MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

VHEeP (and PEPIC)
very high energy eP and eA colliders

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DIS2018 Workshop
Kobe, Japan

Novel accelerators based on plasma wakefields, dielectric structures or direct laser acceleration will bring new scientific opportunities.

With AWAKE and proton-driven wakefield acceleration, we aim to use existing infrastructure for the wakefield driver to accelerate electrons to high energy. We want to develop the program of particle physics applications in parallel.

First ideas:

- Fixed target experiments
- Low luminosity eP/eA using SPS driver : PEPIC
- Low luminosity eP/eA using LHC driver : VHEeP
- For-purpose built proton driver

Proton Drivers for PWFA

Proton bunches as drivers of plasma wakefields are interesting because of the very large energy content of the proton bunches.

Drivers:

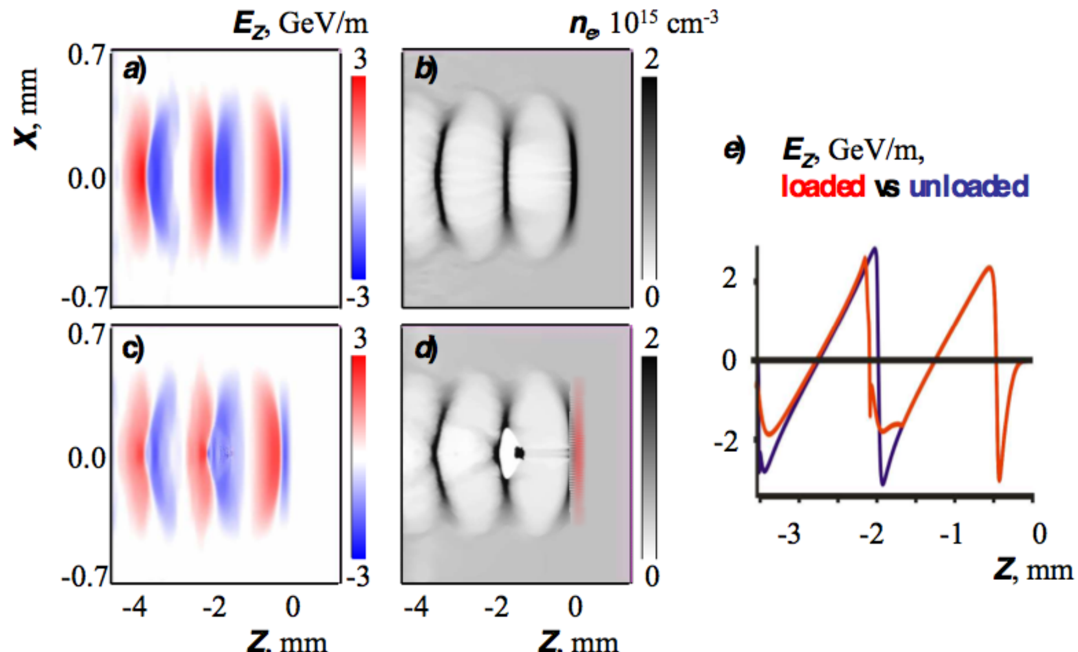
PW lasers today, ~40 J/Pulse

FACET (e beam, SLAC), 30J/bunch

SPS@CERN 20kJ/bunch
LHC@CERN 300 kJ/bunch

Witness:

10^{10} particles @ 1 TeV ≈ few kJ



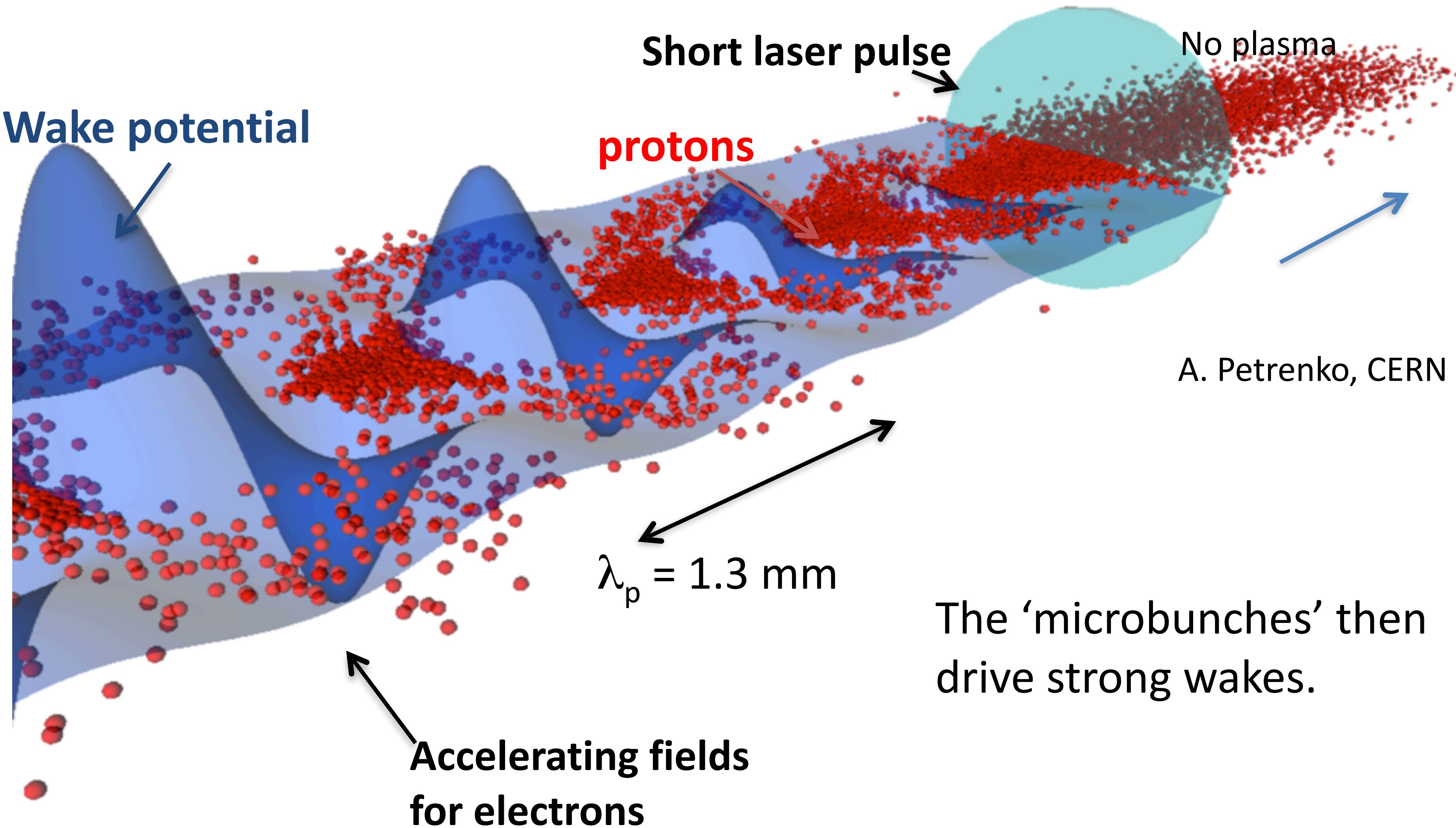
A. Caldwell, K. Lotov, A. Pukhov, F. Simon, Nature Physics 5, 363 (2009).

$$\lambda_p \approx 1 \text{ mm} \sqrt{\frac{1 \cdot 10^{15}\text{cm}^{-3}}{n_p}}$$

Energy content of driver allows to consider single stage acceleration.
Need short drivers to create strong wakefields.

Seeded self-modulation

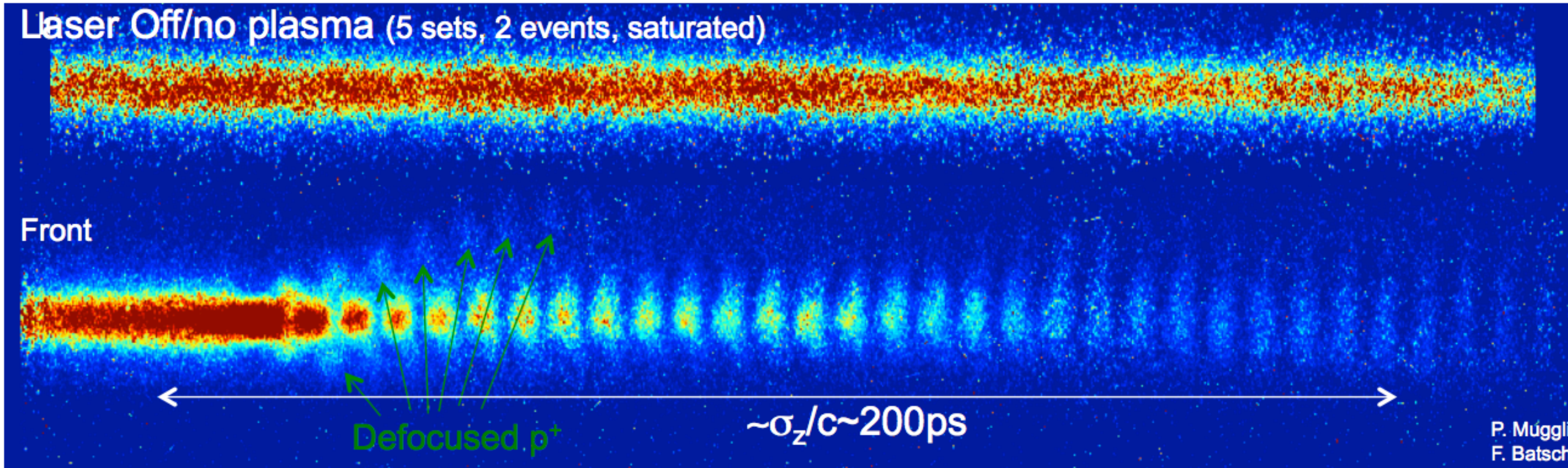
Short high energy bunches do not exist. But, a self-modulation can be seeded by a sharp start of the beam (or beam-plasma interaction).



The 'microbunches' then drive strong wakes.

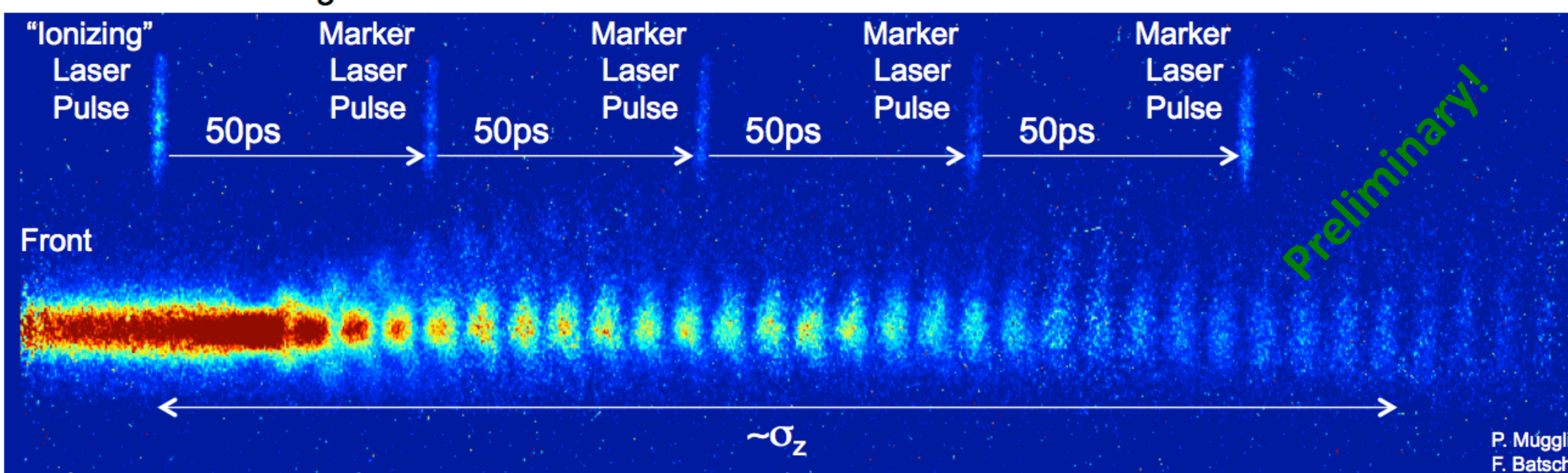
AWAKE Result - 2017

Streak camera Images



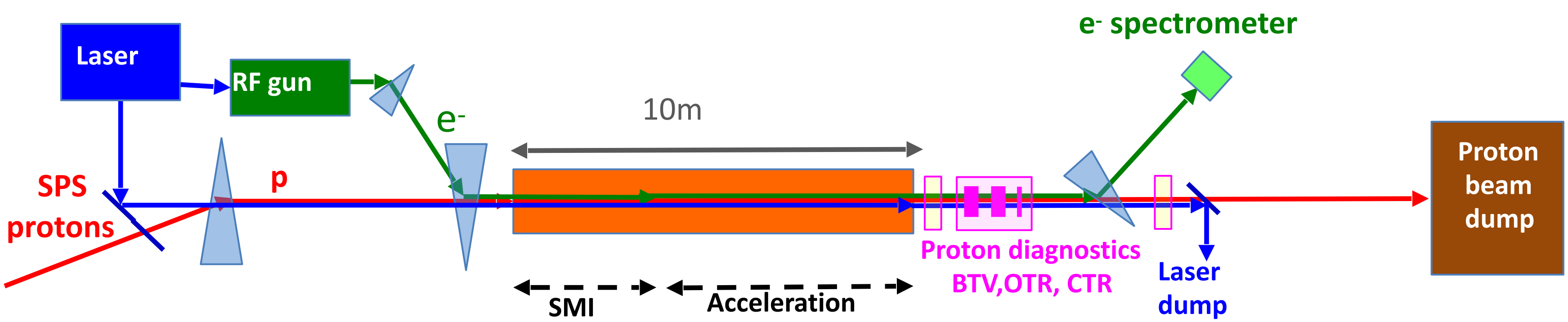
Streak camera Images

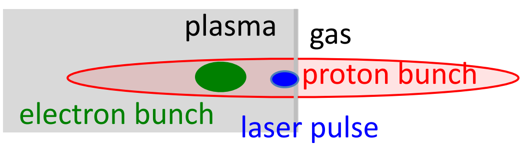
10 events each



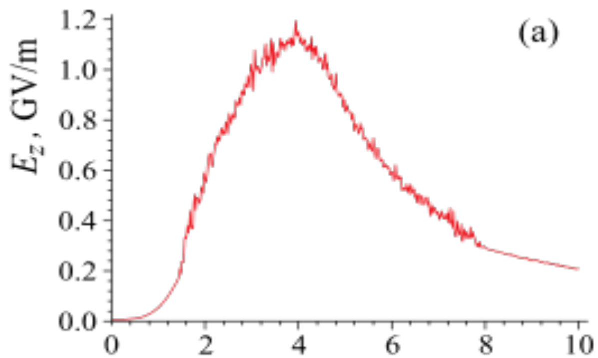
AWAKE Experimental Program

- Phase 1: Understand **the physics of self-modulation instability**.
- Phase 2: **Probe the accelerating wakefields** with externally injected electrons.





→ **Program for 2018**



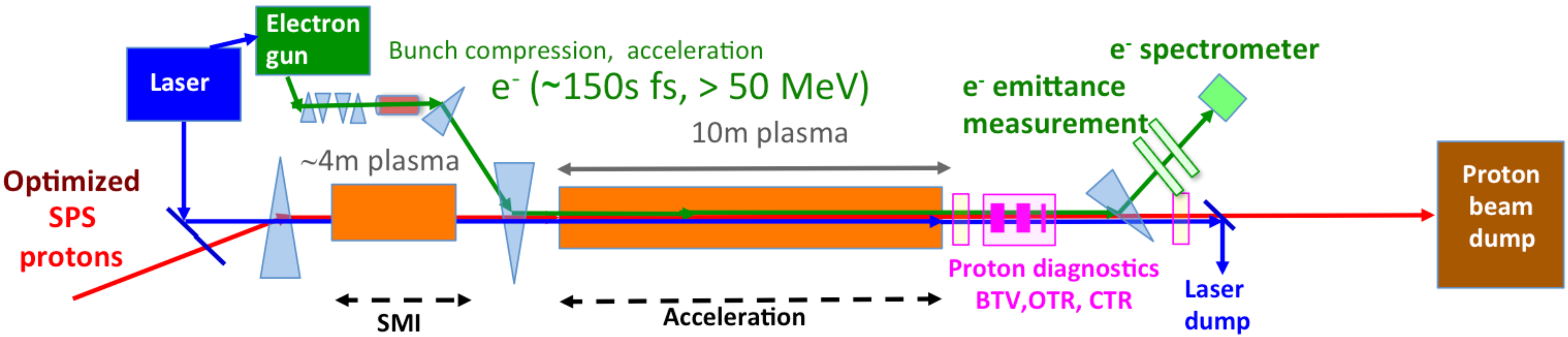
Maximum amplitude of the **accelerating field E_z** as a function of position along the plasma. Saturation of the SMI at ~4m.

Demonstrate GeV scale gradients with proton driven wakefields.

Run II (2021-2024)

Goals:

- stable acceleration of bunch of electrons with high gradients over long distances
- good electron bunch emittance at plasma exit

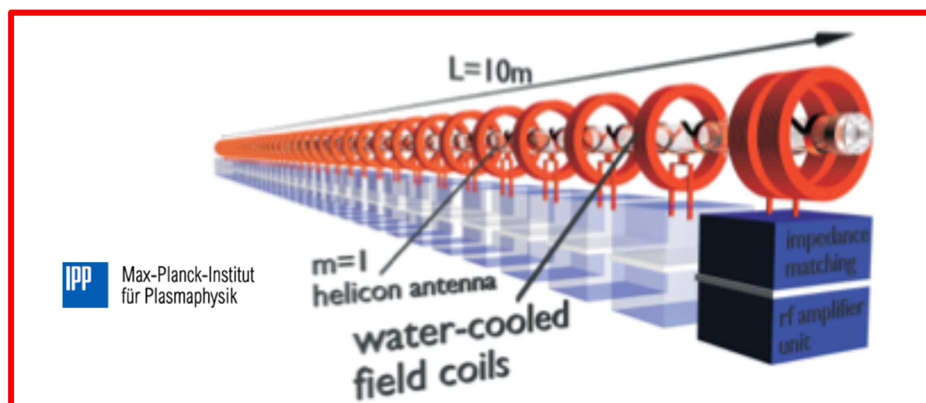


Require:

- Compressed proton beam in SPS
- Possibly short electron bunch with higher energy for loading wakefield
- Density step in plasma for freezing modulation
- Alternative plasma cell developments

O. Grülke, IPP

O. Schmitz, Wisconsin



Particle Physics Perspectives

Started considering:

- **Physics with a high energy electron beam**
  - E.g., search for dark photons

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

Are there fundamental particle physics topics for high energy but low luminosity colliders ?

I believe – yes ! Particle physicists will be interested in going to much higher energies, even if the luminosity is low.

In general – start investigating the particle physics potential of an AWAKE-like acceleration scheme.

QCD at high energies

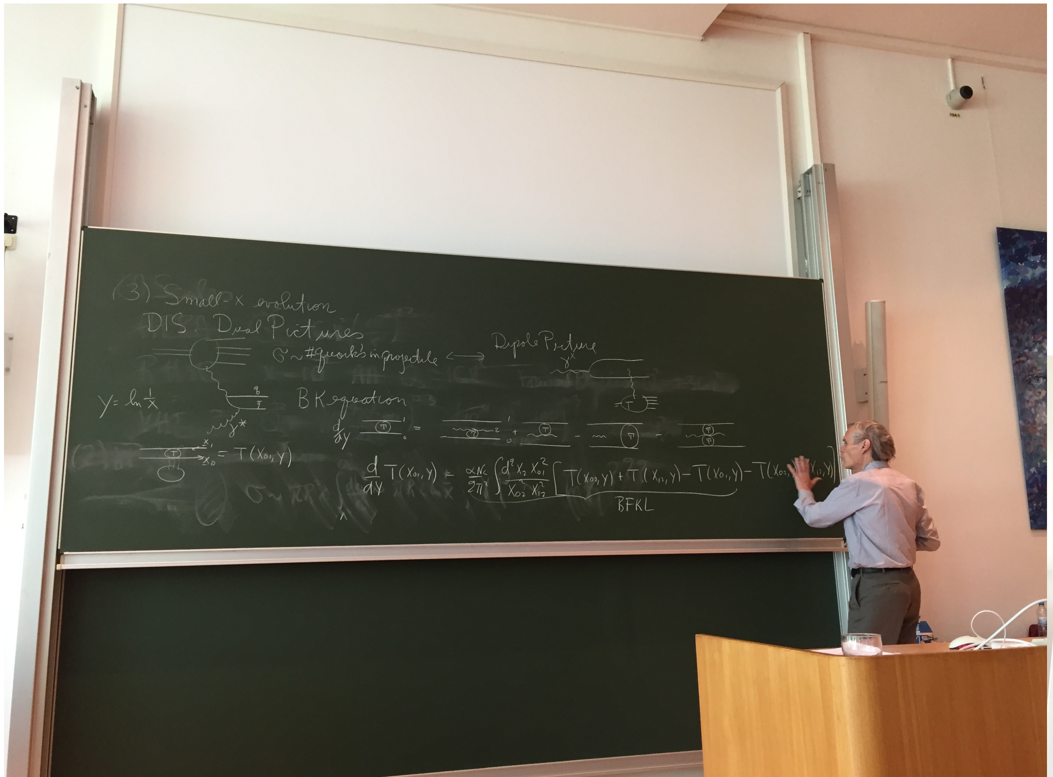
With VHEeP - clearly enter into a new regime that will allow to study and understand the high energy behavior of cross sections. This is fundamental physics, which today lacks understanding. Different targets can be probed (eA as well as eP).

Workshop: June 1-2,2017 at the Max Planck Institute for Physics (titles paraphrased)

A. Mueller	eA physics and nonlinear effects in parton densities
G. Dvali	Classicalization and energy dependence of cross sections
J. Erdmenger	Applying AdS/CFT to very low-x physics
A. Stasto	low-x physics and high-energy neutrino physics
L. Stodolsky	Formation-zone physics
J. Bartels	HERA lessons and perspectives for small-x physics
H. Kowalski	BFKL and dipoles
D. Schildknecht	Color dipoles at small-x
H. Mantysaari	eA physics at very high energies
E. Aschenauer	Polarized eP and eA physics
V. Myronenko	What we know from HERA
F. Keeble	VHEeP kinematics study
S. Plaetzer	Physics simulators for very high energy eP and eA

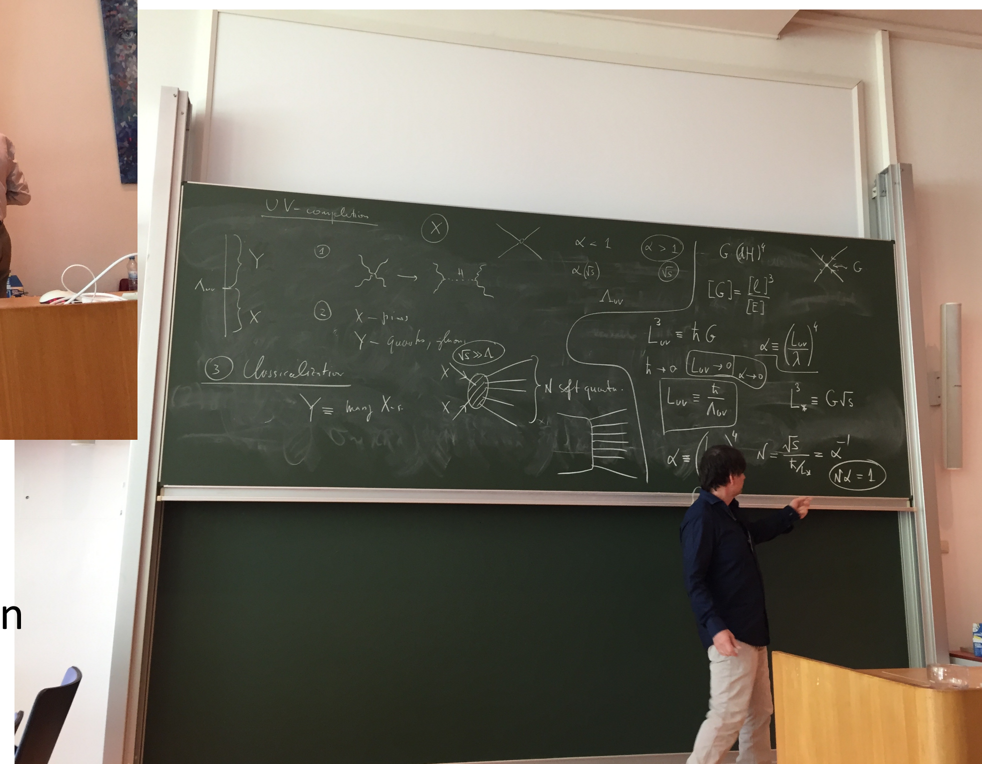
VHEeP

Munich Workshop, June 1-2, 2017



Alfred Mueller, Columbia University
Approach to saturation in eA collisions

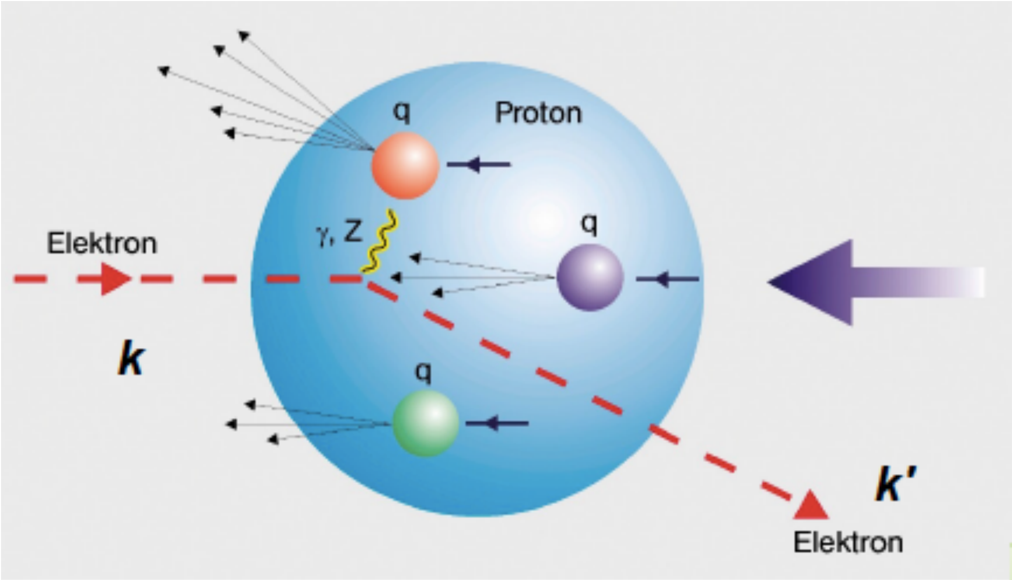
Georgi Dvali, Max Planck Institute for Physics
Alternative high energy theory - classicalization

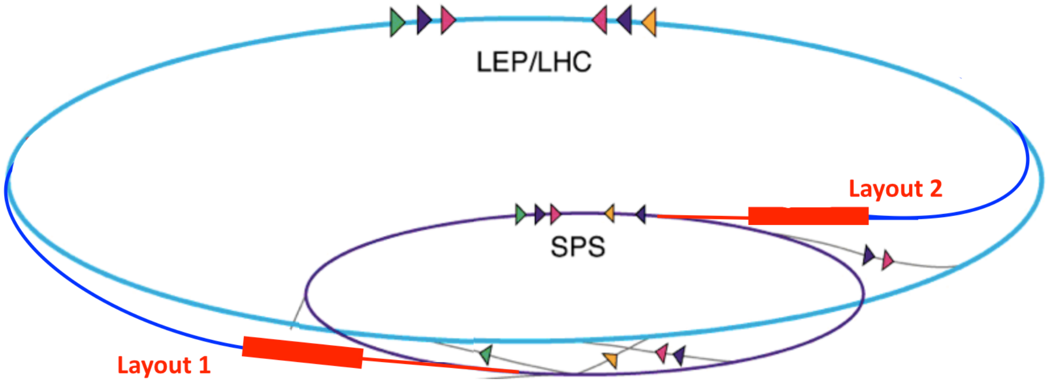


PEPIC: SPS Driver

Focus on QCD:

- Large cross sections – low luminosity (HERA level) enough
- Many open physics questions !
- Consider high energy ep collider with Ee up to O(100 GeV), colliding with LHC proton; e.g. Ee = 10 GeV, Ep = 7 TeV, √s = 530 GeV already exceeds HERA cm energy.





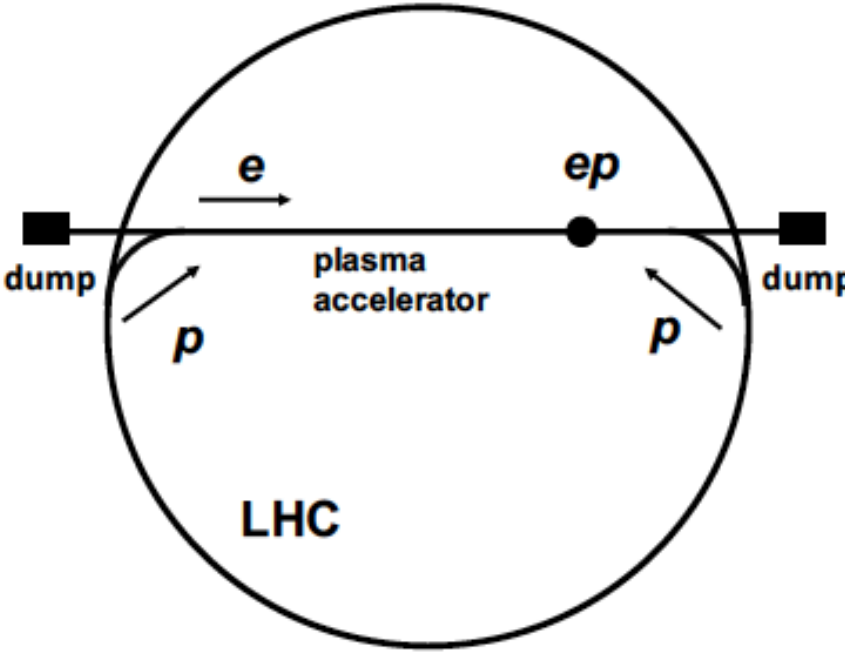
G. Xia et al., Nucl. Instrum. Meth. A 740 (2014) 173.

Create ~70 GeV beam within 100 m of plasma driven by SPS protons and have an LHeC-type experiment.

Clear difference is that luminosity currently expected to be $< 10^{30}$ cm^{-2} s^{-1}.

VHEeP

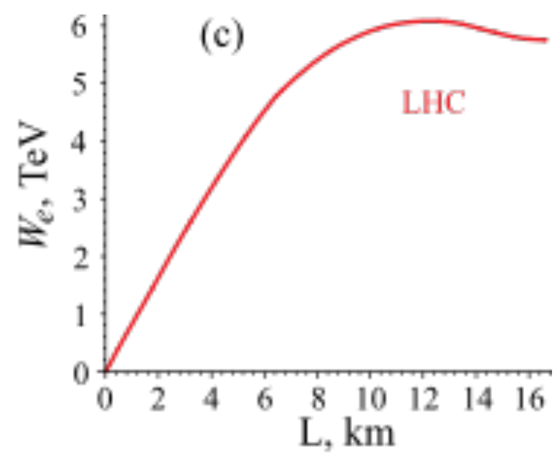
(Very High Energy electron-Proton collider)



One proton beam used for electron acceleration to then collide with one bunch from other proton beam

Luminosity ~ $10^{28} - 10^{29}$ cm^{-2} s^{-1} gives ~ 1 pb−1 per year.

Electron energy from wakefield acceleration by LHC bunch



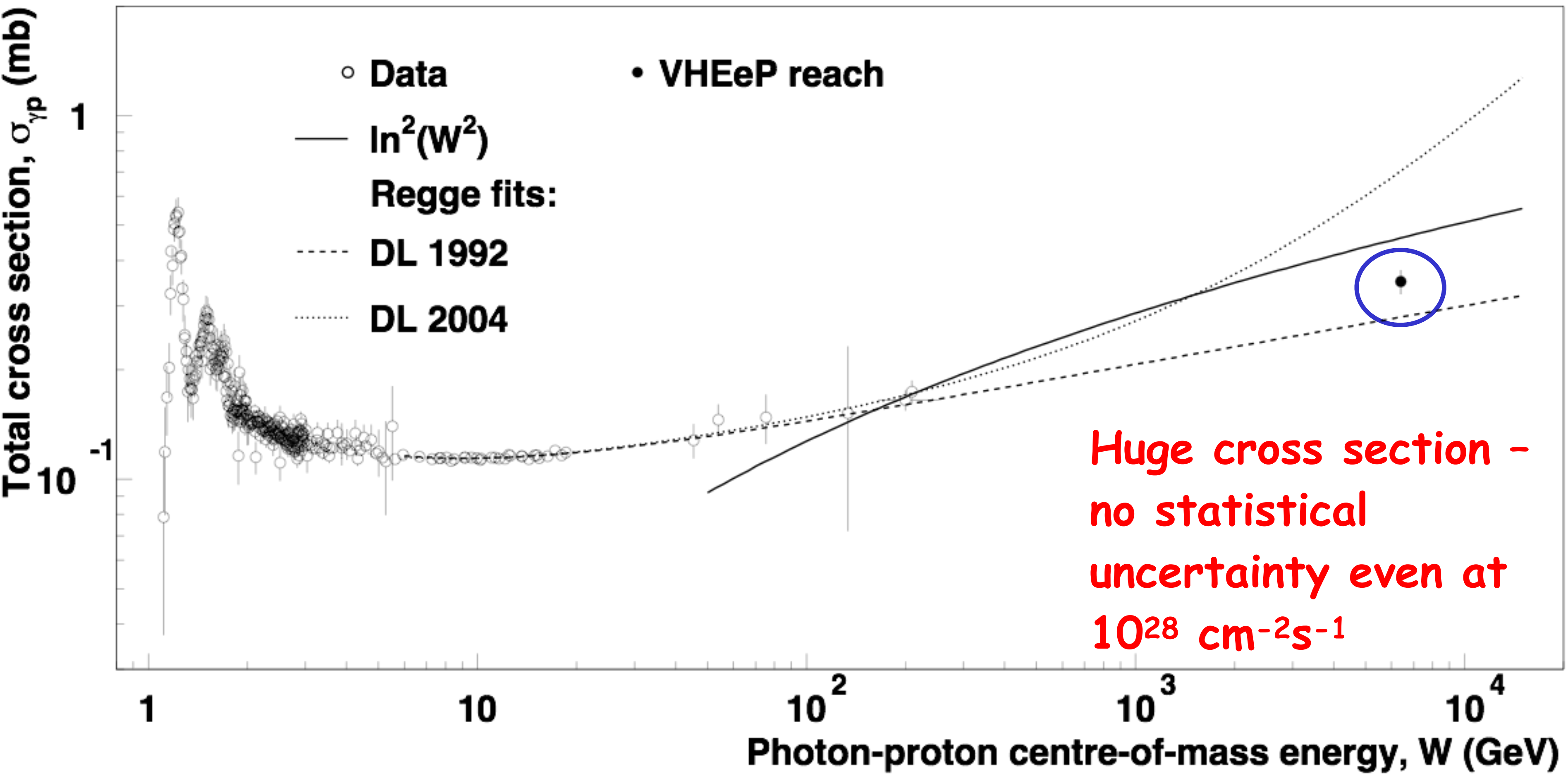
A. Caldwell, K. V. Lotov, Phys. Plasmas **18**, 13101 (2011)

Choose E_e = 3 TeV as a baseline for a new collider with E_p = 7 TeV yields √s = 9 TeV. Can vary.

- Center-of-mass energy ~30 higher than HERA.
- Reach in (high) Q^2 and (low) Bjorken x extended by ~1000 compared to HERA.
- Opens new physics perspectives

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

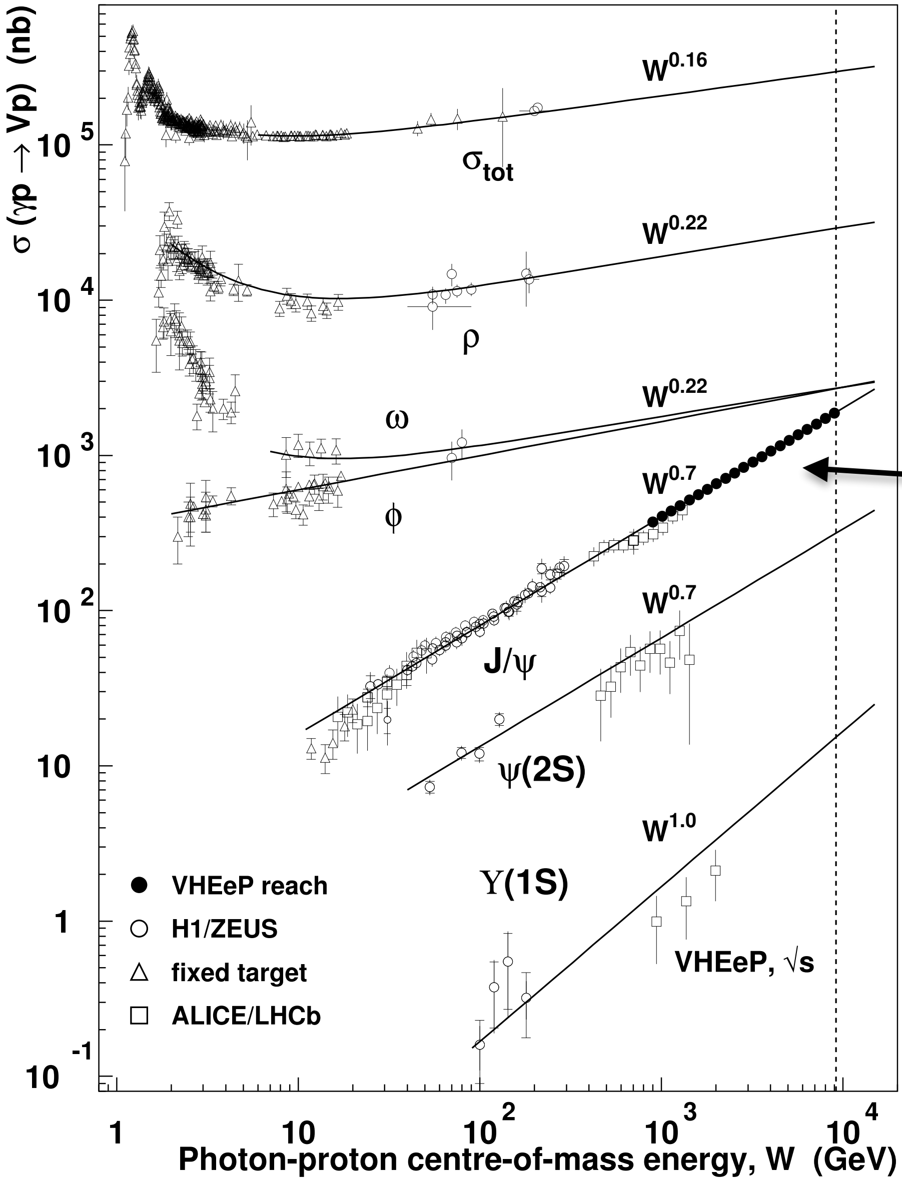
Total Photon-Proton Cross Section



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

Rises – as power of energy, or ln^{2}s (Unitarity Constraint) ? Why ?
High energy behavior needed to understand cosmic ray interactions

Vector Meson Cross Section

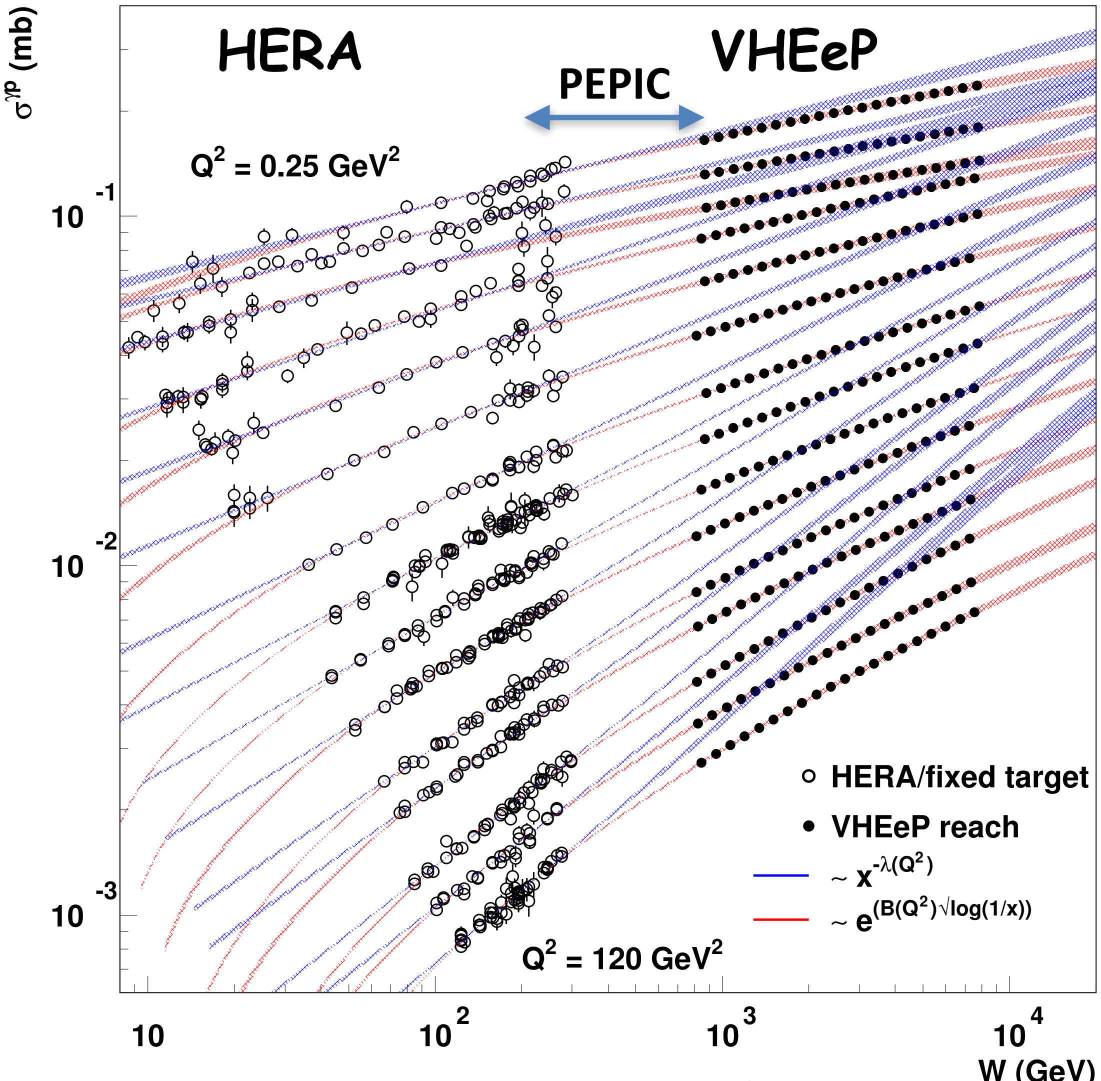


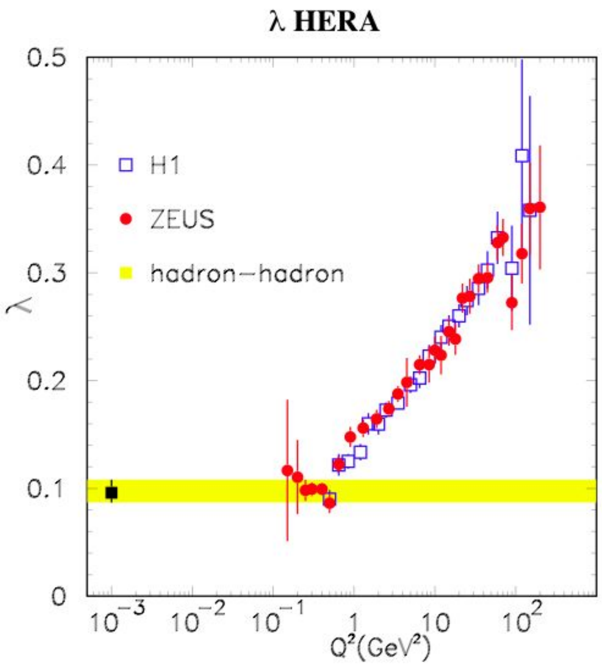
VHEeP W range

$$\sigma(\gamma p \to J/\psi p) \approx \sigma(\gamma p \to \rho p)????$$

Expect to see change in energy dependence

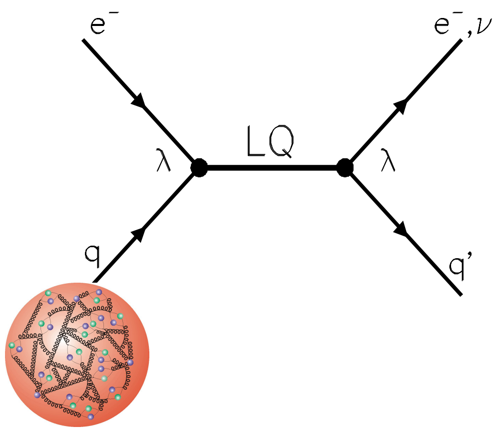
Virtual Photon-Proton Cross Section





Cross sections increasing with energy -> do not require large luminosity to probe this physics. PEPIC & VHEeP will distinguish the important physics.

Beyond the Standard Model



Leptoquarks are predicted in many models for Beyond-the-Standard-Model physics. Electron-proton colliders are the ideal tool to look for this kind of process.

Fixed mass of LQ means fixed x.

$$\sigma_{\mathrm{LQ}}^{\mathrm{NWA}} = (J+1)\frac{\pi}{4s}\lambda^2 q(x_0, M_{\mathrm{LQ}}^2)$$

Sensitivity depends mostly on CM energy

Spin

coupling

At the LHC

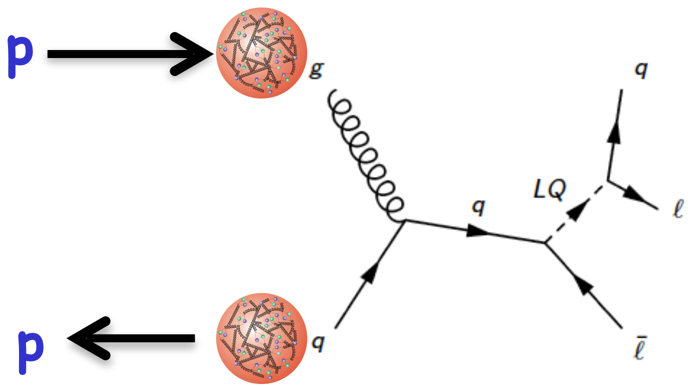


Figure 1: The *s*-channel resonant LQ production diagram.

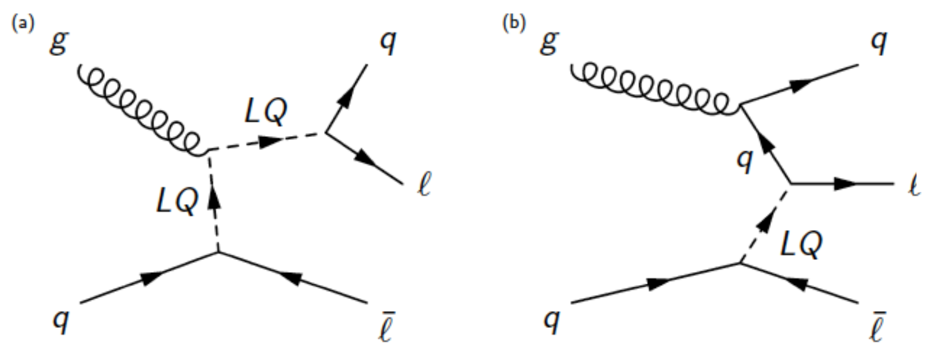
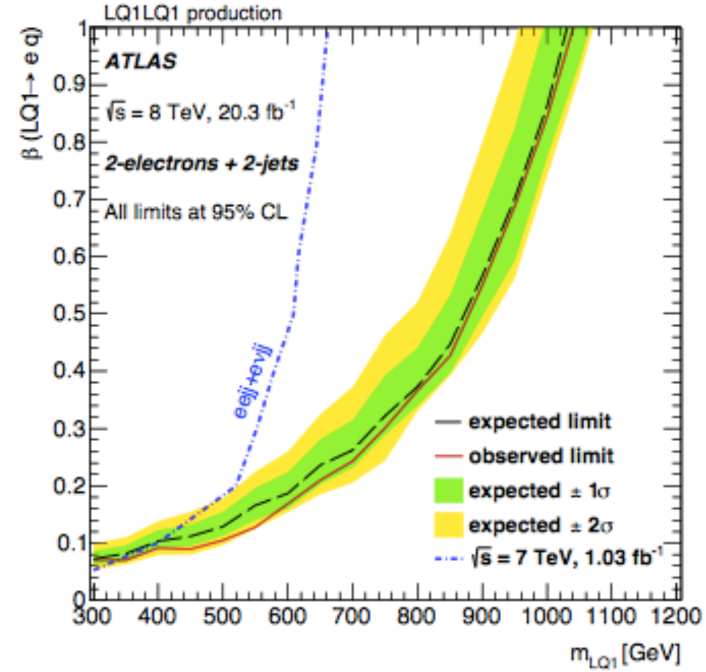
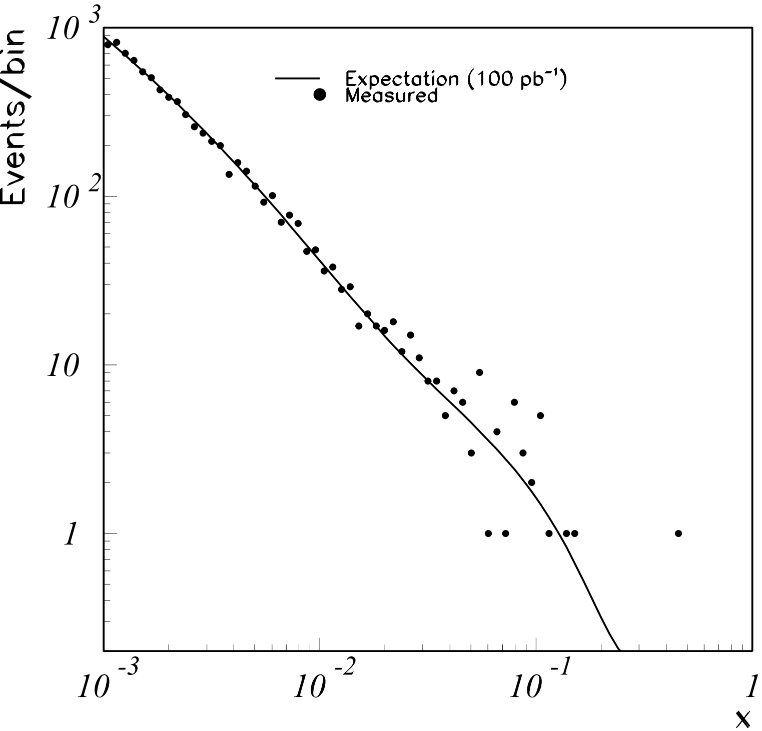


Figure 2: The *t*-channel LQ production diagrams with non-resonant components. The diagram



(b)

VHEeP Study

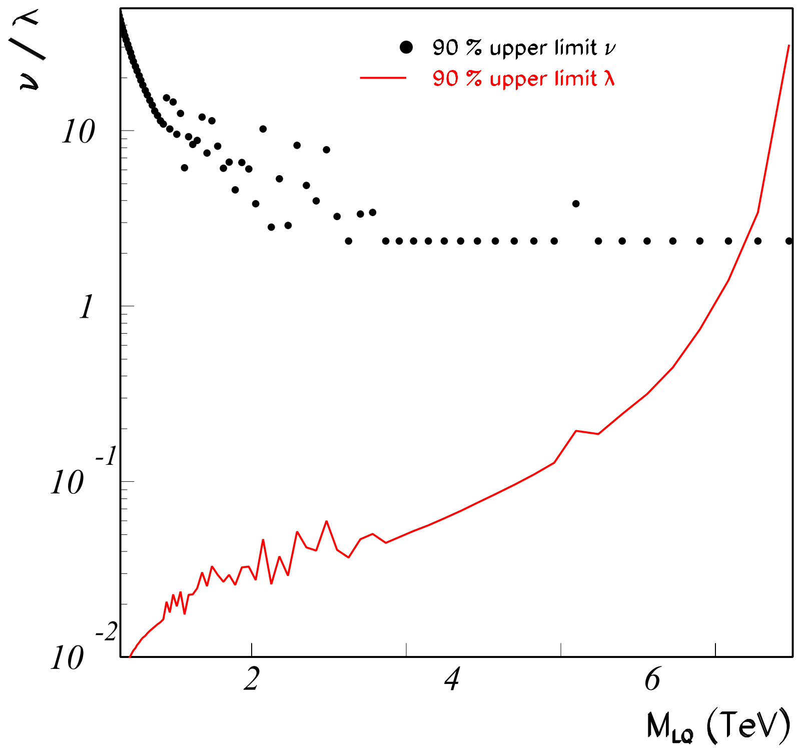


100 pb^{-1}

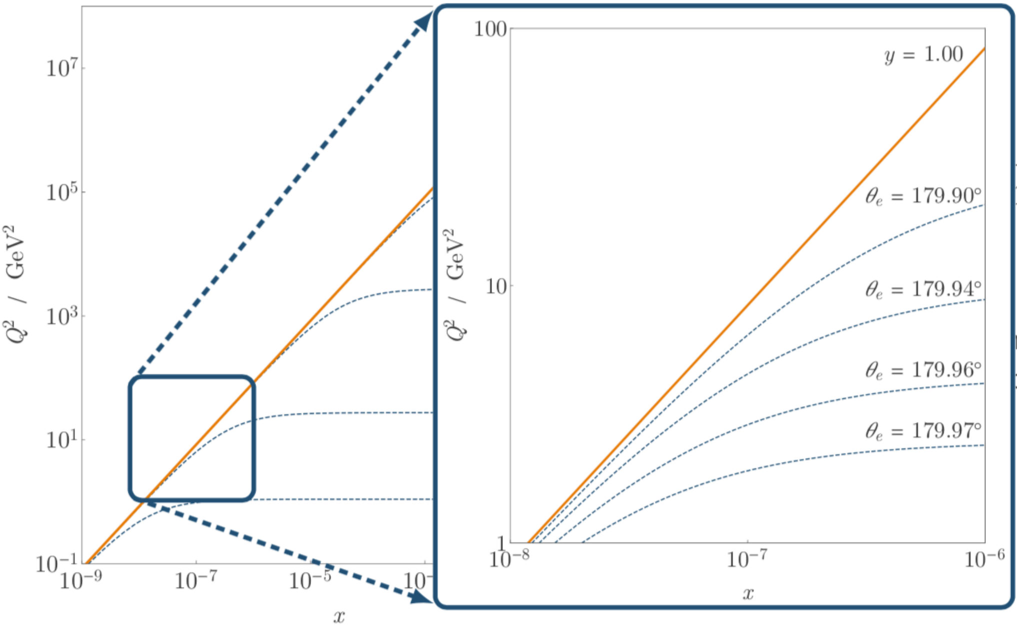
Require Q^2>10000 GeV^2 and y>0.1

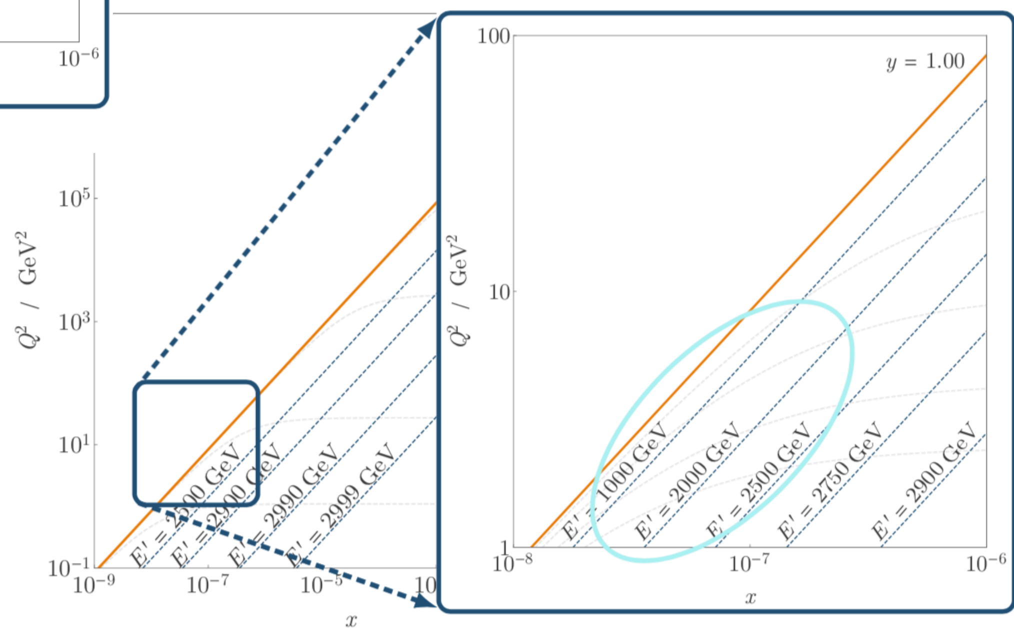
Use Standard Model prediction (no LQ)

Sensitivity goes far beyond what is expected to be reached at LHC. (Currently ~1 TeV, later 2-3 TeV)



There are detector challenges !





Very forward electron detector required.

F. Keeble, UCL

Path Forward (PEPIC&VHEeP)

Technology

- demonstrate electron acceleration
- demonstrate required emittance
- plasma cell scheme

Physics

- total cross sections (real & virtual photon)
- vector meson production
- other aspects of low-x physics (classicalization, AdS/CFT, ???)
- specific eA physics topics
- BSM opportunities (VHEeP)
- anything interesting in the beam dump. E.g.:
  - search for dark photons, like NA64.
  - strong-field QED by colliding electron bunches with laser beam.

Realization

- determine luminosity
- determine range of possible electron energies
- understand how to get rid of defocused protons
- understand how to separate protons from electrons
- beam dump
- IP design
- how fit into CERN infrastructure
- detector studies

Need to push on all aspects in parallel !