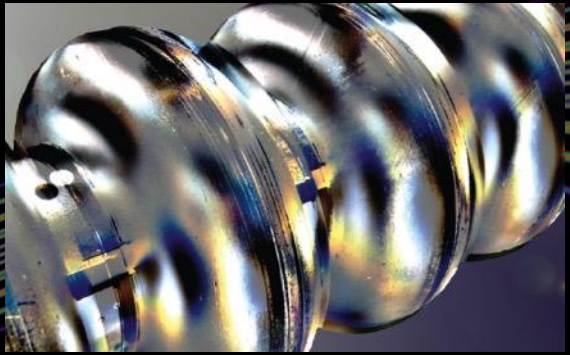
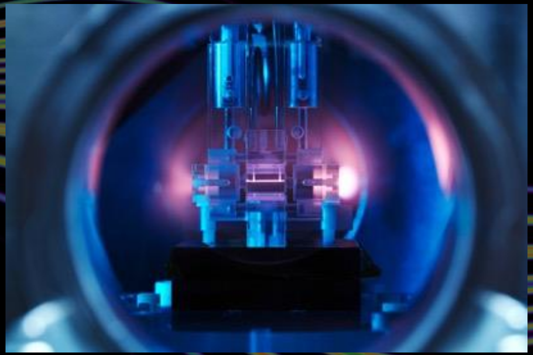
Accelerator R&D





Supporting the High Energy Frontier

European Physical Society
Conference on High Energy Physics

10-17 July 2019, Ghent, Belgium

European Network for Novel Accelerators

EuroNNAc 3

supported by EU via ARIES

Ralph W. Aßmann
Leading Scientist Accelerator R&D
DESY

Thanks for input and material to:
Massimo Ferrario, Manuela Boscolo, Phil Burrows,
Nadia Pastrone, Barbara Marchetti, Frank Zimmermann,
Brigitte Cros, Ulrich Dorda, Ulrich Schramm,
Wim Leemans, Jens Osterhoff, Athony Hartin,
Patric Muggli, Allen Caldwell, Edda Gschwendtner

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

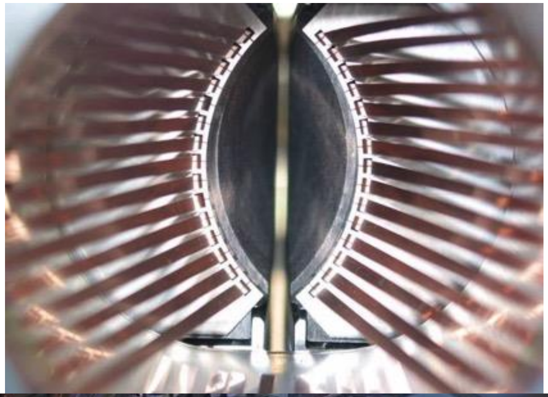
MT
MATTER AND TECHNOLOGIES

DESY

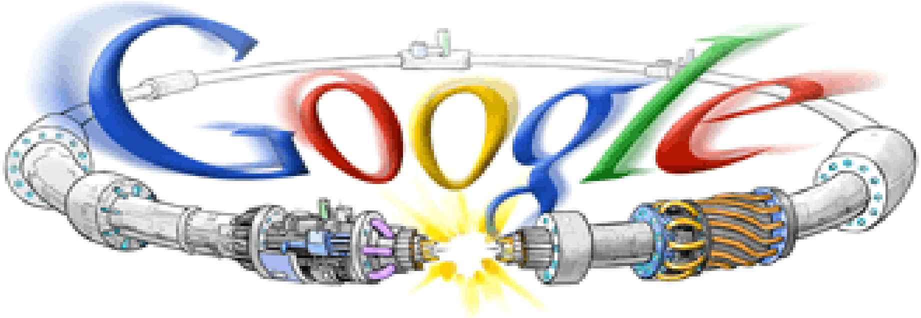
LHC as a Masterpiece of Accelerator Science

80 Years (and many inventions and R&D breakthroughs) after the first RF accelerator in Aachen

Higgs Sem. 4.7. 2012



First beam 10.9. 2008



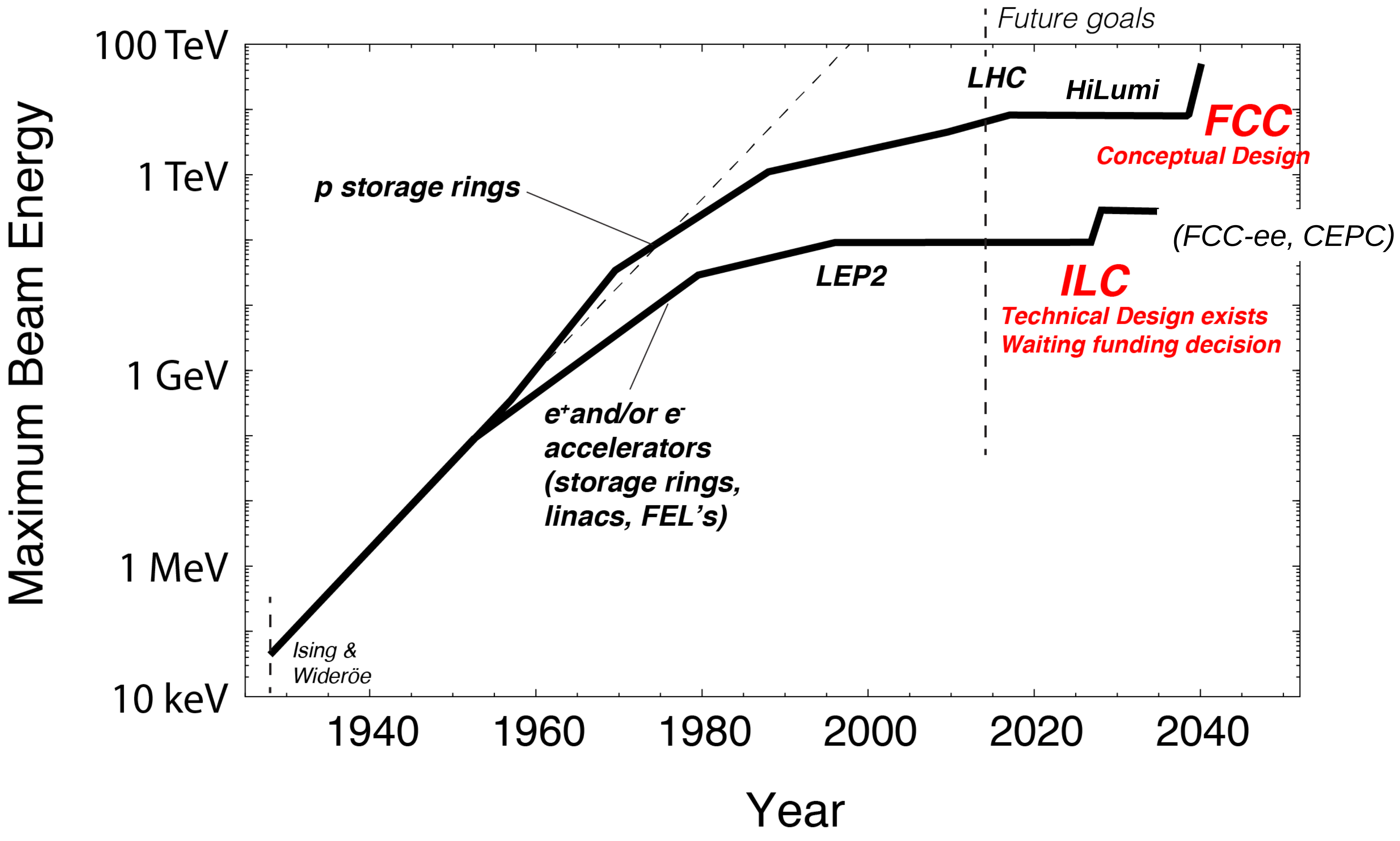
Livingston Plot: Progress at the Energy Frontier

Great success story: RF-based particle accelerators for discoveries and precision

Master-pieces of technology:

- LHC, LHC HiLumi
- SuperKEKb
- LEP, LEP-2
- Tevatron
- HERA
- RHIC
- …

Progress slowing down → **R&D** → new ideas and technologies?



How to Advance the Field of Particle Accelerators?

Looking for solutions

Hadron (p) circular collider

$$p = e \times R \times B_y$$

Increase bending field
SC bend magnet work (FCC-hh)

Increase radius = size (FCC-hh)

Lepton (e-,e+) circular collider

$$p \propto E_0 \times \sqrt[4]{r \times U_0}$$

Increase supplied RF voltage (FCC-ee)

Increase mass of acc. particle (muon)

Increase radius = size (FCC-ee)

Lepton (e-,e+) linear collider

$$p = L \times G_{acc}$$

Increase accelerating gradient
(a) Pushing existing technology (ILC, CLIC)
(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

Increase length (ILC, CLIC)

How to Advance the Field of Particle Accelerators?

Looking for solutions

Hadron (p) circular collider

$$p = e \times R \times B_y$$

Increase bending field

SC bend magnet work (FCC-hh)

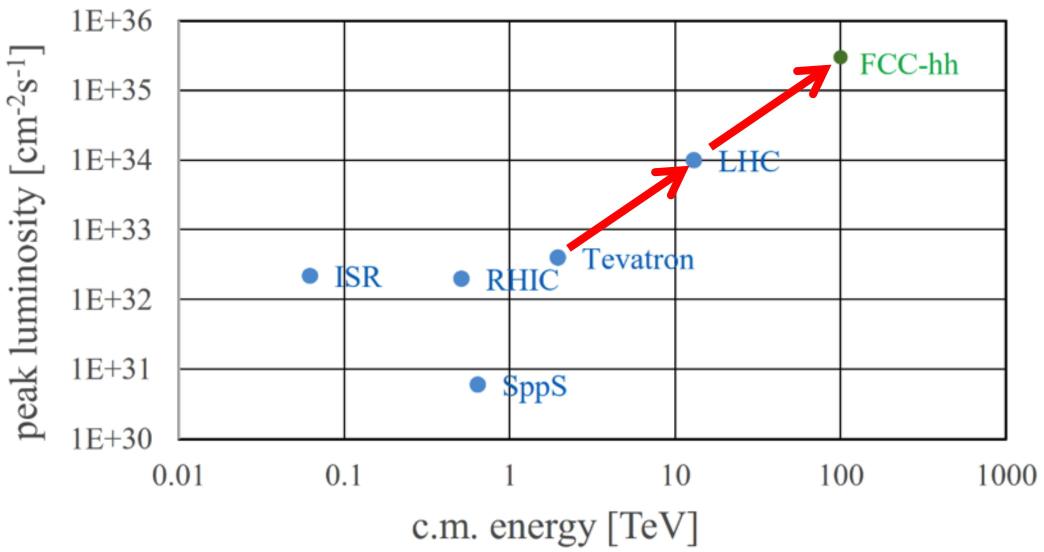
Increase radius = size (FCC-hh)

→ **16 Tesla magnet R&D work for future colliders (FCC, ...)**

Future Circular Collider (FCC)

Material from Frank Zimmermann

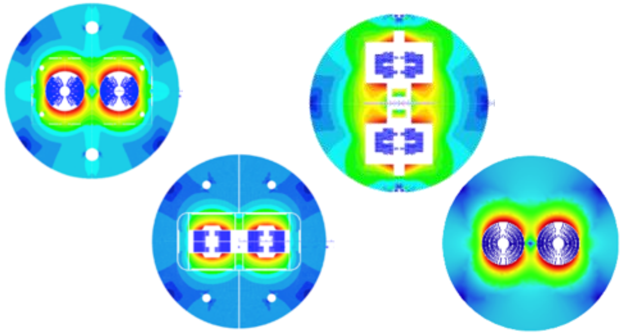
Aim at **~one order of magnitude performance increase** in both **energy and luminosity w.r.t LHC**



From LHC technology
8.3 T NbTi

via HL-LHC technology
11 T Nb_3Sn

to 16 T Nb_3Sn
EuroCirCol, Chart, US MDP

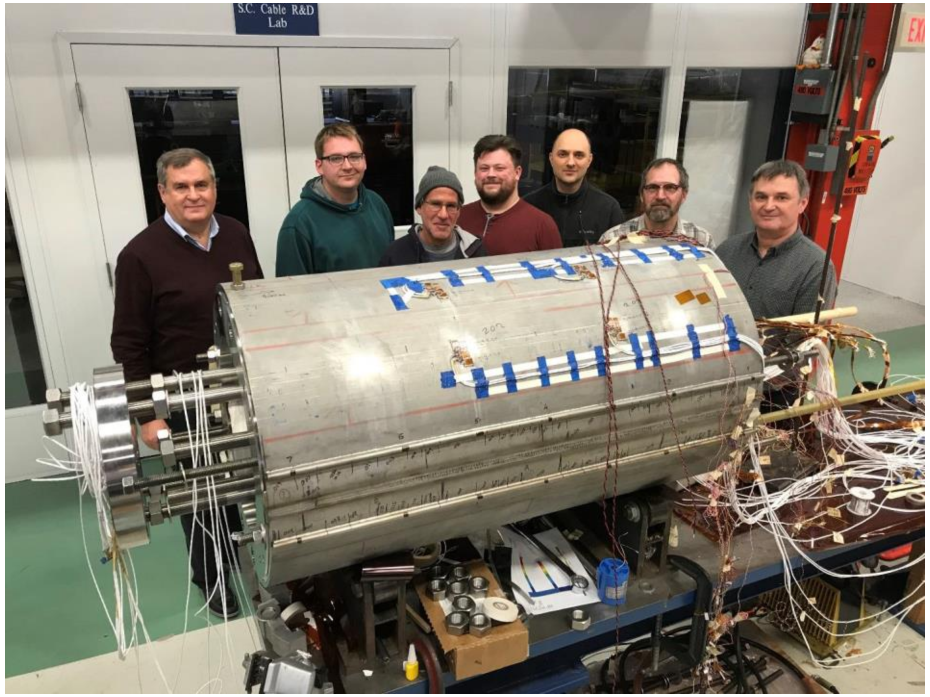


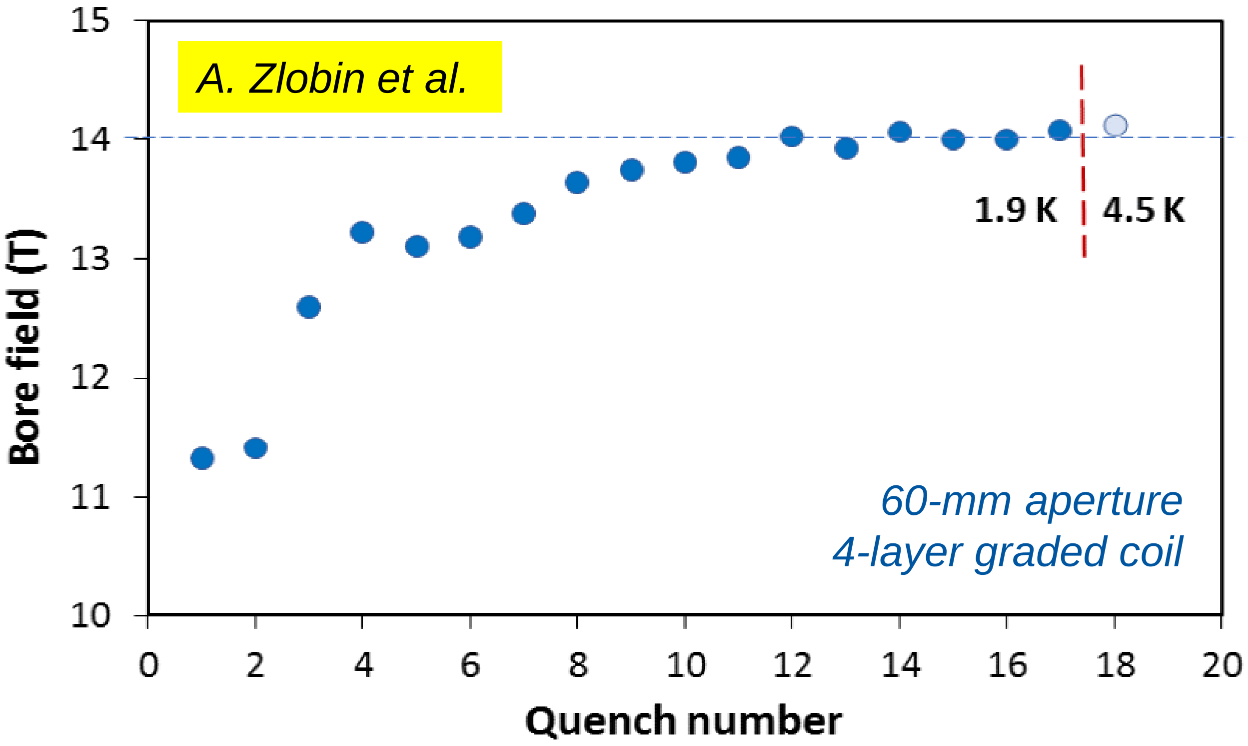
+ BINP

R&D

Future Circular Collider (FCC): 14 T Magnet Tested at FNAL

Material from Frank Zimmermann





- 15 T dipole demonstrator
- Staged approach: In first step pre-stressed for 14 T
- Second test foreseen in fall 2019 with additional pre-stress for 15 T

How to Advance the Field of Particle Accelerators?

Looking for solutions

→ **R&D on high accelerating gradients in metallic structures (CLIC, ILC, …)**

Lepton (e-,e+) linear collider

$$p = L \times G_{acc}$$

Increase length (ILC, CLIC)

Increase accelerating gradient

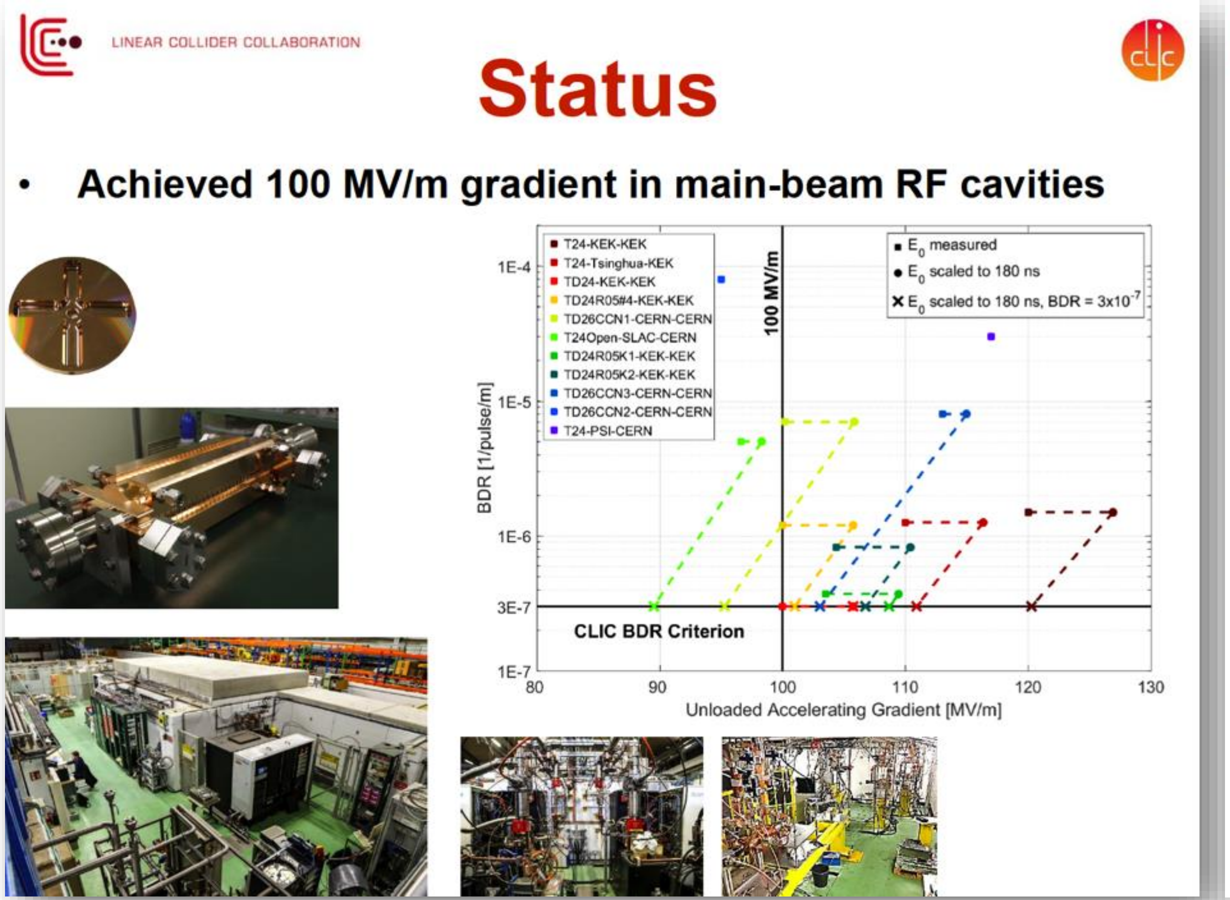
(a) **Pushing existing technology (ILC, CLIC)**

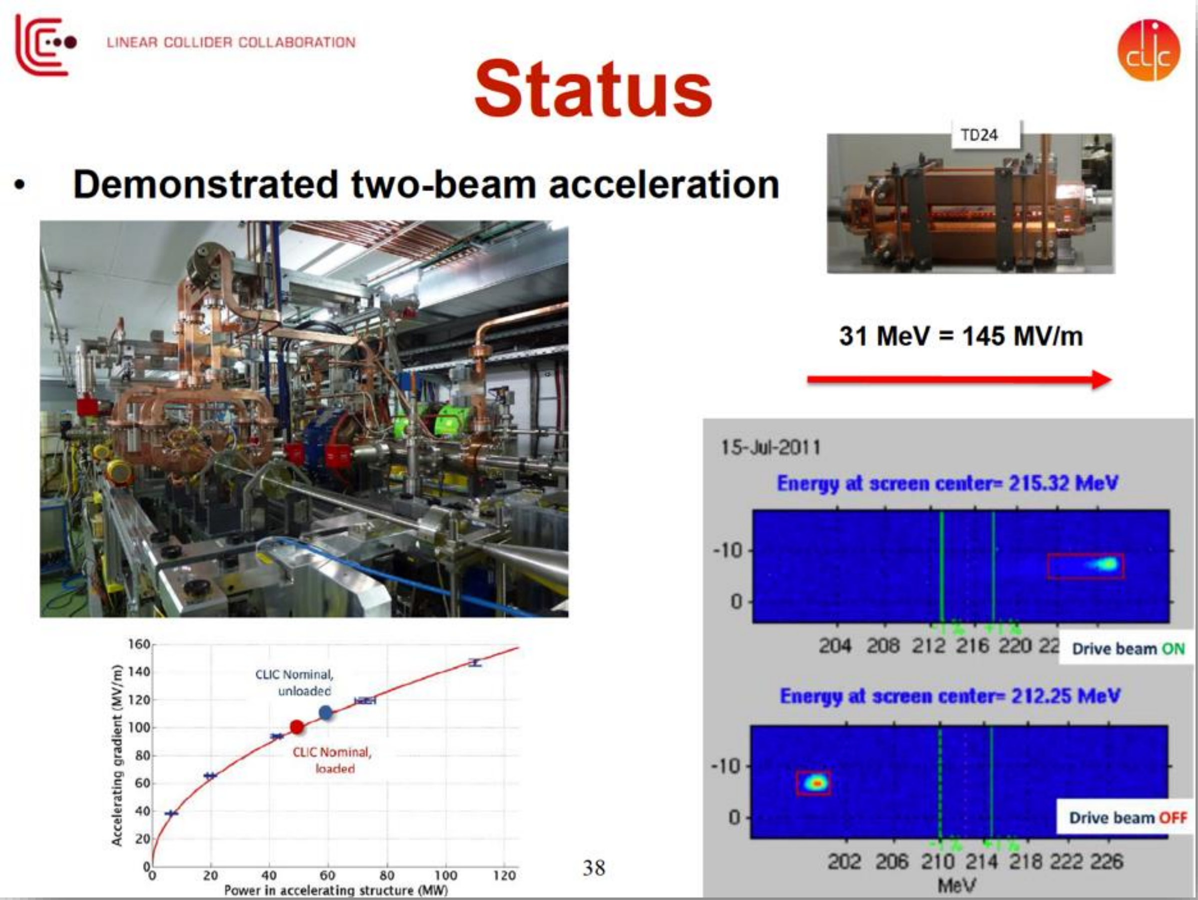
(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

CLIC Work on High Accelerating Gradient: 100 MV/m

See presentation by Phil Burrows

→ reduce accelerator length by factor 2-3

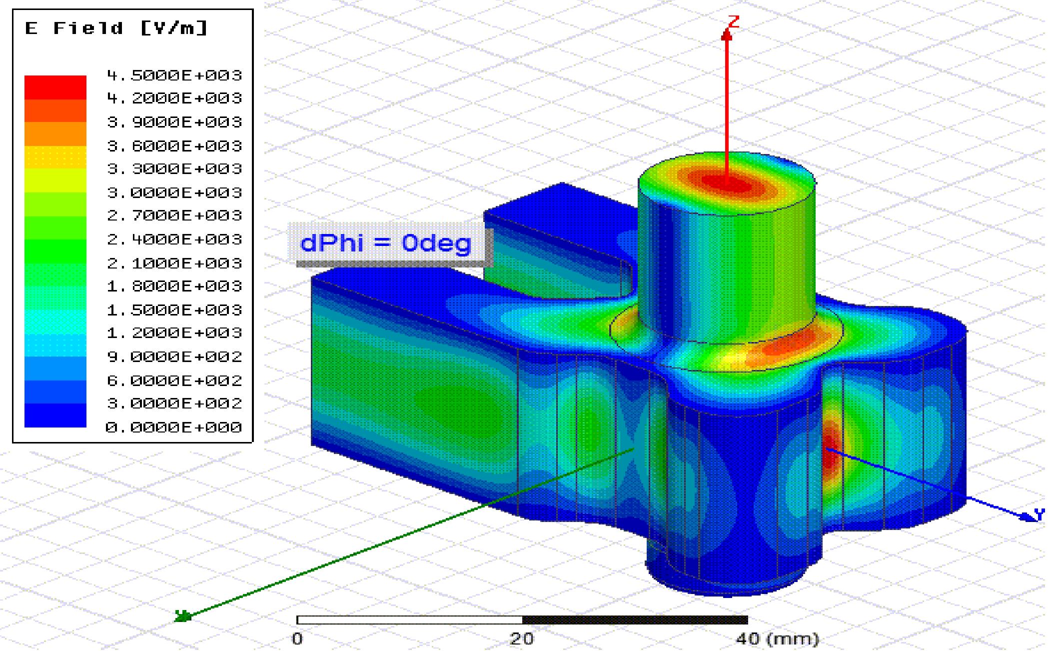




Slides from Phil Burrows and CLIC collaboration

Spin-Off from CLIC Technology: Femto-Second Diagnostics

X Band Transverse Deflecting Structure with Variable Polarization (DESY – CERN – PSI collaboration)

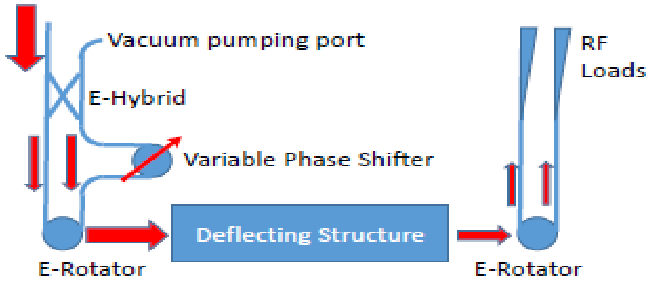


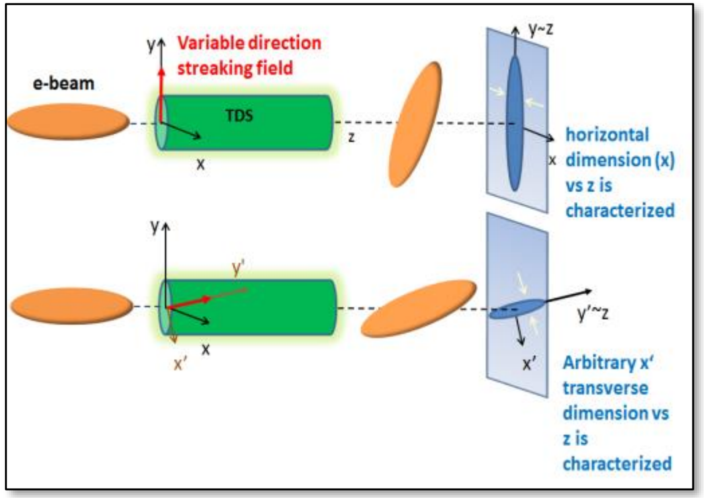
Variable Polarization Circular TE11 Mode Launcher

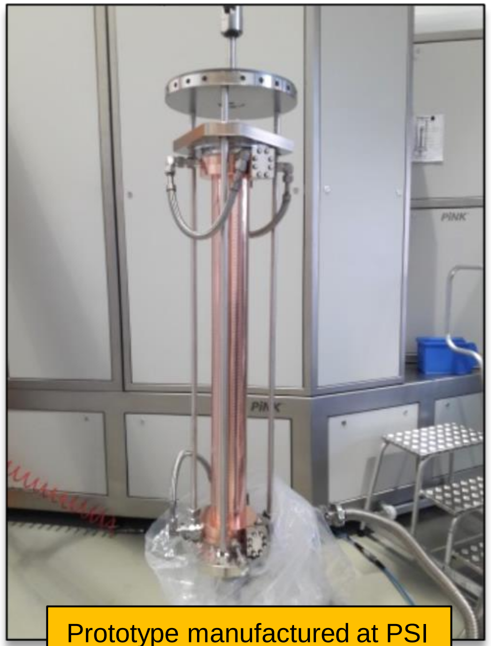
A. Grudiev, CLIC-note-1067 (2016)

Novel X-band TDS Concept with Variable Polarization

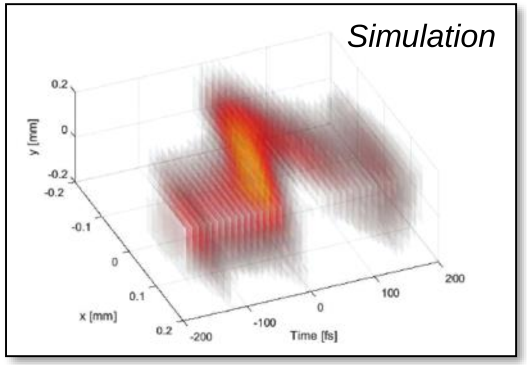
Phase difference between port 1 and port 2:
- 0 degree -> vertically streaking field
- 180 degree -> horizontally streaking field







Prototype manufactured at PSI



How to Advance the Field of Particle Acce

Looking for solutions

BIG factors → Novel concepts pursue transformative concepts that can open new horizons in energy reach for HEP research

Hadron (p) circular collider

$$p = e \times R \times B_y$$

Increase b
SC bend m

Increase radius = size (FCC-hh)

Factor 206.8 higher mass muon versus electron

Lepto

$$p \propto E_0 \times \sqrt[4]{r \times U_0}$$

Increase supplied RF voltage (FCC-ee)

Increase mass of acc. particle (muon)

Increase radius =

Factor 100 – 1000 higher accelerating gradient

Lepton (e-,e+) linear collider

$$p = L \times G_{acc}$$

Increase length (ILC, CLIC)

Increase accelerating gradient
(a) Pushing existing technology (ILC, CLIC)
(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

How to Advance the Field of Particle Accelerators?

Looking for solutions

→ R&D on muon colliders

Lepton (e-,e+) circular collider

$$p \propto E_0 \cdot \sqrt[4]{r \cdot U_0}$$

Increase supplied RF voltage (FCC-ee)

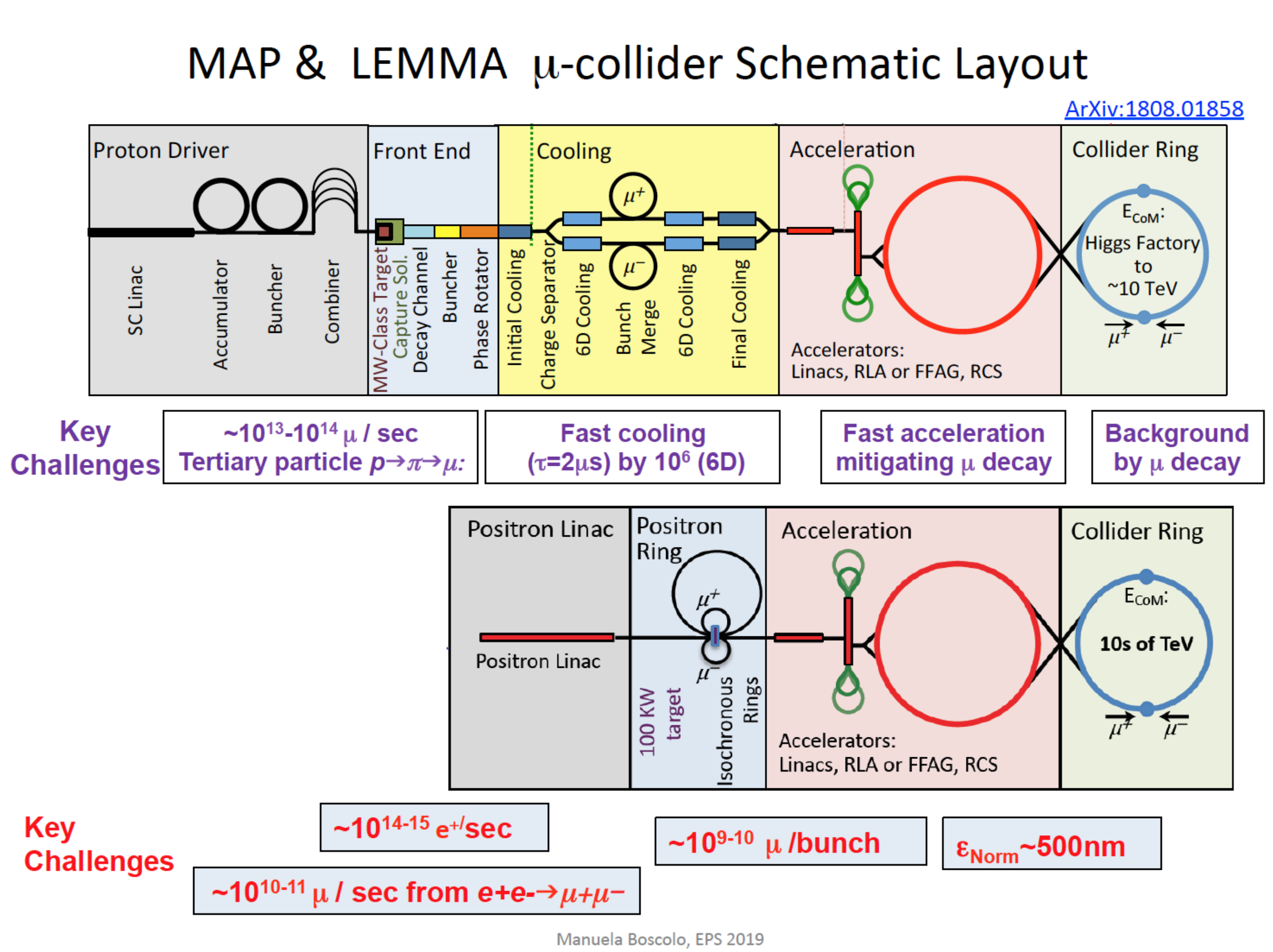
Increase mass of acc. particle (muon)

Increase radius = size (FCC-ee)

Factor 206.8 higher mass muon versus electron

R&D towards a Muon Collider: Known and New Concepts

Muon Collider Working Group (slides from M. Boscolo and N. Pastrone)



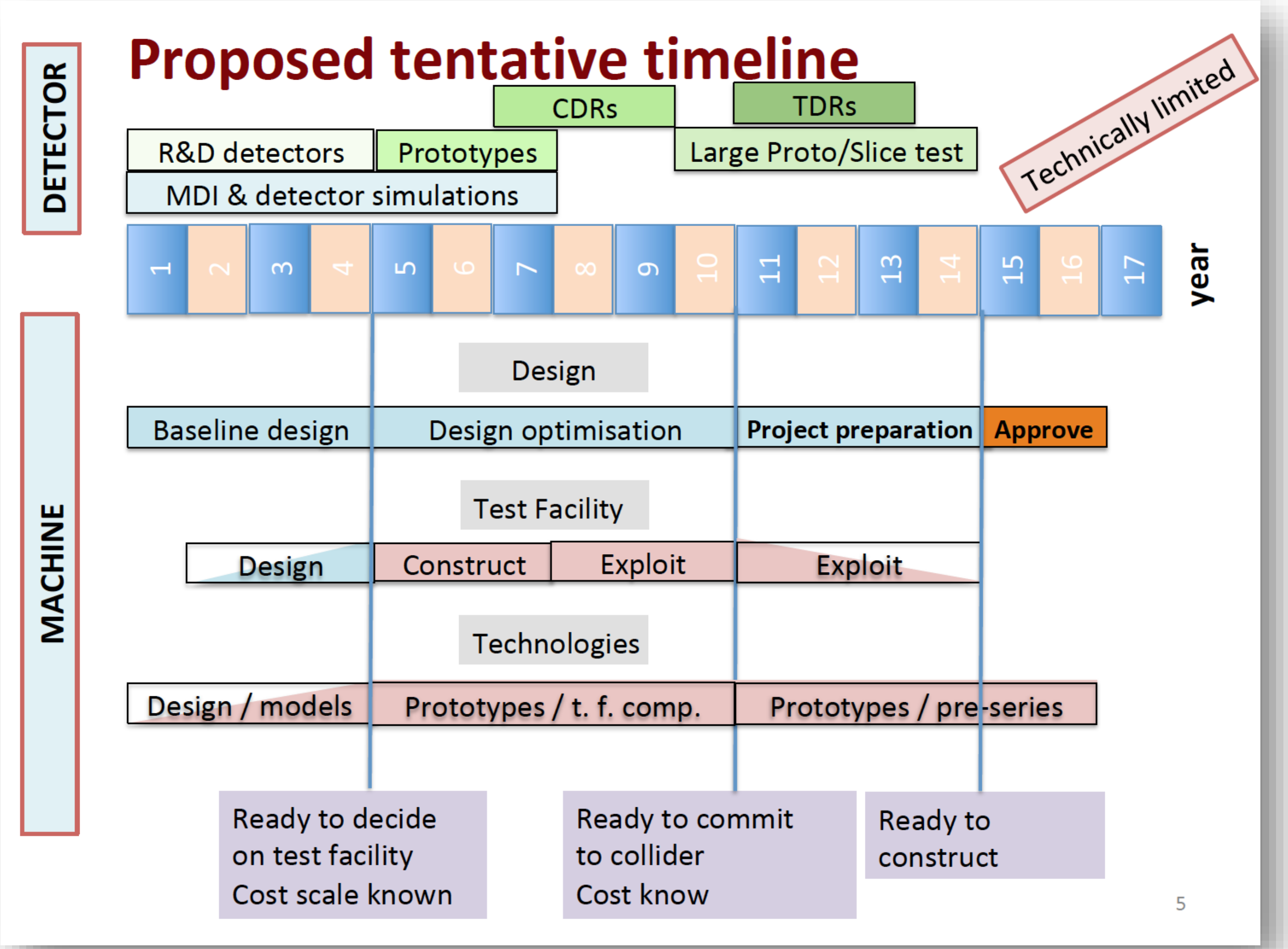
R&D topics identified:

- Integrated design (e.g. reduction of muon losses)
- Neutrino radiation
- Experimental conditions
- Beam production and **beam cooling**
- Acceleration complex design (cost, power, …)
- **Magnets**: fast ramping (for RCS), high field SC magnets
- Collider ring design
- Reuse of existing infrastructure
- LEMMA concept: consolidation

Slide Manuela Boscolo

R&D towards a Muon Collider: Timeline and Test Facility

Muon Collider Working Group (slides from M. Boscolo and N. Pastrone)



Muon collider R&D and timeline:

- Requires strategic support from particel physics
- In 4 years could decide a test facility
- About **6 years of R&D** to be performed before a construction project can be proposed: highly interesting R&D with **synergy to other R&D activities** in accelerators!
- In about 15 years ready for start of construction
- Operation from 2040 onwards or so, if all goes well

Slide Nadia Pastrone

How to Advance the Field of Particle Accelerators?

Looking for solutions

→ **R&D on ultra-high gradient accelerators**

Factor 100 – 1000 higher accelerating gradient

Lepton (e-,e+) linear collider

$$p = L \times G_{acc}$$

Increase length (ILC, CLIC)

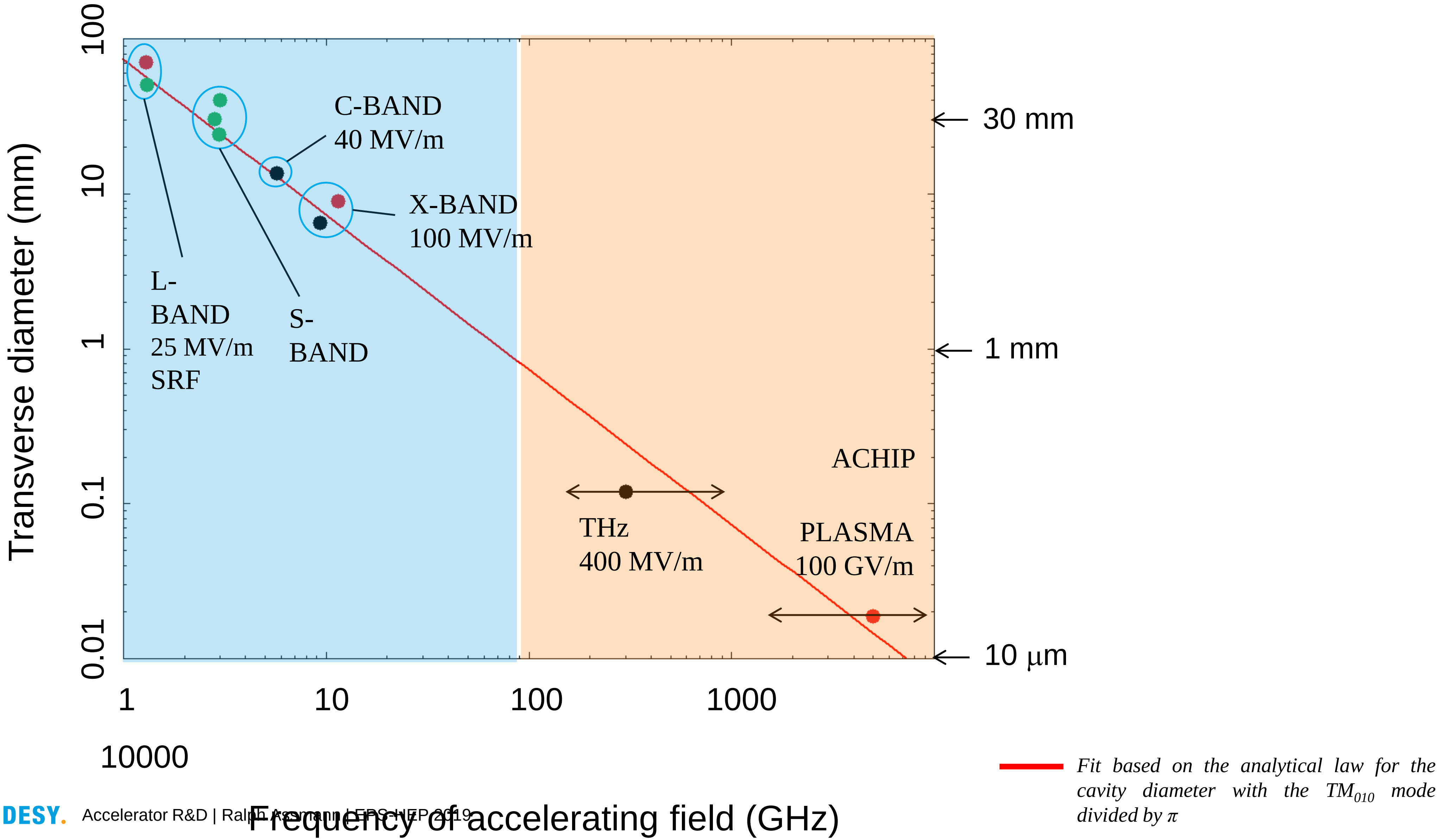
Increase accelerating gradient

(a) Pushing existing technology (ILC, CLIC)

(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

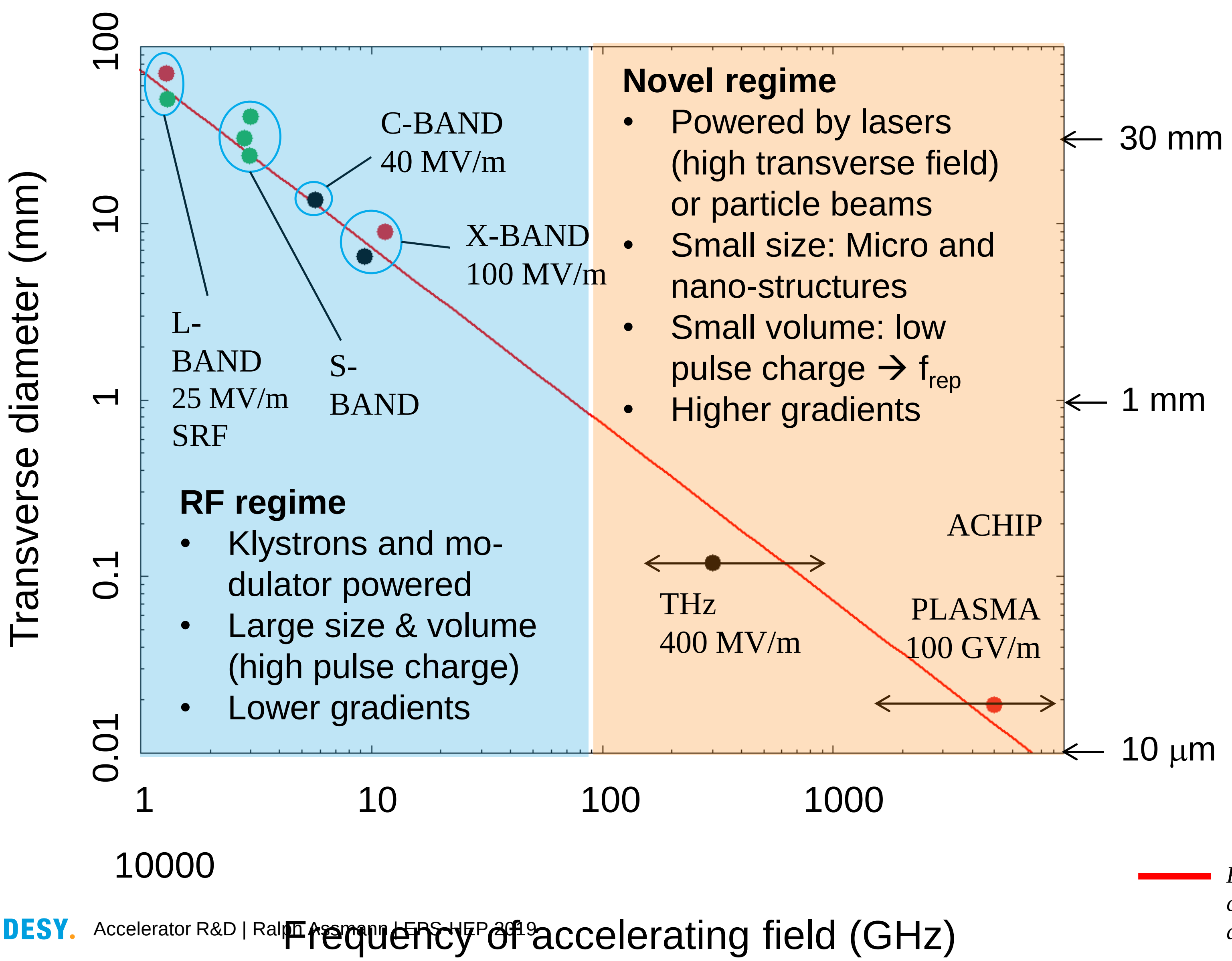
Accelerators: RF and Novel Regimes

High Gradients – High Frequencies – Small Dimensions



Accelerators: RF and Novel Regimes

High Gradients – High Frequencies – Small Dimensions



RF regime:

- **SRF**: High quality, high average power acceleration, long trains → CW
- **S/X band**: Generate high brightness beams for all purposes, ultra-fast science and diagnostics, injector for novel accelerators

Novel regime:

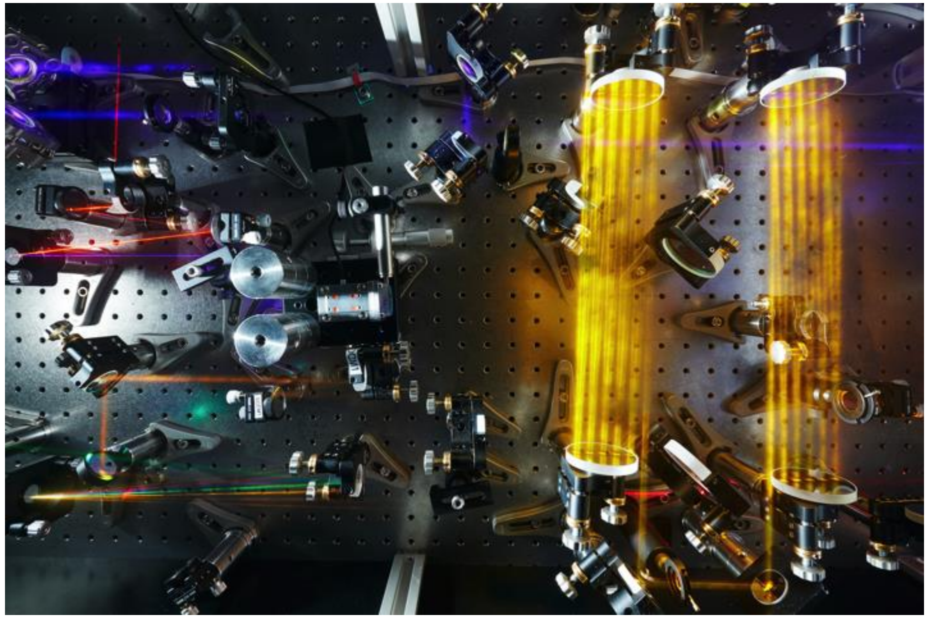
- Novel drivers, in particular **high tech lasers** for compact photon science and medical applications.
- **RF beam drivers** mainly for HEP or other high average power.
- **Compact** foot-print, low pulse charge, **high repetition rate**.
- **Challenges of micro and nano dimensions** – assess with modern tools (synergy with ultra-fast).

Laser-Driven Micro Structures (Vacuum - THz)

Vacuum dielectric accelerator

European Research Council
Established by the European Commission

- 1 GeV/m possible but low absolute energies achieved so far
- **AXSIS project (ERC synergy grant)** at DESY/ Uni Hamburg: THz laser-driven accelerator with atto-second science → *Kärtner/Fromme/Chapman/Assmann*



AXSIS

SMALL DIMENSIONS

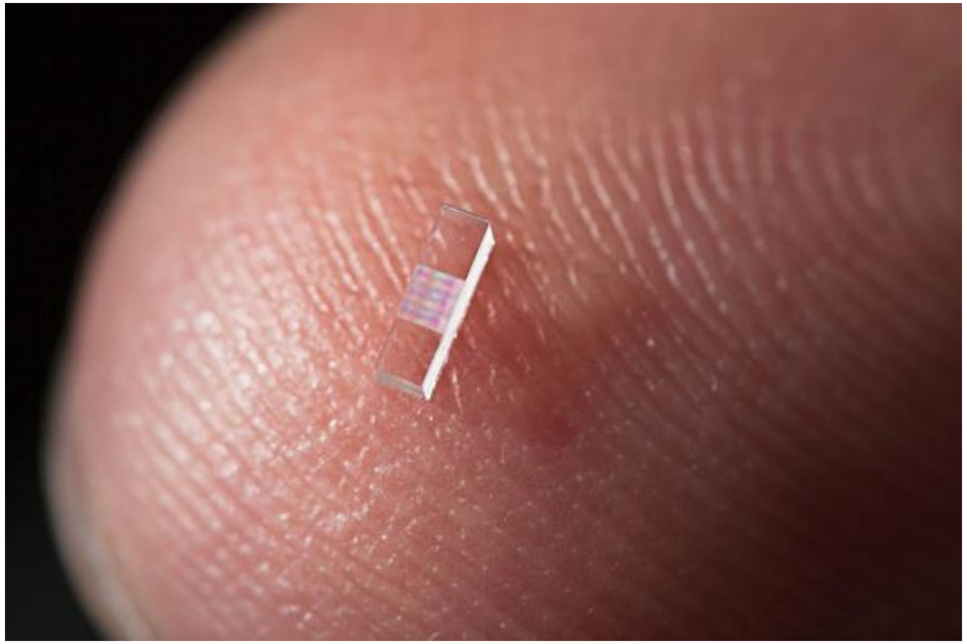
Laser-Driven Micro Structures (Vacuum - Optical)

Vacuum dielectric accelerator

ACHIP
Accelerator on a Chip International Program

- **“Accelerator on a Chip”** grant from Moore foundation for work by/at Stanford, SLAC, University Erlangen, DESY, University Hamburg, PSI, EPFL, University Darmstadt, CST, UCLA
- Lasers drive **structures that are engraved on microchips** (e.g. Silicium)
- Major breakthroughs can be envisaged:
  - **Mass production**
  - **Implantable accelerators** for in-body irradiation of tumors
  - Accelerators for **outer space**

SMALL DIMENSIONS



The Plasma Accelerator

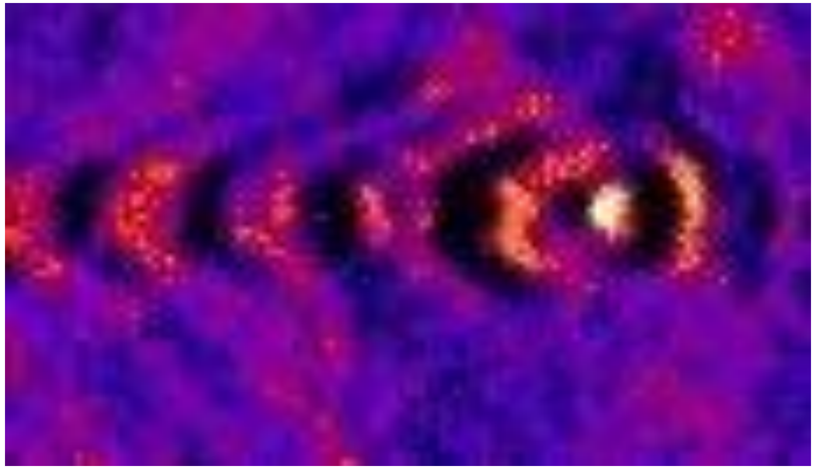
Overcome high-field limitations of metallic walls with dynamic plasma structures (undestructible)

New idea in 1979 by Tajima and Dawson: Wakefields inside a homogenous plasma can convert

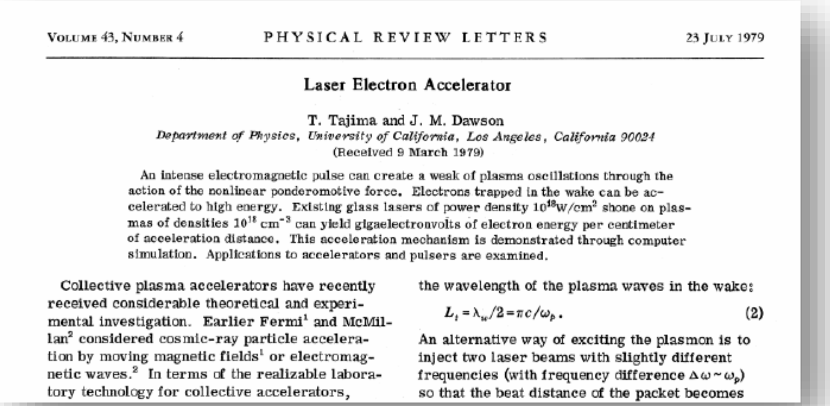
transverse forces into **longitudinal accelerating fields**

Pondero-motive force of a laser — or — Space charge force of a charged particle bunch (e-, p+) → transverse forces

longitudinal accelerating fields → Accelerating gradients of 10 GeV/m to 1,000 GeV/m



Courtesy M. Kaluza



VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

T. Tajima and J. M. Dawson

Department of Physics, University of California, Los Angeles, California 90024

(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

Collective plasma accelerators have recently received considerable theoretical and experimental investigation. Earlier Fermi[1] and McMillan[2] considered cosmic-ray particle acceleration by moving magnetic fields[1] or electromagnetic waves.[2] In terms of the realizable laboratory technology for collective accelerators,

the wavelength of the plasma waves in the wake:

$$L_t = \lambda_w/2 = \pi c/\omega_p . \quad (2)$$

An alternative way of exciting the plasmon is to inject two laser beams with slightly different frequencies (with frequency difference $\Delta\omega \sim \omega_p$) so that the beat distance of the packet becomes

Options for driving wakefields:

- **Lasers**: Industrially available, steep progress, path to low cost
  Limited energy per drive pulse (up to **50 J**)
- **Electron bunch**: Short bunches (need μm) available, need long RF accelerator
  More energy per drive pulse (up to **500 J**)
- **Proton bunch**: Only long (inefficient) bunches, need very long RF accelerator
  Maximum energy per drive pulse (up to **100,000 J**)

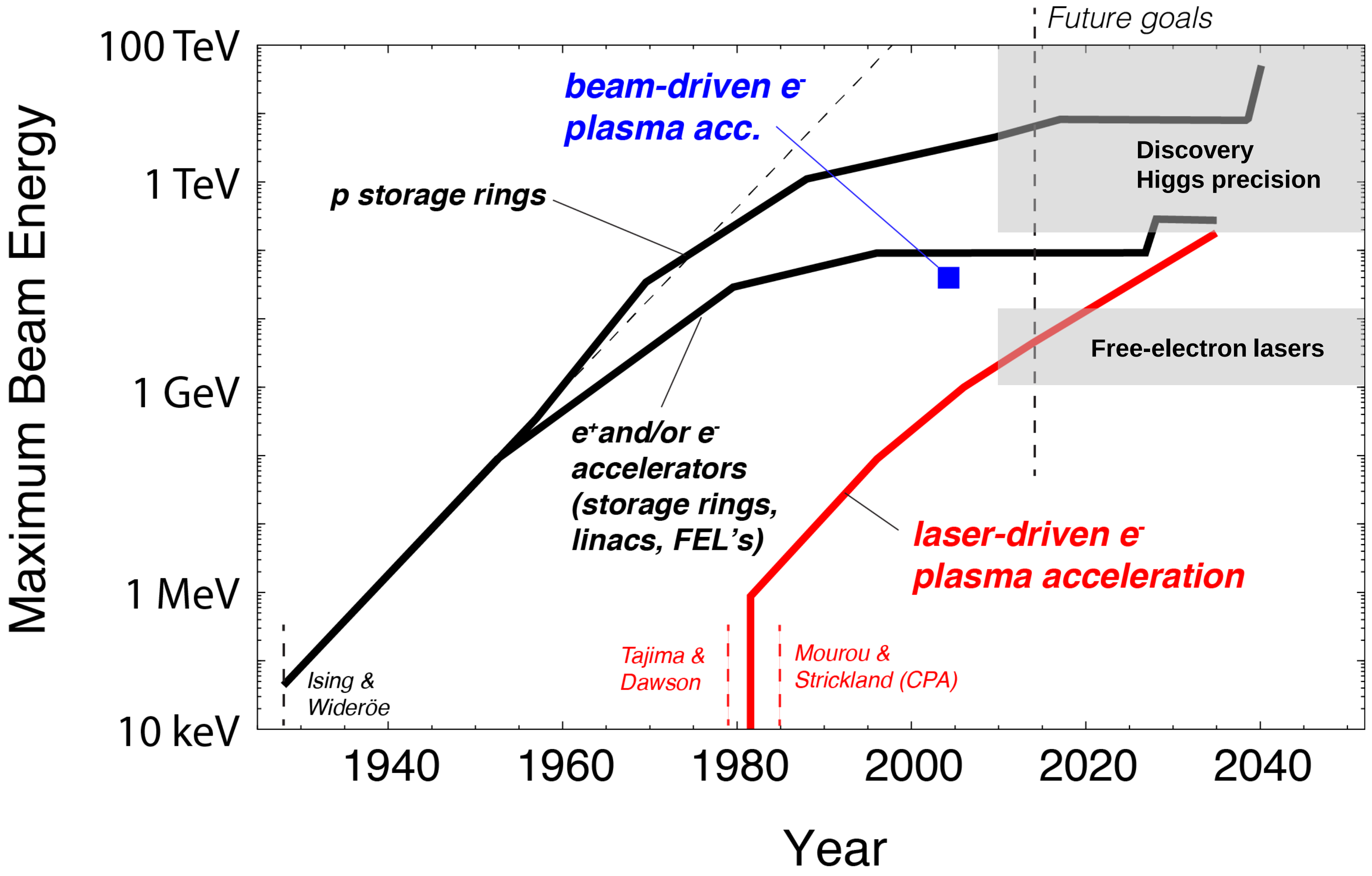
Livingston Plot: Progress at the Energy Frontier

Great success story: RF-based particle accelerators for discoveries and precision

Master-pieces of technology:

- LHC, LHC HiLumi
- SuperKEKb
- LEP, LEP-2
- Tevatron
- HERA
- RHIC
- …

Progress slowing down → **R&D** → new ideas and technologies?



R&D Paths Plasma Accelerators

EuroNNAc Assessment

External RF injection

Betatron radiation in plasma

Power and Efficiency

Stability and beam quality

Polarized beams in plasmas

e- driven PWFA

Multi-stage LWFA

Synchrotron radiation with advanced beams

Positron acceleration

Femto-second synchronization

p+ driven PWFA

External optical injection

Plasma undulator

Laser wakefield acceleration (LWFA) with self injection

Sizes reflect very roughly ongoing efforts in R&D topics

R&D Paths Plasma Accelerators

EuroNNAc Assessment

Can plasma accelerators deliver polarized beams?

Can plasma accelerators deliver integrated luminosity?

Can plasma accelerators deliver peak luminosity?

Can plasma accelerators accelerate positrons?

External RF injection

Betatron radiation in plasma

Power and Efficiency

Stability and beam quality

Polarized beams in plasmas

e- driven PWFA

Multi-stage LWFA

Synchrotron radiation with advanced beams

Positron acceleration

Femto-second synchronization

p+ driven PWFA

External optical injection

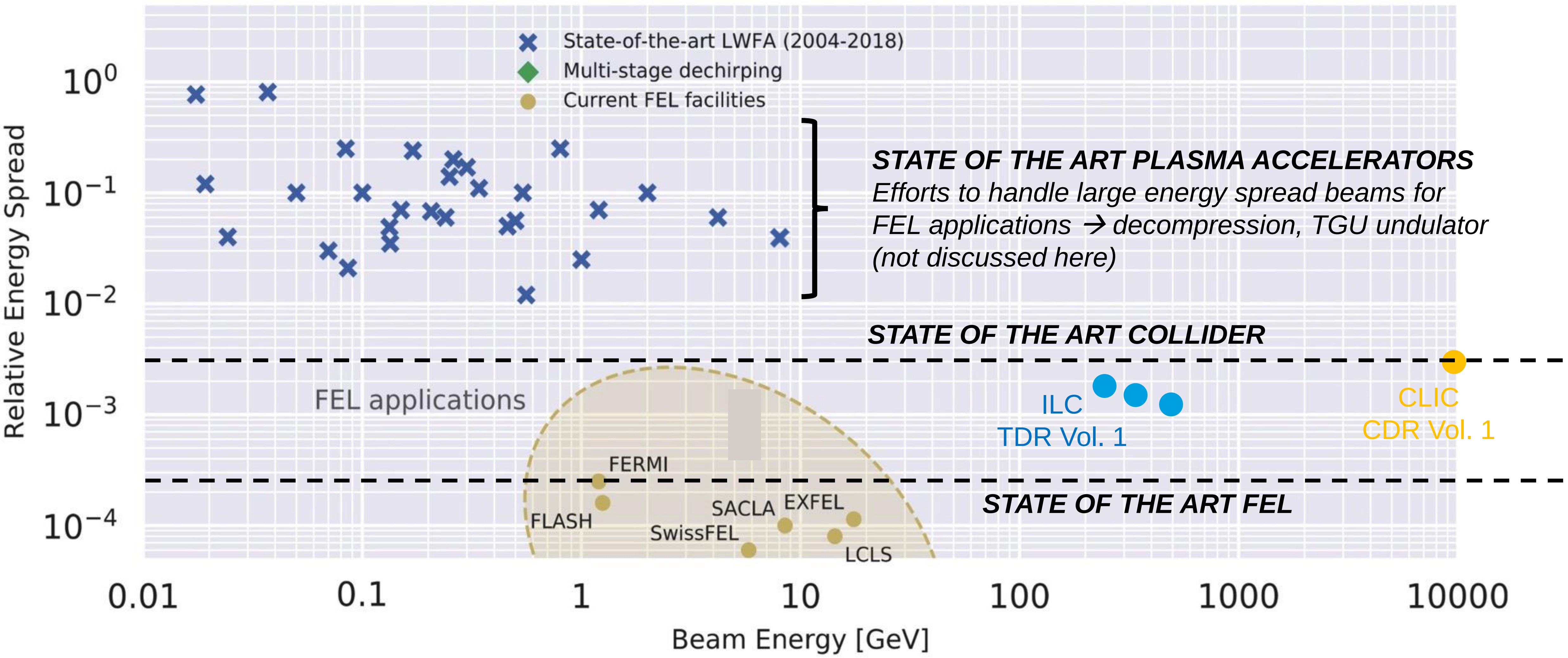
Plasma undulator

Laser wakefield acceleration (LWFA) with self injection

$$L = \frac{N_{e+}N_{e-}f_r}{4ps_xs_y}$$

Energy Spread Challenge

State of the art in plasma accelerators versus requirements



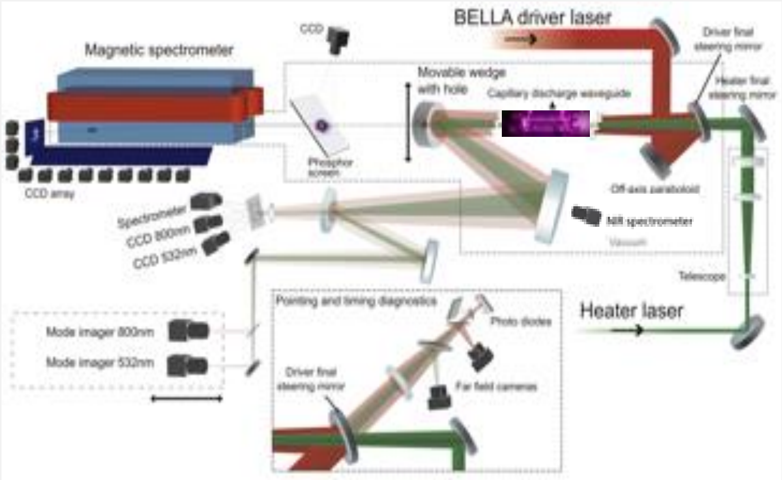
BELLA Berkeley Lab

Slide Edda Gschwendtner

High Energy Laser Plasma Wakefield Acceleration & Multi Stage

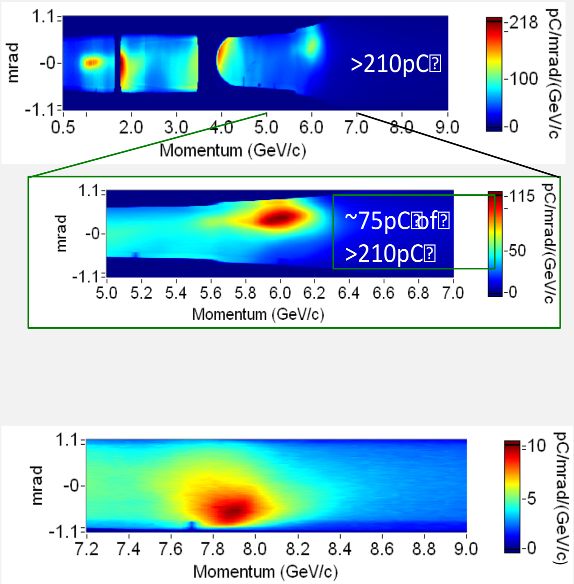
Petawatt laser guiding and electron beam **acceleration to 8 GeV** in a laser-heated capillary discharge waveguide

A.J.Gonsalves et al., Phys.Rev.Lett. ***122****, 084801 (2019)*



Laser heater added to capillary

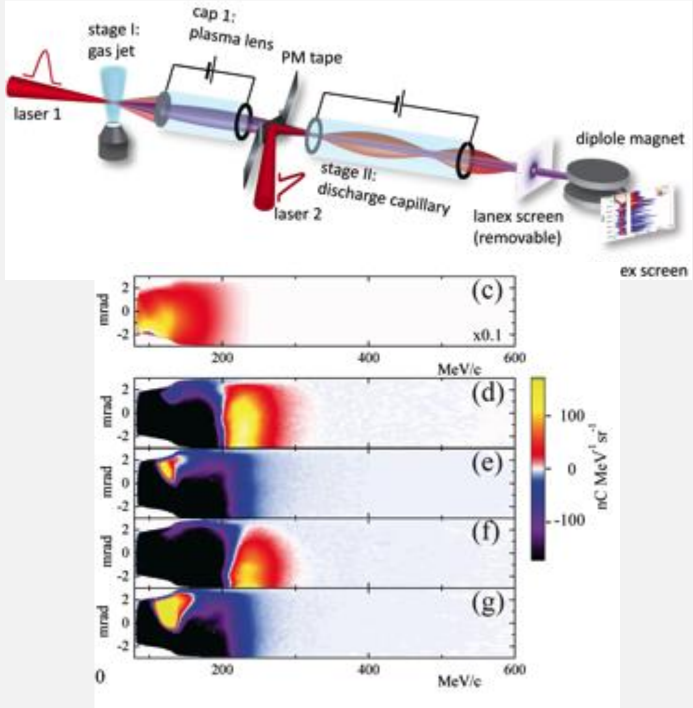
Electron spectra, up to 6-8 GeV



→ path to 10 GeV with continued improvement of guiding in progress

Multistage coupling of independent laser-plasma accelerators

S. Steinke, Nature ***530****, 190 (2016)*



Staging demonstrated at 100MeVs level.

FACET, SLAC, US

Slide Edda Gschwendtner

Premier R&D facility for PWFA: Only facility capable of e+ acceleration

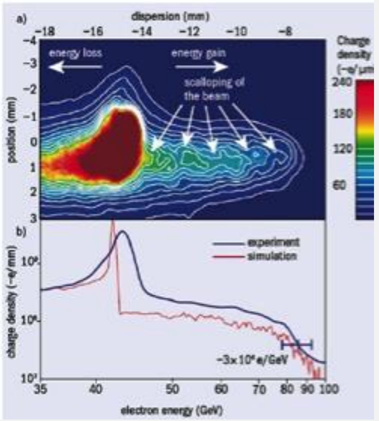
- Facility hosted more than 200 users, 25 experiments
- One high profile result a year
- Priorities balanced between focused plasma wakefield acceleration research and diverse user programs with ultra-high fields
- Unique opportunity to develop future leaders

- **Timeline:**
  - Commissioning (2011)
  - Experimental program (2012-2016)
- **Key PWFA Milestones:**
  - ✓ Mono-energetic e⁻ acceleration
  - ✓ High efficiency e⁻ acceleration
  - ✓ First high-gradient e⁺ PWFA
  - ✓ Demonstrate required emittance, energy spread

Energy doubling of 42 GeV electrons in a metre-scale plasma wakefield accelerator

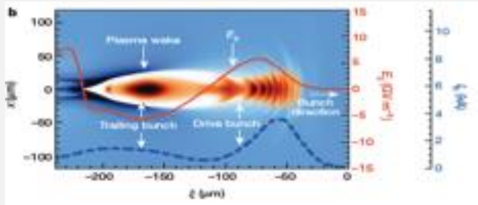
*I. Blumenfeld et al, Nature 455, p 741 (**2007**)*

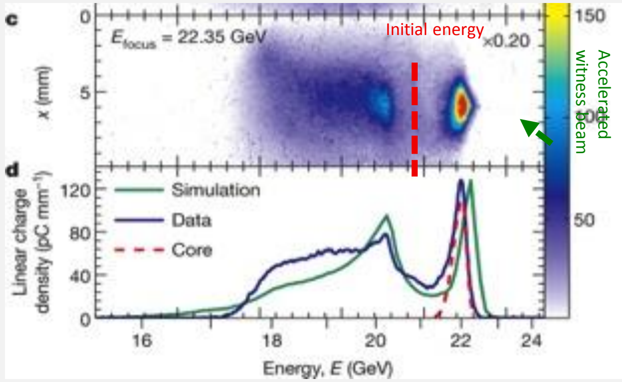
→ **gradient of 52 GV/m**



High-Efficiency acceleration of an electron beam in a plasmas wakefield accelerator, 2014

*M. Litos et al., doi, Nature, 6 Nov **2014**, 10.1038/nature 13882*

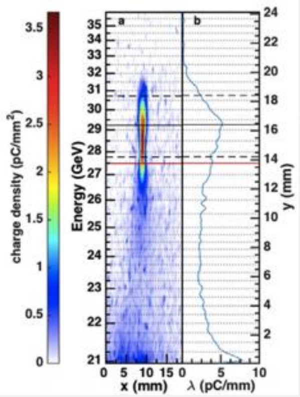




70 pC of charge accelerated, 2 GeV energy gain, 5 GeV/m gradient ➔ **Up to 30% transfer efficiency, ~2% energy spread**

9 GeV energy gain in a beam-driven plasma wakefield accelerator

*M Litos et al **2016** Plasma Phys. Control. Fusion 58 034017*



Positron Acceleration, FACET

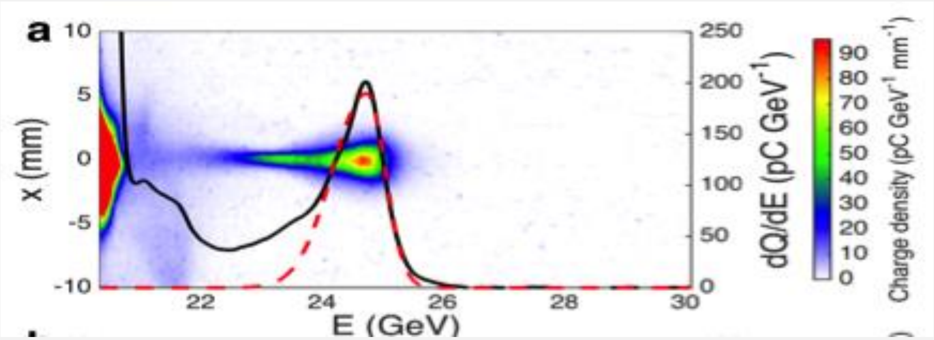
Slide Edda Gschwendtner

Positrons for high energy linear colliders: high energy, high charge, low emittance

First demonstration of positron acceleration in plasma (FFTB)
*B.E. Blue et al., Phys. Rev. Lett. 90, 214801 (**2003**)*
M. J. Hogan et. al. Phys. Rev. Lett. 90 205002 (2003).

Energy gain of 5 GeV. **Energy spread can be as low as 1.8%** (r.m.s.).

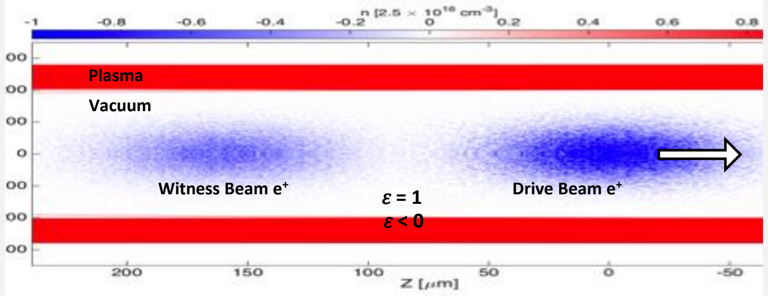
*S. Corde et al., Nature **524**, 442 (2015)*



High-density, compressed positron beam for non-linear PWFA experiments. Energy transfer from the front to the back part of the bunch.

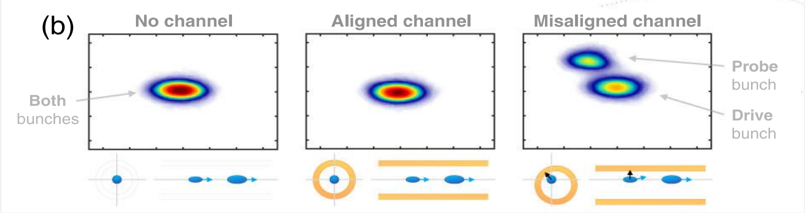
Two-bunch positron beam: First demonstration of controlled beam in positron-driven wake
S. Doche *et al.*, Nat. Sci. Rep. 7, 14180 (2017)

Hollow plasma channel: positron propagation, wake excitation, acceleration in 30 cm channel.
S. Gessner et. al. Nat. Comm. 7, 11785 (2016)



Measurement of **transverse wakefields in a hollow plasma** channel due to off-axis drive bunch propagation.

*C. A. Lindstrøm et. al. Phys. Rev. Lett. 120 124802 (**2018**).*



➔ **Emittance blow-up is an issue!** → Use hollow-channel, so no plasma on-axis, no complicated forces from plasma electrons streaming through the plasma → but then strong transverse wakefields when beams are misaligned.

National Projects in Europe

Growing since the 1990's

In Europe different countries investing into advanced accelerators:

- Since 1990's: **UK** and **France**.
- Since 2000's: Germany, Sweden, Italy
- Since 2010's big accelerator labs: CERN, DESY, GSI

Soon major big steps coming:

- CILEX: multi-PW
- ELI facilities

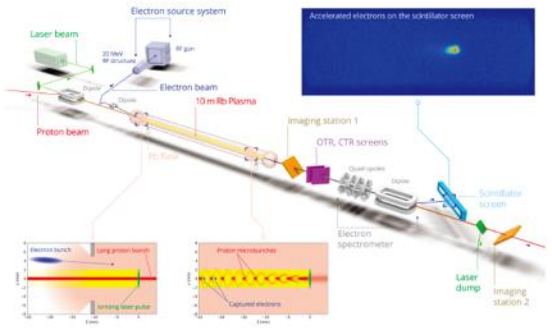
Plus some strategic national/European projects...

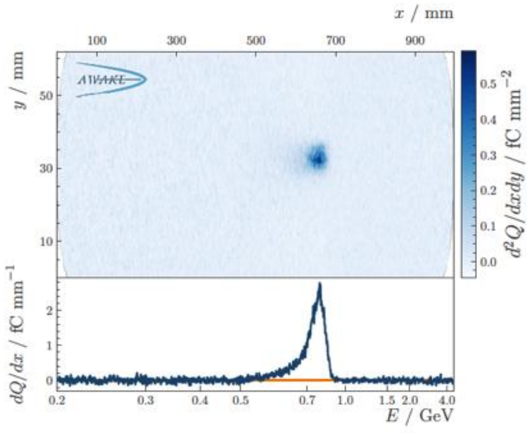
AWAKE: Proton-Driven Plasma Acceleration at CERN

Using energy stored in protons for driving plasma acceleration

AWAKE proton driven plasma wakefield accelerator

[E. Adli et al (AWAKE Collaboration), Nature 561 (2018) 316]





- **AWAKE concept** - PWA with proton driver. Longer propagation length in plasma → wakefield acceleration of e^- to high energy in a single stage
- Pre-ionised Rb plasma in 10 m plasma cell. plasma wavelength $\mathcal{O}(1)$ mm, proton $\sigma_z \mathcal{O}(10)$ cm
- Self modulation of 400 GeV proton bunch observed → microbunches with associated wakefields
- 18 MeV electrons injected, accelerated up to 2 GeV
- Papers available:
  Experiment Nature **561** (2018) 316
  Applications arXiv: 1809.01191, 1809.04478
- For more details, please see POSTER (**824. AWAKE: the proton-driven plasma wakefield accelerator experiment at CERN, presented by E. Adli, Monday 15/7 18h30-21h00**)

A. Hartin | AWAKE physics applications | 3/16

Material from Anthony Hartin (AWAKE collaboration)

2 GeV
electron acceleration

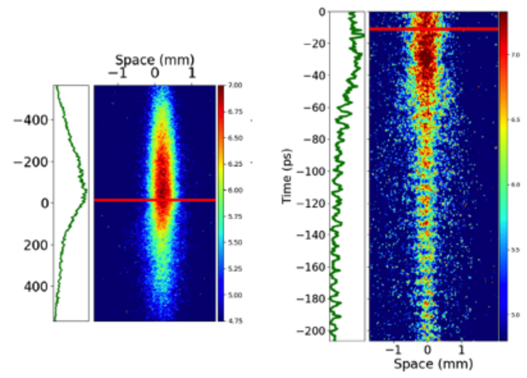
New principle works

AWAKE: Proton-Driven Plasma Acceleration at CERN

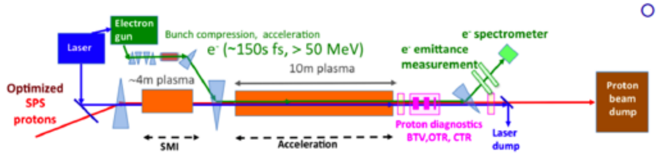
Using energy stored in protons for driving plasma acceleration

AWAKE Outlook

[W. Bartmann et al, AWAKE++, CERN-PBC-REPORT-2018-005]



- **Goals for AWAKE Run 1 (2016-2018) achieved**: Self modulation of proton bunch in plasma, Electron capture and GeV level acceleration
- **AIMs for run 2 (2021-2024)**:
  - Scalable acceleration to 1 GV/m, 100 pC
  - Control emittance to 10 mm mrad
  - High energy electron beams (to order 10 GeV)
- **Goals after the end of run 2:** Increase beam energy ($\geq$ 50 GeV). Use beams for novel and worthwhile physics experiments
- **We are studying three possible experiments**
  - Dark photon beam dump experiment
  - Non perturbative QFT tests
  - High energy ep collisions



A. Hartin | AWAKE physics applications | 4/16

Material from Anthony Hartin (AWAKE collaboration)

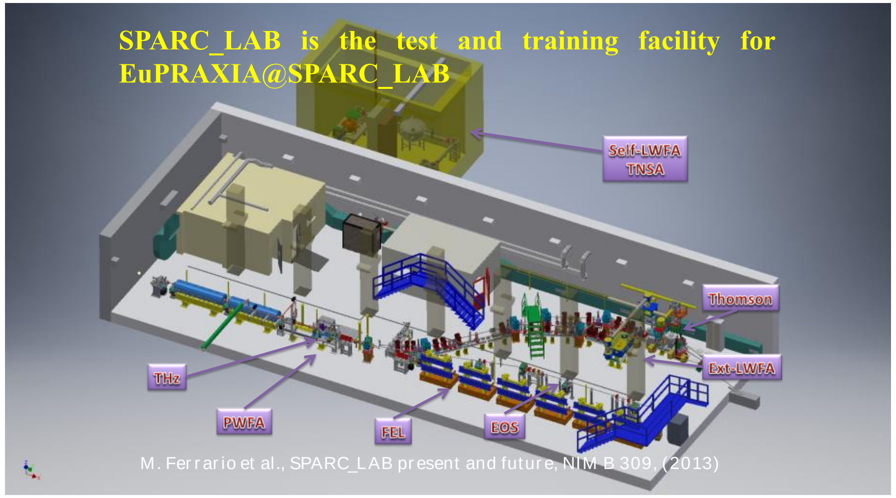
⇨ **1 GV / m** by 2024

⇨ **50 GeV** e- beam

Ideas for **first particle physics experiments**

SPARCLAB, Frascati, Italy

Main challenges addressed in this facility: beam quality, beam transport

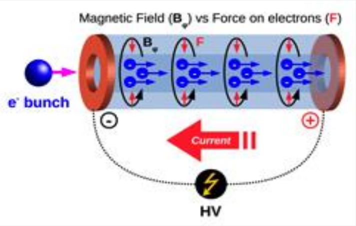


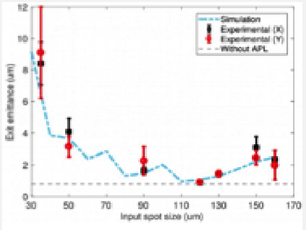
- 150 MeV drive/witness beam
- FEL experiments
- Resonant PWFA
- LWFA with 200 TW laser

Slide Edda Gschwendtner

Plasma Lens Experiments:

Acceleration of high brightness beams and transport to the final application, while preserving the high quality of the 6D phase space



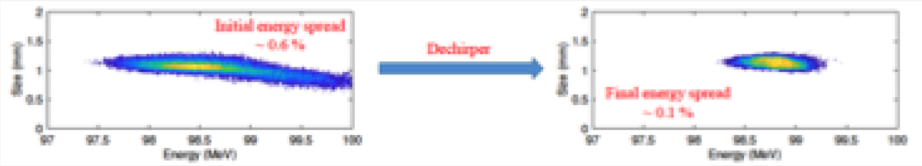


R. Pompili et al., PRL 121 (2018), 174801

***BELLA, LBNL:** J. van Tilborg et al., PRL 115 (2015), 184802*
***CLEAR, CERN**: C.A. Lindstrom et al., PRL 121 (2018), 194801*

Plasma dechirper:

Longitudinal phase-space manipulation with the wakefield induced in plasma by the beam itself.



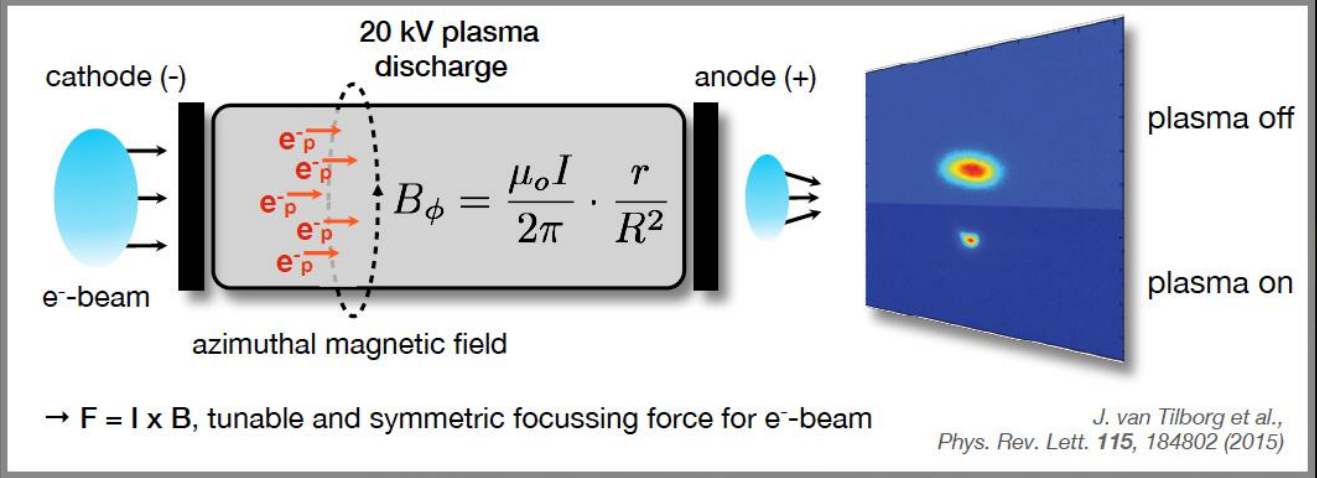
From 0.6% to 0.1% energy spread

V. Shpakov et al., PRL 122 (2019), 114801

***FLASHForward, DESY:** R. D’Arcy et al., PRL 122 (2019), 034801*

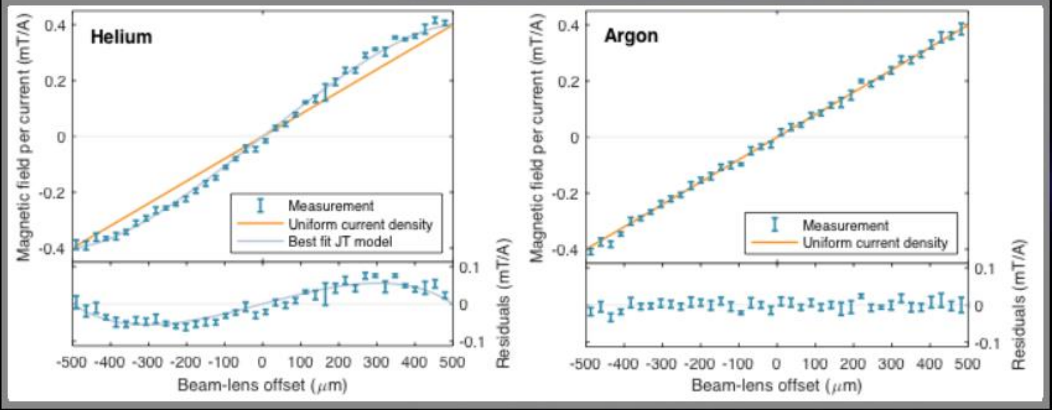
FLASHForward at DESY: e- driven Plasma Acceleration

One research direction: Aberration-free, kT/m Active Plasma Lenses

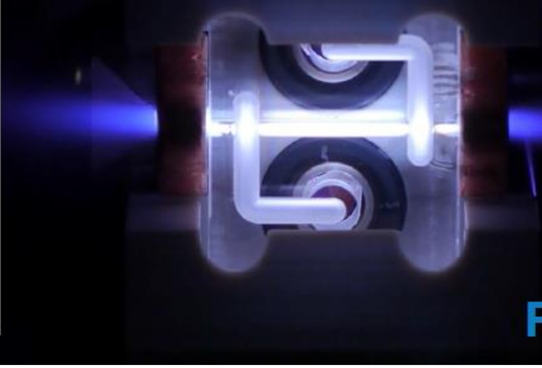


J. van Tilborg et al., Phys. Rev. Lett. **115**, *184802 (2015)*

- *Idea:* utilize APL before temperature equilibration can take place
- Substitute Hydrogen/Helium with Argon to extend timescale ∝ m_{ion}
- Experiment at CLEAR, CERN: 216 MeV, 50 µm rms size, 3 µm norm. emittance, 410 A current at 70 ns
- Argon: emittance conserved
  Helium: emittance not conserved



C. A. Lindstrom *et al.*,
Phys. Rev. Lett. 121, 194801(2018)



- Technology attractive for
  - (positron) beam capturing
  - adiabatic final focussing (Oide limit)

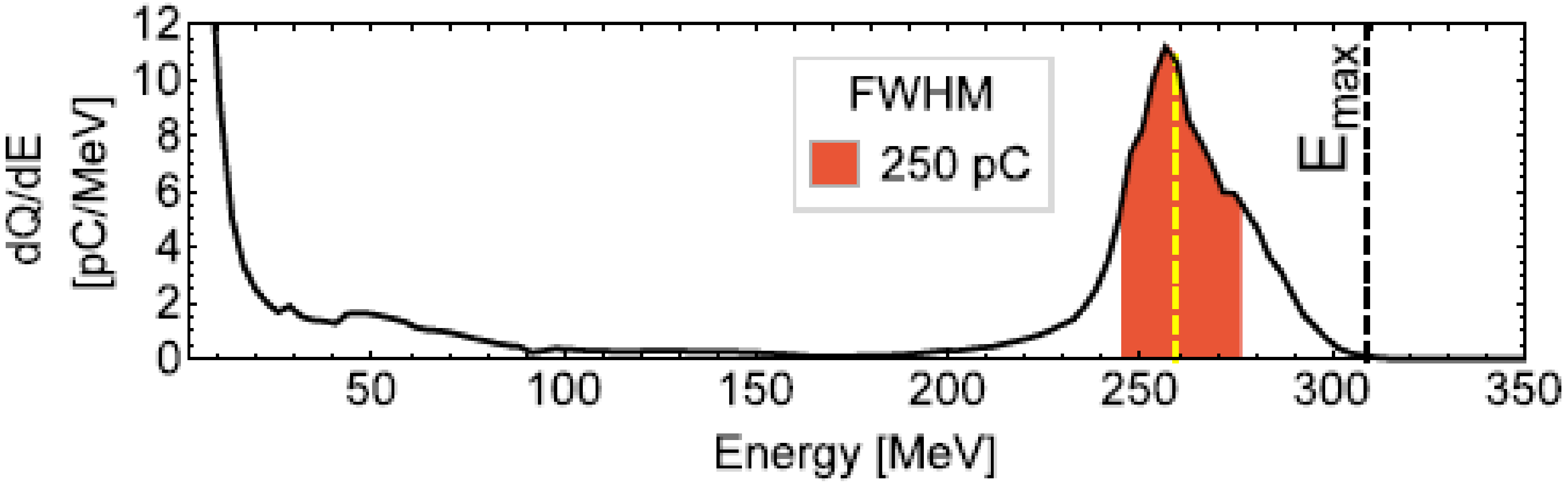
FLASHFORWARD

in collaboration between

J. Osterhoff et al

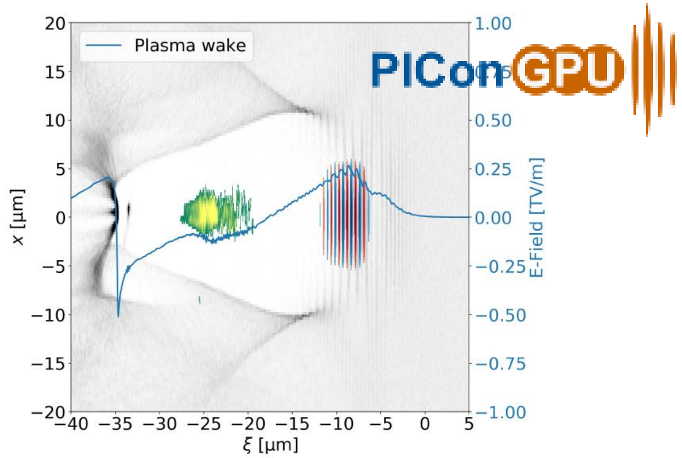
HZDR: Electron Beam 500 pC Charge, > 10 kA

Applying Novel Solutions for Pushing the Charge



J. Couperus, et al., Nat. Commun. 8, 487 (2017)

A.Irman, et al., PPCF 60, 044015 (2018)



World record peak current (~20 kA)

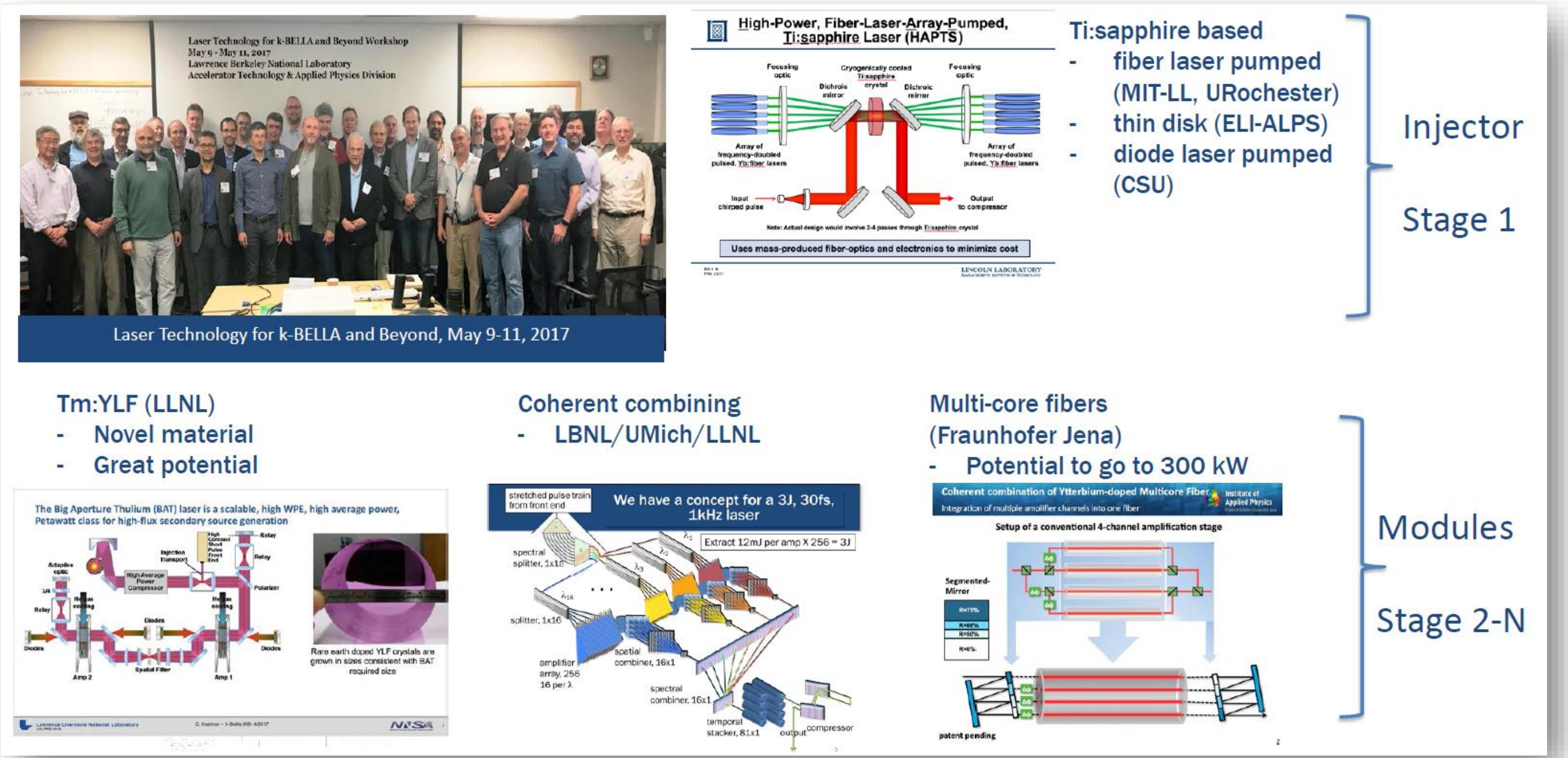
→ Driver of THz sources

→ Beam driven wakefields

→ **Luminosity in colliders**

Lasers Moving towards Higher Efficiency

Peta-Watt lasers can operate with 10^{-4} efficiency at 1-5 Hz → towards the kHz frontier with higher efficiency



Slide by Wim Leemans, DESY

Goal:

3 kW to 300 kW average power regime

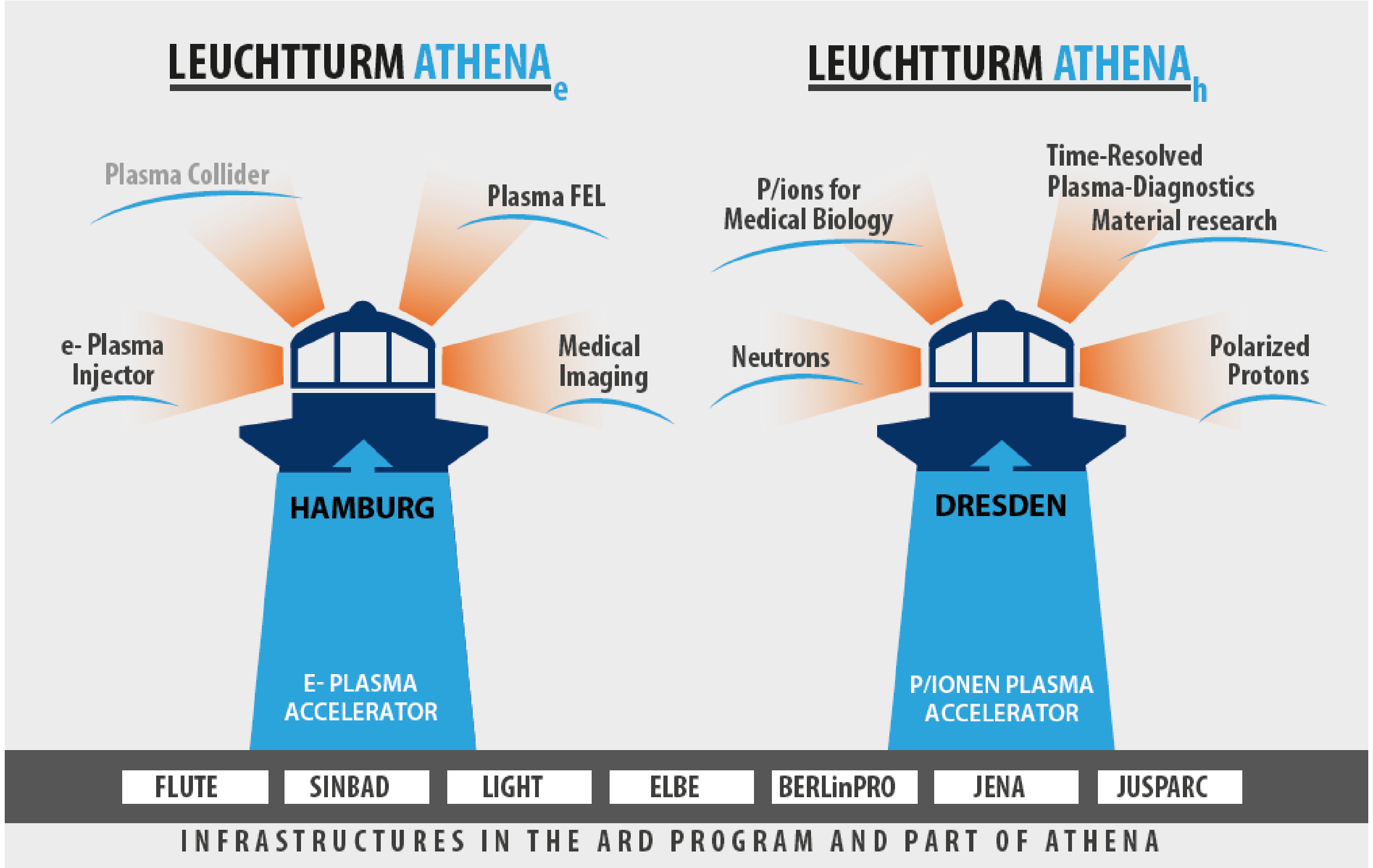
KALDERA project at DESY
→ W. Leemans

Developments at LLNL in the US → K. Häfner

The ATHENA Project

Two Flagships Constructed Together

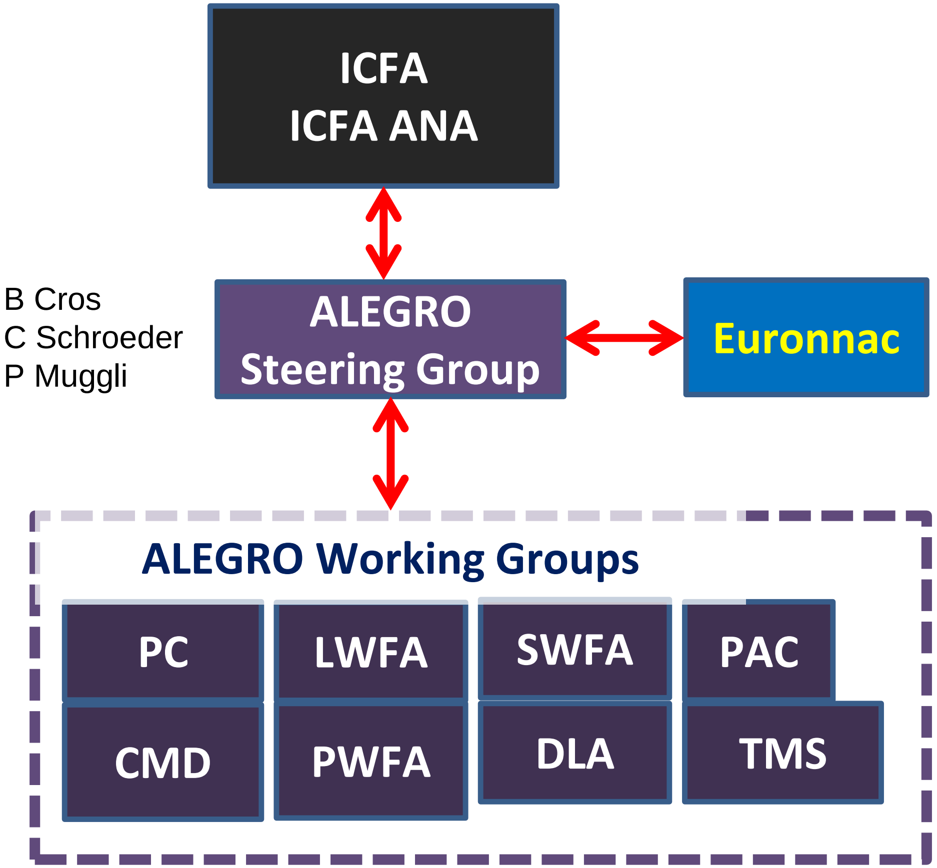
- **30 M€ investment** of Helmholtz association and BMBF.
- Total volume: **42.5 M€** (incl. personnel). OP budget defined.
- Include **work in 7 research infrastructures** in Helmholtz
- Defines **two flagship projects**: e- in Hamburg, p/ions in Dresden
- Targets **applications**



Advanced LinEar collider study GROup

Advanced Linear Collider related activities based on Advanced and Novel Acceleration (ANA) concepts

- To foster and trigger Advanced Linear Collider related activities based on Advanced and Novel Acceleration (ANA) concepts
- Provide a framework to amplify international coordination, broaden the community, involving accelerator labs/institutes
- Identify topics of ANAs requiring intensive R&D and facilities needed



ALEGRO input for the 2020 update of the European Strategy for Particle Physics: comprehensive overview

Contacts: B. Cros[1], P. Muggli[2]
on behalf of ALEGRO collaboration,
member list at http://www.lpgp.u-psud.fr/icfaana/alegro/alegro-members

[1] LPGP, CNRS, Université Paris Sud, Orsay France, email: brigitte.cros@u-psud.fr
[2]Max Planck Institute for Physics, Munich, Germany, email: muggli@mpp.mpg.de

Advanced and Novel Accelerators (ANAs) can provide acceleration gradients orders of magnitude greater than conventional accelerator technologies, and hence they have the potential to provide a new generation of more compact, high-energy machines. Four technologies are of particular interest, all of which rely on the generation of a wakefield which contains intense electric fields suitable for particle acceleration. In the laser wakefield accelerator (LWFA) and plasma wakefield accelerator (PWFA) the wakefields are driven in a plasma by intense laser or particle beams, respectively; in the structure wakefield accelerator (SWFA), the wake is excited by a particle bunch propagating through a structured tube; and in the dielectric laser accelerator (DLA), a laser pulse directly drives an accelerating mode in a dielectric structure.

Material from Brigitte Cros & Patric Muggli

http://www.lpgp.u-psud.fr/icfaana/alegro

Advanced LinEar collider study GROup

Advanced Linear Collider related activities based on Advanced and Novel Acceleration (ANA) concepts

ALEGRO proposal

ALEGRO

Advanced LinEar collider study GROup

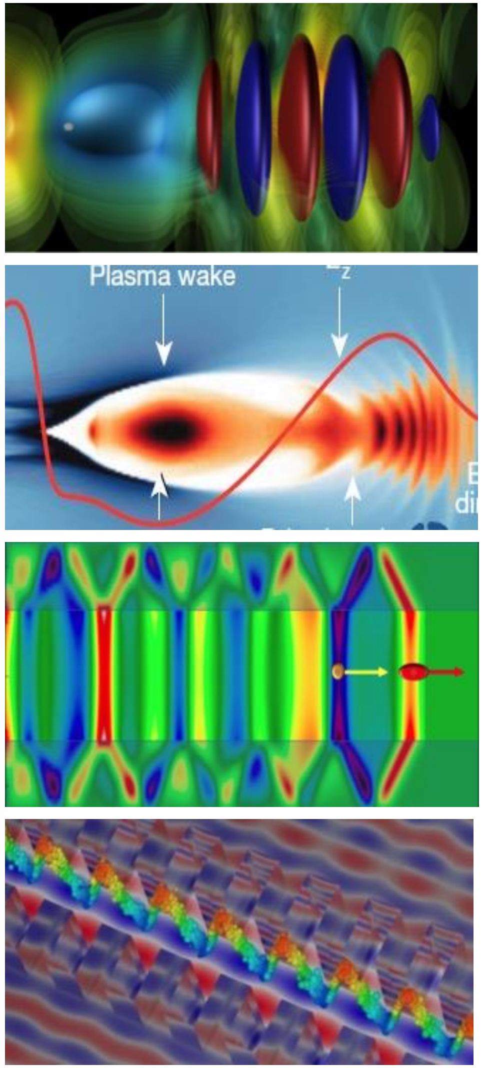
- ALEGRO proposes as **a long-term goal** the design of a e^+/e^-/gamma collider with up to 30 TeV in the center of mass –

the Advanced Linear International Collider (ALIC).

- The major goal for the community **over the next five to ten years is the construction of dedicated ANA facilities** that can reliably deliver high-quality, multi-GeV electron beams from a small number of stages.

A number of key topics related to what could be the **front end of ALIC, consisting of an injector plus accelerator module**, and producing beams in the 5-25 GeV range, are planned to be addressed:

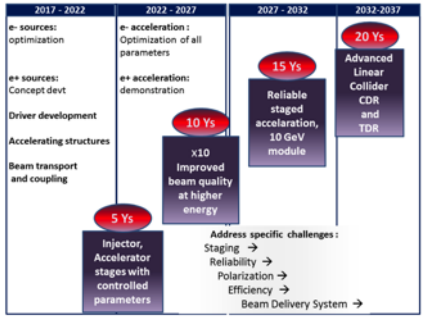
- External injection
- Bunch quality, efficiency, stability and reproducibility
- Plasma sources
- Operation at high repetition rate
- High-quality electron (e^-) and positron (e^+) bunches
- Independently shaped drive- and main-beam
- Multi-stage challenges with high-energy beams



Timeline estimated:

End of 2030's → technical design worked out

Construction afterwards → operation end of 2040's or in the 2050's



Material from Brigitte Cros & Patric Muggli

EuPRAXIA Horizon2020 Design Study *(DESY coordinated)*

European Plasma Accelerator Infrastructure with Pilot Users, site-independent (now mid-term)

- Collaboration of **41 institutes**
  - **16 EU laboratories** are beneficiaries
  - **25 associated partners** from EU, Europe, Asia and US contribute in-kind
- Collaboration brings together:
  - **Big science labs**: photon science, particle physics
  - **Laser laboratories**: high power lasers
  - **International laboratories**: CERN, ELI (associated)
  - **Universities**: accelerator research, plasma, laser
- Organized in **8 EU-funded work packages** and **6 in-kind work packages**
- **125 scientists** in our work list

EuPRAXIA: A European Strategy for Accelerator Innovation

Do the required intermediate step between proof of principle and production facility – make one acc. unit!

PRESENT EXPERIMENTS

Demonstrating
100 GV/m routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

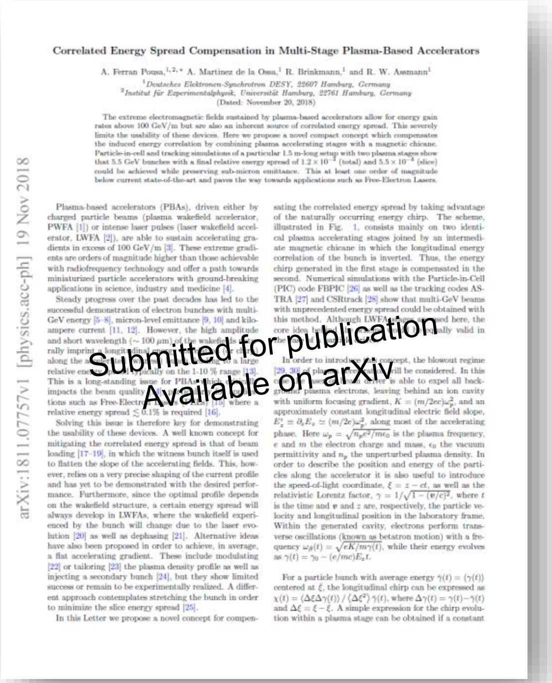
Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

Medical, industrial applications soon

EuPRAXIA: A New, Very Low Energy Spread Solution

A 1.5 meter long, self-compensating plasma acceleration scheme


arXiv:1811.07757v1 [physics.acc-ph] 19 Nov 2018

Correlated Energy Spread Compensation in Multi-Stage Plasma-Based Accelerators

A. Ferran Pousa,[1,2,*] A. Martinez de la Ossa,[1] R. Brinkmann,[1] and R. W. Assmann[1]

[1]Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany
[2]Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germany
(Dated: November 20, 2018)

The extreme electromagnetic fields sustained by plasma-based accelerators allow for energy gain rates above 100 GeV/m but are also an inherent source of correlated energy spread. This severely limits the usability of these devices. Here we propose a novel compact concept which compensates the induced energy correlation by combining plasma accelerating stages with a magnetic chicane. Particle-in-cell and tracking simulations of a particular 1.5 m-long setup with two plasma stages show that 5.5 GeV bunches with a final relative energy spread of 1.2×10^{-3} (total) and 5.5×10^{-4} (slice) could be achieved while preserving sub-micron emittance. This at least one order of magnitude below current state-of-the-art and paves the way towards applications such as Free-Electron Lasers.

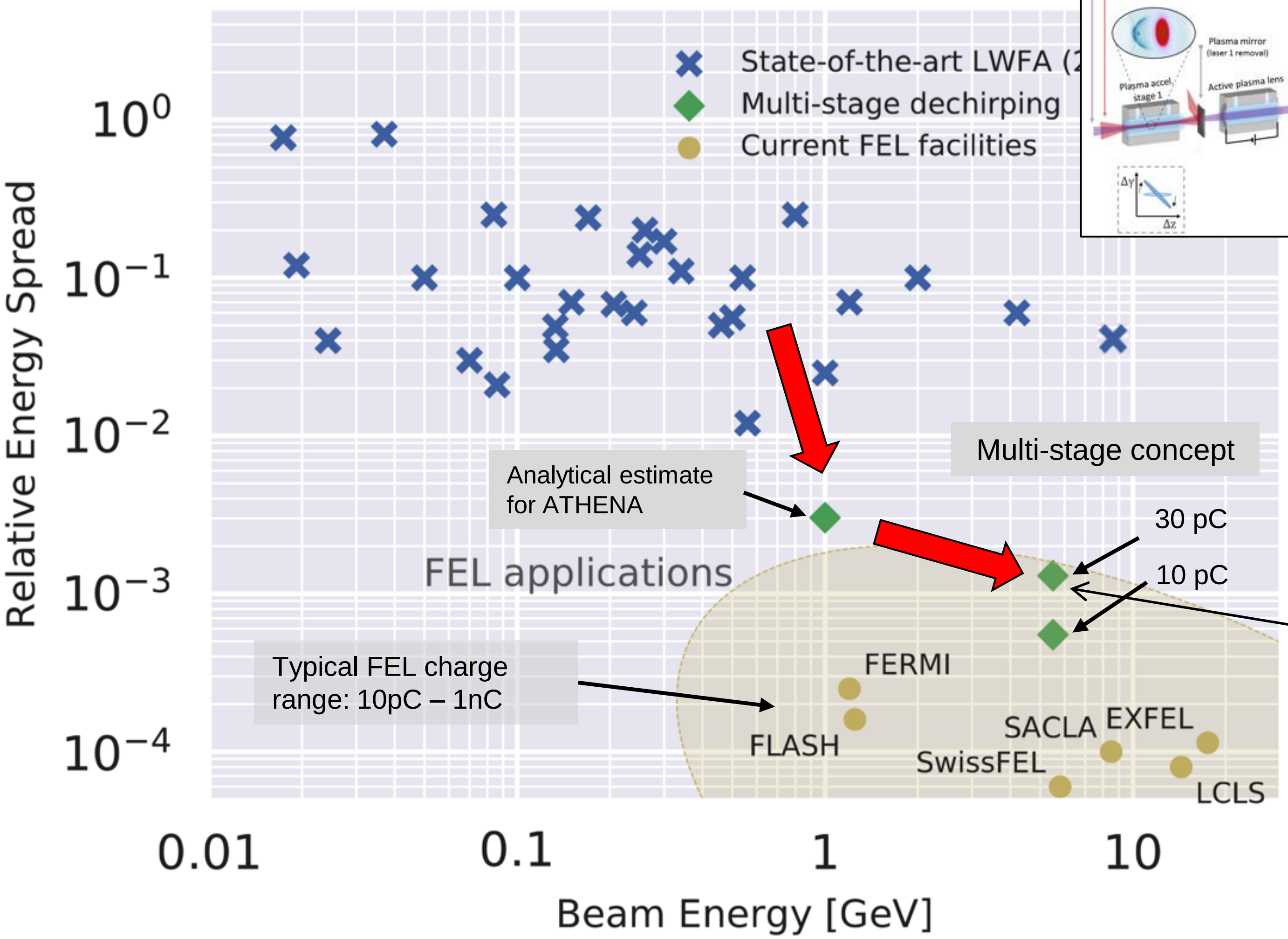
Plasma-based accelerators (PBAs), driven either by charged particle beams (plasma wakefield accelerator, PWFA [1]) or intense laser pulses (laser wakefield accelerator, LWFA [2]), are able to sustain accelerating gradients in excess of 100 GeV/m [3]. These extreme gradients are orders of magnitude higher than those achievable …

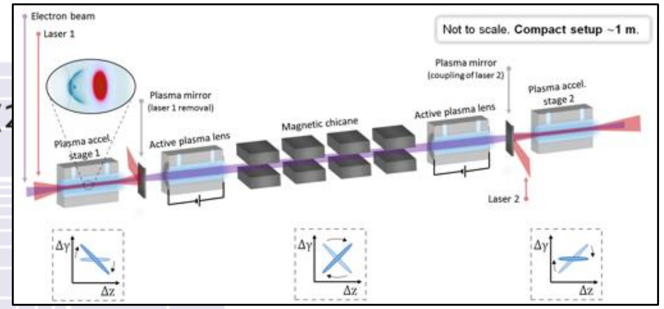
… sating the correlated energy spread by taking advantage of the naturally occurring energy chirp. The scheme, illustrated in Fig. 1, consists mainly on two identical plasma accelerating stages joined by an intermediate magnetic chicane in which the longitudinal energy correlation of the bunch is inverted. Thus, the energy …

Submitted for publication
Available on arXiv

Ref.: Ferran Pousa, Martinez de la Ossa, Brinkmann, Assmann, **arXiv:1811.07757**

Accepted by PRL





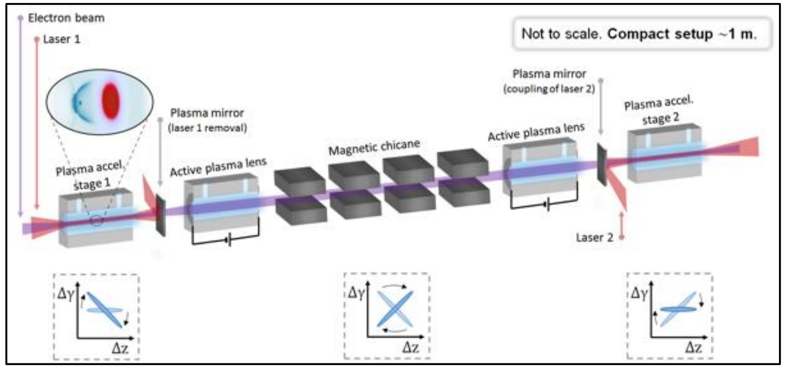
Simulated cases for EuPRAXIA

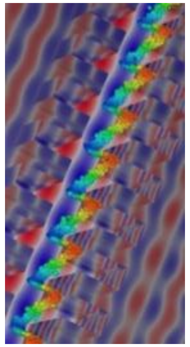
→ At linear collider design level, good for particle physics

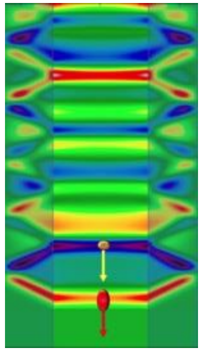
Conclusion

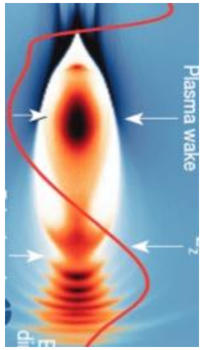
Advanced Accelerator Technology

- **Particle accelerators** have been used extensively by particle physics for amazing discoveries and insights into the laws of our universe.
- We are **still developing the metallic RF technology, super-conducting magnets and many other technologies further**, opening new possibilities for colliders.
- Progress in peak energy is slowing down due to practical limitations: **size and cost**.
- **Muon colliders and plasma accelerators** open the horizon to transformative steps with several orders of magnitude to be gained.
- Encouraging R&D ongoing, new ideas developing and use of unique test facilities will bring **significant progress in alternative approaches**.
- Present roadmaps indicate that we will need a clear, stable strategy and long-term R&D investments before the **new concepts will eventually materialize as particle physics colliders**.









Thank you for your attention