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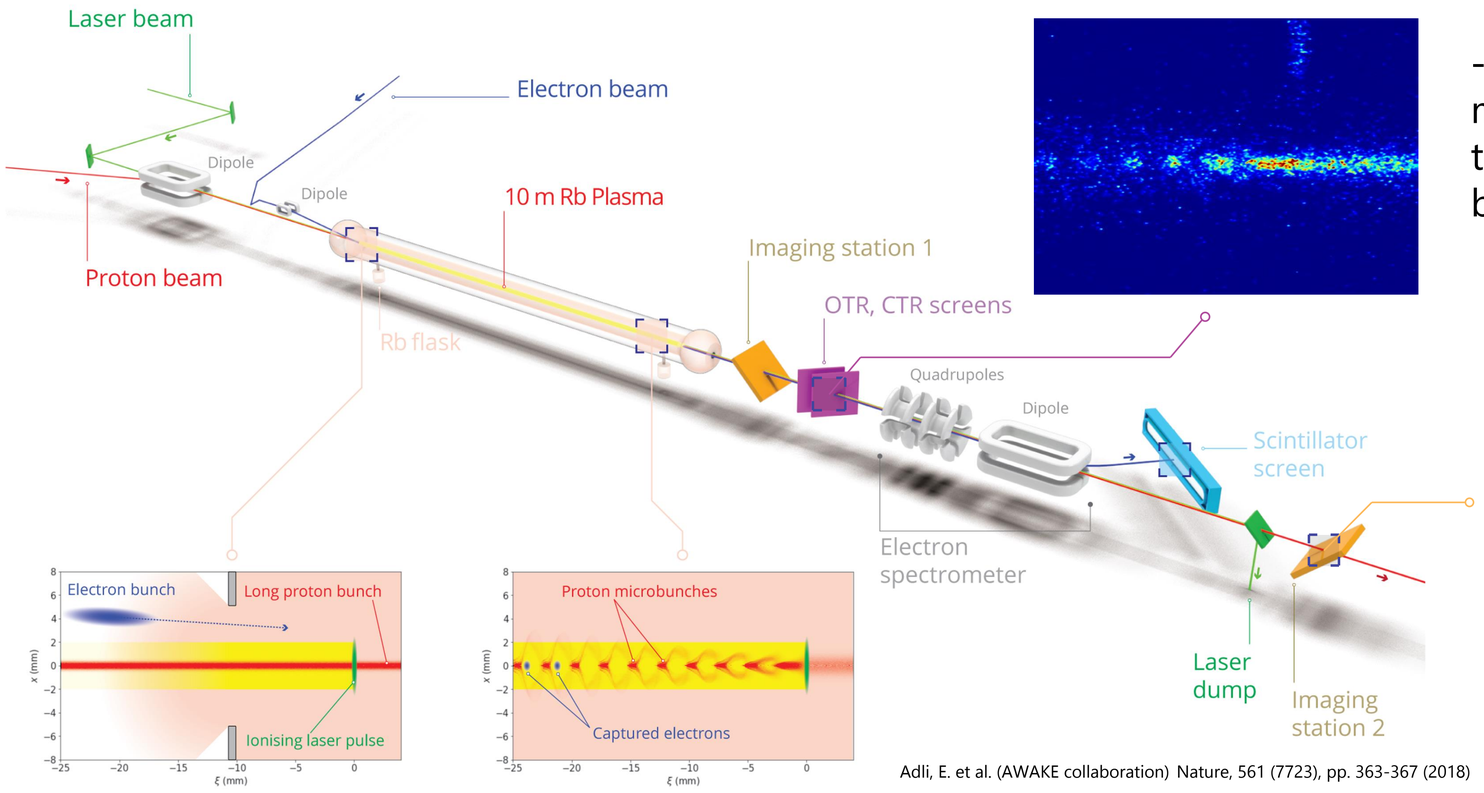
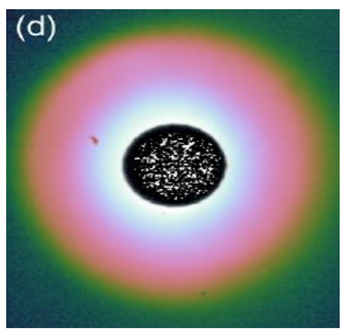
Comparison of OSIRIS/LCODE/QV3D simulations with the measurements of the proton beam in AWAKE experiment

PROTON BEAM DIAGNOSTICS IN AWAKE



- Streak camera collects the light from the OTR screen and measures a time resolved beam profile. One image gives the information about the size of proton beam micro-bunches and unmodulated beam head after SSM.



Turner, M. et al. (AWAKE collaboration) Physical Review Letters, 122 (5), 054801 (2019)

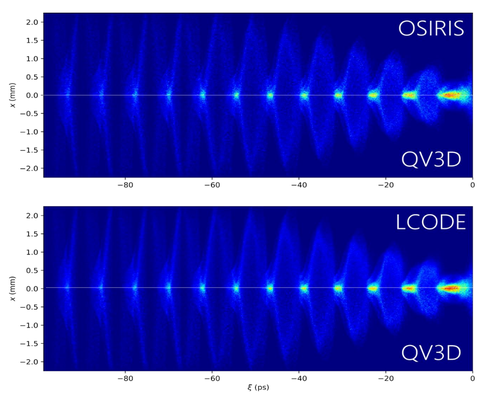
- Imaging stations measure time integrated transverse profile of the protons being defocused during the SSM. Radii of the outmost protons on these screens depend on the maximum fields excited in plasma.

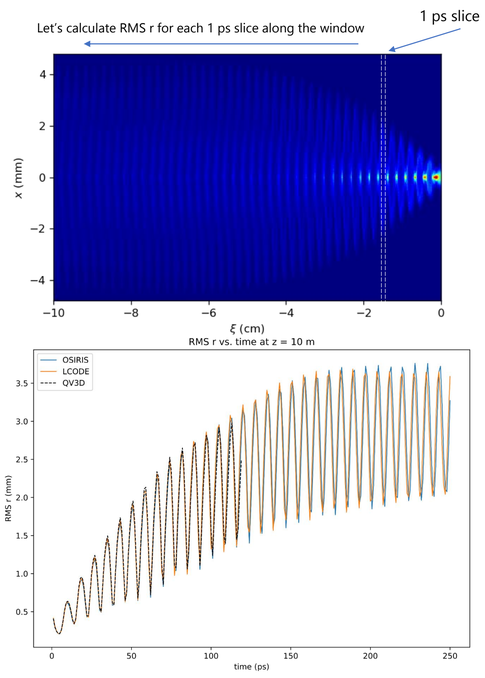
Adli, E. et al. (AWAKE collaboration) Nature, 561 (7723), pp. 363-367 (2018)

CODE BENCHMARKING

Three different codes showed perfect agreement in 120 ps time window (15 plasma periods).

Code	Geometry	Model
LCODE	2D cylindrical	Quasistatic
OSIRIS	2D cylindrical	Full PIC
QV3D	3D	Quasistatic

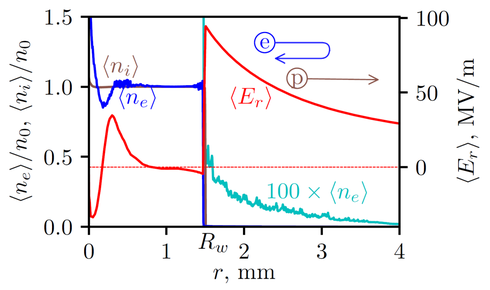




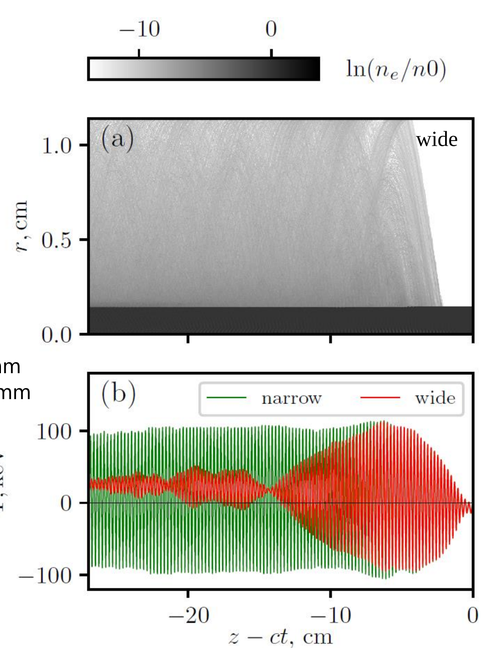
Simulations were performed by Alexey Petrenko and Alexander Pukhov (QV3D), Mariana Moreira (OSIRIS) and Alexander Gorn (LCODE)

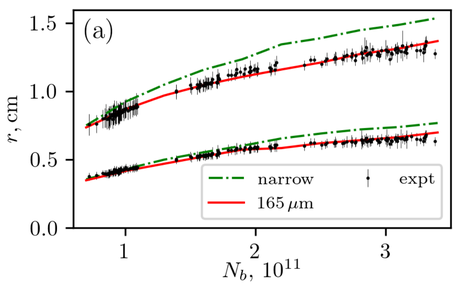
PARAMETRIC SCANS

We compare radii of outmost electrons at two Imaging Stations and in LCODE simulations. For quantitative agreement, the simulation window must be wide. This is necessary for correct simulation of high-energy plasma electrons that escape from the plasma as a result of wavebreaking. The electrons then create charge-separation field, return back and destroy the plasma wave.



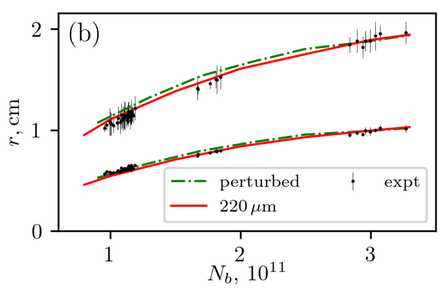
Simulation window,
wide: 11.4 mm
narrow: 1.7 mm
at z = 4 m





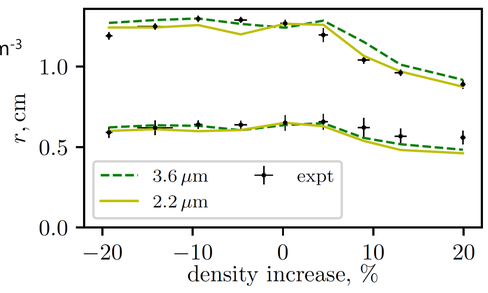
Beam population scan:
Plasma density = 1.95 10^{14}cm^{-3}
Beam length σ_z = 6.57 cm
Laser pulse position = σ_z/4
Beam radius σ_r = 165 μm
Beam emittance = 2.2 μm
Also with narrow window

Plasma gradient scan:
Plasma density = 1.8 10^{14}cm^{-3}
Beam length σ_z = 7.4 cm (246 ps)
Laser pulse position = 2.4 cm
Beam radius σ_r = 220 μm
Beam emittance - variable



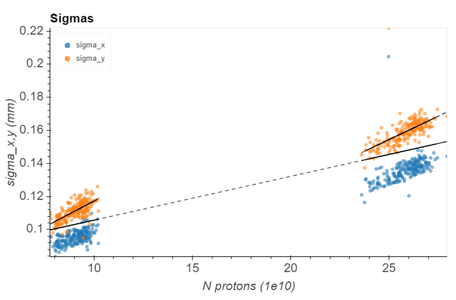
Beam population scan:
Plasma density = 7.7 10^{14}cm^{-3}
Beam length σ_z = 7.5
Laser pulse position = σ_z/4
Beam radius σ_r = 220 μm
Beam emittance = 2.2 μm

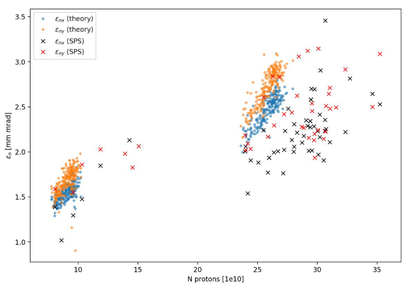
Beam length σ_z = 6 cm
Beam emittance = 1.1 μm
Plasma radius = 2 mm



COMPARISON WITH STREAK CAMERA

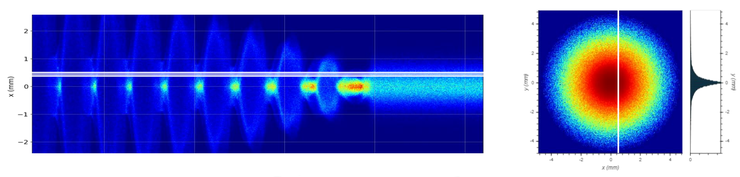
Comparison with streak camera images required accurate measurements of the initial proton beam parameters.





$N_{protons} = 2.73 \cdot 10^{11}$
$\varepsilon_n = 2.122\ mm \cdot mrad$
$\sigma_r = 155\ \mu m$
$\beta = 4.82\ m$

We took into account the effects of the finite streak camera slit. In order to get the best agreement we also assumed that the slit had an offset with respect to the beam axis.



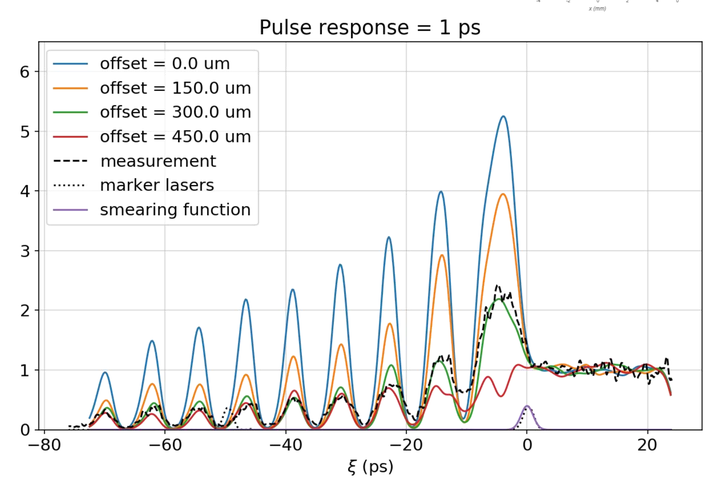


Image size 672 x 512 px
dt = 0.14 ps (0.042 mm)
dx = 0.23 mm

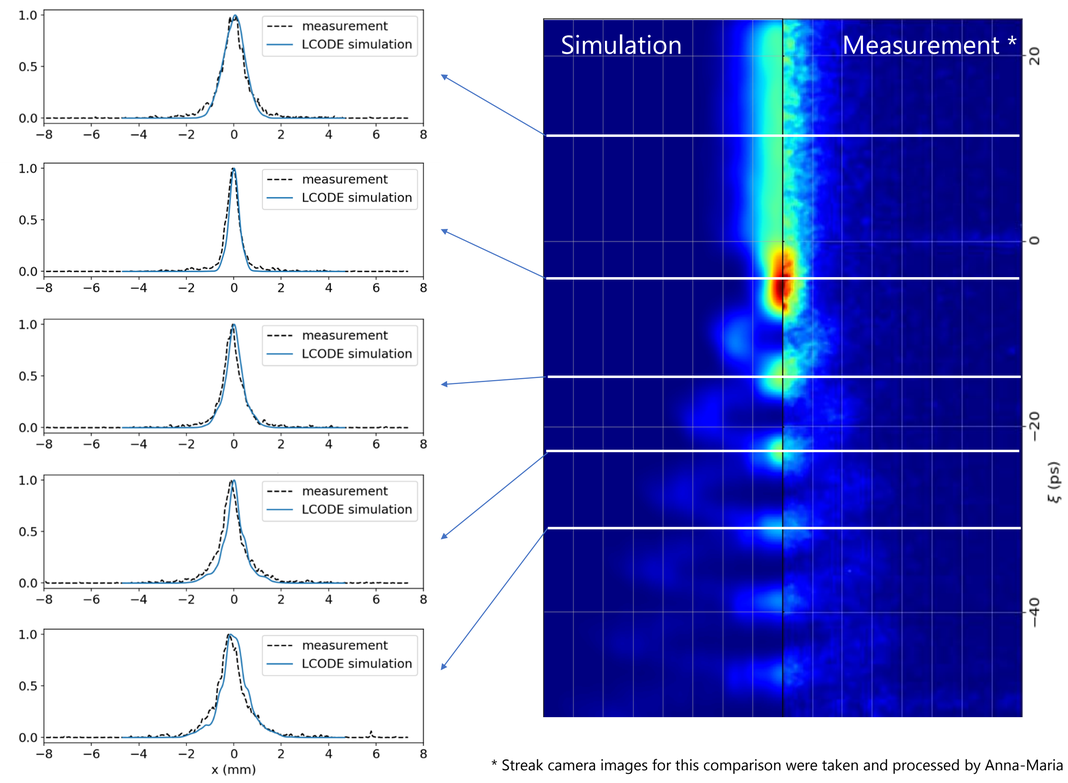
Slit width:
20 um (74 um on the screen)

Transverse smearing:
sigma = 0.0794 mm

Longitudinal smearing:
sigma = 1ps = 0.299 mm

Speculative slit offset:
300 um

For input parameters corresponding to the measured initial proton beam state, simulations showed the agreement in the longitudinal beam density profile and transverse size of the micro bunches and the beam head.



* Streak camera images for this comparison were taken and processed by Anna-Maria Bachman