AWAKE : A proton-driven plasma wakefield acceleration experiment

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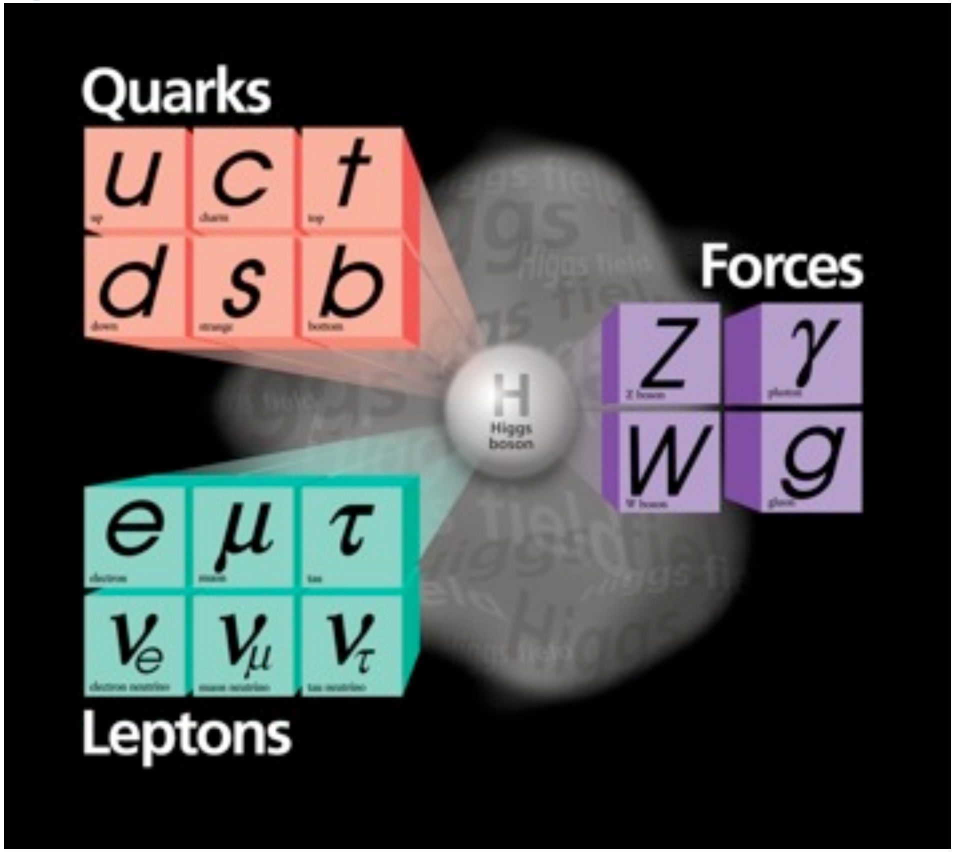
On behalf of the AWAKE Collaboration

- Motivation : particle physics; large accelerators
- General concept : proton-driven plasma wakefield acceleration
- AWAKE experiment at CERN
- Outlook

LPAW 2013 — 2−6 September 2013

Motivation

Big questions in particle physics



Particle accelerators have been crucial in elucidating the Standard Model.

Culmination in *27-km* long LHC (*pp*); a future e^+e^- collider is planned to be *30–50-km* long.

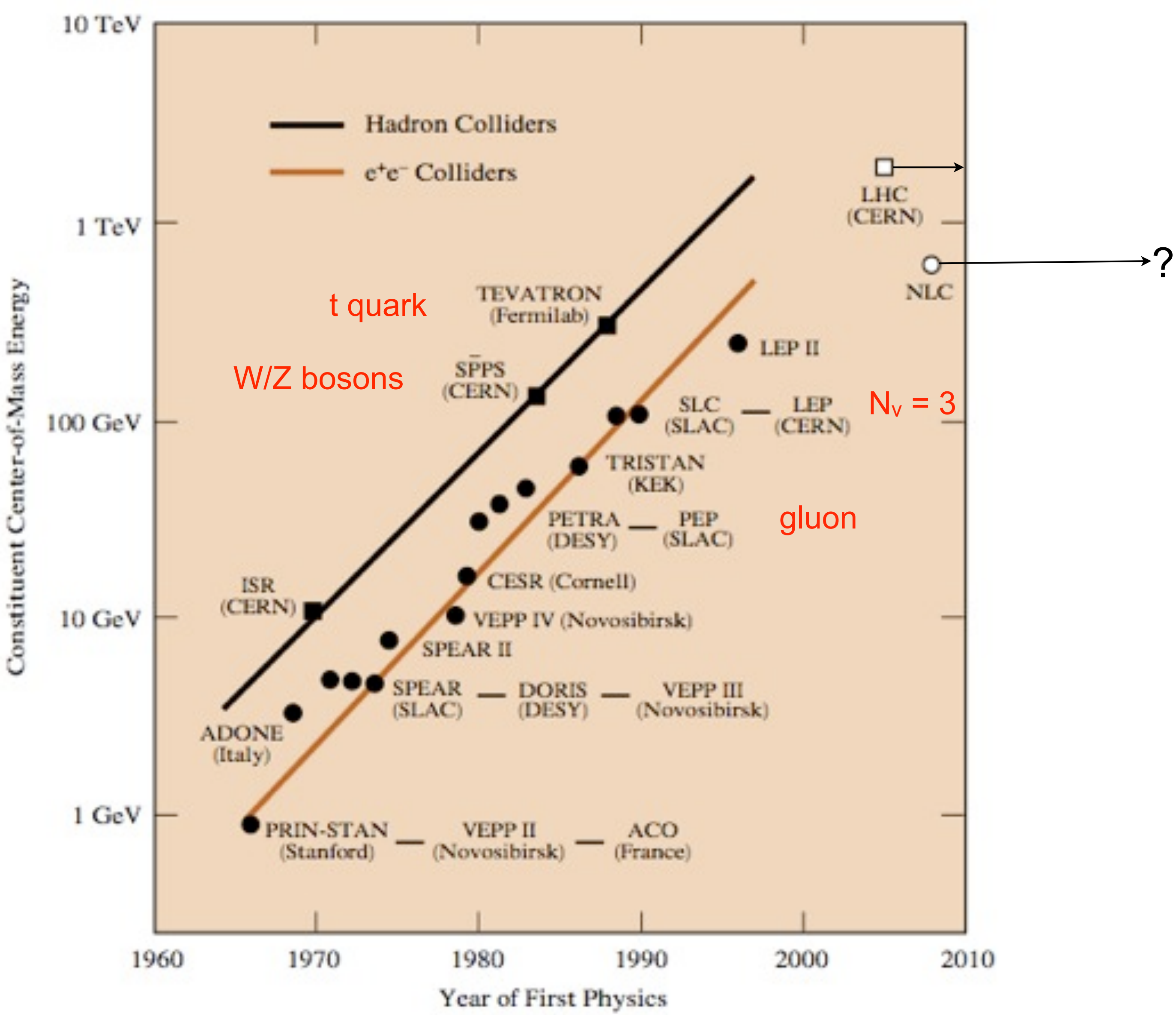
Can we reduce their size and their costs ?

Ultimately, can we build a (up to) TeV-scale e^+e^- collider of a few *km* in length ?

The Standard Model is amazingly successful, but some things remain unexplained :

- what are the consequences of the “Higgs” particle discovery ?
- why is there so much matter (vs anti-matter) ?
- why is there so little matter (*5%* of Universe) ?
- can we unify the forces ?

Collider history



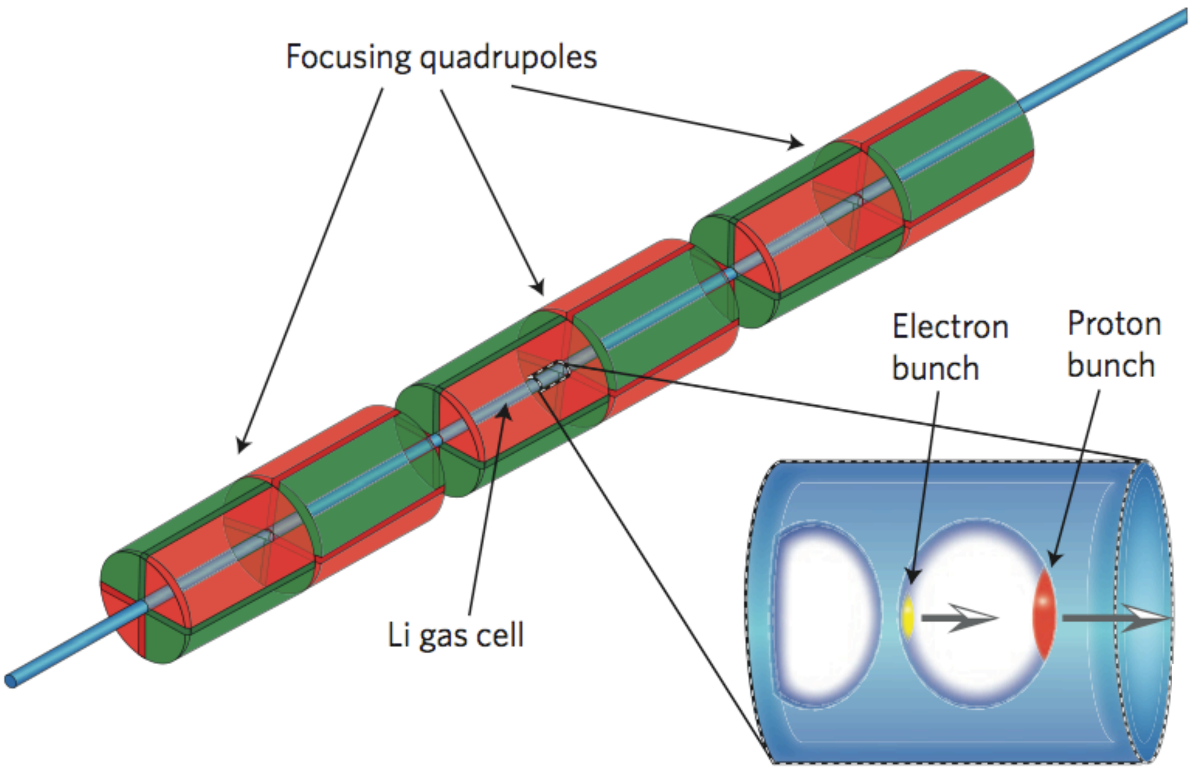
Collider parameters e^- beam

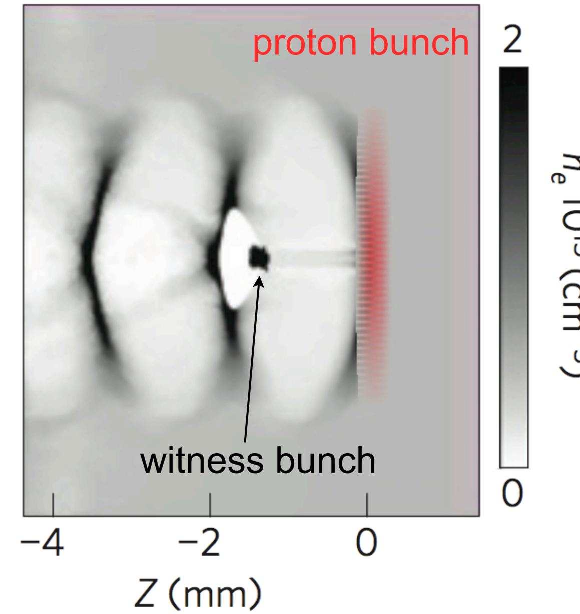
	ILC	LHeC
Energy (GeV)	125	60
Bunch population	2×10^{10}	2×10^{9}
Number of bunches	1312	
Bunch separation (ns)	554	25 or 50
Collision rate (Hz)	5	-
Energy spread	0.19%	0.03%
Horizontal emittance	10 μm	50 μm
Vertical emittance	35 nm	50 μm
Beam size	729×7.7 nm^2	7×7 μm^2
Luminosity $\times 10^{34}$ cm^{-2}s^{-1}	0.75	0.1 (~1)

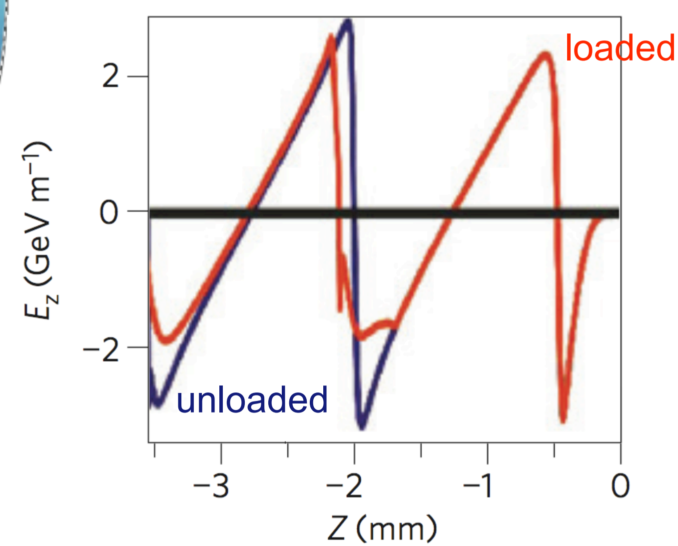
ILC TDR, June 2013
LHeC CDR, June 2012

Proton-driven plasma wakefield acceleration

PDPWA concept*





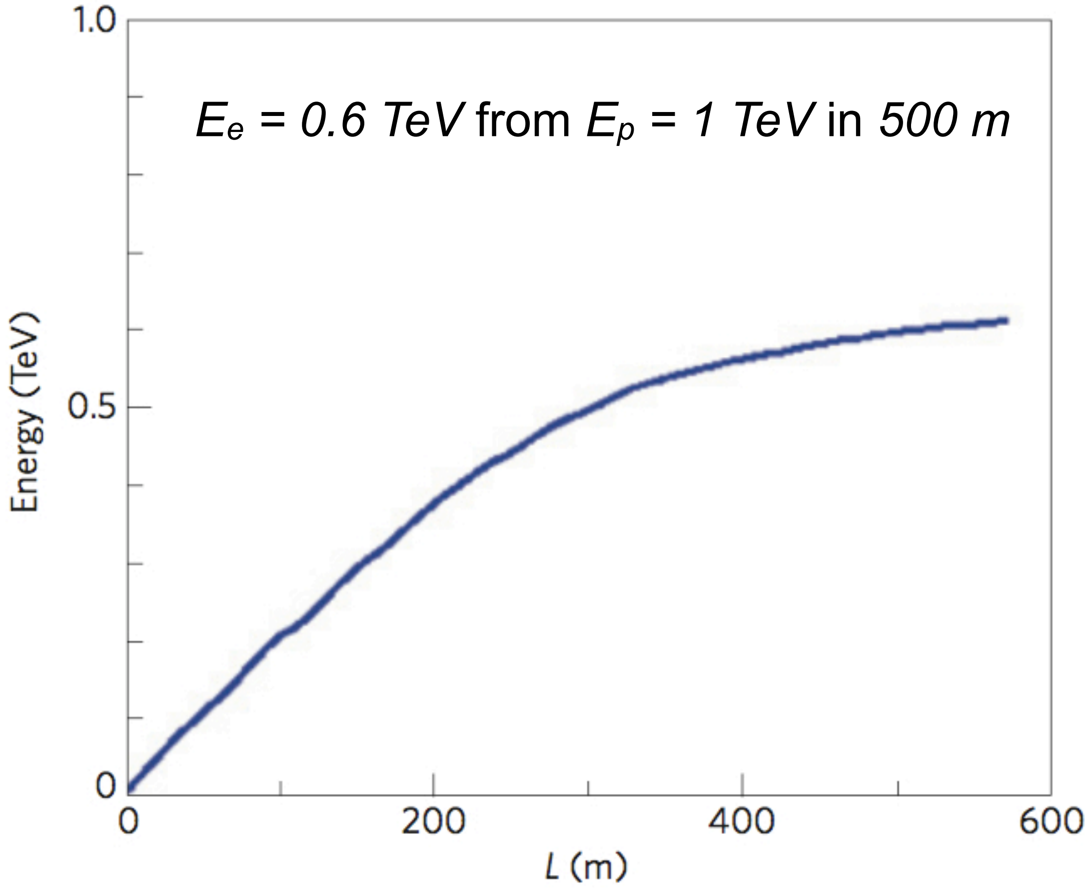


- Electrons 'sucked in' by proton bunch.
- Continue across axis creating a depletion region.
- Transverse electric fields focus witness bunch.
- Maximum accelerating gradient of *3 GV/m*.

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

PDPWA concept

Proton beam impacting on a plasma to accelerate and electron witness beam



PDPWA concept

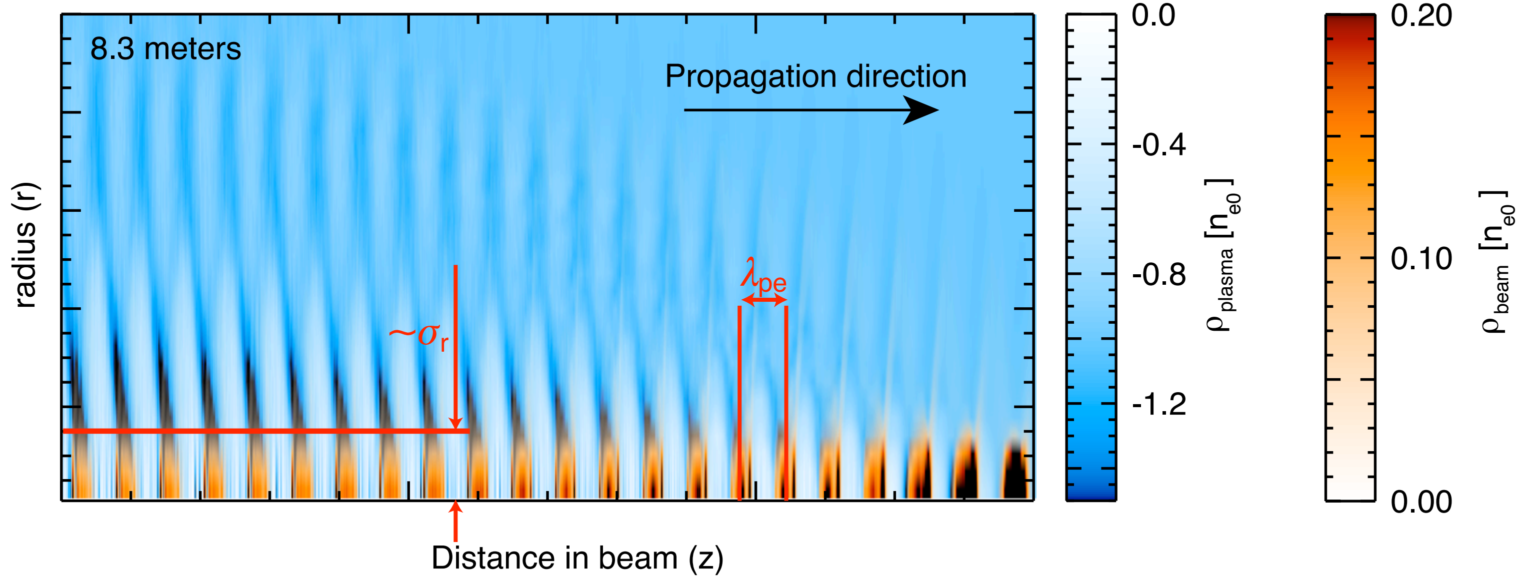
Table 1 | Table of parameters for the simulation.

Parameter	Symbol	Value	Units
Protons in drive bunch	N_P	10^{11}	
Proton energy	E_P	1	TeV
Initial proton momentum spread	σ_p/p	0.1	
Initial proton bunch longitudinal size	σ_z	100	µm
Initial proton bunch angular spread	σ_θ	0.03	mrad
Initial proton bunch transverse size	$\sigma_{x,y}$	0.43	mm
Electrons injected in witness bunch	N_e	1.5×10^{10}	
Energy of electrons in witness bunch	E_e	10	GeV
Free electron density	n_p	6×10^{14}	cm^{-3}
Plasma wavelength	λ_p	1.35	mm
Magnetic field gradient		1,000	$\mathrm{T\,m}^{-1}$
Magnet length		0.7	m

- Needs significant bunch compression < *100 µm* (or new proton source).
- Challenges include : sufficient luminosities for an e^+e^- machine, repetition rate, focusing, accelerating positrons, etc..

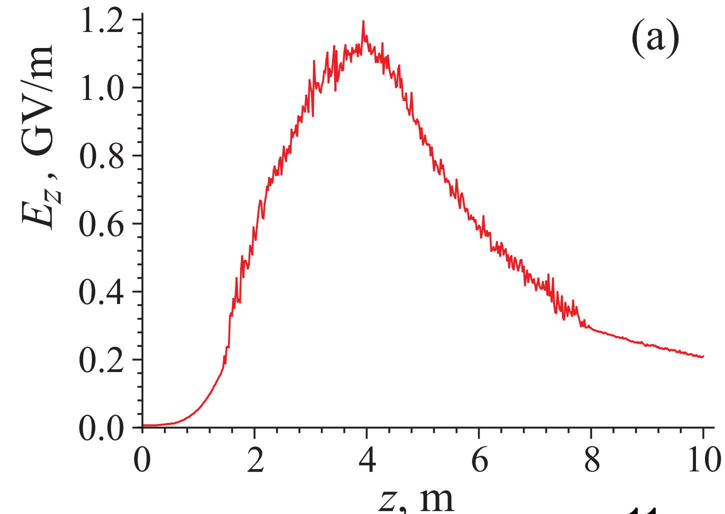
The AWAKE experiment at CERN

Self-modulation of the proton beam



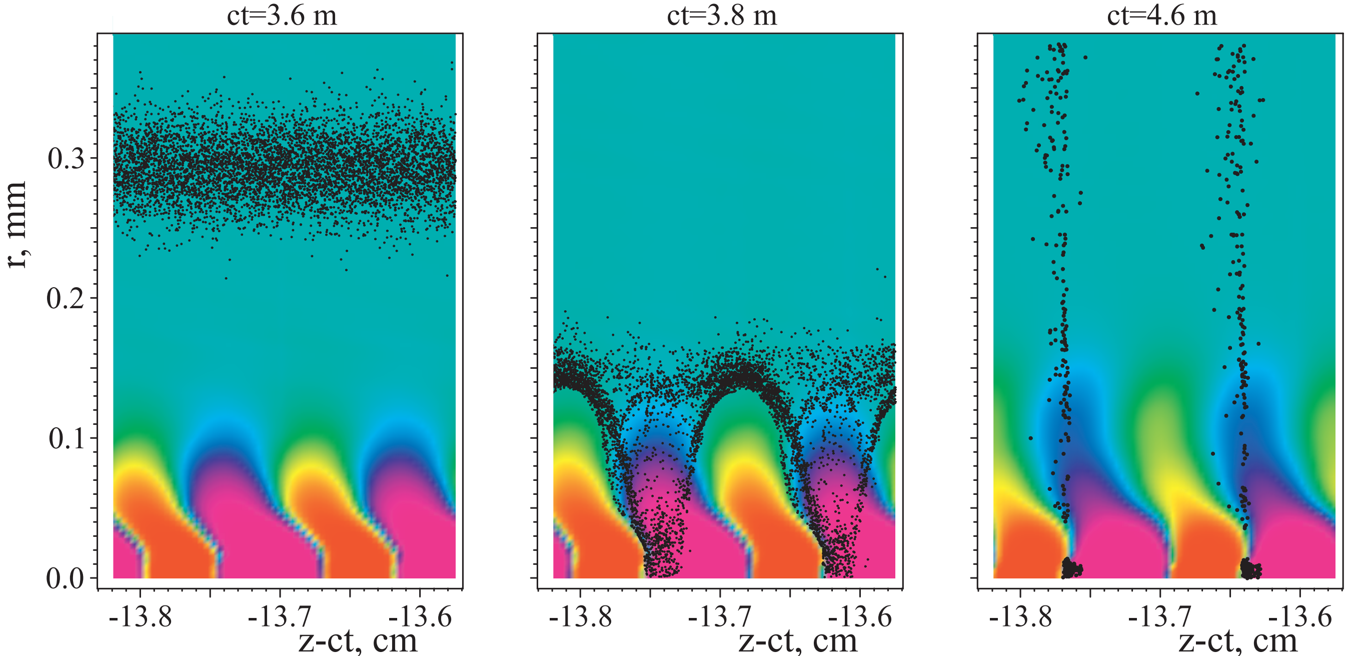
CERN SPS proton beam

Proton bunch population, N_b	3×10^{11}
Proton bunch length, σ_z	12 cm
Proton bunch radius, σ_r	0.02 cm
Proton energy, W_b	400 GeV
Proton bunch relative energy spread, $\delta W_b/W_b$	0.35%
Proton bunch normalized emittance, ϵ_{bn}	3.5 mm mrad



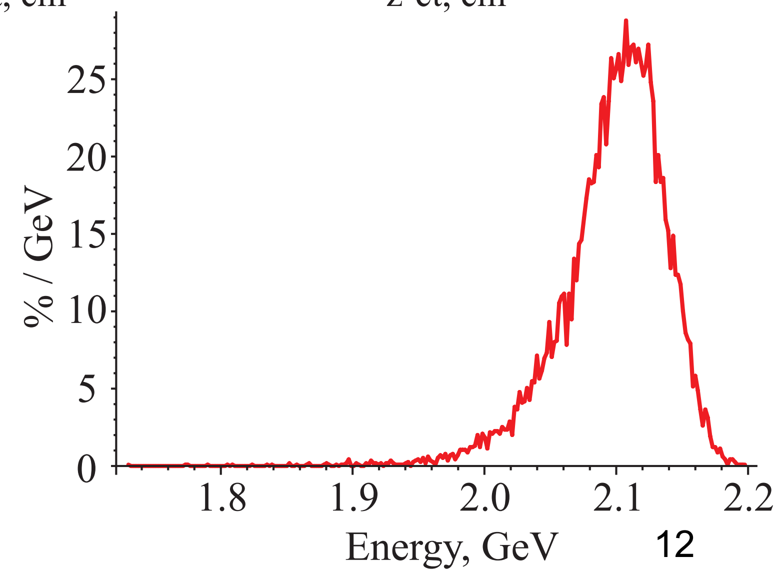
K.V. Lotov Phys. Plasmas **18** (2011) 024501

Injection of witness electrons

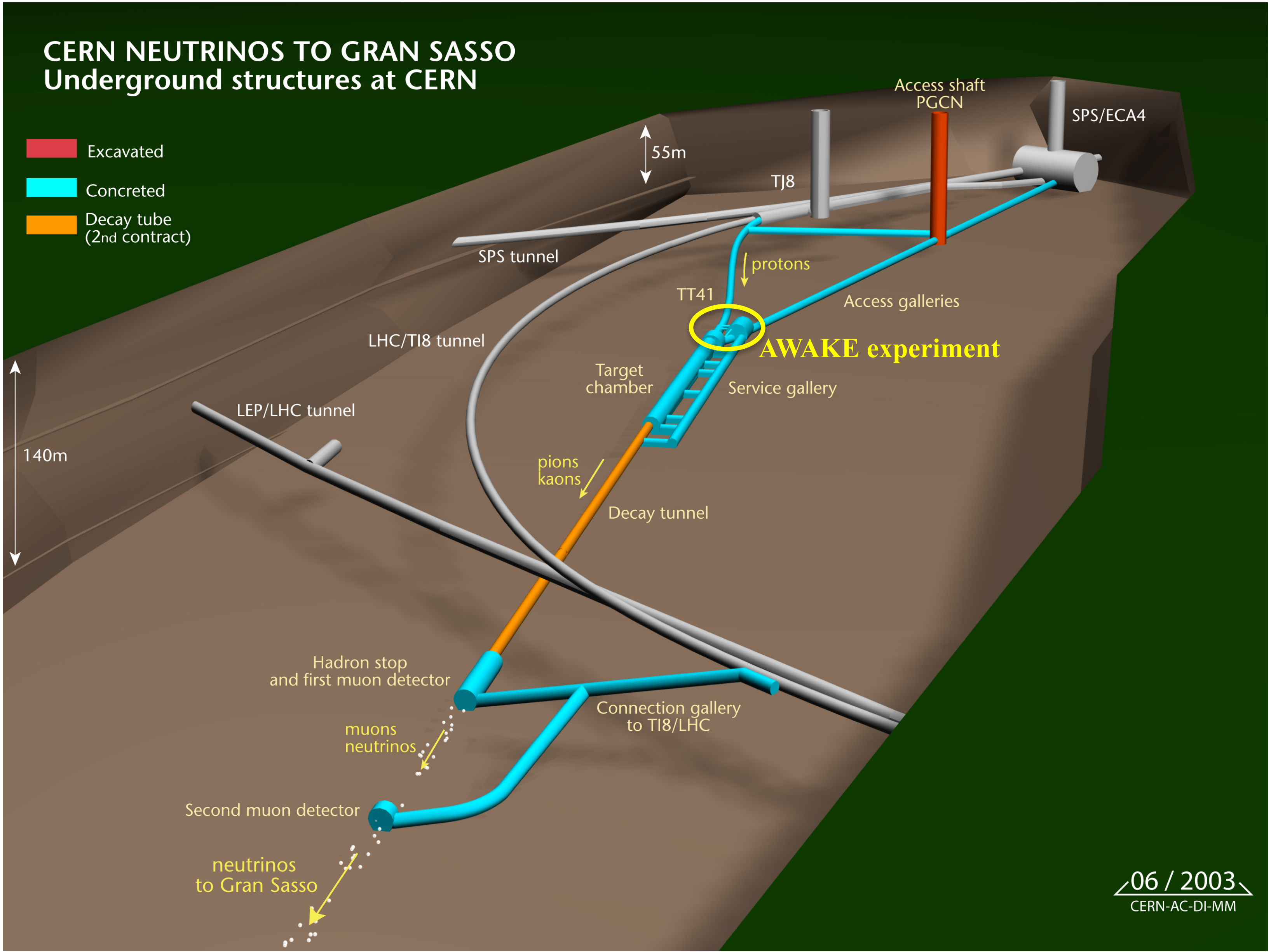


K.V. Lotov, J. Plasma Phys. **78** (2012) 455

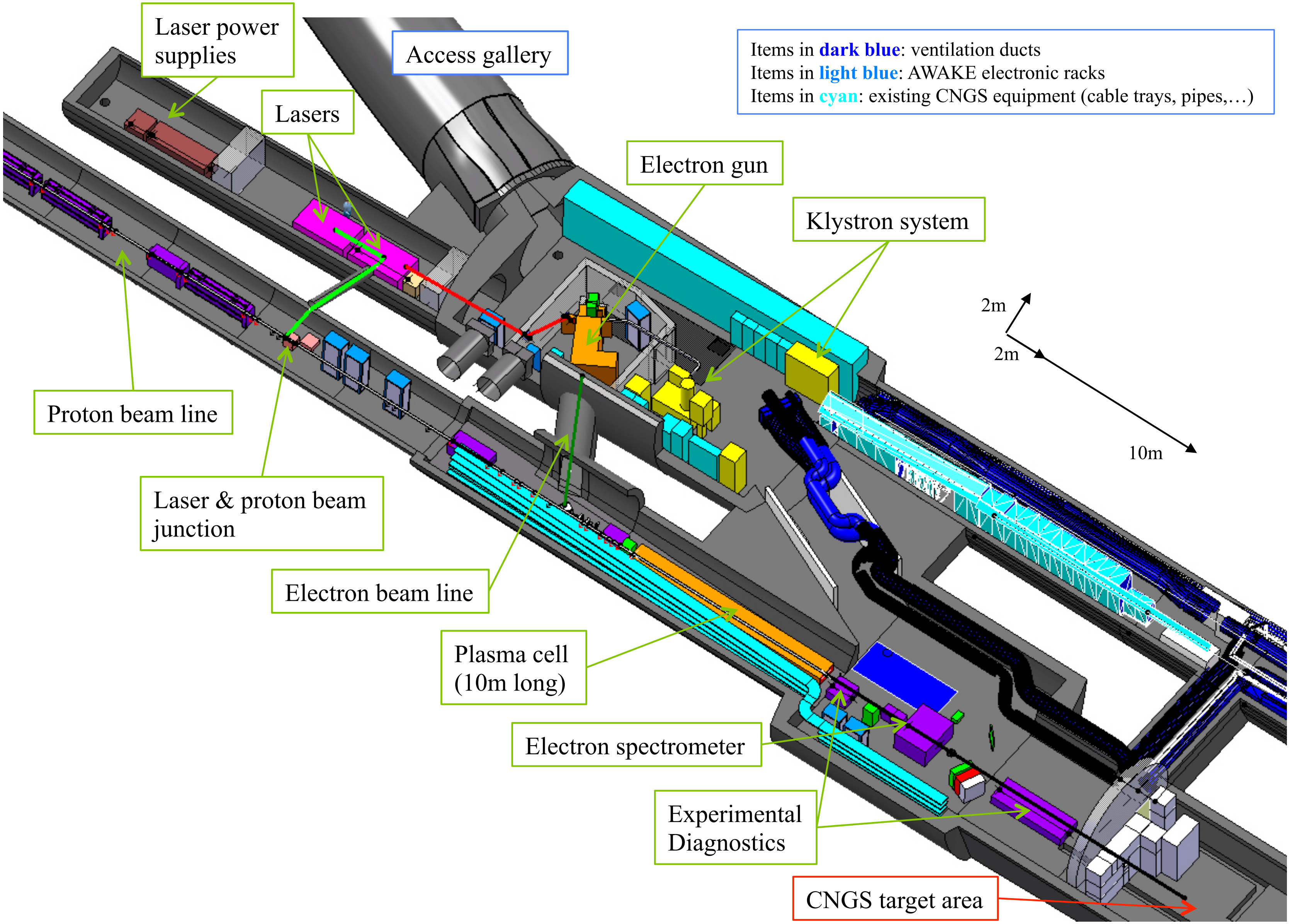
Electron bunch population, N_e	1.25×10^9
Electron bunch length, σ_{ze}	0.25 cm
Electron bunch radius at injection point, σ_{re}	0.02 cm
Electron energy, W_e	16 MeV
Electron bunch normalized emittance, ϵ_{en}	2 mm mrad
Injection angle for electron beam, ϕ	9 mrad
Injection delay relative to the laser pulse, ξ_0	13.6 cm
Intersection of beam trajectories, z_0	3.9 m



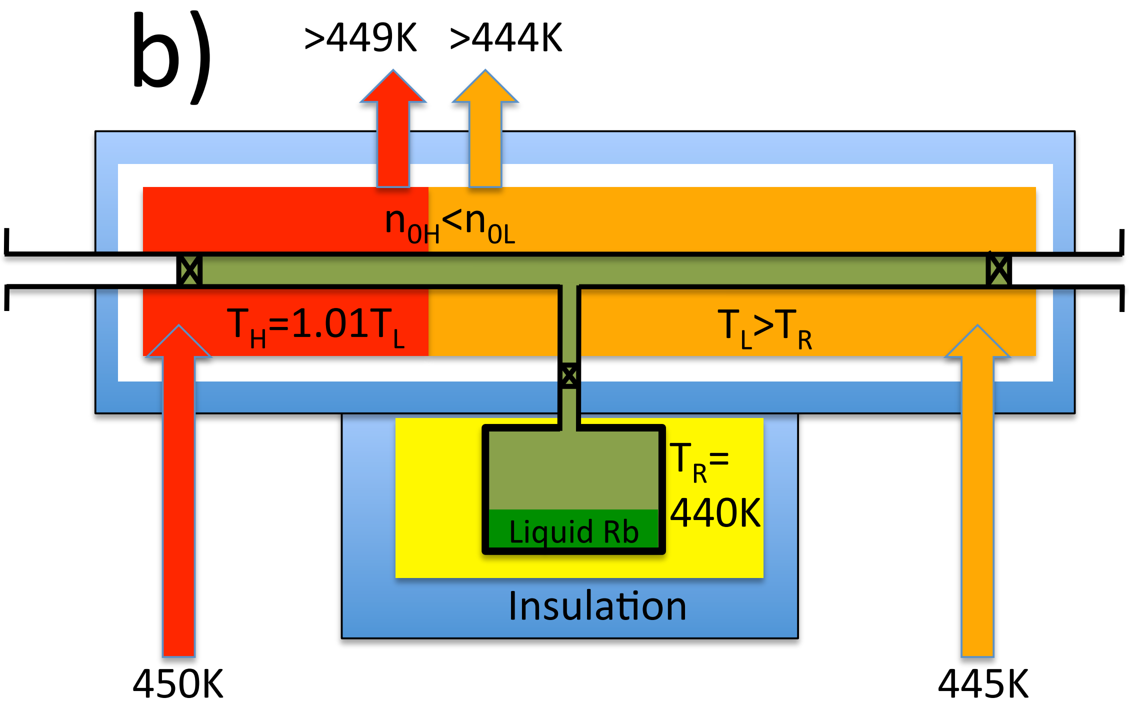
CNGS facility at CERN



Layout of AWAKE experiment



Plasma source



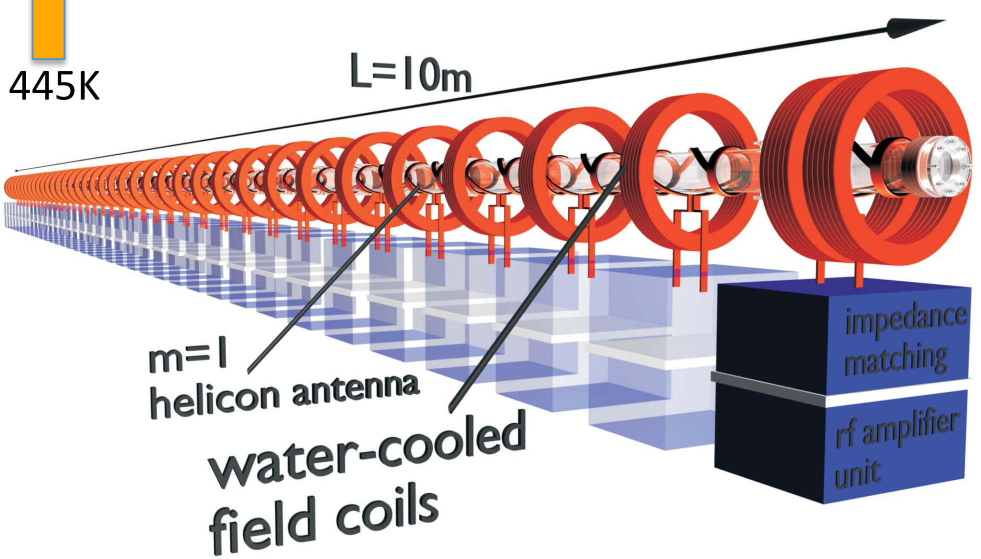
Three possibilities :

- Rubidium vapour
- Helicon cell
- Discharge cell

Must satisfy :

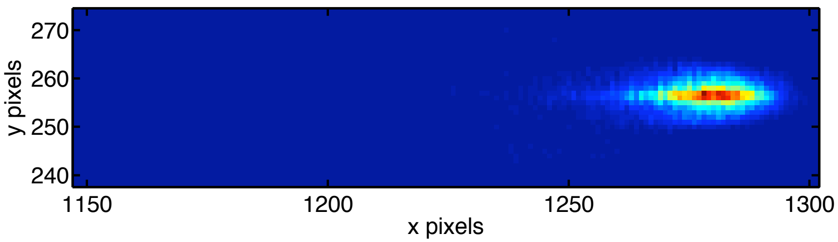
- length ~ *10 m*
- density $10^{14} - 10^{15}\ cm^{-3}$
- uniformity ~ *0.2%*

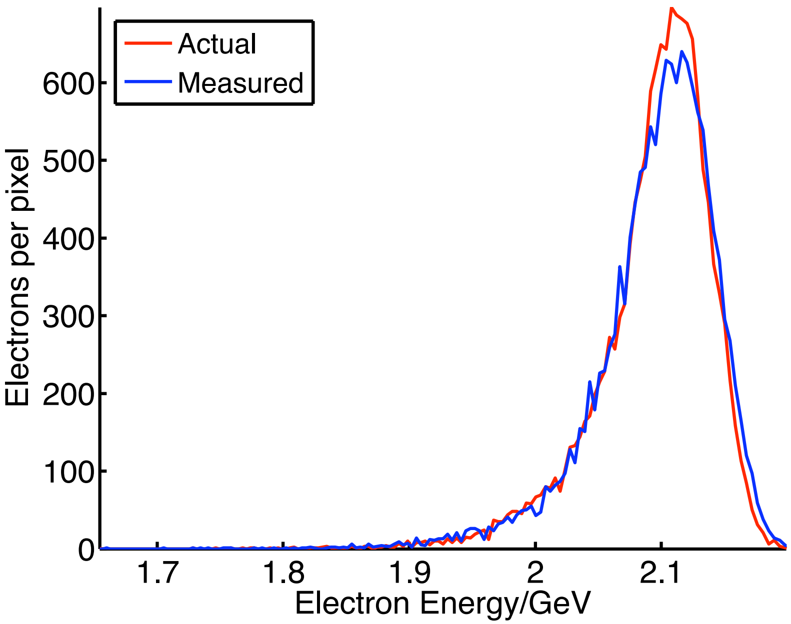
- Synthetic oil surrounding Rb for temperature stability
- Vacuum tube surrounding oil suppressing heat loss
- Need *1 − 2 TW* laser with *30 − 100 fs* pulse



Diagnostics

Electron spectrometer

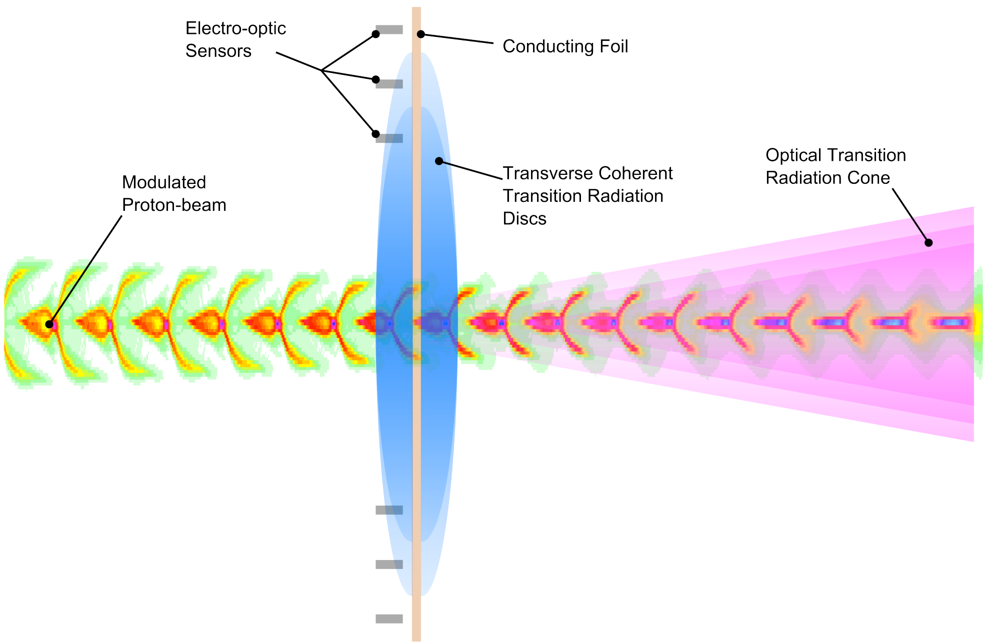




- Use *1 m, 1.8 T* magnet.
- Can measure wide range of energies.

Some examples, also looking at others, CTR, photon acceleration, THz diagnostics, ...

OTR and TCTR



TCTR : A. Pukhov, T. Tueckmantel, Phys. Rev. STAB **15** (2012) 111301

AWAKE Collaboration and practicalities

Collaboration of accelerator, plasma and particle physicists and engineers formed.

AWAKE Design Report

A Proton-Driven Plasma Wakefield Acceleration Experiment at CERN

AWAKE Collaboration

Abstract

The AWAKE Collaboration has been formed in order to demonstrate proton-driven plasma wakefield acceleration for the first time. This technology could lead to future colliders of high energy but of a much reduced length compared to proposed linear accelerators. The SPS proton beam in the CNGS facility

9.2.1 Institutes Committed to AWAKE

ASTeC, STFC Daresbury Laboratory, Warrington, UK
Budker Institute of Nuclear Physics (BINP), Novosibirk, Russia
CERN, Geneva, Switzerland
Cockroft Institute (CI), Daresbury, UK
Heinrich Heine University, Düsseldorf (D), Germany
Instituto Superior Técnico, Lisboa (IST), Portugal
Imperial College (IC), London, UK
Ludwig Maximilian University (LMU), Munich, Germany
Max Planck Institute for Physics (MPP), Munich, Germany
Max Planck Institute for Plasma Physics (IPP), Greifswald, Germany
Rutherford Appleton Laboratory (RAL), Chilton, UK
University College London (UCL), London, UK
University of Strathclyde (S), Glasgow, Scotland, UK

More institutes committing.

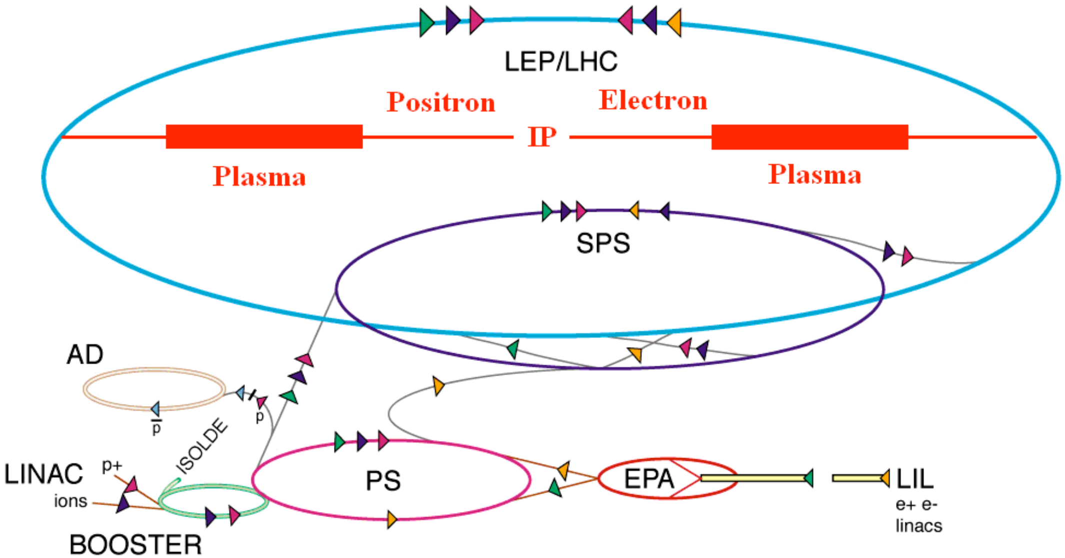
Now a (fully) approved CERN project; on their Medium-Term Plan and significant funding.

- Expect first protons to plasma cell end of 2016
- Expect electron injection end of 2017
- Periods of running for 3 – 4 years

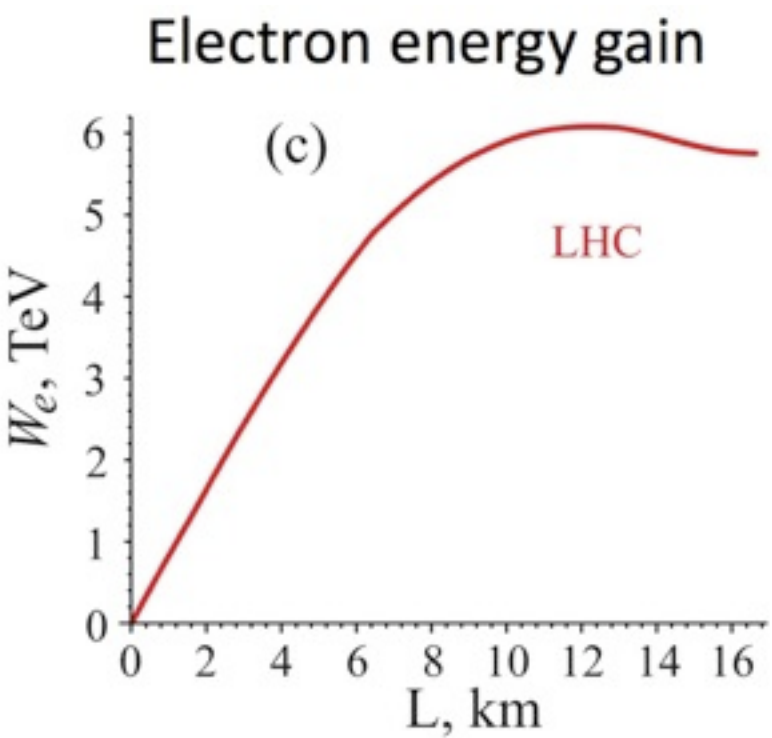
Outlook

The future

- Consider intermediate stage to possible “full” experiment.
- Consider compressing proton beam —magnetic compression, cutting the beam into slices, etc..
- Ultimate goal of application to future collider.



G. Xia et al. EAAC proc.



Could be used for :

- *ep* (*60×7000 GeV*) LHeC collider
- TeV-scale e^+e^- collider

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

Summary

- Plasma wakefield acceleration could have a huge impact on many areas of science and industry using particle accelerators.
- Presented an idea to have a high energy lepton collider based on proton-driven plasma wakefield acceleration.
- Proof-of-principle AWAKE experiment at CERN.
- To realise a TeV-scale lepton collider a factor of ~ *10* shorter than current designs.

See, AWAKE Design Report, CERN-SPSC-2013-013, http://cds.cern.ch/record/1537318/files/SPSC-TDR-003.pdf