Particle Physics Application

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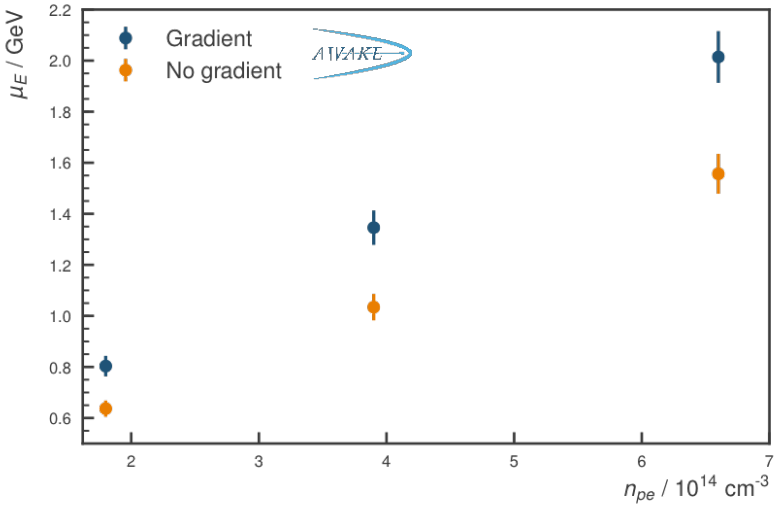
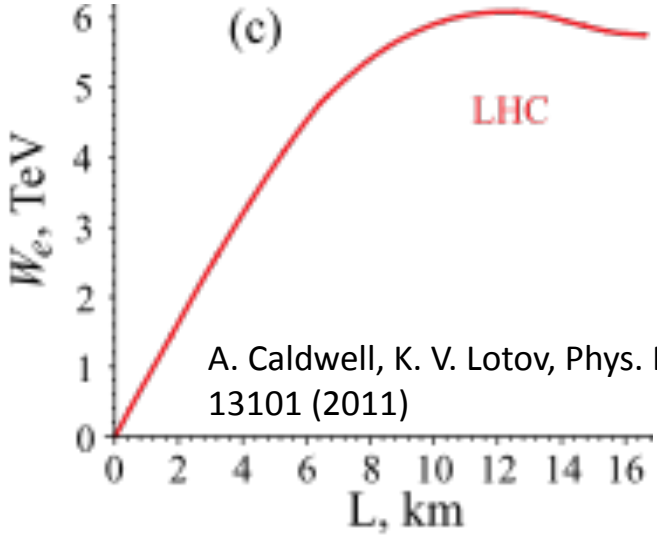
E. Adli et al., AWAKE Collaboration, Nature **561,** 363 (2018)





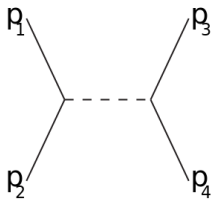
A. Caldwell, K. V. Lotov, Phys. Plasmas **18,** 13101 (2011)

5 TeV/electron bunch, with 10^{10} electrons/bunch on average 1/s ?

What if we could provide 1 PeV/electrons with 10^{9}electrons/bunch on average 1/1000s - who's interested?

General Considerations

s-channel cross sections scale as $\sigma \propto \frac{1}{s}$



$n_{\text{fixed}} \Longrightarrow \mathscr{L} \propto s$

Power!

very difficult to see today how high luminosity and high energy and affordability can be achieved in a linear collider:

LWFA - need high power AND high energy AND high efficiency laser …

PWFA - electron driver will need many stages, emittance preservation, positrons (for s-channel), …

PWFA - proton driver. With LHC, many TeV foreseeable but low rep rate, dedicated short cycling time proton accelerator?

As intermediate step, think what physics we can get from single high energy beams or low luminosity collider.

Particle Physics Applications

- **Physics with a high energy electron beam**
  - search for dark photons in beam dump experiments
  - Fixed target experiments in new energy regime
  - Probe non-linear QED

Energy & Flux important - luminosity determined by target properties. Much more relaxed parameters for plasma accelerator

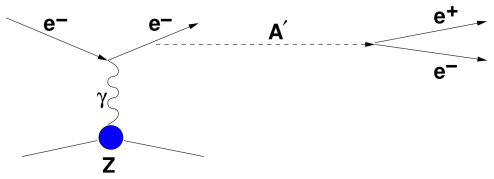
- **Physics with an electron-proton or electron-ion collider**
  - Low luminosity version of LHeC
  - Very high energy electron-proton, electron-ion collider

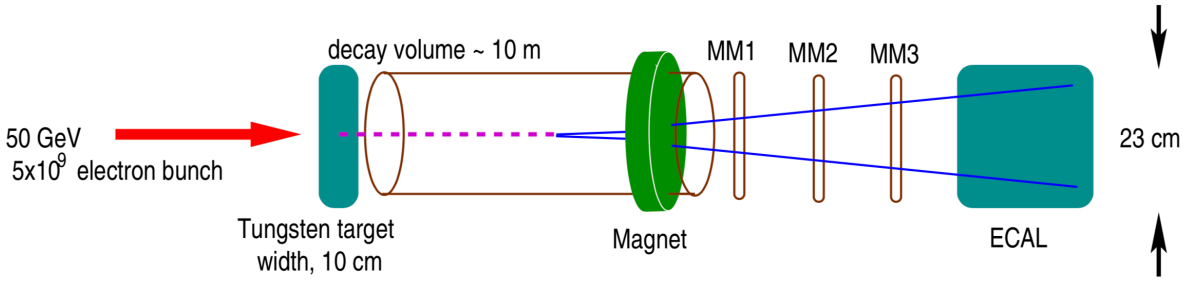
New energy regime means new physics sensitivity even at low luminosities !

- **To be evaluated:**
  - AWAKE-like scheme with ions
  - acceleration of muons
  - AWAKE-like scheme with FCC

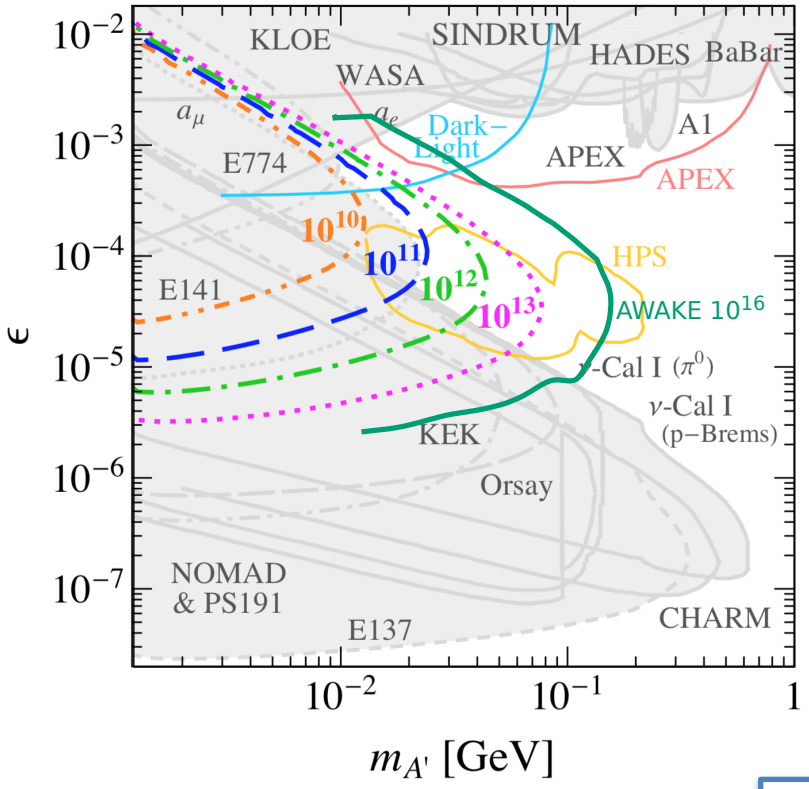
We have just started to evaluate the particle physics potential of plasma acceleration. Need creative thinking !

Beam Dump

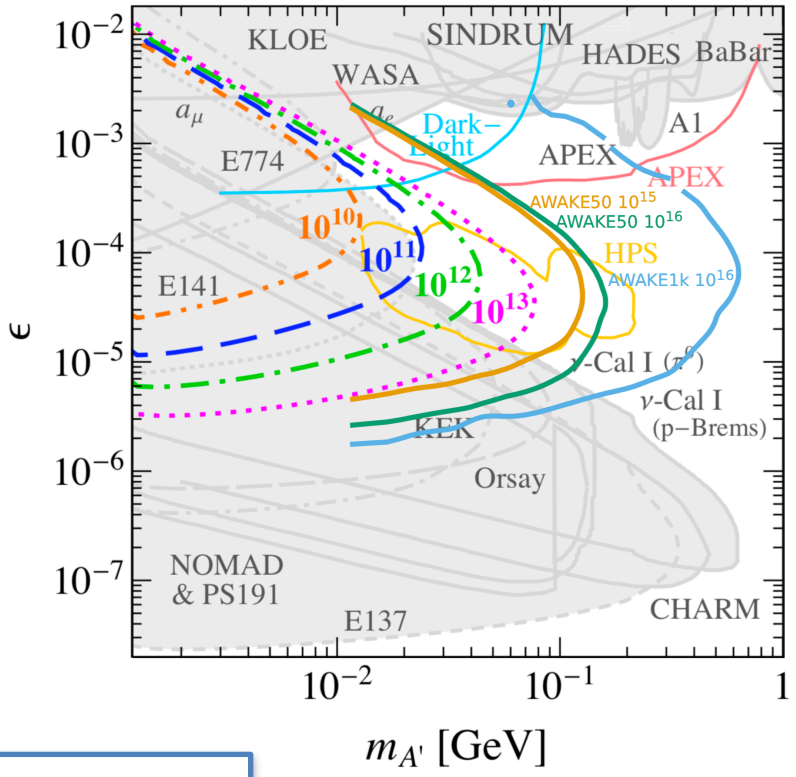




Expectation for 3 month run



Expectation for 10^{16} 1 TeV electrons



A. Hartin, M. Wing UCL

Fixed Target

Using LHC as driver, AWAKE style acceleration could reach energy regime that is comparable to the planned EIC at BNL in a fixed target mode.

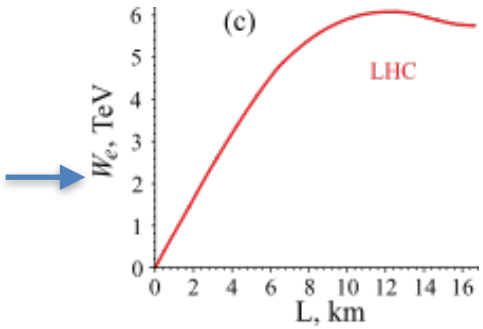
Advantage: luminosity achieved via the target
Disadvantage: very forward geometry for experiment. Exclusive states may be difficult to reconstruct. Pile-up if have `thick' target.

Has not been studied … some part of the EIC program could be covered … to be investigated

Electron beam polarization maintained in blowout regime (J. Vieira et al., PRST-AB **14**, 071303(2011)
Needs investigation for AWAKE scheme

$$E_{\mathrm{CM}} = \sqrt{2 M_P E_e} = 14 - 110 \ \mathrm{GeV}$$

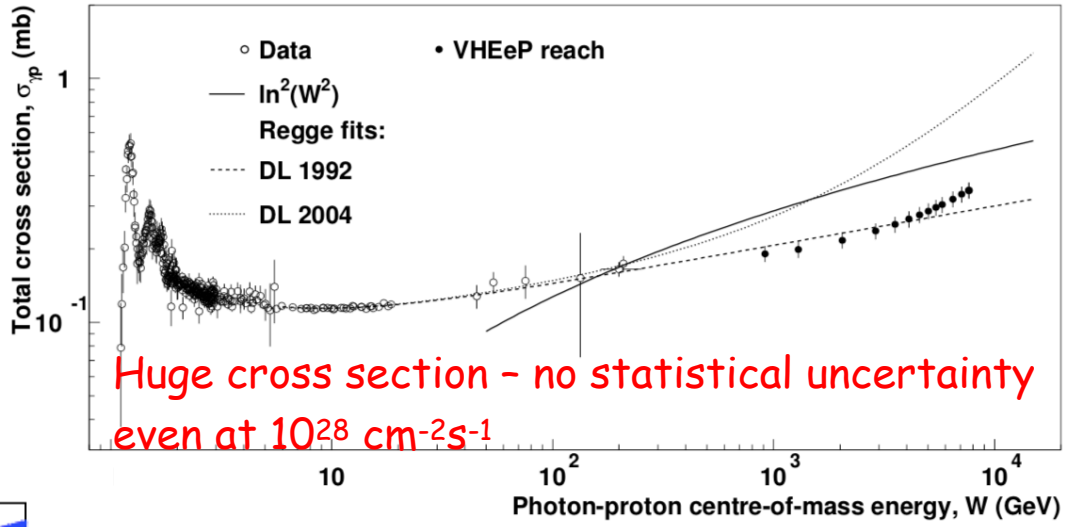
for E_e=100-6000 GeV LHC Driver



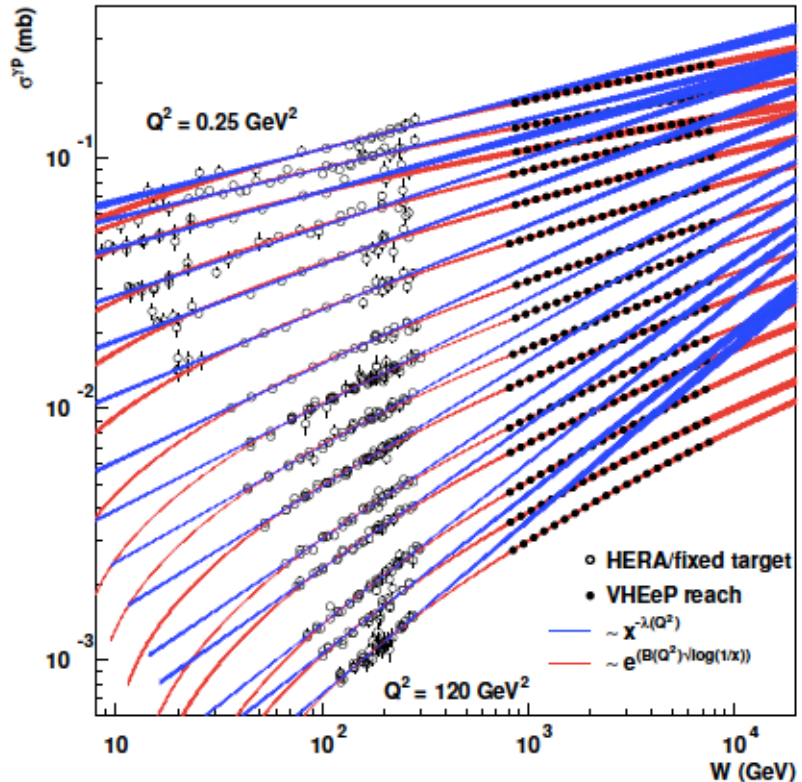
Compass: ~20 GeV
EIC: 15-140 GeV

Colliding 3 TeV electrons with LHC Protons

Total photoproduction cross section – energy dependence ?
See approach to Froissart bound ?
Impact on cosmic ray physics



Huge cross section – no statistical uncertainty even at 10^{28} $cm^{-2}s^{-1}$



Virtual photon cross section: unphysical extrapolation of cross sections -> observation of saturation of parton densities ?

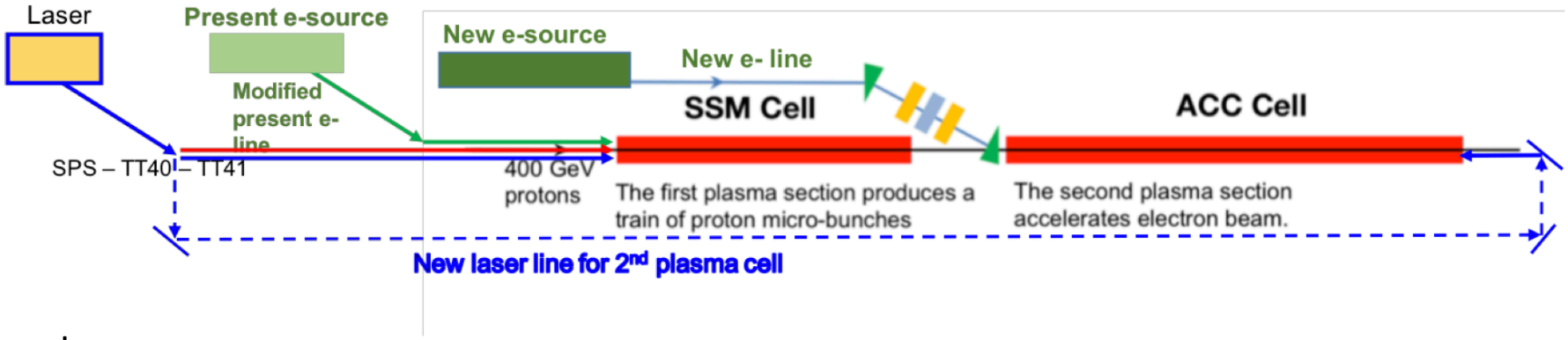
With the three orders of magnitude extension in the range at small-x, expect to see signs of the fundamental saturated regime.

VHEeP: A. Caldwell and M. Wing, Eur. Phys. J. C 76 (2016) 463

AWAKE Run 2 (2021-)

Goals:
stable acceleration of bunch of electrons with high gradients over long distances
'good' electron bunch emittance at plasma exit
Be prepared to start particle physics experiment after Run 2

Baseline design



Four phases:
- seeding the SSM with an electron bunch
- plasma cell with density step to freeze the modulation structure
- inject electrons & accelerate without emittance blowup
- implement scalable plasma cell technologies

Q&A

PART 1

1) Where do you see HEP applications of advanced accelerators in 30 years?
   Physics with single beams as outlined in previous slides

2) What intermediate physics applications/steps do you see until a HEP linear collider?
   Physics with single beams as outlined in previous slides

3) What is the synergy with related fields?
   Great interest in eP, fixed target from nuclear physics
   Nonlinear QED effects of general interest
   Understanding the plasma physics of interest for astrophysics (e.g., acceleration mechanism of highest energy cosmic rays)

4) What is the role of your work here?
   ?

Q&A

PART 2

1) What are the important milestones for the next 10 years to get there from today?

Demonstrate seeding of proton bunch modulation with electron bunch
Demonstrate ability to maintain strong acceleration gradients over long distances
Demonstrate acceleration of bunch of electrons with satisfactory emittance
Demonstrate scalable plasma cell technology

2) What additional support is needed to achieve these?

Building up a strong plasma acceleration team at CERN
Building up team of experts from non-CERN institutes to carry out research program at CERN
Securing the required financial resources
Developing the laboratory infrastructure so as suitable to carry out experimental progra

3) What should be proposed as deliverables until 2026? Please list in order of priority.

Demonstrate ability to modulate the full proton bunch
Demonstrate stabilization of the acceleration gradient
detailed scheme for electron bunch injection
demonstrated scalable plasma technology

Q&A

PART 2

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

The program to seed with an electron bunch is funded

The program for stabilizing acceleration gradients is part funded, resources being applied for

The program for developing scalable plasma sources is partially funded, additional resources will be needed

It is critical that CERN builds up a team of experts in the different aspects of plasma acceleration (experimental, plasma, simulation) to develop and maintain the required knowledge to bring the program to a successful conclusion. Such a move would also provide a strong signal to outside institutes that this program has a long-term future.

Q&A

PART 3

1) What key R&D needs can be achieved in existing R&D facilities?

The electron seeding and gradient stabilization will happen in the existing facilities

2) What is the role of the already planned future facilities in Europe and world-wide?

Proton-driven PWA could be carried out at any lab with a high energy proton beam. E.g. at BNL or FNAL.

3) What can be done with the existing and planned funding base?

The experimental program until 2026 is largely funded, but new resources will be necessary to build an electron bunch injection system for the next running period.

4) Is a completely new facility needed?

The existing facility must be extended by clearing out the CNGS target area to carry out the program of electron bunch acceleration and the demonstration of scalable plasma sources. A new facility will be needed for the particle physics program

5) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?

A design study group for the realization of the different particle physics options discussed + new ones that will appear is required.