Yield and Ion Temperature Measurements in Exploding Pusher Experiments at OMEGA in Preparation for NIF Experiments

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INTRODUCTION AND MOTIVATION

Abstract

We have compared measurements of yield and ion temperature from a variety of diagnostics used in our March 4 2010 exploding pusher experiments at OMEGA. This work was conducted in preparation for their application at the NIF. In particular, we have compared ion temperatures inferred from the Doppler width of the D^3He-proton spectrum and from the ratio of DD- and D^3He-proton yields. In addition, we have assessed the consistency of yield measurements from several nuclear diagnostics that will be employed in the upcoming campaign at the NIF.

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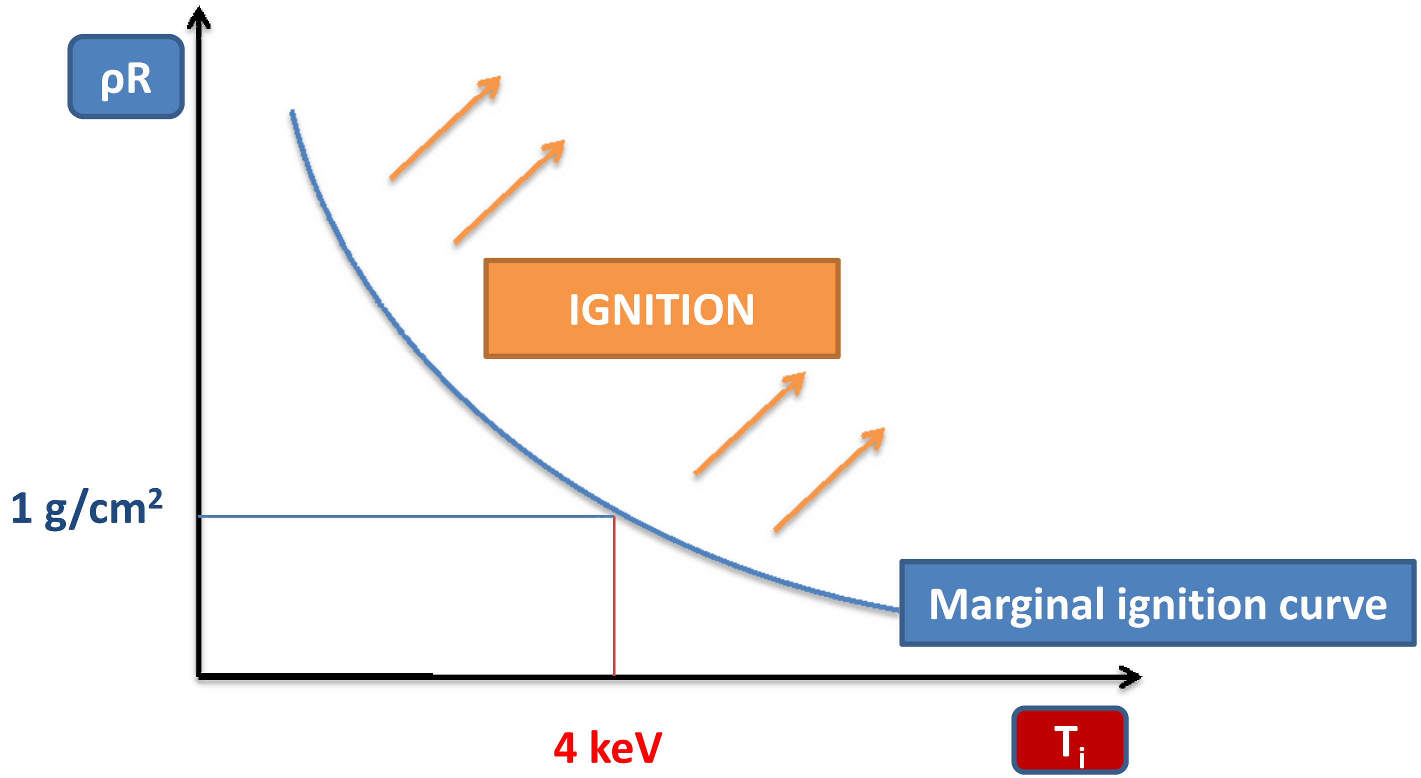
Accurate measurements of the ion temperature – in addition to ρR – will be essential for guiding the National Ignition Campaign (NIC) towards ignition and gain



The marginal ignition criterion is defined by two quantities: ρR and T_i

R. Betti, *et al.* Phys. Plasmas (2010), J. Frenje, *et al.* Phys. Plasmas (2010)

Several fusion products are used in the measurement of yield and ion temperature

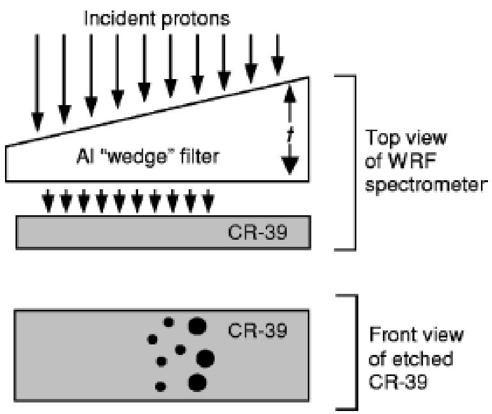
$$D + D \rightarrow \boxed{n}\ (2.45\ \mathrm{MeV}) + {}^{3}He\ (0.82\ \mathrm{MeV})$$

$$D + D \rightarrow \boxed{p}\ (3.02\ \mathrm{MeV}) + T\ (1.01\ \mathrm{MeV})$$

$$D + {}^{3}He \rightarrow \boxed{p}\ (14.68\ \mathrm{MeV}) + \alpha\ (3.67\ \mathrm{MeV})$$

We are developing the capability to make accurate yield and temperature measurements at the NIF by cross-calibrating measurements from several fusion product diagnostics at OMEGA

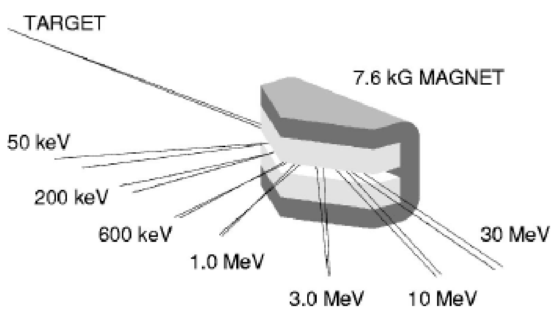
Wedge Range Filter Proton Spectrometer (WRF)



D³He-p Yield

T_i

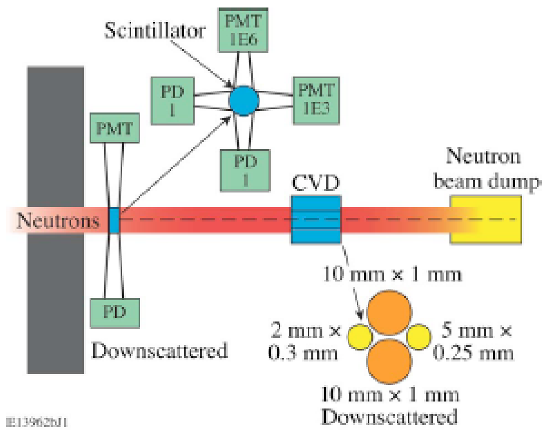
Charged Particle Spectrometer (CPS)



D³He-p Yield **DD-p Yield**

T_i

Neutron Time of Flight (nTOF)



DD-n Yield

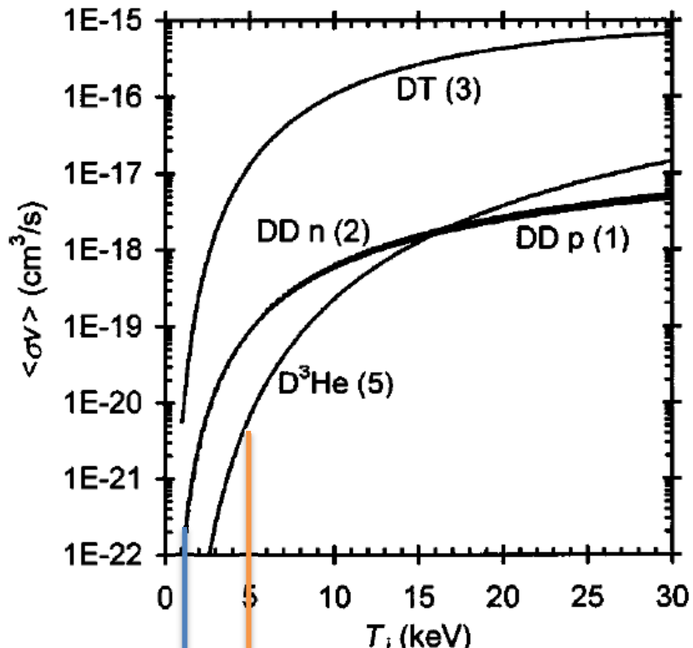
T_i

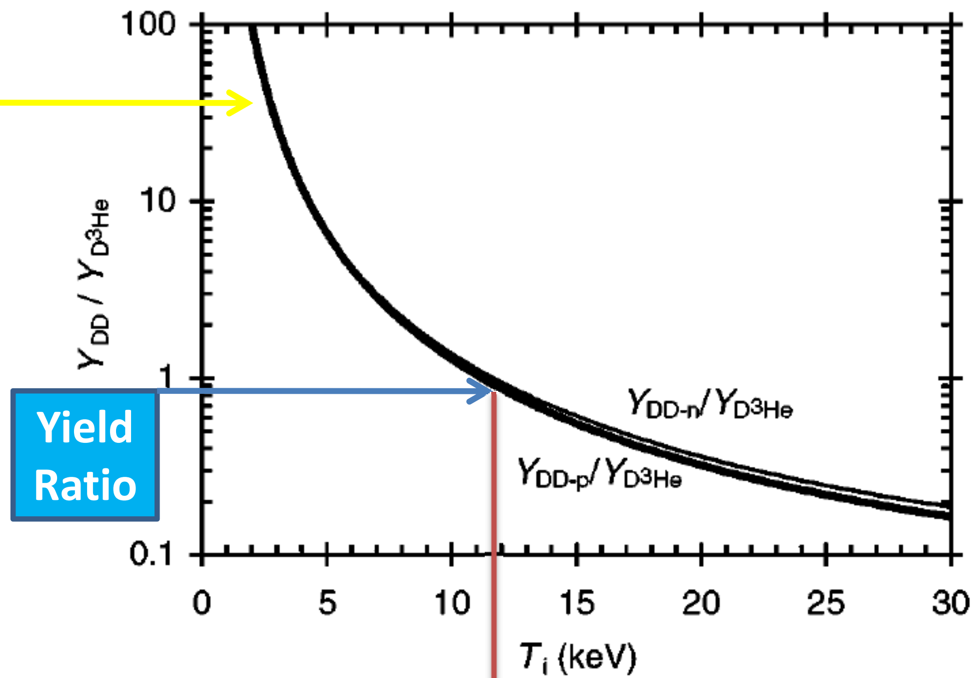
F.H. Seguin, *et al.* Rev. Sci. Inst. **74** *2* (2003), V. Yu. Glebov, *et al.* Rev. Sci. Inst. **77** (2006)

MEASUREMENT TECHNIQUES

Technique 1

Ion temperatures can be inferred from the ratio of DD and D^{3}He yields because the DD and D^{3}He reactivities depend differently on T_i





Yield Ratio (T_i) =

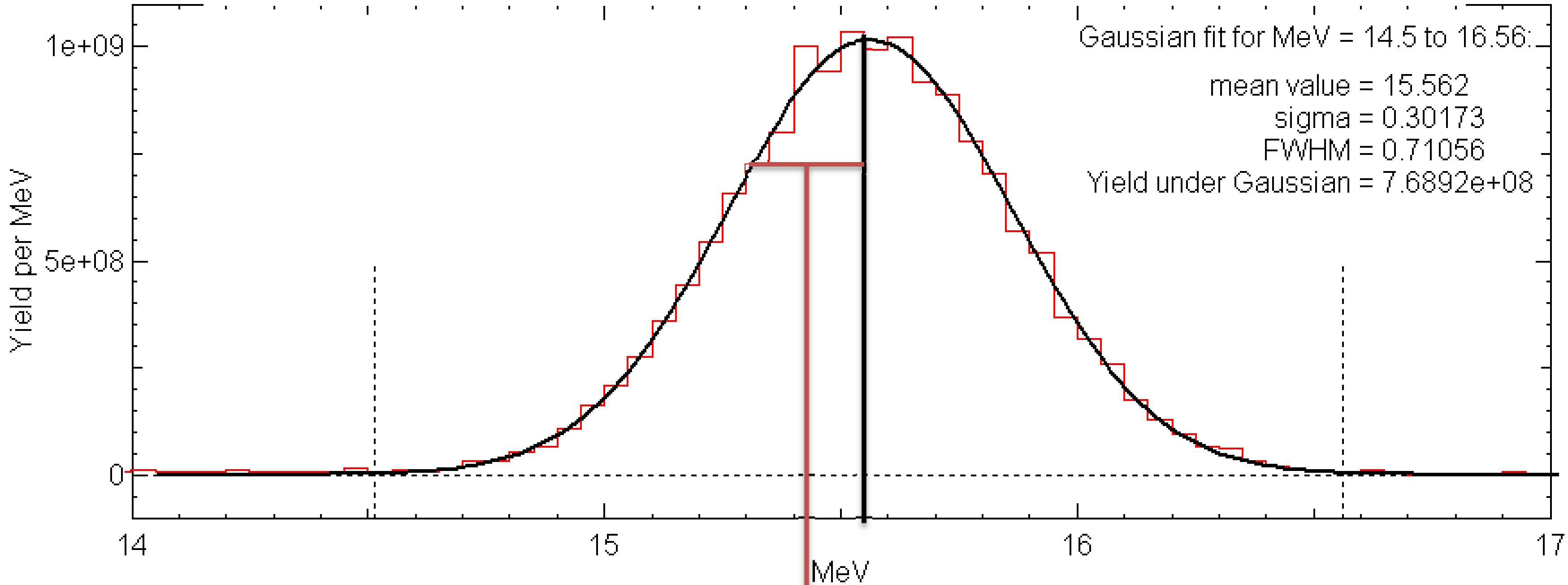
$(\langle\sigma v\rangle_{DD}/\langle\sigma v\rangle_{D3He})*(1/2)*(n_D/n_{3He})*(V_{DD}/V_{D3He})$

T_i

C.K. Li, *et* al. Phys. Plasmas. **7** *6* (2000), F.H. Seguin, *et al.* Rev. Sci. Inst. **74** *2* (2003)

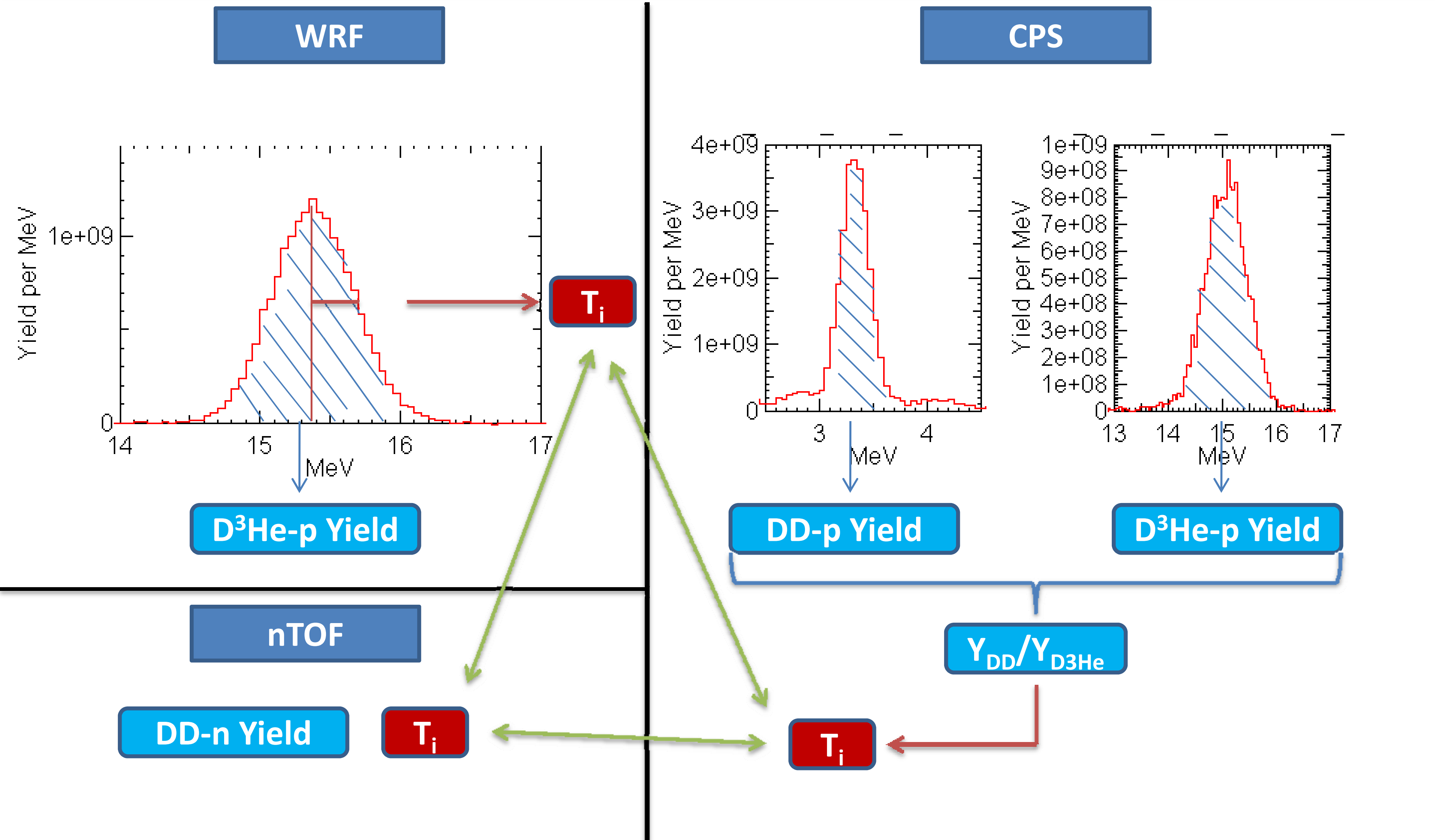
Technique 2

The ion temperature can also be determined from the Doppler-broadened D^{3}He-proton spectrum



$\sigma^2_{thermal}$ / 5880 = T_i (keV)

Absolute measurements of the DD-p and D^3He-p spectra, using several diagnostics, were compared to each other to evaluate the fidelity of the different techniques



An ion temperature can be accurately inferred from the linewidth of the D^{3}He-proton spectrum if the other broadening mechanisms are well characterized

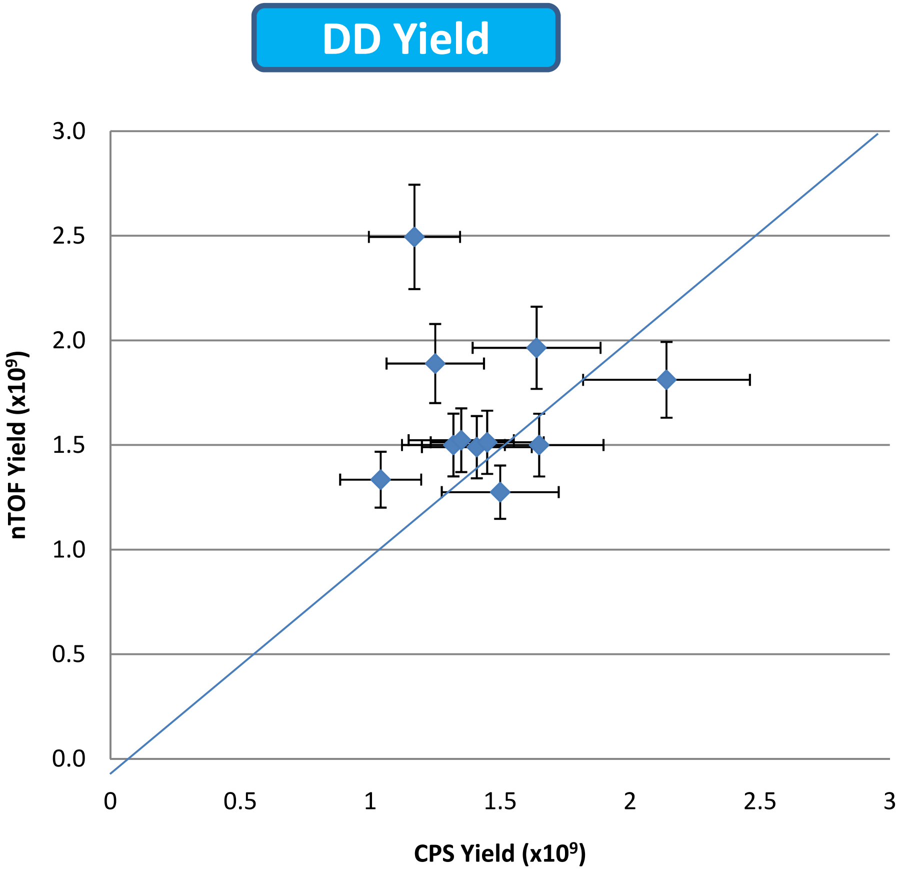
$$\sigma^2_{total} = \sigma^2_{thermal} + \sigma^2_{other}$$

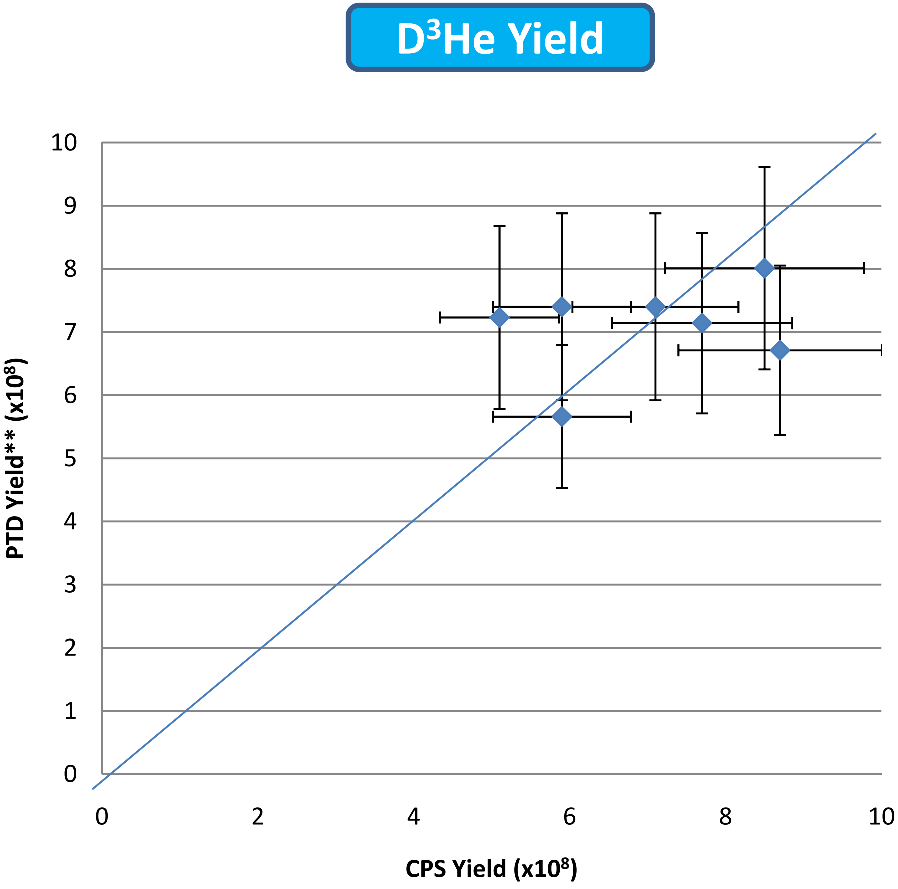
Source**	σ (keV)
Instrumental Broadening	150-190
High mode ρR modulations	10-20
Low mode ρR modulations	5-10
ρR Temporal Evolution	10-20
Geometric Broadening	~ 25
ρR Dispersion	25
ρR Straggling	18
Electric Field Evolution	?
Ablated Mass	?

** See A.B. Zylstra poster for details

EXPLODING PUSHER DATA

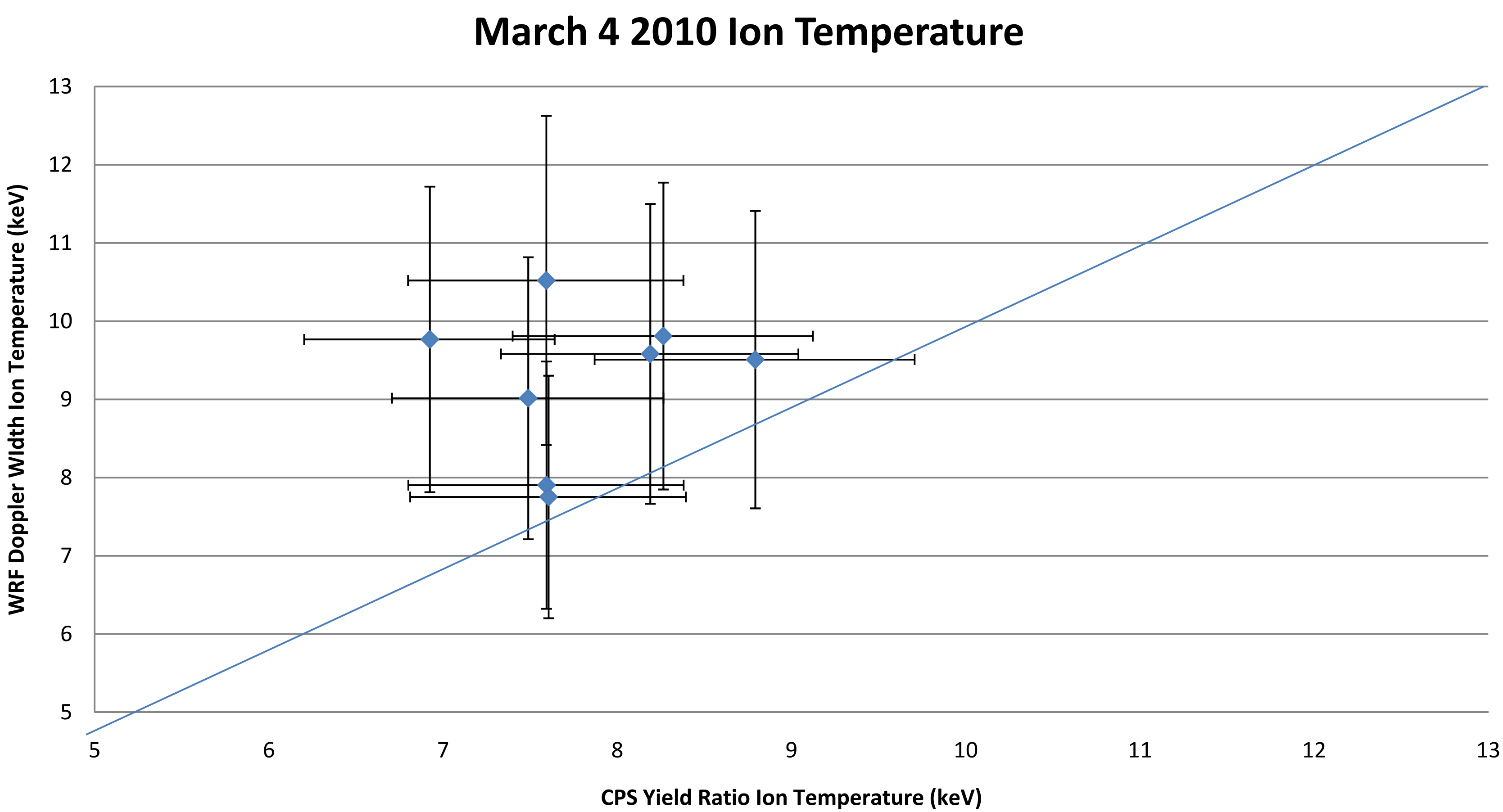
March 4 2010 yield data determined from several diagnostics are in good agreement





** Proton Temporal Diagnostic, J. Frenje, *et al.* Phys. Plasmas (2004)

March 4 2010 temperature data determined from the ratio method and from Doppler broadening are in relatively good agreement



A comparison of yield and T_i data suggests that nTOF provides a reliable yield measurement and that WRFs provide reliable ion temperatures

DD Yield

Diagnostic	Average ($x10^9$)
nTOF	1.6 $\pm$ 0.2
CPS	1.5 $\pm$ 0.2

D^3He Yield

Diagnostic	Average ($x10^8$)
CPS	7.0 $\pm$ 1.0
PTD	6.9 $\pm$ 1.4
WRF	****

T_i

Diagnostic	Average
WRF (Doppler)	9.0 $\pm$ 1.8 keV
CPS (Ratio)	7.8 $\pm$ 0.8 keV
nTOF	12.3 $\pm$ 11.9 keV

Differences in the ion temperatures inferred from the ratio method and the Doppler method may be the result of other broadening mechanisms' contributing to the total linewidth

Linewidth

Ratio

T_i

Predicted broadening from ratio temperature

$$\sigma^2_{total} - \sigma^2_{thermal} \rightarrow \sigma^2_{other}$$

March 4 2010 Data

7.8 keV

$$(290\ \text{keV})^2 - (210\ \text{keV})^2 \rightarrow (\sigma_{other} = 200\ \text{keV})^2$$

Source**	σ (keV)
Instrumental Broadening	150-190
High mode ρR modulations	10-20
Low mode ρR modulations	5-10
ρR Temporal Evolution	10-20
Geometric Broadening	~ 25
ρR Dispersion	25
ρR Straggling	18
Electric Field Evolution	?
Ablated Mass	?
Total	> 170

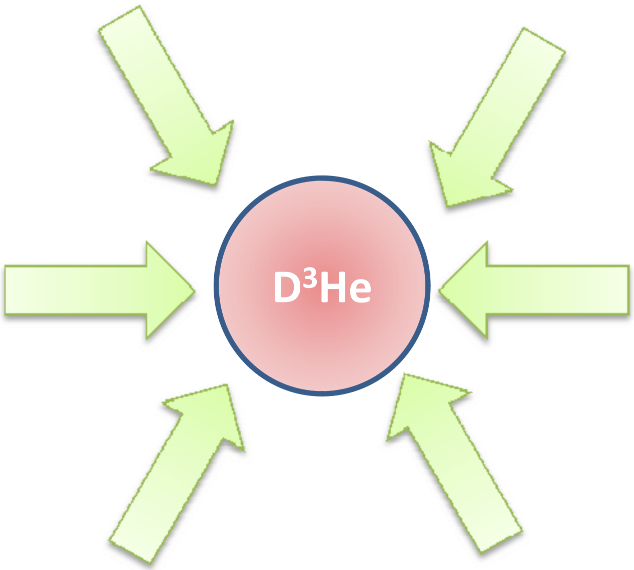
** See A.B. Zylstra poster

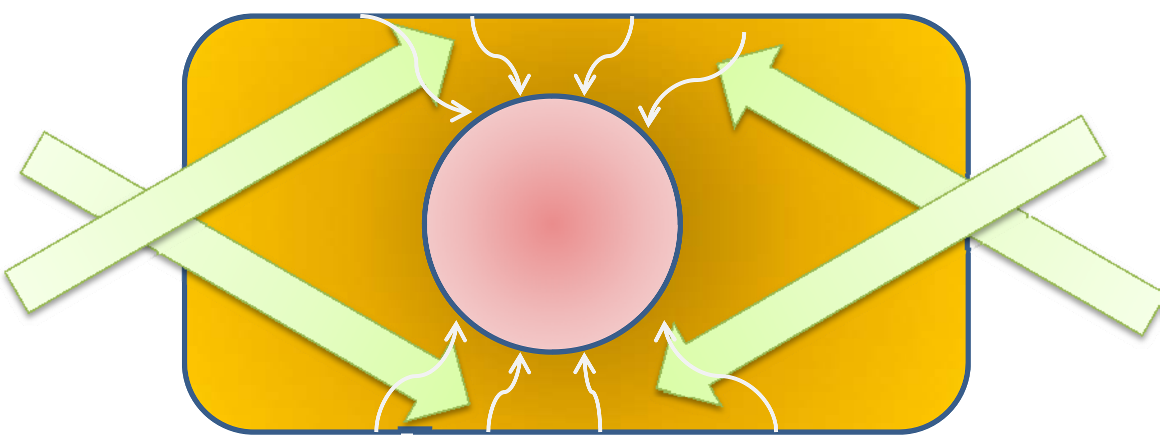
FUTURE WORK AT NIF

The upcoming NIF campaign consists of several types of experiments, including the direct-drive D^3He exploding pushers** and indirect-drive SymCaps, THD, and more

Direct-drive
Exploding pusher

Indirect-drive
SymCaps
THD

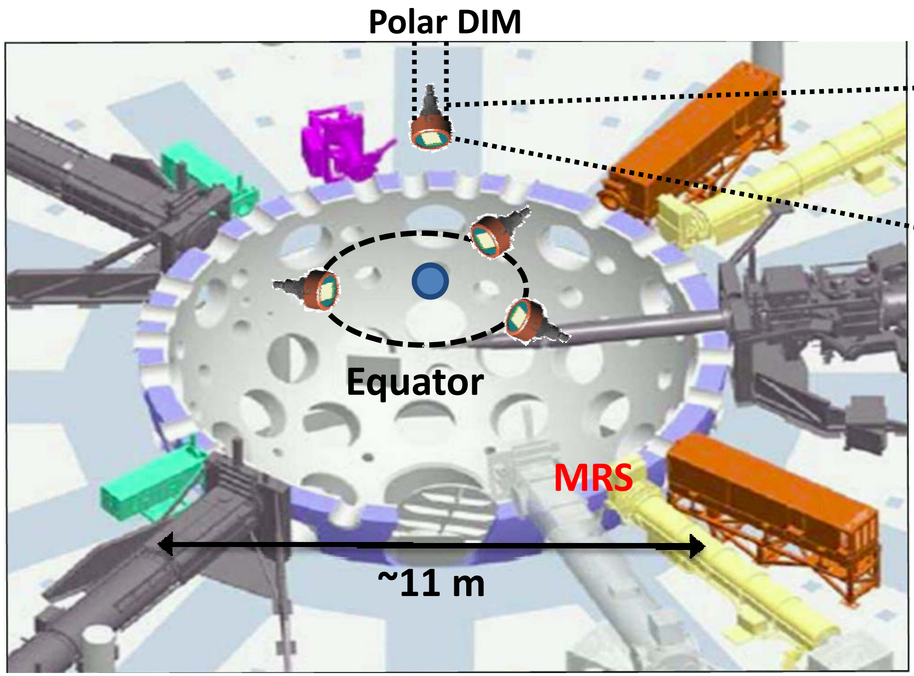


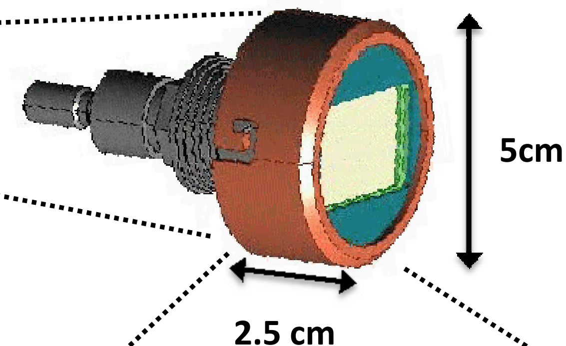


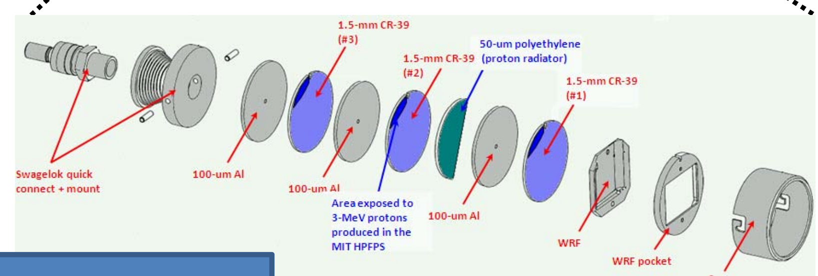
**Exploding pushers will be used for the commissioning of the ignition diagnostic suite

Several of the diagnostics employed at OMEGA will be used in these NIF experiments, including WRF spectrometers along both polar and equatorial views

NIF Chamber

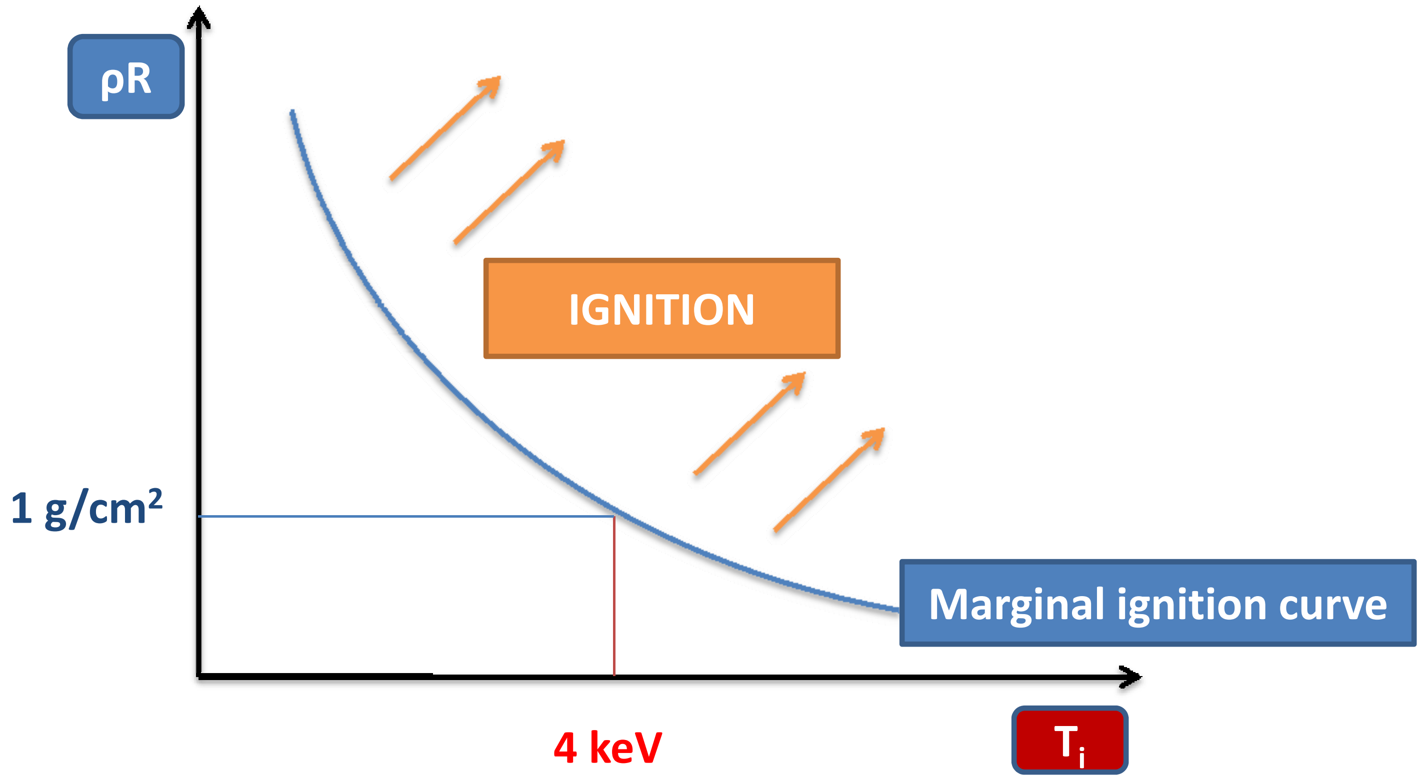






We will field WRFs at both the pole and at the equator, with multiple WRFs in a single DIM

Accurate measurements of the ion temperature will be essential for guiding the NIC towards ignition and gain; we have demonstrated the viability of several independent T_i measurement techniques



The marginal ignition criterion is defined by two quantities: ρR and T_i

R. Betti, *et al.* Phys. Plasmas (2010), J. Frenje, *et al.* Phys. Plasmas (2010)

Conclusions

- **We have cross-calibrated – at OMEGA – several diagnostics used to measure yields and ion temperatures**

- **Using data from our March 4 2010 D^3He exploding pusher experiment, we have compared DD yields, D^3He yields, and ion temperatures measured by WRFs, CPS, and nTOF**

- **We have established the fidelity of WRF-based temperature measurements and have confirmed the reliability of nTOF yield measurements**

- **<u>Many of these techniques for diagnosing the ion temperature and yield will be applied at the NIF</u>**