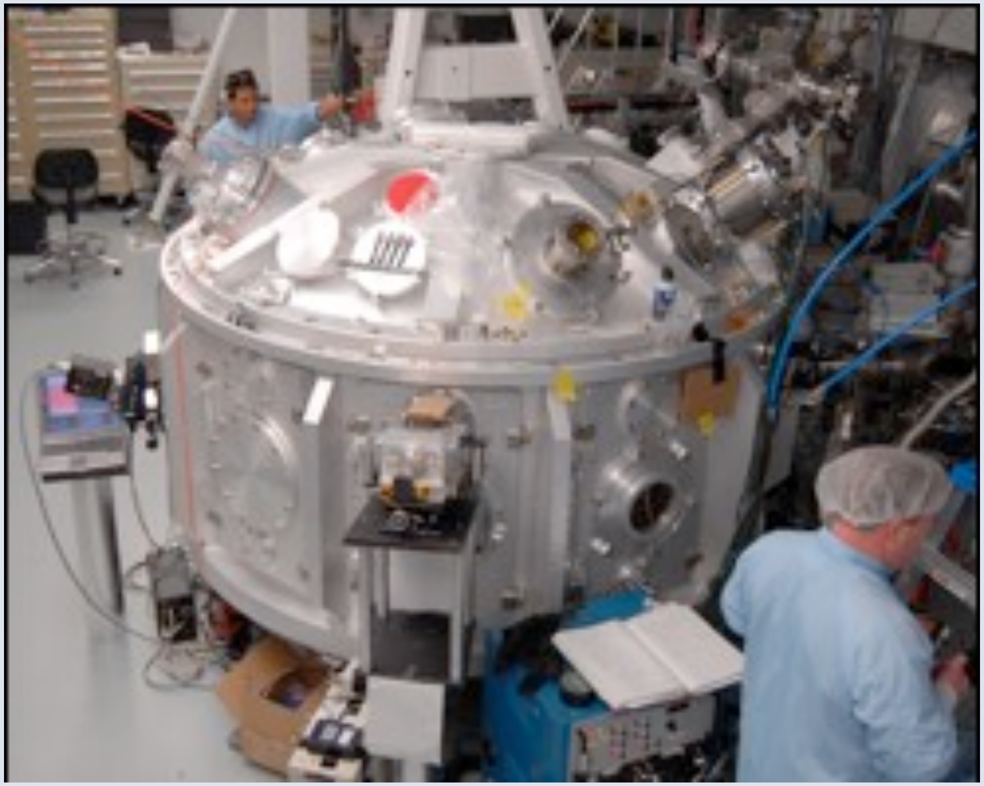
- T_{hot} ~ 1.4x vacuum ponderomotive potential
- Total conversion of light into electron energy flux is 60%
- 50% of electron flux is in 80 deg opening angle

5 million cells
1 billion particles
81 hours on 128 cpus

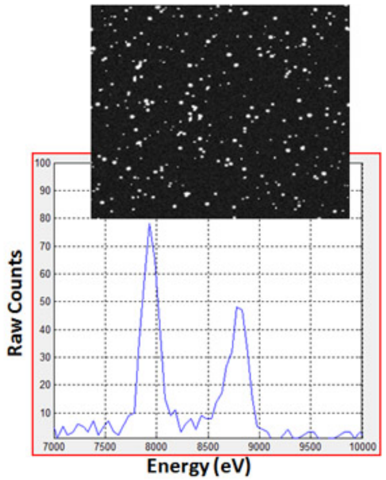
Experimental Benchmarking
Titan Laser Experiments @ LLNL

- **Wavelength: 1054nm**
- **Energy ~ 150 J**
- **Pulse Length ~ 0.7 ps**
- **Spot Size ~ 7 um**
- **Intensity ~ 10^{20} W/cm^2**



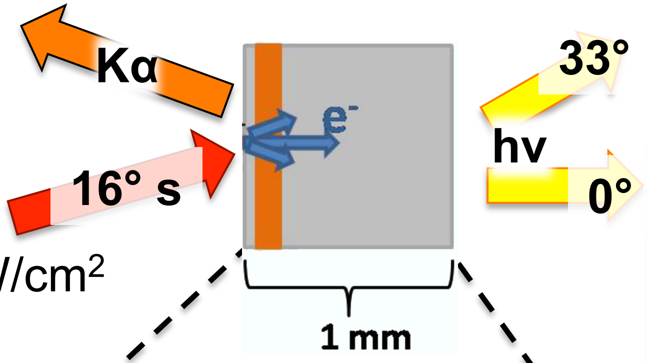


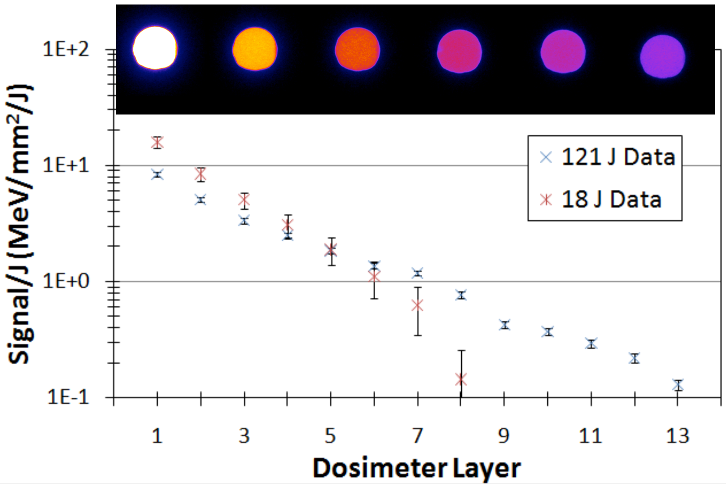
Bremsstrahlung measurements provide information about the internal electron distribution

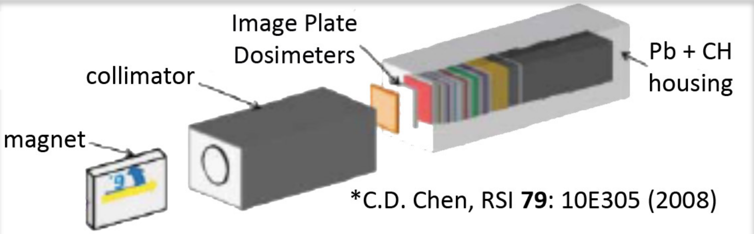


5-150 J, 0.7 ps

I=3×10^{18} - 10^{20} W/cm^2







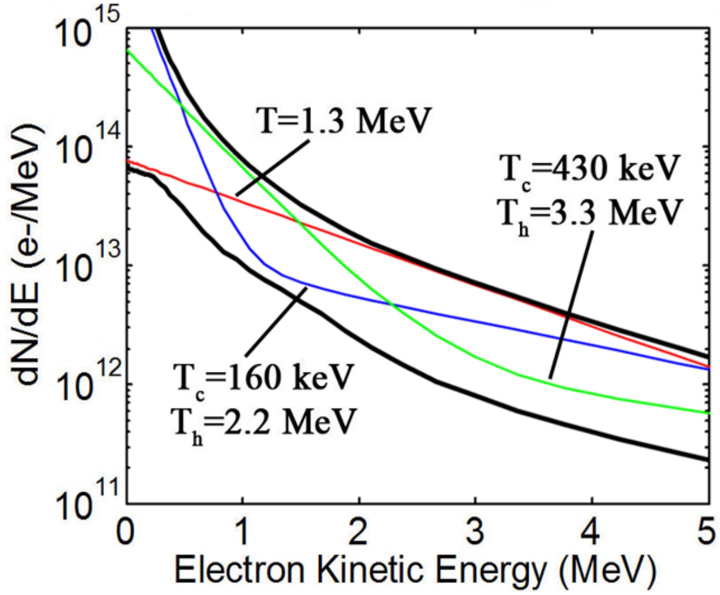
*C.D. Chen, RSI **79**: 10E305 (2008)

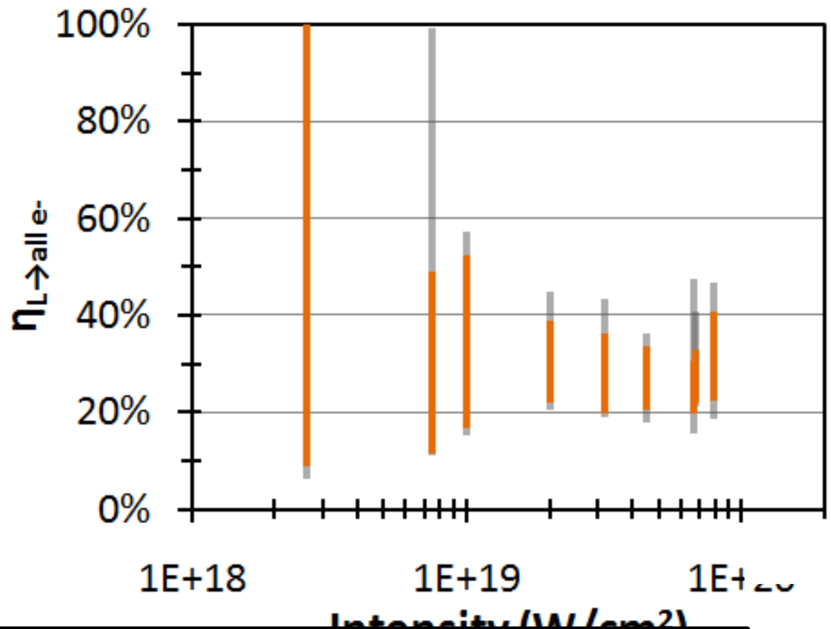
- Differential sensitivity up to 700 keV
- Calibrated from 8-662 keV

10 µm Al	Ablation layer, prevent heating of fluor
25 µm Cu	Fluorescent layer for k-shell emission
1 mm Al	Anti-refluxing layer, prevents multiple passes through fluor

Monte Carlo modeling of the Bremsstrahlung and Kα emission is used to infer the electron spectrum and coupling

- X-ray emission modeled with the Monte Carlo code Integrated Tiger Series 3.0
- Assumed classical ejection angle for injected electron angular distribution





•Raw Data
to 10 MeV
•Many dis
Bremsstrahlung profile in the <500 keV range

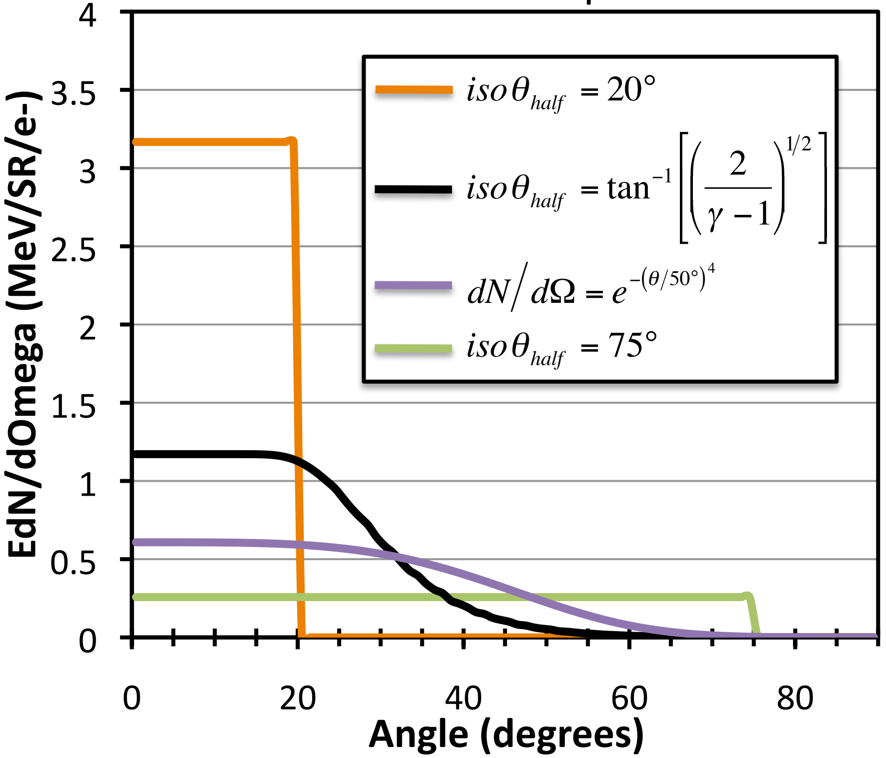
unded
cm²
•Conv. Eff. depends on angular distribution

Bremsstrahlung measurements in the 1-5 MeV range would significantly reduce the uncertainty

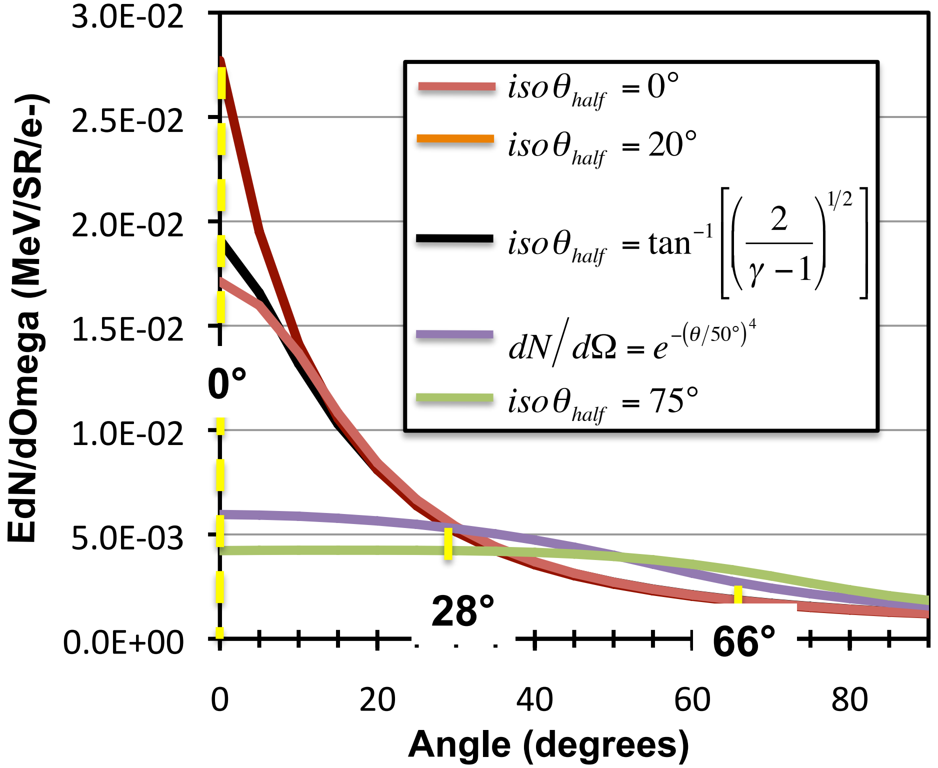
C.D. Chen, *Phys. Plasmas* ***16****:082705* (2009)

The angular distribution of Bremsstrahlung emission constrains the divergence angle and conversion efficiency

Ag Foil Target



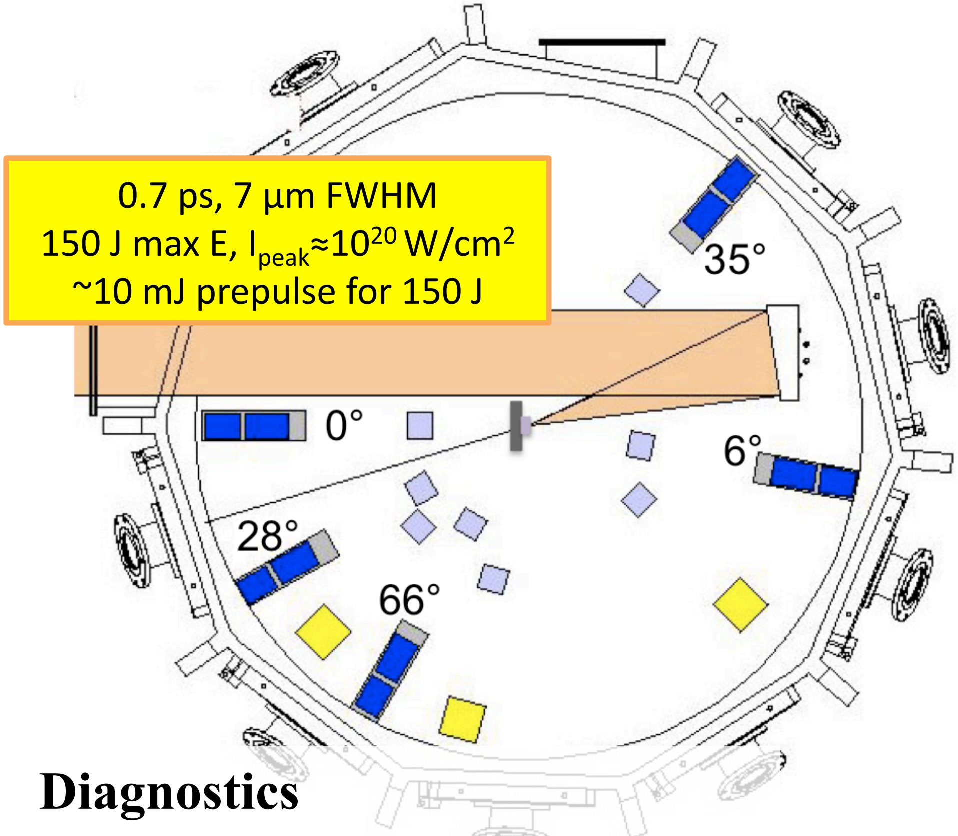
Injected Electron Distribution 1.2 MeV 1-Temp



Bremsstrahlung Response for 1.2MeV 1-Temp. Electron Source

The angular distribution of Bremsstrahlung may be useful for inferring the electron divergence angle.

Divergence Experiments



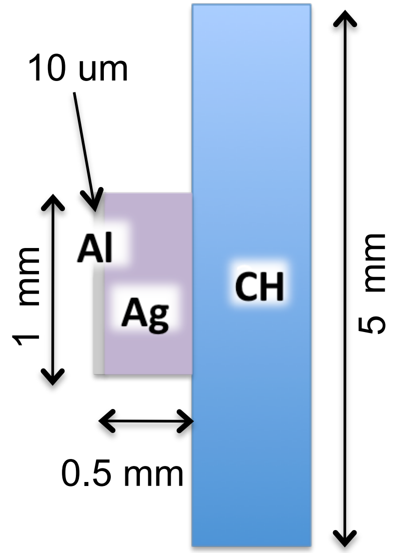
0.7 ps, 7 μm FWHM
150 J max E, $I_{peak} \approx 10^{20}$ W/cm^2
~10 mJ prepulse for 150 J

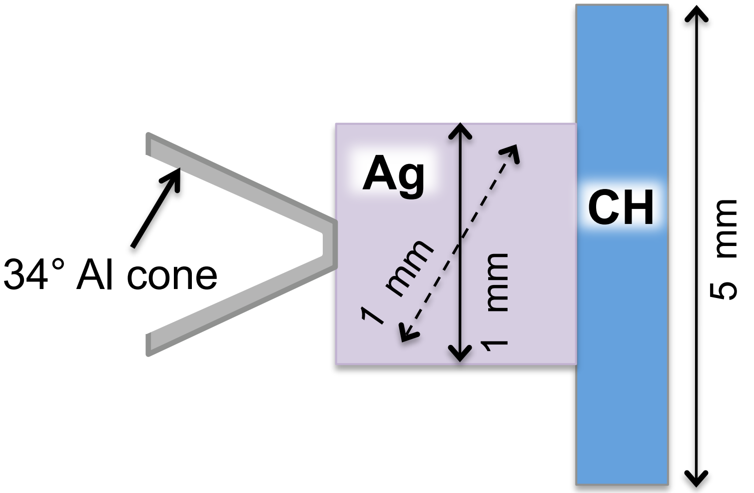
Diagnostics

-5 Filter Stack Bremsstrahlung Spectrometer (10 keV-700 keV)

-3 Stepfilter Bremsstrahlung Spectrometers (~100 keV-700 keV)

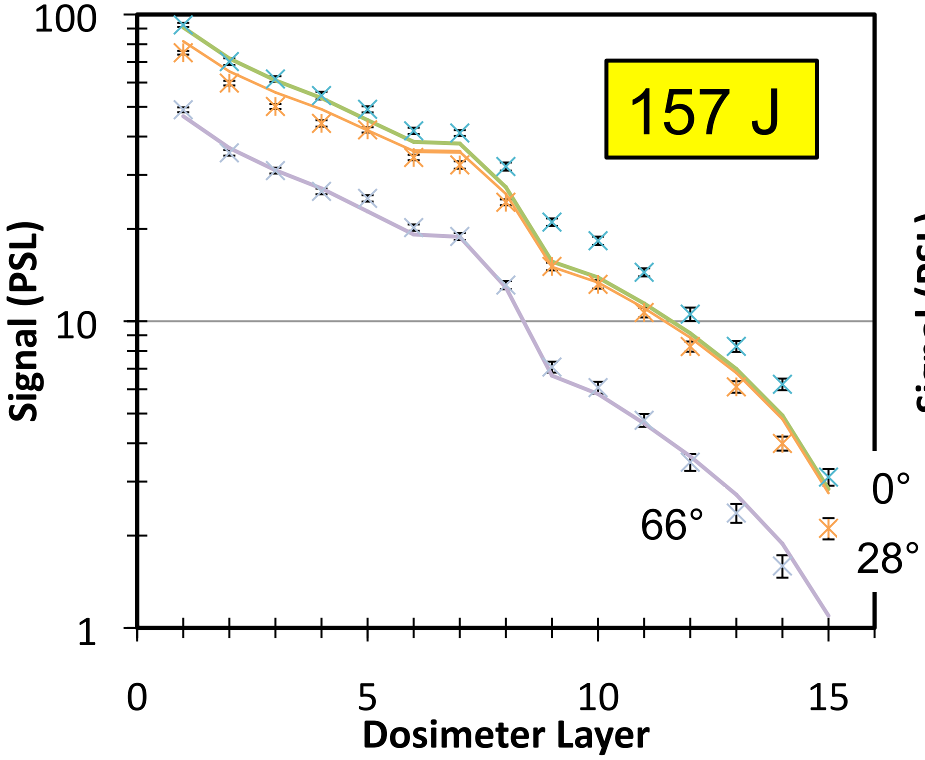
-HOPG spectrometer (rear)

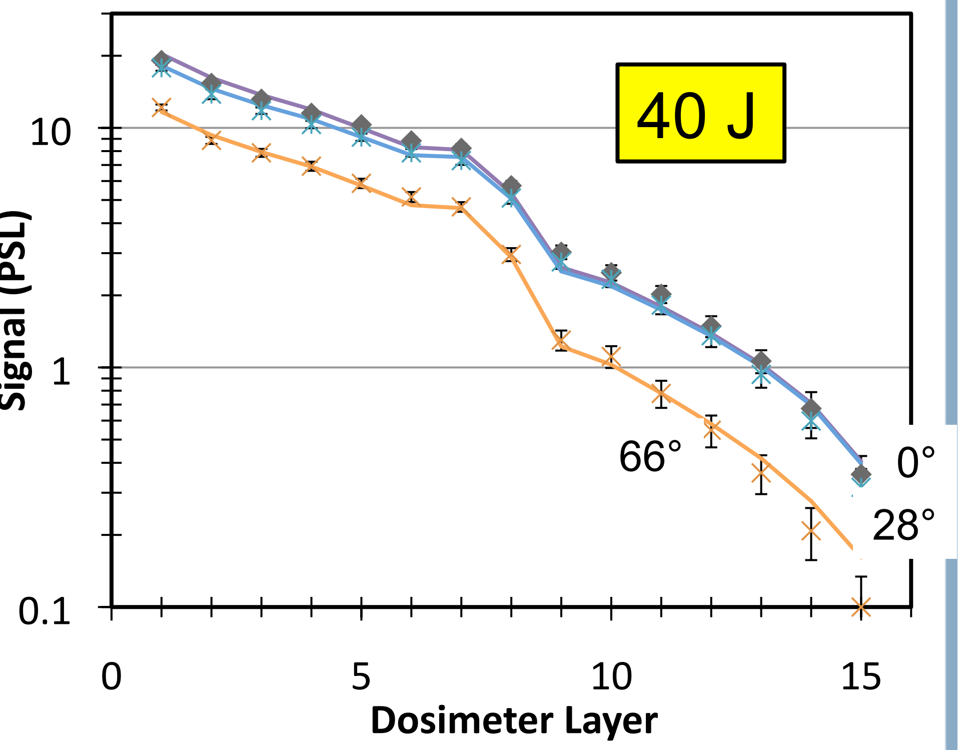




3 rear surface spectrometers are simultaneously fit using Monte Carlo modeling of an electron beam

PLANAR GEOMETRY





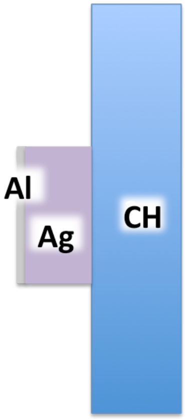
Best Fit = 60±5°, $\eta_{L\rightarrow e-}$=30%

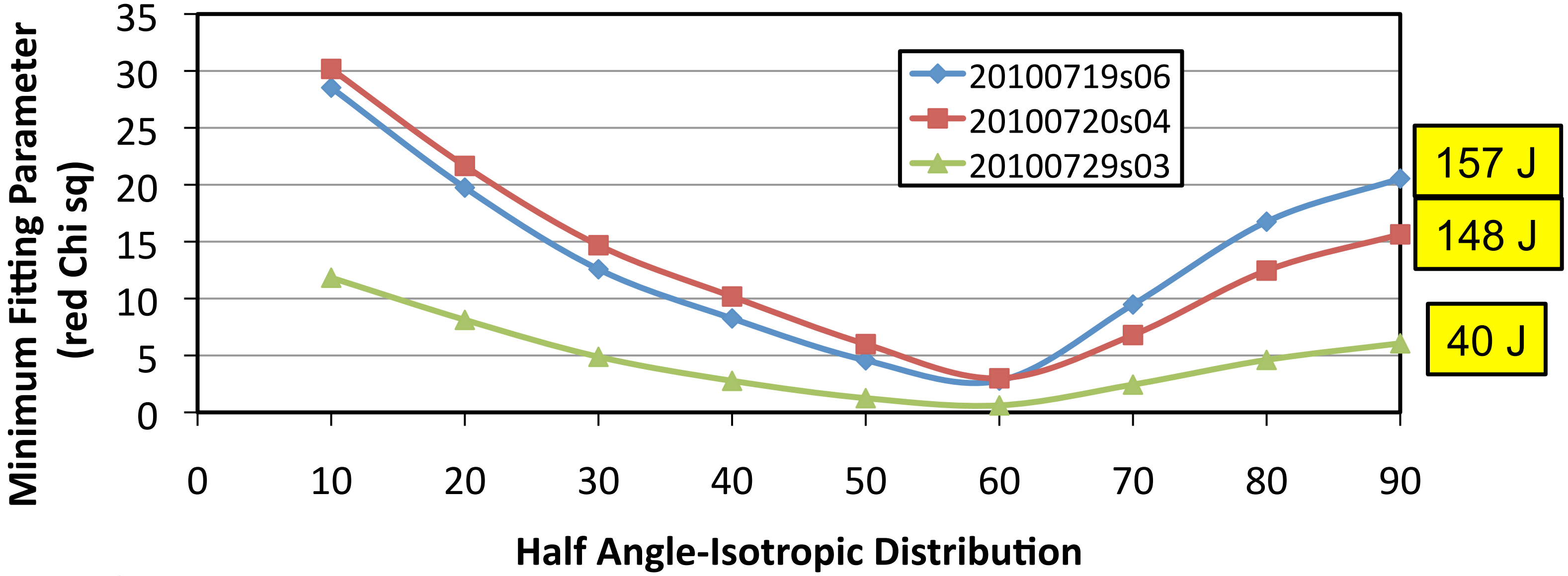
Fitting hv > 100 keV
= 50±5°, $\eta_{L\rightarrow e-}$=34%

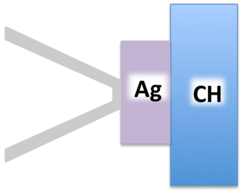
Best Fit = 60±5°, $\eta_{L\rightarrow e-}$=32%

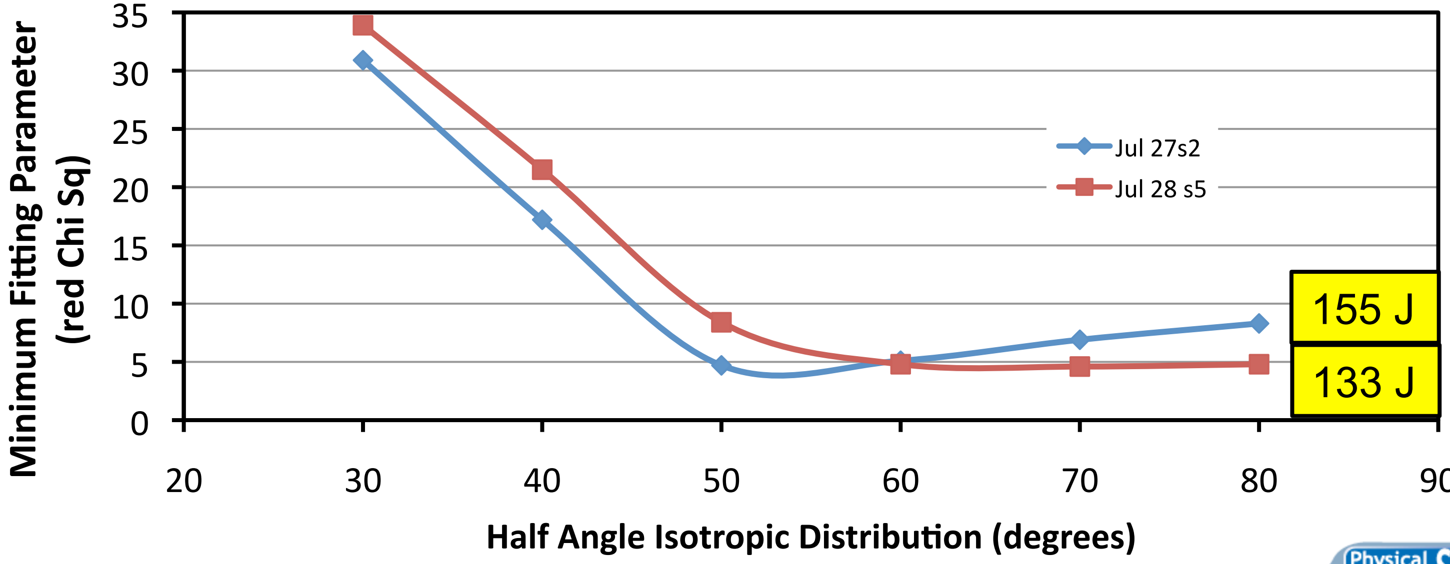
Fitting hv > 100 keV
= 50±5°, $\eta_{L\rightarrow e-}$=36%

Bremsstrahlung distribution suggests divergence angles of 50-60°









Summary

- Properties of the electron source are critical for evaluating the success of Fast Ignition
- Coupling efficiency has a minimum bound of 20-40%
- Higher energy Bremsstrahlung measurements are needed to constrain the T_{hot}
- Initial Monte Carlo simulations of the Bremsstrahlung angular distribution suggest electron divergence angles of 50-60° half angle