AWAKE status

L. Deacon, University College London

Institute of Physics Particle Accelerators and Beams group annual conference, Strathclyde, Tuesday 14 April 2015

Outline

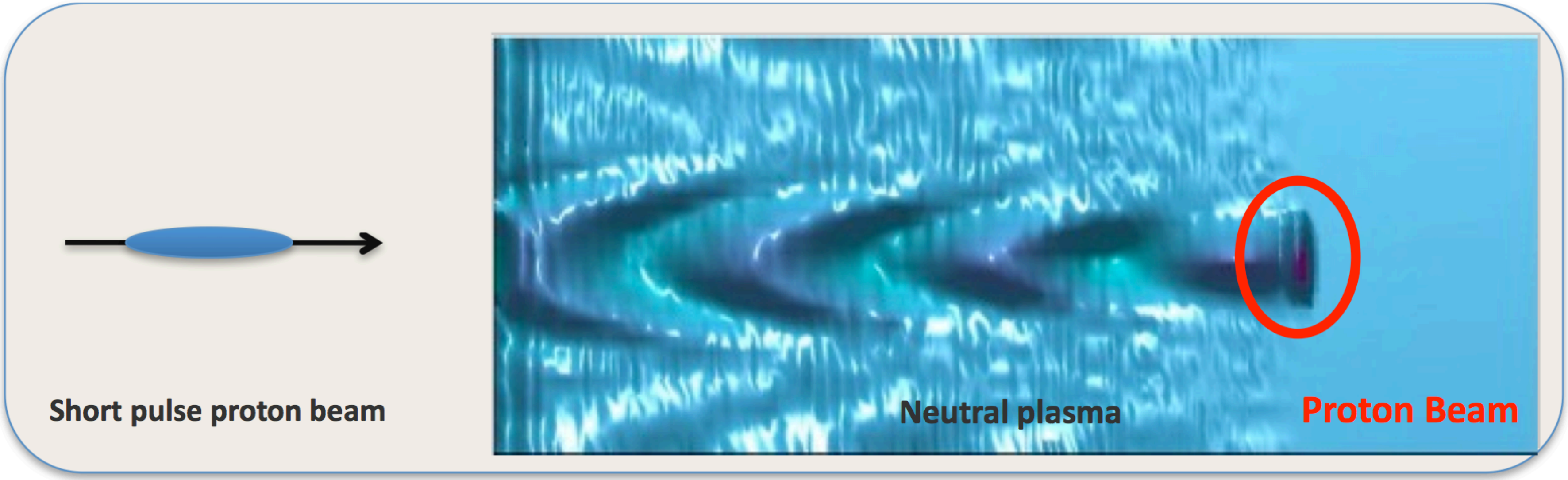
- Motivation
- Plasma wakefield acceleration
- AWAKE layout
- Beams status: proton, electron, laser
- Plasma cell status
- Diagnostics status
- Summary

Motivation

- The use of (large) particle accelerators has been central to advances in particle physics.
- A future e^-e^+ collider is planned to be 30-50km long
- Normal conducting RF cavities with drive beam (e.g. CLIC) can achieve ~150 MV/m (breakdown occurs)
- Best superconducting cavities reach ~ 50 MV/m
- A possible way to increase field gradient: use a plasma wave
- Particles injected at correct phase in a plasma wave will experience gradient of several GV/m or more (52 GV/m achieved at SLAC)
- Therefore using plasma wakefield acceleration future e^-e^+ could theoretically be made ~10 times shorter

Plasma wakefield acceleration

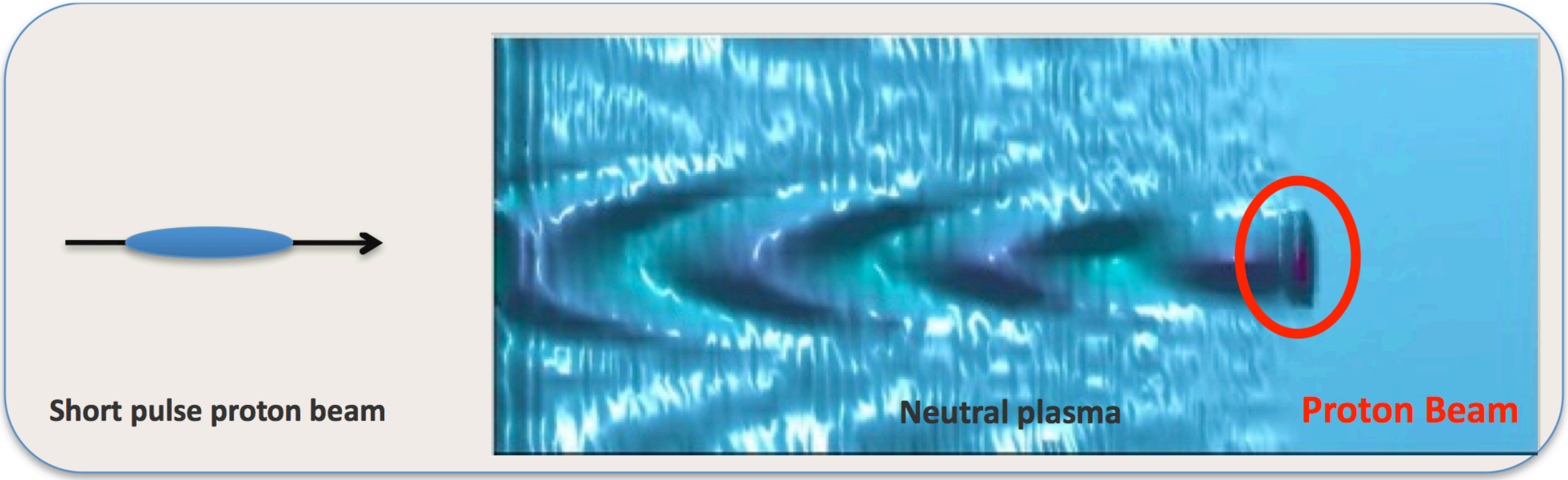
- In a neutral plasma, equal quantities of free electrons and atomic nuclei
- Can often be considered two separate gases due to huge difference in mass between electrons and nuclei
- From the electrons' point of view, nuclei are virtually static
- Displacement of electrons leads to a "depletion region"
- Electrostatic field is therefore set up between +ve depletion region and –ve electron gas region



Thanks J. Holloway (UCL)

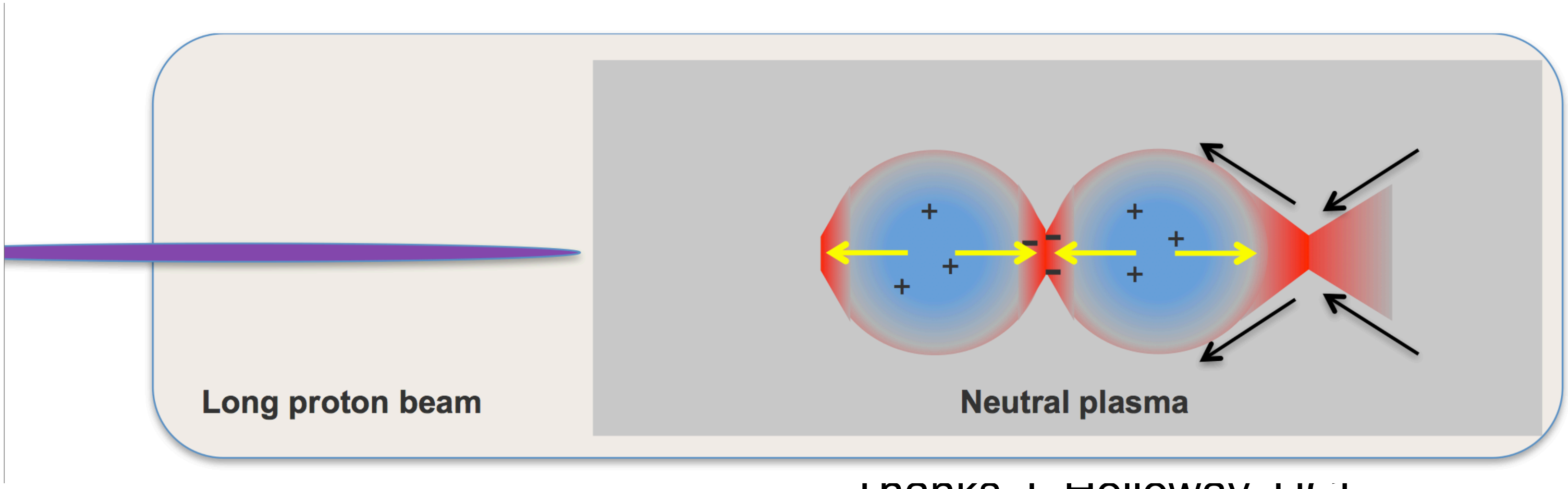
Plasma wakefield acceleration

- This field acts on electrons as a “restoring force” pulling electrons back into depletion region
- Electrons begin to oscillate around the mean position creating a wave which propagates though the plasma (plasma wakefield)
- Wavelength (“plasma wavelength”) of plasma wave depends on plasma density
- Highest acceleration gradients are achievable with short excitation bunch lengths not much greater than 100 mum, pulses with a large number or particles, and high plasma density



Proton driven plasma wakefield acceleration

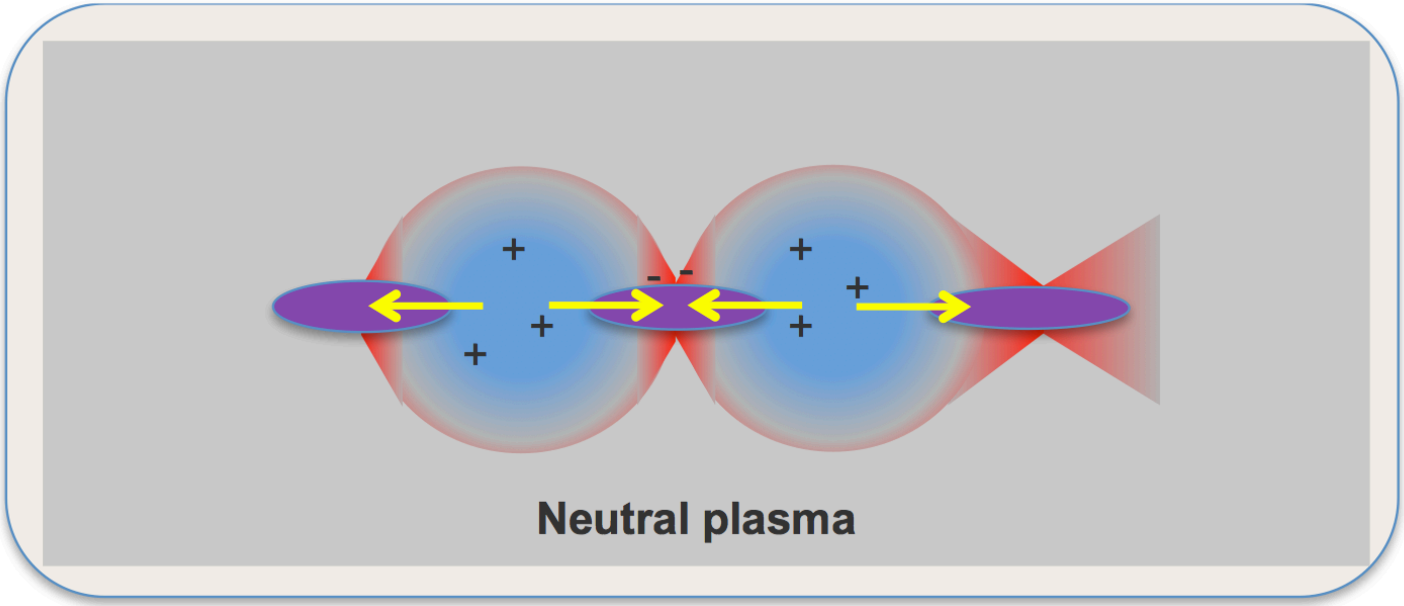
- AWAKE: first **proton driven** plasma wakefield experiment
- Lasers cannot propagate long distance in plasma. For high energy, need multiple stages.
- Electrons limited by transformer ratio: $(E_{witness}/E_{drive})<2$ therefore many stages are need
- TeV protons are around today - LHC e.g. could be used as drive beam
- However, to drive high gradient bunch length needs to be short (~100 mum)
- AWAKE will use the proton beam from the CERN synchrotron proton source (SPS), 12cm bunch length



Thanks J. Holloway, UCL

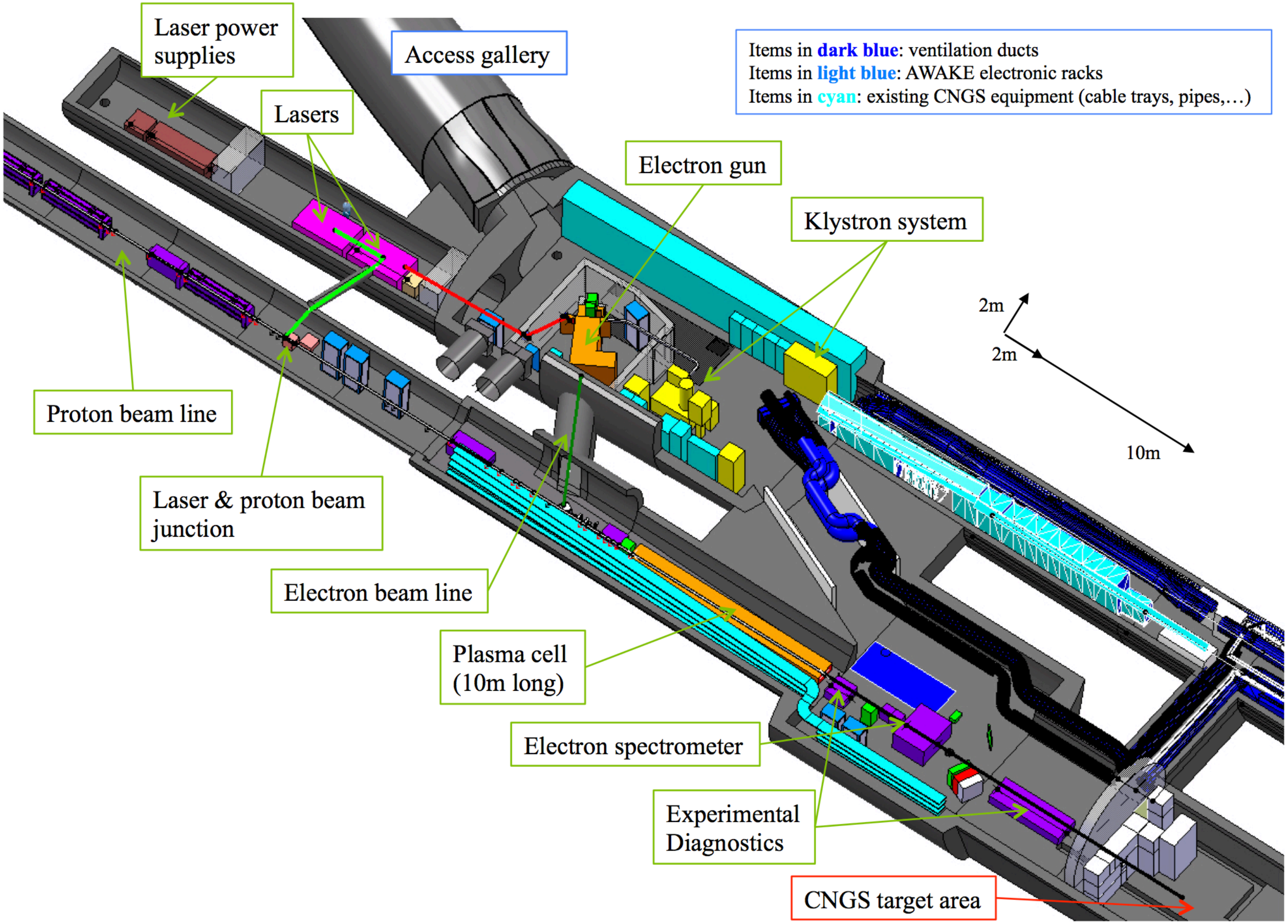
Proton driven plasma wakefield acceleration

- However, 3 GeV/m possible due to the self-modulation instability – proton bunch will form microbunches due to plasma wakefield
- These microbunches drive the plasma wakefield which in turn further modulate the proton bunch – “self modulation instability”



Thanks J. Holloway, UCL

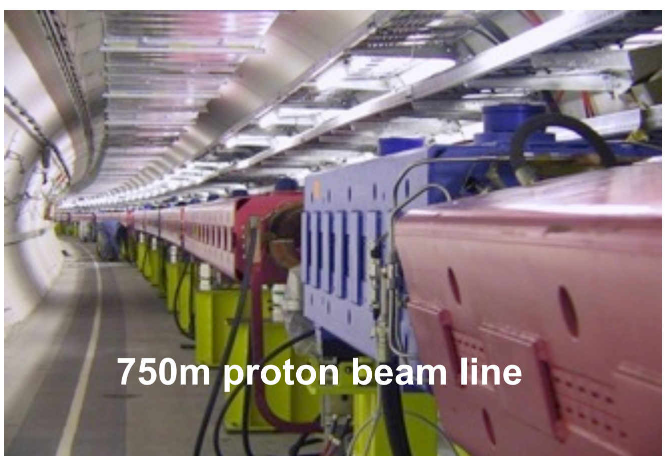
AWAKE layout



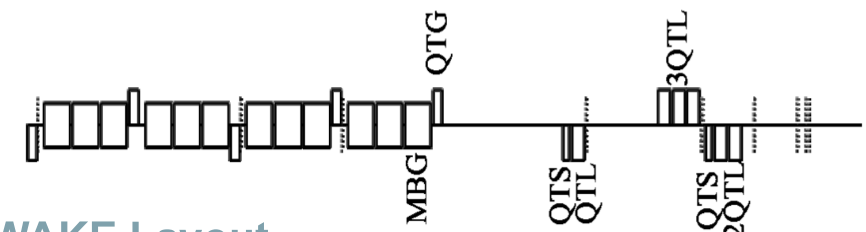
SPS Proton Beam

- LHC type proton beam
- σ_z=12cm $\sigma_{x,y}$=200μm
- Created chicane to merge laser beam
- Synchronization with laser beam @ 100 ps level

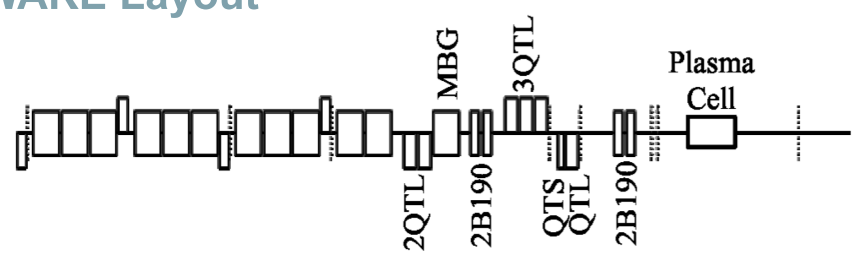
p+ beam Characteristics	
# bunches	1
p+ per bunch	3e11
Repetition rate	0.5 Hz
r.m.s. norm. emittance	3.5 mm mrad
Bunch length	12 cm (0.4 ns)
Momentum	400 GeV/c
Momentum spread	0.35%



CNGS Layout



AWAKE Layout



Thanks J. Schmidt, CERN

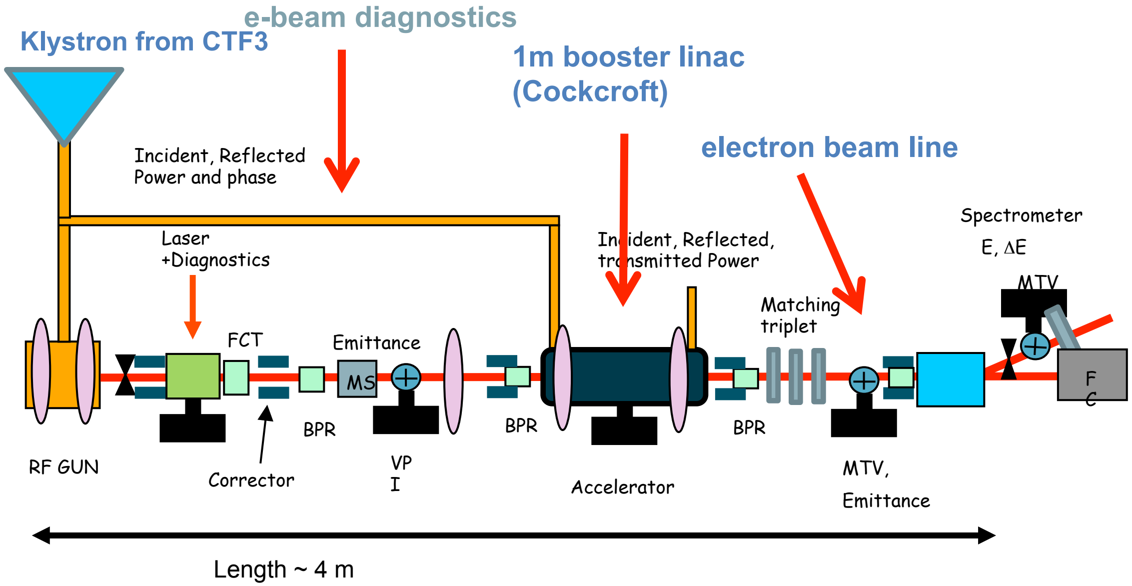
Status of the “Phase 1 beam line”

- Design frozen
- Drawings approved until start of the common beam line
- Drawings for the whole line close to approval
- Elements marked in tunnel up to BTV for synchronization measurement

Thanks J. Schmidt, CERN

Electron Beam

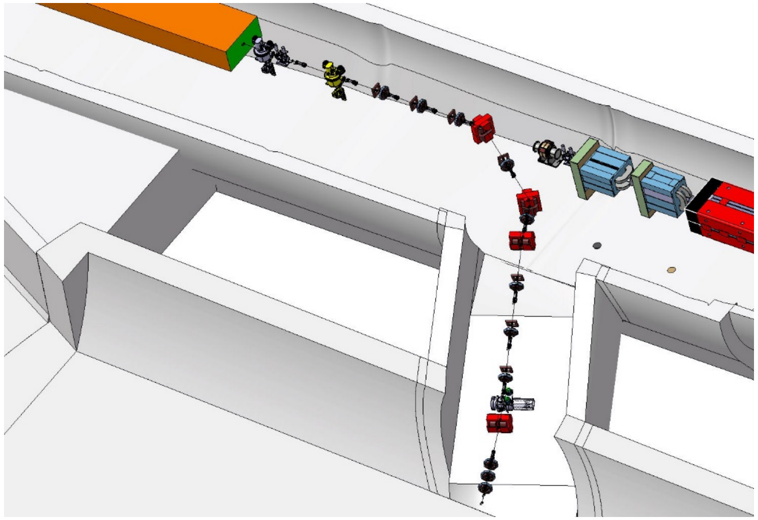
- Reuse of the PHIN photo-injector (from CTF3/CLIC)
- 14m transfer line
- Diagnostic of acceleration with spectrometer magnet

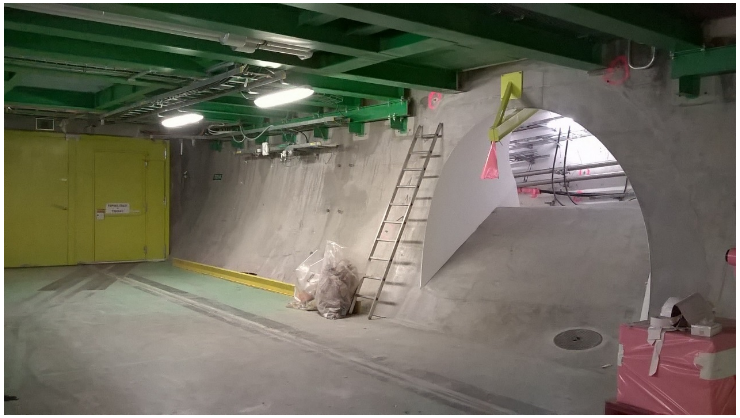


Electron beam	
Momentum	**16 MeV/c**
Electrons/bunch (bunch charge)	**1.2 E9 (0.2 nC)**
Bunch length	**σ_z =4ps (1.2mm)**
Bunch size at focus	**$\sigma^*_{x,y}$ = 250 μm**
Normalized emittance (r.m.s.)	2 mm mrad
Relative energy spread	$\Delta p/p$ = 0.5%
Beta function	$\beta^*_x = \beta^*_y$ = 0.4 m
Dispersion	$D^*_x = D^*_y = 0$

Thanks J. Schmidt, CERN

Electron transfer line





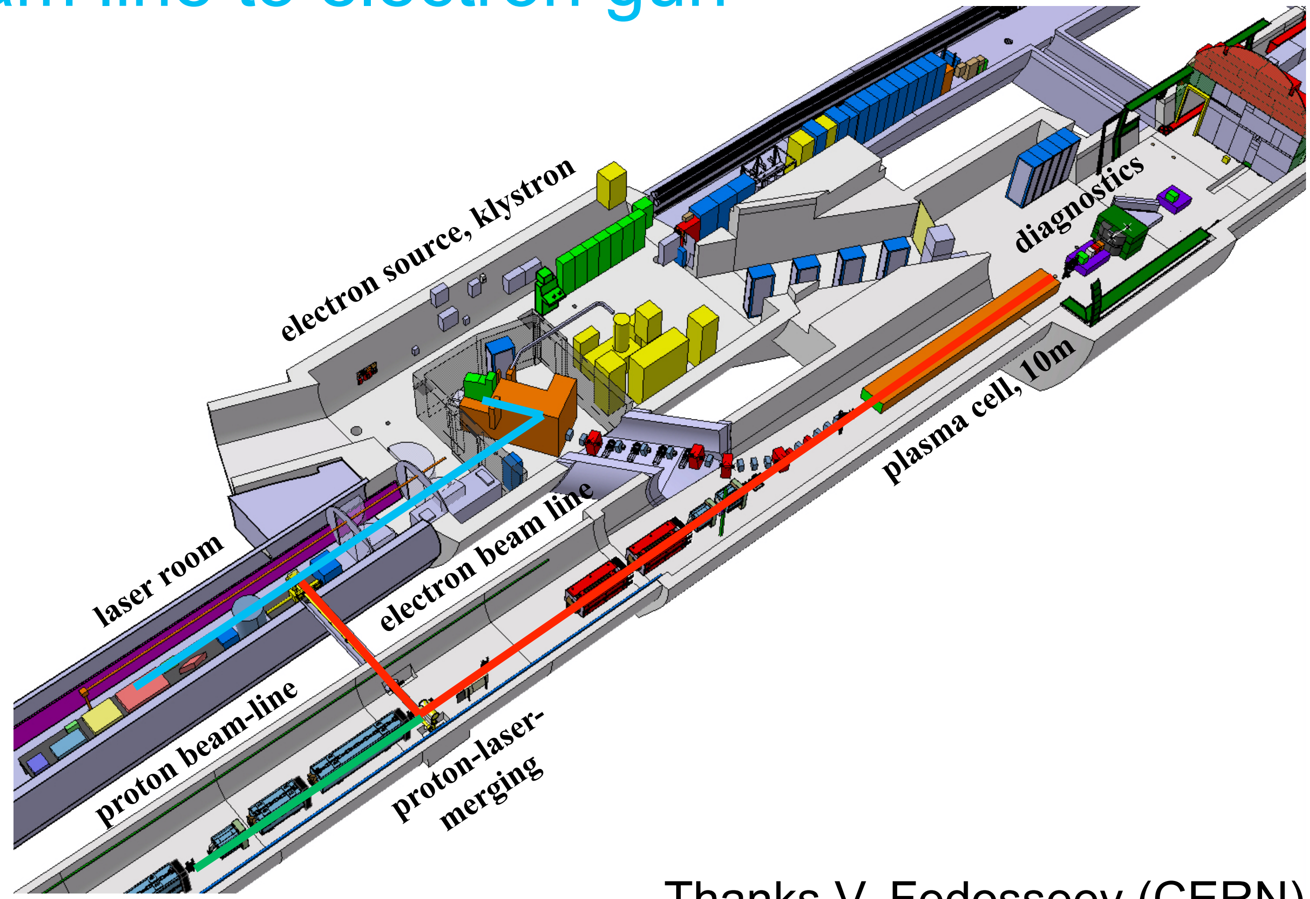
- Transfer line layout fixed
- Primary magnet design for electron line completed
- Optics design and error studies performed

- Next steps
  - Corrector design
  - Delta p / over p influence
  - Tracking studies

Thanks J. Schmidt, CERN

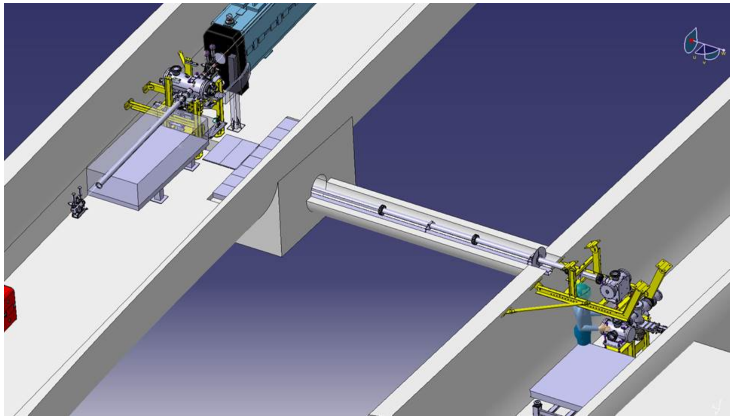
Laser lines in AWAKE

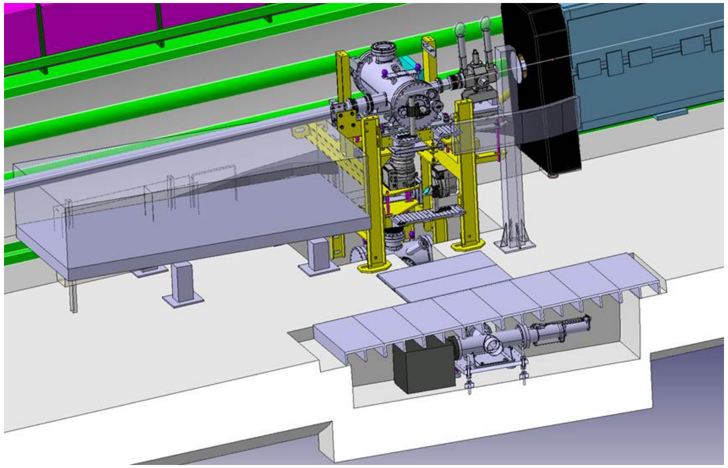
- Laser beam line to plasma cell
- Diagnostic beam line ("virtual plasma")
- Laser beam line to electron gun



Thanks V. Fedosseev (CERN)

Vacuum laser line



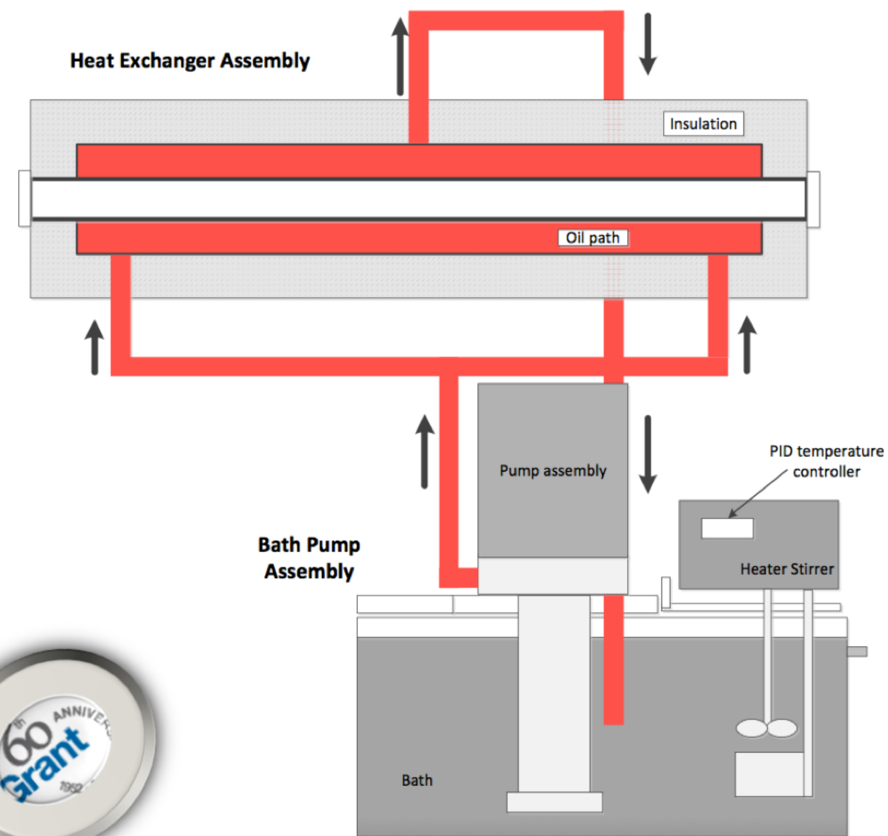


- Laser core completed and laser room painted (right)
- General layout of vacuum laser line is approved (top left)
- Work on detailed drawing is close to completion and procurement has begun (top right)

Thanks V. Fedosseev (CERN)

Plasma cell status

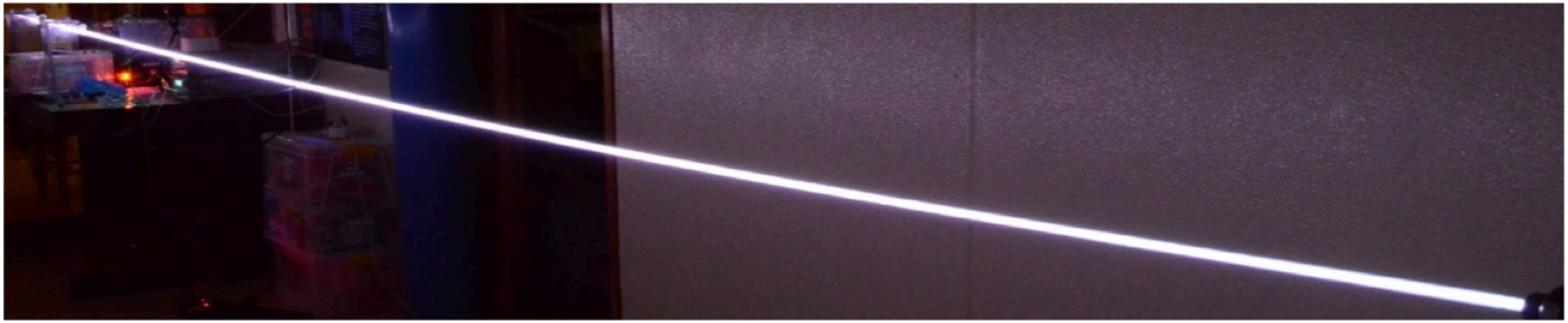
- Uniform plasma density requires uniform temperature (<2% uniformity)
- Will use rubidium vapour cell
- 3 metre long prototype oil heater purchased from grant instruments.
- Temperature uniformity requirement was satisfied by the prototype
- Next step: 10 metre long prototype
- Support frame under construction at Grant Instruments
- Fast valves and controller delivered to CERN for test and integration.
- Rubidium reservoir prototype will be ready to be tested soon.
- Ionization tests stating in April – goal is to create a long, uniform plasma



Thanks P. Muggli, MPI

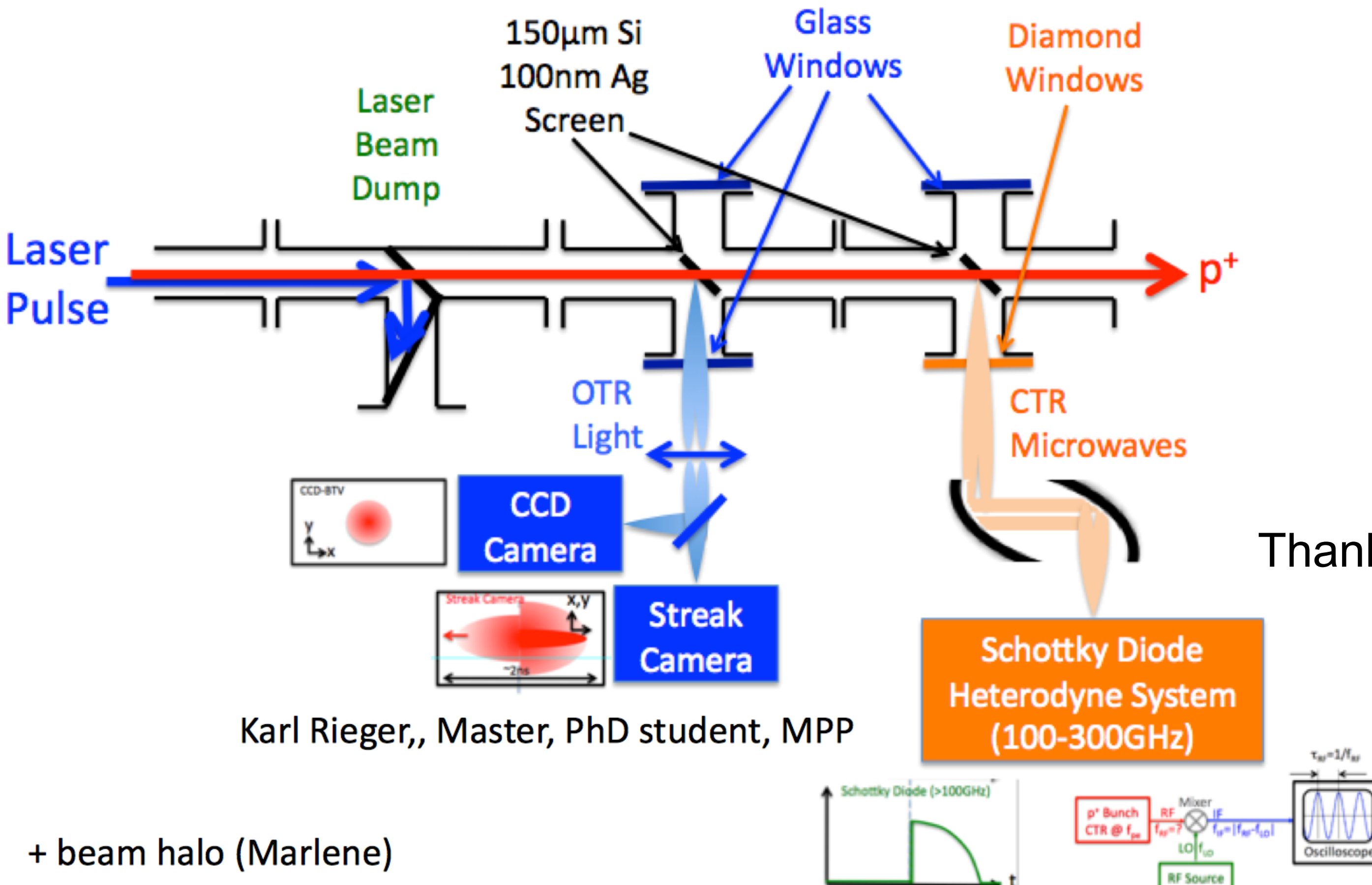
Discharge plasma source status

- Plasma discharge sources are scalable to long lengths and can be integrated with other sources
- Plasma source compatible with pdPWFA at CERN getting closer
- Demonstration of main characteristics done... 6 meter long plasmas demonstrated
- …close to 100% ionisation
- …jitter can be made a fraction of HV pulses (sub mus)… $n_e=10^{15}$ cm^{-3} measured by interferometry



N. C. Lopes, Z. Najamudin

Diagnostics



Karl Rieger,, Master, PhD student, MPP

Thanks P. Muggli

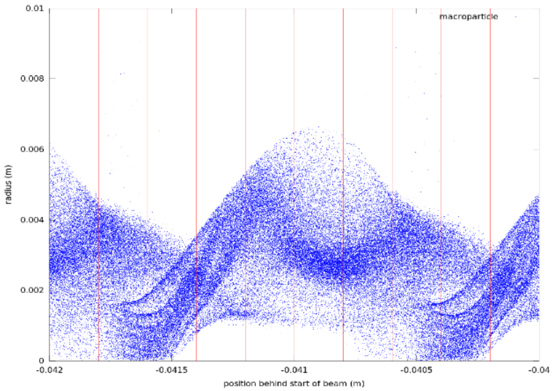
+ beam halo (Marlene)
+electron spectrometer (Lawrence)
+photon acceleration (Muhammad)
(streak camera, Karl)

MAX-PLANCK-GESELLSCHAFT
P. Muggli, ACM 03/13/2015

Streak camera status

Use Optical Transition Radiation for time-resolved measurement of self-modulation

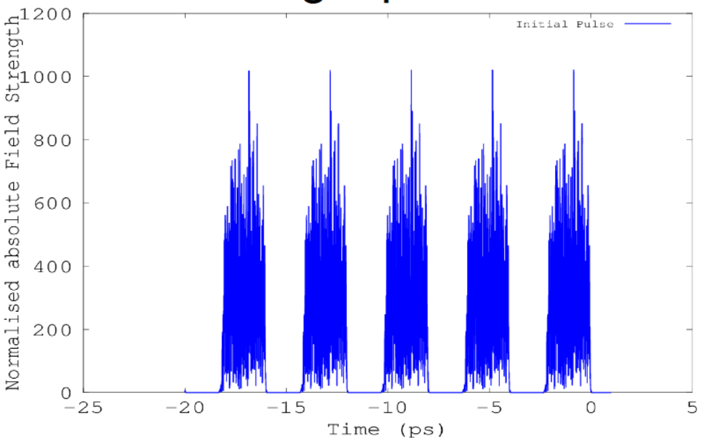
Proton bunch after plasma



Propagation

OTR created by screen

OTR Light pulses

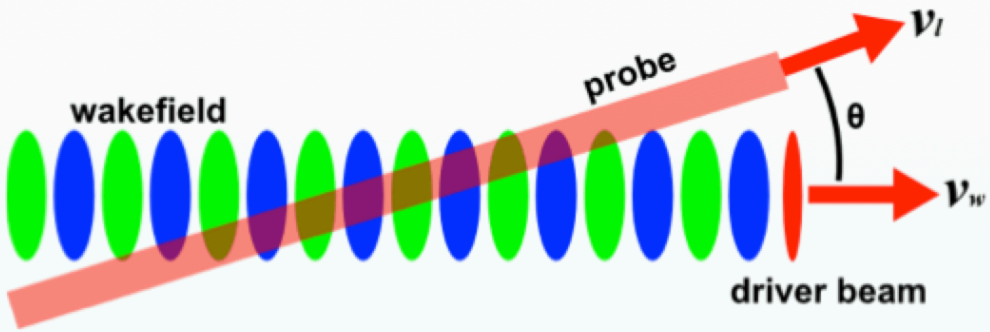


K. Rieger

- Simulated OTR pulses with laser show ability to detect ~250 GHz pulse trains
- Measurement to be done in June to decide which streak camera to order
- OTR foil holder design underway
- Work to be done on optical beam line (transport of OTR light to camera)

Photon acceleration status

- Sending the laser probe with oblique angle of incidence relative to the wakefield



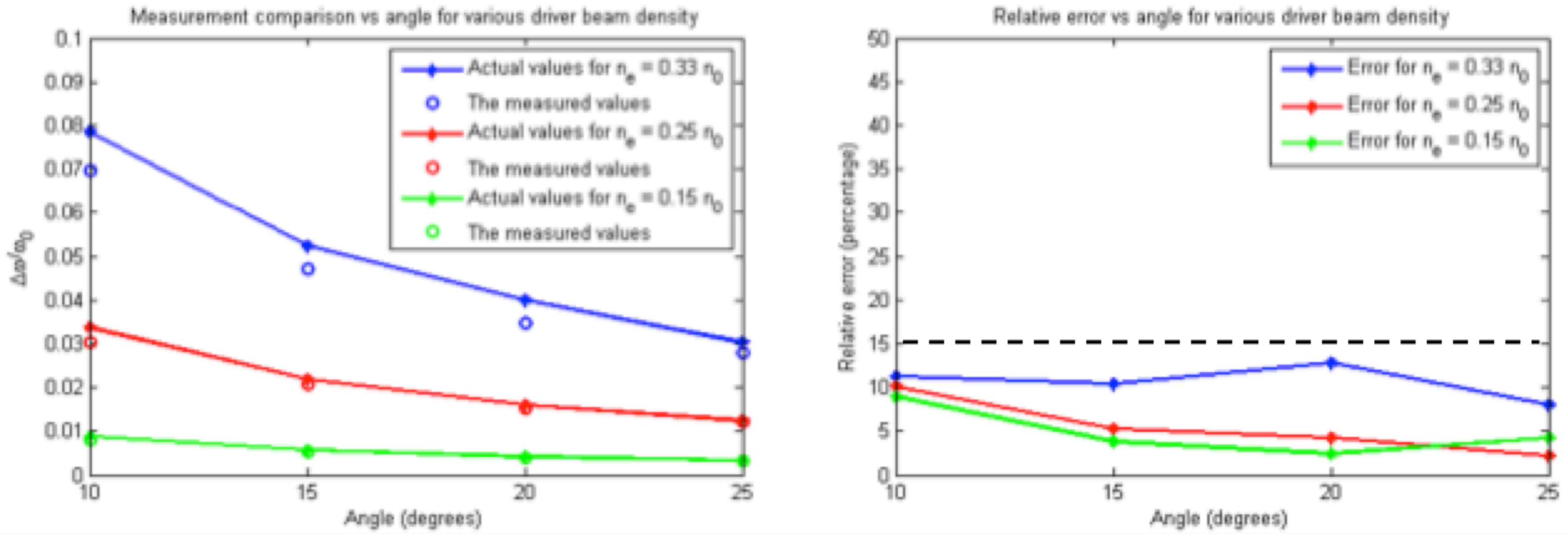
- By choosing the crossing point, we can diagnose the wakefield at that point.

M. Firmansyah Kasim, Oxford

- Change of plasma density causes frequency shift of laser.

Photon acceleration status

- **Quantitative comparison between the density data and the measured data.**

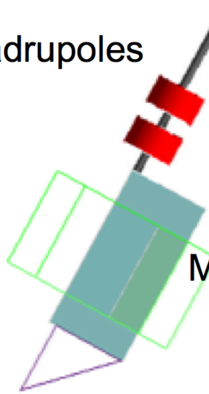


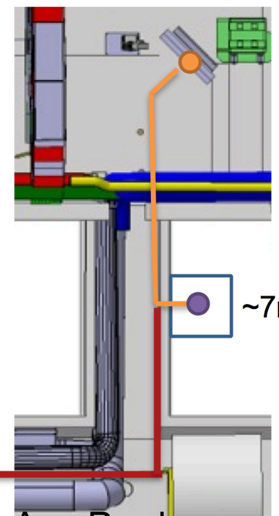
Less than 15% relative error

M. Firmansyah Kasim, Oxford

Electron spectrometer status

L. Deacon, S. Jolly, M. Wing, UCL





Thanks Ans Pardons, CERN

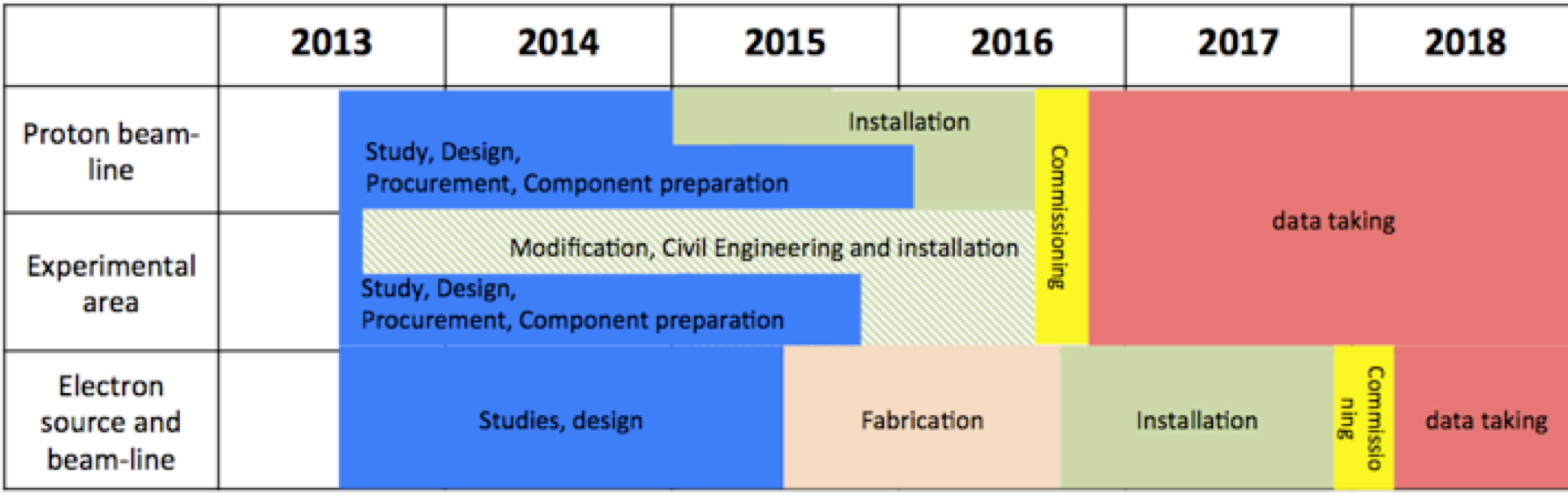
Sigma APO F#/2.8 200-500mm

» Simulation of background radiation from upstream vacuum window shows peak signal/background ~1300

» Magnet choice has changed to c-shaped magnet HB4

» Initial studies of optical line with camera 20m away show sufficient light yield. Studies are ongoing

AWAKE timeline



2014-2015
- Design, procurement and installation of the equipment, development of plasma cells.
- Modification and installation of the beam line and the experimental facility.

2016
- First proton beam to the AWAKE experiment, beam–plasma commissioning.
- Beginning taking data

2017
- Installation of the Electron source and beam line.
- Delivery and installation of the electron photo-injector, commissioning of the magnetic spectrometer.
- More data taking!

Summary

- Proton driven plasma wakefield acceleration could potentially be used for future high energy lepton colliders ~10 times shorter than current designs.
- The pre-commissioning phases of a proof of principle experiment for proton driven plasma acceleration, AWAKE, are underway.

Thanks

Thanks to the AWAKE collaboration:

InstitutesBudker Institute of Nuclear Physics, Novosibirk, Russia
CERN, Geneva, Switzerland
Cockroft Institute, Daresbury, UK
Heinrich Heine University, Düsseldorf, Germany
Instituto de Plasmas e Fusao Nuclear, IST, Lisboa, Portugal
Imperial College, London, UK
Ludwig Maximilian University, Munich, Germany
Max Planck Institute for Physics, Munich, Germany
Max Planck Institute for Plasma Physics, Greifswald, Germany
Rutherford Appleton Laboratory, Chilton, UK
University College London, London, UK
University of Strathclyde, Glasgow, Scotland, UK
DESY, Hamburg, Germany
John Adams Institute for Accelerator Science, Oxford, UK
TRIUMF, Vancouver, Canada
Oslo, Norway

Backup slides…

Plasma considertions

Based on linear fluid dynamics :

$$\omega_p = \sqrt{\frac{n_p e^2}{\epsilon_0 m_e}}$$

$$\lambda_p \approx 1\,[\mathrm{mm}]\sqrt{\frac{10^{15}\,[\mathrm{cm}^{-3}]}{n_p}} \quad \text{or} \quad \approx \sqrt{2}\,\pi\,\sigma_z$$

$$E \approx 2\,[\mathrm{GV\,m^{-1}}]\left(\frac{N}{10^{10}}\right)\left(\frac{100\,[\mu\mathrm{m}]}{\sigma_z}\right)^2$$

Relevant physical quantities :

- Oscillation frequency, ω_p
- Plasma wavelength, λ_p
- Accelerating gradient, E

where :

- n_p is the plasma density
- e is the electron charge
- ε_0 is the permittivity of free space
- m_e is the mass of electron
- N is the number of drive-beam particles
- σ_z is the drive-beam length

High gradients with :

- Short drive beams (and short plasma wavelength)
- Pulses with large number of particles (and high plasma density)

Original idea: laser wakefield acceleration (T. Tajima & J.W. Dawson, Phys. Rev. Lett. **43** (1979) 267)

Can also use particle beams (P. Chen et al., Phys. Rev. Lett. 54 (1985) 693)

Thanks M. Wing, UCL