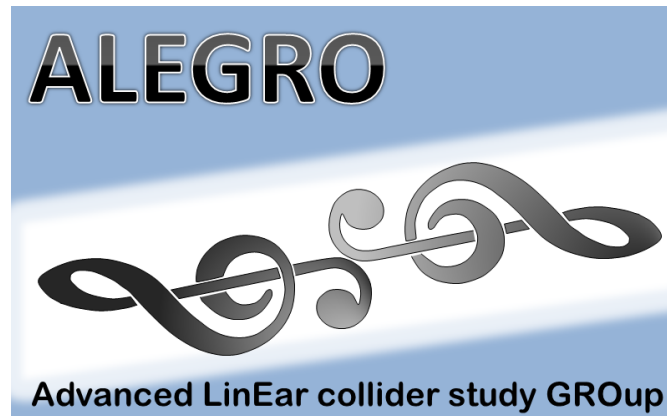




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# *The Advanced LinEar collider study GROup*

**Patric Muggli, for ALEGRO**

*Max Planck Institute for Physics, Munich*

**CERN**

[muggli@mpp.mpg.de](mailto:muggli@mpp.mpg.de)

<https://www.mpp.mpg.de/~muggli>



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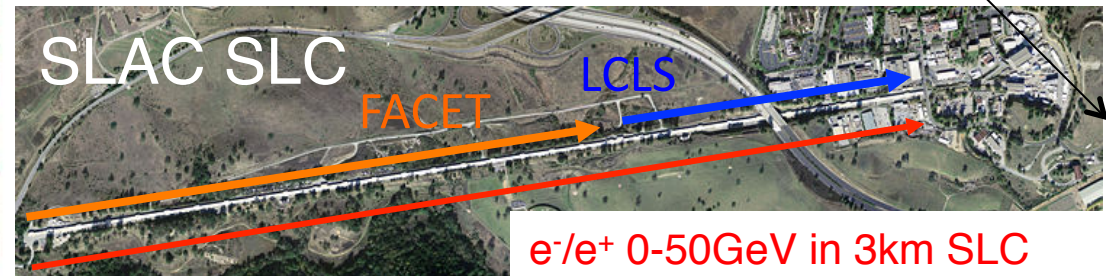
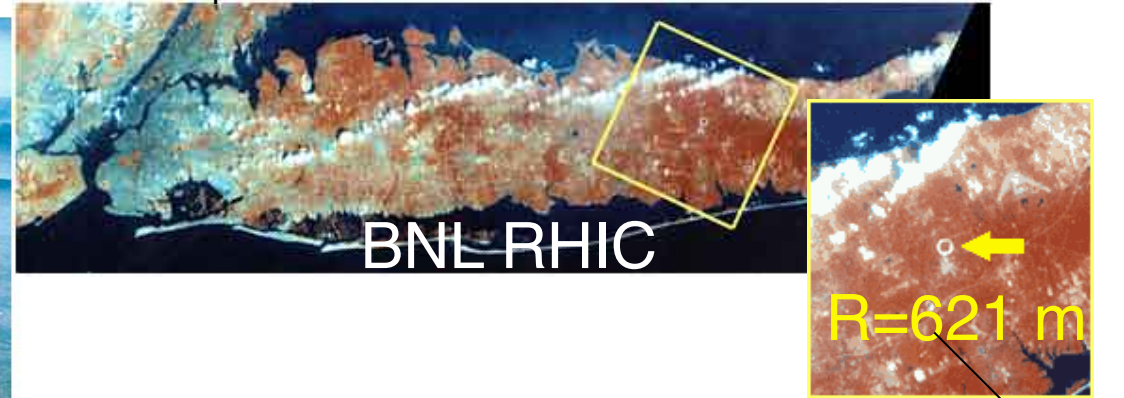
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P. Muggli, ARIES 05/25/2018



# PARTICLE ACCELERATORS



“The 2.4-mile circumference RHIC ring is large enough to be seen from space”



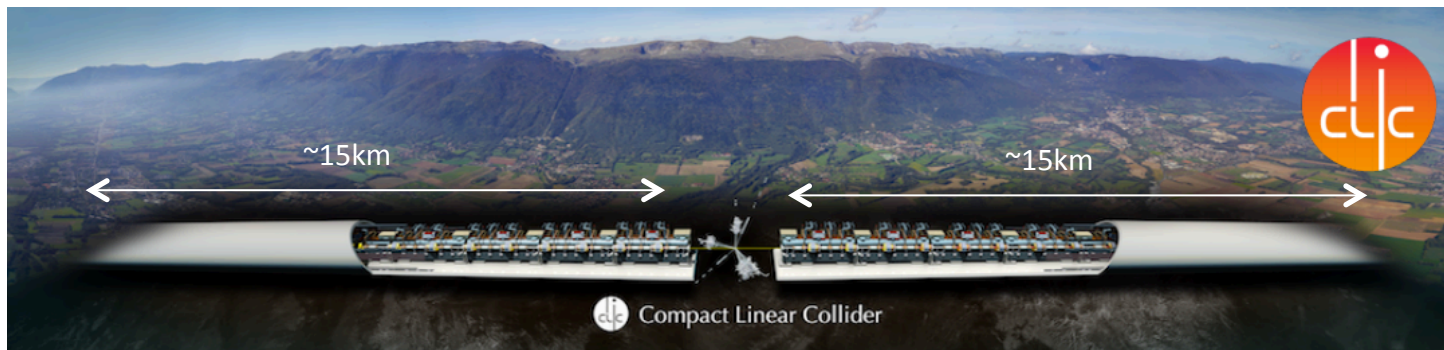
$e^-/e^+$  0-50GeV in 3km SLC  
 $e^-/e^+$  0-20GeV in 2km FACET  
 $e^-$  0-14GeV in 1km LCLS

❖ Some of the largest and most complex (and most expensive) scientific instruments ever built!





# FUTURE ACCELERATORS

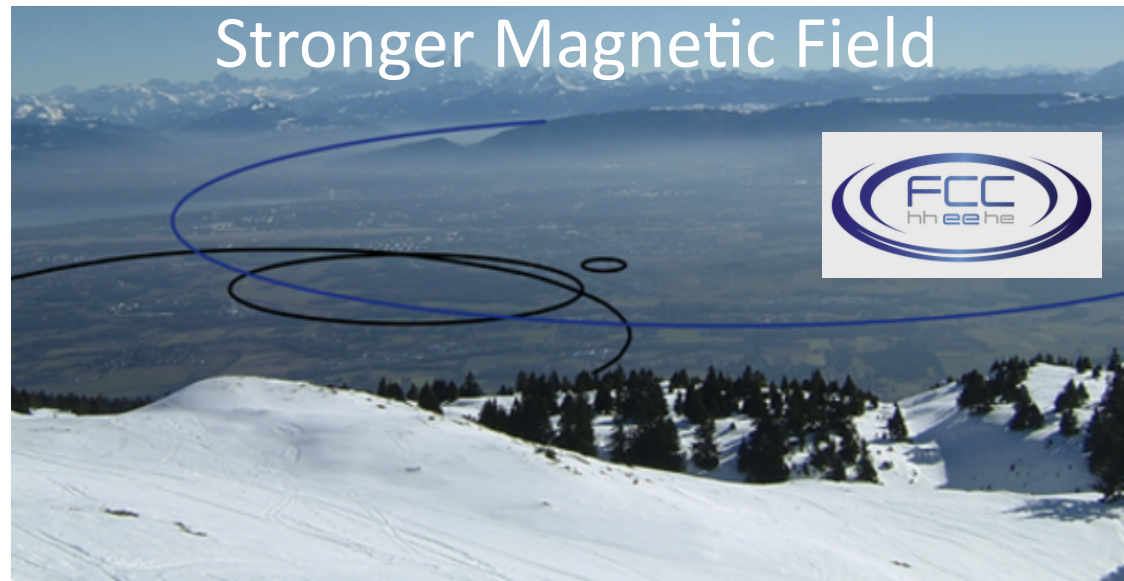


❖ Can we make them ... “less larger” ...





# FUTURE ACCELERATORS



- ✧ Can we make them ... “less larger” ...
- ✧ ALEGRO: high-gradient acceleration for linear ( $e^-/e^+$ ,  $e^-/e^+$ ,  $\gamma/\gamma$ , collider)





# FUTURE ACCELERATORS



- ❖ There is a community working on advanced and novel accelerator (ANA) concepts
- ❖ ANA  $\Leftrightarrow$  high-gradient acceleration
- ❖ EAAC 2017: >200 participants, worldwide





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# ICFA – ICFA-ANA



SPONSORED BY THE PARTICLES AND FIELDS COMMISSION OF IUPAP

## International Committee for Future Accelerators

---

ICFA, the International Committee for Future Accelerators, was created to facilitate international collaboration in the construction and use of accelerators for high energy physics. It was created in 1976 by the International Union of Pure and Applied Physics. Its purposes, as stated in 1985, are as follows:

- To promote international collaboration in all phases of the construction and exploitation of very high energy accelerators.
- To organize regularly world-inclusive meetings for the exchange of information on future plans for regional facilities and for the formulation of advice on joint studies and uses.
- To organize workshops for the study of problems related to super high-energy accelerator complexes and their international exploitation and to foster research and development of necessary technology.

The Committee has 16 members, selected primarily from the regions most deeply involved in high-energy physics.

## Panels

- [ICFA Instrumentation Innovation and Development Panel](#) (Chair — Ariella Cattai, CERN)
- [ICFA Beam Dynamics Panel](#) (Chair — Yong Ho Chin, KEK)
- [ICFA Panel on Advanced and Novel Accelerators](#) (Chair — Brigitte Cros, Paris)
- [ICFA Standing Committee on Interregional Connectivity](#) (Chair — Harvey Newman, Caltech)
- [ICFA Study Group on Data Preservation in High Energy Physics](#) (Chair – Cristinel Diaconu, CPPM, Marseille)
- [Linear Collider Board](#) (Chair – Tatsuya Nakada, EPFL, Lausanne)
- [ICFA Neutrino Panel](#) (Chair — Kenneth Long, Imperial College London)
- [ICFA Panel on Sustainable Accelerators and Colliders](#) (Chair — Mike Seidel, PSI)



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# ICFA-ANA



**International Committee for Future Accelerators**

**Panel on Advanced and Novel Accelerators**

## Mission:

**To extend and support the international collaboration and communication in the field of new acceleration techniques.**

- To promote and encourage international collaboration/workshop/school on advanced and novel accelerators.
- Especially emphasize on advanced compact accelerator and their application to not only high energy physics, particle physics, nuclear physics but also medical physics, nondestructive evaluation, security and so on, in order to maintain accelerator science and technology.

## ANA Panel Members (2013–2016)

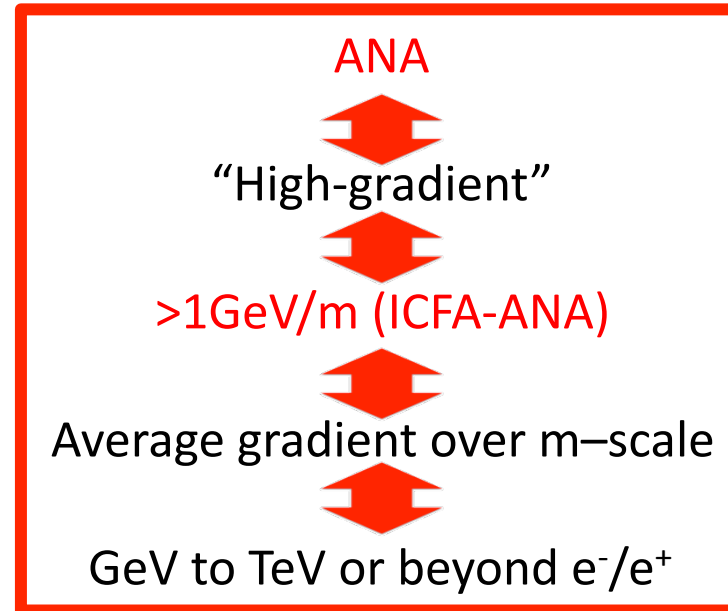
Name	Affiliation
Brigitte Cros (chair)	LPGP-CNRS- Univ Paris Sud, France
Bruce Carlsten (Contact USA)	Los Alamos National Laboratory, USA
Massimo Ferrario	INFN, Italy
Brian Foster	Univ. Hamburg & Univ. Oxford, DESY, Germany
Ryoichi Hajima	Japan Atomic Energy Agency, Japan
Dino Jaroszynski	Uni Strathclyde, UK
Patric Muggli (Contact Europe)	Max-Planck-Institut für Physik, Germany
Philippe Piot (Contact USA)	Northern Illinois Univ (USA), Fermi Nat Accel. Lab.
James Rosenweig	Univ California Los Angeles, USA
Carl Schroeder	Lawrence Berkeley National Laboratory, USA
Chuanxiang Tang (Contact Asia)	Tsinghua University, China
Mitsuru Uesaka	Univ. Tokyo, Japan
Mitsuhiro Yoshida	KEK, Japan

<http://www.lpgp.u-psud.fr/icfaana>





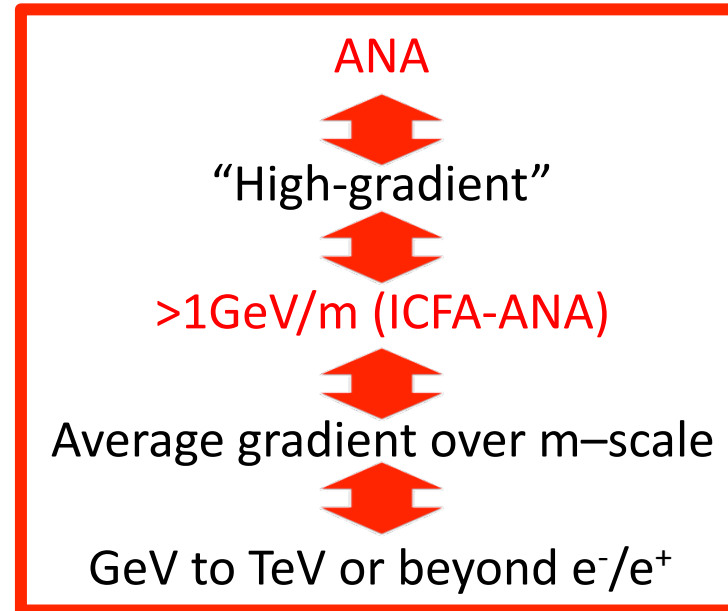
# ADVANCED & NOVEL ACCELERATORS (ANAs)







# ADVANCED & NOVEL ACCELERATORS (ANAs)



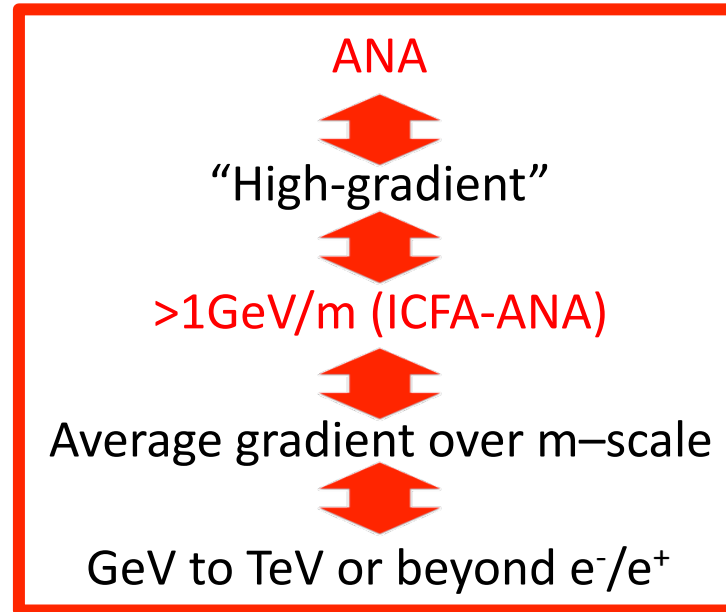
Advanced materials with higher damage threshold:

- ✧ Dielectrics (~GV/m)
- ✧ Plasmas (10-100GV/m or ∞)





# ADVANCED & NOVEL ACCELERATORS (ANAs)



Advanced materials with higher damage threshold:

- ✧ Dielectrics (~GV/m)
- ✧ Plasmas (10-100GV/m or ∞)

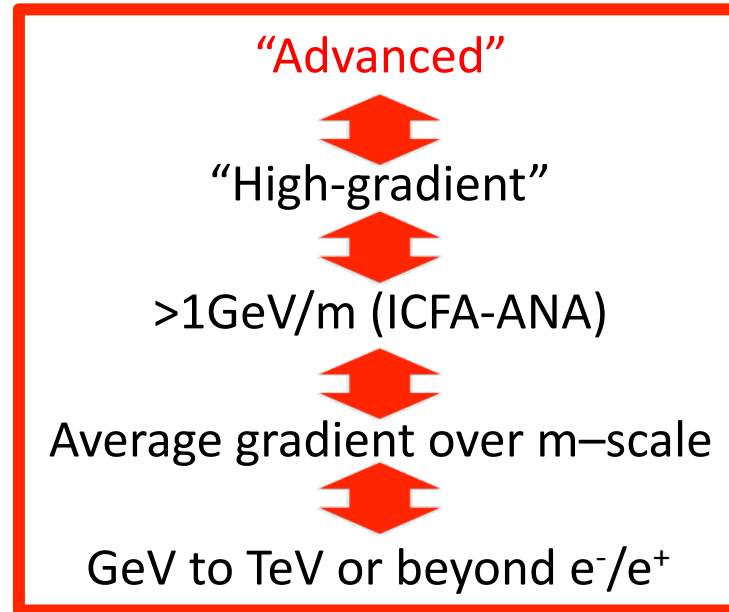
Novel drivers:

- ✧ Laser pulse(s)\*
- ✧ Charged particle bunch(es)





# ADVANCED & NOVEL ACCELERATORS (ANAs)



**Advanced** materials with higher damage threshold:

- ✧ Dielectrics (~GV/m)
- ✧ Plasmas (10-100GV/m or ∞)

**Novel** drivers:

- ✧ Laser pulse(s)\*
- ✧ Charged particle bunch(es)

	Medium	
Driver	Dielectric	Plasma
Laser Pulse	Dielectric Laser Accelerator DLA	Laser Wakefield Accelerator LWFA
Particle Bunch	Structure Wakefield Accelerator SWFA	Plasma Wakefield Accelerator PWFA

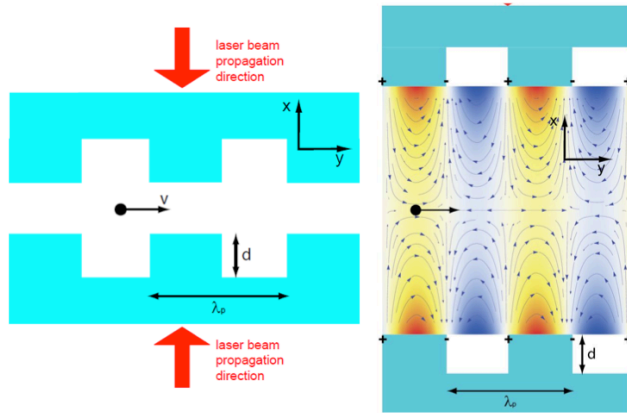




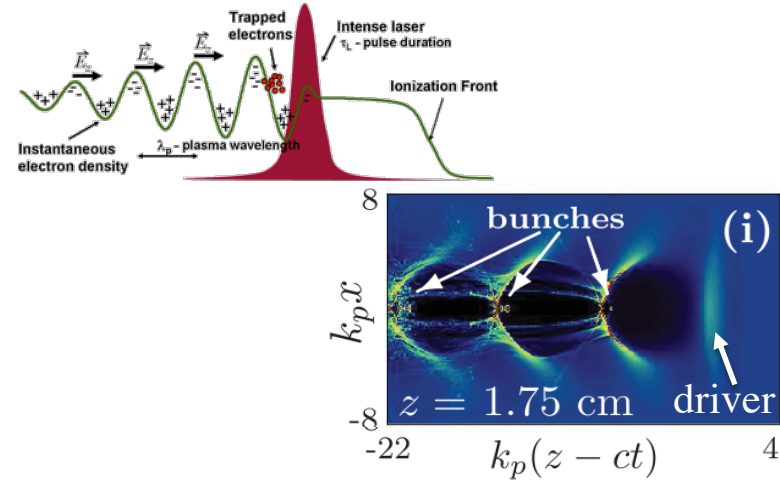
# ADVANCED & NOVEL ACCELERATORS (ANAs)



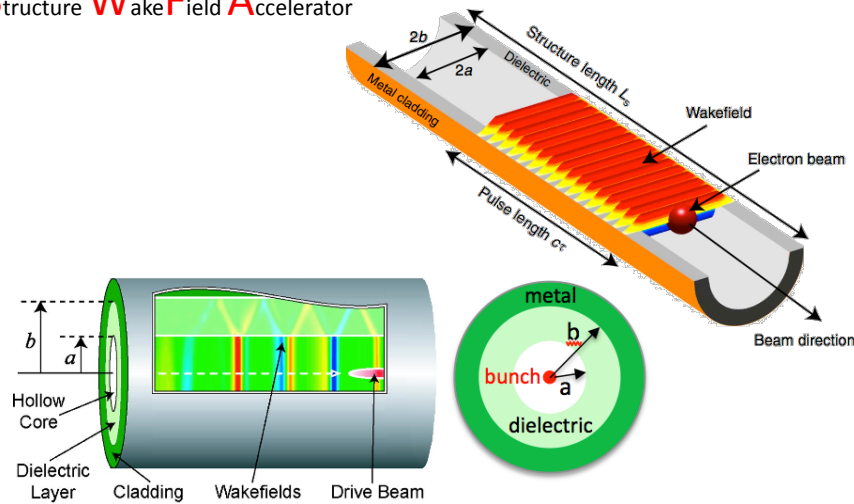
## Dielectric Laser Accelerator



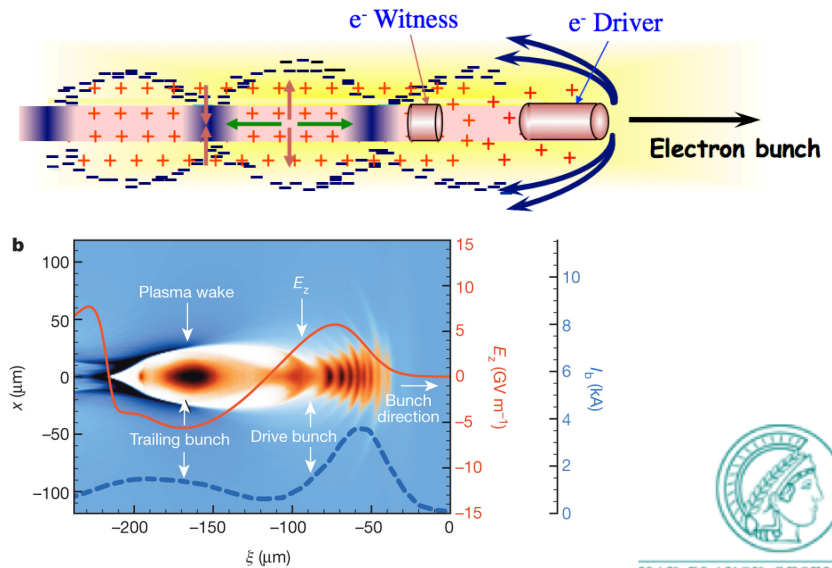
## Laser Wakefield Accelerator



## Structure Wakefield Accelerator

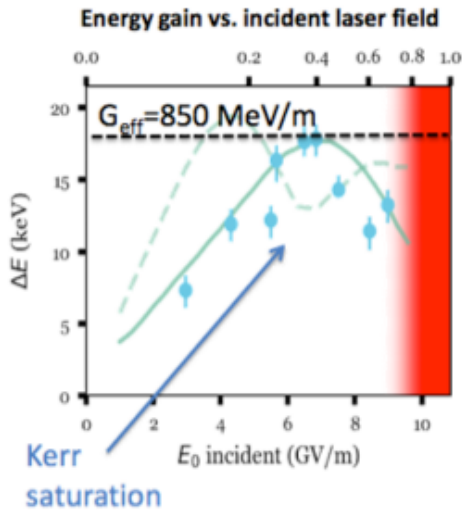


## Plasma Wakefield Accelerator





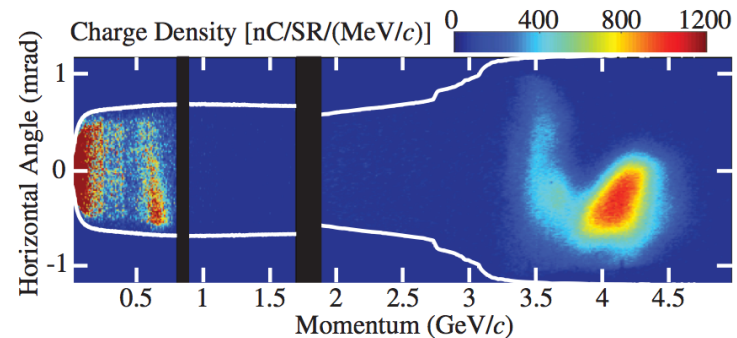
# DEMONSTRATIONS OF GeV/m



Dielectric Laser Accelerator

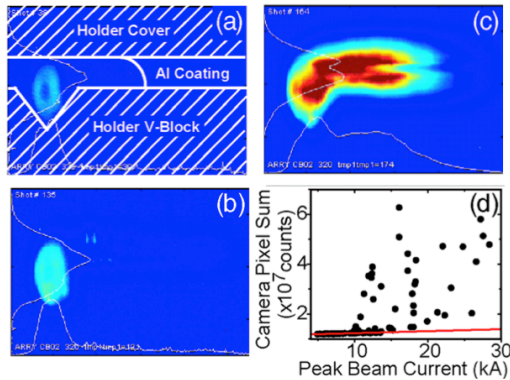
Presented by D. Cesar (UCLA) @ EAAC 2017

Laser Wakefield Accelerator



- Peak energy gain 4.2 GeV in 9cm (46 GeV/m)
  - Self-trapped plasma  $e^-$ , 6pC (no injector needed)
- Leemans, PRL 113, 245002 (2014)

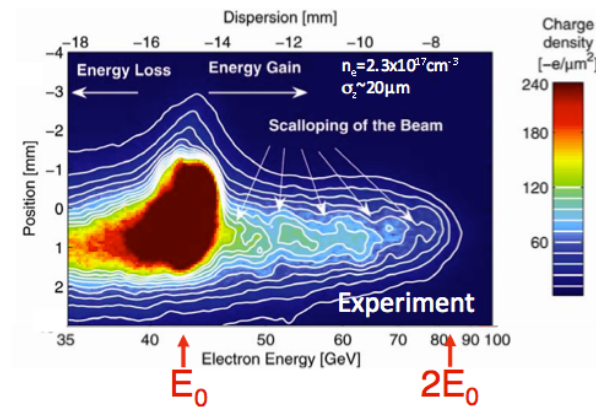
Structure Wakefield Accelerator



- Breakdown field:  $13.8 \pm 0.7 \text{ GV/m}$
- Estimated max. decelerating field:  $11 \text{ GV/m}$
- Estimated max. accelerating field:  $17 \text{ GV/m}$

Thompson, PRL 100, 214801 (2008)

Plasma Wakefield Accelerator



42 => 84 GeV in 85cm! 50 GeV/m

Blumenfeld, Nature 445, 741 (2007)

Many more key and interesting results

<https://indico.cern.ch/event/667672/contributions/2730847/>

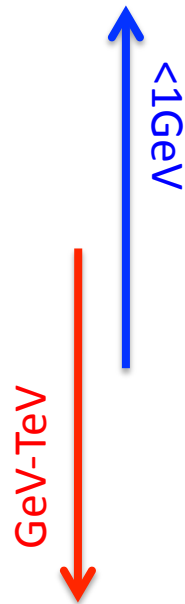




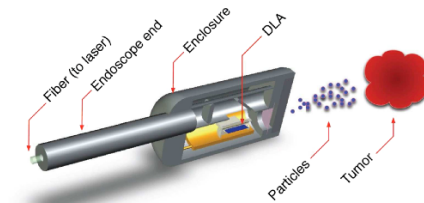
# APPLICATIONS OF ANAs



- ✦ X-ray for radiography (advanced: phase contrast, etc.)
- ✦  $e^-$  for medical applications
- ✦ Require low energy  $< \text{GeV}$
- ✦ Can operate at very large peak gradient, mm-cm accelerator
- ✦ Efficiency not an issue
- ✦ Luminosity “not an issue”
- ✦ Special characteristics: ultra-short, synchronized (laser), pump probe, etc.
- ✦ Biological advantage ...
- ✦ Unique applications, compact



Dielectric Laser Accelerator DLA	Laser Wakefield Accelerator LWFA
Structure Wakefield Accelerator SWFA	Plasma Wakefield Accelerator PWFA



England, Rev. Mod. Phys., 86, 1337, (2014)

- ✦ Powerful radiation source, THz to  $\gamma$ -rays (x-ray FEL)
- ✦ High-energy physics (HEP)
  - ✦  $e^-/e^+$  collider
  - ✦  $e^-/p^+$  collider
  - ✦ Energy upgrade for a conventional, future collider (ILC, CLIC)





# APPLICATIONS OF ANAs

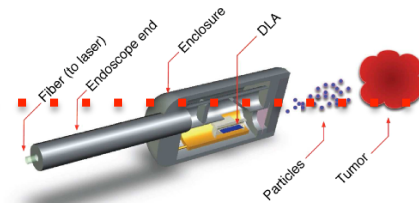


“Small”

- ✧ X-ray for radiography (advanced: phase contrast, etc.)
- ✧  $e^-$  for medical applications
- ✧ Require low energy  $< \text{GeV}$
- ✧ Can operate at very large peak gradient, mm-cm accelerator
- ✧ Efficiency not an issue
- ✧ Luminosity “not an issue”
- ✧ Special characteristics: **ultra-short**, synchronized (laser), pump probe, etc.
- ✧ Biological advantage ...
- ✧ **Unique applications, compact**

$< 1 \text{ GeV}$

Dielectric Laser Accelerator DLA	Laser Wakefield Accelerator LWFA
Structure Wakefield Accelerator SWFA	Plasma Wakefield Accelerator PWFA



England, Rev. Mod. Phys., 86, 1337, (2014)

GeV-TeV

“Large”

- ✧ Powerful radiation source, THz to  $\gamma$ -rays (x-ray FEL)
- ✧ High-energy physics (HEP)
  - ✧  $e^-/e^+$  collider
  - ✧  $e^-/p^+$  collider
  - ✧ Energy upgrade for a conventional, future collider (ILC, CLIC)





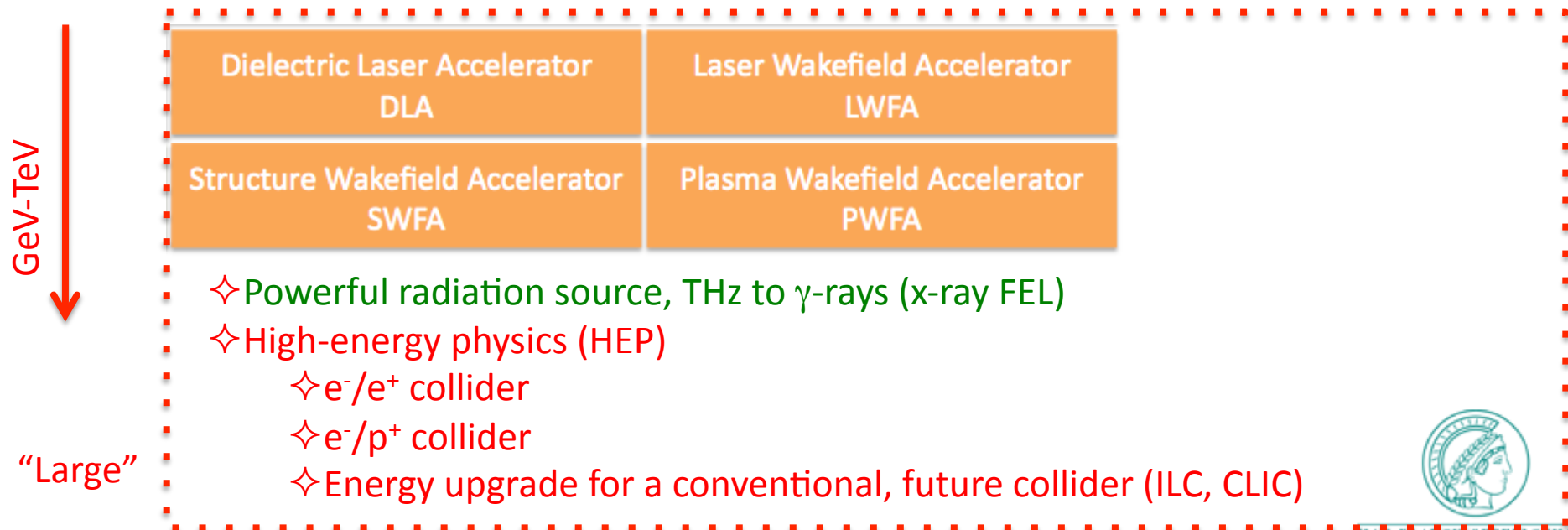
# APPLICATIONS OF ANAs TO HEP



## ✧ ICFA-ANA panel:

- ✧ Application to HEP does require World-wide cooperation
- ✧ ANA community quite fragmented (by nature)
- ✧ Urgent need for ANA community to gather
- ✧ Urgent need to overlap with non-ANA accelerator community
- ✧ Wealth of experience in non-ANA accelerator community
- ✧ Need to approach ANA-collider (or  $A_{\text{dvanced}}L_{\text{inear}}C_{\text{ollider}}$ ) globally, from physics case to IP

■ To promote and encourage international collaboration/workshop/school on advanced and novel accelerators.







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# ANAR WORKSHOP 2017 (April)



Advanced and Novel Accelerators Roadmap workshop



Organised at the initiative of the ICFA panel for Advanced and Novel Accelerators, the ANAR2017 workshop aims at discussing issues to be addressed in the near future to be in a position to identify promising technologies for future advanced accelerators, and to establish an international scientific and strategic roadmap. The general goal is to define an international roadmap towards colliders based on advanced accelerator concepts, including intermediate milestones, and to discuss the needs for international coordination.

- LWFA: Arnd Specka (CNRS), Dan Gordon (NRL), Carl Schroeder (LBNL)
- PWFA: Allen Cadwell (MPP), Mark Hogan (SLAC), Edda Gschwendtner (CERN)
- SWFA: John Power (ANL), Paolo Craievich (PSI), Philippe Piot (FermiLab)
- DLA: Joel England (SLAC) , Joshua McNeur (U Erlangen) , Bruce Carlsten (LANL)



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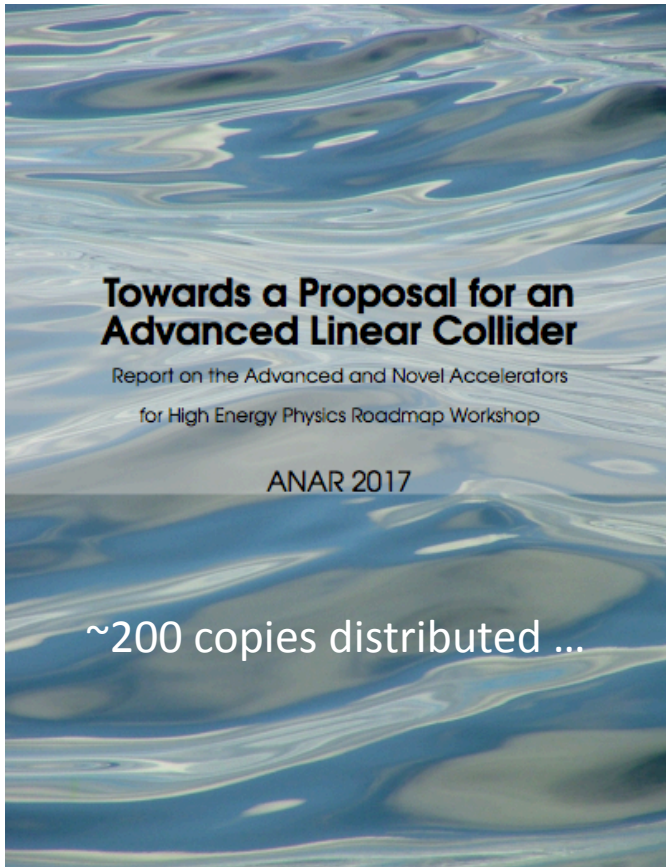


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# ANAR WORKSHOP 2017 (April)



Advanced and Novel Accelerators Roadmap workshop



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Science

Strategy



LANCK-GESELLSCHAFT



# ANAR WORKSHOP 2017 (April)

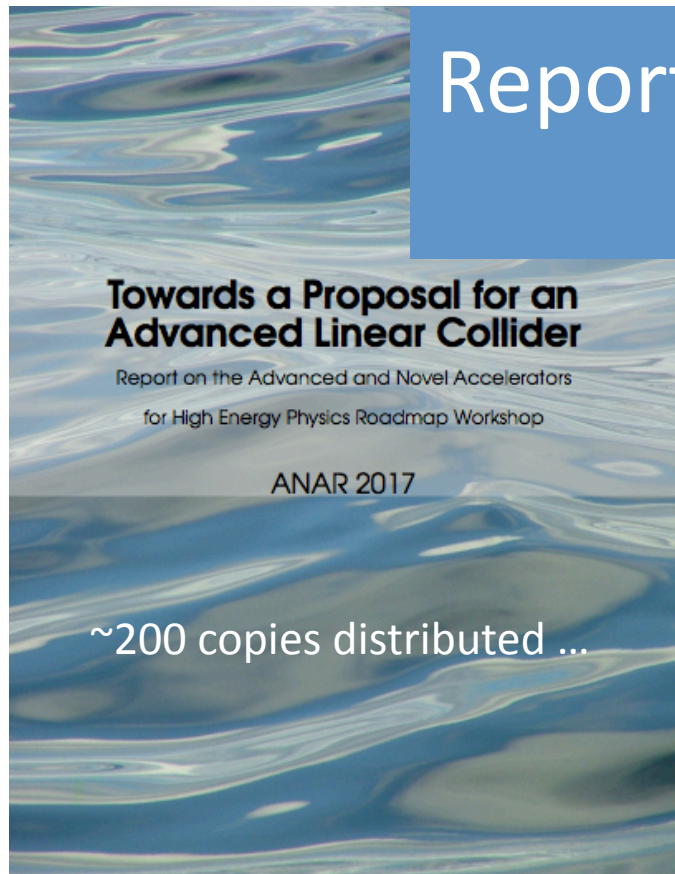


Advanced and Novel Accelerators Roadmap workshop



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Report widely distributed (~200 copies)



Science

Strategy





# ANAR WORKSHOP 2017 (April)



## 3 Main Challenges Towards an ALC

### 3.1 Challenges Related to Novel Accelerator Components

3.1.1 Injectors

3.1.2 Accelerating Structures

3.1.3 Diagnostics

3.1.4 **Staging**

3.1.5 **Stability, Reproducibility, Reliability, Need for Dedicated Experiments**

### 3.2 Challenges Related to Beam Dynamics at High Energy

3.2.1 Narrow Energy Spread

3.2.2 **Efficiency and Beam Loading**

3.2.3 Emittance Preservation

3.2.4 **Scattering**

3.2.5 Beam Break-up and Hosing Instabilities

3.2.6 **Spin-Polarization Preservation**

3.2.7 Ion Motion

3.2.8 Numerical Simulations

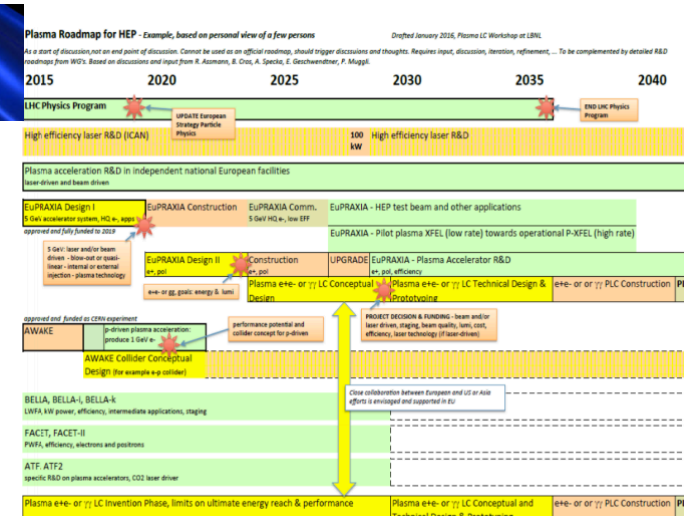
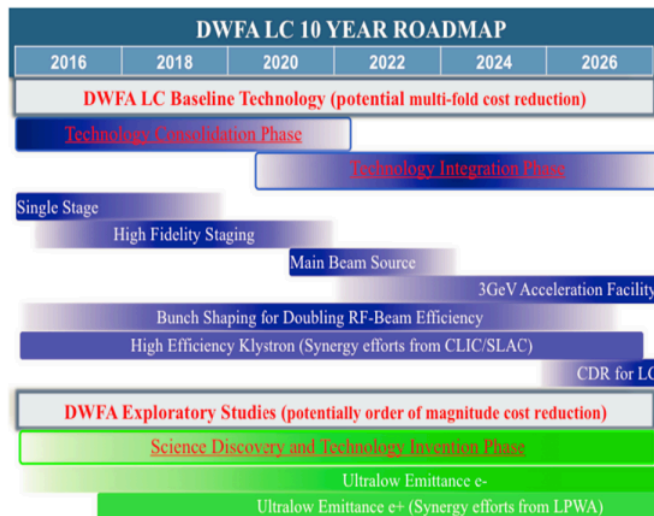
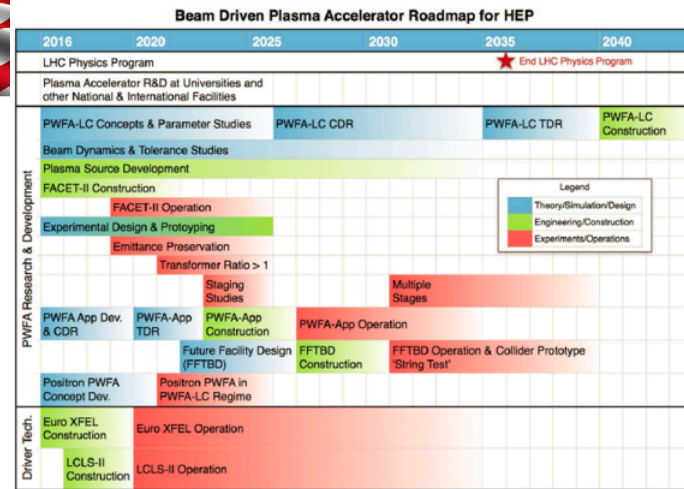
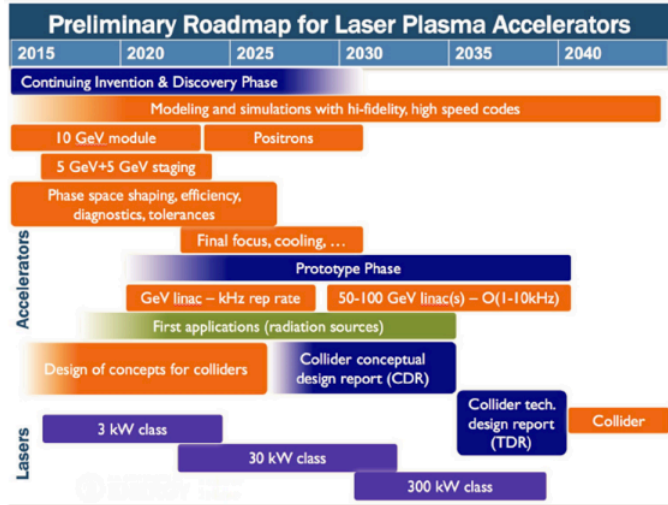
**\*Larger scale experiments**





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# EXISTING "LOCAL" ROADMAPS



SWFA, LWFA, PWFA, x-ray FEL and e<sup>-</sup>/e<sup>+</sup> collider  
 LWFA, PWFA, x-ray FEL and e<sup>-</sup>/e<sup>+</sup> and e<sup>-</sup>/p<sup>+</sup> collider



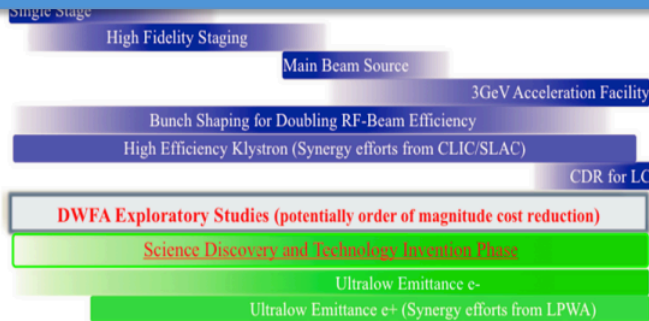


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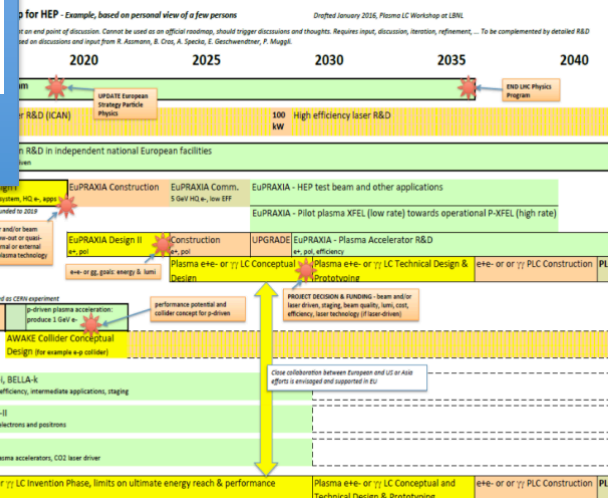
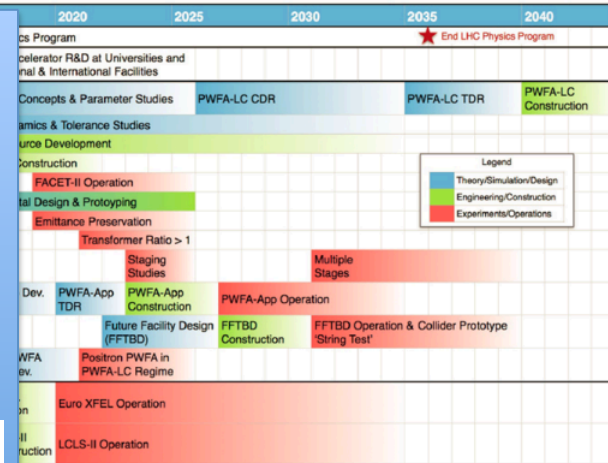
# EXISTING "LOCAL" ROADMAPS



## Preliminary Roadmap for Laser Plasma Accelerators



## Beam Driven Plasma Accelerator Roadmap for HEP



SWFA, LWFA, PWFA, x-ray FEL and  $e^-/e^+$  collider

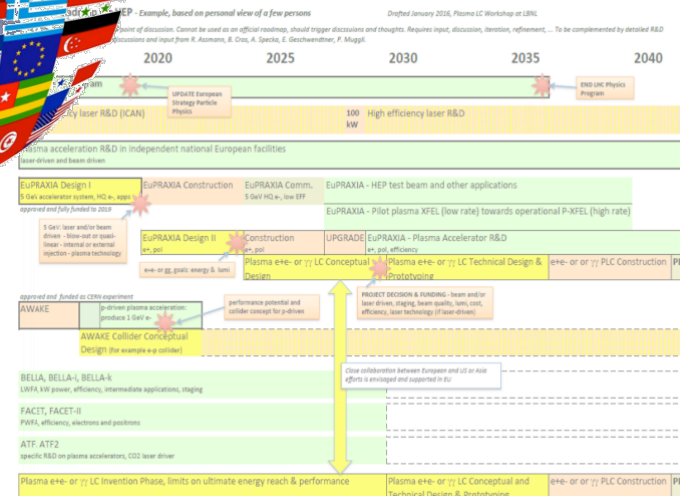
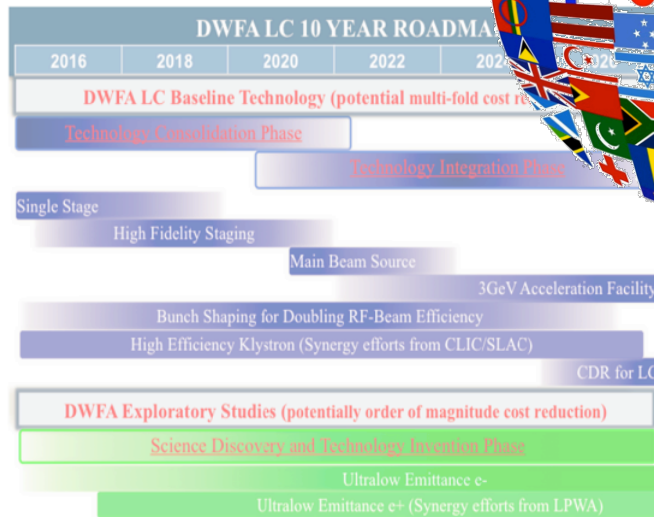
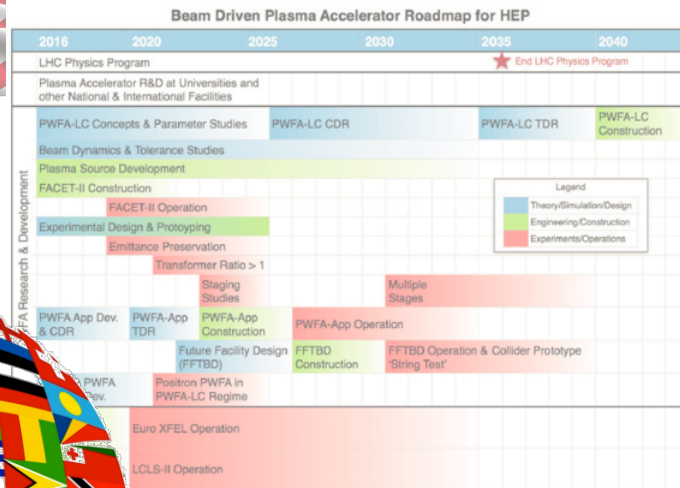
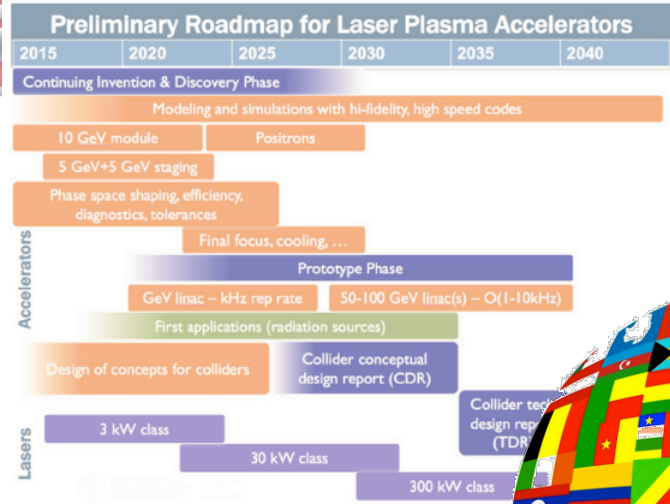
LWFA, PWFA, x-ray FEL and  $e^-/e^+$  and  $e^-/p^+$  collider





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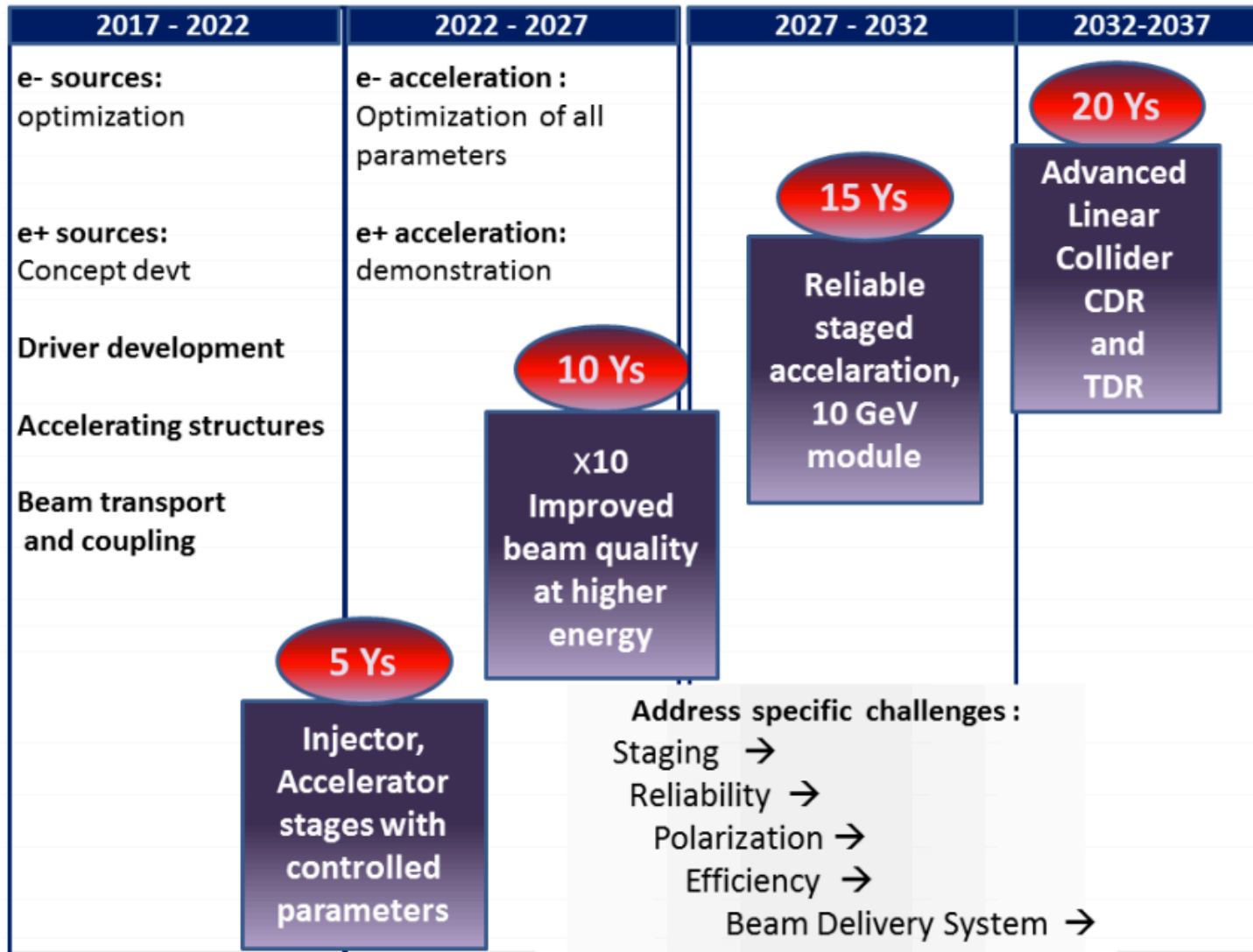
# WORLDWIDE ROADMAP



SWFA, LWFA, PWFA, x-ray FEL and e-/e+ collider  
LWFA, PWFA, x-ray FEL and e-/e+ and e-/p+ collider



# ANAR SCIENTIFIC ROADMAP



✧ Schedule driven by LHC physics/schedule and ILC/CLIC?







# ANAR WORKSHOP OUTCOME



As an outcome of the workshop, it was decided to **constitute a study group towards Advanced Linear Colliders, named ALEGRO for Advanced LinEar collider study GROup**. ALEGRO's general charge will be to coordinate the preparation of a proposal for an advanced linear collider in the multi-TeV energy range.

**The ALEGRO will consist of (30) scientists** with expertise in advanced accelerators concepts or accelerator physics and technology, drawn from national institutions or universities in Europe, America and Asia.

**The ALEGRO will organize a series of workshops** on relevant topics where the scientific community should, in a first phase, discuss and iterate the roadmaps, discuss ways to tackle key challenges, and, **over time, monitor the progress of the community as a whole on collider-oriented R&D**.

The first objective of ALEGRO is to prepare and deliver by the end of 2018 a document detailing the roadmap and strategy of ANAs, with clear priorities, as input for the European Strategy Research Group (ESRG).

In order to prepare the document for the ESRG, three workshops are planned: the first is scheduled during the EAAC 2017 where a WG on colliders is organized; a second at the beginning of 2018 hosted by the JAI, and a third jointly with the AAC2018.





# ANAR WORKSHOP OUTCOME



As an outcome of the workshop, it was decided to constitute a study group towards **Advanced Linear Colliders**, named **ALEGRO** for **Advanced LinEar collider study GROUp**. ALEGRO's general charge will be to study the feasibility of a multi-TeV energy linear collider in the US, Europe, Asia, and Australia. The ALEGRO will study concepts or ideas in Europe, America and Asia.

The ALEGRO will study scientific concepts or ideas in Europe, America and Asia. The community should be encouraged to tackle key challenges, and, oriented R&D.

The first objective is to develop the roadmap and to constitute a Research Group (ESRG).

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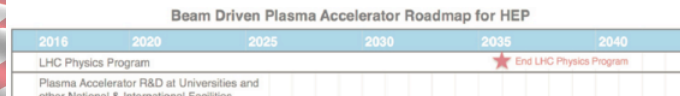
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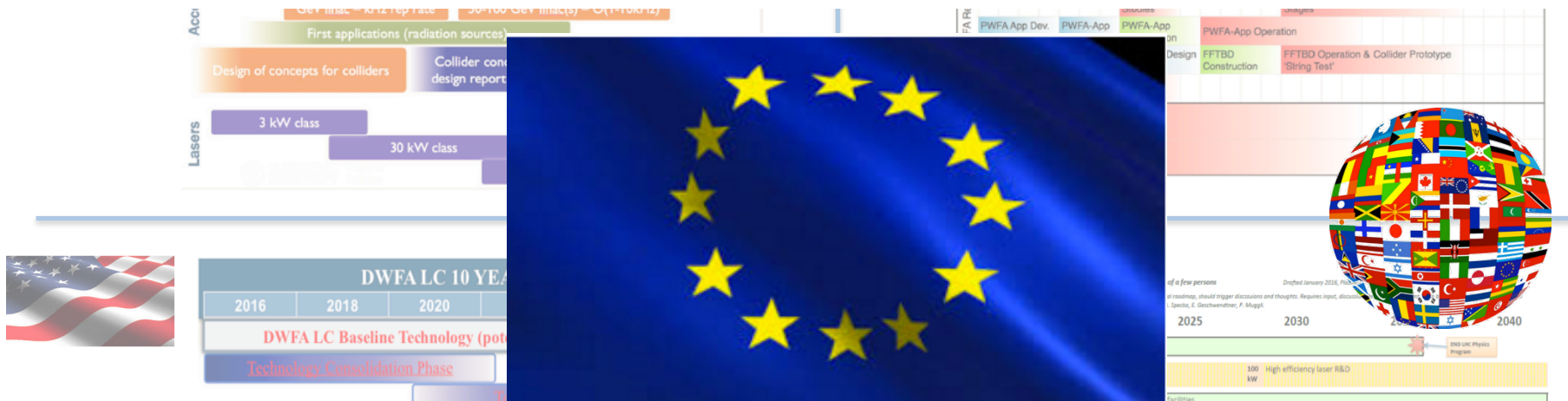


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# 1<sup>ST</sup> ALEGRO GOAL



## Input for the 2020 European Particle Physics Strategy Update



2018: Input from the physics community - collaborations, projects, national institutes, individuals, etc.

2019: discussion by the Physics Preparation Group


2020: EPPSU proposal to and approval by the CERN Council

<http://vms.fnal.gov/asset/detail?recid=1952953>





# 1<sup>ST</sup> ALEGRO WORKSHOP WGs



**ALEGRO 2018**  
**Advanced LinEar collider study GROup**  
**Workshop 2018**  
26-29 March 2018, University of Oxford, JAI  
<https://indico.cern.ch/event/677640/>

- **Physics Case (PC); WG1: Michael Peskin (SLAC), Junping Tian (U. Tokyo)**
- **Collider Machine Design/definitions (CMD); WG2: Daniel Schulte (CERN), Andrei Seryi (JAI), Hitoshi Yamamoto (Tohoku Uni)**
- **Theory, Modeling, Simulations (TMS); WG3: Jean-Luc Vay (LBNL), Jorge Vieira (IST), Henri Vincenti (CEA)**
- **LWFA; WG4: Carl Schroeder (LBNL), Simon Hooker (JAI/Oxford), Brigitte Cros (CNRS/Univ Paris Sud)**
- **PWFA; WG5: Jens Osterhoff (DESY), Edda Gschwendtner (CERN), Patric Muggli (MPP)**
- **SWFA; WG6: Philippe Piot (NIU), John Power (ANL)**
- **DLA; WG7: Joel England (SLAC), Ben Cowan (Tech-X)**
- **Joint sub-WG on positron acceleration (PAC): Sebastien Corde (LOA), Spencer Gessner (CERN)**





# 1<sup>ST</sup> ALEGRO WORKSHOP




GLOBAL design: Physics case, injector, accelerator, BDS, detector

GLOBAL approach: Asia, Europe, USA, ...



## DISCUSSIONS HIGHLIGHTS:



**ALEGRO 2018**  
**Advanced LinEar collider study GROup**  
**Workshop 2018**  
26-29 March 2018, University of Oxford, JAI  
<https://indico.cern.ch/event/677640/>


- ✧ Long term and ambitious goals for HEP to give a new impulse to ANA development: need coordinated efforts to be undertaken for faster progress and increased funding
- ✧ ANAs are still partly in the exploratory/discovery phase
- ✧ Mid term milestones associated to the construction of specific facilities (e.g. EuPRAXIA, kBella, FACET II, AWAKE, ...)
  - ✧ to validate the reliability of ANAs
  - ✧ to demonstrate their capability to achieve higher average power
  - ✧ to develop compact positron sources





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# ALEGRO WORKSHOP OUTCOMES



**ALEGRO 2018**  
**Advanced LinEar collider study GROup**  
**Workshop 2018**  
26-29 March 2018, University of Oxford, JAI  
<https://indico.cern.ch/event/677640/>

- ✧ Ambitious long term goals (0.5 to multi-TeV in the report):  
advanced Linear Collider (ALIC), 30 TeV CM collision energy, luminosity in the  $10^{36} \text{ cm}^{-2}\text{s}^{-1}$  range for studying Higgs coupling to the top quark, Higgs self-coupling and for precision measurements
- ✧ ALEGRO will submit a document for the European Particle Physics Strategy Update
- ✧ First outline of the document



MAX-PLANCK-GESELLSCHAFT

P. Muggli, ARIES 05/25/2018



# ALEGRO WORKSHOP NEXT STEPS



Advanced LinEar collider study Group  
Workshop 2019  
26-29 March (TBC), 2019, CERN

- ✧ One day meeting at advanced accelerator concepts (AAC) workshop (12<sup>th</sup> Aug. 2018) to work on draft document
- ✧ **ALEGRO will submit a document for the European Particle Physics Strategy Update (Dec. 2018)**





# ALEGRO COMMUNITY SHOULD GROW AND MEET REGULARLY

- ✧ Next ALEGRO workshop at CERN, March 26-29 (TBC), 2019
- ✧ WGs organized according to colliders systems:
  - ✧ physics case
  - ✧ acceleration (plasma, dielectrics)
  - ✧ power sources (drive beam, laser, etc)
  - ✧ luminosity delivery (beam sources, beam cooling, tolerances, stabilization, focusing)
  - ✧ detector (machine detector interface)
- ✧ Other workshops will follow ...





# ALEGRO AGENDA



- ✧ First version of the ALEGRO input to EPPSU: end of June, input from ALEGRO WGs
- ✧ ALEGRO compiles first version of the document
- ✧ Document review and improvement at one day meeting (11/08) at AAC'2018, Aug. 12-17, Breckenridge CO, USA (<http://aac2018.org/>)
- ✧ Submission of the document Dec. 2018
  
- ✧ 2<sup>nd</sup> ALEGRO workshop, March 26-29, 2019 (TBC), CERN
  - ✧ WG Physics Case
  - ✧ WG Acceleration (plasma, dielectric, etc)
  - ✧ WG Power Sources (drive beam, laser, etc)
  - ✧ WG Luminosity Delivery (beam sources, beam cooling, tolerances, stabilization, focusing)
  - ✧ WG Detector (machine detector interface)
  
- ✧ Continuous energizing of the community towards ANA applications to HEP: CLIC/ILC upgrade,  $e^-/p^+$  collider,  $e^-/e^+$  collider,  $\gamma\gamma$  collider ...
  
- ✧ Draw a roadmap for an ANA-based linear collider: Advanced Linear Collider
  
- ✧ Participation/participants WELCOME ...





Thank You!

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<https://www.mpp.mpg.de/~muggli>