First electron acceleration results of the AWAKE Experiment at CERN

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On behalf of the AWAKE Collaboration

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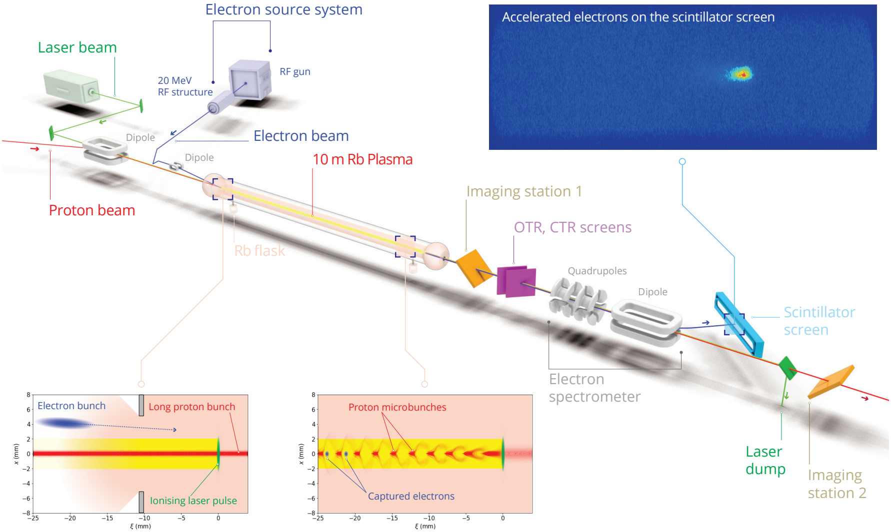
LEVERHULME TRUST

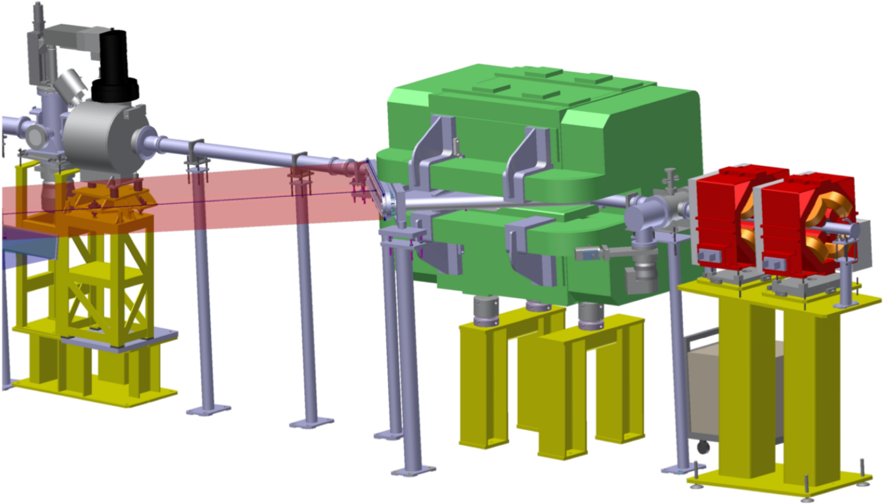
Outline

- Introduction to AWAKE.
- Spectrometer design.
- Spectrometer image analysis.
- Position - energy conversion and related uncertainties.
- First electron acceleration results.

Introduction to AWAKE



Spectrometer Design



Spectrometer Image Analysis

There are three main considerations when analysing images of the spectrometer screen:

1. Spectrometer optical line
2. Screen calibration
3. Background subtraction

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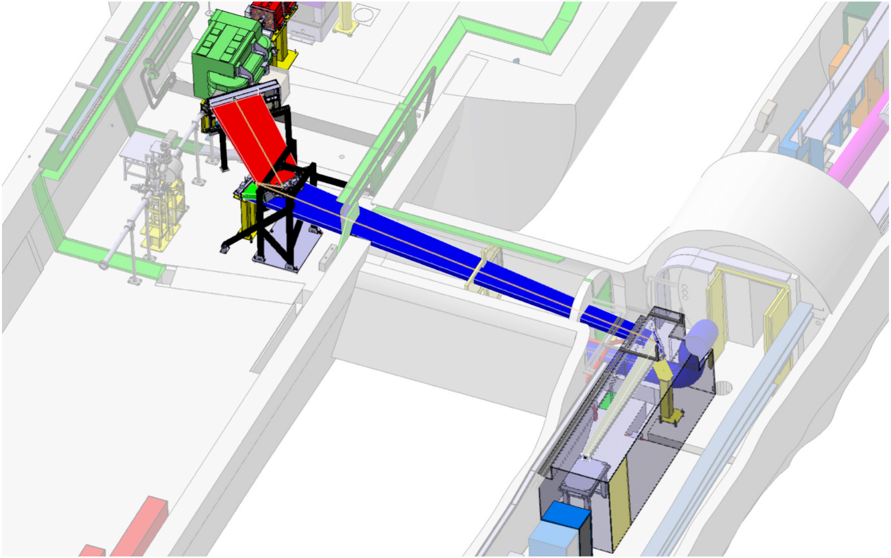
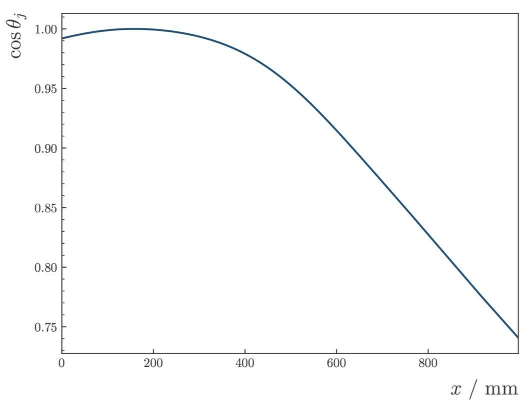
Spectrometer Optical Line



Spectrometer Optical Line: Corrections

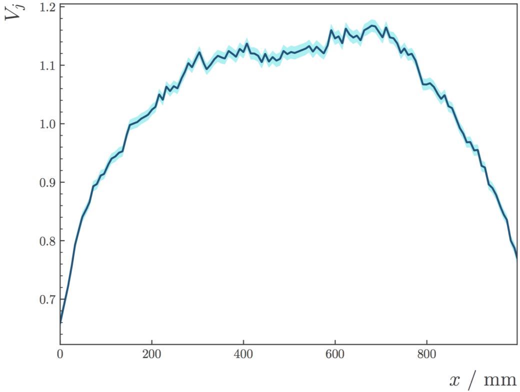
Incident Angle Correction:



Electrons are incident on the plane of the screen at different angles (θ_j) $\Rightarrow$ different path lengths within the scintillator. Scintillator response $\propto$ path length, so correction must be applied.

Spectrometer Optical Line: Corrections

Vignetting correction:



The amount of light collected from the screen varies with position due to the finite optics size. This was measured by scanning a known light source across the screen and measuring the relative brightness.

Spectrometer Image Analysis

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2. Screen calibration
3. Background subtraction

Screen Calibration

- Within the current AWAKE setup, it is not possible to propagate an electron beam of known charge to the spectrometer screen.
- The screen and camera were taken to the CLEAR facility at CERN where precisely defined electron beams were used to calibrate the screen scintillator response.
- The measured charge response was then corrected to the AWAKE setup by considering:
  - Relative camera position.
  - Measurement of a known light source.
  - Exposure settings (e.g. MCP gain, gate width, delay).
- This resulted in a charge response calibration measurement for the AWAKE setup:

$$6.9 \pm 2.1 \times 10^{6}\,\mathrm{pC}^{-1}$$

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- The scintillator screen is subject to significant background radiation due to interaction between protons and a window separating the SPS and AWAKE transfer lines.

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- This background contribution is dependent on the proton bunch charge, $b_{ij} = \alpha_{ij} N_p + \beta_{ij}$, where β_{ij} is the intrinsic contribution from camera dark noise.
- This is then rescaled according to a ratio of two regions in the signal and background images that do not have electrons present:

$$b'_{ij}(N_p) = b_{ij} \frac{\sum_{k,l \in \mathcal{R}} s_{kl}}{\sum_{k,l \in \mathcal{R}} b_{kl}}$$

- The signal is then extracted:

$$s'_{ij} = s_{ij} - b'_{ij}$$

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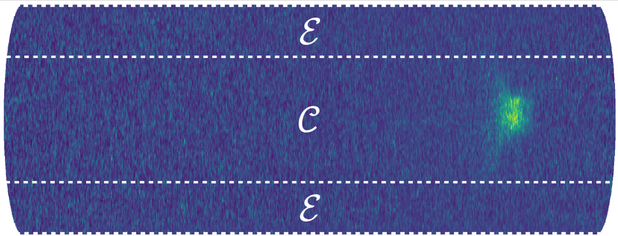

$$S_{ij} = s'_{ij} - \frac{\sum_{k,l\in\mathcal{E}} s'_{kl}/\sigma^2_{s'_{kl}}}{\sum_{k,l\in\mathcal{E}} 1/\sigma^2_{s'_{kl}}}$$

$$\mu_j = \frac{\cos\theta_j}{V_j} \cdot \frac{\sum_{i\in\mathcal{C}_j} S_{ij}/\sigma^2_{S_{ij}}}{\sum_{i\in\mathcal{C}_j} 1/\sigma^2_{S_{ij}}}$$

Position → Energy Conversion

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- An energy uncertainty of approximately 2% was calculated when considering the accuracy of the field maps, the precision of distance measurements and the 1.5mm resolution of the optical system.

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- An energy uncertainty of approximately 2% was calculated when considering the accuracy of the field maps, the precision of distance measurements and the 1.5mm resolution of the optical system.
- Overall uncertainty is dominated by the emittance of the accelerated electron beam and can be larger than 10%. The use of quadrupoles to focus the beam was calculated to limit this uncertainty to approximately 5% for electrons near the focal energy.

Results

N.B. These results have not yet been published and are still under embargo.

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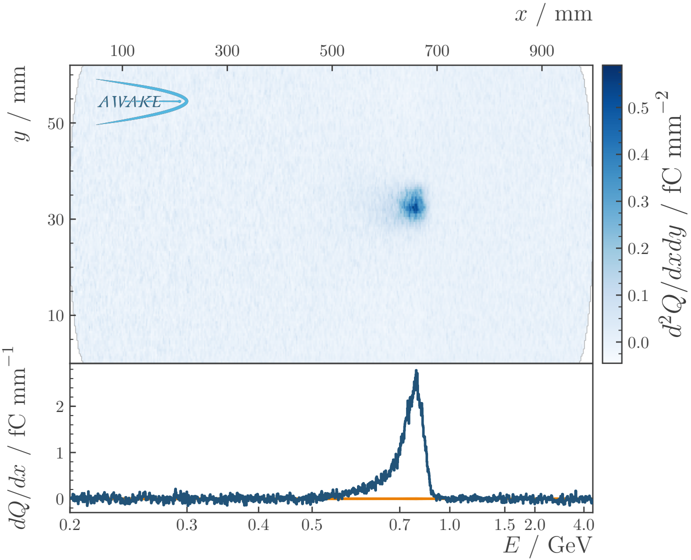
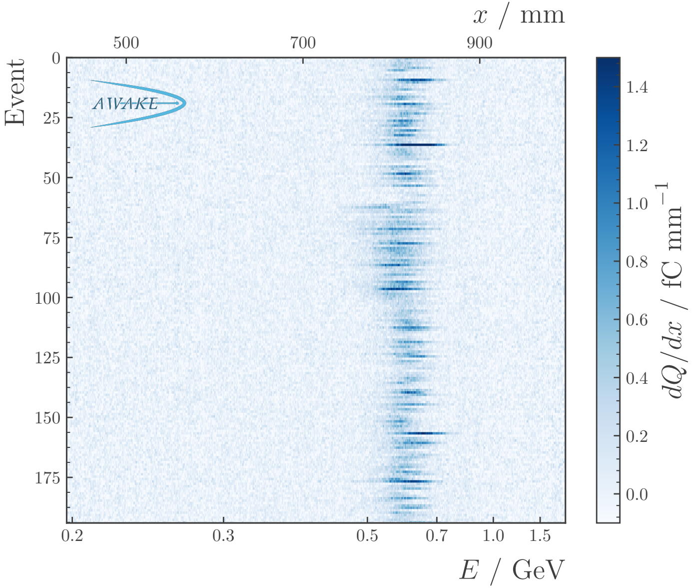
- These results are from the experimental run in May 2018.
- Three different plasma densities were tested: $n_{pe} = \{1.8, 3.9, 6.6\} \times 10^{14}\,\mathrm{cm}^{-3}$.
- At each density, different longitudinal plasma gradients were tested and an 'optimum' value was found.

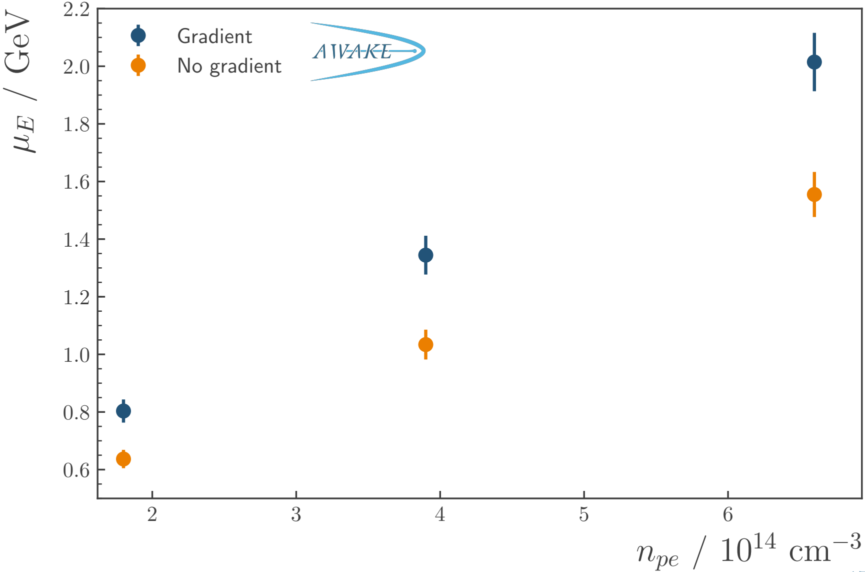
Results: $n_{pe} = 1.8 \times 10^{14}\,\mathrm{cm}^{-3}$ with 5% gradient



Results: $n_{pe} = 1.8 \times 10^{14}\,\mathrm{cm}^{-3}$ with no gradient



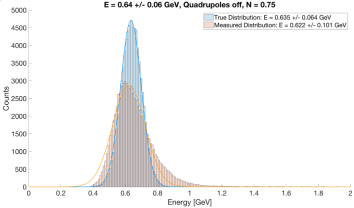
Results: Variation with n_{pe}

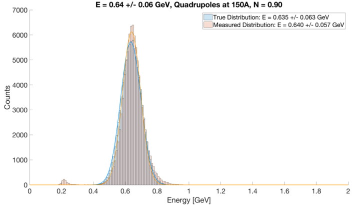


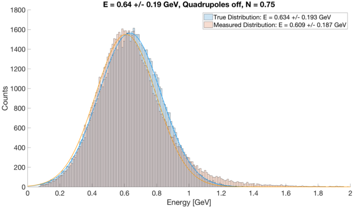
Summary

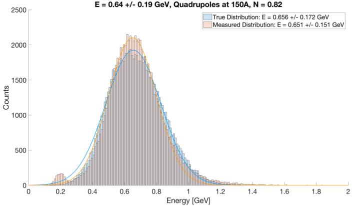
- This is the first demonstration of electron acceleration using a proton-driven plasma wakefield.
- The energies achieved are within the range of values originally predicted by particle-in-cell and fluid code simulations of the AWAKE experiment.
- The amount of charge that was captured and subsequently accelerated was lower than predicted.
- Future experimental runs that will take place between now and the end of the year will be focused on understanding the injection process through optimisation of electron bunch delay, injection angle and other parameters.
- A measurement of the emittance of the accelerated electron bunch is also planned to be performed.

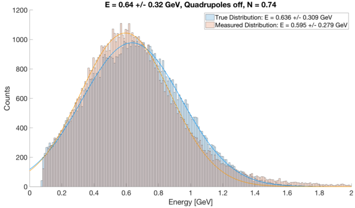
Thank you for listening.

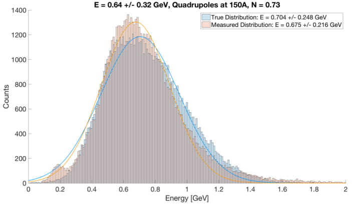

E = 0.64 +/- 0.06 GeV, Quadrupoles off, N = 0.75
True Distribution: E = 0.635 +/- 0.064 GeV
Measured Distribution: E = 0.622 +/- 0.101 GeV
Counts
Energy [GeV]


E = 0.64 +/- 0.06 GeV, Quadrupoles at 150A, N = 0.90
True Distribution: E = 0.635 +/- 0.063 GeV
Measured Distribution: E = 0.640 +/- 0.057 GeV
Counts
Energy [GeV]

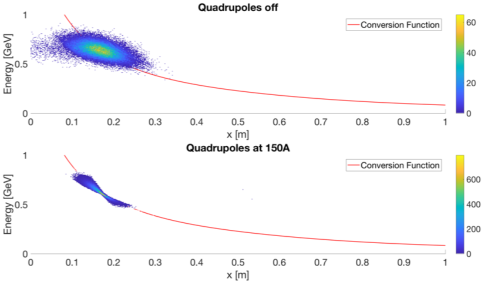

E = 0.64 +/- 0.19 GeV, Quadrupoles off, N = 0.75
True Distribution: E = 0.634 +/- 0.193 GeV
Measured Distribution: E = 0.609 +/- 0.187 GeV
Counts
Energy [GeV]

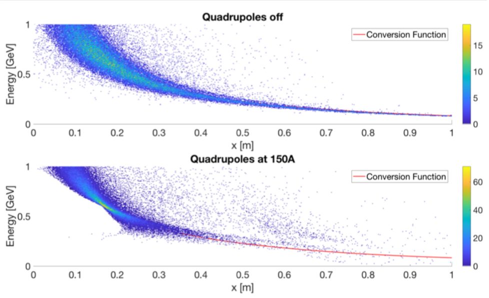

E = 0.64 +/- 0.19 GeV, Quadrupoles at 150A, N = 0.82
True Distribution: E = 0.656 +/- 0.172 GeV
Measured Distribution: E = 0.651 +/- 0.151 GeV
Counts
Energy [GeV]


E = 0.64 +/- 0.32 GeV, Quadrupoles off, N = 0.74
True Distribution: E = 0.636 +/- 0.309 GeV
Measured Distribution: E = 0.595 +/- 0.279 GeV
Counts
Energy [GeV]


E = 0.64 +/- 0.32 GeV, Quadrupoles at 150A, N = 0.73
True Distribution: E = 0.704 +/- 0.248 GeV
Measured Distribution: E = 0.675 +/- 0.216 GeV
Counts
Energy [GeV]

Backup slides: Quadrupole Analysis





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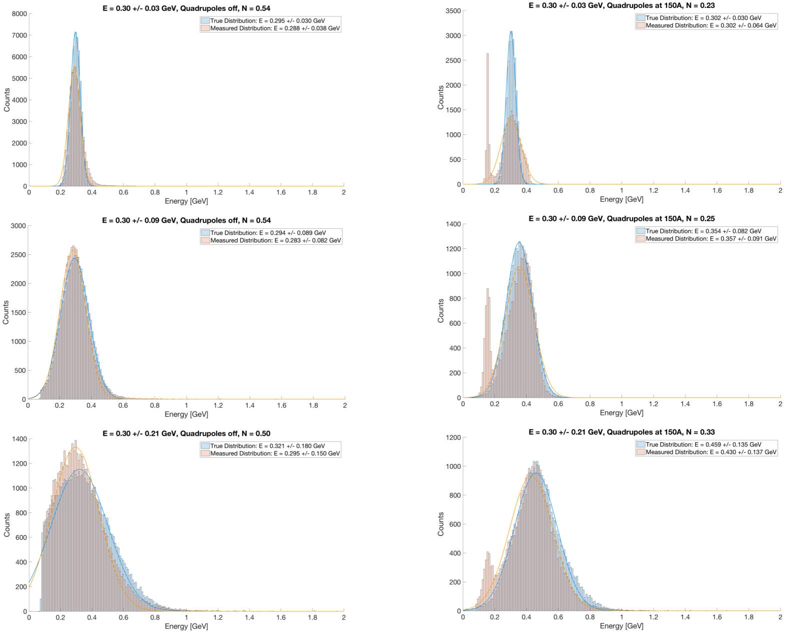

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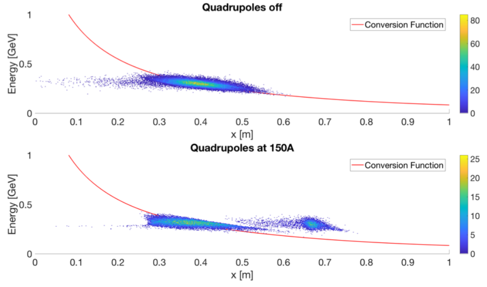

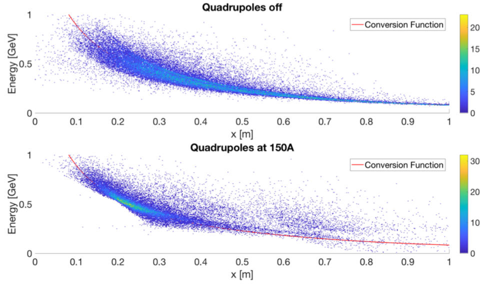

Backup slides: 2GeV shot