



Benchmarking LWFA simulations with VORPAL, OSIRIS and QuickPIC



D.L. Bruhwiler,¹ K. Paul,¹ B. Cowan,¹ J.R. Cary,^{1,4}
C. Huang,² F.S. Tsung,² W.B. Mori,²
C.G.R. Geddes,³ E. Cormier-Michel,³ E. Esarey³

1. Tech-X Corporation
2. University of California at Los Angeles
3. Lawrence Berkeley National Lab
4. University of Colorado



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- **Motivation**
 - software verification is part of the SciDAC mission
 - benchmarking software is sometimes the only way
- **Benchmarking Simulation Parameters**
 - we consider the 3D wake of an intense laser pulse
 - uniform density electron plasma
 - parameters typical of gas jet experiments
- **Simulation Results & Comparisons**
 - time-explicit electromagnetic PIC
 - including 2nd-order spline-based particle shapes
 - in one case, the new cold, relativistic fluid model
 - Quasi-static and Ponderomotive Guiding Center PIC
- **Conclusions**

Numerical parameters – 3D domain



Laser & Plasma Parameters

Normalized Vector Potential of Laser (a_0)	<i>0.5, 1.0, 2.0, 4.0</i>
Laser Wavelength (λ_0)	0.8 μm
Laser Pulse Length (FWHM)	15 fs
Laser Pulse Width (W_0)	8.2 μm
Plasma Density (n_0)	$1.38 \times 10^{19} \text{ cm}^{-3}$

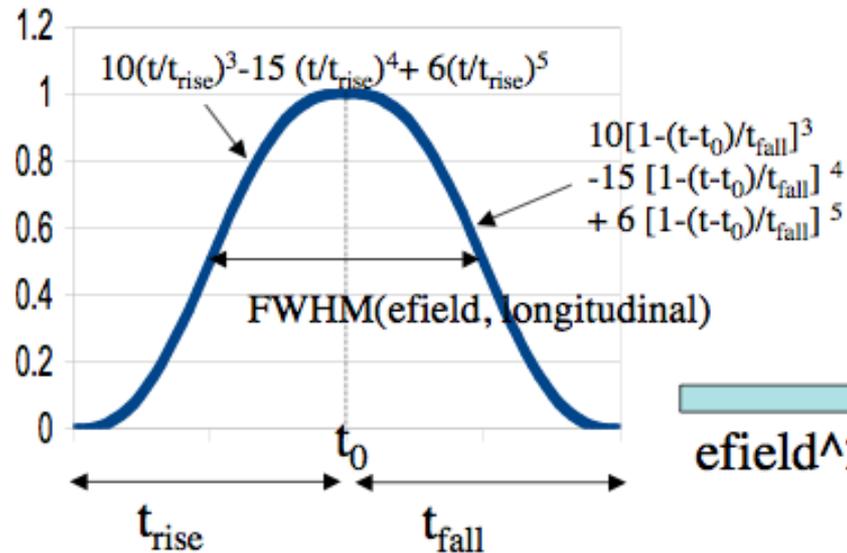
- zero-length ramp in plasma

Grid & Simulation Parameters

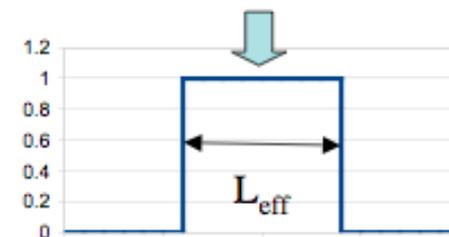
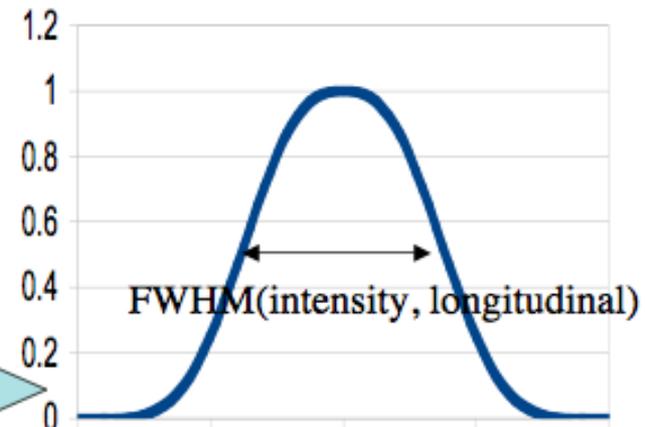
Transverse Box Size	81.52 μm
Longitudinal Box Size	20.5 μm
Box Grid Size in Cells	512 \times 512 \times 512
Transverse Cell Size	0.16 μm
Longitudinal Cell Size	0.04 μm
Time Step Size	0.1 fs
Number of Time Steps	1600
Number of Particles per Cell	8

Longitudinal Laser Profile

Laser electric field envelope
(longitudinal)



Laser intensity
(longitudinal)



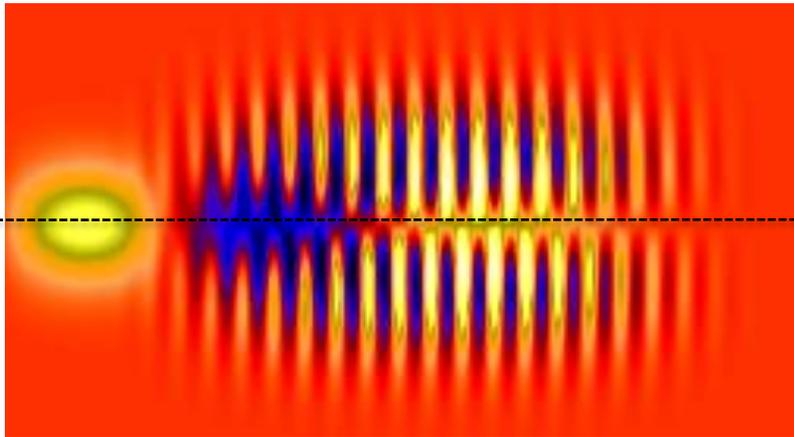
$$\text{FWHM}(e_{field}, \text{longitudinal}) = 0.5 (t_{rise} + t_{fall})$$

$$\text{FWHM}(\text{intensity}, \text{longitudinal}) = 0.772 \text{FWHM}(e_{field}, \text{longitudinal})$$

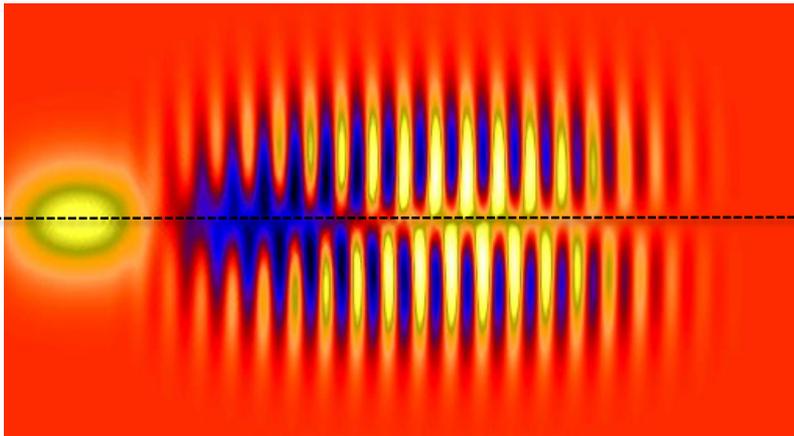
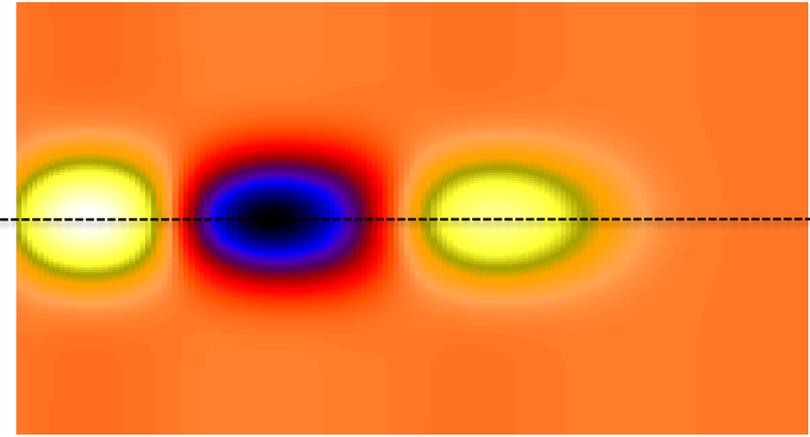
$$L_{eff} = 0.78 \text{FWHM}(e_{field}, \text{longitudinal}) = 1.01 \text{FWHM}(\text{intensity}, \text{longitudinal})$$

Case 1: $a_0 = 0.5$; 1st-order ptcl shapes

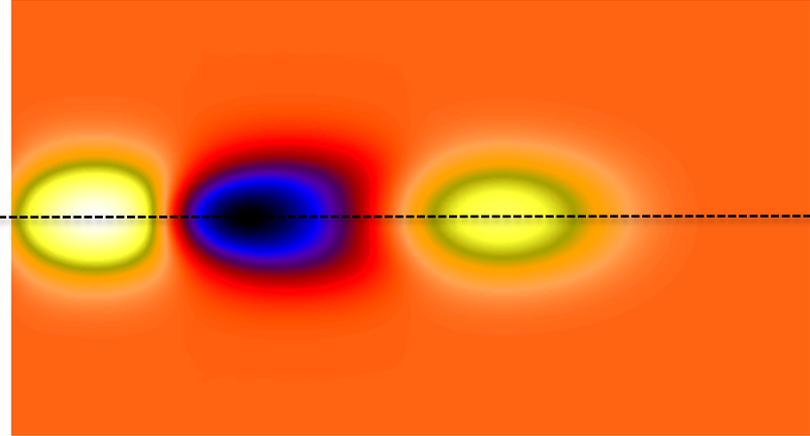
OSIRIS



QuickPIC

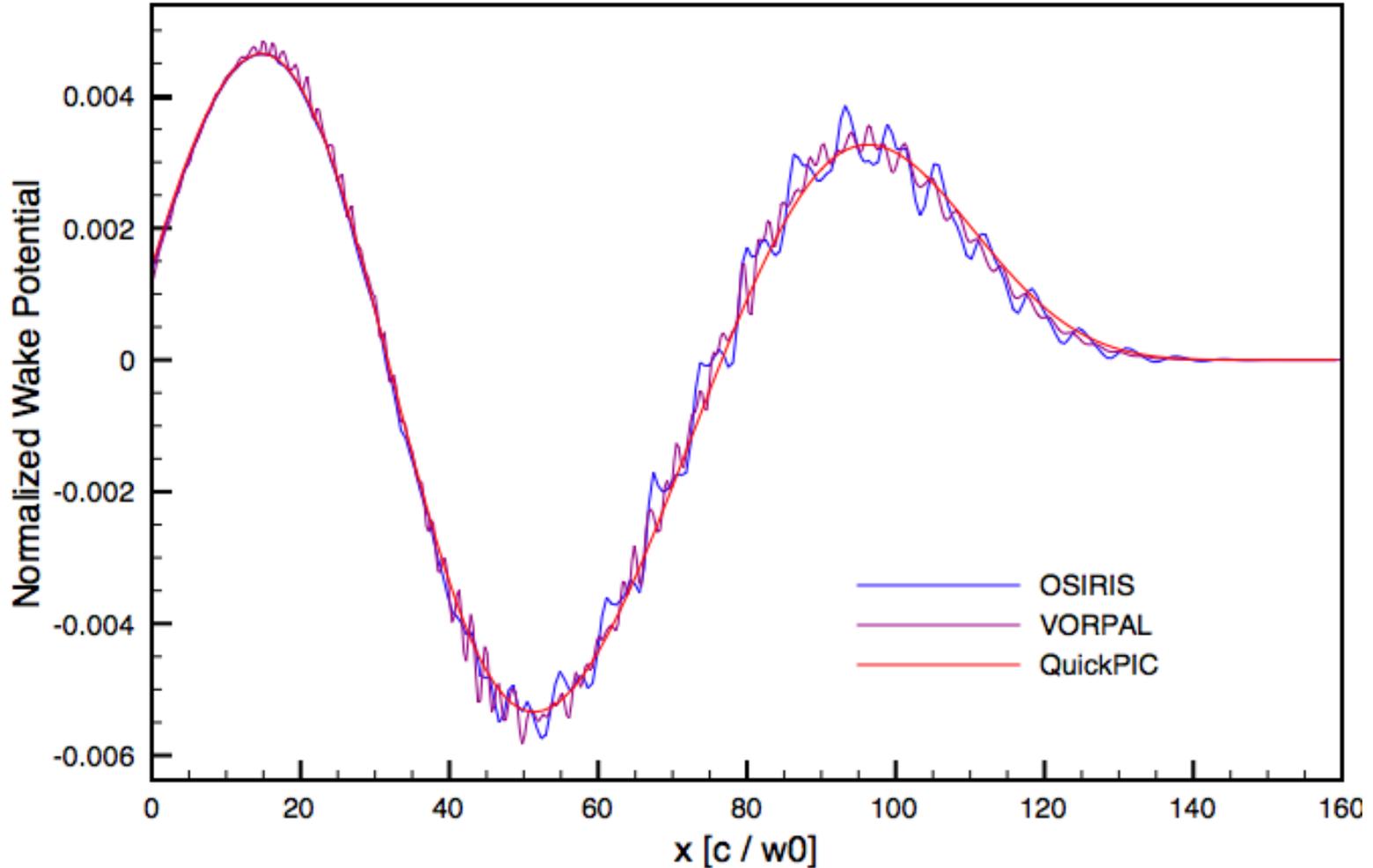


VORPAL – *time-explicit PIC*

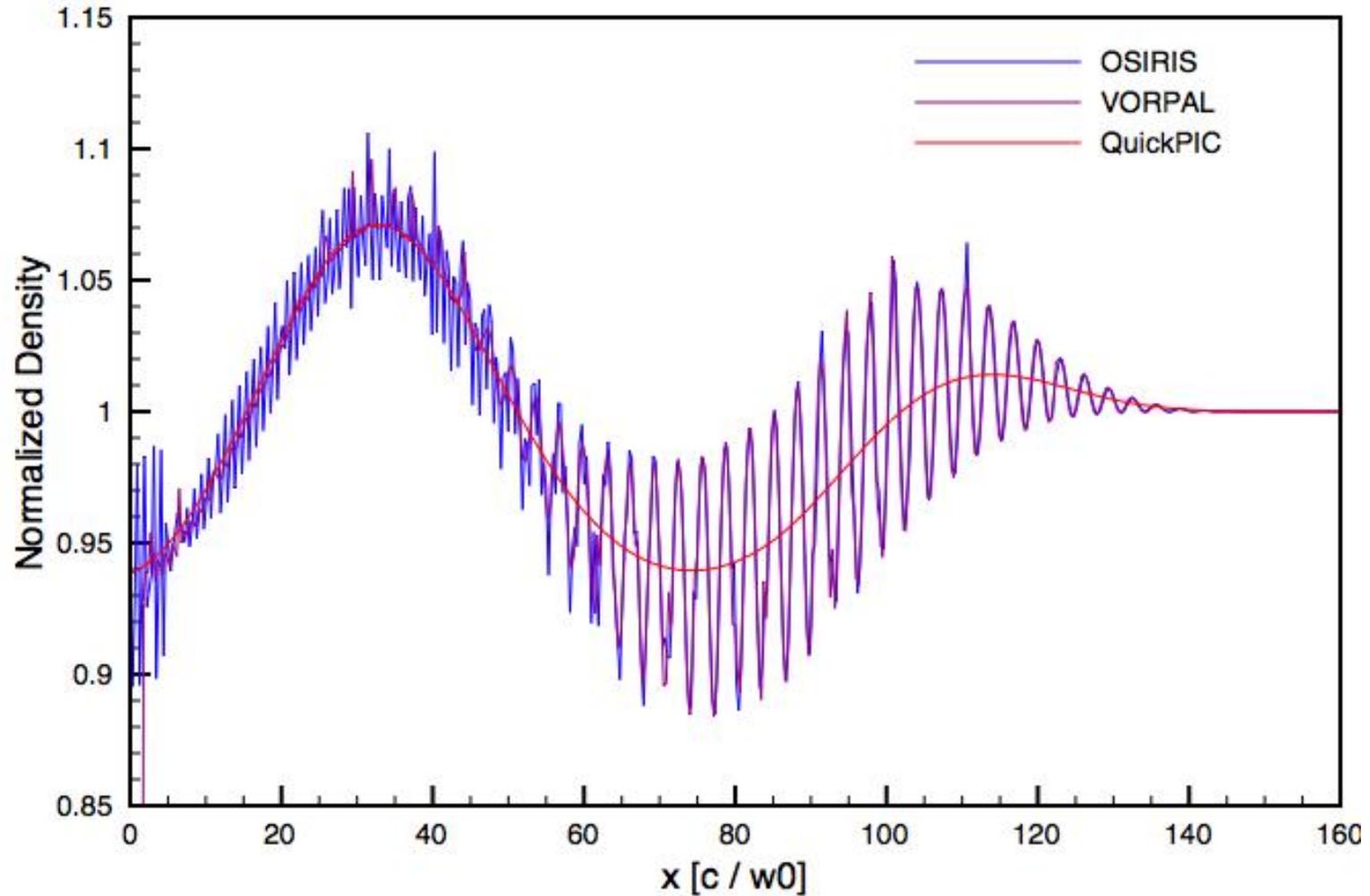


VORPAL – *envelope model*

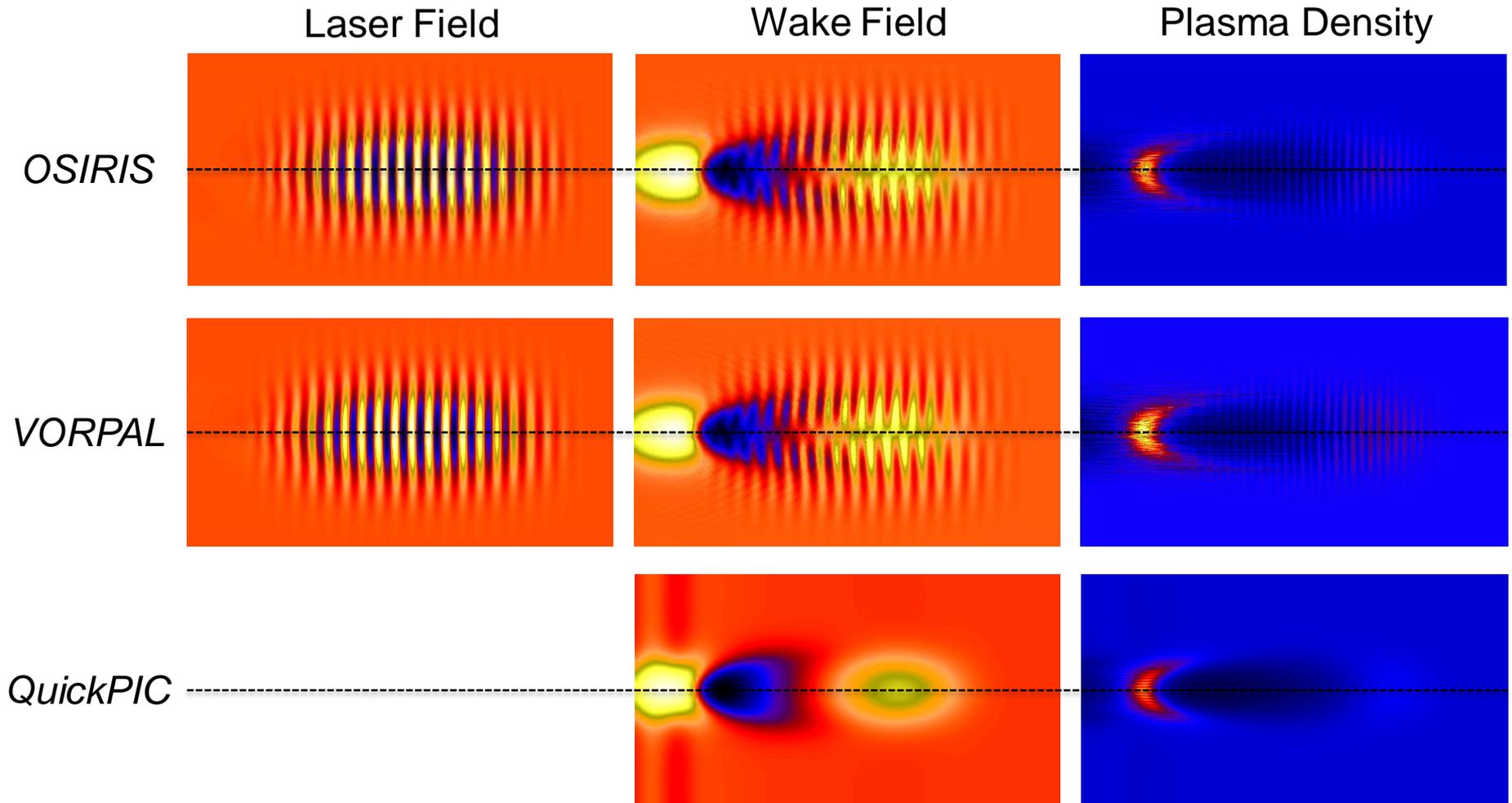
Case 1: $a_0 = 0.5$; 1st-order ptcl shapes



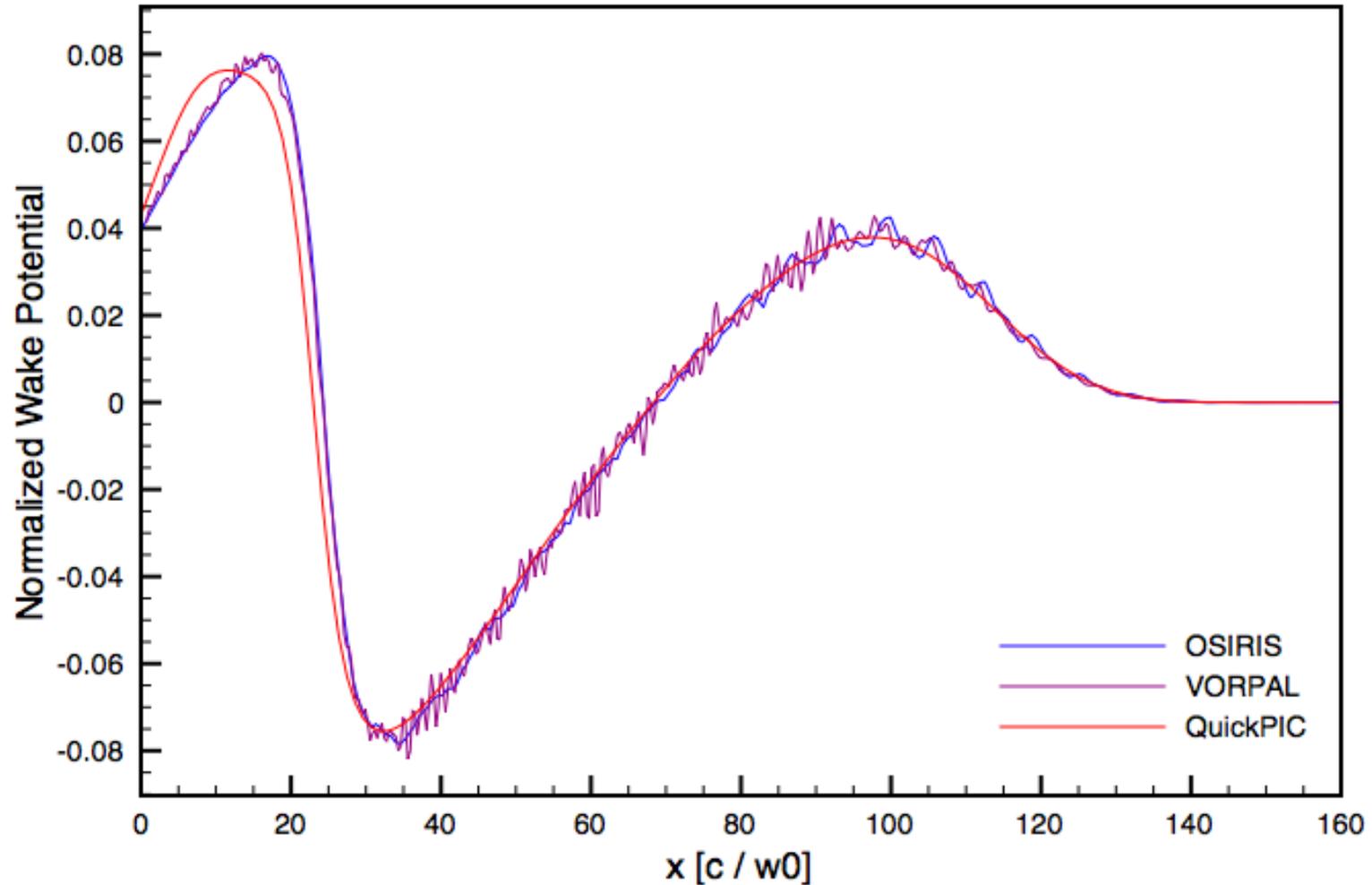
Case 1: $a_0 = 0.5$; 1st-order ptcl shapes



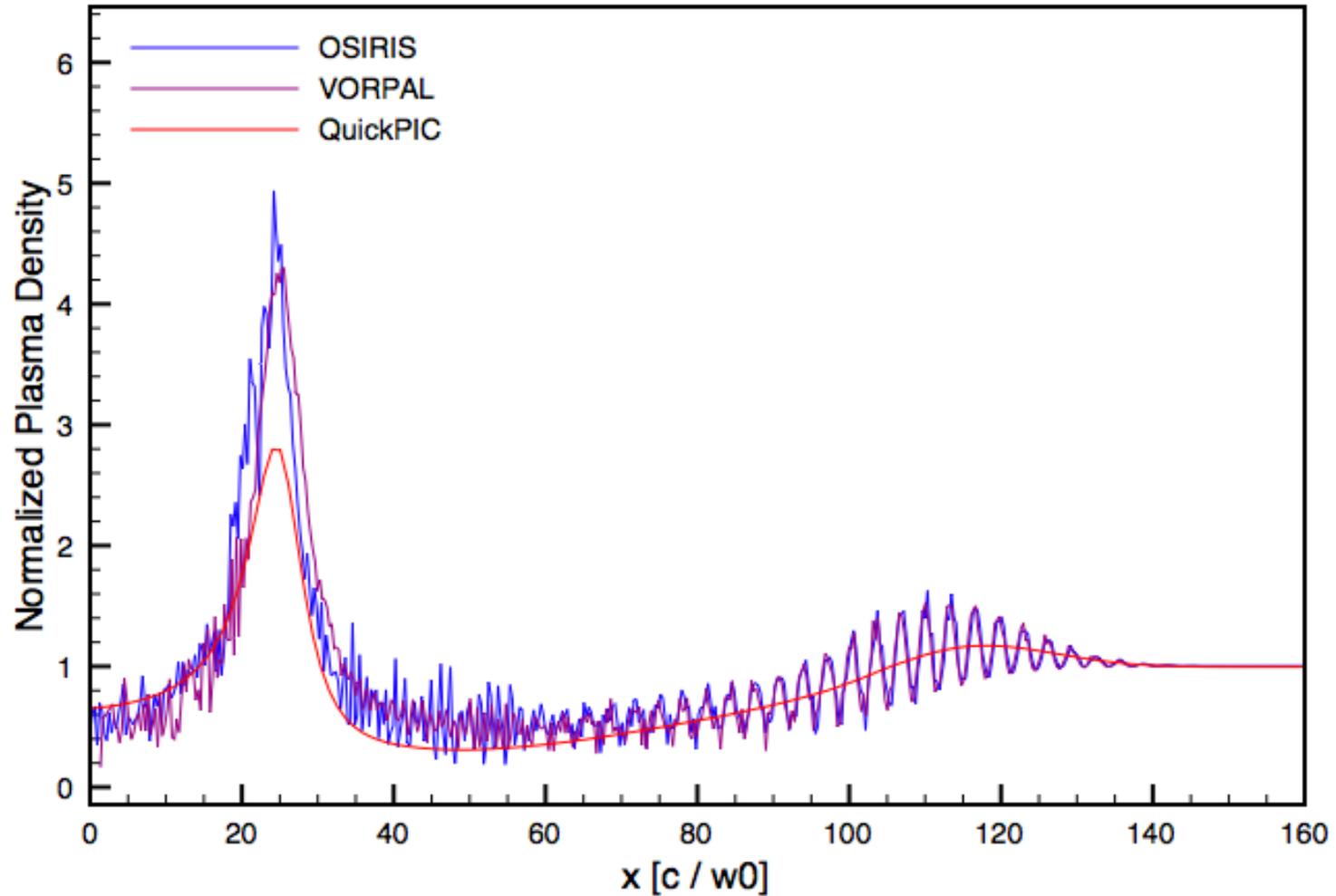
Case 2: $a_0 = 2$; 1st-order ptcl shapes



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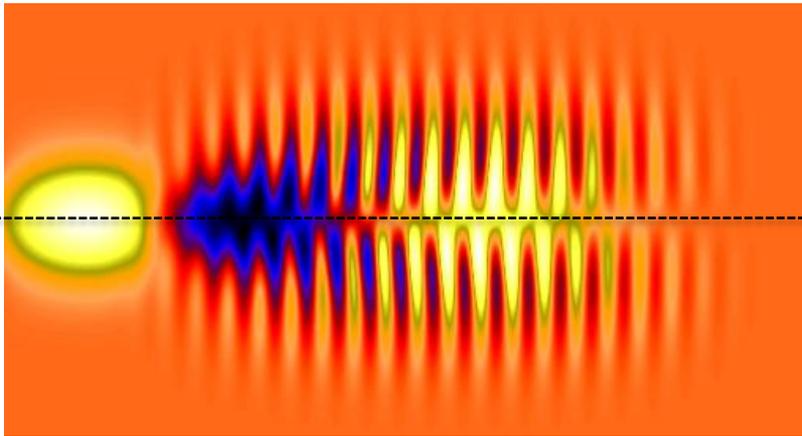


Case 2: $a_0 = 2$; 1st-order ptcl shapes

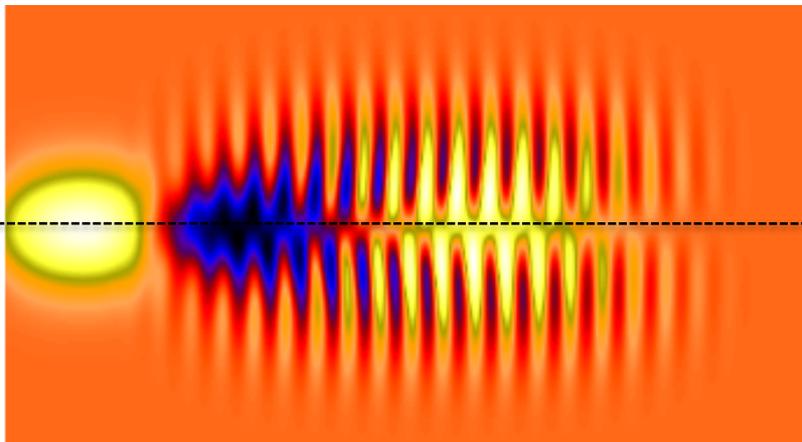
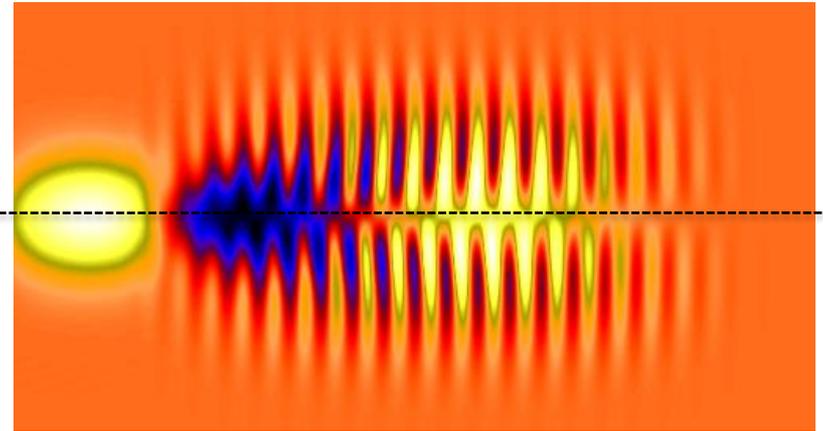


Case 3: $a_0 = 1$; 2nd-order ptcl shapes

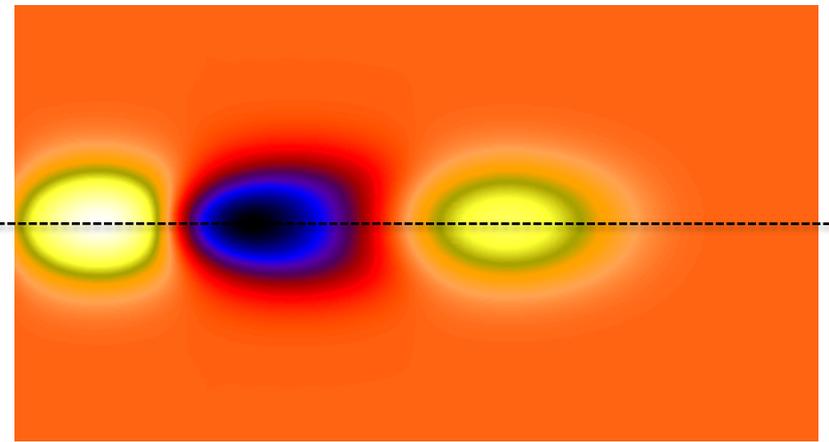
OSIRIS



VORPAL

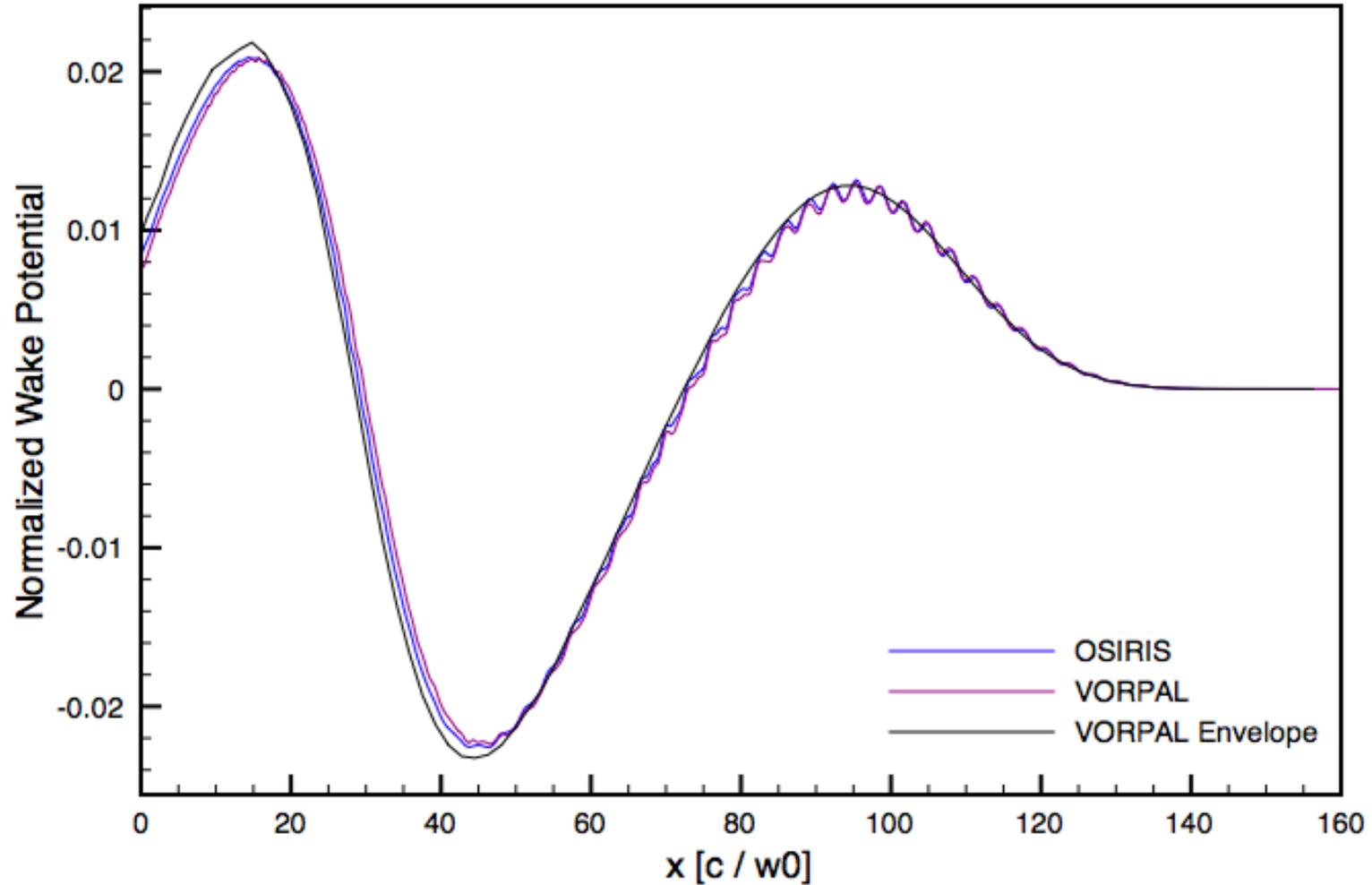


VORPAL – cold fluid

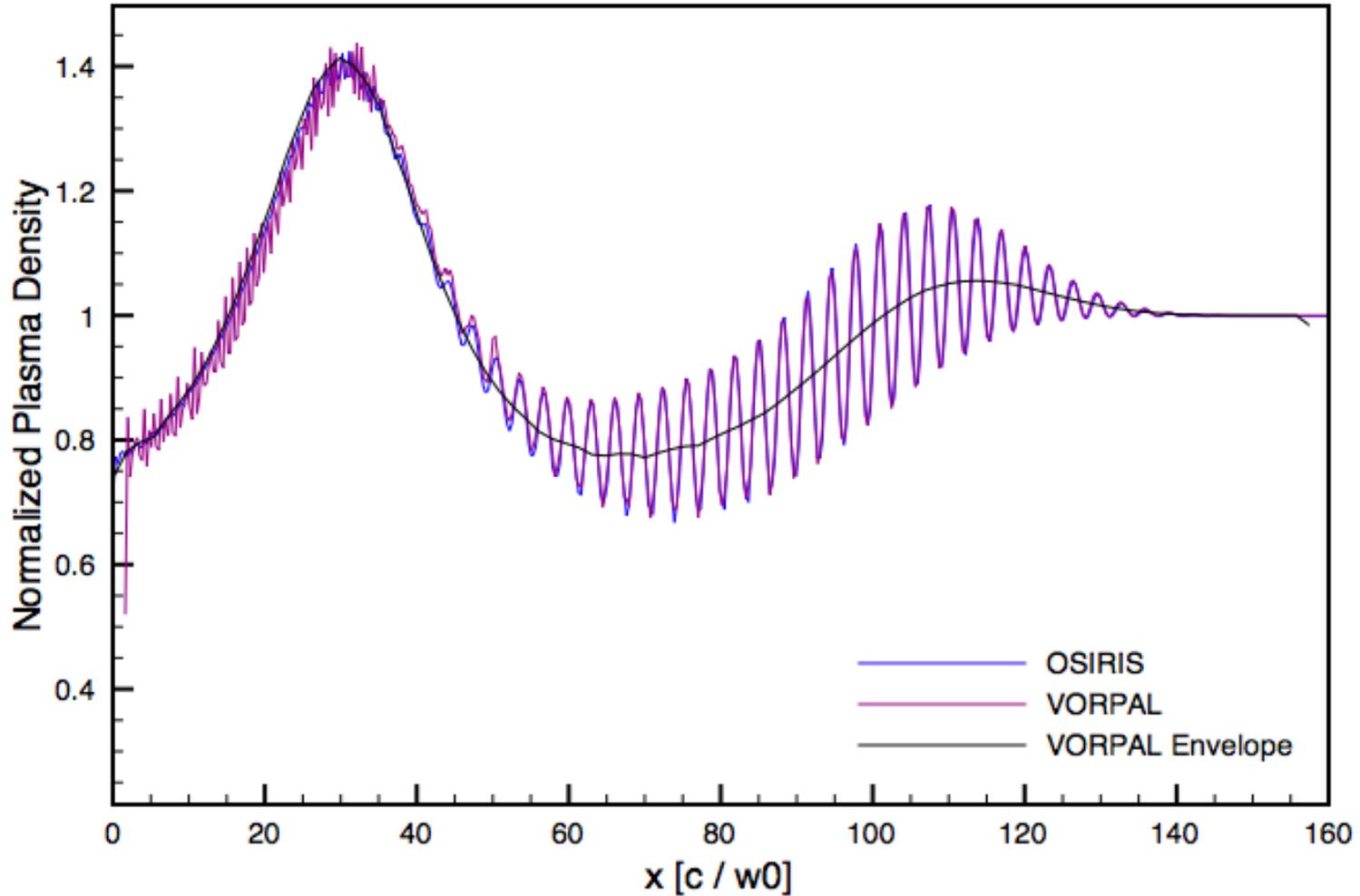


VORPAL – envelope model

Case 3: $a_0 = 1$; 2nd-order ptcl shapes



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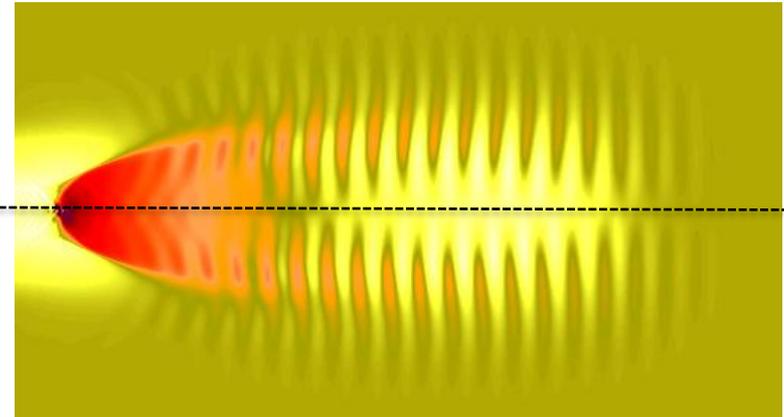
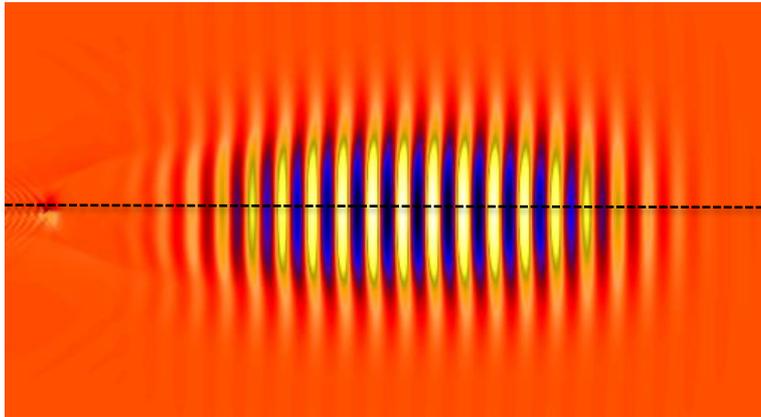


Case 4: $a_0 = 4$; 2nd-order ptcl shapes

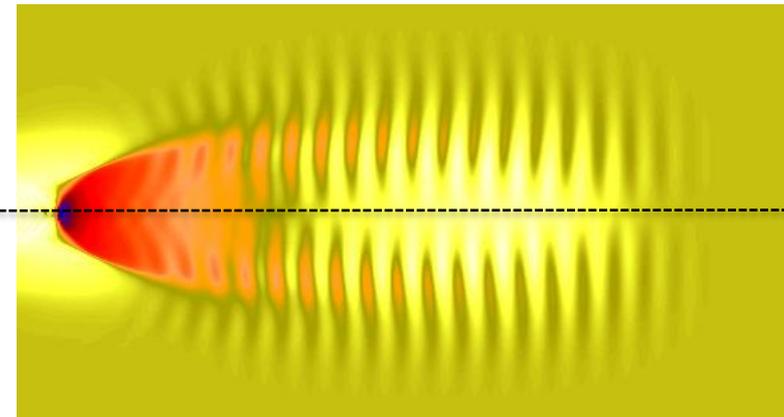
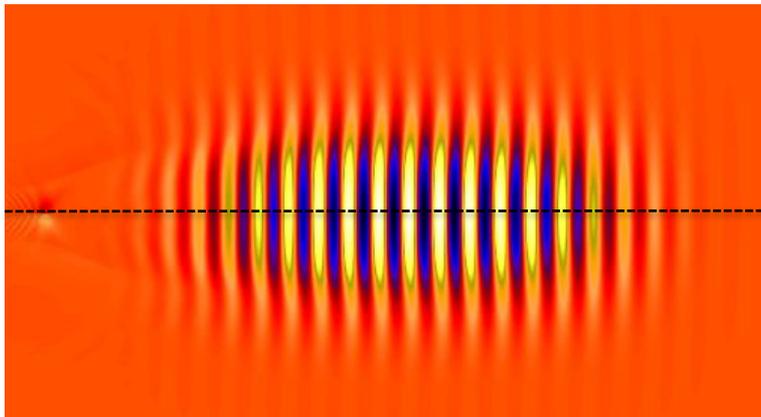
Laser Field

Wake Field

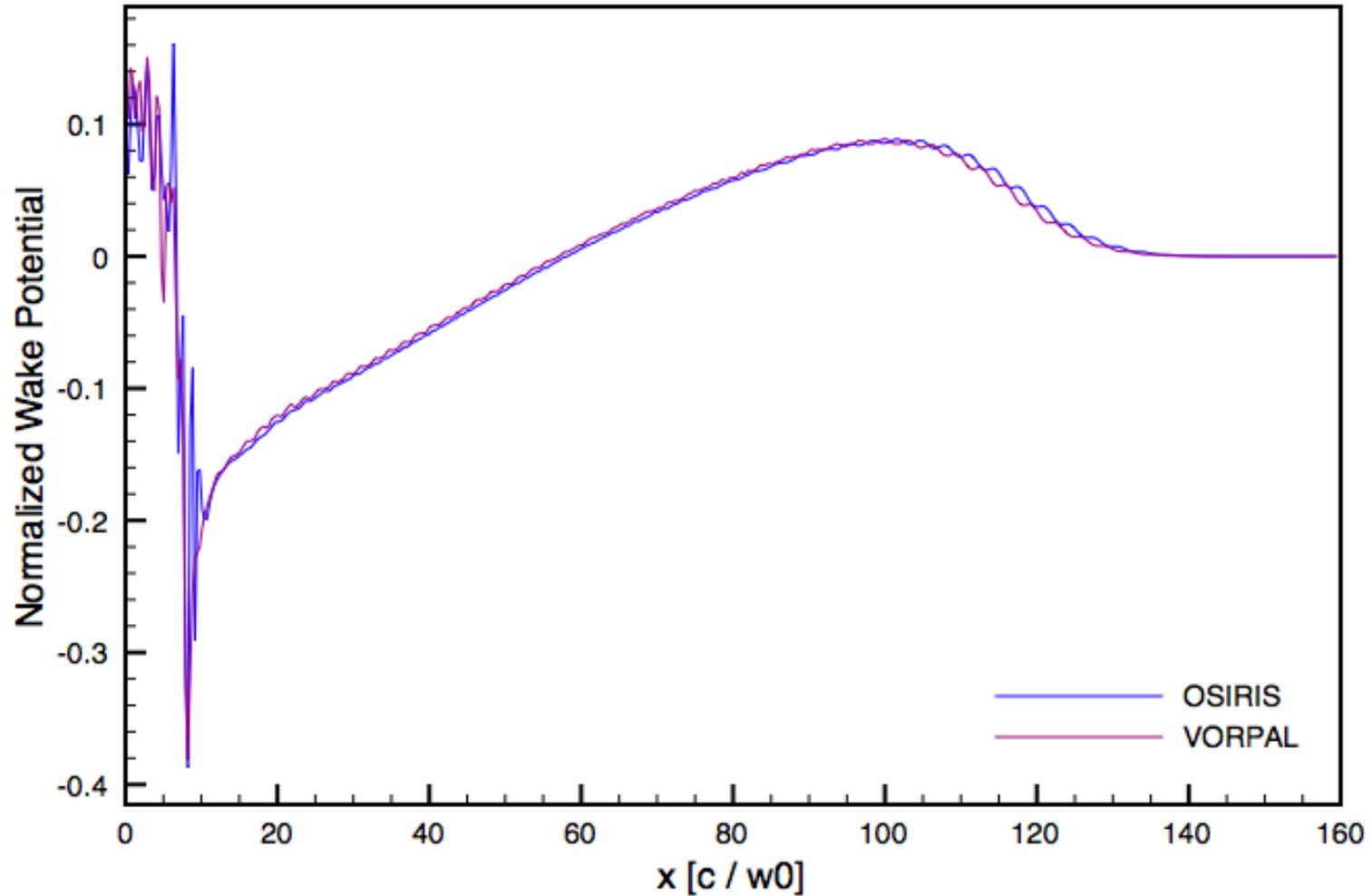
OSIRIS



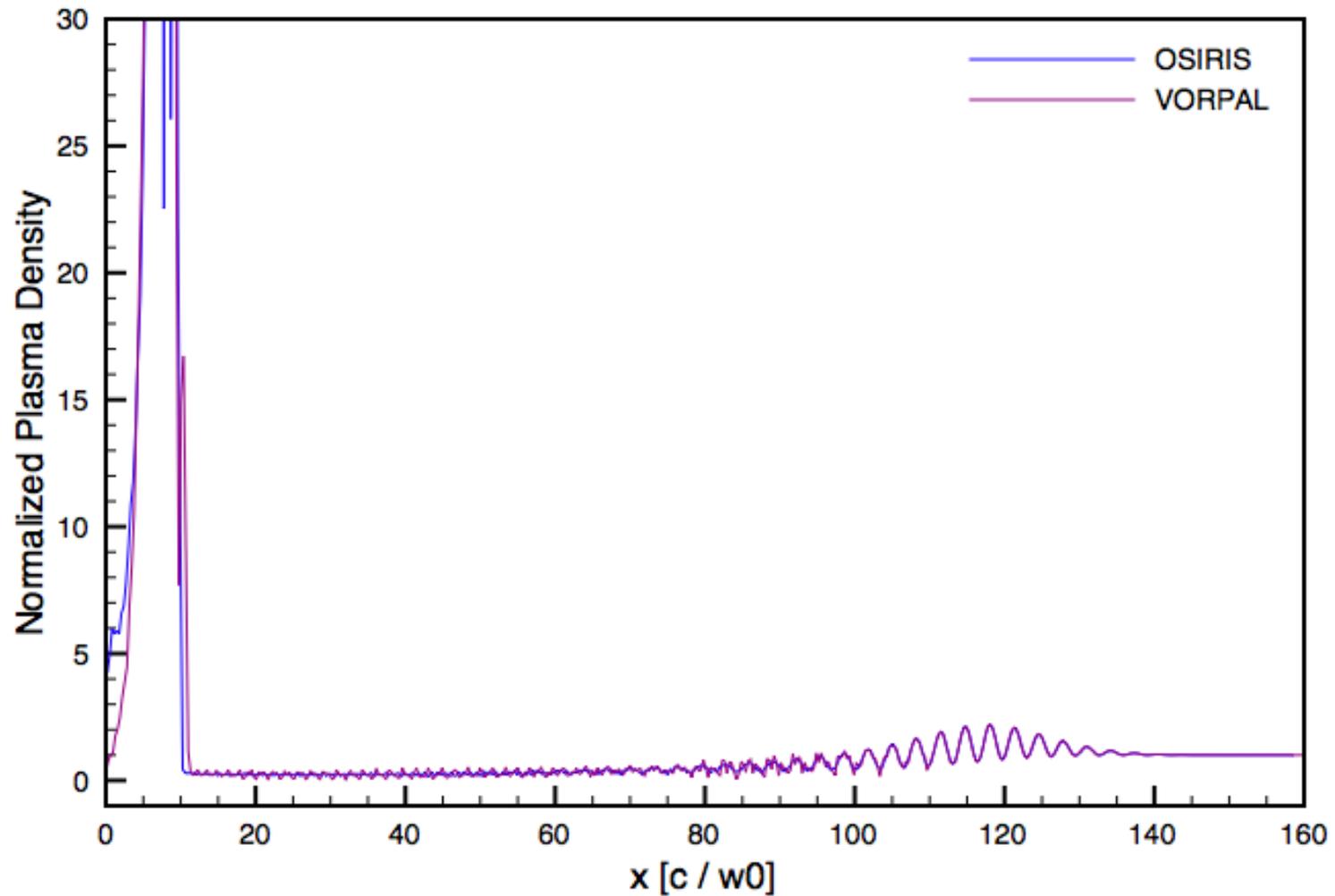
VORPAL



Case 4: $a_0 = 4$; 2nd-order ptcl shapes



Case 4: $a_0 = 4$; 2nd-order ptcl shapes



- **The AA team is pleased with this effort**
 - we plan to do more in the future
 - limited by time and resource constraints
- **Observed agreement is considered acceptable**
 - some differences are seen and not fully understood
 - PIC loop is complicated, with noise & many details
 - 3D convergence studies are expensive (not done)
- **Software benchmarking is time consuming**
 - use the same laser pulse shape; plasma profile
 - use the same boundary conditions
- **Benchmarking efforts require mutual trust**
 - success helps to build trust and confidence