Proton-driven Plasma Wakefield Acceleration

John Adams Institute, Oxford

February 9, 2012

1. Introduction – why do we need new technologies ?
2. Plasma Wakefield Acceleration
    a) In general
    b) Beam driven
    c) CERN demonstration experiment for proton-driven PWA

Allen Caldwell
Max-Planck-Institut für Physik

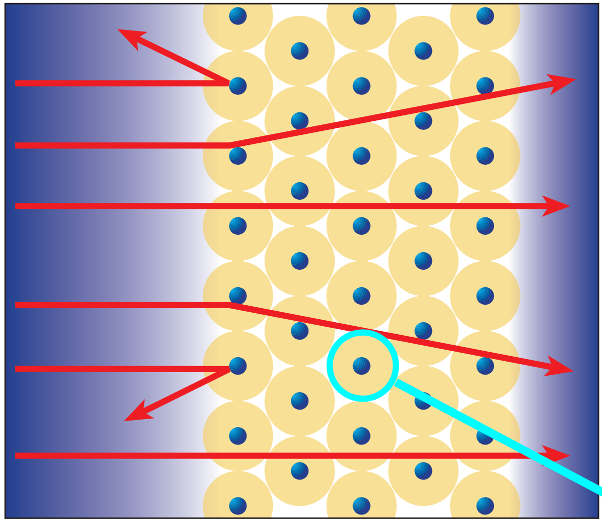
MAX-PLANCK-GESELLSCHAFT

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

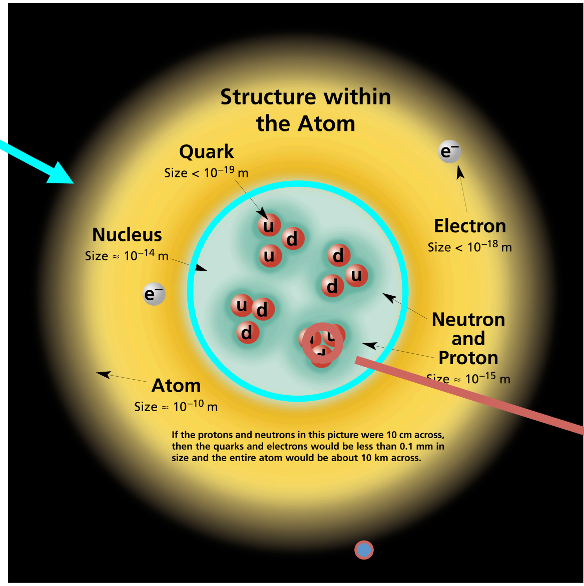
Particle Physics

Rutherford

Few MeV alpha particles

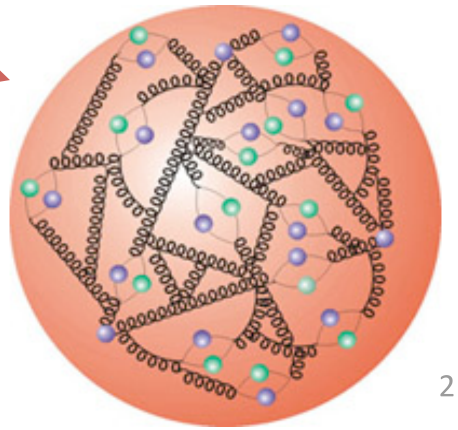


SLAC-MIT,… 7-18 GeV electrons



HERA:
high resolution proton structure measurements

HERA



27.5 GeV electrons
920 GeV protons

The nuclear structure story …

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

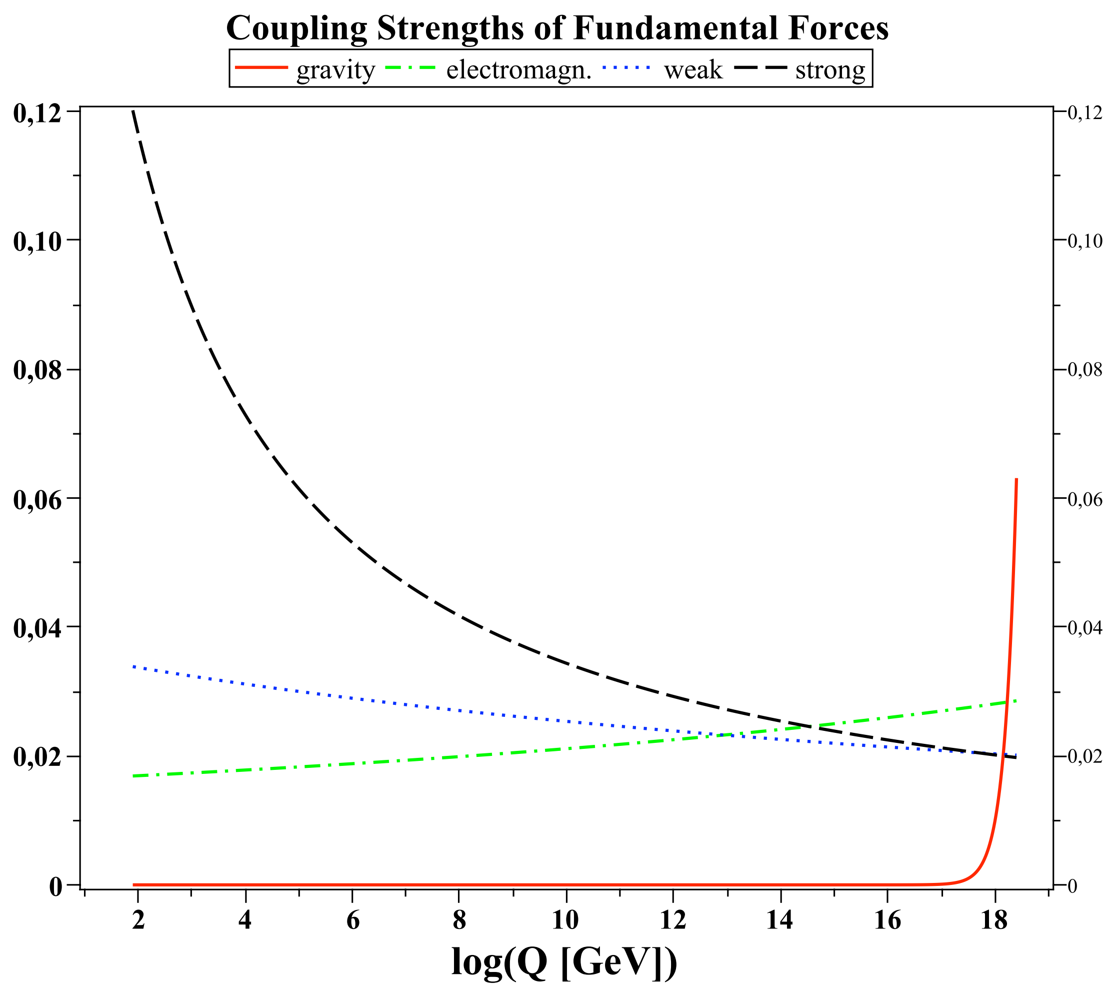
The most important tool in this story was the particle accelerator.

Particle physicists are convinced there are more discoveries to come:

Standard Model not consistent without the Higgs particle – expect to discover at LHC

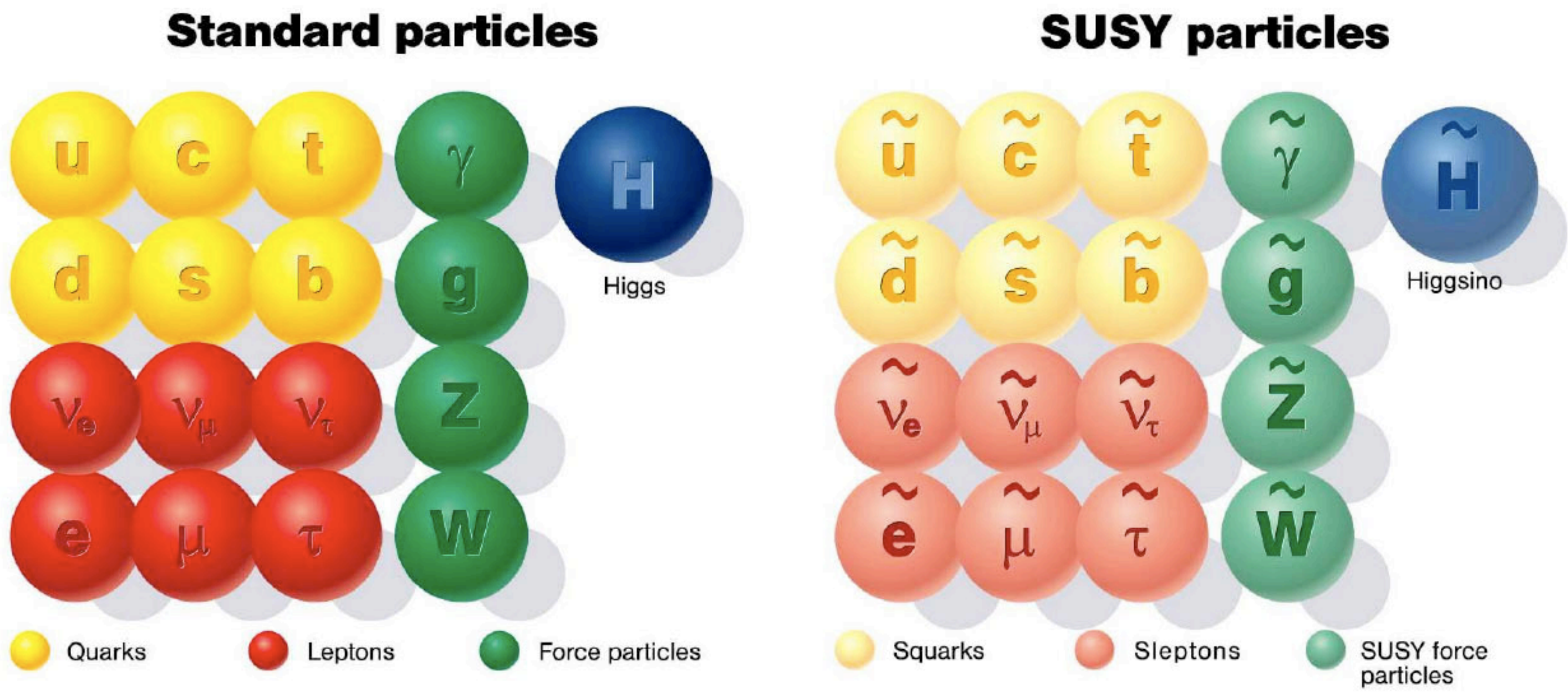
Many things not explained in the standard model:

- why three families
- matter/antimatter imbalance
- neutrinos and neutrino mass
- hierarchy problem/unification
- dark matter
- dark energy
- …



Beyond the Standard Model …

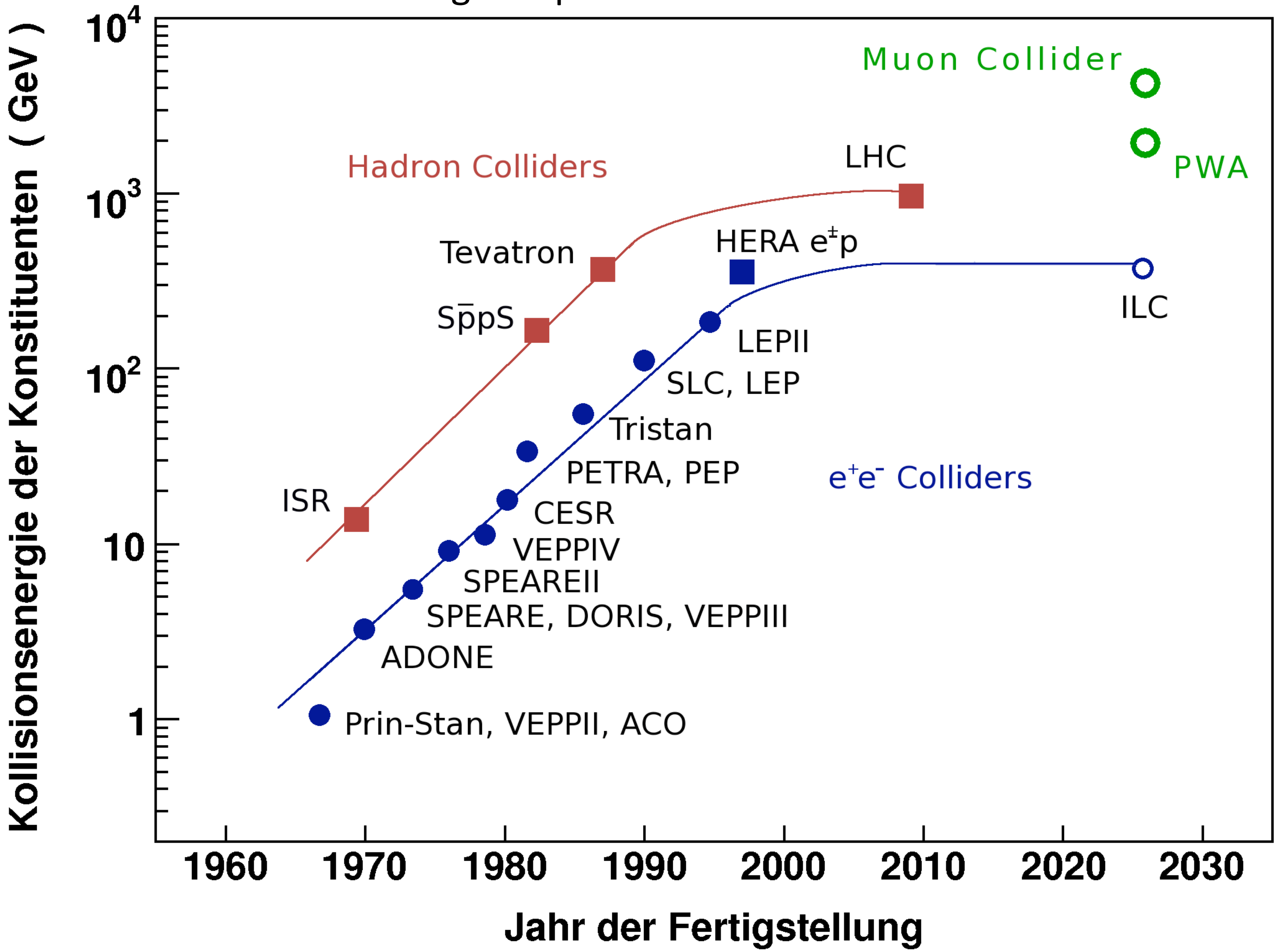
Supersymmetry



↳Extends symmetries (fermion-boson symmetry)
↳possible candidate for dark matter
↳unification of forces at extremely high energies
↳>1/2 the particles have not been seen [and still no sign at LHC]

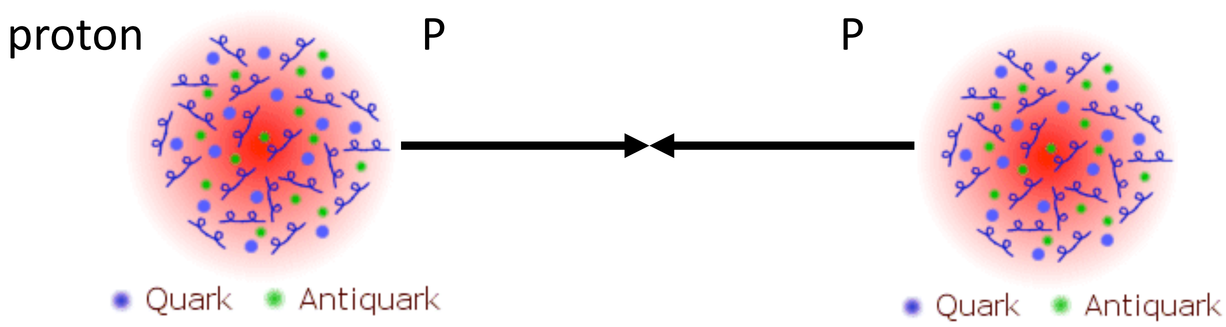
Superstrings ? Smallest objects are not point-like but finite-dimensional. 10 space dimensions, 3 are discovered. Most of the others small, invisible. Some large extra dimensions?

The Livingston plot shows a saturation …



Practical limit for accelerators at the energy frontier: Project cost increases as the energy must increase! New technology needed…

Why a Linear Electron Collider or Muon Collider?

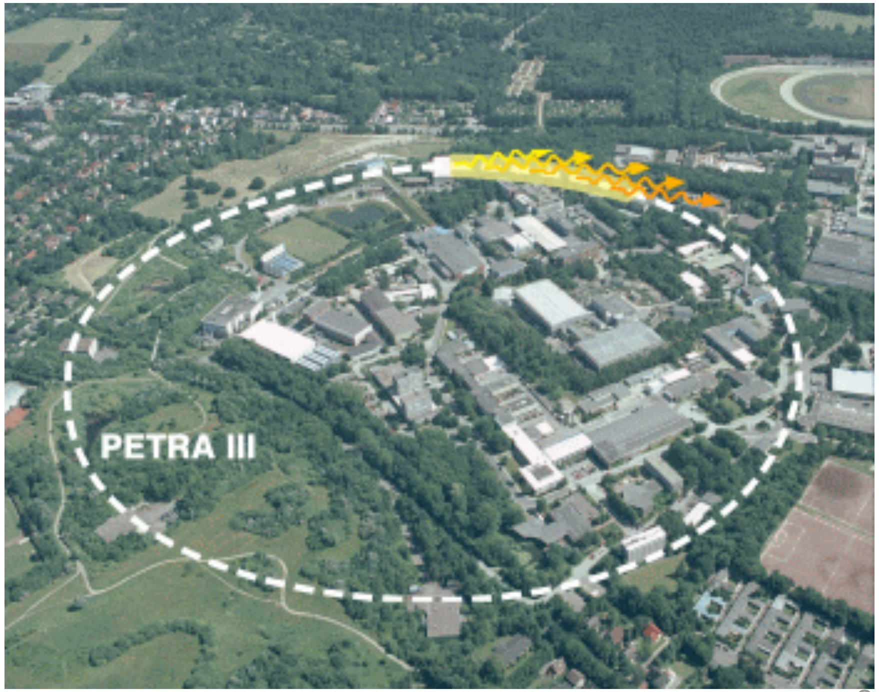


Leptons preferred: Collide point particles rather than complex objects

But, charged particles radiate energy when accelerated.

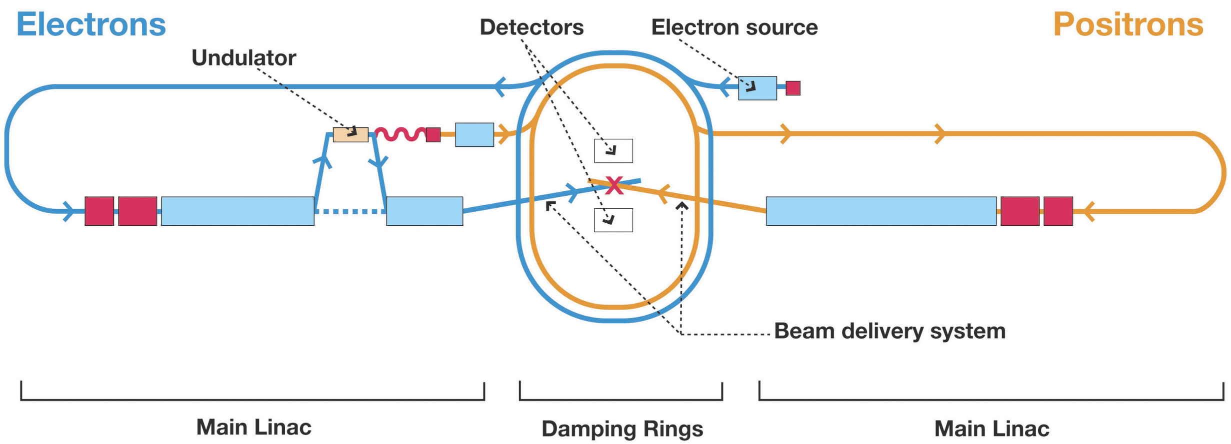
Power α $(E/m)^4$

Need linear electron accelerator or m large (muon 200 heavier than electron)

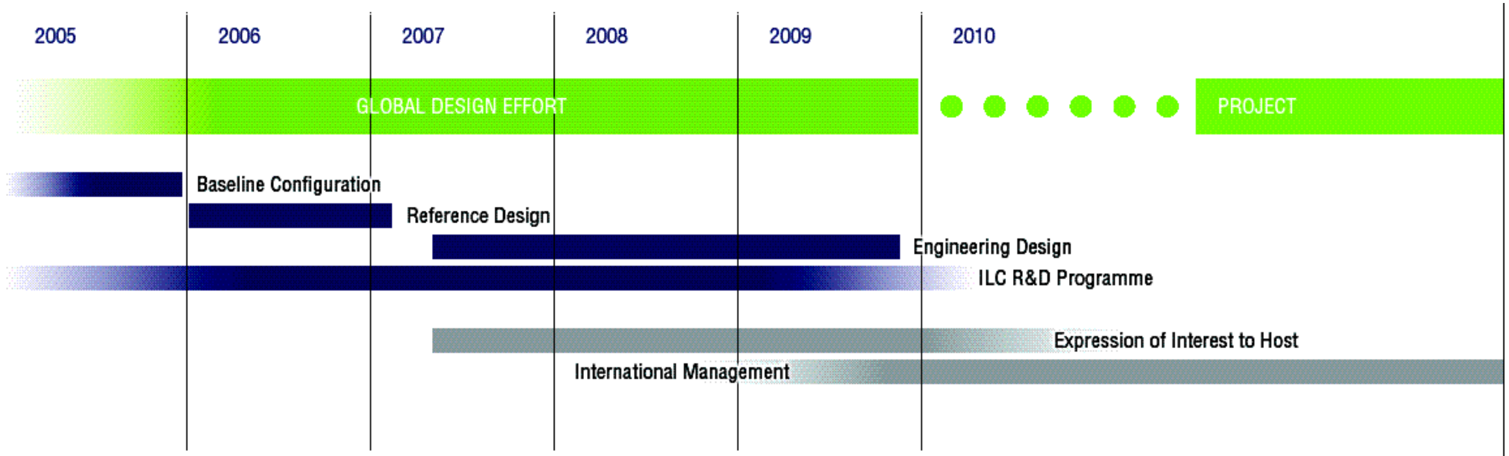


Linear Colliders are expensive with today's gradients

e^+e^- collisions at 500-1000 GeV

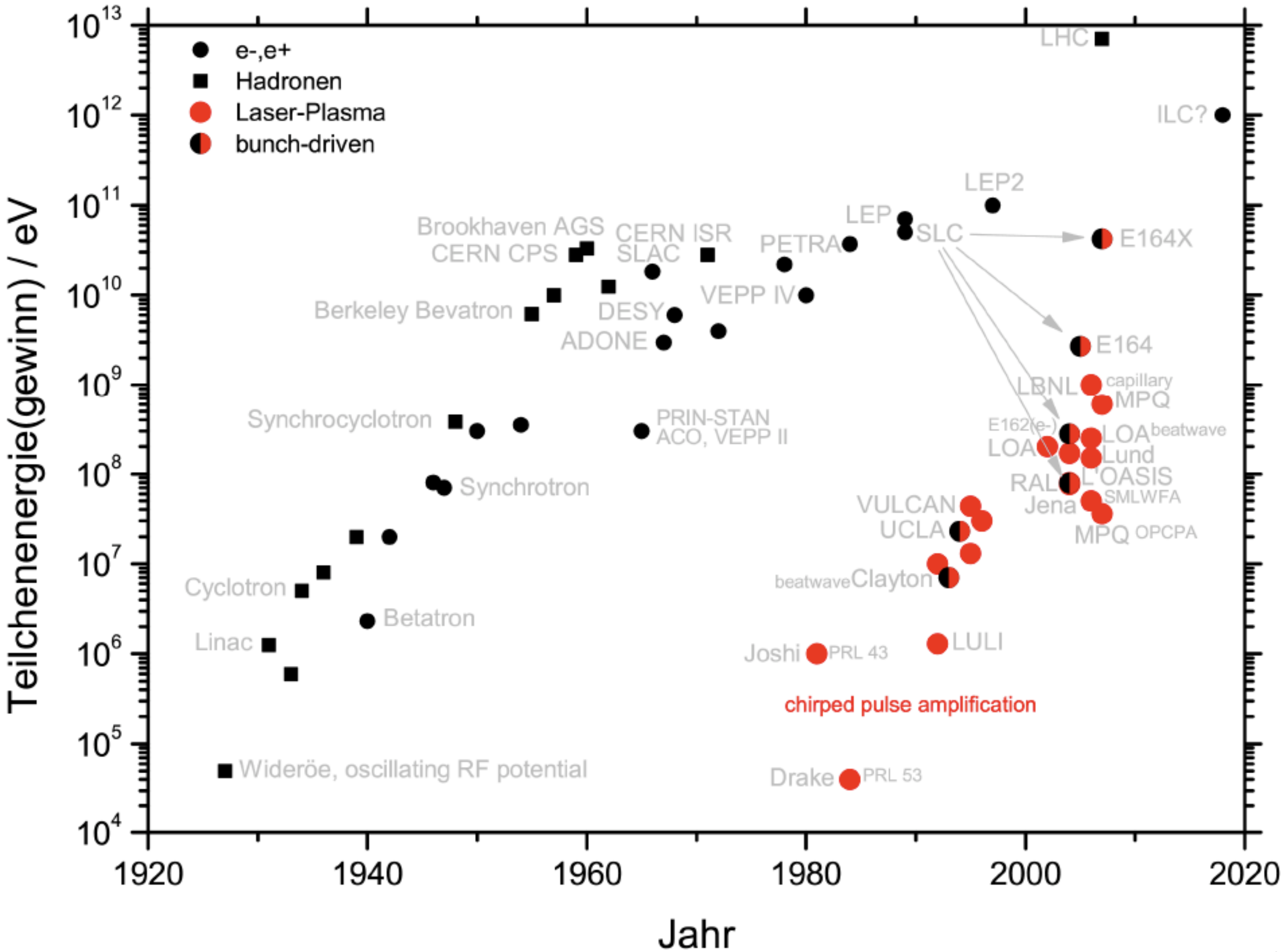


>30 km, > 10G$



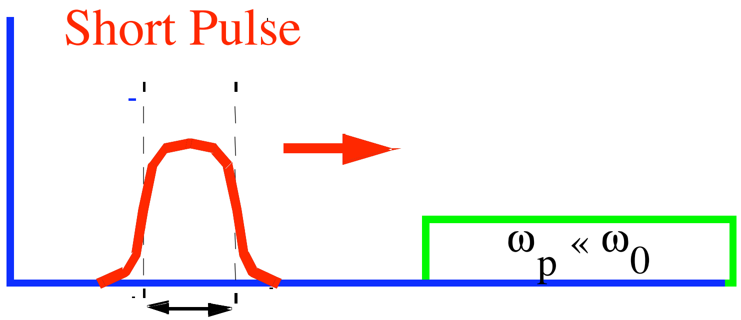
A possible projected timeline for the ILC

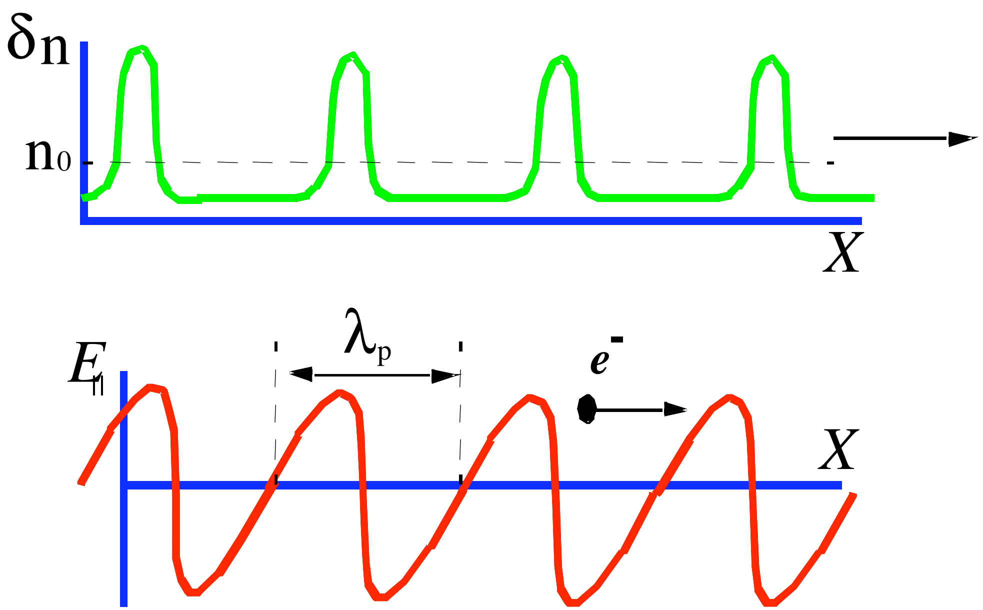
New Livingston Plot – Plasma Wakefield Acceleration



Acceleration of Electrons in a Plasma Wave

The idea was proposed by T. Tajima and J. W. Dawson, *Phys.Rev.Lett.* Vol. 43 , p.267, (1979)





Original proposal – use a laser

$$eE_\parallel \cong mc\omega_p \cdot \frac{\delta n}{n} \sim 1 \text{ TeV/m}$$

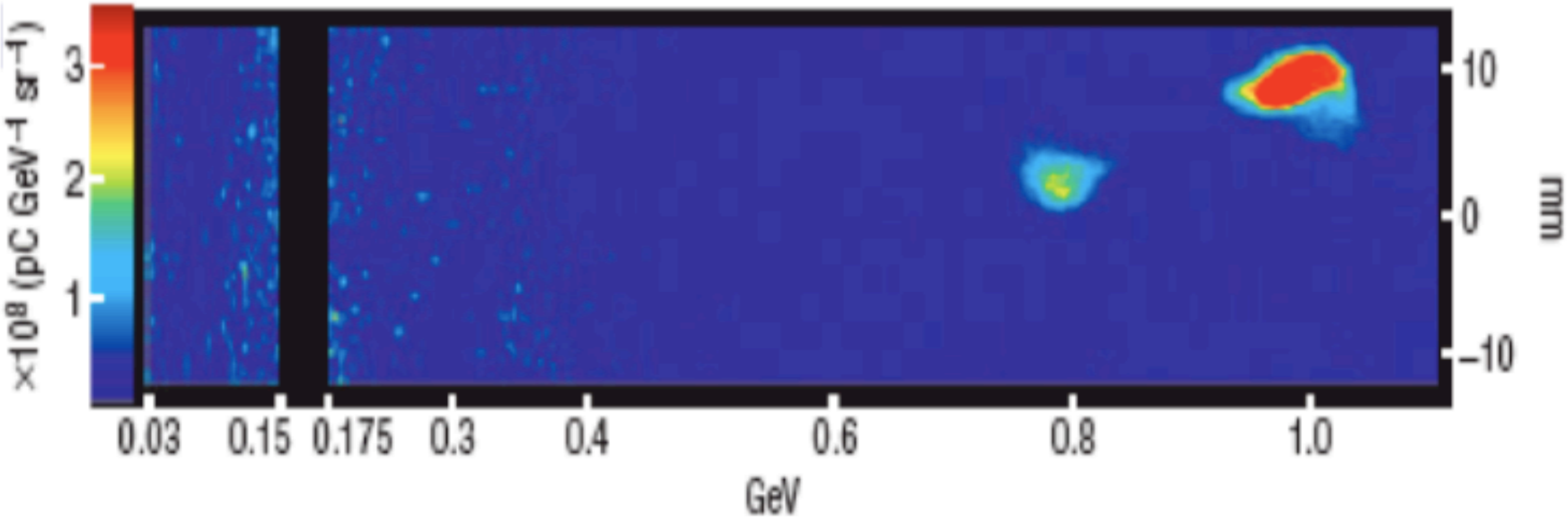
$$\omega_p^2 = \frac{4\pi n_p e^2}{m} \qquad k_p = \frac{\omega_p}{c} \qquad \lambda_p = \frac{2\pi}{k_p} = 1mm\sqrt{\frac{1 \cdot 10^{15}\ \text{cm}^{-3}}{n_p}}$$

GeV Beam Generation

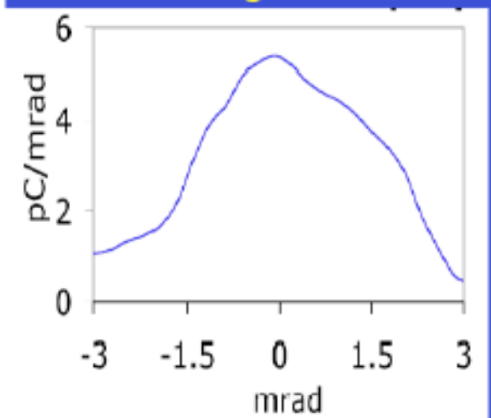
312 μm diameter and 33 mm length capillary

1 GeV beam: $a_0 \sim 1.46$ (40 TW, 37 fs)

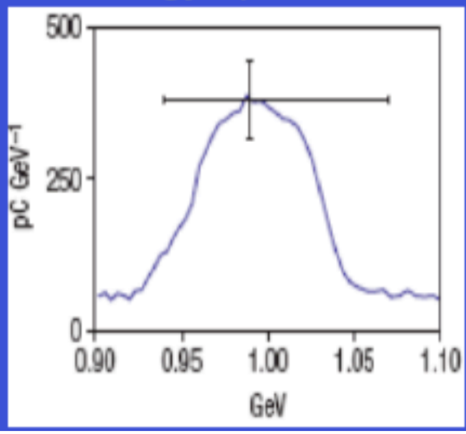
Laser Wakefield Acceleration



Divergence



Energy spectrum



Divergence(rms): 2.0 mrad
Energy spread (rms): 2.5%
Resolution: 2.4%
Charge: >30.0 pC

But – Acceleration is ***DEPLETION-LIMITED***
i.e., the lasers today do not have enough energy to accelerate a bunch of particles to very high energies

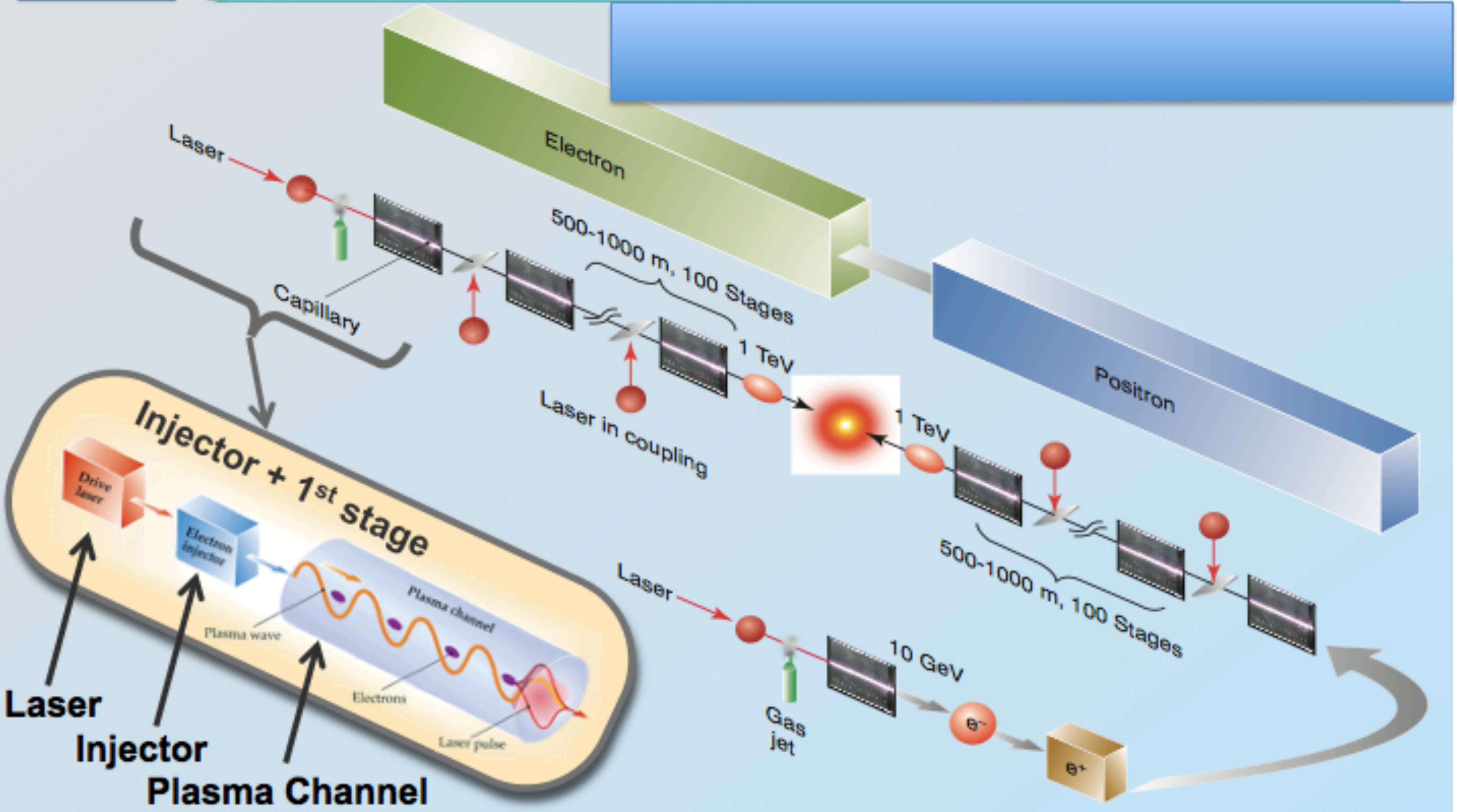
e.g.,

$$10^{10}\ \text{electrons} \cdot 10^{12}\ \text{eV} \cdot 1.6 \cdot 10^{-19}\ \text{J/eV} = kJ$$

This is orders of magnitude larger than what can be done today.

If use several lasers – need to have relative timing in the 10's of fs range
Many stages, effective gradient reduced because of long sections between accelerating elements …

Strawman design of a TeV LPA Collider



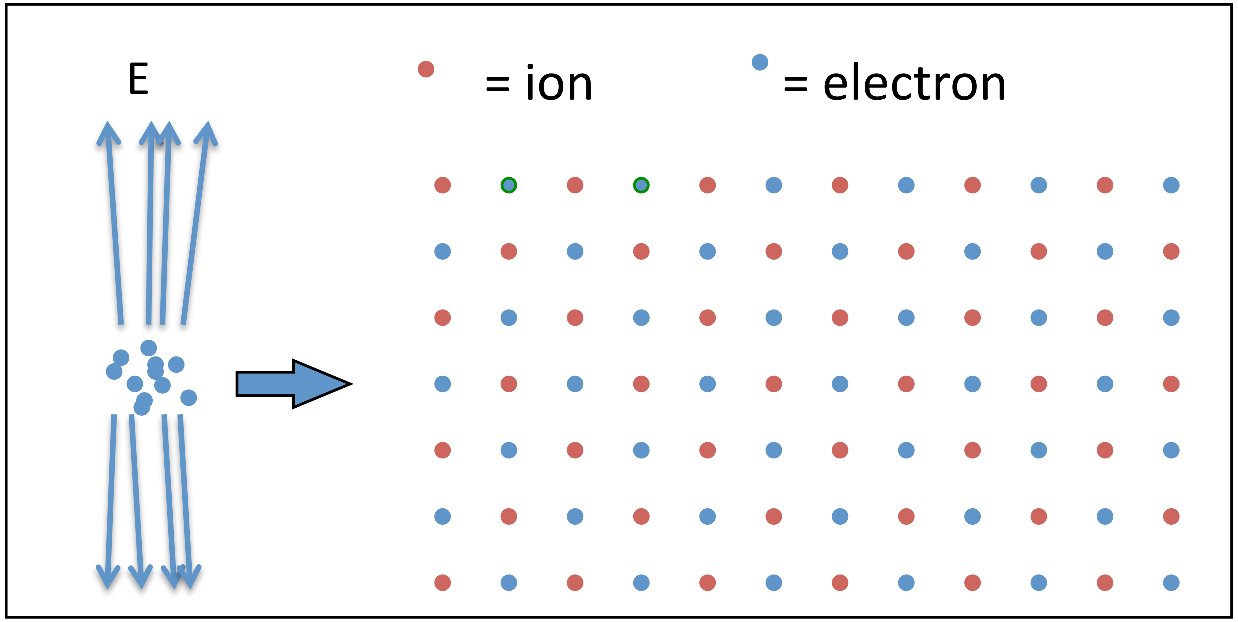
Leemans & Esarey, Physics Today, March 2009

(Electron) Beam Driven Plasma Wakefield Acceleration

I) Generate homogeneous plasma channel:

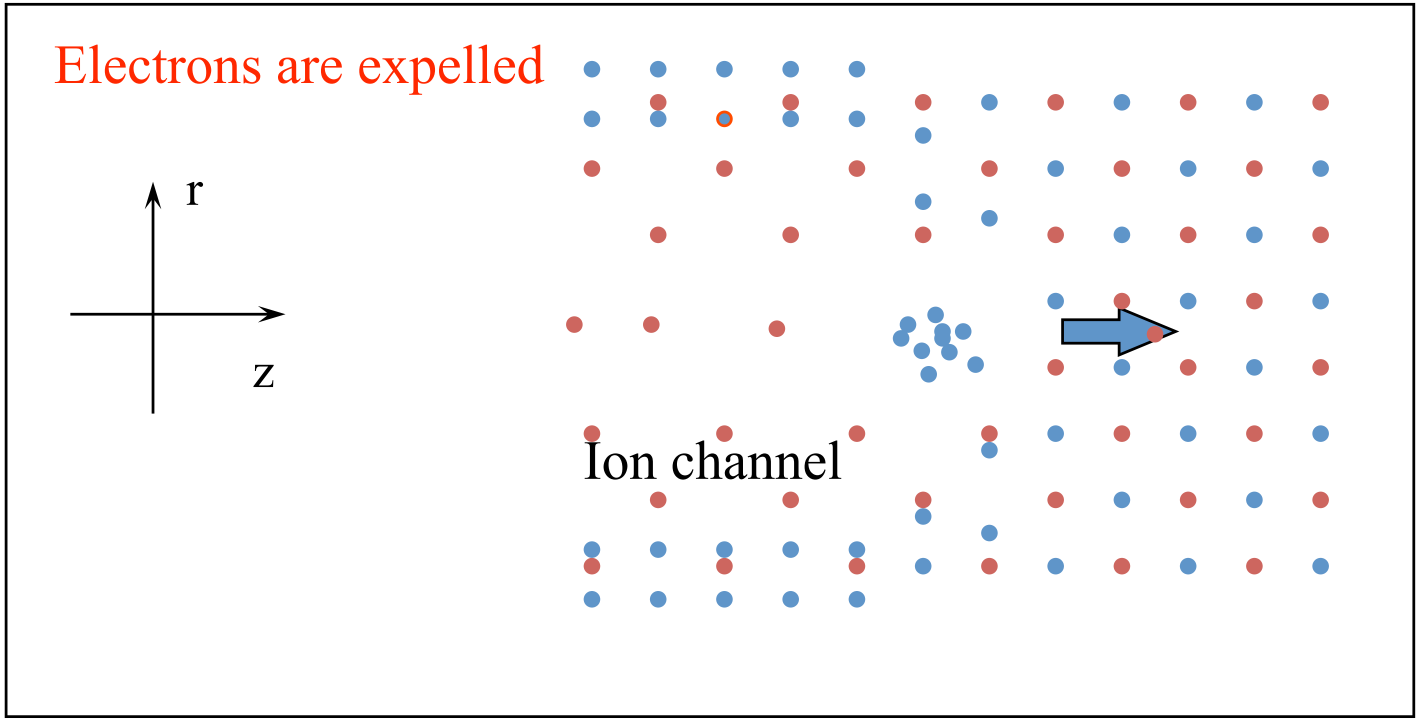
Ionization of gas via:
- Laser
- Beam
- RF

II) Send dense relativistic electron beam towards plasma (E field radial in rest frame of plasma):



Beam density n_b
Gas density n_0

III) Excite plasma wakefields:



Space charge force of beam ejects plasma electrons promptly along radial trajectories

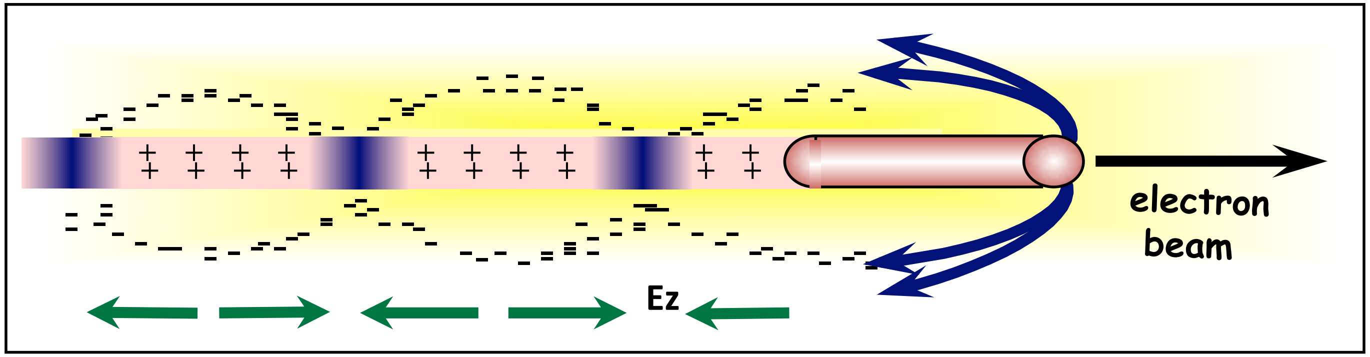
Positively charged channel is left

Electron motion solved with ...

driving force: Space charge of drive beam displaces plasma electrons.

restoring force: Plasma ions exert restoring force

→ **Space charge oscillations (Harmonic oscillator)**



Longitudinal fields can **accelerate** and **decelerate**!

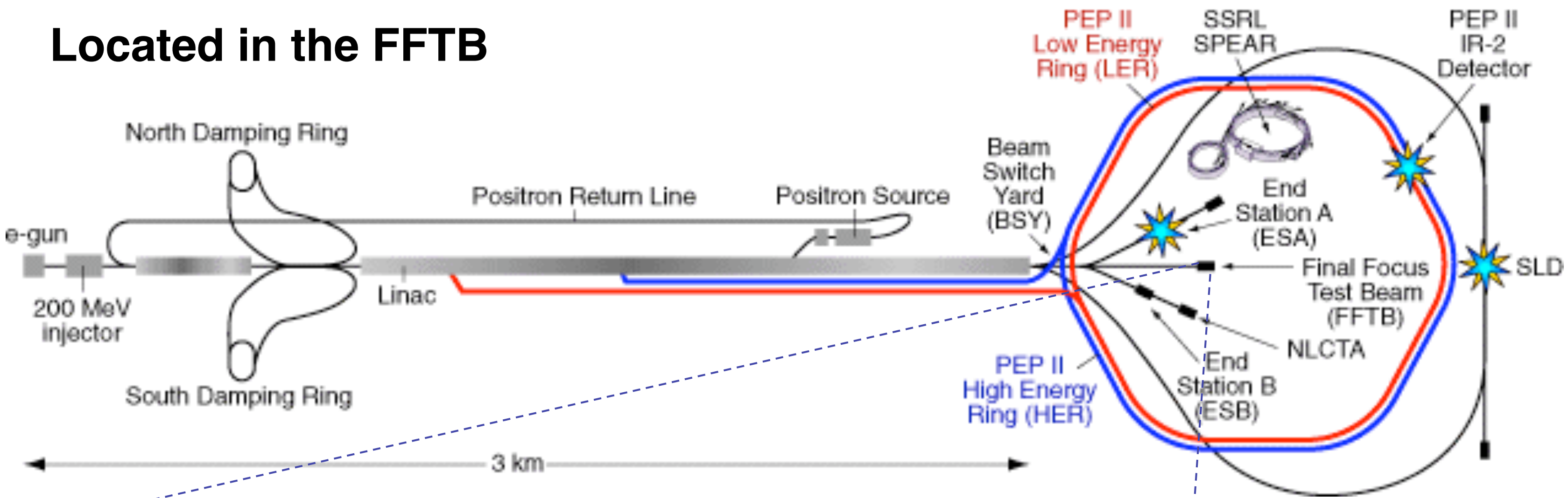
Plasma also provides super-strong focusing force !
(many thousand T/m in frame of accelerated particles)

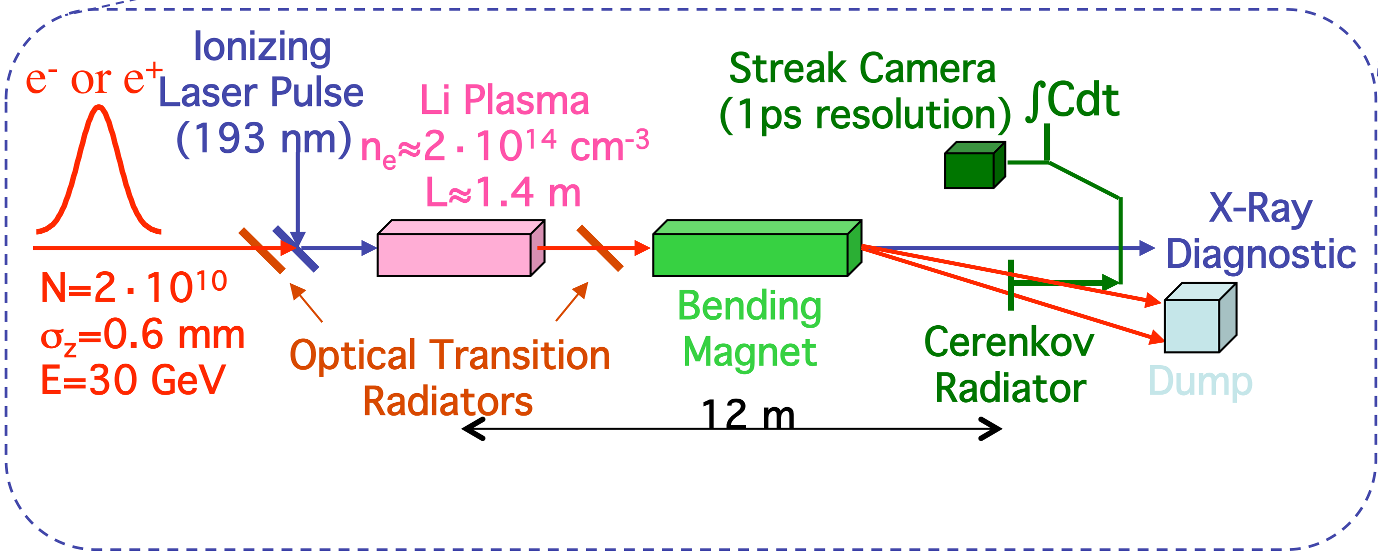
Stanford Linear Accelerator Center

Experimental Layout (E-157)

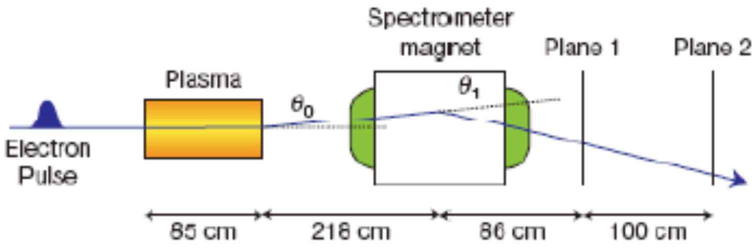
UCLA USC

Located in the FFTB

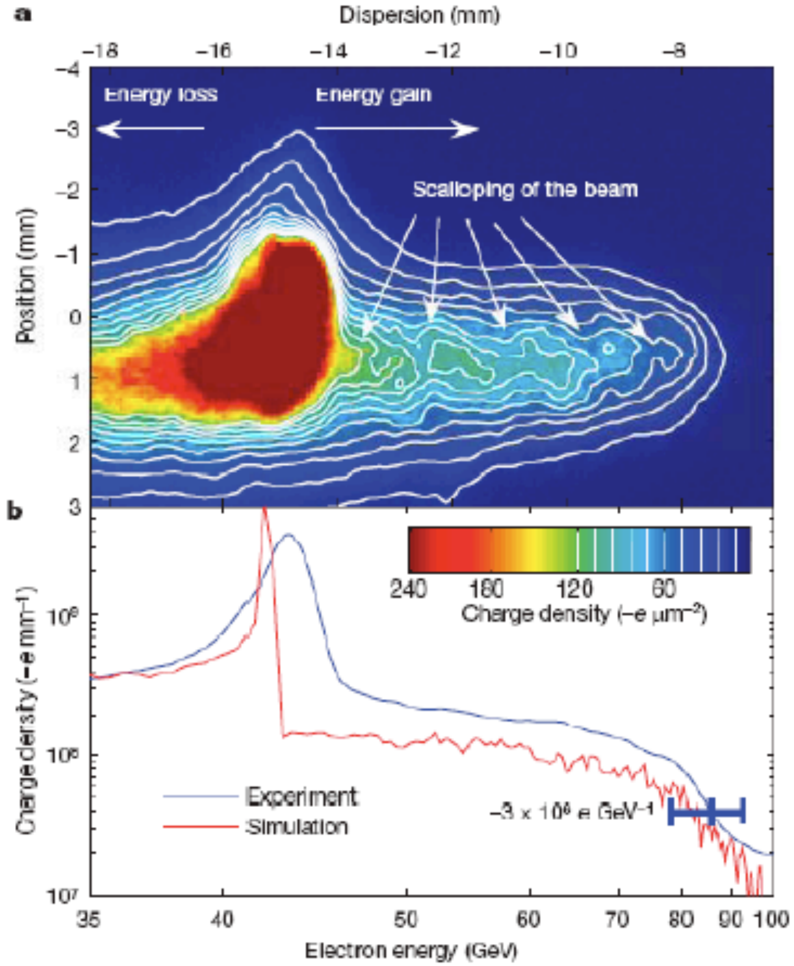




Highlight: latest SLAC/UCLA/USC results
(Nature 2007)



SLAC beam
- 42 GeV
- 3 nC @ 10 Hz
- focused to 10 µm spot size
- compressed to 50 fs



- Some electrons double their energy: from 42 to > 80 GeV
- E=50 GV/m over 0.8 meters

I. Blumenfeld et al., Nature **445**, 741 (2007)

Why not continue with electrons ???

There is a limit to the energy gain of a trailing bunch in the plasma:

$$R = \frac{\Delta T^{\mathrm{witness}}}{\Delta T^{\mathrm{drive}}} \leq 2 \quad \text{T is the kinetic energy}$$

(for longitudinally symmetric bunches).

See e.g. SLAC-PUB-3374, R.D. Ruth et al.

This means many stages required to produce a 1TeV electron beam from known electron beams (SLAC has 45 GeV)

Proton beams of 1TeV exist today - so, why not drive plasma with a proton beam ?

Why Proton-Driven Wakefield Acceleration

Both laser-driven and electron-bunch driven acceleration will require many stages to reach the TeV scale.

We know how to produce high energy protons (many TeV) in bunches with population > 10^{11}/bunch today, so if we can use protons to drive an electron bunch we could potentially have a simpler arrangement - single stage acceleration.

Linear regime ($n_b < n_0$):

$$E_{z,\max} \approx 2\ \mathrm{GeV/m} \cdot \left(\frac{N_b}{10^{10}}\right) \cdot \left(\frac{100\ \mu\mathrm{m}}{\sigma_z}\right)^2$$

Need very short proton bunches for strong gradients. Today's proton beams have

$$\sigma_z \approx 10 - 30\ \mathrm{cm}$$

Issues with a Proton Driven PWA:

- Small beam dimensions required

$$eE_{linear} = 240(\mathrm{MeV/m})\left(\frac{\mathrm{N}}{4\cdot 10^{10}}\right)\left(\frac{0.6}{\sigma_z(\mathrm{mm})}\right)^2$$

$$\sigma_z = 100\mu m \text{ ,N} = 1\ 10^{11} \text{ yields 21 GeV/m}$$

Can such small beams be achieved with protons ? Typical proton bunches in high energy accelerators have rms length >20 cm

Issues with a Proton Driven PWA:

- Phase slippage because protons heavy (move more slowly than electrons)

$$\delta = \frac{\pi L}{\lambda_p}\left[\frac{1}{\gamma_{1i}\gamma_{1f}} - \frac{1}{\gamma_{2i}\gamma_{2f}}\right] \approx \frac{\pi L}{\lambda_p}\left[\frac{M_P^2 c^4}{E_{driver,i}E_{driver,f}}\right]$$

$$L \leq \frac{1}{2}\left[\frac{E_{driver,i}E_{driver,f}}{M_P^2 c^4}\right]\lambda_p \approx 300 \text{ m for } E_{driver,i} = 1TeV, E_{driver,f} = 0.5TeV, \lambda = 1mm$$

Few hundred meters possible but depends on plasma wavelength

Issues with a Proton Driven PWA continued:

- Longitudinal growth of driving bunch due to energy spread

$$d = \Delta v \cdot t \approx \Delta\beta \cdot L = \left(\gamma_1^{-2} - \gamma_2^{-2}\right)L \approx 2\left(\frac{\Delta E}{E}\right)\frac{M_P^2 c^4}{E^2} L$$

$$\text{For } d = 100\mu m, \quad L = 100m, \quad E = 1.TeV, \quad \frac{\Delta E}{E} = 0.5$$

Large momentum spread is allowed !

Issues - continued

- Proton interactions

$$\lambda = \frac{1}{n\sigma} < \frac{1}{n(10^{-23}\ \mathrm{cm}^2)} \qquad n = 1\cdot 10^{15} cm^{-3} \quad \Rightarrow \quad \lambda = 1000\ \mathrm{km}$$

Only small fraction of protons will interact in plasma cell

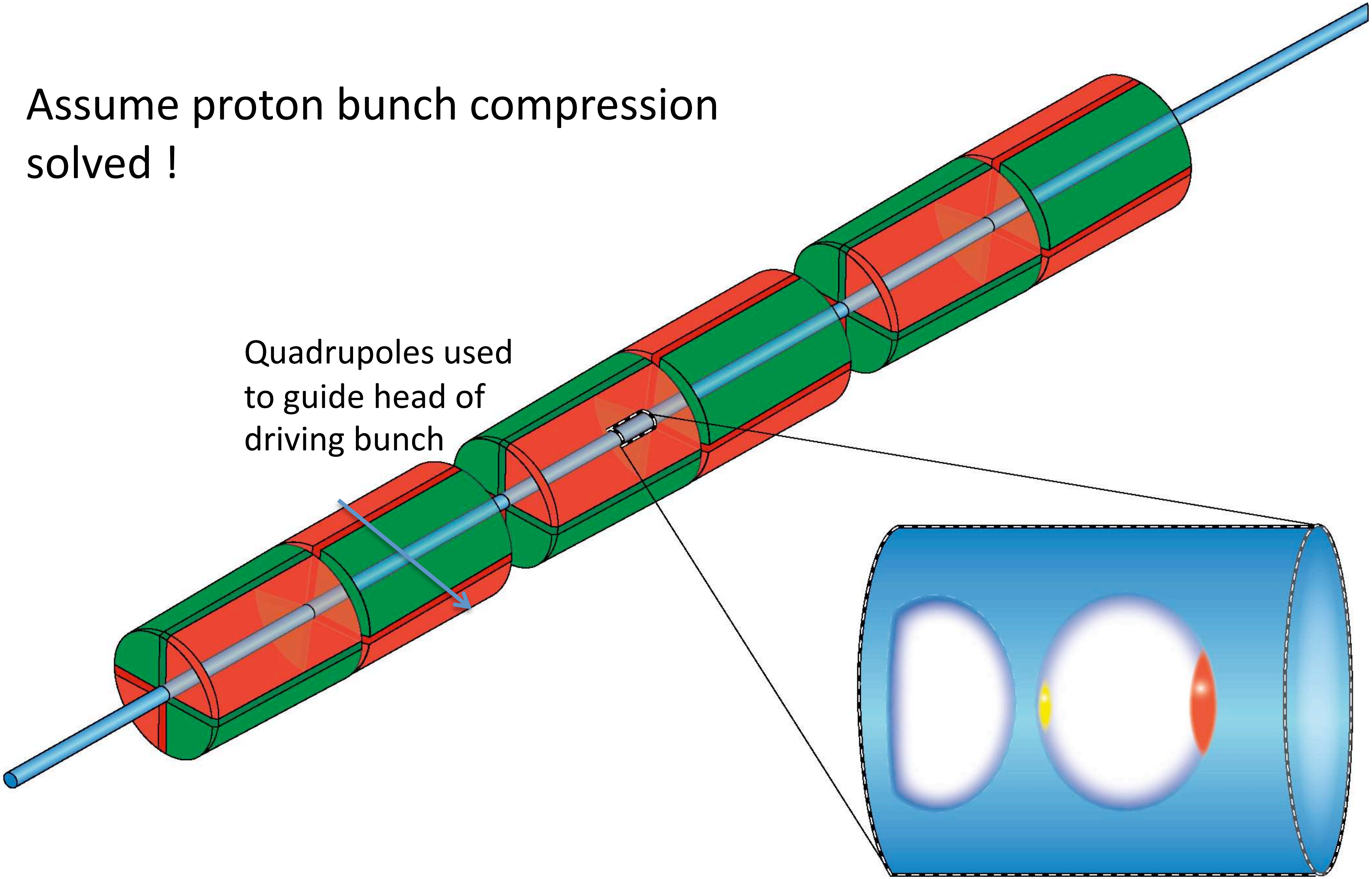
Biggest issue identified so far is proton bunch length.

Need large energies to avoid phase slippage because protons are heavy.

Large momentum spread is allowed.

Simulation study

Assume proton bunch compression solved !



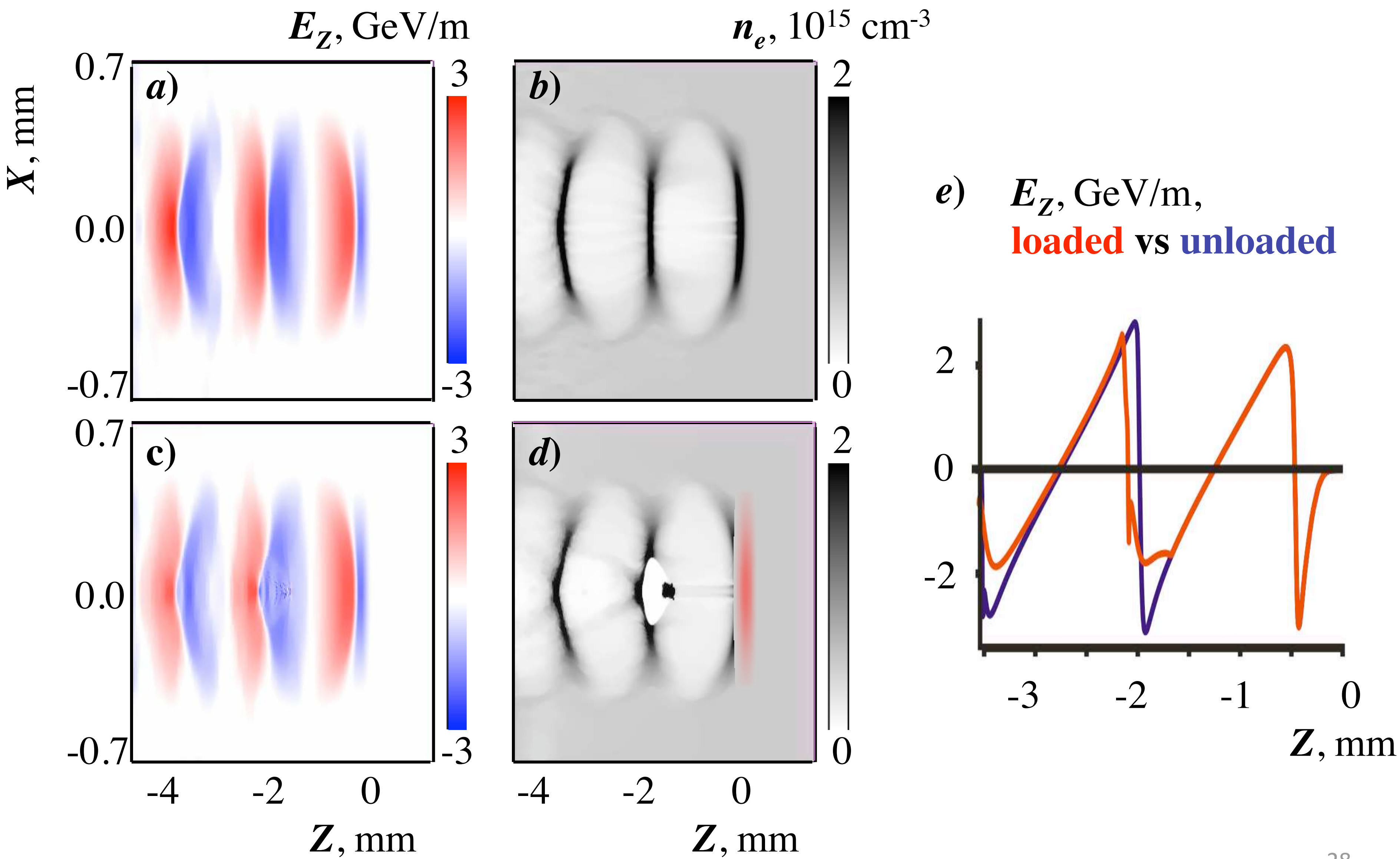
A. Caldwell, K. Lotov, A. Pukhov, F. Simon *Nature Physics* ***5, 363 - 367 (2009)***

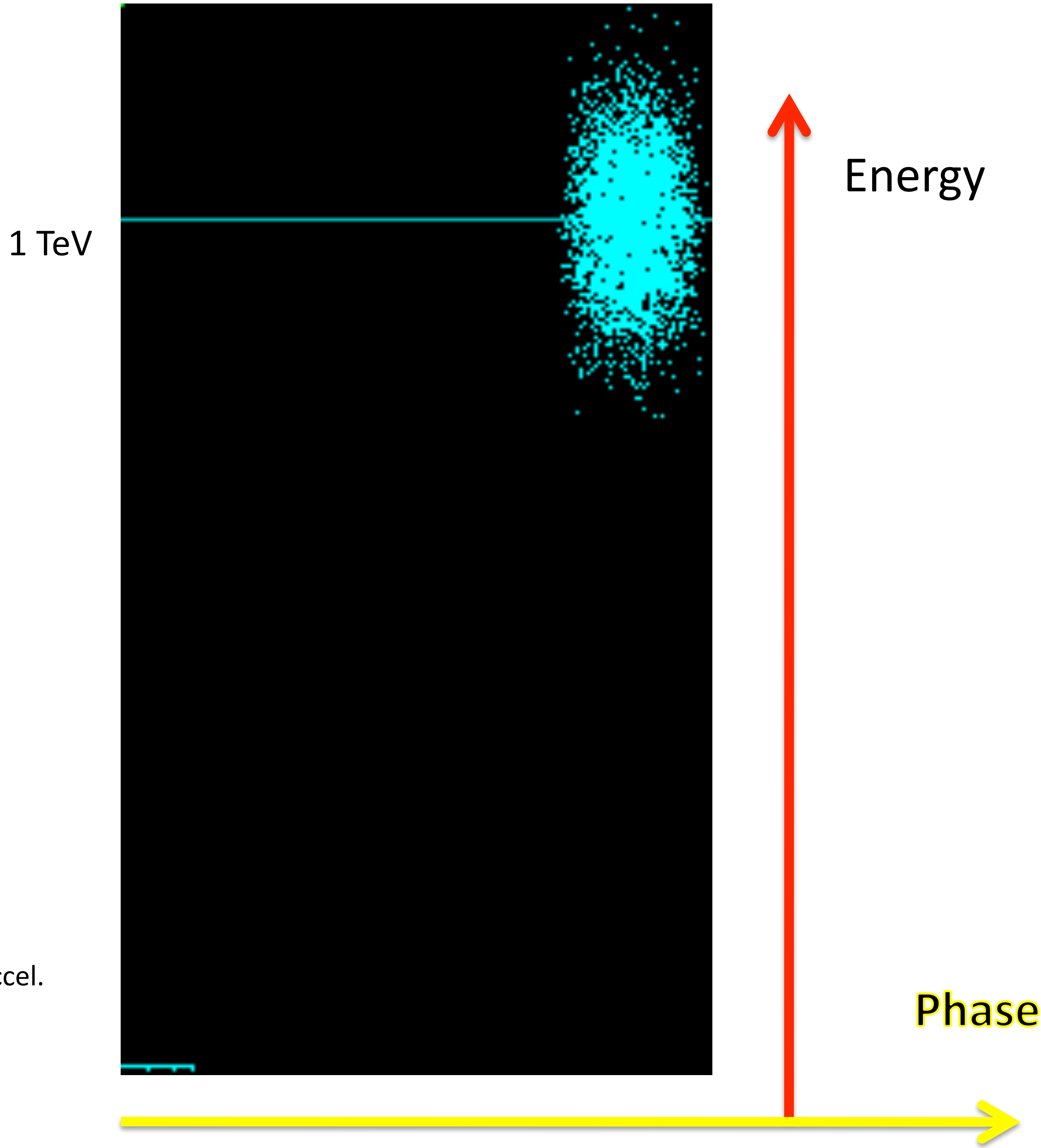
Simulation

Table 1: Table of parameters for the simulation.

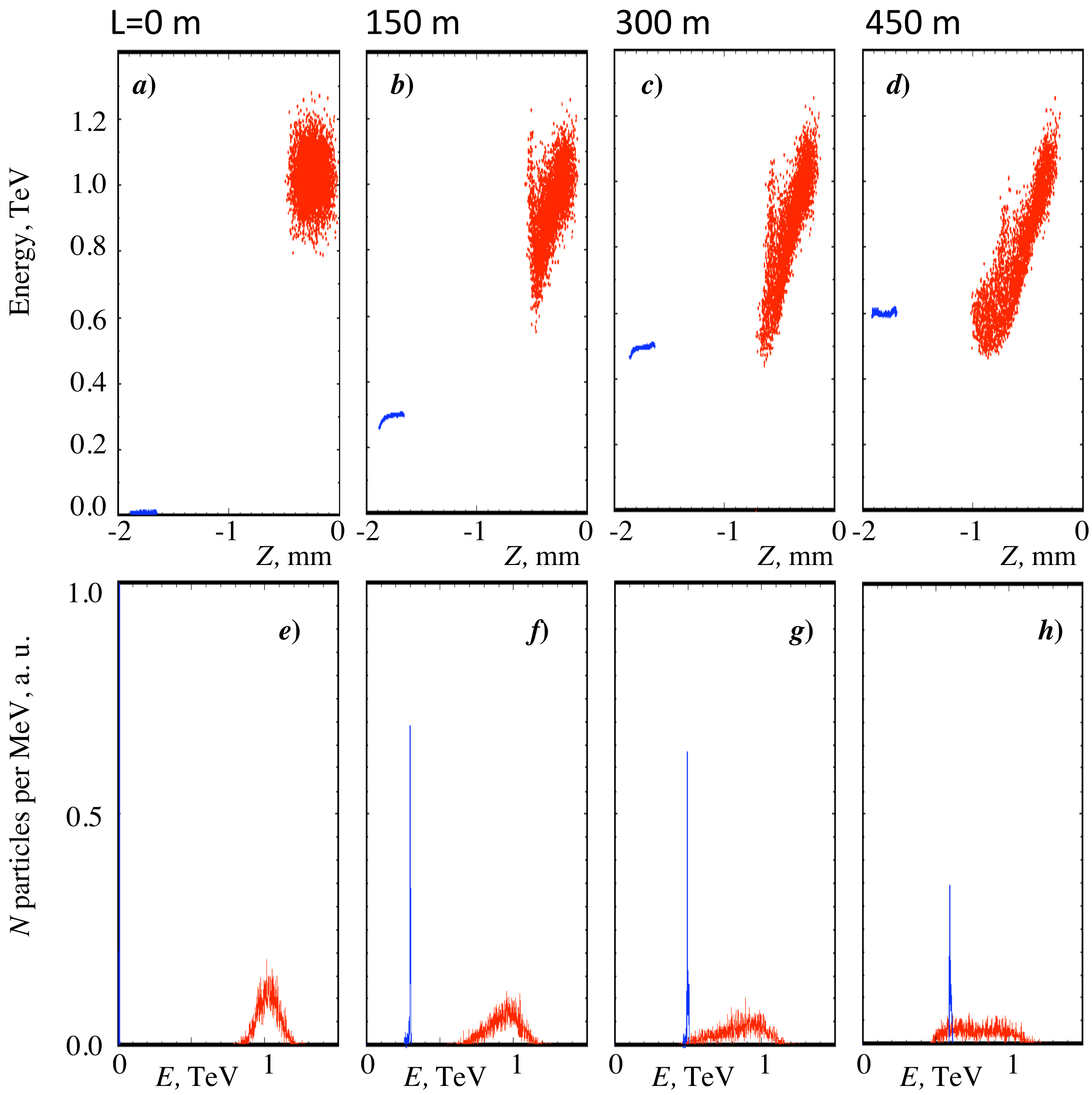
Parameter	Symbol	Value	Units
Protons in Drive Bunch	N_P	10^{11}	
Proton energy	E_P	1	TeV
Initial Proton momentum spread	σ_p/p	0.1	
Initial Proton longitudinal spread	σ_Z	100	μm
Initial Proton bunch angular spread	σ_θ	0.03	mrad
Initial Proton bunch transverse size	$\sigma_{X,Y}$	0.4	mm
Electrons injected in witness bunch	N_e	$1.5 \cdot 10^{10}$	
Energy of electrons in witness bunch	E_e	10	GeV
free electron density	n_p	$6 \cdot 10^{14}$	cm^{-3}
Plasma wavelength	λ_p	1.35	mm
Magnetic field gradient		1000	T/m
Magnet length		0.7	m

Densities & Fields





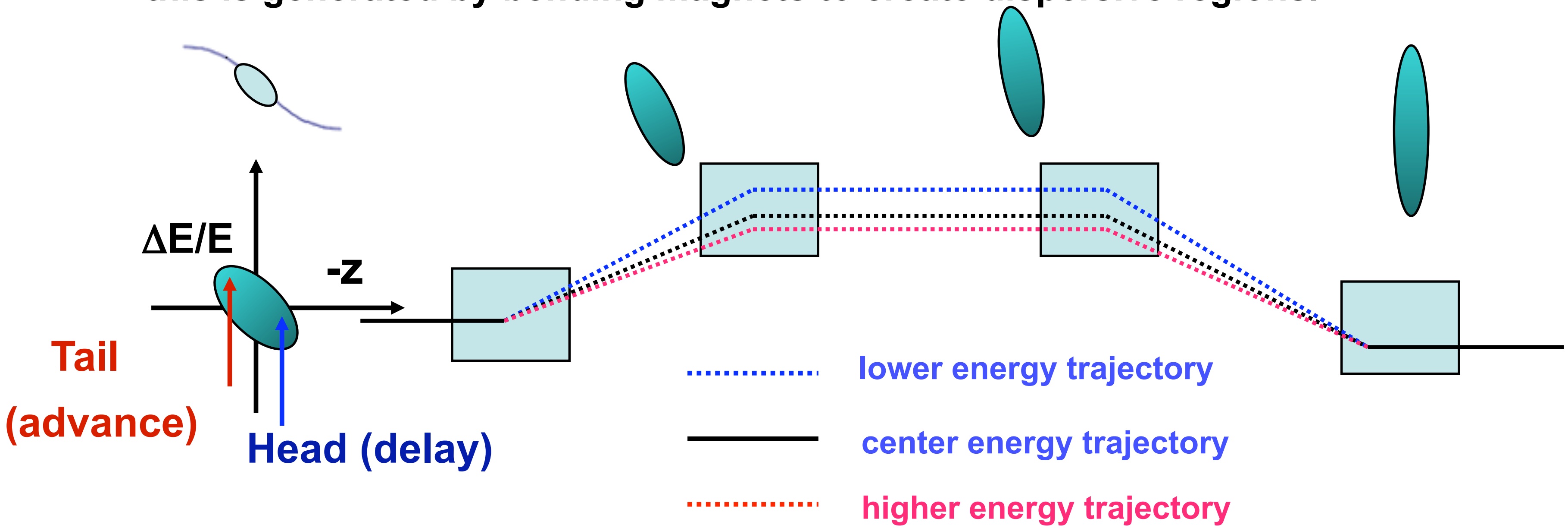
K. V. Lotov, Phys. Rev. ST Accel. Beams **13**, 041301 (2010).



L=0 m
150 m
300 m
450 m
a)
b)
c)
d)
Energy, TeV
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-2
-1
0
Z, mm
e)
f)
g)
h)
N particles per MeV, a. u.
1.0
0.5
0.0
0
E, TeV
1

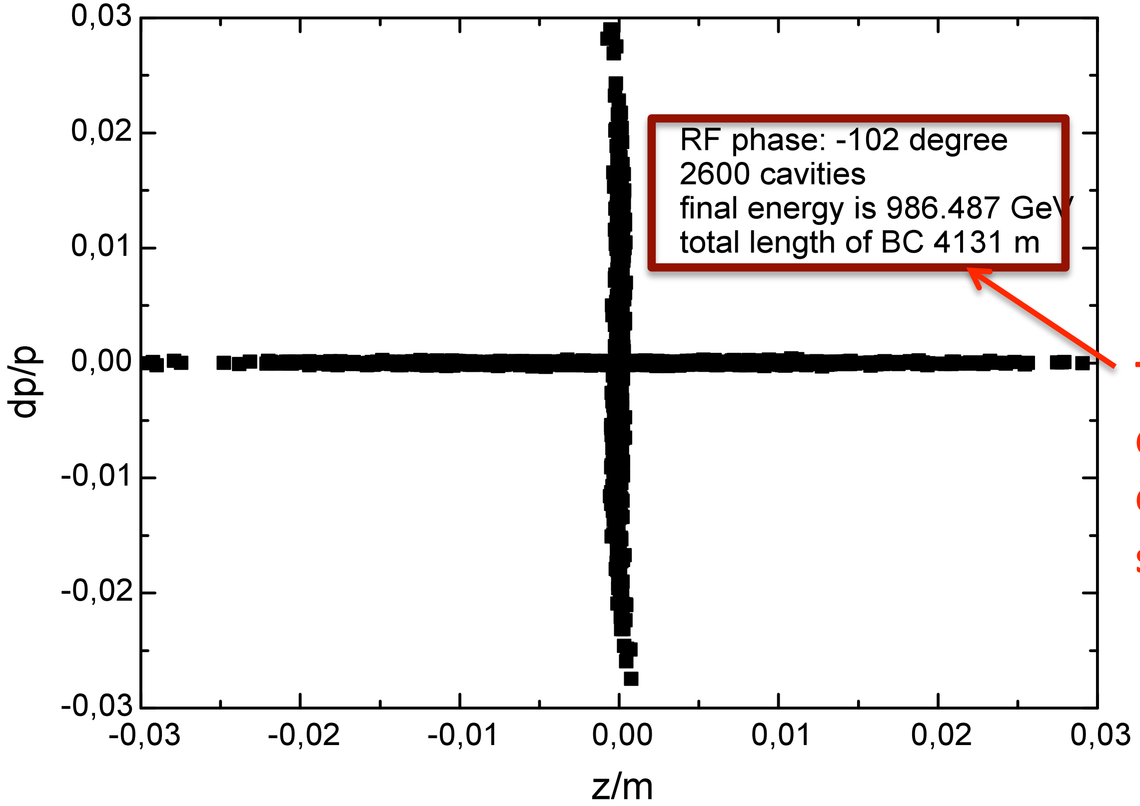
Magnetic bunch compression (BC)

- **Beam compression can be achieved:**
  - **(1) by introducing an energy-position correlation along the bunch with an RF section at zero-crossing of voltage**
  - **(2) and passing beam through a region where path length is energy dependent: this is generated by bending magnets to create dispersive regions.**



- **To compress a bunch longitudinally, trajectory in dispersive region must be shorter for tail of the bunch than it is for the head.**

Phase space of beam

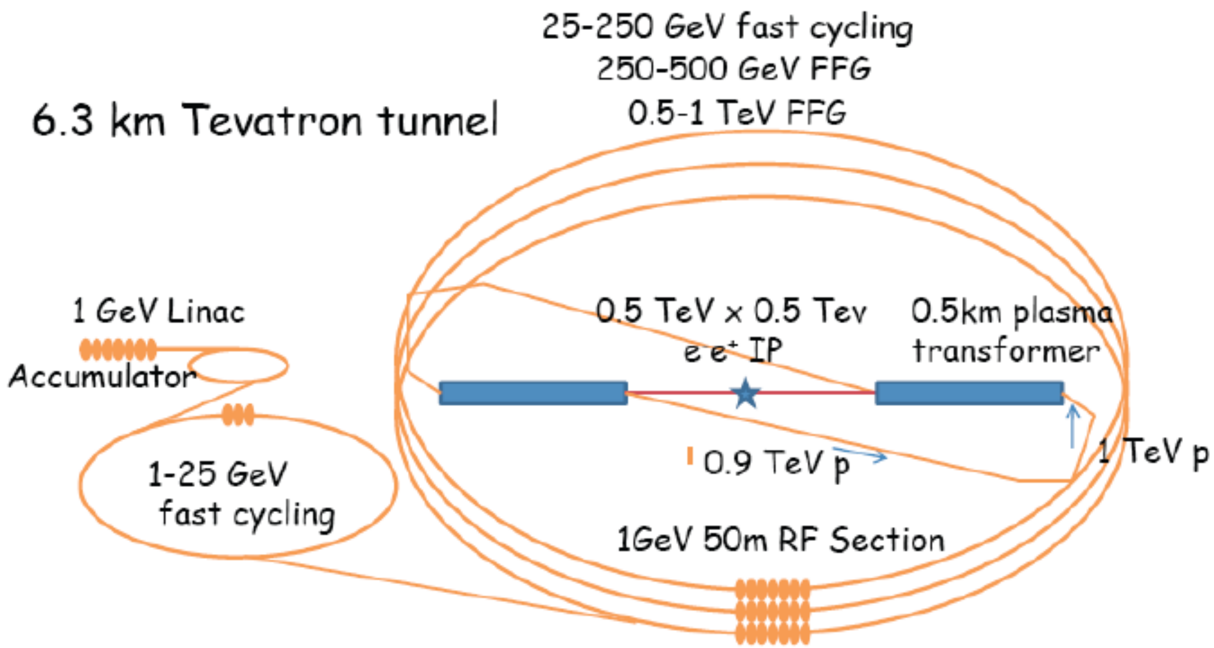


Too long – use in combination with other compression schemes

See A. Caldwell, G. Xia et al., Preliminary study of proton driven plasma wakefield acceleration, Proceedings of PAC09, May 3-8, 2009, Vancouver, Canada

PDPWA-based LC

V. Yakimenko, BNL, T. Katsouleas, Duke



Concept for high repetition rate of proton driven plasma wakefield acceleration

3 ring + injectors + recovery

Luminosity

$$L = f \frac{N_1 N_2}{4\pi\sigma_x\sigma_y} \quad \text{Gaussian shaped beams}$$

$$\text{suppose} \quad N_1 = N_2 = 10^{11}$$

$$\text{SPS} \quad \text{cycle time} \;\; 22s \quad 288 \;\; \text{bunches} \;\; \text{so assume} \;\; f = 15 \text{ Hz}$$

$$L \approx \left(\frac{1 \; \mu\text{m}^2}{\sigma_x\sigma_y} \right) 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$$

Will need very small cross section beams for significant luminosity

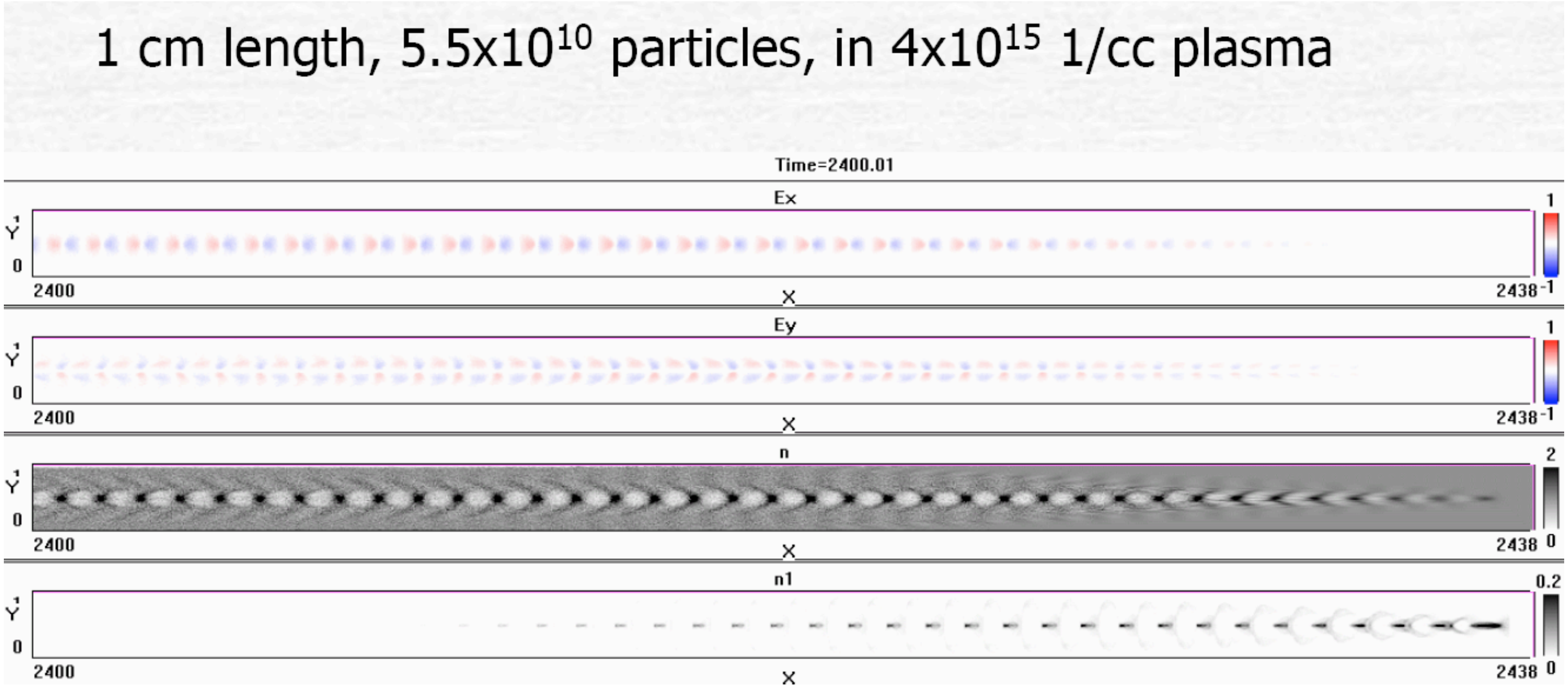
PWA via Modulated Proton Beam

Producing short proton bunches not possible today w/o major investment. Not an option for the short term …

Instead, we investigated modulating a long bunch to produce a series of 'micro'-bunches in a plasma.

The microbunches are generated by a transverse modulation of the bunch density (transverse two-stream instability). The microbunches are naturally spaced at the plasma wavelength, and act constructively to generate a strong plasma wake. Investigated both numerically and theoretically (N. Kumar, A. Pukhov, and K. V. Lotov, Phys. Rev. Lett. **104**, 255003 (2010)).

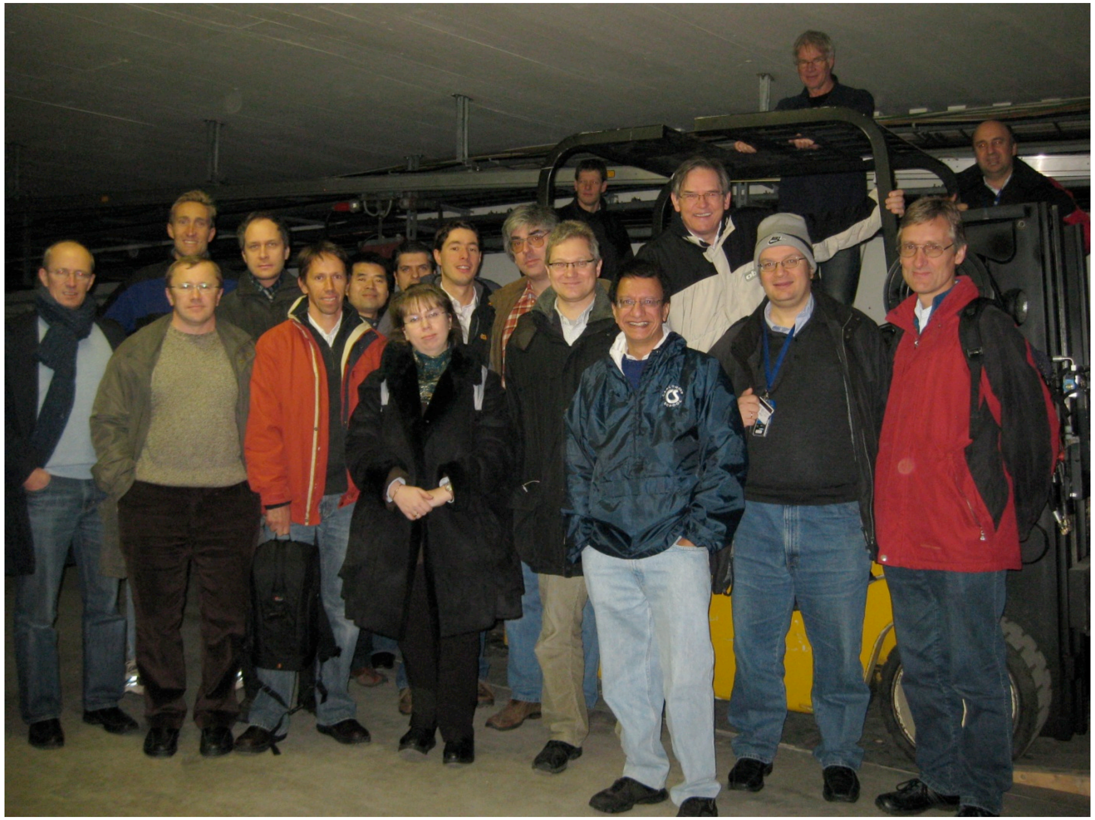
Alternative to short bunch – modulation of long bunch



Few hundred MeV/m expected. Under study.

SPS beam simulation, A. Pukhov

- Kick-off meeting-PPA09 held at CERN December 2009. Several workshops/ meetings since (Munich, London, CERN)
- PS and SPS options considered. From simulation studies, concluded SPS is much better. An unused SPS tunnel for demonstration experiment located.
- Experimental plan has crystallized: demonstrate 1 GeV acceleration of injected electrons within 10 m of plasma.



PPA09 workshop photo

Longer term – design/propose 100 GeV acceleration in 100m.

electric field from one microbunch:

(9) $$E_{\mu,\mathrm{z,max}} = eN_\mu Z(k_p,\sigma_z)R(k_p\sigma_r)$$

where N_μ is the number of protons in the microbunch and $\sigma_z \approx \sqrt{2}k_p^{-1}$ is the rms length of the protons in the microbunch. If we assume for hard edged beams that all microbunches within $\pm\sigma_{z,0}/2$ of the center of the proton bunch add coherently to the produced electric field, then we have

(10) $$E_{\mathrm{z,max}} = e\frac{0.38\cdot N}{2}Z(k_p,\sigma_z)R(k_p\sigma_r)\ .$$

We now calculate the maximum electric field by taking $k_p\sigma_r = 1$, substituting $\sigma_z \approx \sqrt{2}k_p^{-1} = \sqrt{2}\sigma_r$, and using (3), (4). This yields

(11) $$E_{\mathrm{z,max}} \approx 0.07\,\frac{Ne}{\sigma_r^2} \approx 0.1(\mathrm{GV/m})\cdot\left(\frac{N}{10^{10}}\right)\left(\frac{100\ \mu\mathrm{m}}{\sigma_r}\right)^2\ .$$

The maximum field from this expression is given in Table 2. The fields can be compared to the wave-breaking field

$$eE_0 = mc^2\frac{\omega_p}{c}$$

to determine the dimensionless field amplitude

(12) $$\alpha = \frac{E_{\mathrm{z,max}}}{E_0} \approx 0.018\left(\frac{N}{10^{10}}\right)\left(\frac{100\ \mu\mathrm{m}}{\sigma_r}\right)\ .$$

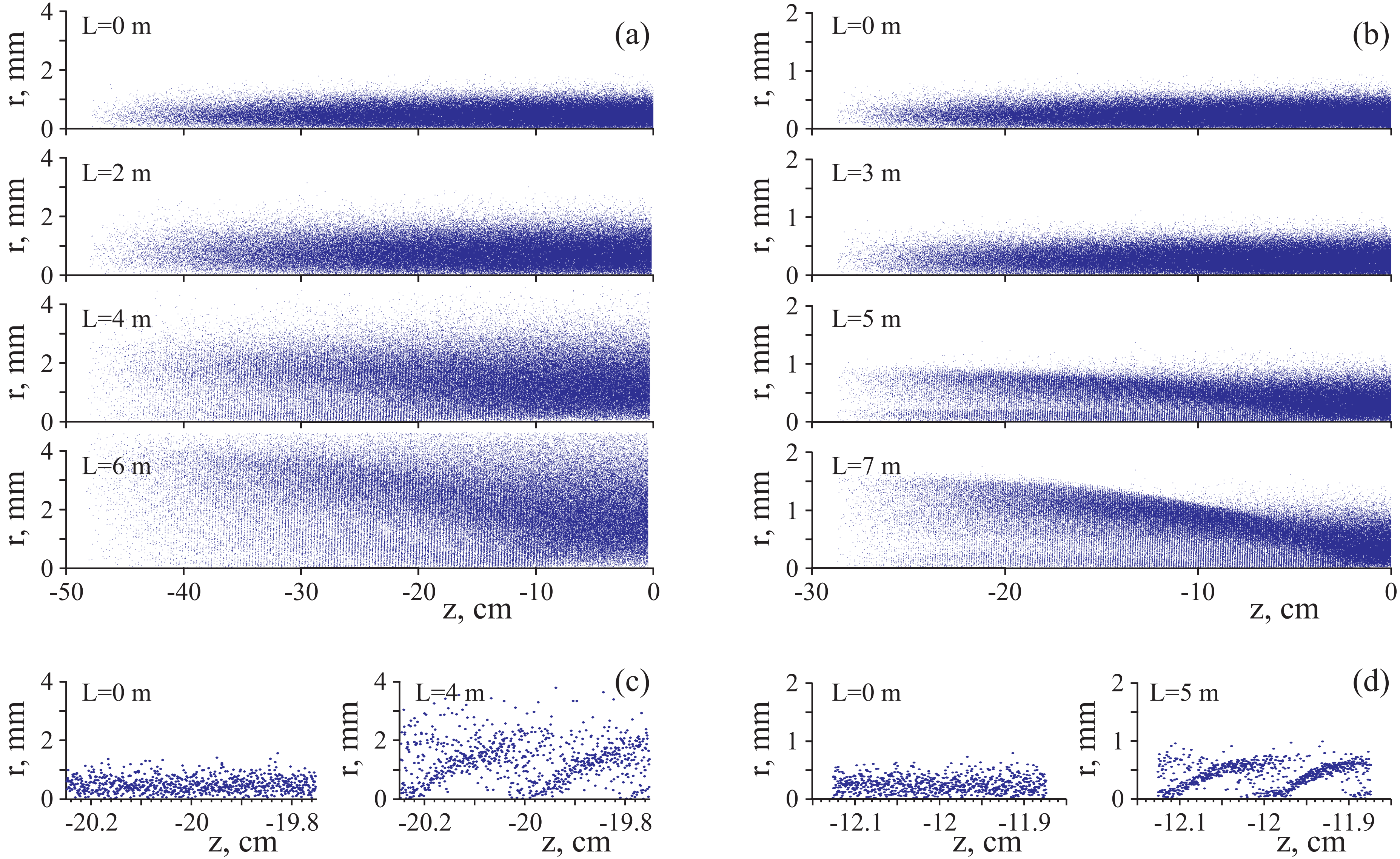
A. Caldwell[1] and K. V. Lotov[2], Phys. Plasmas **18, 103101 (2011); *Plasma wakefield acceleration with a modulated proton bunch***

Table 1. PS, SPS and LHC parameter sets. The different symbols are defined in the text. SPS-LHC means the standard parameters of bunches in the SPS for injection into the LHC. SPS-Totem means the special parameters for bunches for use by the Totem experiment.

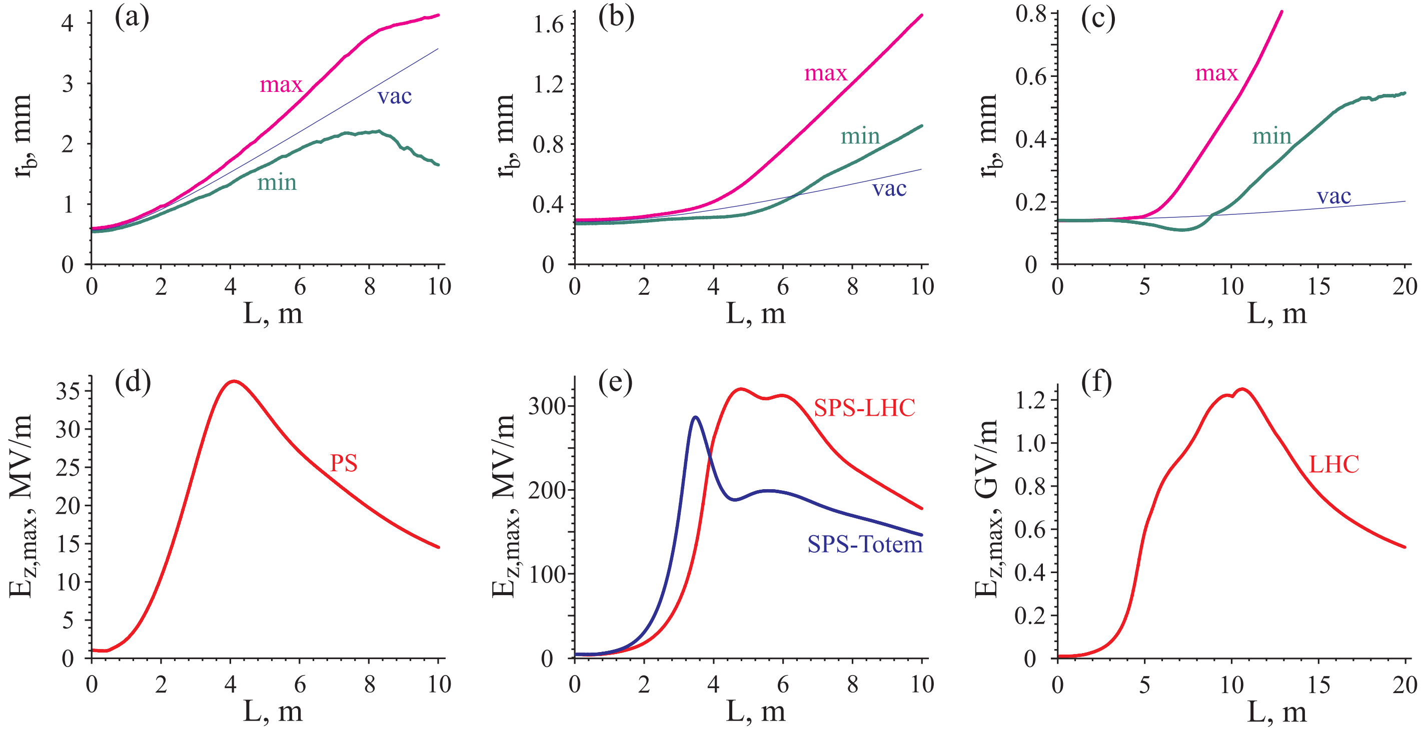
Parameter	PS	SPS-LHC	SPS-Totem	LHC
W_P (GeV)	24	450	450	7000
N_P (10^{10})	13	11.5	3.0	11.5
σ_P (MeV)	12	135	80	700
$\sigma_{z,0}$ (cm)	20	12	8	7.6
σ_r (μm)	400	200	100	100
c/ω_b (m)	2.3	4.0	3.2	6.3
σ_θ (mrad)	0.25	0.04	0.02	0.005
L_θ (m)	1.6	5	5	20
ϵ (mm-mrad)	0.1	0.008	0.002	$5\cdot10^{-4}$

Table 2. Characteristics of beam interaction with the uniform density plasma.

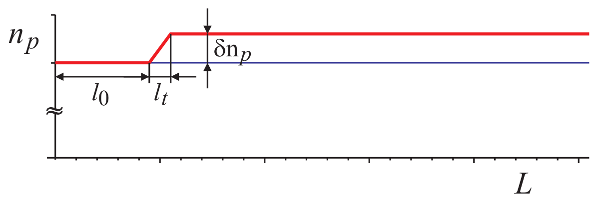
Parameter	PS	SPS-LHC	SPS-Totem	LHC
n_p (10^{15} cm^{-3})	0.18	0.7	3	3
λ_p (mm)	2.5	1.3	0.6	0.6
W_f (eV)	180	280	100	410
W_{tr} (eV)	750	360	90	90
$eE_{\mathrm{z,max}}$ (GeV/m)	0.08	0.3	0.3	1.1
eE_0 (GeV/m)	1.3	2.5	5.3	5.3
α	0.06	0.1	0.05	0.2

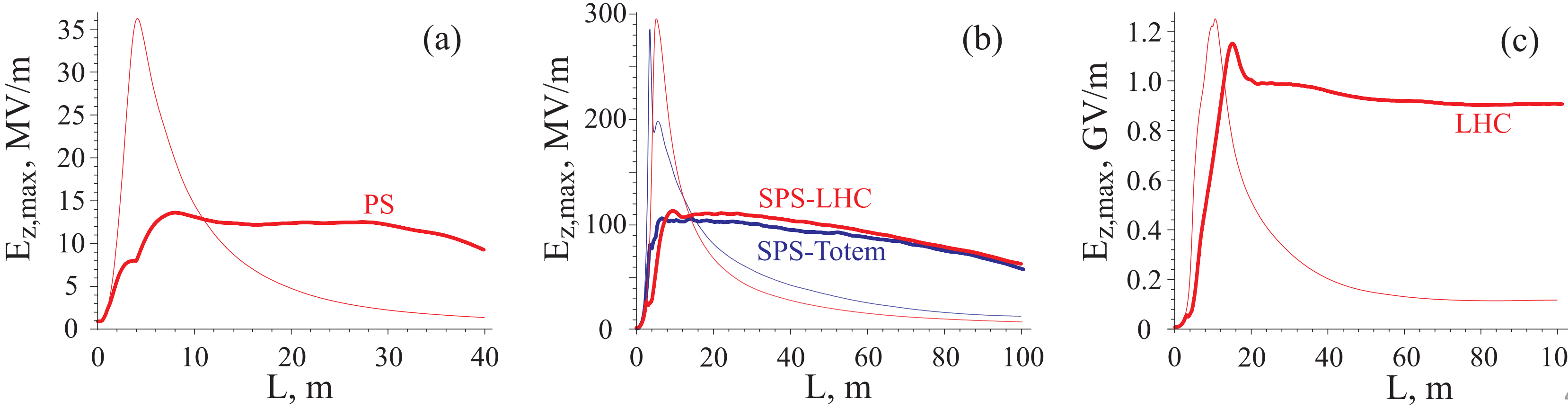


(a)
L=0 m
L=2 m
L=4 m
L=6 m
r, mm
z, cm
-50 -40 -30 -20 -10 0
(b)
L=0 m
L=3 m
L=5 m
L=7 m
-30 -20 -10 0
(c)
L=4 m
-20.2 -20 -19.8
(d)
L=5 m
-12.1 -12 -11.9

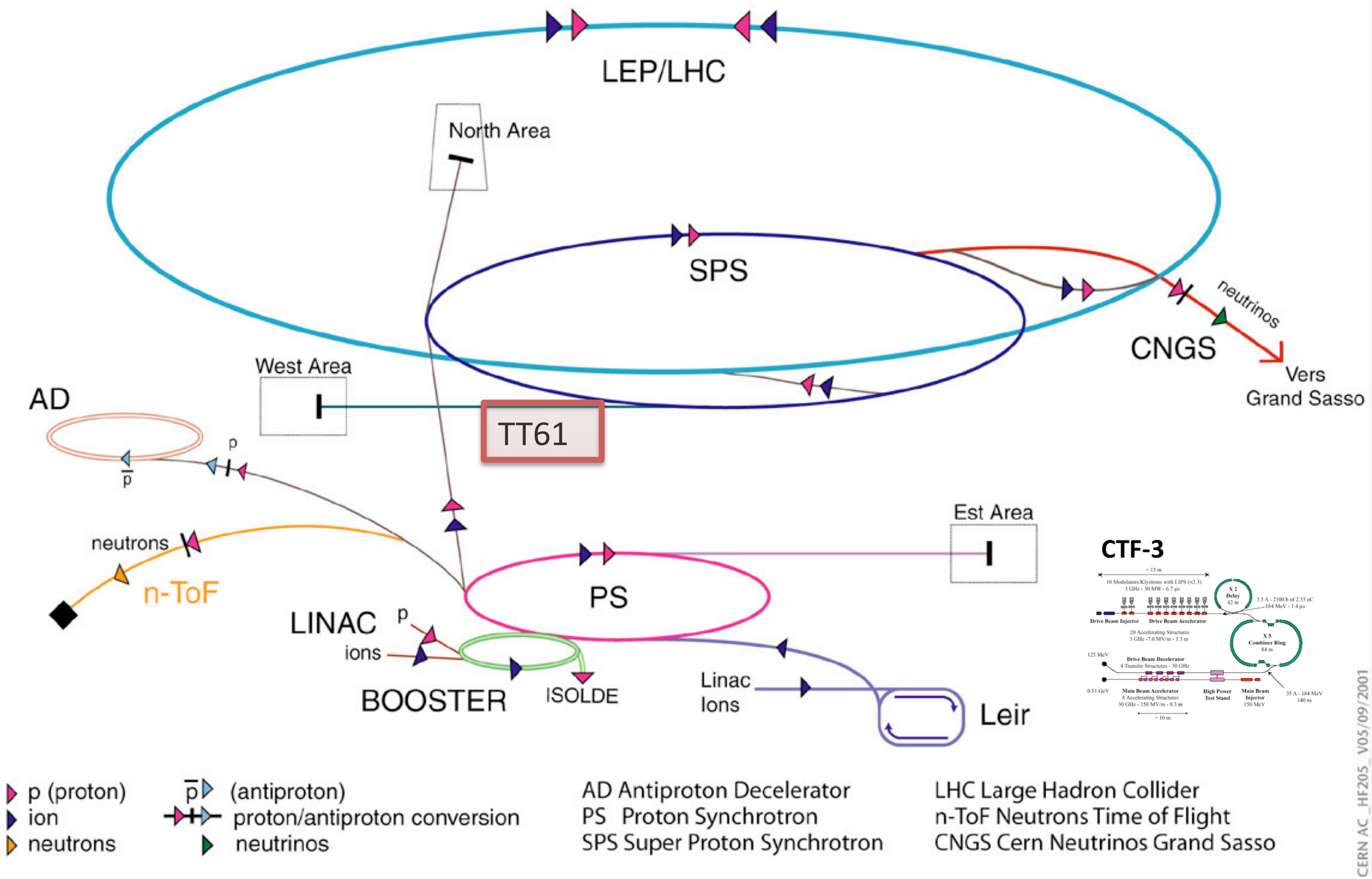


Modulations will eventually destroy the beam. Density step freezes modulations

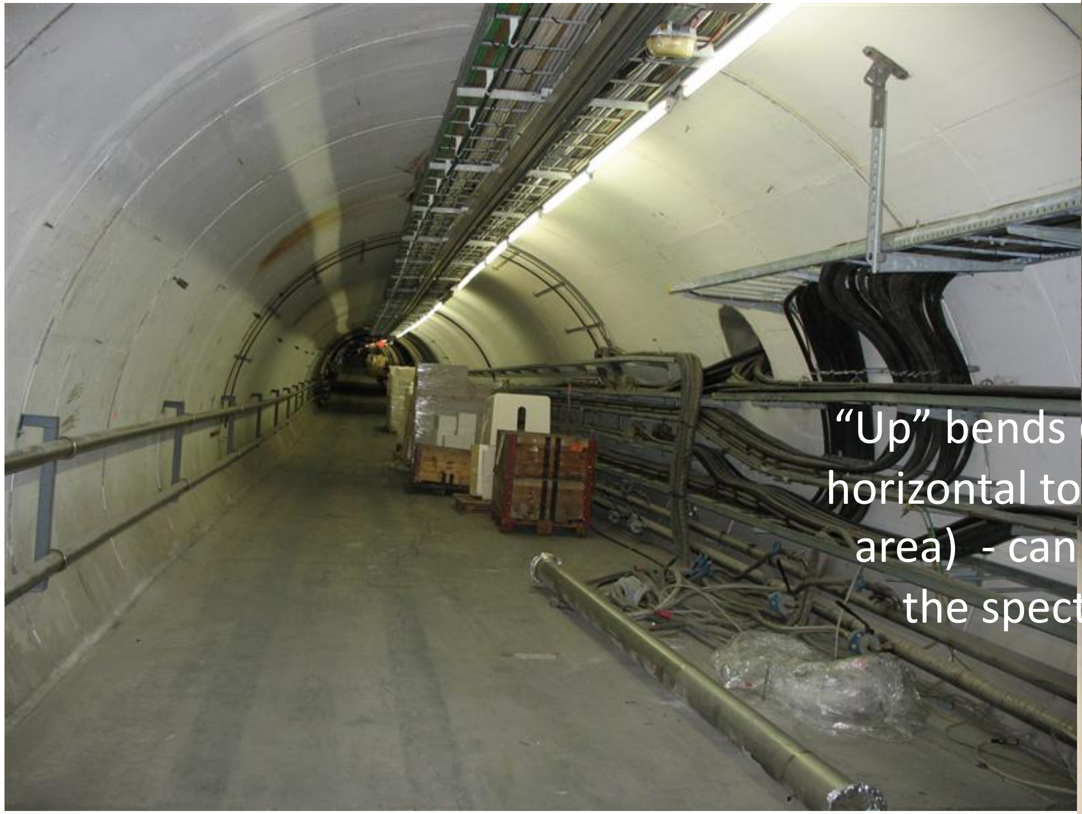




Accelerator chain of CERN (operating or approved projects)

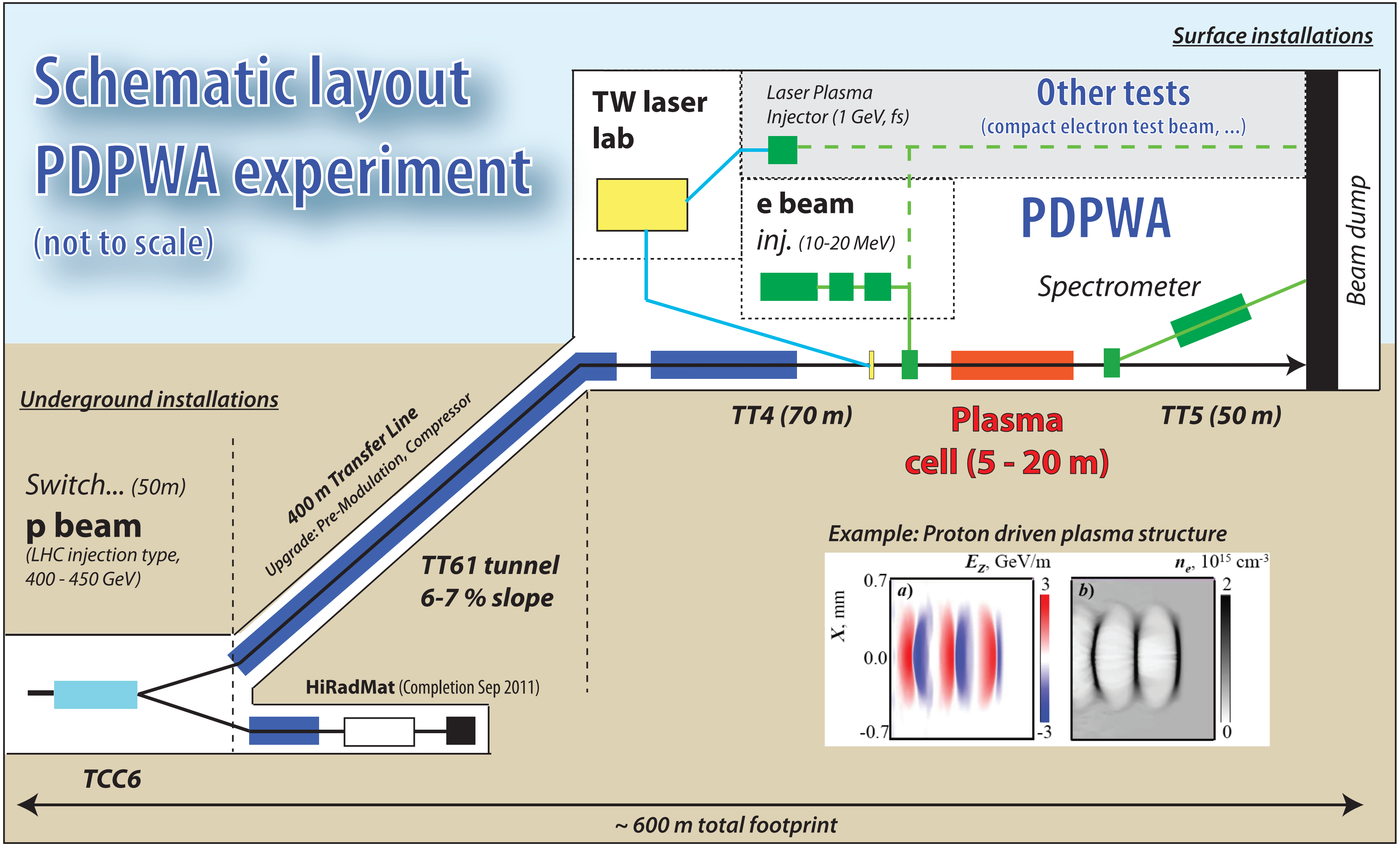


TT61 tunnel today



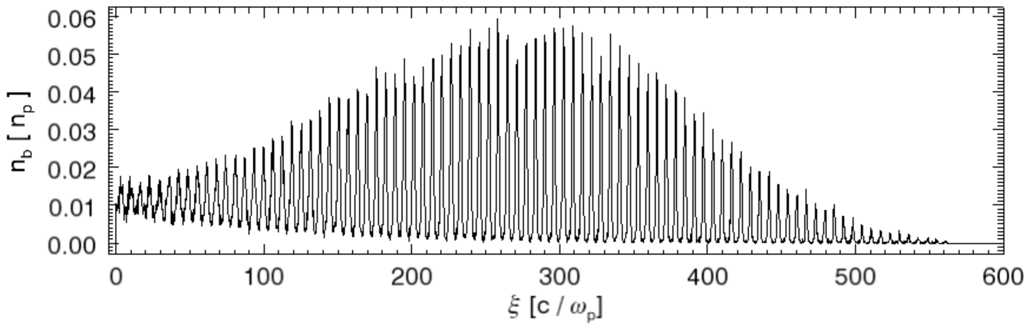
"Up" bends (bring beam horizontal to the old exp. area) - can be used as the spectrometer

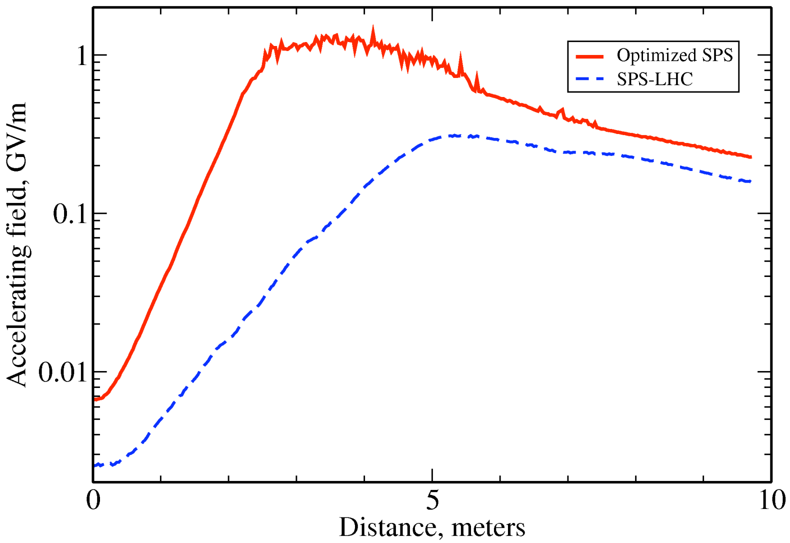
End tunnel to be converted to **beam dump**


Surface installations
Schematic layout
PDPWA experiment
(not to scale)
TW laser lab
Laser Plasma Injector (1 GeV, fs)
Other tests
(compact electron test beam, ...)
e beam inj. (10-20 MeV)
PDPWA
Spectrometer
Beam dump
Underground installations
400 m Transfer Line
Upgrade: Pre-Modulation, Compressor
TT4 (70 m)
Plasma cell (5 - 20 m)
TT5 (50 m)
Switch... (50m)
p beam
(LHC injection type, 400 - 450 GeV)
TT61 tunnel
6-7 % slope
Example: Proton driven plasma structure
E_z, GeV/m
n_e, 10^15 cm^-3
X, mm
0.7
0.0
-0.7
a)
b)
3
-3
2
0
HiRadMat (Completion Sep 2011)
TCC6
~ 600 m total footprint

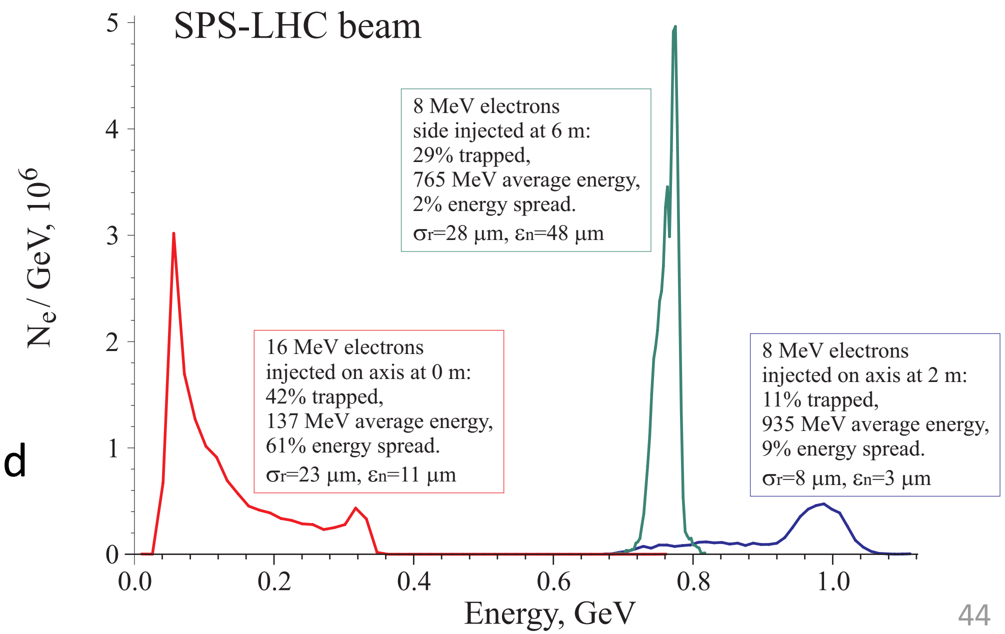
Expected Results

A long SPS drive beam will be sent into a 5-10m long plasma cell. A self-modulation of the beam due to the transverse wakefield occurs which produces many ultrashort beam slices.





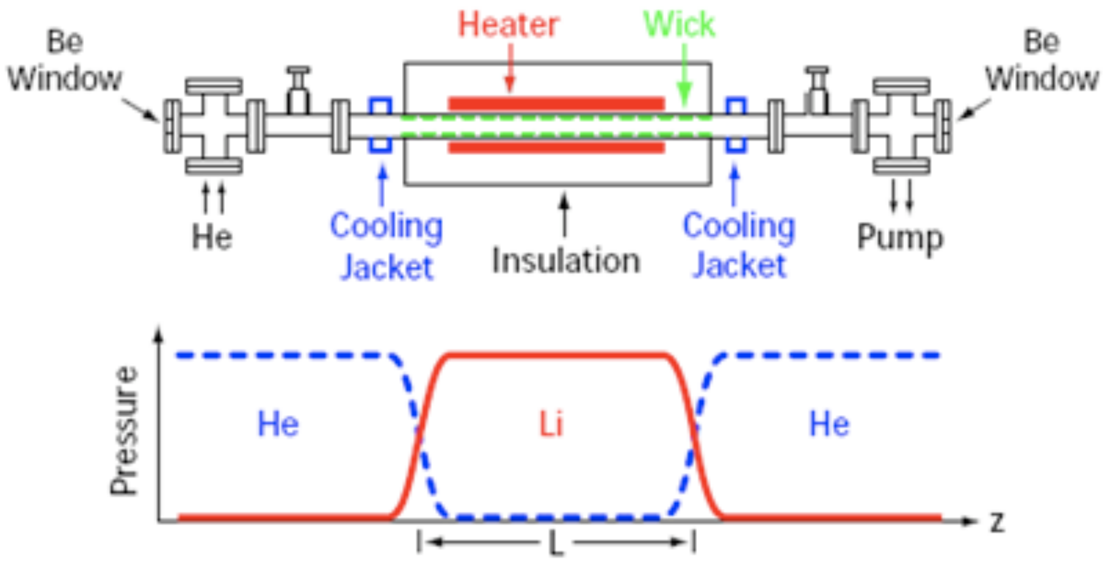
The modulation resonantly drives wakefields in the 100-1000 MV/m regime.

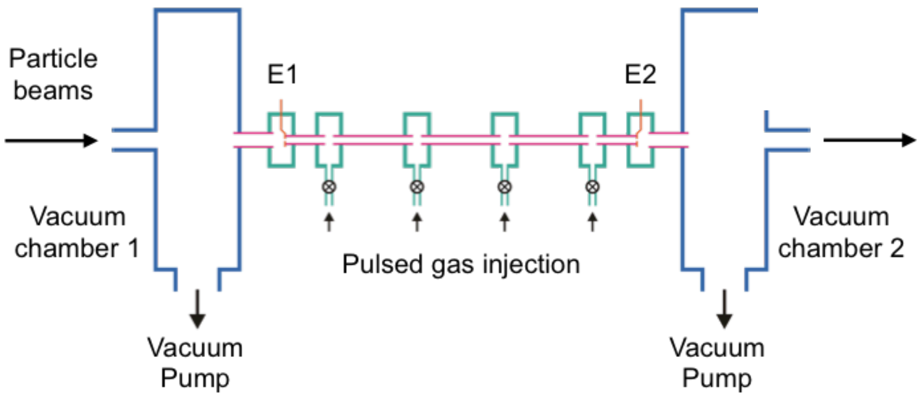


Particle-in-cell simulations predict acceleration of injected electrons to beyond 1 GeV.

Plasma Cell ideas:

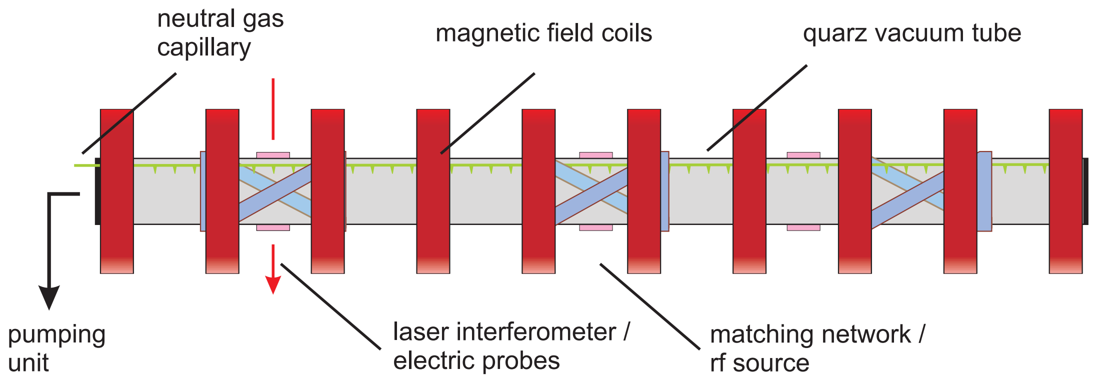
Metal vapor, a la SLAC experiment:
UCLA, Max Planck Institute for Physics





Discharge: IST, Imperial College

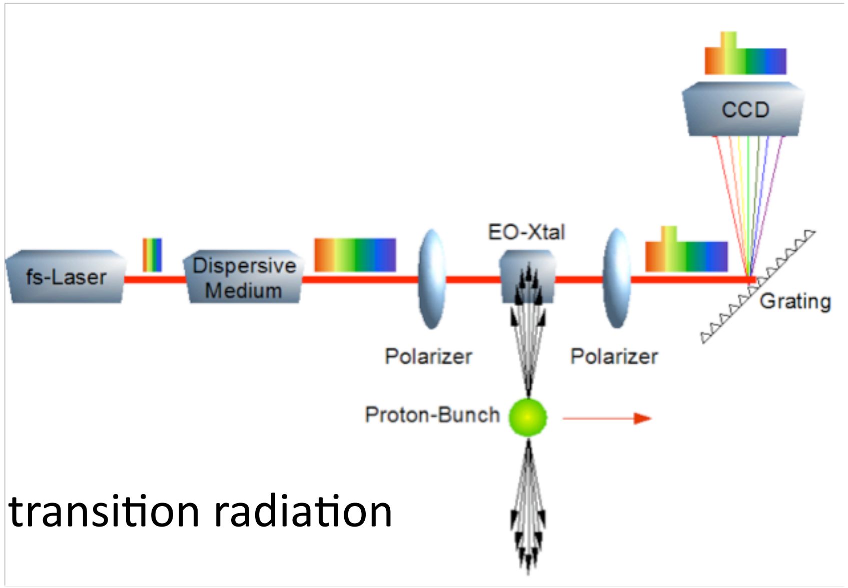
Helicon – Max Planck Institute for Plasma Physics

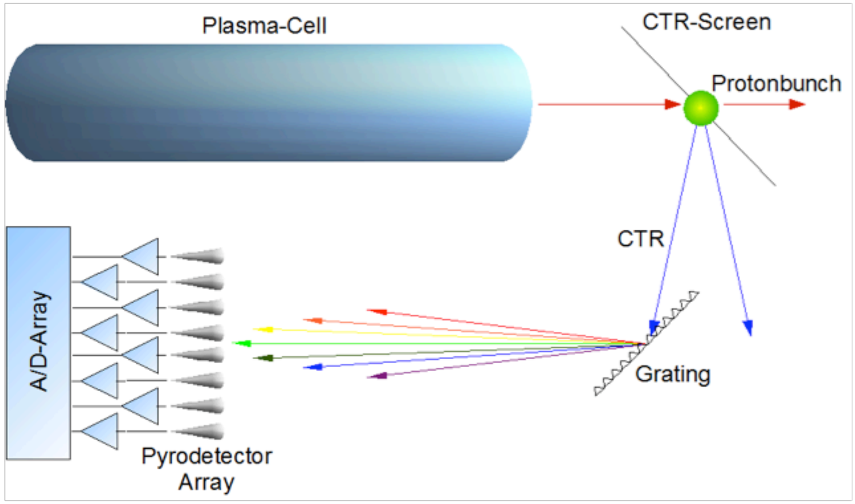


Diagnostics

Electro-optical sampling for modulations, field strength:

University College, RAL, DESY, Imperial College, Cockroft Institute, Strathclyde, MPP



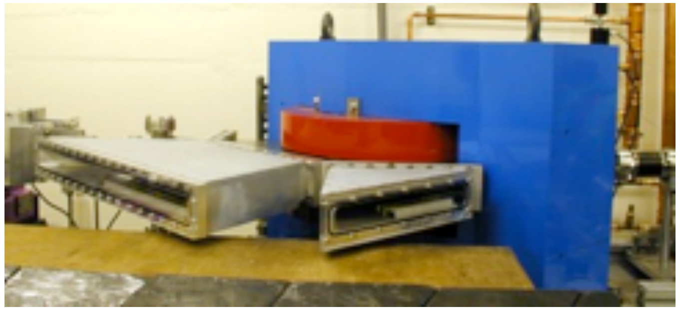


Coherent transition radiation

Electron spectrometer:

CERN, Imperial College, Cockroft Institute, Strathclyde, KIT, UCL, D

Injector/spectrometer for electron bunch



Date: May 31, 2011

Proto-collaboration with 25 institutes, including world-experts in all needed categories

Letter of Intent
for a Demonstration Experiment in
Proton-Driven Plasma Wakefield Acceleration

E. Adli[24], W. An[22], R. Assmann[3], R. Bingham[19], A. Caldwell[16], S. Chattopadhyay[4], N. Delerue[12], F. M. Dias[8], I. Efthymiopoulos[3], E. Elsen[5], S. Fartoukh[3], C. M. Ferreira[8], R. A. Fonseca[8], G. Geschonke[3], B. Goddard[3], O. Grülke[17], C. Hessler[3], S. Hillenbrand[11], J. Holloway[19,23], C. Huang[14], D. Jarozinsky[25], S. Jolly[23], C. Joshi[22], N. Kumar[7], W. Lu[21,22], N. Lopes[8], M. Kaur[18], K. Lotov[2], V. Malka[13], M. Meddahi[3], O. Mete[3], W.B. Mori[22], A. Mueller[11], P. Muggli[16], Z. Najmudin[9], P. Norreys[19], J. Osterhoff[5], J. Pozimski[9], A. Pukhov[7], O. Reimann[16], S. Roesler[3], H. Ruhl[15], H. Schlarb[5], B. Schmidt[5], H.V.D. Schmitt[16], A. Schöning[6], A. Seryi[10], F. Simon[16], L.O. Silva[8], T. Tajima[15], R. Trines[19], T. Tückmantel[7], A. Upadhyay[7], J. Vieira[8], O. Willi[7], M. Wing[23], G. Xia[16], V. Yakimenko[1], X. Yan[20], F. Zimmermann[3]

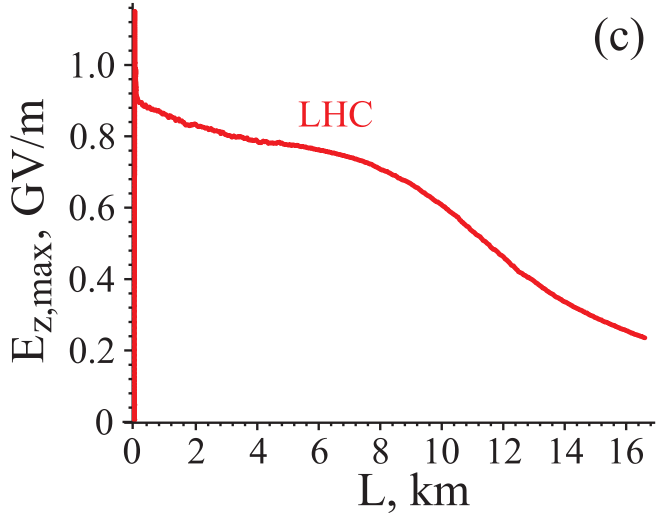
1 Brookhaven National Laboratory, Brookhaven, USA
2 Budker Institute of Nuclear Physics, Novosibirk, Russia
3 CERN, Geneva, Switzerland
4 Cockroft Institute, Daresbury, UK
5 DESY, Hamburg, Germany
6 Universität Heidelberg, Heidelberg, Germany
7 Heinrich Heine University, Düsseldorf, Germany
8 Instituto de Plasmas e Fusao Nuclear, IST, Lisboa, Portugal
9 Imperial College, London, UK
10 John Adams Institute for Accelerator Science, Oxford, UK
11 Karlsruher Institute of Technology KIT, Karlsruhe, Germany
12 LAL, Univ Paris-Sud, CNRS/IN2P3, Orsay, France
13 LOA, Laboratoire dOptique Applique, CNRS/ENSTA/X, France
14 Los Alamos National Laboratory, NM, USA
15 Ludwig Maximilian University, Munich, Germany
16 Max Planck Institute for Physics, Munich, Germany
17 Max Planck Institute for Plasma Physics, Greifswald, Germany
18 Panjab University, Chandigarh, India
19 Rutherford Appleton Laboratory, Chilton, UK
20 State Key Laboratory of Nuclear Physics and Technology, Peking University, China
21 Tsinghua University, Beijing, China
22 University of California, Los Angeles, CA, USA
23 University College London, London, UK
24 University of Oslo, Oslo, Norway
25 University of Strathclyde, Glasgow, Scotland, UK

Positive review by SPSC October 2011

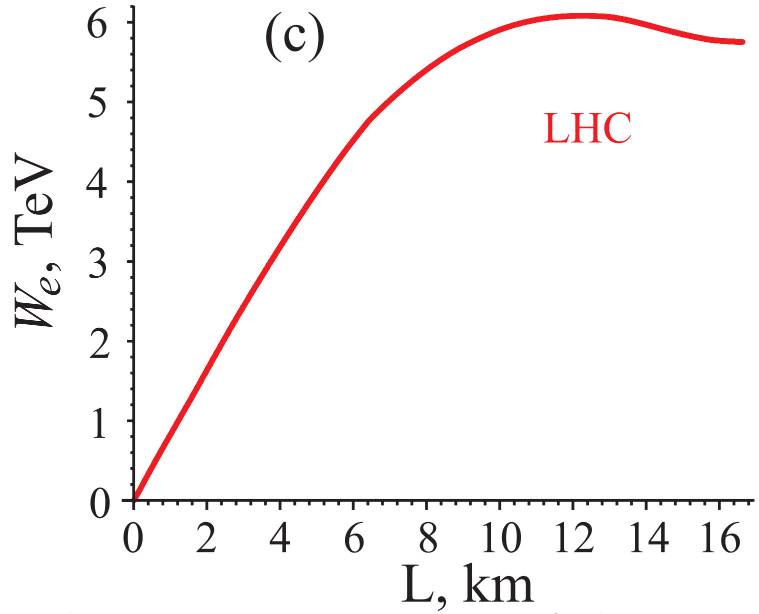
Outlook

Long term prospects for modulated proton bunch intriguing:

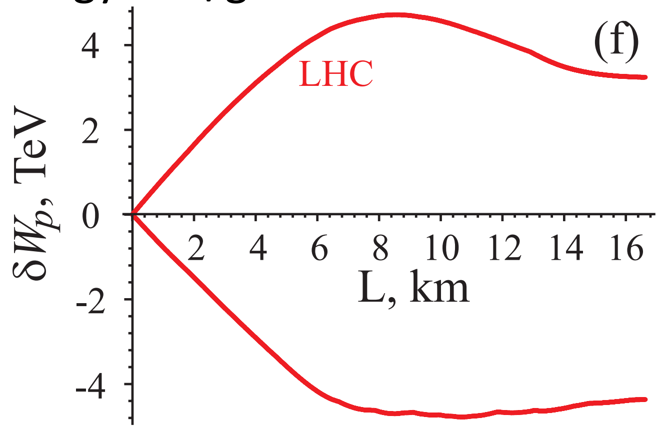
simulation of existing LHC bunch in plasma with trailing electron bunch …
A. Caldwell, K. V. Lotov, Phys. Plasmas **18**, 13101 (2011)



Electron energy gain



Proton energy loss/gain



Miracle: no guiding magnetic fields necessary !

Conclusions

Accelerator based particle physics has had a tremendous impact on our knowledge and has been the key to the development of the Standard Model of particle physics.

But, we are in need of novel ideas …

Plasma Wakefield Acceleration has been proposed many years ago – steady progress in developing the technology, but there is still a long way to go.

Look for interesting developments in the next 5 years

Work Packages CERN

(under discussion)

- WP C1: CERN project management.
- WP C2: Interaction region design p-beam, e-beam and laser light.
- WP C3: Beam/plasma simulations to observation points.
- WP C4: Proton beam switch, transfer line, beam delivery, collimation and beam dump.
- WP C5: *Electron beam RF acceleration, beam transport,* beam delivery, collimation, beam separation and dump.
- WP C6: Experimental area.
- WP C7: Radiation protection and safety.
- WP C8: Future uses of CERN advanced test facility.

Work Package C2

- WP C2: Interaction region design p-beam, e-beam and laser light.
  - Theoretical study and simulations of interaction region.
  - Specification for proton delivery system (magnets, collimation, dump)
  - Specification for e-beam delivery system (magnets, collimation, dump)
  - Specification for laser light path (optics)
  - Specification for incoming beams and laser (emittance, stability, momentum, energy spread, …)
  - Specification for timing system
  - Specification for diagnostics (p-beam, e-beam, laser, plasma, position, intensity, losses, transverse size, energy spread, momentum, …)
  - Specification of correction system (dipoles, matching sections, …).
  - Specification for vacuum system (apertures, windows, pumping, …)
  - Specification for spectrometer(s)
  - Definition of all interfaces
  - Integration, design and drawings.

Note

- This is THE difficult area for this experiment.
  - Bring together electron beam, proton beam, laser light beam and long plasma cell within tolerances.
  - Beam position/angle in 6D is characterized by x, x', y, y', t, p
  - Beam size/divergence in 6D is characterized by σ_x, σ_x', σ_y, σ_y', σ_z, σ_p
  - Similar for laser light and plasma column…
- In total: ~48 parameters for our CERN experiment!
  - These parameters must first be measured
  - Then they must be matched to each other in the plasma cell
  - Side injection does not make things easier!
  - Then we must separate beams and diagnose plasma effect
- Was much easier for the SLAC experiment:
  - Best results by just sending the electron beam into the gas, creating the plasma column itself (no laser light beam and no proton beam)

Some examples…

- Radiation constraints will define transverse distances to respect, e.g. proton beam delivery to electron source to laser …
- This defines length of guiding, transport and delivery → overall longitudinal footprint.
- We must try to use standard components as much as possible → fixes apertures that are realistic.
- This will impose constraints on proton/electron beam energies, emittances, stability/reproducibility, …
- Number of required windows (e.g. Beryllium) will impose additional constraints. Safety might impose some windows!
- Shows that we need approved conceptual layout before we can start to agree on components. A good solution here will make us successful…

Collaborative Help Needed

- This is a very complicated experiment (2 beams, 1 laser and 1 plasma cell): **this is what makes it so interesting!**
- We cannot prepare the facility with a decoupled CERN team:
  - Need to learn about lasers and plasmas.
  - Need rapid turn-around in simulations: input from plasma specialists outside CERN.
  - Outside teams need to understand CERN boundary conditions.
- The 1 year goal for a technical design report is short!!!
- Hope for a team of ~20 persons regularly present and working at CERN (~12 from CERN – not full time).
  - Can easily accommodate 3 good PhD students plus 5 visitors from outside institutes.
  - Now we need people who invest time at CERN.