Chaires internationales de recherche Blaise Pascal

Financée par l'État et la Région d'Ile de France,
gérée par la Fondation de l'École Normale Supérieure

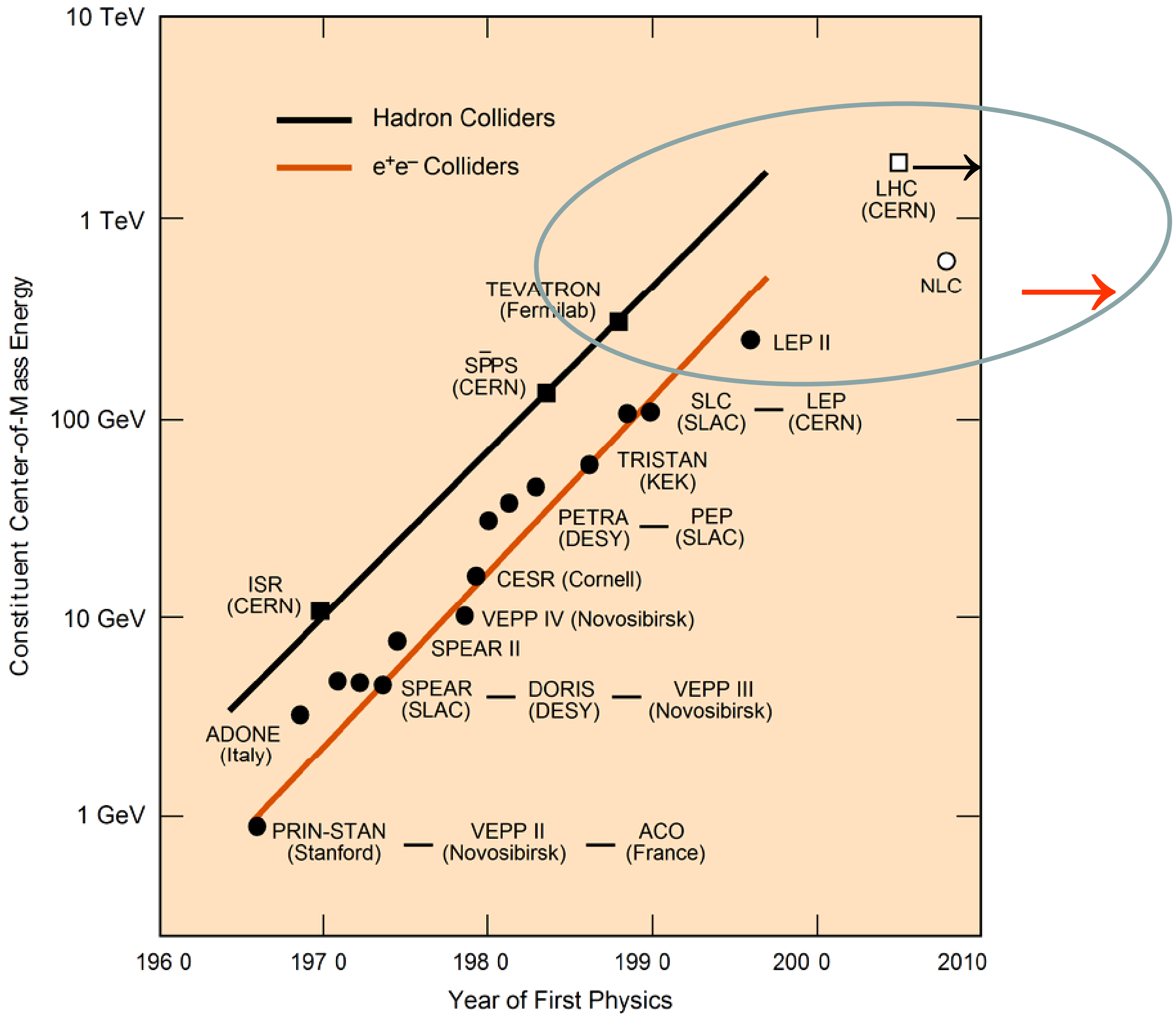
International Bridgelab Symposium
for Laser Acceleration: Route toward Reality
Frifayday, Jan.14, 2011
L'Orme des Merisiers, CEA
Gif sur Yvette

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, J.E.Chen

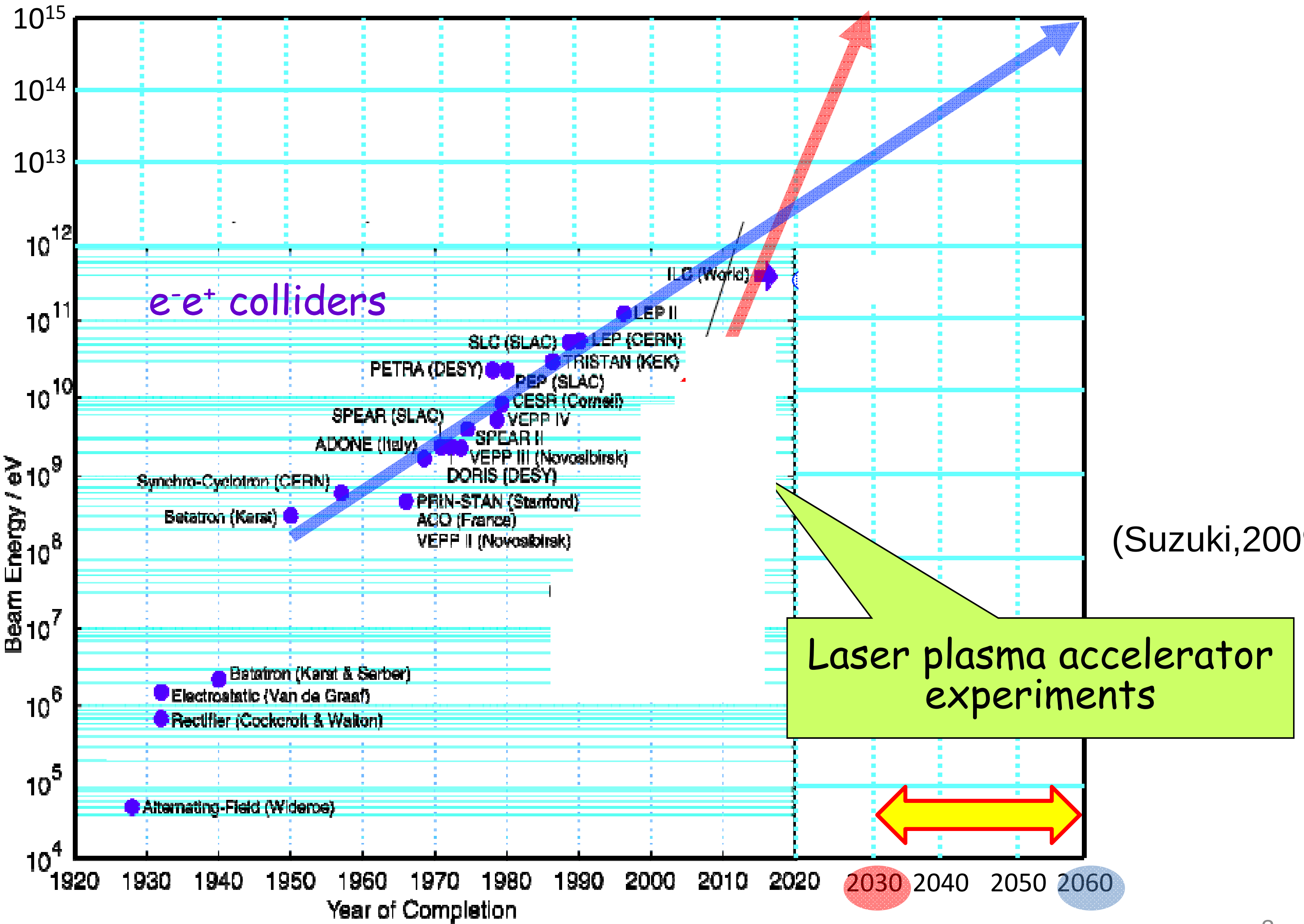
Livingston Chart and Recent Saturation



(Suzuki, 2009)

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

When can we reach 1 PeV ?: Suzuki Challenge



(Suzuki,2009)

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

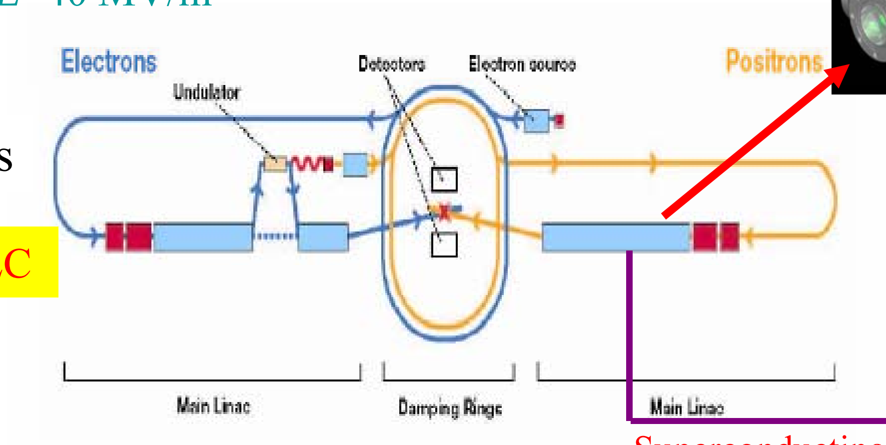
Accelerator

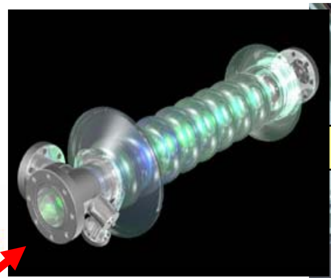
Evolution of Accelerators and their Possibilities (Suzuki,2008)

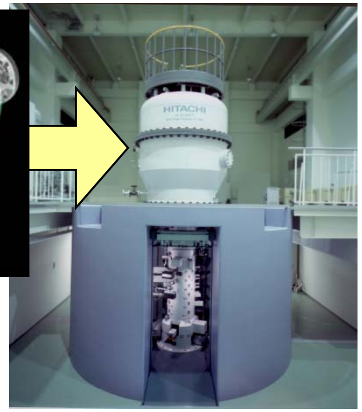
2020s

ILC

E=40 MV/m

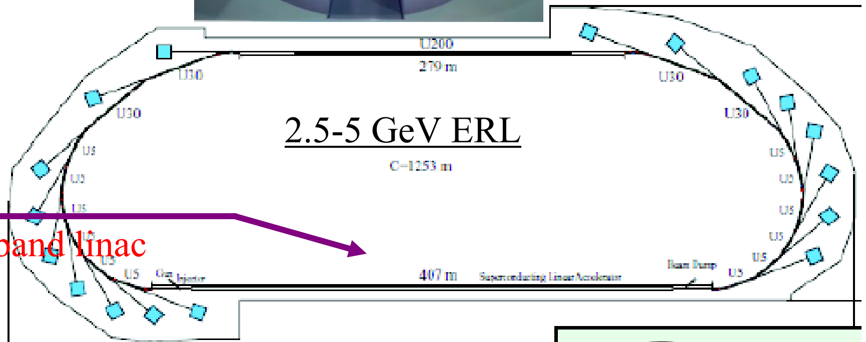






Ultra-High Voltage STEM with Superconducting RF cavity

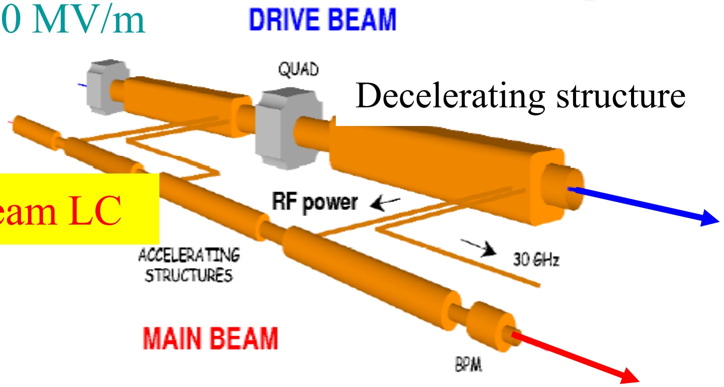
Superconducting L-band linac

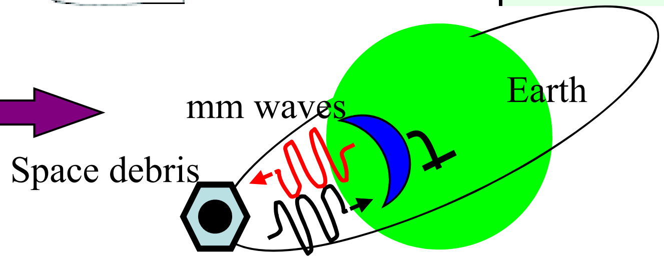


2030s

Two-beam LC

E=200 MV/m





Earth-based space debris radar

2040s

Laser-plasma LC

E=10 GV/m

10cm-10GeV Plasma Channel Accelerator

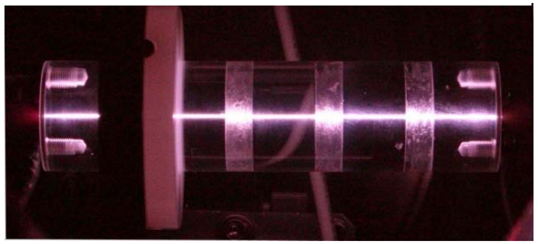


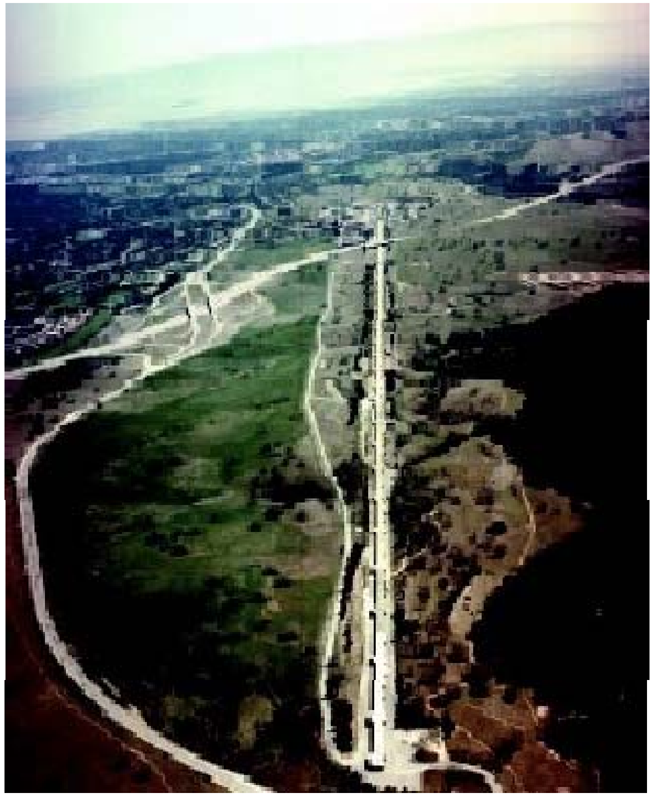
Table-top high energy accelerator

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,…*



→

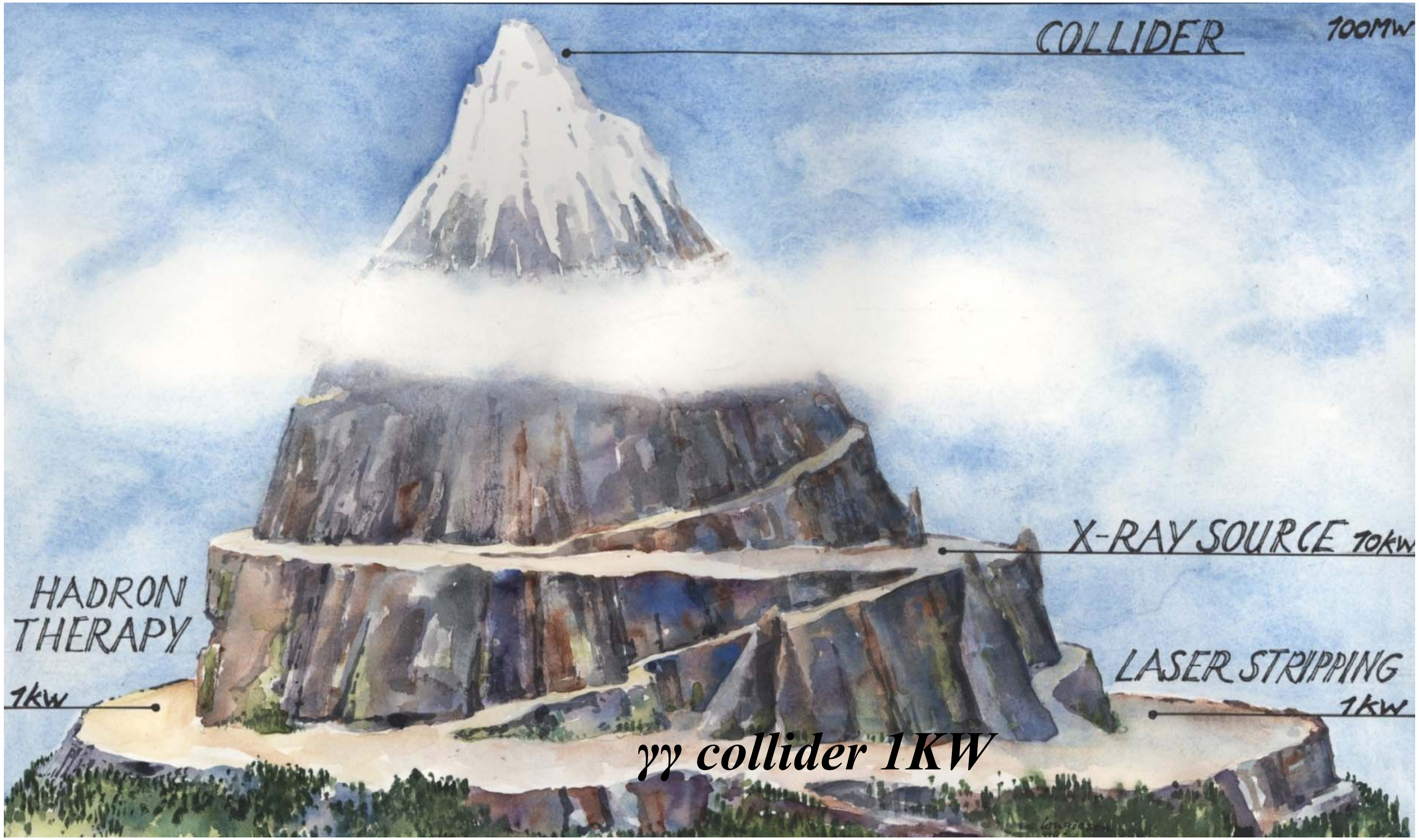
***SLAC*'s 2 mile linac**
(50GeV)

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)



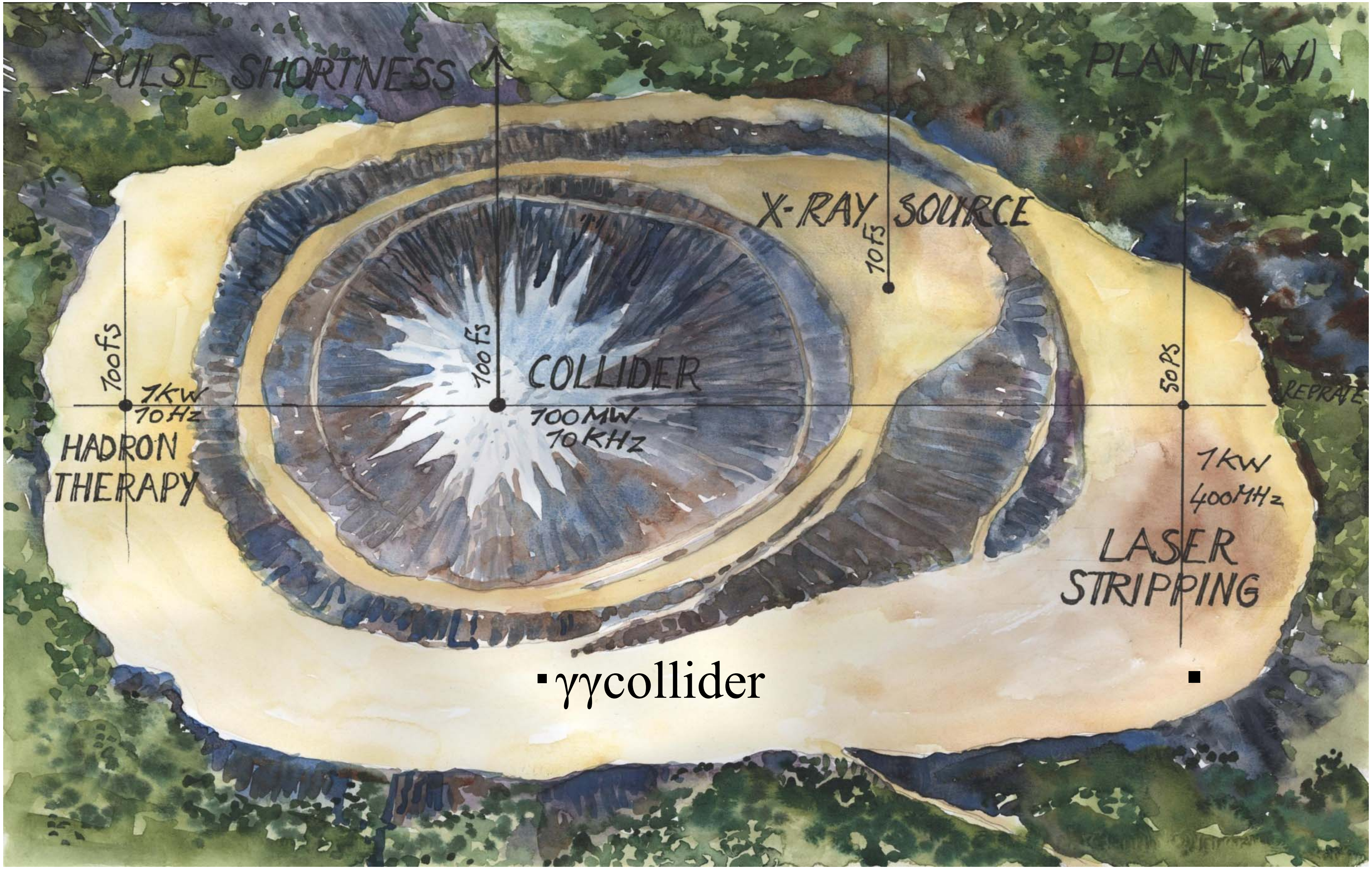
↑ average power

→ rep rate

→ pulse shortness

(HEP Examples from *ICFA-ICUIL* JTF)
Friday 6pm Rochester: open JTF

Range of laser parameters



- γγcollider
-

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, $\gamma\gamma$ collier, X-ray sources, hadron therapy, H^- stripping
- Identify future laser system requirements
  - Identify key technological bottlenecks
  - 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

W. Leemans(2010)

- 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 =**

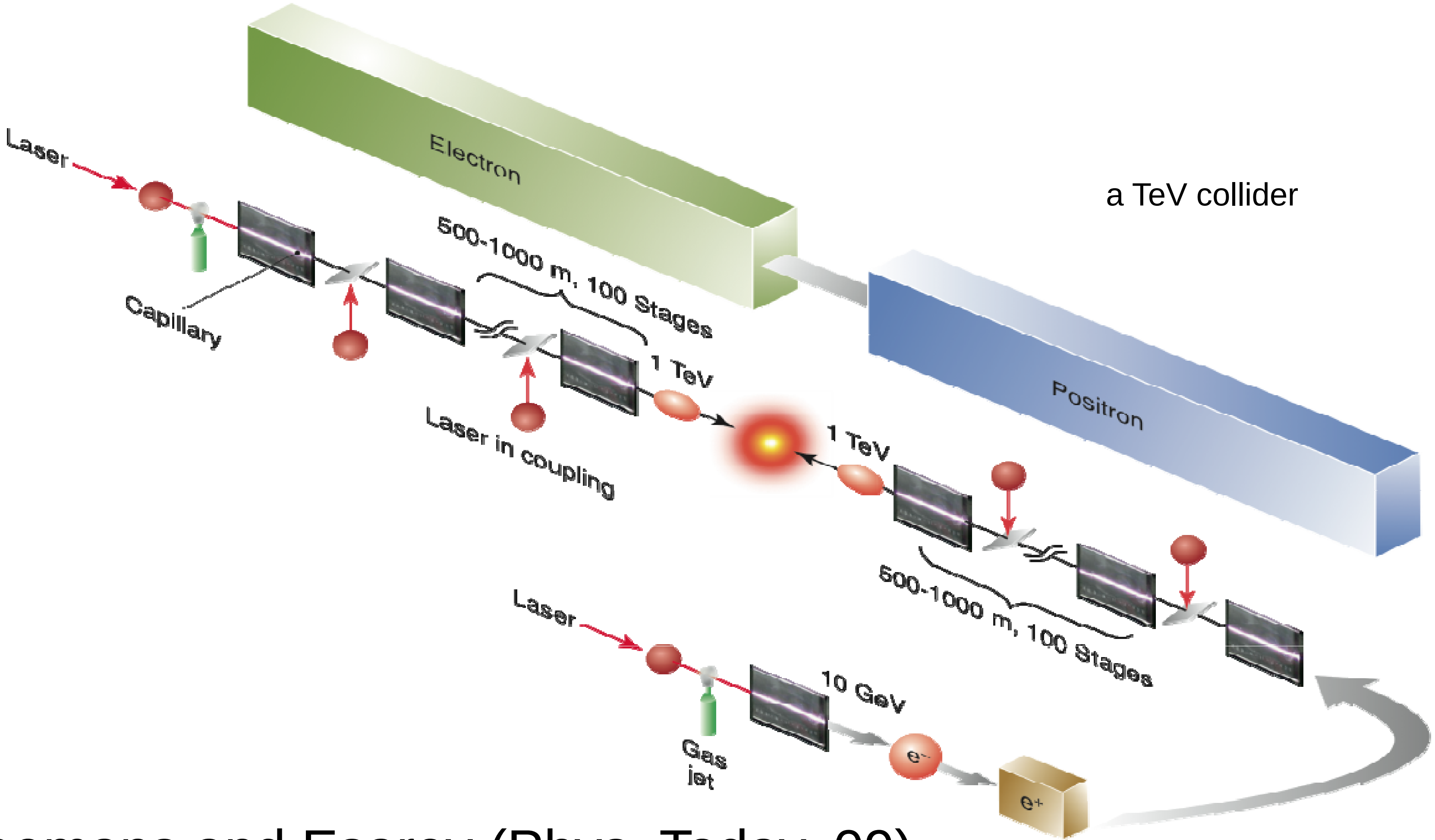
  slab laser; thin disk laser ; fiber laser

Suggestions to ICFA-ICUIL JTF

- Science efforts by US, Europe, Asia mounting to extend the laser technology toward HEP accelerators
- Technology efforts still lacking 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



Leemans and Esarey (Phys. Today, 09)
ICFA-ICUIL Joint Task Force on Laser Acceleration(Darmstadt,10)

ICFA-ICUIL Joint Task Force
on laser acceleration (Darmstadt, 2010)

W. Leemans,
Chair of JTF

Case	1 TeV	10 TeV (Scenario I)	10 TeV (Scenario II)
Energy per beam (TeV)	0.5	5	5
Luminosity (10^{34} cm^{-2}s^{-1})	1.2	71.4	71.4
Electrons per bunch ($\times 10^{8}$)	4	4	1.3
Bunch repetition rate (kHz)	13	17	170
Horizontal emittance $\gamma\varepsilon_x$ (nm-rad)	700	200	200
Vertical emittance $\gamma\varepsilon_y$ (nm-rad)	700	200	200
β^* (mm)	0.2	0.2	0.2
Horizontal beam size at IP σ^*_x (nm)	12	2	2
Vertical beam size at IP σ^*_y (nm)	12	2	2
Luminosity enhancement factor	1.04	1.35	1.2
Bunch length σ_z (μm)	1	1	1
Beamstrahlung parameter Υ	148	8980	2800
Beamstrahlung photons per electron n_γ	1.68	3.67	2.4
Beamstrahlung energy loss δ_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

Collider subgroup
List of parameters
(W. Chou)

Table 1
Collider parameters

Laser requirements for such colliders

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^2)	3×10^{18}	3×10^{18}	3×10^{18}
Laser strength parameter a_0	1.5	1.5	1.5
Plasma density (cm^{-3}), with tapering	10^{17}	10^{17}	10^{18}
Plasma wavelength (μm)	105	105	33

JTF Report #3: Comparison of Choices

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^+/e^-	250 × 2	21	0.16	RF + cryo + cooling
CLIC	e^+/e^-	1500 × 2	29.4	0.09	RF + cooling
LPA	e^+/e^-	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	✓	✓	✓	✓	↑	↑↑
ΔE/E	✓	✓	↓	↓	↓↓	↓↓
ε	✓	✓	✓	✓	✓	↓↓
Charge	✓	✓	✓	↑	✓	↑
Bunch duration	✓	✓	✓	✓	✓	✓
Avg. power	↑	↑	↑	↑	↑	↑↑

✓ : 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 management) as well as medical and defense apps

W. Leemans (2010)

Main challenges for laser technology

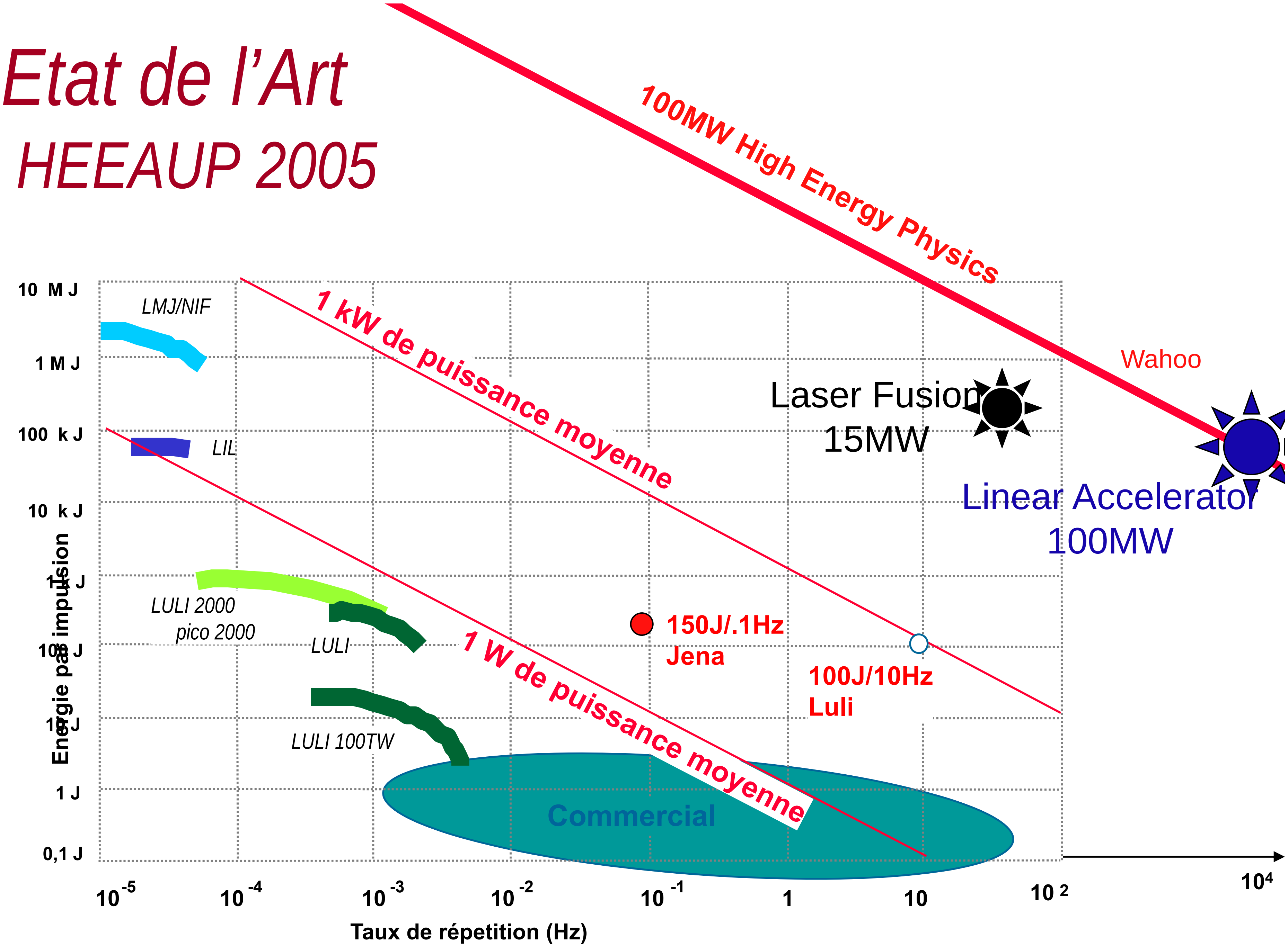
W. Leemans (2010)

- 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, $\gamma\gamma$ collider, X-ray sources, H^- 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 <u>*no showstoppers*</u> found
7. There other areas of fundamental physics laser can assist
8.. Long-raged collaborative/complementary relation necessary between ICFA and ICUIL

Etat de l'Art
HEEAUP 2005



G. Mourou (2005)

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

„Beyond Petawatt means Kilowatt“

W. Sandner (2010)

Laserlab
Europe

Proposed Study:

ICAN, International Coherent Amplification Network

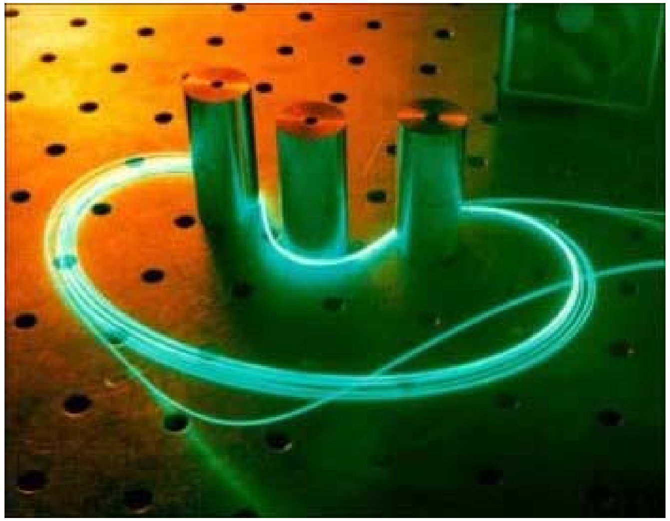
"Solving the efficiency problem in high peak and high average power laser:

an international effort"

(Coordinator G. Mourou, submitted to the EU November 25, 2010)

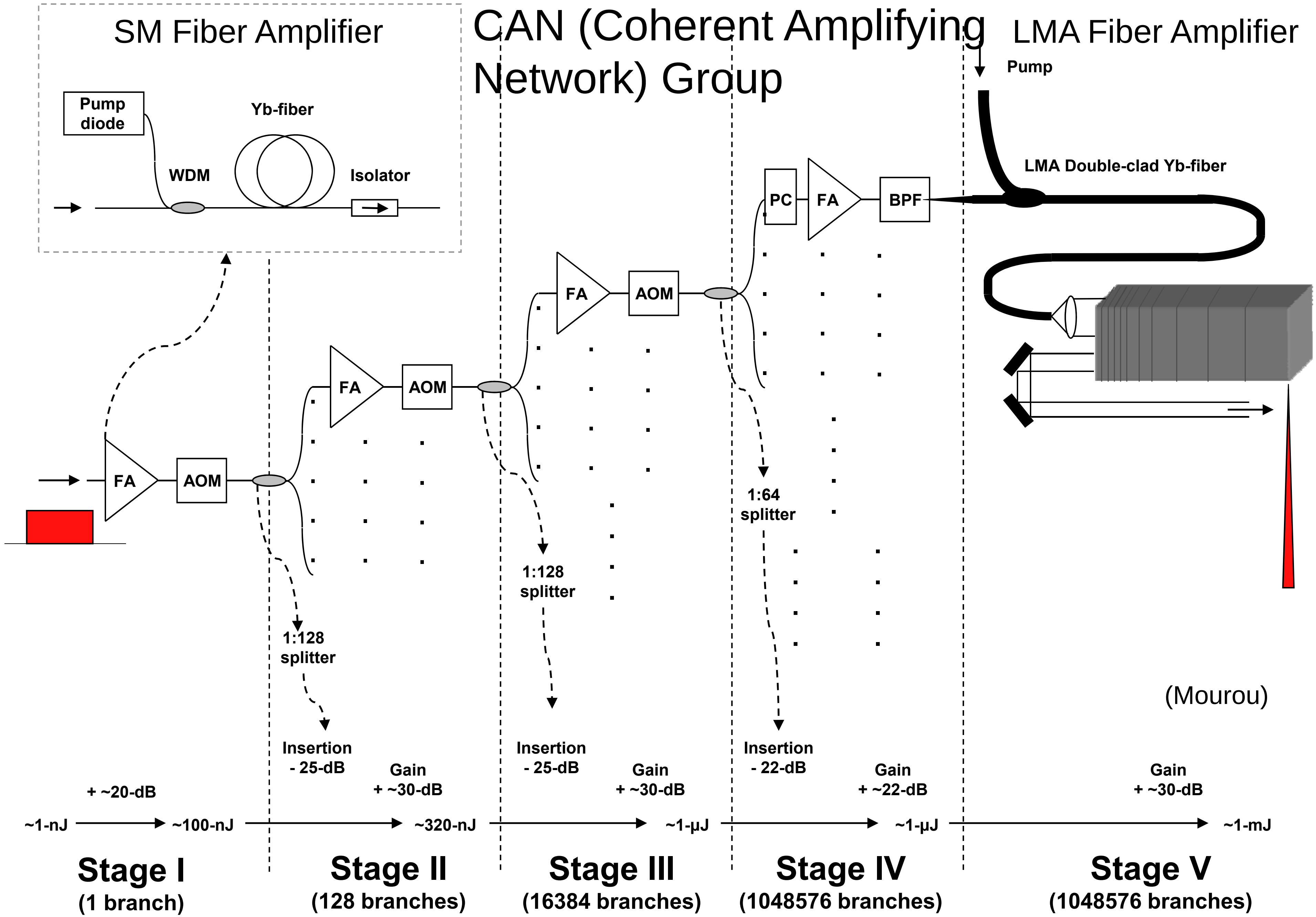
Fiber vs. Bulk lasers

- 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.



(G. Mourou)

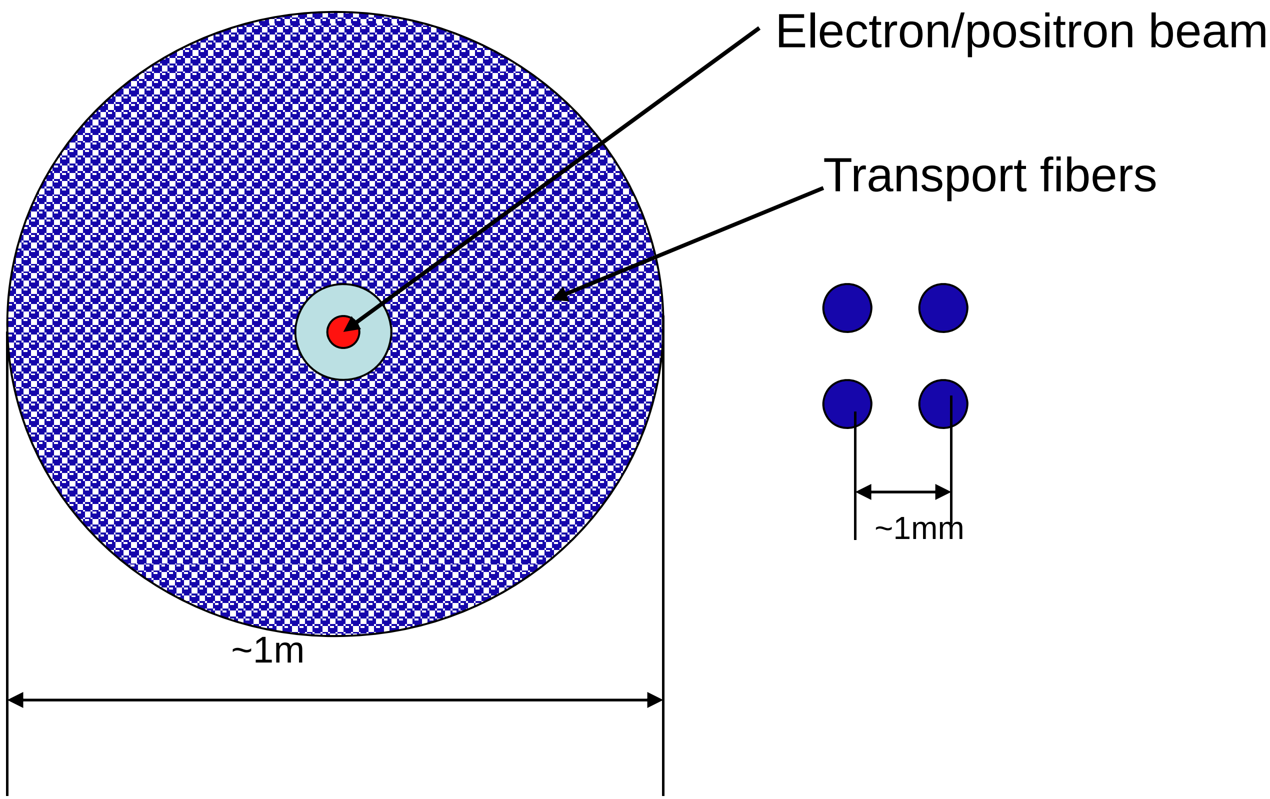
CAN (Coherent Amplifying Network) Group



(Mourou)

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.



Length of a fiber ~5m   Total fiber length~ $5\ 10^4$km

(Mourou et al)

ICFA-ICUIL JTF Conclusions

(April, 2010; Darmstadt)

- *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)

Centaurus A:

cosmic
wakefield
linac?

Merci Beaucoup!