Use of CLIC zero for Accelerator R&D

R. Assmann

CLIC Collaboration Meeting, CERN

10.5.2012

EuroNNAc

European Network for Novel Accelerators

- Network status:
  - **52 institutes are members of our network** (Europe, US, Asia)
  - Part of EuCARD2 project. Network results will feed into TIARA.
  - Ideas about first plasma acceleration facility for HEP (discussed in ICFA/ICUIL task force):
    - Electron injector for LHeC and other future projects (~10 GeV)
    - In addition, follow-up on plasma linac as compact test beam for HEP
  - Activities for synchrotron radiation facilities picking up speed:
    - LUNEX5 (F)
    - ARD/LAOLA (DE)
- Connection to linear colliders:
  - Potential path to **cost effective, compact accelerators** and colliders. Generic R&D. Table top FEL's…
  - Supported by High Energy Physics (e.g. US) and more strongly by photon and laser science communities. Billion Euro activity…

EuroNNAc Members I

Institute	Country	Member's board
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Possible Scenario

Year	R&D	Application and Science
2012 – 20	Laser driver – electron driver – proton driver – positrons acc.? – plasma – e-/p+/ion beam quality – beam radiation tests	**Test facilities in various countries targeted to photon science and medical applications** (Distributed Test Facility?)
		Low luminosity paradigm: selected high energy events
2020 – 30	efficiency, cost, scalability, reliability, e-/e+/p+/ion beam quality	**Operational compact photon science facility (e- beams)**
		Compact medical test accelerators
		Compact high energy physics test facility (**low luminosity Z production**, e+e- beams)
		Advanced beams for multi-GeV injection
2030 – 40	efficiency, cost, scalability, reliability, e-/e+/p+/ion beam quality	**Operational compact medical accelerators** **Operational high luminosity Z factory** Test low luminosity Higgs factory?
2040 – 50		**Operational high energy frontier collider**

Research Topics	CILEX	LUNEX5	LUND	IZEST/ PETAL/ ICAN	LAOLA	SPARC LAB	PDPWA	ALPHA-X / SCAPA
	Paris, France	Paris, France	Lund, Sweden	Paris & Bordeaux, France	Hamburg, Germany	Frascati, Italy	Geneva, Switzerlan d	Glasgow, UK
External optical injection	***		*		***	*	*	***
External RF injection	**	*			***	***	**	
LWFA self injection	***		***	*** 100GeV		***		***
Multi-stage LWFA	***				**			***
Synchr. radiation with adv. beams	**	**			***	***		***
electron beam driven PWFA					**	***		
proton beam driven PWFA							**	
Betatron radiation in plasma	***		***		**	***		***
Plasma undulator	*					*		***
Stability and beam quality	***	**	***		***	***	**	***
Polarized beams in plasmas								
Positron acceleration								
Power and efficiency				***				
femto-second synchronization	***	**			***	***	**	*
Condition of access	User, Comm.	Coll.	Coll., Laser Lab	Coll.	Coll.	User, Comm.	Coll.	Collaborati on
Availability	2015	?	OP	2015	2013-15	2014	2016	ALPHA-X (2012) - SCAPA (2014)

European Network
for Novel Accelerators

European Facility Review

- preliminary -

***** = funded**
**** = advanced project, not funded**
*** = possible but additional resources**

Plasma Accelerator R&D

External RF injection

Betatron radiation in plasma

Power and efficiency

Stability and beam quality

Polarized beams in plasmas

Electron beam driven PWFA

Multi-stage LWFA

Synchrotron radiation with advanced beams

Positron acceleration

Femto-second synchronization

Proton beam driven PWFA

External optical injection

Plasma undulator

Laser wakefield acceleration (LWFA) with self injection

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Proton beam driven PWFA

External optical injection

Plasma undulator

Laser wakefield acceleration (LWF

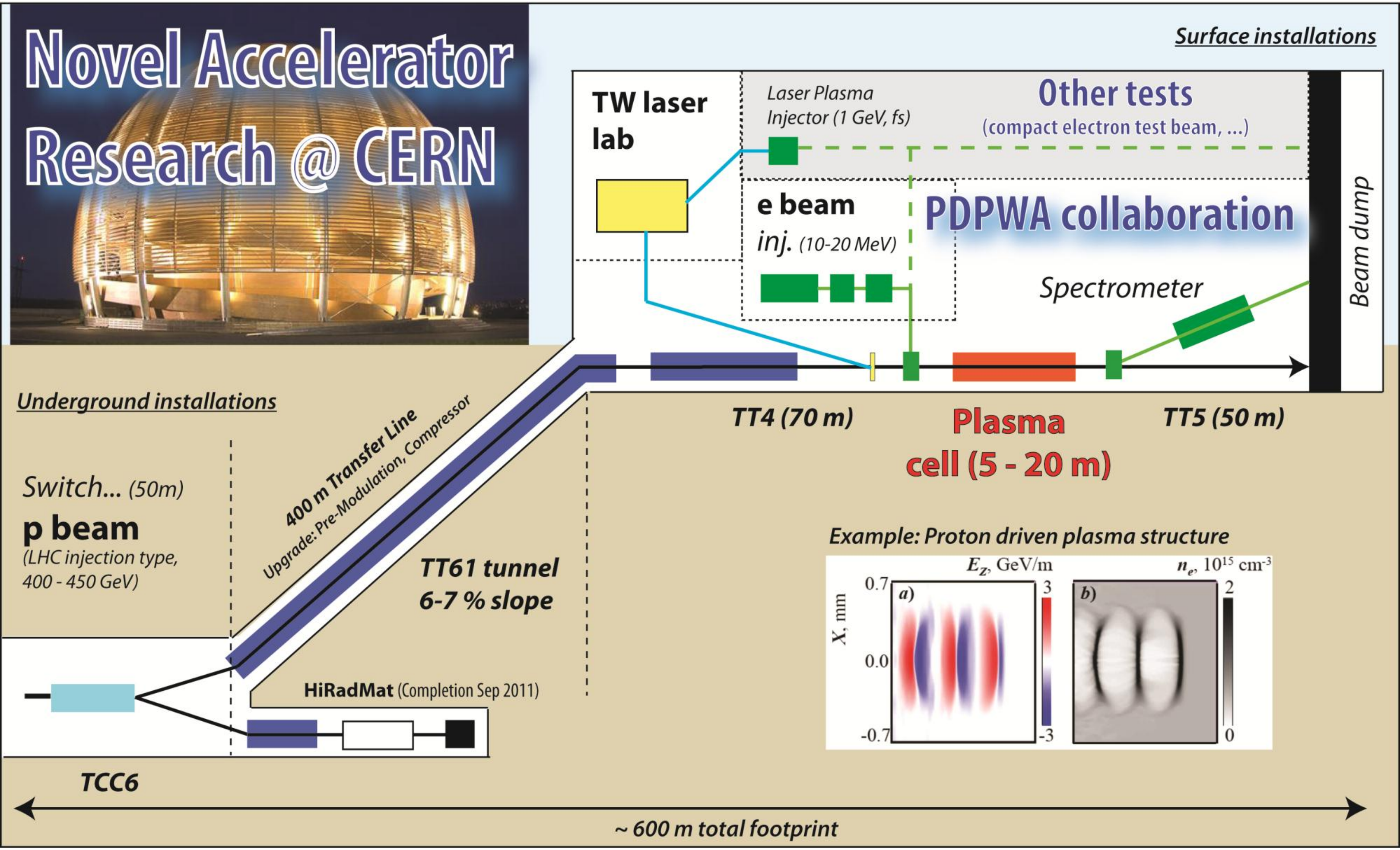
Linear Collider Topics
Should be supported by Particle Physics

CERN today….into the future

- CLIC conceptual design report by 2012
- Participation in all LC activities
- LHeC conceptual design report 2011/early2012
- R&D for high-field magnets (towards HE-LHC)
- Generic R&D (high-power SPL, Plasma Acc)

Slide from R. Heuer, DG CERN, 18 Nov 2011

p-Driven Plasma Acceleration
The First CERN Experiment



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

Use CLIC zero for Advanced Accelerator R&D?

$CLIC_{zero}$ Parameters

Parameter	Nominal value	Unit
Drive Beam Energy	480	MeV
Pulse Length	6-140/ 243.7	μs / ns
Drive Beam Current (linac)	4.2	A
Decelerator Current	101	A
Combination Factor	24	
Bunch Spacing	1.992	ns
Drive Beam Emittance	~100	mm mrad
Decelerator Bunch Length	1	mm
Repetition Rate	50	Hz
Main Beam Energy	6.5	GeV
Main Beam Current	1.2	A
Main Beam Pulse Length	156	ns
Main Beam Bunch Length	~0.5	mm
Main Beam Emittance	~30	mm mrad

S. Doebert

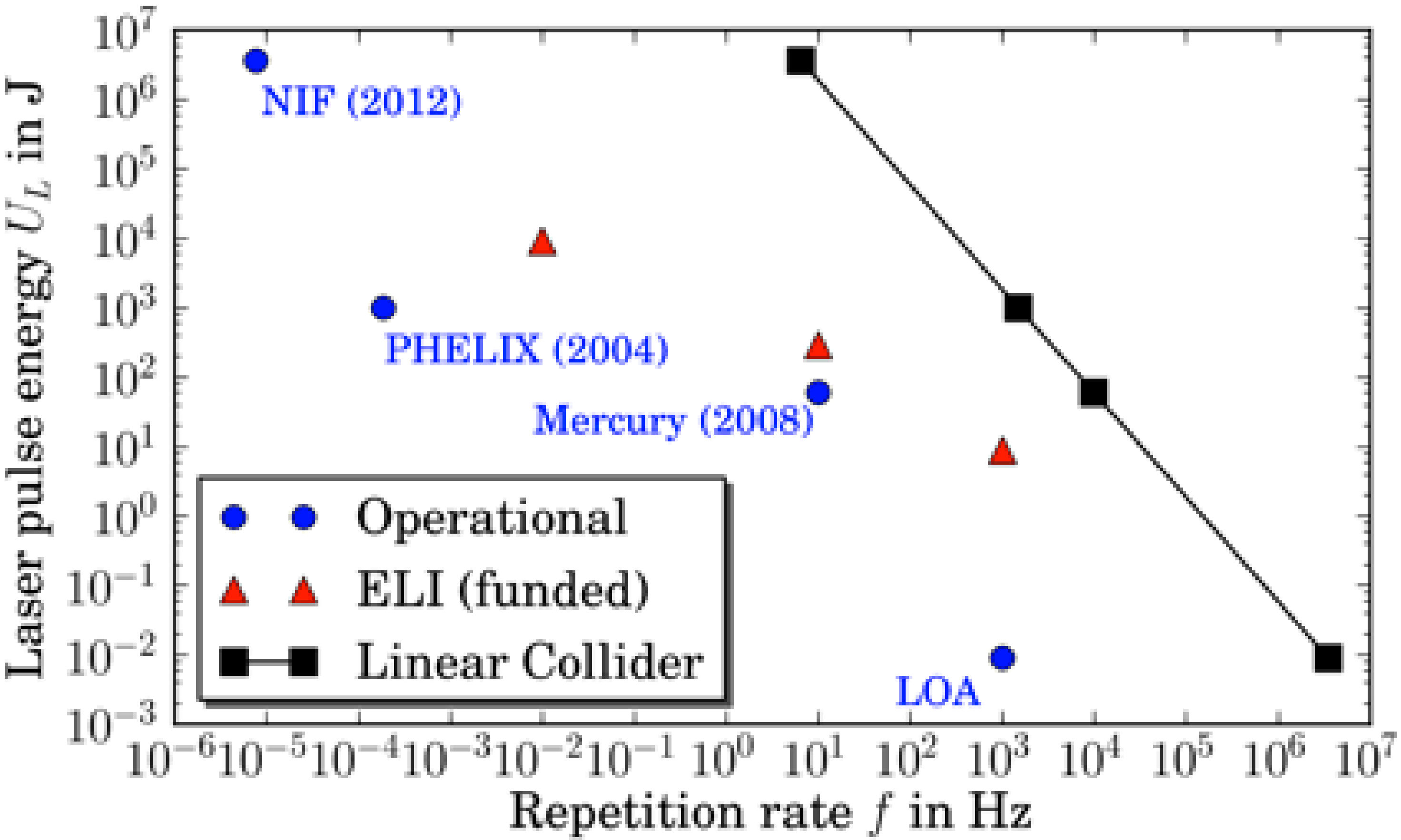
Timeline would fit…

2015 – 2020: West Area
Proton-driven plasma acceleration tests
Laser facility
Laser plasma fs injector

2020 – 2025: CLIC zero facility
CLIC zero e- beam and lasers
Laser-driven plasma booster
Injection of e+ into plasma accelerator
Polarized beams in plasmas
Electron-beam driven plasma acceleration
Power and efficiency measurements

Where would be CLIC zero located?

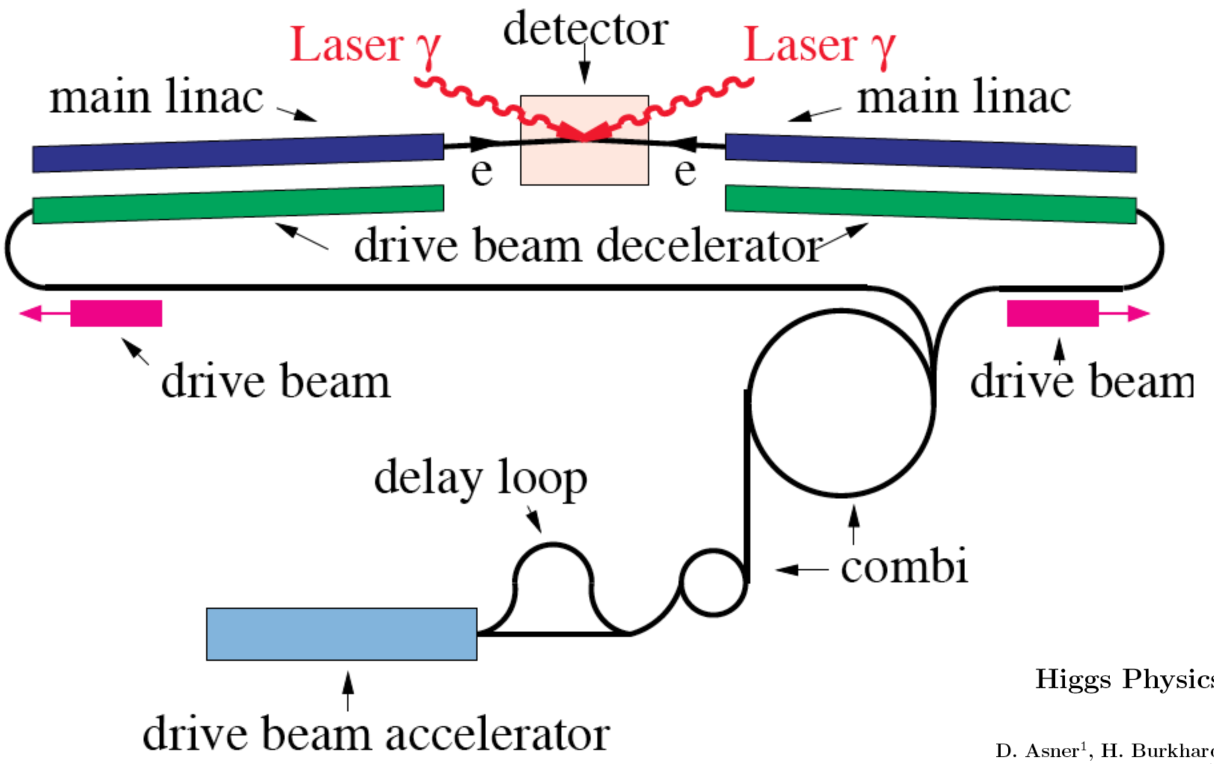
Laser Development
Work S. Hillenbrand



CLIC zero for Advanced Acceleration R&D

- The **beam energy of CLIC zero** is in the B-factory range. Physics applications?
- CLIC zero **e- beam and lasers** → $\gamma\gamma$ collider
  - Bring or copy laser lab from advanced acceleration research west area to CLIC zero. Use laser experience and know-how.
  - Requires two CLIC zeros or an SLC type arc at the end of linac.
  - Laser parameters not really the same
  - Energy of main beam too low
  - Looks unlikely to me…
- CLIC zero could be used to **focus on HEP collider advanced accelerator R&D issues**.
  - Nobody might do it otherwise.
  - **Real benefit to drive accelerator technology for HEP!**

A CLIC zero γγ Collider?



E_{beam} = 75 GeV at CLIC1

versus

6.5 GeV at CLIC zero

BNL-HET-01/32
CERN/PS Note-2001-062 (AE)
CERN-SL/2001-055 (AP)
CERN-TH/2001-235
CLIC-Note 500
NUHEP-EXP/01-050
UCRL-JC-145692

Higgs Physics with a $\gamma\gamma$ Collider Based on CLIC 1

D. Asner[1], H. Burkhardt[2], A. De Roeck[2], J. Ellis[2], J. Gronberg[1], S. Heinemeyer[3], M. Schmitt[4], D. Schulte[2], M. Velasco[4] and F. Zimmermann[2]

Figure 1: *Schematic sketch of a layout for a $\gamma\gamma$ collider based on CLIC 1.*

Laser beam parameters		
Wavelength	λ_L	0.351 μm
Photon energy	$\hbar\omega_L$	3.53 eV = 5.65×10^{-19} J
Number of laser pulses per second	N_L	169400 s^{-1}
Laser peak power	W_L	2.96×10^{22} W/m^2
Laser peak photon density		5.24×10^{40} photons/m^2/s

CLIC zero for Advanced Acceleration R&D

- Requirements:
  - **Bunch compression** to ~30 micron bunch length for main or drive beam
- Wishes (typical collider requirements):
  - **Polarized e- beam**
  - **Positron source**
- Laser-driven plasma booster:
  - Inject main beam into laser-driven plasma booster: 6.5 → 20+ GeV?
  - Several stages to reach physics potential?
- Injection of e+ into laser-driven plasma accelerator
  - Basic R&D to develop positron acceleration technology
- Once it works we can dream:
  - Design LC with CLIC zero at 6.5GeV, ultra-compact SLC-type arcs for e+e-
  - Short plasma boosters at the end of each compact arc
  - Test collider cases: Z, Higgs, …

CLIC zero for Advanced Acceleration R&D

- Polarized beams in plasmas
  - Basic R&D on polarized beam transport in plasmas
- Power and efficiency measurements
  - Measure power
  - Characterize efficiency of advanced acceleration in detail
  - Optimize efficiency (use of ICAN laser technology, …)
- Electron-beam driven plasma acceleration
  - Inject electrons as short drivers into plasma cells
  - Use excited wakefields to accelerate a witness bunch from CLIC zero or laser plasma injector
  - Can the drive or main beam be used to more efficiently drive the plasma wakefields?

Conclusion

- Plasma accelerator R&D is presently driven by steep developments in laser science.
- The field is rapidly growing with many accelerator labs joining and funding agencies pushing for a concerted effort.
- Believe is that laser-driven compact beam and light sources for medicine and photon science are achievable and in reach.
- There are many HEP specific R&D problems. Support by HEP is crucial to make sure that these issues are developed.
- CLIC zero can be the test facility to test many of these issues. Requires bunch compression, positrons and maybe polarization.
- One can dream about plasma boosting CLIC zero to higher energies with compact e+e- arcs. Feasibility would require further work!

Invitation…

- We have started planning for the **1st European Advanced Accelerator Conference (EAAC)**
- Will take place in Summer 2013
- Two candidate locations have volunteered, to be decided
- Should bring together advanced and conventional accelerator physicists:
  - We hope that linear collider experts will be well represented
  - CLIC colleagues are particularly welcome
  - Will also cover advanced RF structure developments, like the AAC does (e.g. dielectric structures)

Reserve Slides

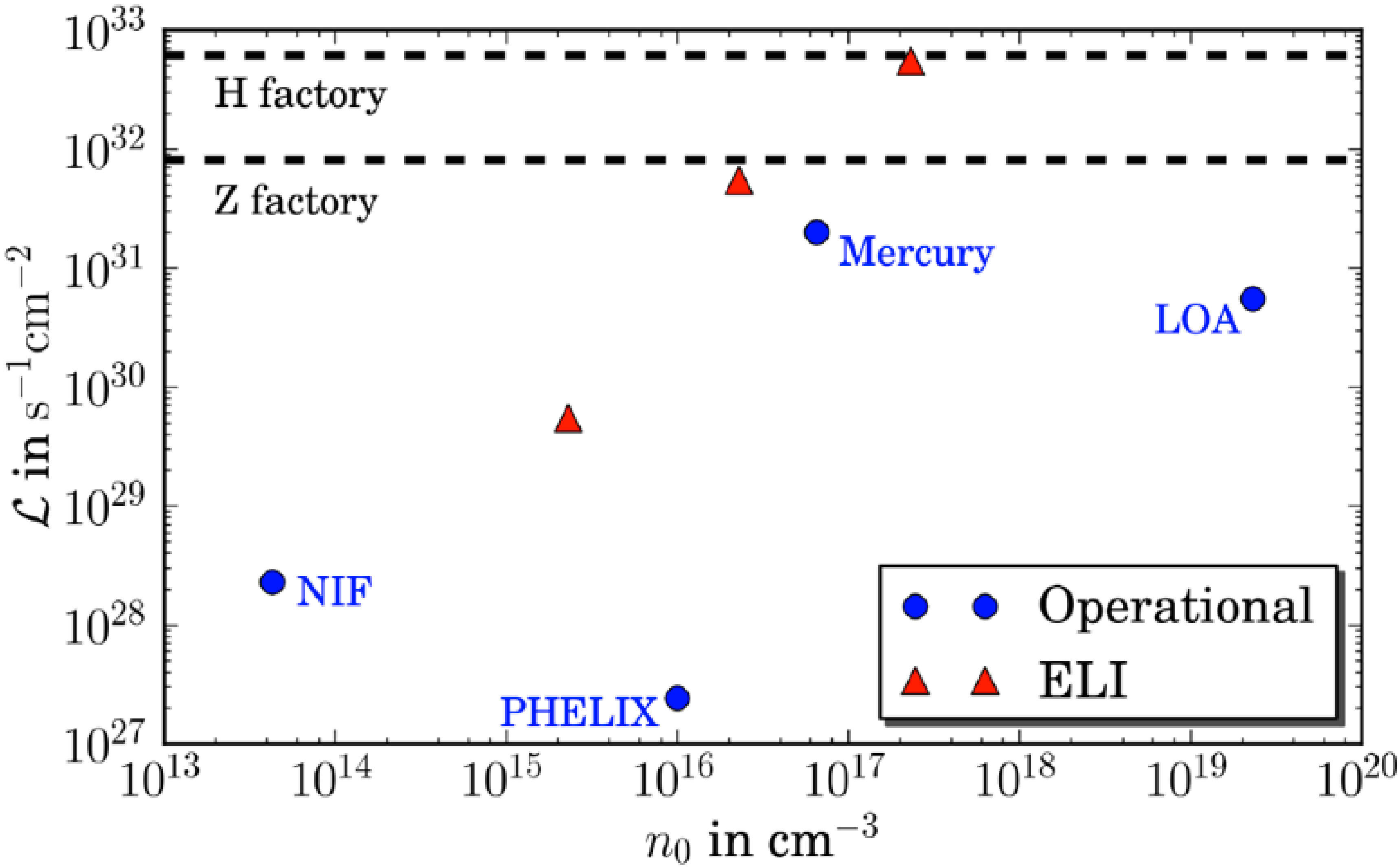
S. Hillenbrand: LC and Lasers

Assuming bunch energy E_b = 500 GeV and sigma_x* = sigma_y* = 10nm
For Luminosity L = 2e34 /cm^2s, laser wavelength of 1um

		NIF	PHELIX	Mercury	LOA	ELI	ELI	ELI
plasma electron density	n_0 [1/cm^3]	4.30E+013	1.00E+016	6.50E+016	2.32E+019	2.30E+015	2.30E+016	2.33E+017
particles per bunch	N_bunch [1e9]	192.9	12.6	5.0	0.3	26.4	8.3	2.6
Energy gain per stage	W_stage [GeV]	23255.8	100.0	15.4	0.0	434.8	43.5	4.3
Number of stages	N_stages	1	5	33	11600	2	12	117
Laser energy per stage	U_L [J]	3588783.8	1011.93	61.1	0.0091	9174.0	290.1	9.0
avg laser power per stage	P_avg [kW]	23147.7	1517.9	595.4	31.5	3165.0	1000.9	314.5
collision frequency	f [kHz]	0.00645	1.5	9.75	3480	0.345	3.45	34.95
total wall-plug power	P_wall [MW]	3.3	50.6	129.0	2437.0	24.3	76.7	244.2
laser pulse duration	tau_laser [fs]	2700.6	177.1	69.5	3.7	369.3	116.8	36.7
beam power	P_beam [MW]	0.1	1.5	3.9	73.1	0.7	2.3	7.3
Beamstrahlung parameter	Y	8680.4	569.2	223.3	11.8	1186.9	375.3	117.9
Length of single stage	L_stage [m]	112149.5	31.6	1.9	0.0	286.7	9.1	0.3
total lincac length (1 arm)	as in scaling	224299.0	316.2	125.9	6.6	1146.7	217.6	65.8
	0m for coupling	112149.5	158.1	63.0	3.3	573.4	108.8	32.9
	5m for coupling	112154.5	183.1	228.0	58003.3	583.4	168.8	617.9
	10m for coupling	112159.5	208.1	393.0	116003.3	593.4	228.8	1202.9
	25m for coupling	112174.5	283.1	888.0	290003.3	623.4	408.8	2957.9
		2.28E+28	2.3557E+27	1.959E+31	5.4885E+30	5.5363E+29	5.5363E+31	5.465E+32

Required parameters for a luminosity of 2*10^34 cm^-2s^-1, based on the plasma density.
Facilities with corresponding laser pulse energy are listed above.
Resulting Luminosity when using the real repetition rate of the facilities listed above.

S. Hillenbrand: LC and Lasers



S. Hillenbrand: LC and Lasers

Figure 2.2: Achievable luminosity $\mathcal{L}$ versus plasma electron density n_0 based on laser pulse energy and repetition rate of exemplary high power laser facilities [90,93, 96,97,104,105]. Plasma density and number of particles per bunch were calculated from the pulse energy via the scalings in [1] (here, it has been assumed the pulse length can be adjusted accordingly and that enough modules are staged to reach the desired final energy). A spot size at the collision point of $\sigma_x^* = \sigma_y^* = 10\,\text{nm}$ has been assumed. The broken horizontal lines denote the luminosity requirements for a Higgs / Z-boson factory, as given by the scaling $\mathcal{L}[10^{34}\,\text{cm}^{-2}\text{s}^{-1}] \approx E[\text{TeV}]^2$ [79]. A full scale linear collider would require a luminosity in excess of $10^{34}\,\text{s}^{-1}\text{cm}^{-2}$. Also see figure 2.1, tables 2.1 and 2.2, as well as chapters 3.2 and 3.3.1.

Research Topics I

- External optical injection
  - Create a particle beam with laser-driven plasma source
  - Inject into a laser-driven plasma accelerator
  - Characterize final beam energy, quality, …
  - 12 Star
- External RF injection
  - Create a particle beam with an RF injector
  - Inject into a laser-driven plasma accelerator
  - Characterize final beam energy, quality, …
  - 11 Star
- Laser wakefield acceleration (LWFA) with self injection
  - Create a particle beam with laser-driven plasma source
  - Maximize energy and/or charge
  - 15 Star

Research Topics II

- Multi-stage LWFA
  - Similar to external optical injection
  - A generic stage of laser-driven wakefield acceleration
  - 8 star
- Synchrotron radiation with advanced beams
  - Transport beam from plasma injector
  - Use to generate synchrotron radiation in classical undulators
  - 13 star
- Electron beam driven PWFA
  - Use an electron beam to drive plasma wakefields
  - Test with external injection of beam
  - 5 star

Research Topics III

- Proton beam driven PWFA
  - Use a proton beam to drive plasma wakefields
  - Test with external injection of beam
  - 2 star
- Betatron radiation in plasma
  - Off-axis oscillations of electrons within plasma wakefields
  - Use and manipulate this process to generate synchrotron radiation
  - Possibility for ultra-compact radiation sources (injector + transport + undulator within plasma cell)
  - 14 star
- Plasma undulator
  - External off-axis injection into a plasma wakefield stage
  - 5 star

Research Topics IV

- Stability and beam quality
  - Measure, characterize, optimize advanced beams
  - 19 star
- Polarized beams in plasmas
  - Transport of polarized beams in plasmas
  - 0 star
- Positron acceleration
  - Acceleration and transport of positrons in plasma accelerators
  - 0 star
- Femto-second synchronization
  - Set up of femto-second timing and synchronization systems
  - Cross synchronization between multiple particle and laser beams
  - 14 star

Access to Facilities

- Condition of access
  - User, Comm: User facility with defined access conditions. Selection by a committee at the facility.
  - Collaboration: Access by joining an existing collaboration at the facility.
  - Laser Lab: Access through the Laser Lab Program

Other Experiments @CERN?

- Laser-driven plasma linear accelerators.
- Test of a plasma beam dump for proton and linear collider beams.
- Test of energy recovery from plasma beam dumps (idea T. Tajima and A. Chao).
- Second plasma source on surface for acceleration. Inject e-beam into first or second plasma source. Second plasma as acceleration stage.
- Second plasma source in tunnel for seeding. Use correlated energy spread after plasma for micro-bunch generation (compression).

Laser-Driven Compact Test Beam Accelerator for HEP?

- Idea: Build **compact test beam accelerator (CTBA)** for HEP.
  - Beam energy: 1 GeV (10 GeV later)
  - Energy spread: 1 – 0.1%
  - Rate: as low as possible (single electrons)
  - Repetition freq: ~ kHz
- Make it operational: 24h operation, 7/7, stable
- Accelerate with proton-driven plasma accelerator as 2nd stage.
- Copy, distribute the CTBA to HEP labs. In house detector tests…
- With two CTBA's:
  - Test collisions
  - Final test and proof of stability
- Lots of synergy with photon science efforts!
- Needs work on design, cost, dimensions, …

Laser-Driven Electron Injector for HEP, e.g. for LHeC or LEP3?

- Idea: Investigate use laser-driven plasma linac as injector to future HEP projects. Build prototype injector.
- Advantages: Start with a low energy linac. Requirements much more relaxed than a full linear collider. Demonstrate feasibility and cost savings.
- The LHeC collider is under study at CERN: Put electron ring on top if LHC for generating e-p collisions. (ring-ring concept). Alternative: linac – ring collider. Could come in 10-15 years.
- Look at ring-ring parameters, as an example:
  - Electrons per bunch: 2.6e10
  - Electron energy: 10 GeV
  - Norm. trans. emittance: 0.6 mm-rad

Towards Plasma Linear Colliders

- Plasma linear colliders are not around the corner but will be result of a sustained R&D effort over many years.
- It is important to define a roadmap with early applications along the path (e.g. HEP test beam accelerators, injectors, synchrotron radiation).
- Natural collaboration between HEP lab and synchrotron light labs!
- We are forming the EuroNNAc network for this.
- Ideas how to make use of advanced accelerators in the near term are emerging. We will further pursue these ideas and plan to propose pilot facility(ies).