Plasma Density Profile From Laser Diagnostics In FLASHForward

DESY SUMMER STUDENT PROJECT

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Presentation Outline

01 Plasma Wakefield Acceleration

02 FLASHForward

03 Project Motivations and Outline

04 Longitudinal Laser Diagnostics

05 Laser induced Plasma Production

06 Code Outline
- Motor Control
- Realignment
- Data Analysis

07 Results
- Laser Characteristics
- Plasma Density Profile

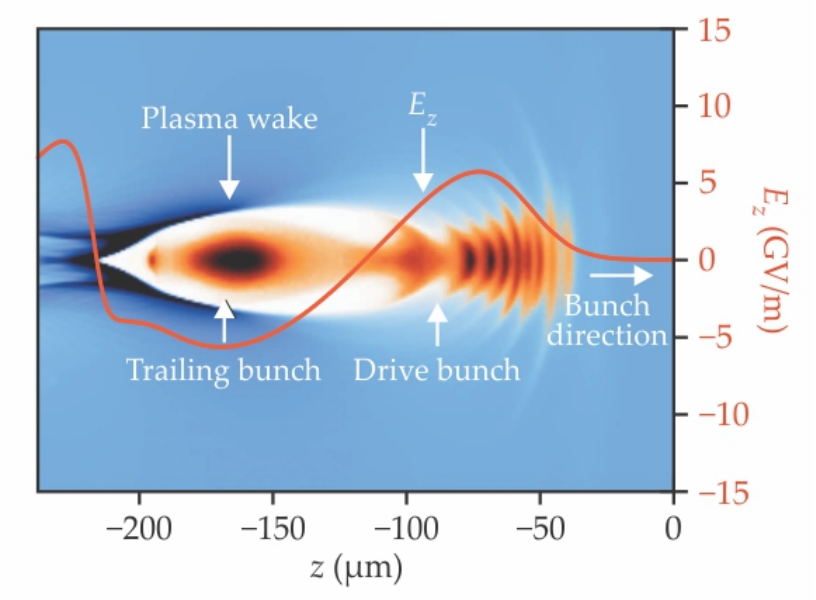
08 Summary and Next Steps

Background

Plasma Wakefield Acceleration

Theory

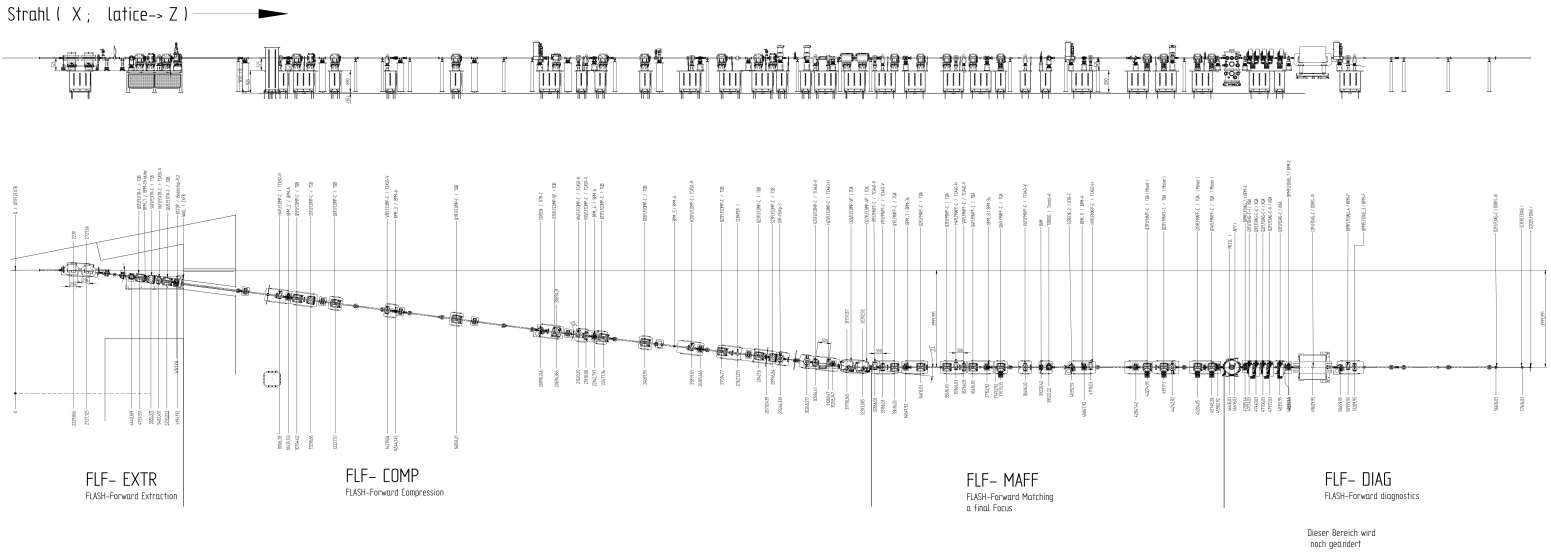
- Using particle beam to excite wake in plasma medium
- Ions stay approximately static whilst lighter electrons move in beam's repulsive field
- Large accelerating gradients of ≈10 GV/m
- Successful wakefield production in FLASHForward



Johanna L. Miller - Precision plasma wakefield acceleration (2014)

FLASHForward

- DESY's contribution to PWFA
- 1.25GeV FLASH beam as drive for plasma wake
- Investigate issues with PWFA
- Demonstrate PWFA electron beam being used for free electron laser
- Complex setup – my project focuses on longitudinal laser diagnostics and plasma chamber



Project Motivation and Aims

Motivations

- Large divergence in accelerated electrons
- Possible to control divergence through tailored plasma profile
- Neutral plasmas can drive ultra-relativistic electron beams
- Understanding of plasma density helps with controlling beam

Aims

- Measure intensity of ionising laser
- Characterise laser beam and beam quality
- Calculate plasma density distribution in plasma cell
- Make MATLAB script to do this automatically and in a user-friendly way

Longitudinal Laser Diagnostics

Purpose

- Cannot measure laser profile inside plasma cell
- Split laser beam and use same travel distance
- Mobile delay stage allows scanning over longitudinal laser direction
- Measure intensity profile with camera

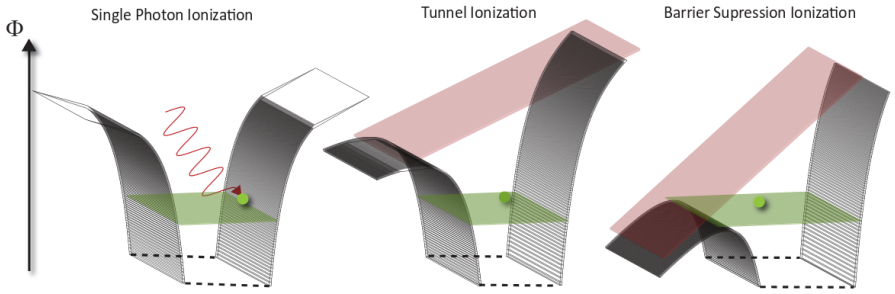
Set-up

- OWIS motor for delay stage position
- 2 pico motors for alignment both with XY axis mobility
- Camera for laser measurements

Laser Induced Plasma Creation

Tunneling Ionisation

- Laser reduces the experienced electric field of the atomic electron
- Reduced potential increases probability of electron tunneling



Alexander Knetsch, Acceleration of laser-injected electron beams in an electron-beam driven plasma wakefield accelerator

Ammosov-Delone-Krainov (ADK) Model

- ADK rate models tunneling ionisation probability per unit time
- Electric field dependent calculation
- Product of rate and Gaussian wave packet integrated over pulse time to find total ionisation

$$W(s^{-1}) = 1.52 * 10^{15} \frac{4^{n^*\xi_i(eV)}}{n^*\Gamma(2n^*)} \left(20.5 \frac{\xi_i^{\frac{3}{2}}(eV)}{E[GV/m]}\right)^{2n^*-1} \times exp\left(-6.83 \frac{\xi_i^{\frac{3}{2}}(eV)}{E[GV/m]}\right)$$

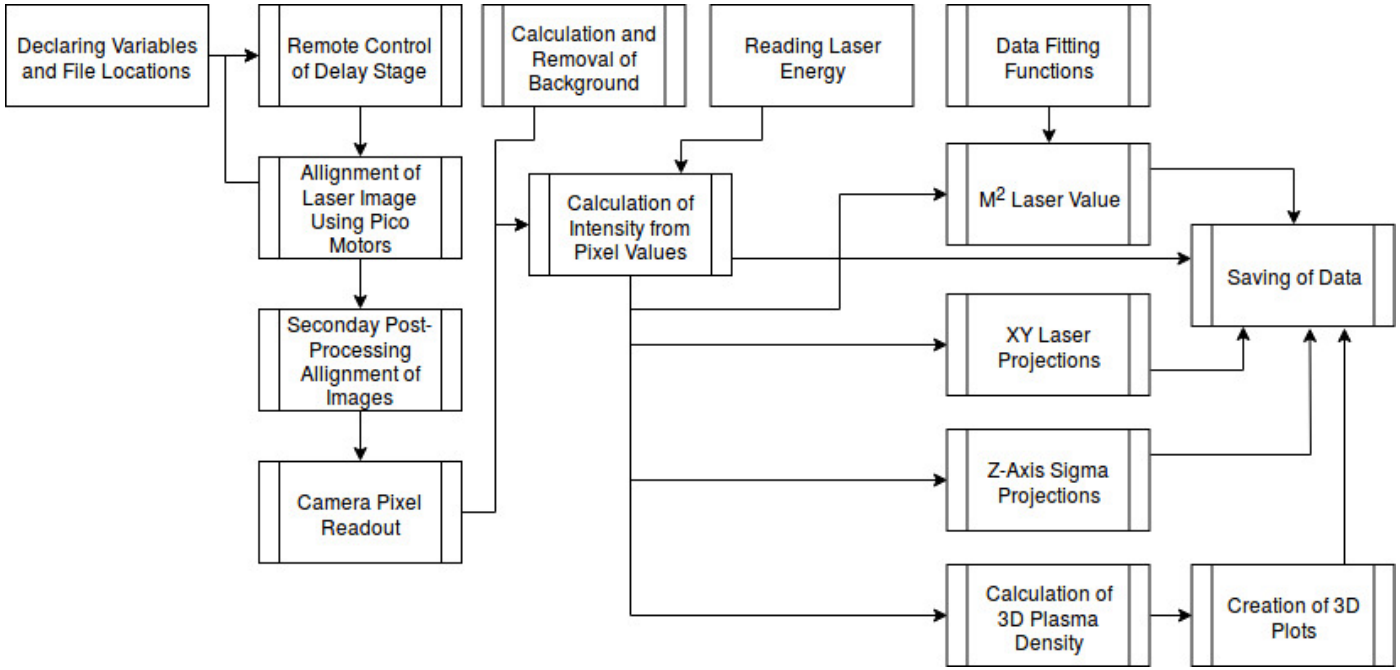
MATLAB Script Outline

Intensity Profile Measurements

- Controlling OWIS motor to move delay stage along beam path
- Controlling PICO motor for reallignment
- Reading intensity image from camera

Data Analysis

- Laser Characteristics: Intensity images, X\Y laser projections, σ_x/σ_y values of beam, Beam parameter product and M^2 Value
- Plasma: Plasma Density Profile



Laser Characteristics Code

XY Projection and σ_x/σ_y

- XY Projection from simple sum of columns – has been scaled in image
- σ_x/σ_y calculated as standard deviation in x and y beam direction

M^2 Fit

- Value always ≥ 1. Value of 1 is perfect beam.
- Calculate the D4σ value: z-dependent positionally weighted width
- Fit parameters to:

$$W^2(z) = W_0^2 + M^4(\lambda/\pi W_0)^2 (z-z_0)^2$$

- Where $W^2(z) = (D4\sigma(z))^2/2$

Results

Laser Characteristics

X/Y Projection of Beam

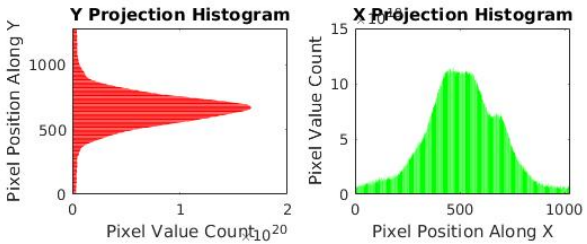
- Y axis has close to Gaussian distribution
- X axis is clearly smeared out as seen in image and projection

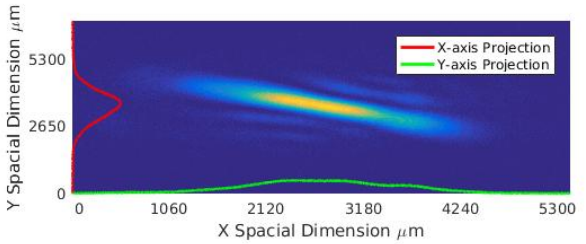
σx/σy Values of Beam

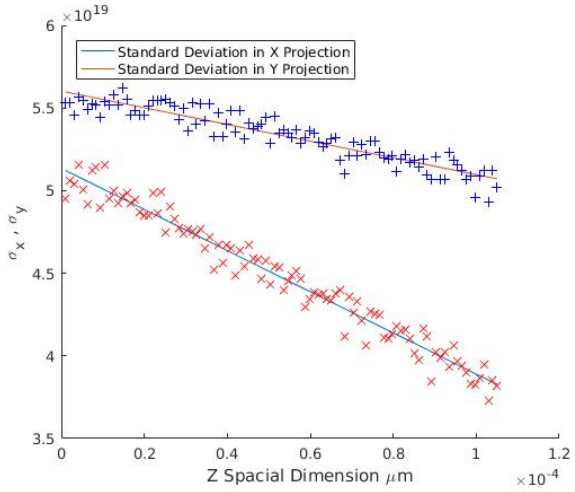
- Fairly consistent beam width over scan length
- Values expected to have minimum at beam waist but this is not seen. This behavior effects BPP and M^2 calculation due to poor parameters for fit

M^2 Value

- Calculated independently for X and Y directions due to asymmetry







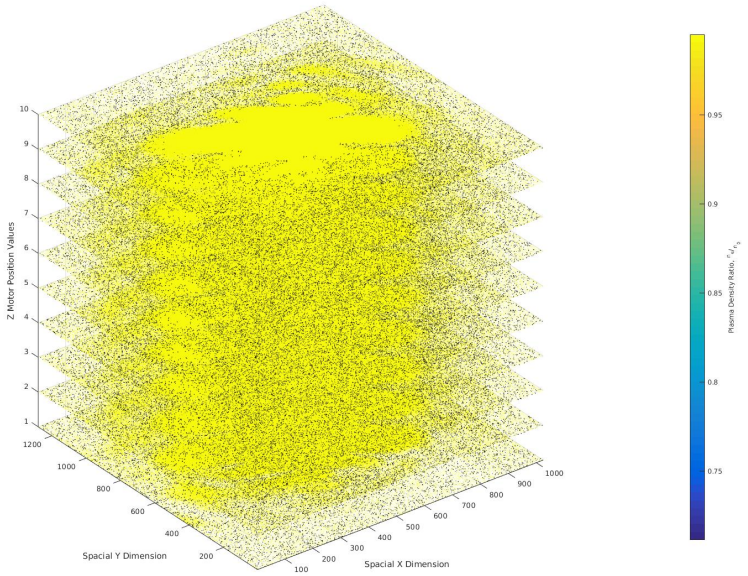
Plasma Density Profile

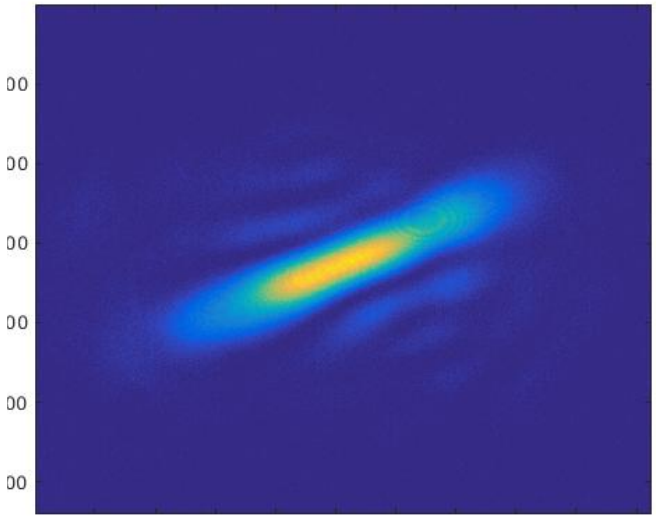
3D Plasma Density Distribution

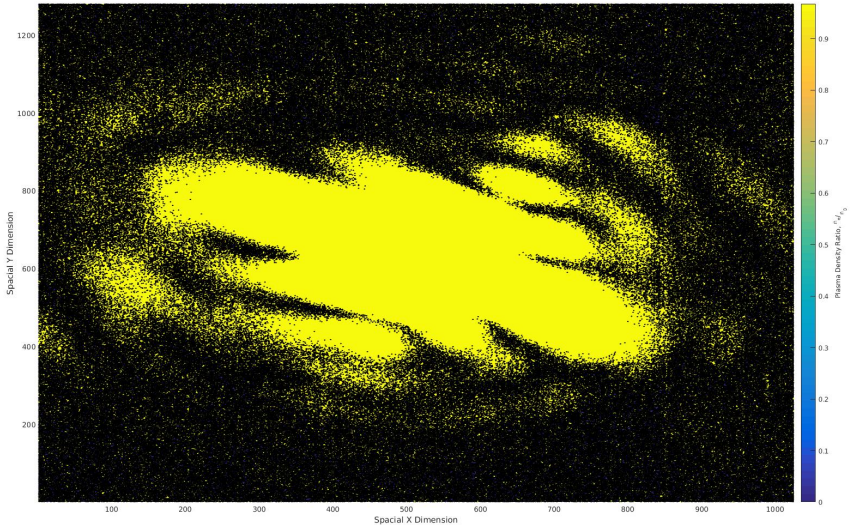
- Shows plasma density:neutral gas ratio

Single Slice

- Clear similarity to laser intensity as expected







Summary and Future Research

Summary

- Data taken correctly and automatically over set range
- Data converted to true values using measured beam energies
- Analysis on beam characteristics and plasma density successfully completed
- Multifunction code created for future investigation in PWFA experiments

Future Research

- Use secondary PICO motor for two point alignment
- Calculate ADK rate for hydrogen/helium mix as required for future injection techniques
- Model laser dispersion through plasma to gain more realistic plasma density

Thank you

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Code available - https://github.com/wisky02/DESY