

de recherche Blaise Pascal

Financée par l'État et la Région d'Ile de France, gérée par la Fondation de l'École Normale Supérieure International Bridgelab Symposium for Laser Acceleration: Route toward Reality Frifayday, Jan.14, 2011 L'Orme des Merisiers, CEA Gif sur Yvette

## Bridgelab: Introduction

Toshiki Tajima LMU,MPQ, Garching and Blaise Pascal Chair, Fondation Ecole Normale Supérieure Institut de Lumière Extrême

Acknowledgments for Collaboration and advice: G. Mourou, W. Leemans, C., Barty, C. Labaune, P. Chomaz, D. Payne, H. Videau, P. Martin, V. Malka, , F. Krausz, T. Esirkepov, S. Bulanov, M. Kando, W. Sandner, A. Suzuki, M. Teshima, X. Q. Yan, B. Cros, J. Chambaret, W. Leemans, E. Esarey, R. Assmann, R. Heuer, A. Caldwell, S. Karsch, F. Gruener, M. Zepf, M. Somekh, E. Desurvire, D. Normand, J. Nilsson, W. Chou, F. Takasaki, M. Nozaki, K. Yokoya, D. Payne, S. Chattopadhyay, K. Nakajima, P. Bolton, E. Esarey, S. Cheshkov, C. Chiu, M. Downer, C. Schroeder, J.P. Koutchouk, K. Ueda

#### Livingston Chart and Recent Saturation



(http://tesla.desy.de/~rasmus/media/Accelerator%20physics/slides/Livingston%20Plot%202.html)



V. Yakimenko (BNL) and R. Ischebeck (SLAC), AAC2006 Summary report of WG4



#### **Brief History of ICUIL – ICFA Joint Effort**

- ICUIL Chair sounded on A. Wagner (Chair ICFA) and Suzuki (incoming Chair) of a common interest in laser driven acceleration, Nov. 2008
- Leemans appointed in November 2008 to lay groundwork for joint standing committee of *ICUIL*
- ICFA GA invited Tajima for presentation by ICUIL and endorsed initiation of joint efforts on Feb. 13, 2009
- ICFA GA endorsed Joint Task Force, Aug. 2009
- Joint Task Force formed of ICFA and ICUIL members, W.
   Leemans, Chair, Sept, 2009
- First Workshop by *Joint Task Force* held @ GSI, Darmstadt, April, 2010
- Report to ICFA GA (July,2010) and ICUIL GA (Sept, 2010) on the findings

# *'World Lab' (Bridgelab)* goal = Put *SLAC* on a football field

Initiatives considered, emerging: ILE; CERN; KEK; LBL, DESY,...



#### SLAC's 2 mile linac (50GeV)



#### Laser acceleration =

- no material breakdown (→ 3/4 orders higher gradient); however:
- 3 orders finer accuracy, and
  2 orders more efficient laser needed

## Mountain of Lasers (average power)



rate

### **Range of laser parameters**

![](_page_7_Picture_1.jpeg)

# Activities around the Workshop

Joint workshop on laser technology for future colliders

- Planning by Barty, Leemans and Sandner (prior to WS)
- Convene international panel of experts on laser technology
- Create a comprehensive survey of the requirements: laser based light and particle sources; require lasers beyond the state of the art.

-colliders, γγ collier, X-ray sources, hadron therapy, H<sup>-</sup> stripping

- Identify future laser system requirements
  - Identify <u>key technological bottlenecks</u>
  - No downselection; inclusive approach
- Visions for technology paths forward survey goals and required laser technology R&D steps/roadmaps (action on going!)
  - Write technical report

Joint Task Force Workshop:

GSI, Darmstadt, April 8-10, 2010, hosted by I. Hoffmann

#### Main challenges for laser driven accelerators

- Phase space quality and control of e-beam
- Staging of modules/structures
  - Pointing alignment tolerances
  - In- and out-coupling of high power beams
- Power handling inside structures:
  - Can they survive?
  - How can we extract as much laser energy as possible into e-beam so that energy leaves structure at speed of light?
- Repetition rate for plasma based schemes:
  - Can we handle gas and plasma production at >10 kHz rep rates?
- Can we avoid the use of conventional magnets?
  - Would be big cost saving in construction and operation
  - etc.

However, most glaringly,

#### Needs of <u>high average-power</u>, <u>high efficiency</u>, <u>high rep-rate</u> laser technologies: Candidates identified =

slab laser; thin disk laser ; fiber laser

W. Leemans(2010)

# Suggestions to ICFA-ICUIL JTF

- <u>Science efforts</u> by US, Europe, Asia mounting to extend the laser technology toward HEP accelerators
- Technology efforts <u>still lacking</u> in developing suited laser technology(ies) for HEP accelerators
- Technologies: emerging and credible for these
- ICFA-ICUIL collaboration: important guide of direction
- Lead lab(s) necessary to lead and do work on this initiative
- World Test Facility ('Bridgelab')?
- Other applications important (light sources, medical, nuclear waste management, fusion, defense, etc.)

( Tajima; April 10, 2010)

### Laser driven collider concept

![](_page_11_Figure_1.jpeg)

ICFA-ICUIL Joint Task Force on Laser Acceleration(Darmstadt, 10)

![](_page_12_Picture_0.jpeg)

## ICFA-ICUIL Joint Task Force

on laser acceleration (Darmstadt, 2010)

![](_page_12_Picture_3.jpeg)

	_	·		
Case	1 TeV	10 TeV (Scenario I)	10 TeV (Scenario II)	
Energy per beam (TeV)	0.5	5	5	
Luminosity (10 <sup>14</sup> cm <sup>-2</sup> s <sup>-1</sup> )	1.2	71.4	71.4	
Electrons per bunch (×10 <sup>9</sup> )	4	4	13	
Bunch repetition rate (kHz)	13	17	170	
Horizontal emittance yes (nm-rad)	700	200	200	
Vertical emittance ys, (nm-rad)	700	200	200	
D* (mm)	0.2	0.2	0.2	
Horizontal beam size at IP $\sigma^*_{s}$ (nm)	12	2	2	
Vertical beam size at IP $\sigma_y^*(nm)$	12	2	2	
Luminosity enhancement factor	1.04	1.35	1.2	
Bunch length $\sigma_i$ (µm)	1	1	1	
Beamstrahlung parameter T	148	8980	2800	
Beamstrahlung photons per electron n <sub>7</sub>	1.68	3.67	2.4	
Beamstrahlung energy loss $\delta_E$ (%)	30.4	48	32	
Accelerating gradient (GV/m)	10	10	10	
Average beam power (MW)	4.2	54	170	
Wall plug to beam efficiency (%)	10	10	10	
One linac length (km)	0.1	1.0	0.3	

W. Leemans, Chair of JTF

> Collider subgroup List of parameters (W. Chou)

Table 1 Collider parameters

## Laser requirements for such colliders

![](_page_13_Picture_1.jpeg)

Case	1 TeV	10 TeV (Scenario I)	10 TeV (Scenario II)
Wavelength (µm)	1	1	1
Pulse energy/stage (J)	32	32	1
Pulse length (fs)	56	56	18
Repetition rate (kHz)	13	17	170
Peak power (TW)	240	240	24
Average laser power/stage (MW)	0.42	0.54	0.17
Energy gain/stage (GeV)	10	10	1
Stage length [LPA + in-coupling] (m)	2	2	0.06
Number of stages (one linac)	50	500	5000
Total laser power (MW)	42	540	1700
Total wall power (MW)	84	1080	3400
Laser to beam efficiency (%) [laser to wake 50% + wake to beam 40%]	20	20	20
Wall plug to laser efficiency (%)	50	50	50
Laser spot rms radius (µm)	69	69	22
Laser intensity (W/cm <sup>2</sup> )	$3 \times 10^{18}$	$3  imes 10^{18}$	$3  imes 10^{18}$
Laser strength parameter $a_0$	1.5	1.5	1.5
Plasma density (cm <sup>-3</sup> ), with tapering	1017	1017	10 <sup>18</sup>
Plasma wavelength (µm)	105	105	33 14

![](_page_14_Picture_0.jpeg)

#### JTF Report #3: Comparison of Choices

![](_page_14_Picture_2.jpeg)

Accelerator	Beam	Beam energy (GeV)	Beam power (MW)	Efficiency AC to beam	Note on AC power
PSI Cyclotron	H+	0.59	1.3	0.18	RF + magnets
SNS Linac	H-	0.92	1.0	0.07	RF + cryo + cooling
TESLA (23.4 MV/m)	e*/e-	250 × 2	23	0.24	RF + cryo + cooling
ILC (31.5 MV/m)	e <sup>+</sup> /e <sup>-</sup>	250 × 2	21	0.16	RF + cryo + cooling
CLIC	e <sup>+</sup> /e <sup>-</sup>	1500 × 2	29.4	0.09	RF + cooling
LPA	e <sup>+</sup> /e <sup>-</sup>	500 × 2	8.4	0.10	Laser + plasma

# Areas of improvement in LPA performance for various applications

	THz	X-rays (betatron)	FEL (XUV)	Gamma- rays	FEL (X-rays)	Collider
Energy		1	1	1	1	ተተ
ΔF/E	) <	1	¥	¥	$\mathbf{v}\mathbf{v}$	$\mathbf{v}\mathbf{v}$
3	1	<b>√</b>	1	1	1	$\mathbf{v}\mathbf{v}$
Charge	1	1	1	1		1
Bunch duration	1	<ul> <li>Image: A second s</li></ul>	1	<ul> <li>Image: A second s</li></ul>	<ul> <li>Image: A second s</li></ul>	<ul> <li>Image: A second s</li></ul>
Avg. power	1	1	1	1	1	<b>†</b> †

: OK as is
: increase needed

↓: decrease needed

#### Laser development crucial for success of field

- Key challenges for high peak/ultrafast laser technology •
  - Reliable turn-key operation: much progress in past 5 years but still ways to go
  - Low cost systems: \_
    - Driver for GeV module: commercial 30 W (10 Hz), 100 TW system ~ \$1.5 M (FY09)
    - High energy pump laser price has dropped from ~\$75K/J in FY01 to ~\$30K/J in FY10 (factor 3 lower, accounting for inflation)
    - Laser diode price drops 15% / yr, heads toward 10c/W over 20yrs. (G. Bonati LTJ(2010)
  - Average power:
    - Need 1-100 kW and even near MW-class high peak power lasers
    - Requires diodes, ceramics, fibers, etc...
- Many science communities need it (colliders, light sources, fusion, nuclear waste ٠ management) as well as medical and defense apps 17

#### Main challenges for laser technology

W. Leemans (2010)

- High average power:
  - Light sources kW to 10 kW class
  - Colliders 100MW class (wall plug power), 15kHz
  - $-\gamma\gamma$  collider- 1kW , 15kHz
  - Medical 1kW, 10Hz
- Short pulse:
  - Light sources few fs to ps
  - Colliders 100-300 fs pulses
  - Medical 30-300fs
- Contrast, spatial and temporal profiles
- Handling of enormous average power:
  - 0.1% loss in mirror is 600 W at 600 kW incident power
  - Cooling requirements; adaptive optics; beam dumps; etc...

# **Conclusions at Darmstadt**

- 1. Requirements identified for various HEP-related applications: colliders, γγ collider, X-ray sources, H<sup>-</sup> stripping, hadron therapy
- 2. Bottlenecks identified:
  - laser driver technology at high average power, high reprate, high efficiency
- 3. Technology candidates identified:
  - slab laser; thin disk laser; fiber laser
    needs long-ranged (> 10 years)basic research and development
    necessary
  - needs accelerator centers' guidance and 'lead labs' (newtworking) laser community's directed work
  - roadmap of development of candidate technologies needed
- 4. Technologies relevant to applications: broader than collider technological marriage possible (e.g. LWFA and telecom)
- 5. Scientific proof-of-principle at HEP relevant energies needed *'world test facility'* at level of 100GeV-----*Bridgelab today!*
- 6. Challenges are tall, but *no showstoppers* found
- 7. There other areas of fundamental physics laser can assist
- 8.. Long-raged collaborative/complementary relation necessary between<sup>19</sup> ICFA and ICUIL

![](_page_19_Figure_0.jpeg)

G. Mourou (2005)

# The bottleneck in high-power lasers is the average power !

### "Beyond Petawatt means Kilowatt"

W. Sandner (2010)

![](_page_20_Picture_3.jpeg)

**Proposed Study:** 

#### ICAN, International Coherent Amplification Network "Solving the efficiency problem in high peak and high average power laser: an international effort" (Coordinator G. Mourou, submitted to the EU November 25, 2010)

## Fiber vs. Bulk lasers

- High Gain fiber amplifiers allow ~ 40% total plug-to-optical output efficiency
- Single mode fiber amplifier have reached multi-kW optical power.
- large bandwidth (100fs)
- immune against thermo-optical problems
- excellent beam quality
- efficient, diode-pumped operation
- high single pass gain
- They can be mass-produced at low cost.

![](_page_22_Picture_9.jpeg)

![](_page_23_Figure_0.jpeg)

## 150 MW Fiber bundle

Because the transport fibers are lossless they will be assembled in a bundle just before the focusing optics. They will be all coherently phased.

![](_page_24_Figure_2.jpeg)

![](_page_25_Picture_0.jpeg)

- Science of LWFA (US, Europe, Asia) matured to extend toward HEP accelerators
- Laser technology lacking suited for HEP accelerators: laser efficiency, average power
- Technologies to rectify emerging and credible:
   1. thin disk; 2. ceramic; 3. fiber laser
- ICFA(Suzuki: chair)-ICUIL (Tajima: chair) collaboration: important guide of direction

( JTF: Joint Task Force)

![](_page_26_Picture_0.jpeg)

Centaurus A:

cosmic wakefield linac?

#### **Merci Beaucoup!**