An *ep* collider based on proton-driven plasma wakefield acceleration

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- A high energy *ep* collider and motivation
- Proton-driven plasma wakefield acceleration
- AWAKE experiment at CERN
- An *ep* collider based on PDPWA
- Summary

A high energy *ep* collider

A high energy ep collider complements the pp programme from the LHC (also a future e^+e^- collider)

- Deep inelastic scattering and parton distribution functions
- Measurements of Higgs production
- Precise extractions of α_s and search for new physics
- *eA* physics

See LHeC talks for further motivation

Describe a mechanism (particularly) applicable to accelerating electrons to high energies

Talk based on G. Xia et al., Nucl. Instrum. Meth. A 740 (2014) 173

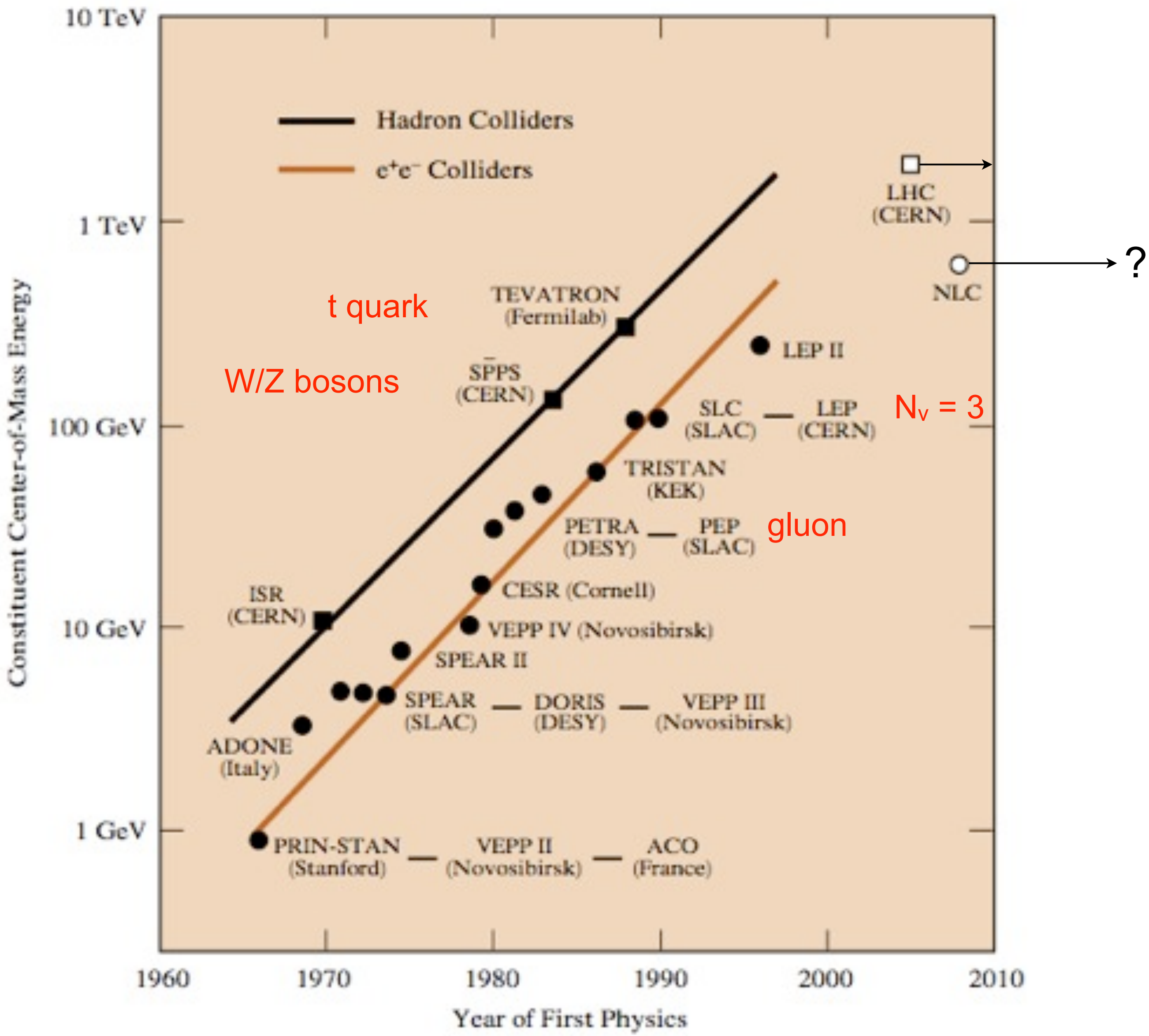
Collider history

Limitations in RF acceleration

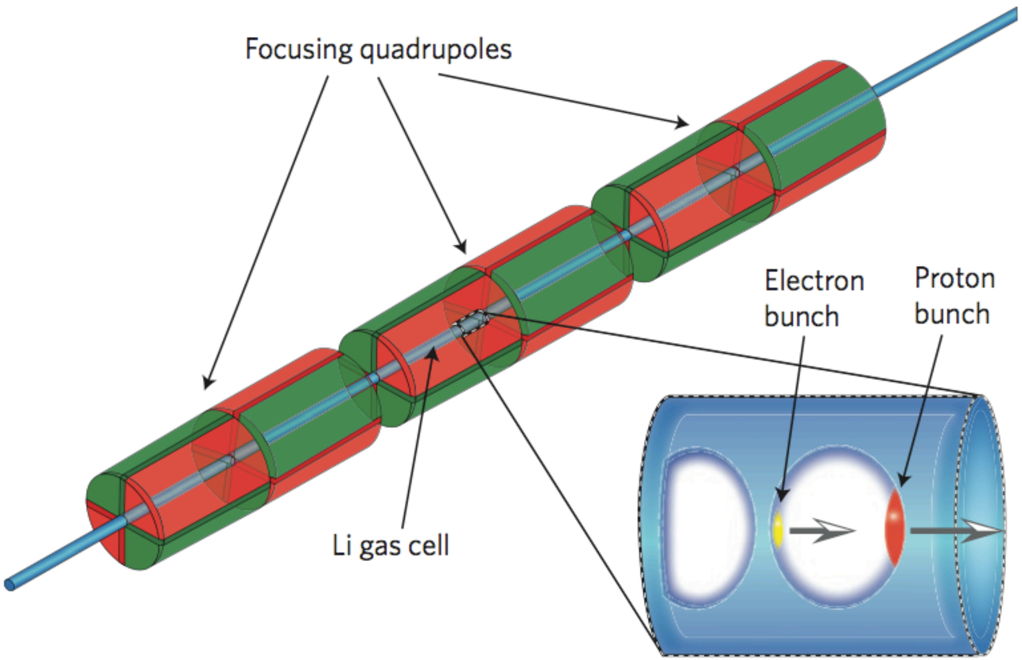
Principle holds for *ep* colliders

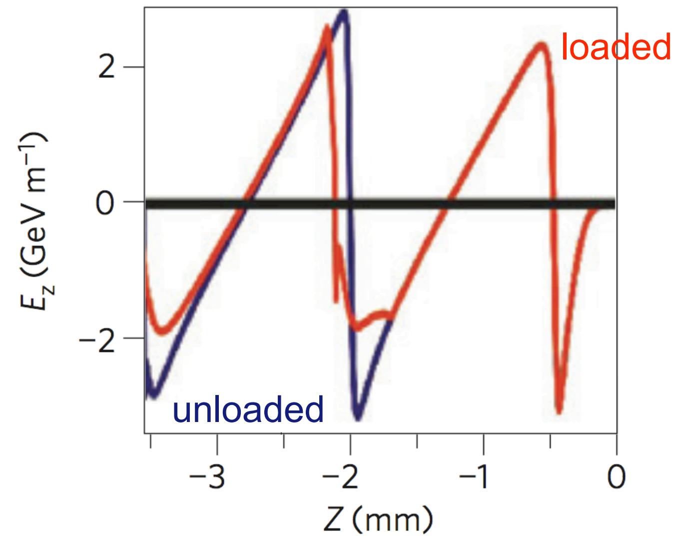
Can we develop new technologies ?

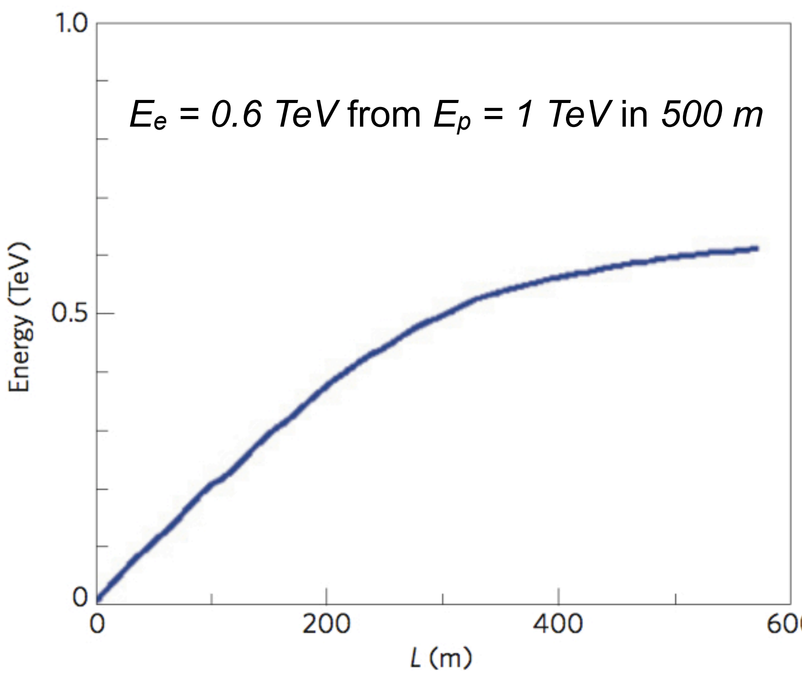
Plasma wakefield acceleration has up to *~100 GV/m*



PDPWA concept*







- Electrons 'sucked in' by proton bunch
- Continue across axis creating a depletion region
- Transverse electric fields focus witness bunch
- Maximum accelerating gradient of *3 GV/m*

* A. Caldwell *et al.*, Nature Physics **5** (2009) 363.

AWAKE: an experiment to demonstrate proton-driven plasma wakefield acceleration at CERN

- Several workshops, phone meetings, CERN site visit, etc.. Strong international collaboration (communities from accelerators, plasma and particle physics)
- Submitted Letter of Intent in June 2011 to CERN SPSC
- AWAKE Design Report submitted to CERN, April 2013
- AWAKE approved at CERN Research Board, August 2013

Proton-driven plasma wakefield acceleration: a path to the future of high-energy particle physics

AWAKE Collaboration

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Abstract. New acceleration technology is mandatory for the future elucidation of fundamental particles and their interactions. A promising approach is to exploit the properties of plasmas. Past research has focused on creating large-amplitude plasma waves by injecting an intense laser pulse or an electron bunch into the plasma. However, the maximum energy gain of electrons accelerated in a single plasma stage is limited by the energy of the driver. Proton bunches are the most promising drivers of wakefields to accelerate electrons to the TeV energy scale in a single stage. An experimental program at CERN – the AWAKE experiment – has been launched to study in detail the important physical processes and to demonstrate the power of proton-driven plasma wakefield acceleration. Here we review the physical principles and some experimental considerations for a future proton-driven plasma wakefield accelerator.

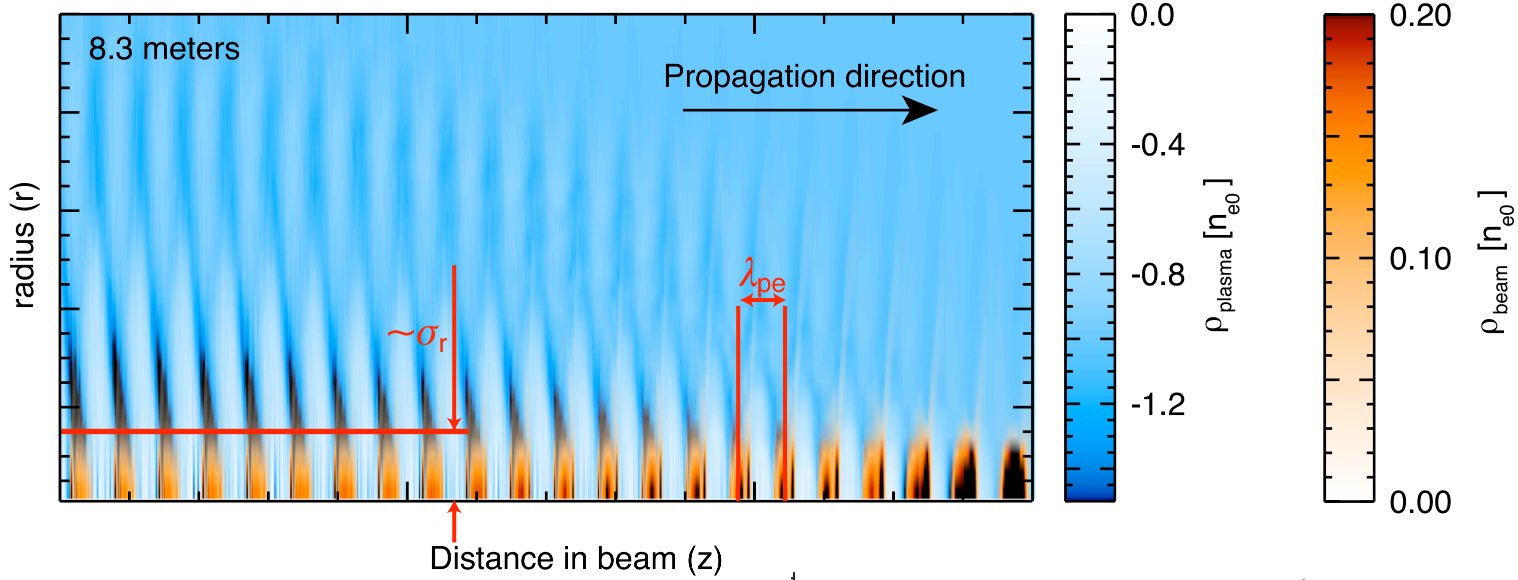
arXiv:1401.4823, to appear in Plasma Phys. Control. Fusion

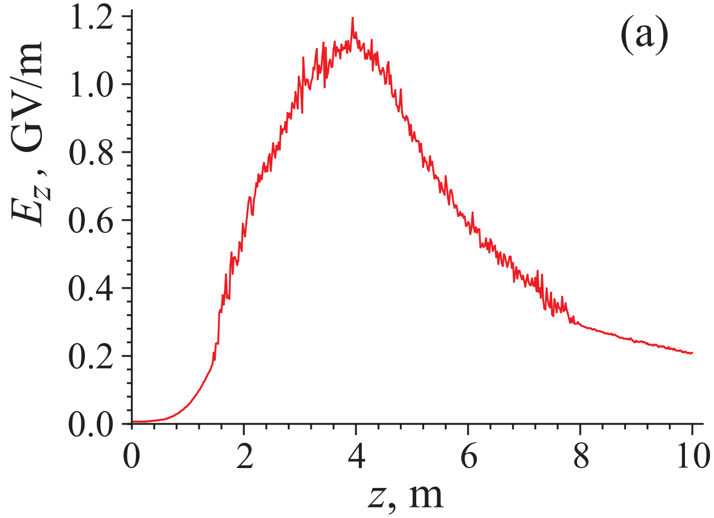
http://awake.web.cern.ch/awake/

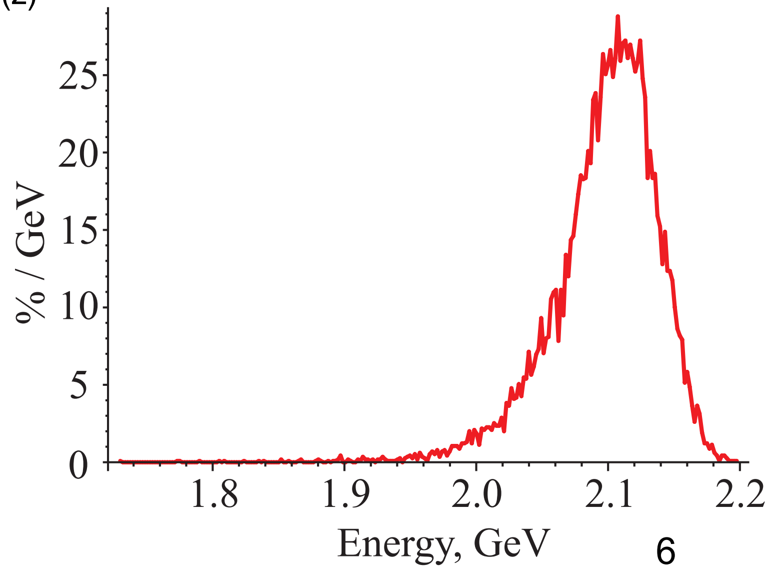
Self-modulation and electron acceleration

Proton bunches are long

Rely on micro-bunching

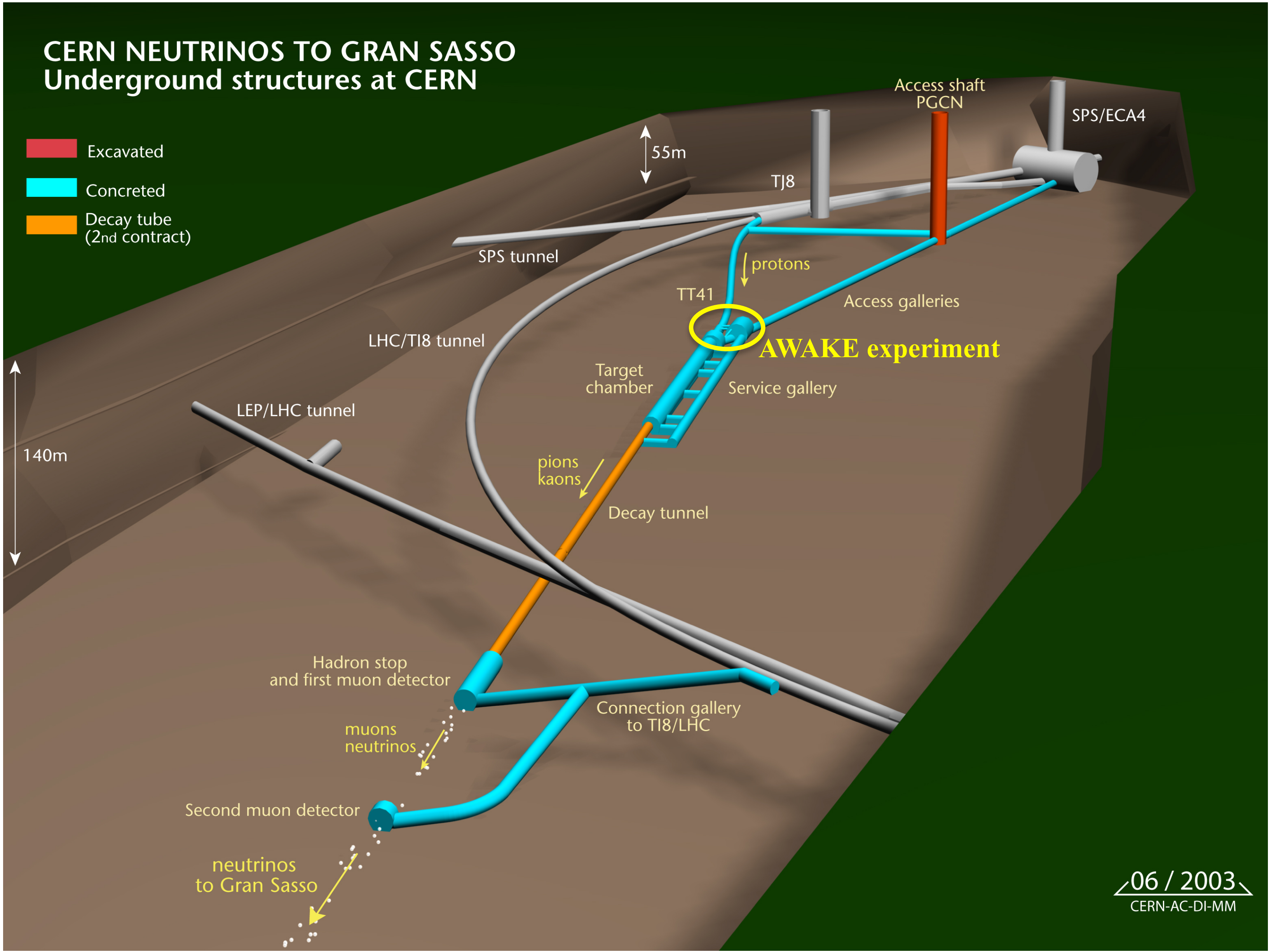




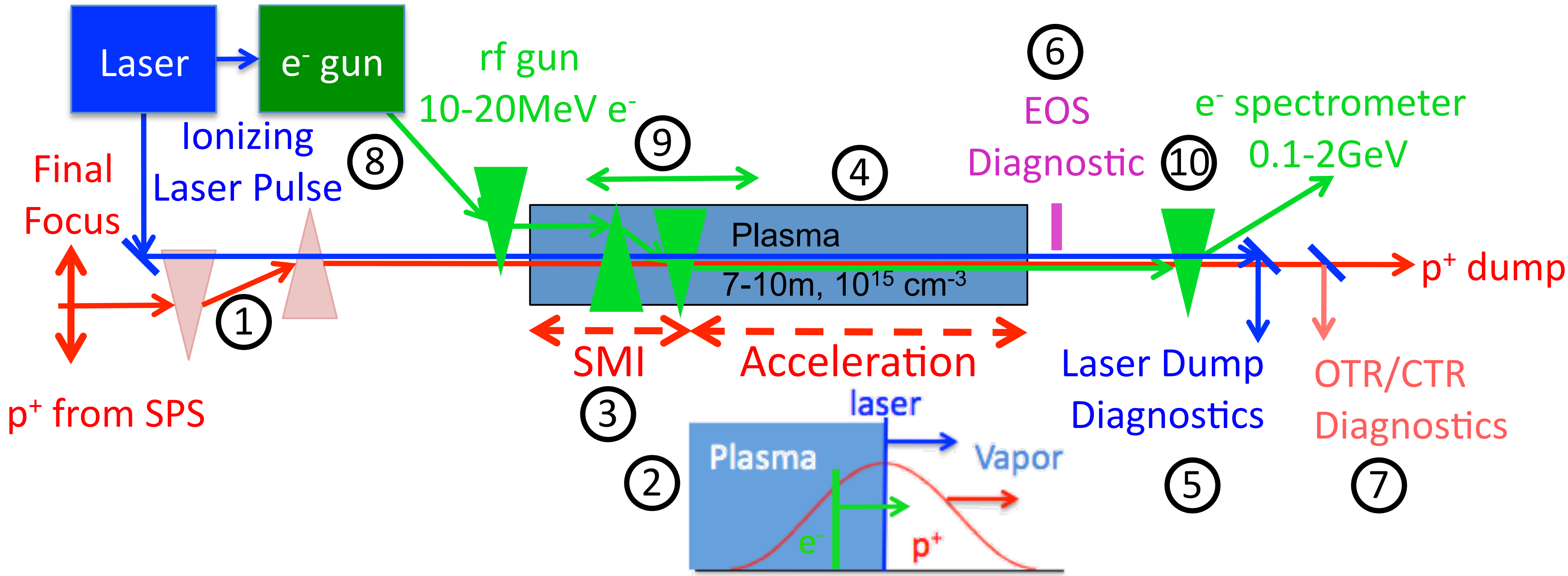


K.V. Lotov Phys. Plasmas **18** (2011) 024501

CNGS facility at CERN



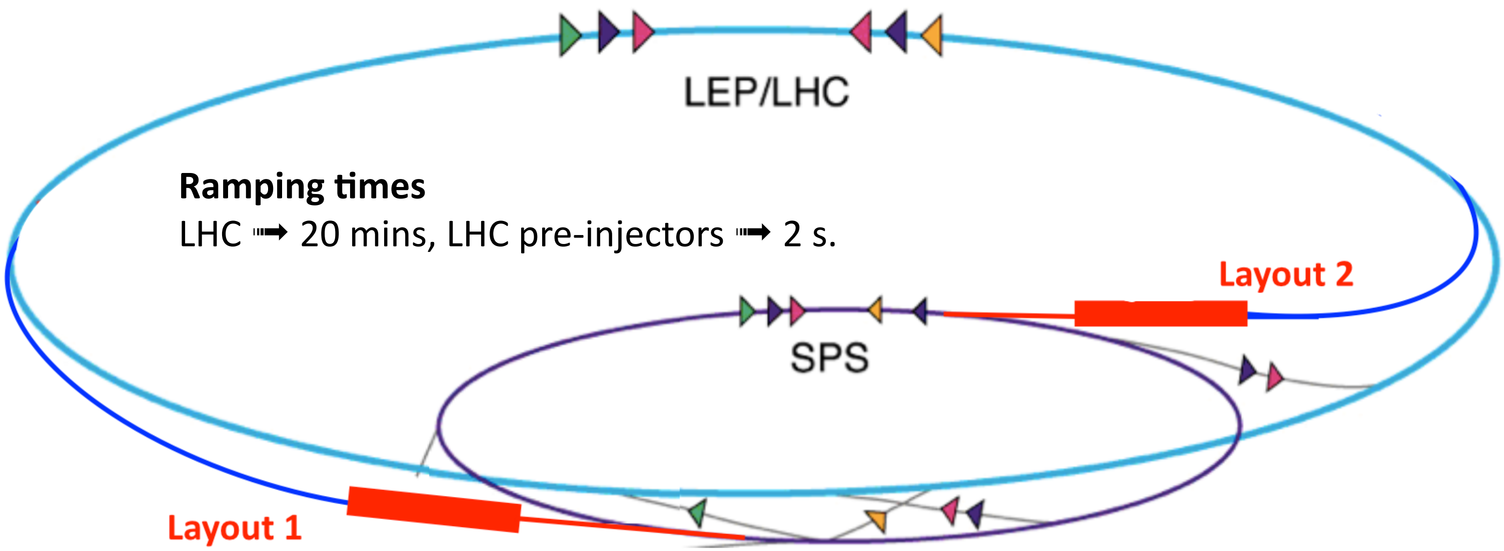
AWAKE experiment and programme



- Demonstrate self-modulation effect of a long proton bunch and realise > *1 GeV* electron energy gain in *10 m* plasma
- Develop and test diagnostic equipment for first and later experiments
- Benchmark simulations against data
- Provide input for future experiment of *~100 GeV* energy gain in *~100 m* plasma

Data taking to start 2016, first electron acceleration in 2018

An *ep* collider, example layouts



- SPS protons excite plasma during LHC ramping. Gradients ~*1 GV/m*, accelerate e^- to *100 GeV* in *170 m* plasma.
- Parasitic *ep* collisions with LHC *pp* running
- Utilisation of CERN infrastructure: prospects of cost-effective collider
- Basic sub-systems: transfer and matching of protons to plasma section; electron source; plasma section; beam delivery final focus; beam dumping / recycling

Issues

Phase slippage

The phase slippage (or dephasing) is a limiting factor of proton-driven plasma wakefield acceleration. Have different particles travelling at different velocities; dephasing ?

Velocity of wakefield is the velocity of the proton driver, γ_p

Velocity of the accelerating electrons, γ_e, can soon be greater than γ_p and so electrons overrun the wakefield !

• Can get *~4 km* for the LHC beam (plasma density dependent) and $E_e \sim 1$ *TeV*

• Can get *170 m* for the SPS beam and $E_e \sim 100$ *GeV*

Proton beam propagation

Will the proton beam propagate without spreading over hundreds of metres or kilometres of plasma ?

• Transverse focusing can be achieved with external quadrupole magnets or the wakefields themselves

• Large relative momentum spreads should not be an issue for long stages as long as the drive beam is ultra relativistic

Issues

Electron–plasma interactions

Witness particles can scatter from plasma ions and plasma electrons

Previous studies from damping rings and for ILC

Model being developed using plasma simulation code and GEANT

Positron acceleration

Clear issue for e^+e^- collisions, but also for e^+ running at and *ep* collider

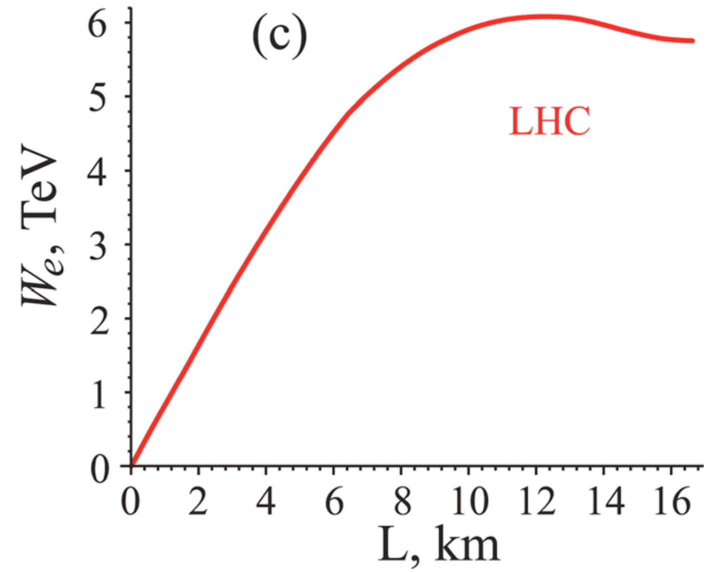
Simulations show can accelerate witness protons

At high energies, positron acceleration should be feasible too

An *ep* collider, basic parameters

$$\sqrt{s} = 2\sqrt{E_e E_p} = 1.67\ \text{TeV}$$

$$\mathcal{L}_{ep} = \frac{1}{4\pi}\frac{P_e}{E_e}\frac{N_p}{\epsilon_p^N}\frac{\gamma_p}{\beta_p^*}, \qquad P_e = N_e E_e n_b f_{rep}$$



A. Caldwell & K. Lotov, Phys. Plasmas **18** (2011) 103101

N_e = 1.15 x 10^{10}, E_e = 100 GeV, n_b = 288, f_{rep} = 15

L_{ep} = 1 x 10^{30} $cm^{-2}s^{-1}$

Significantly lower than current LHeC designs.

Can the electron bunch intensity and repetition rate be improved ?

Physics at high energy, low luminosity

10 − 12 September 2012
Krakow, Poland

- Classicalisation in EW and gravity
- QCD and Beyond SM
- Lorentz invariance
- High energy cosmic rays

Particle Physics at High Energies but Low Luminosities

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1 Introduction

The main focus of the particle physics community, when considering future accelerators, has been on high luminosity colliders since s-channel cross sections scale as $1/s$, with s the square of the center-of-mass energy. This focus has led to ILC, CLIC or Muon Collider parameter sets requiring luminosities in excess of 10^{34} cm^{-2} s^{-1} for center-of-mass energies beyond 1 TeV. This requirement on the luminosity then leads to very demanding requirements on parameters such as beam sizes at the interaction point, repetition rate, etc., and huge power requirements. The former will be difficult to achieve technologically, while the latter will be very hard to justify in an age of diminishing energy resources and increasing energy costs.

Focus on lepton colliders. Should can consider further and for *ep* physics too.

Summary

- Proton-driven plasma wakefield acceleration can be used to accelerate electrons to the energy frontier in a single stage
- AWAKE will demonstrate proton-driven plasma wakefield acceleration for the first time
  - Demonstration of self-modulation
  - Acceleration of electrons
- AWAKE experiment will inform future possibilities for high energy colliders in *ep* and e^+e^-
- Such an *ep* collider can reach centre-of-mass energy *1.67 TeV* and luminosity $10^{30}\ cm^{-2}s^{-1}$
  - Consider schemes to increase electron bunch intensity and repetition rate
  - Consider physics possibilities for a high energy, low luminosity *ep* collider