R&D for Future Accelerators

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ECFA Plenary, 21.11.2014

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+ the EuPRAXIA scientists + the Helmholtz ATHENA preparation team

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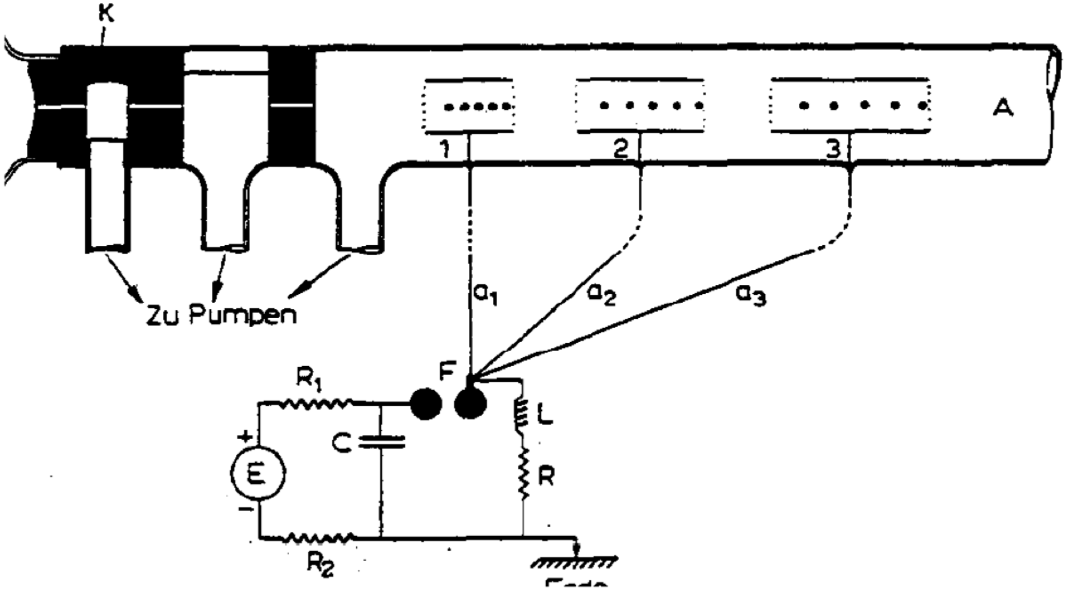
DESY

Accelerator R&D Starting in Sweden in 1924…

> 1924: **Gustav Ising** (*19 February 1883 in Finja, Sweden, † 5 February 1960 in Danderyd, Sweden), Prof. at the technical university Stockholm, publishes in 1924 idea how to realize multiple acceleration of an ion with a given high voltage: $U_{tot} >> U_{HV}$



ARKIV FÖR MATEMATIK, ASTRONOMI OCH FYSIK.
BAND 18. N:o 30.

Prinzip einer Methode zur Herstellung von Kanalstrahlen hoher Voltzahl.

Von

GUSTAF ISING.

Mit 2 Figuren im Texte.

Mitgeteilt am 12. März 1924 durch C. W. OSEEN und M. SIEGBAHN.

Die folgenden Zeilen beabsichtigen eine Methode zu skizzieren, welche im Prinzip erlaubt, mit einer zu Verfügung stehenden mässigen Spannung Kanalstrahlen (ev. Kathodenstrahlen) beliebiger Voltzahl zu erzeugen. Dies soll dadurch erreicht werden, dass die Strahlenpartikel während ihrer Bahn die Spannung mehrmals durchlaufen müssen. Die Spannung wird als Ladungswellen längs Drähten an verschiedenen Stellen des Teilchenbahns mit passenden Zeitdifferenzen zugeführt.

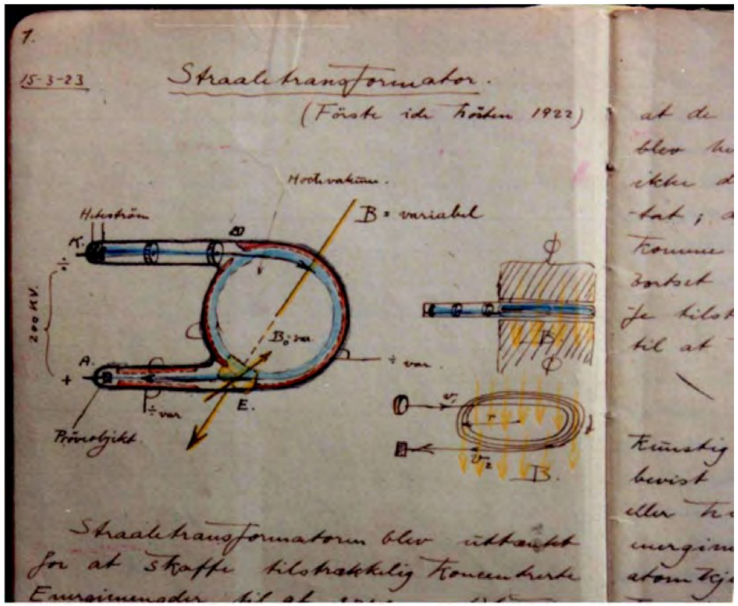
Eine diesbezügliche Anordnung zeigt schematisch die Fig. 1: Von dem Entladungsraum links treten Kanalstrahlen durch die geerdete Kathode K nach rechts in das gut evakuierte Accelerationsrohr A ein. In diesem befinden sich eine Reihe zylindrischer Metallkäfige 1, 2, 3 ..., deren Enden mit Drahtgitter verschlossen sind. Die Käfige sind durch die verschieden langen Drähte a_1, a_2, a_3 ... über den grossen Widerstand R (ev. auch eine Selbstinduktionsspule L) geerdet und besitzen somit im allgemeinen die Spannung Null gegen Erde. In diesem Falle gehen die Partikel durch die Zylinderreihe hin mit der konstanten Geschwindigkeit, welche sie im Entladungsraum erhielten. Wenn aber eine Funke bei F überschlägt[1], wandern Ladungswellen längs der Drähte a_1, a_2, a_3 ...

[1] E ist eine Elektrizitätsquelle, R_1 und R_2 grosse Widerstände, C eine Kapazität.

Arkiv för matematik, astronomi o. fysik. Bd 18. N:o 30. 1

90 Years of RF Accelerators

First Demonstration: Wideröe's PhD in 1927 in Aachen



Über ein neues Prinzip zur Herstellung hoher Spannungen

Von der Fakultät für Maschinenwirtschaft der Technischen Hochschule zu Aachen

zur Erlangung der Würde eines Doktor-Ingenieurs

genehmigte

Dissertation

vorgelegt von

Rolf Wideröe, Oslo

Referent: Professor Dr.-Ing. W. Rogowski
Korreferent: Professor Dr. L. Finzi

Tag der mündlichen Prüfung: 28. November 1927

Sonderdruck aus Archiv für Elektrotechnik 1928, Bd. XXI, Heft 4
(Verlag von Julius Springer, Berlin W 9)

27 pages

Wideröe

Idea 1: switch high voltage

Total energy gain >> available high voltage

First short ion linac!

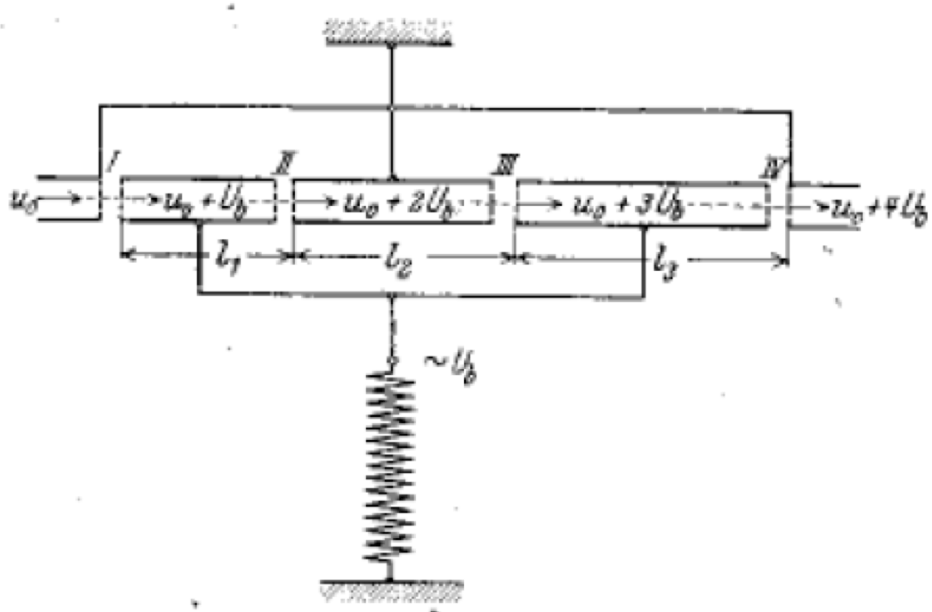


Bild 1. Prinzip der Spannungstransformation mit Potentialfeldern.

Idea 2: Circular acc.

Did not work in Wideröe’s thesis due to stability issues

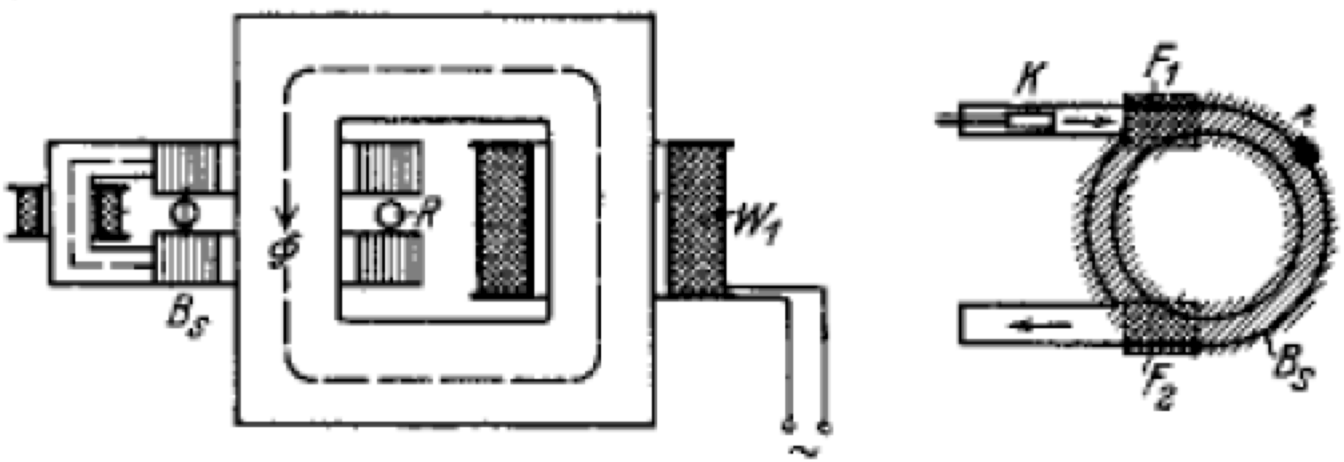
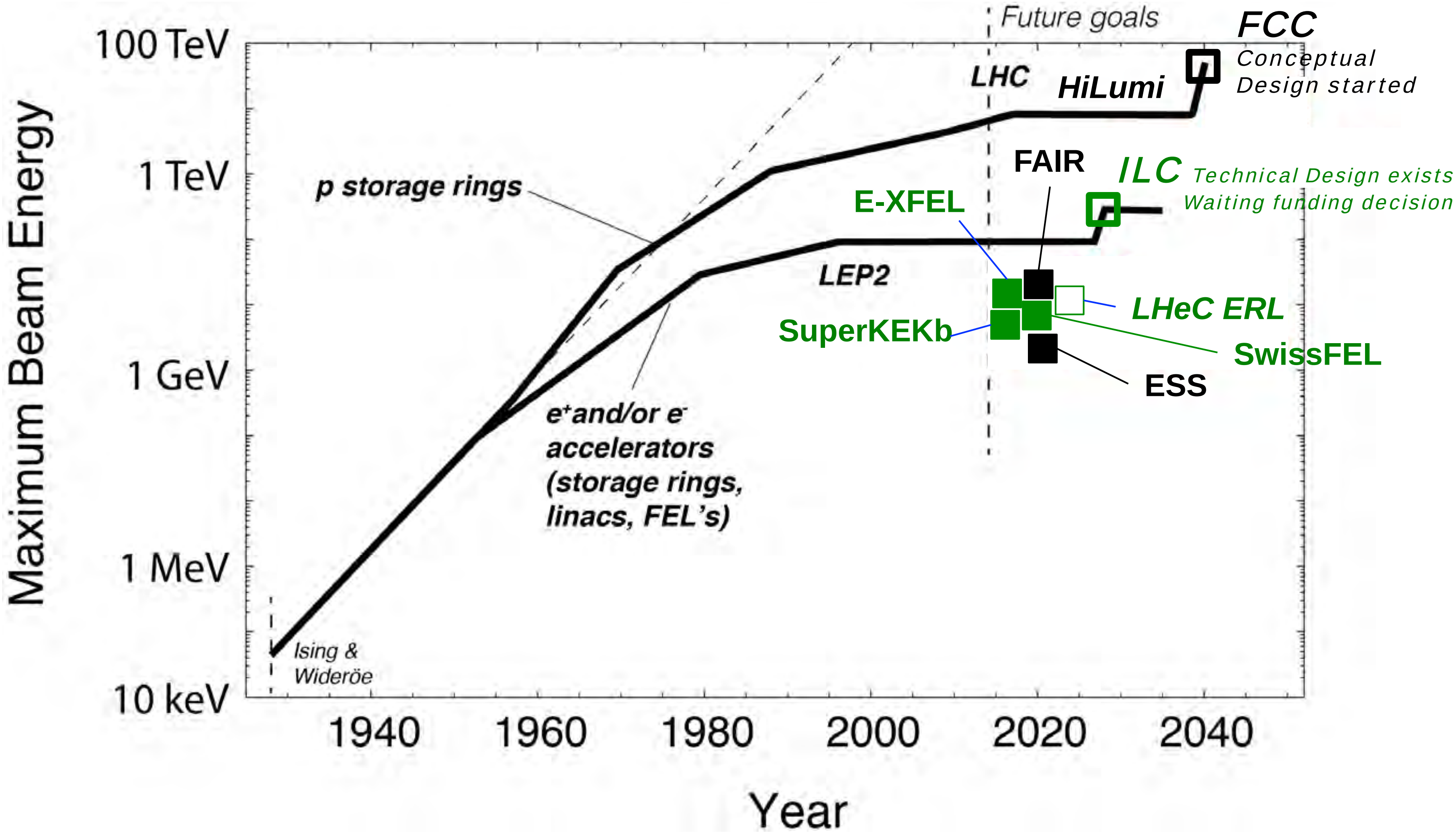


Bild 11. Wirkungsweise des Strahlentransformators.

Die Beschleunigung in Wirbelfeldern würde sehr hohe Spannungen erzeugen können. Das Verfahren scheitert daran, daß die Möglichkeiten fehlen, die Elektronen auf einer Kreisbahn zu binden. Die Lösung dieser Frage scheint zur Zeit große Schwierigkeiten zu bereiten.

Livingston and Future Accelerators (here e^+/e^- and p)



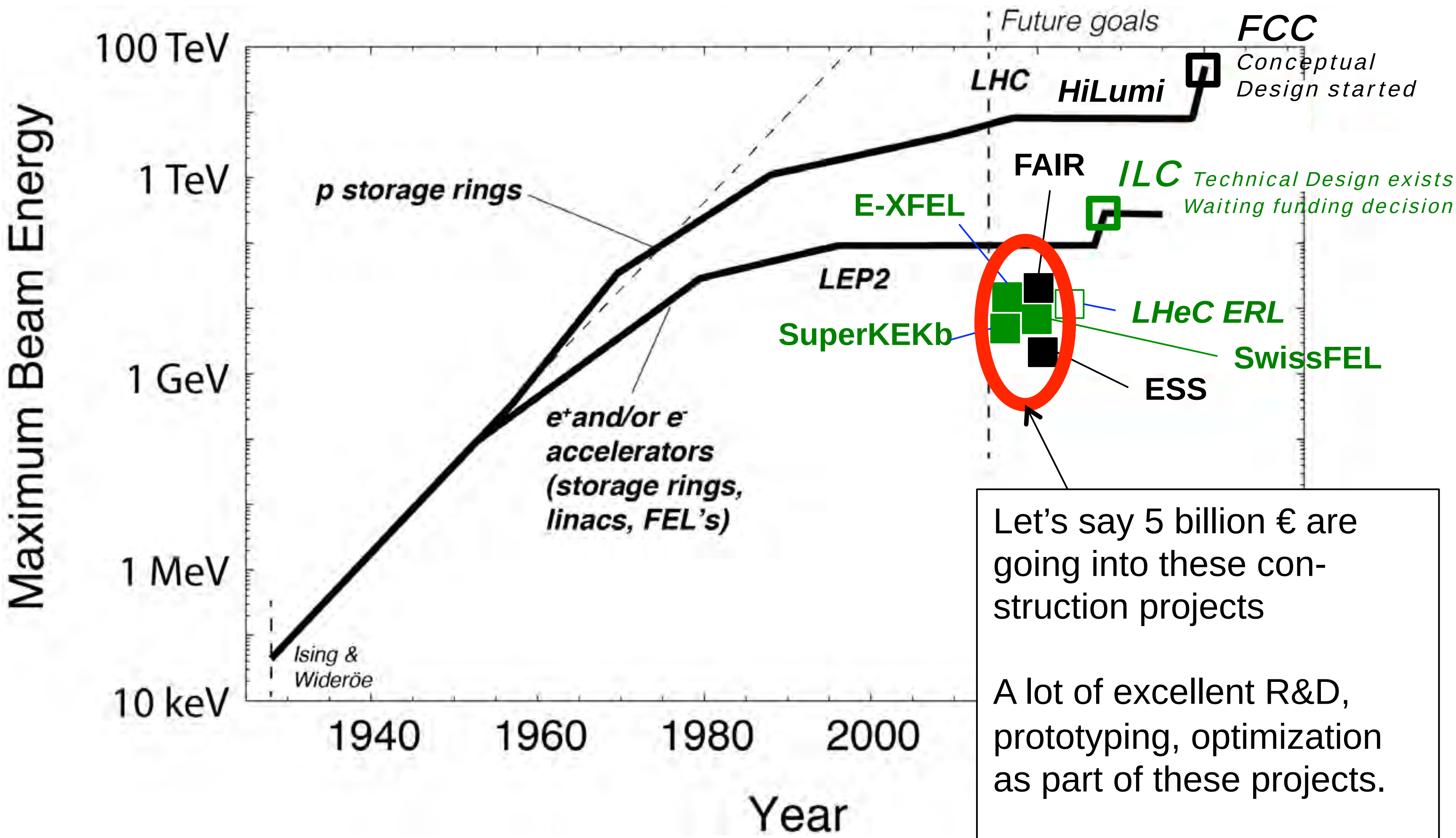
■ Hadron acc. project

□ Hadron acc. proposal

■ Lepton acc. project

□ Lepton acc. proposal

Livingston and Future Accelerators (here e^+/e^- and p)



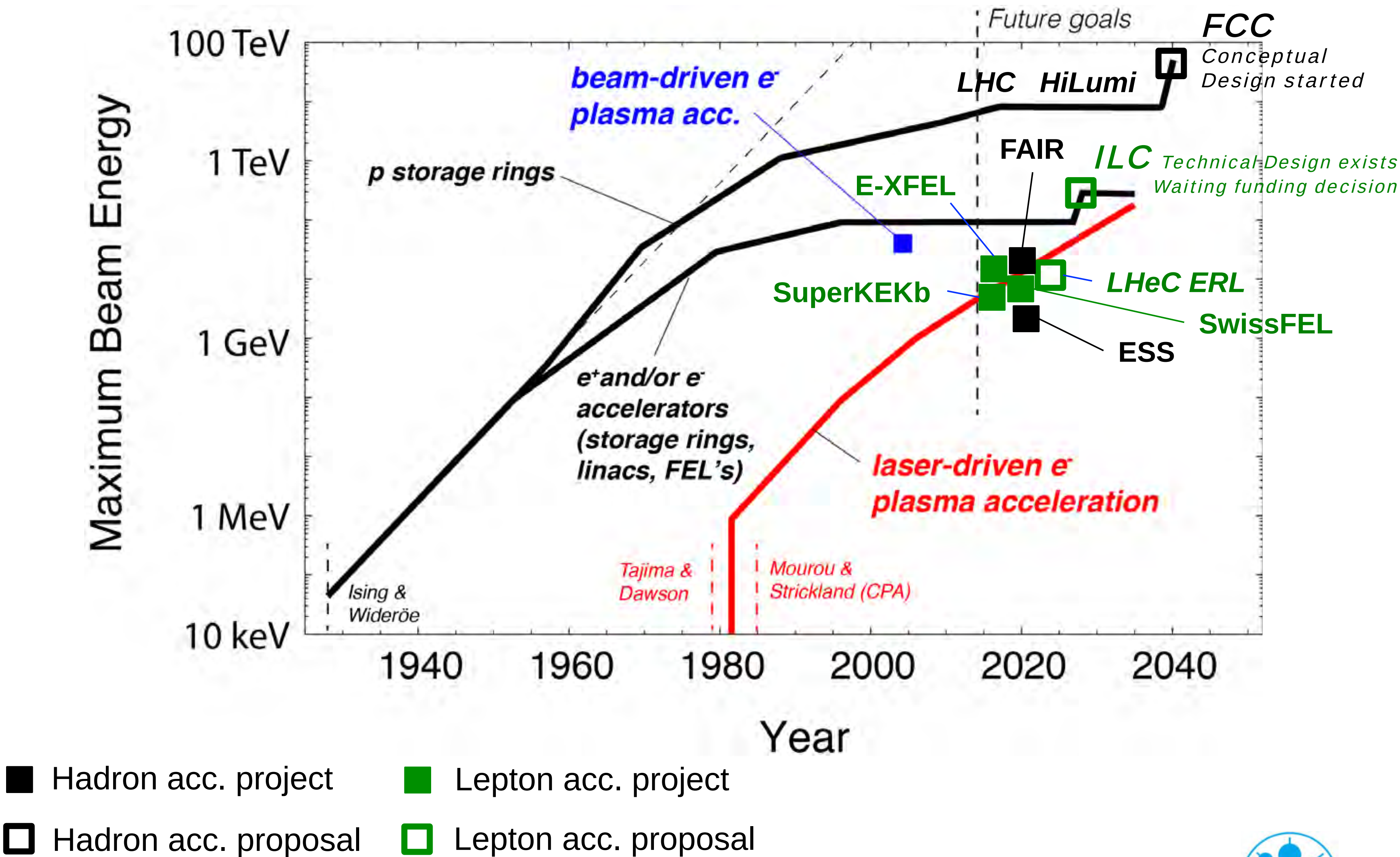
Let's say 5 billion € are going into these construction projects

A lot of excellent R&D, prototyping, optimization as part of these projects.

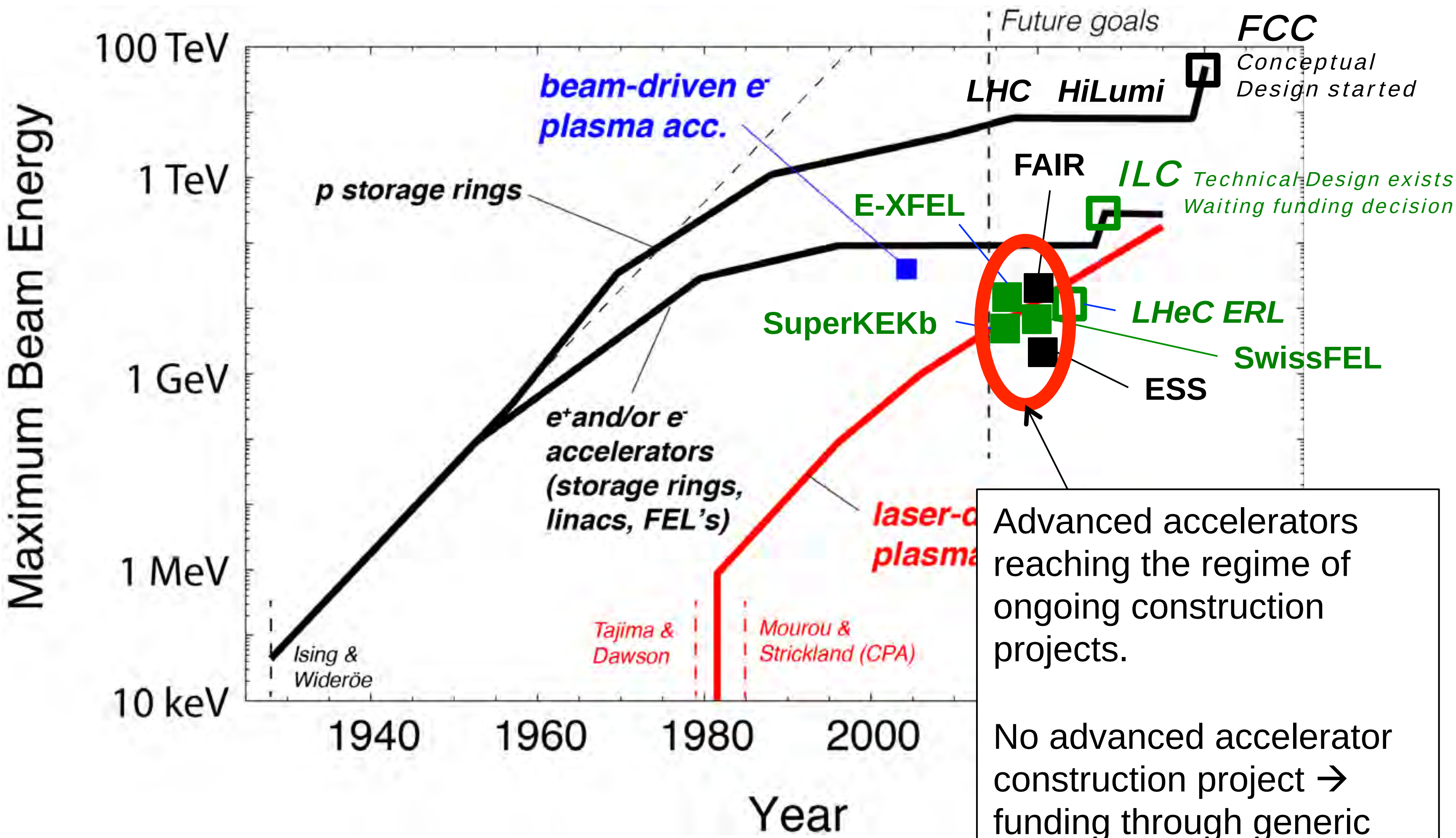
10% = 500 M€

- ■ Hadron acc. project
- □ Hadron acc. proposal
- ■ Lepton acc. project
- □ Lepton acc. proposal

Livingston and Future Accelerators (here e^+/e^- and p)



Livingston and Future Accelerators (here e^+/e^- and p)



Advanced accelerators reaching the regime of ongoing construction projects.

No advanced accelerator construction project → funding through generic R&D (much lower budget available)

- ■ Hadron acc. project
- □ Hadron acc. proposal
- ■ Lepton acc. project
- □ Lepton acc. proposal

Project-Driven Acc. R&D

> More budget through project budgets.

> Time-critical and high priority.

> Lot's of innovations but must deliver! Therefore must have conservative component.

More evolutionary developments.

Generic Accelerator R&D

> Limited budget from generic R&D budgets.

> Not time-critical and often considered optional.

> Can address very innovative and risky approaches.

Revolutionary developments possible.

Outline

1. Project-Driven Accelerator R&D
2. R&D towards a New Kind of Accelerators
3. Conclusion

Outline

1. **Project-Driven Accelerator R&D**
2. R&D towards a New Kind of Accelerators
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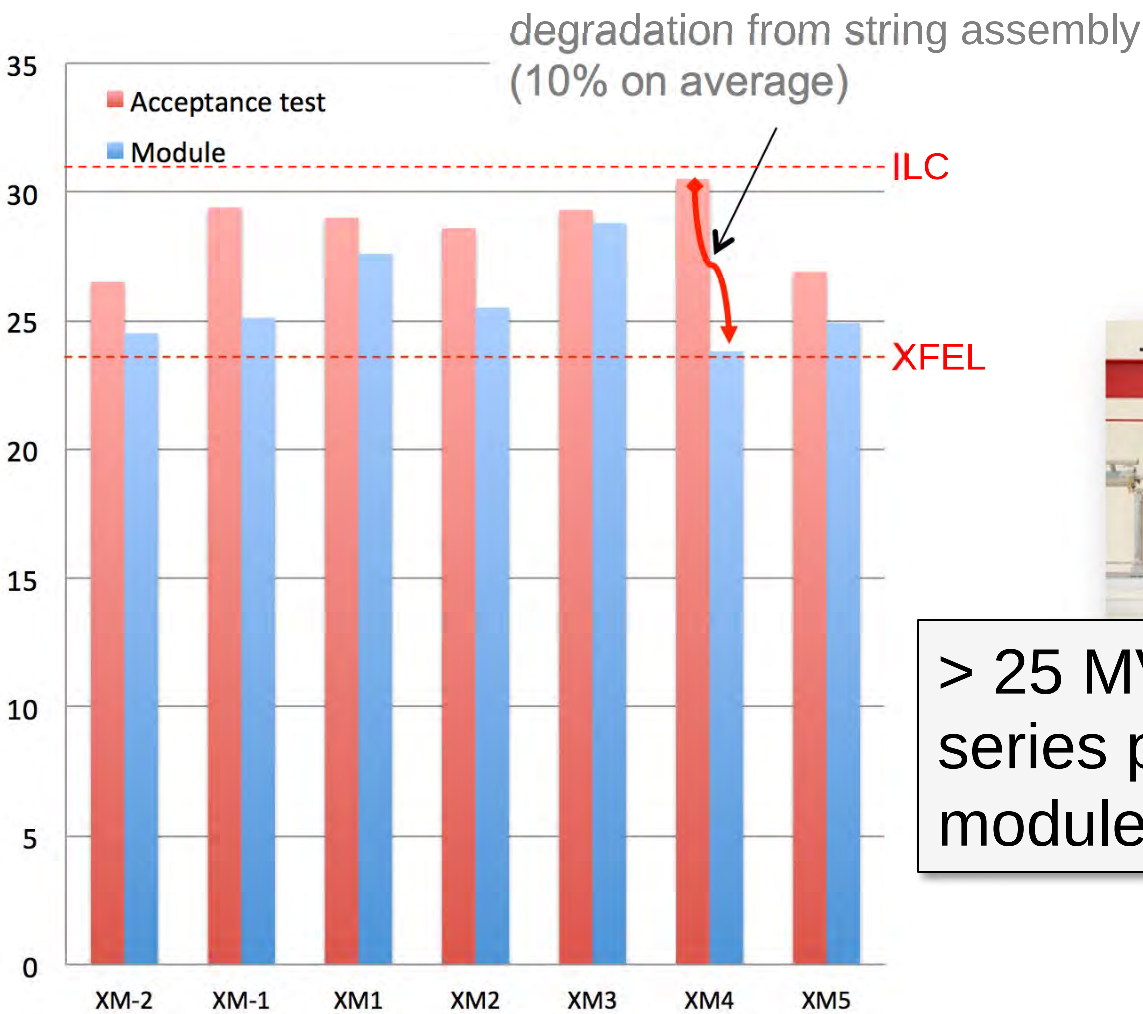
A) Success of Super-Conducting RF

XFEL Module Performance



> 25 MV/m in XFEL series production modules

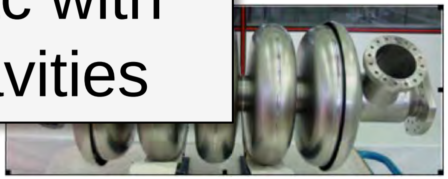
Historically always seen such degradation.
Many issues identified (and fixed). Watch this space!
(total: 100 modules)

First Modules are Installed in the Linac Tunnel

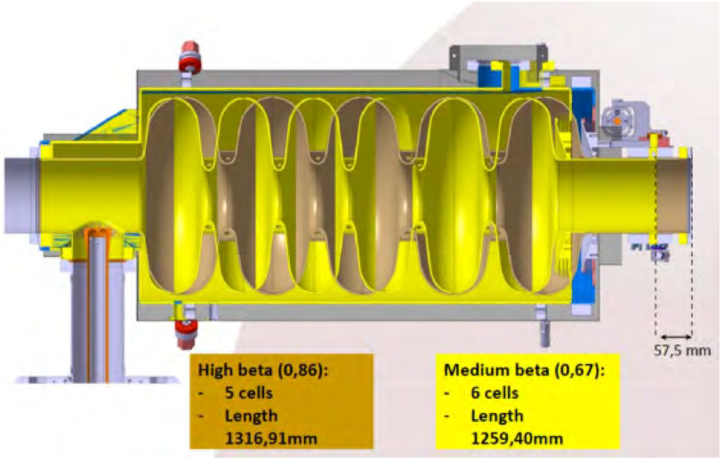
Series production XFEL modules being installed.
Successful industrialization!

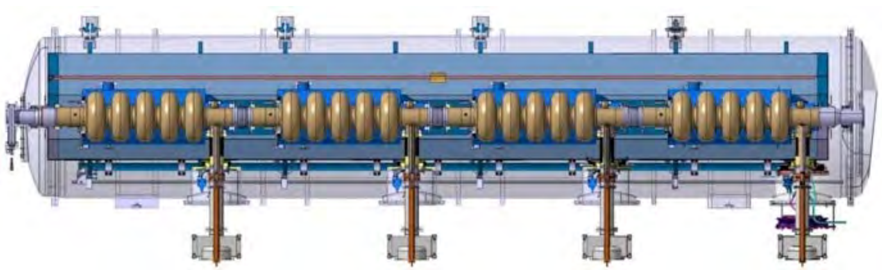
Elliptical Cavities and Cryomodules

ESS is based on SC RF linac with elliptical cavities



Superconducting five-cell elliptical cavity (not ESS). Two families, for beta = 0.67, energy 216->561 MeV and beta = 0.86, energy 561->2000 MeV.

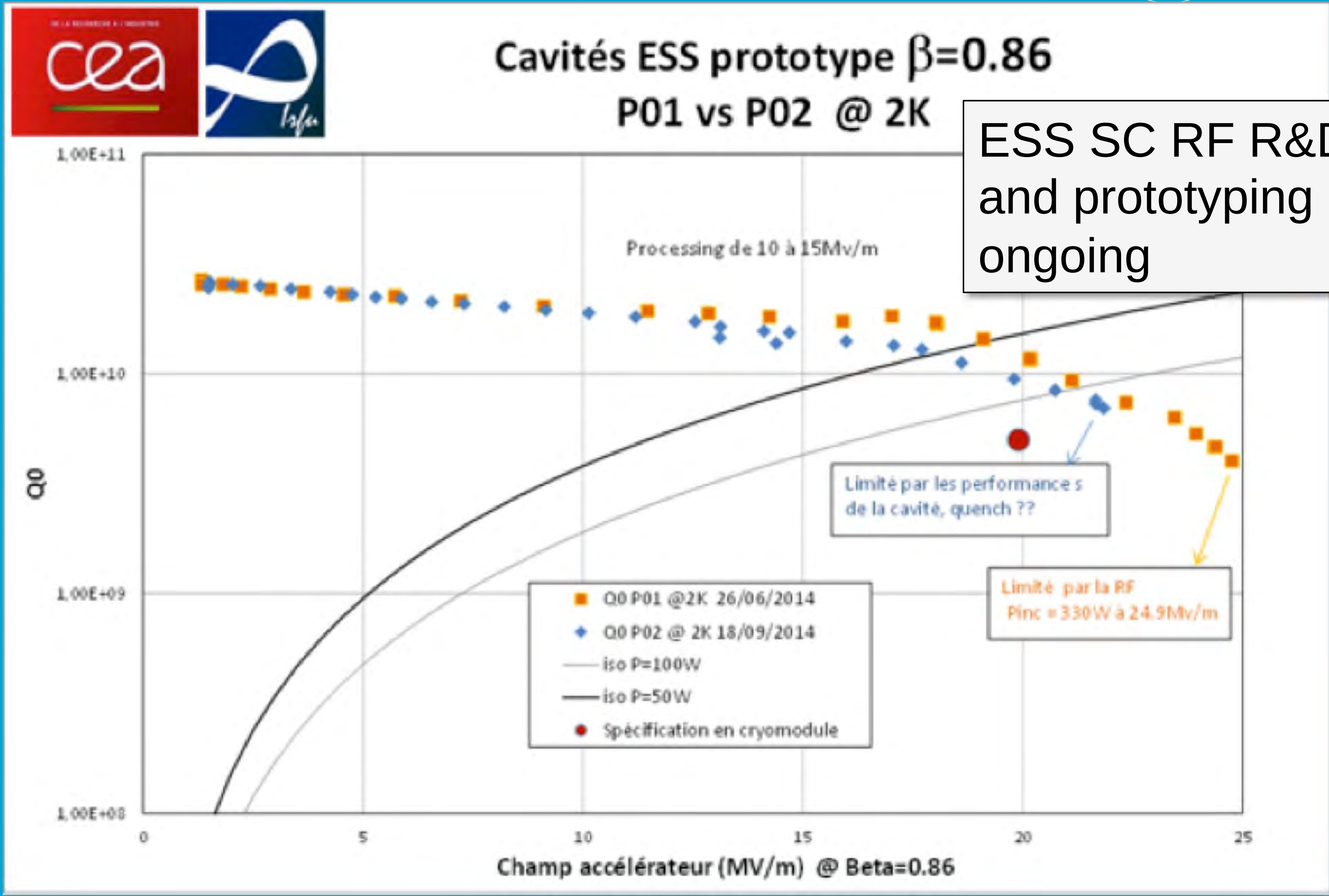




ESS elliptical cryomodule (not final) with 4 5-cell cavities and 4 power couplers for up to ~1 MW peak RF power.

Test results of the two SRF high-beta cavities

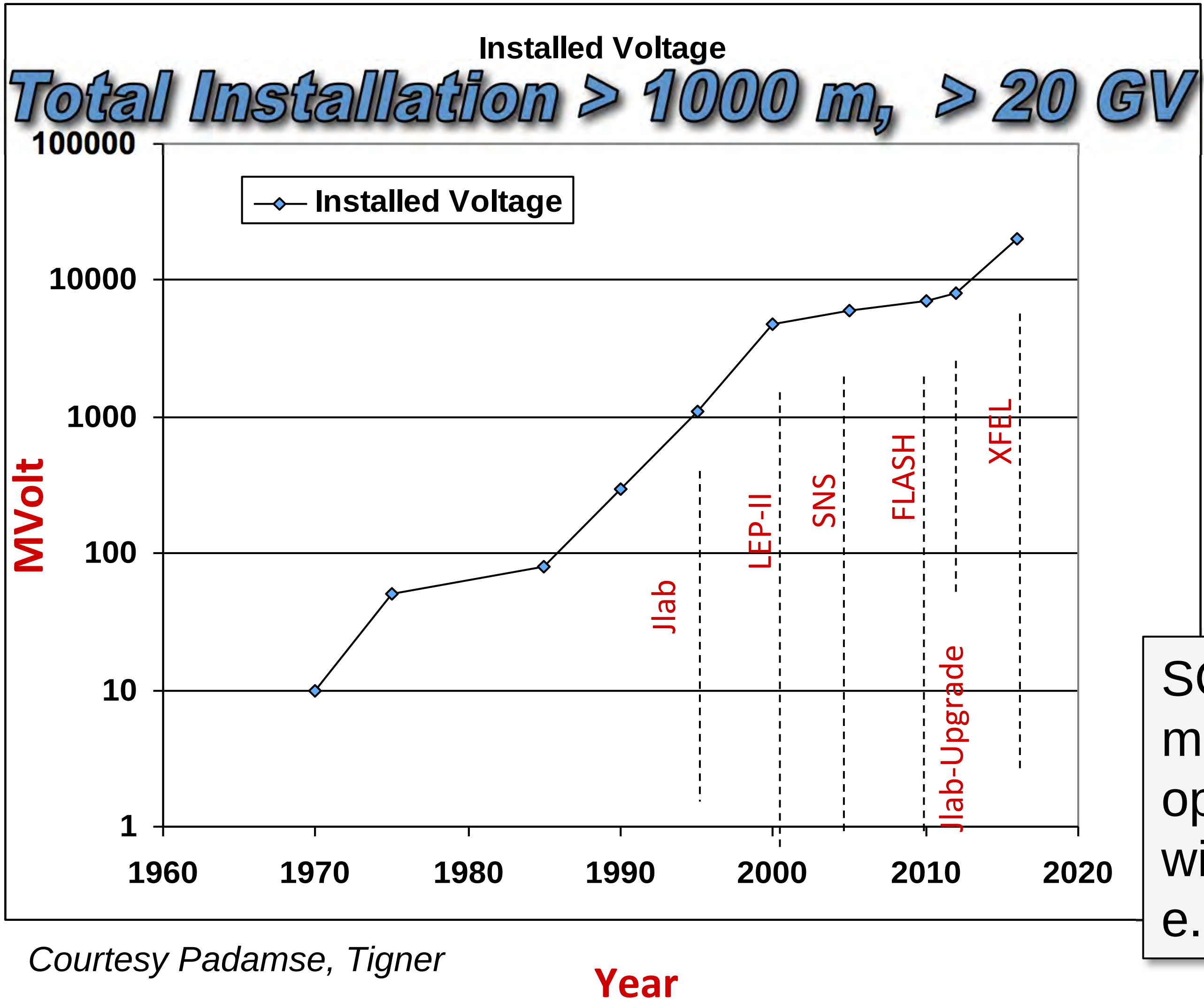
EUROPEAN SPALLATION SOURCE



ESS SC RF R&D and prototyping ongoing

50 Yr-Growth of Installed Voltage *for v/c=1 Accelerators*

A "Livingston Plot" for RF Superconductivity



Courtesy Padamse, Tigner

R&D towards much higher accelerating gradients (not achieved yet):

Nb3Sn :Tc = 18 K, Hsh = 3000 Oe => **E_{acc} = 80 MV/m** (improved shape cavity)

MgB2:Tc = 38 K, Hsh = 6200 Oe =**> E_{acc} = 172 MV/m** (improved shape cavity)

SC RF technology with many applications, opening new research windows (CW FEL → e.g. LCLS2).

B) The Super-Conducting Magnet Frontier

High-field magnet R&D (FCC-hh)

- **FHC baseline is 16T Nb_3Sn technology for ~100 TeV c.m. in ~100 km**

Develop Nb_3Sn-based 16 T dipole technology (at 4.2 K?),
- conductor developments
- short models with sufficient aperture (40 – 50 mm
- accelerator features (margin, field quality, protect-
  operation).

16 T Nb3Sn and 20T HTS dipoles for FCC

Goal: 16T short dipole models by 2018/19 (America, Asia, Europe)

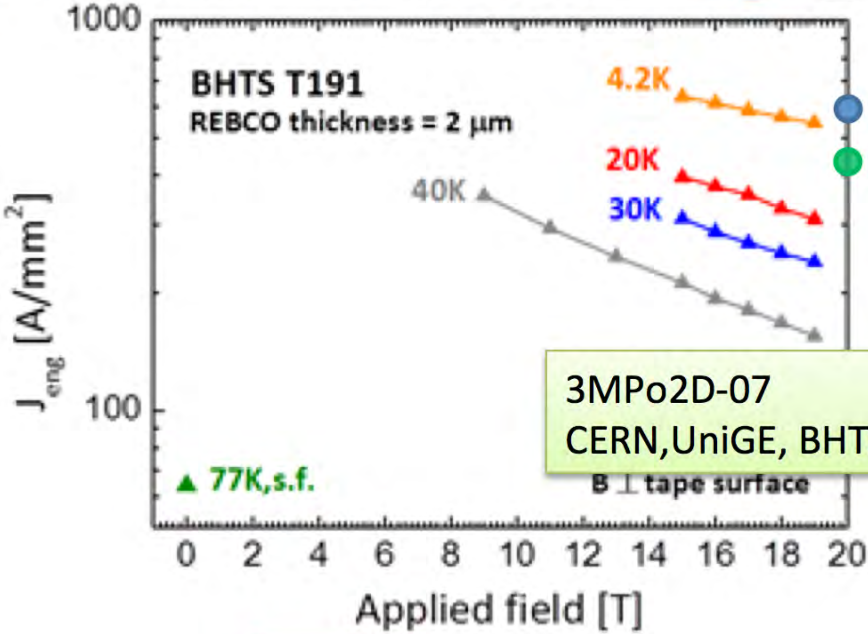
- **In parallel HTS development targeting 20 T (option and longer term)**

Goal: Demonstrate HTS/LTS 20 T dipole technology:
- 5 T insert (EuCARD2), ~40 mm aperture and accelerator features
- Outsert of large aperture ~100 mm, (FRESCA2 or other)

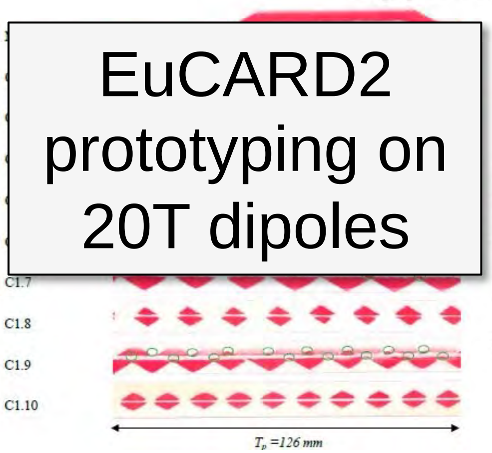
- High-field SC magnet R&D for FCC will be a “natural” continuation of HL-LHC developments and ensure continuation of of long-lasting worldwide research efforts and efficient use of past investments

Task 10.2 Conductor: Eucard2 goal and first results

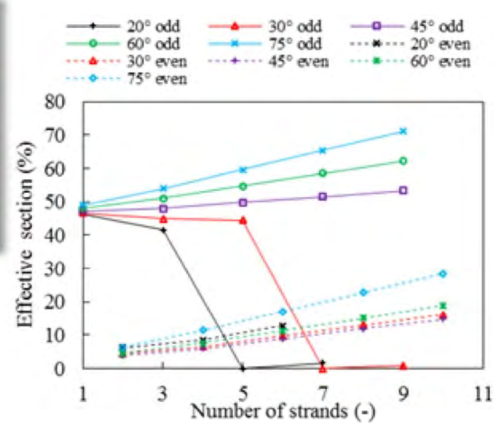
- J_{eng}= **600 A/mm² @20T** ⟹ 675@15T or 750@12T
- J_{eng}= **450 A/mm² @20T** is OK for demonstrator
- U.L. ≥ 100 m (50 m is OK for demonstrator)
- Easy bending (in one direction)
- Transverse stress > 100 MPa (possibly 150 MPa)



3MPo2D-07
CERN,UniGE, BHTS



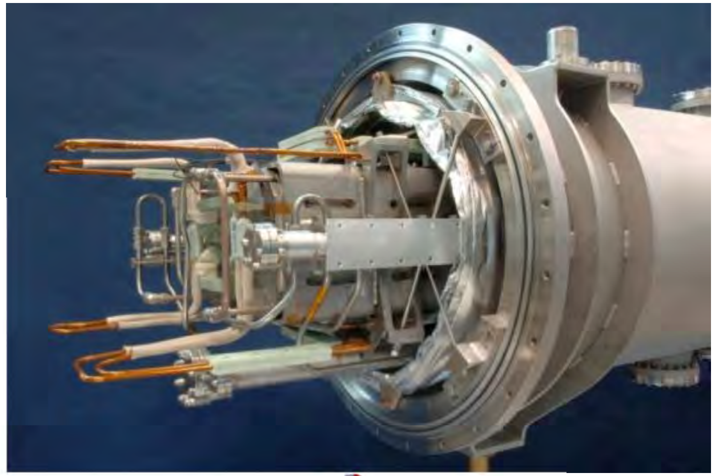
EuCARD2 prototyping on 20T dipoles



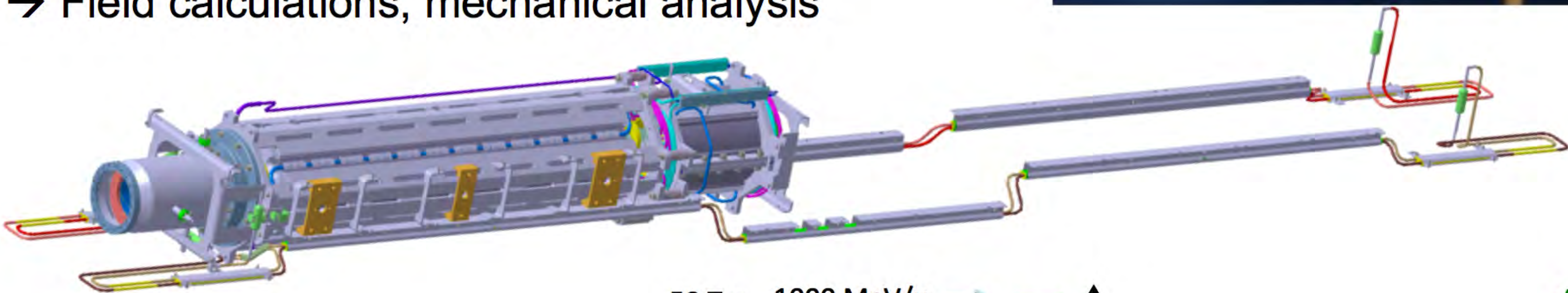
J. Fleiter et al., 3LPo1C-05

Magnet development

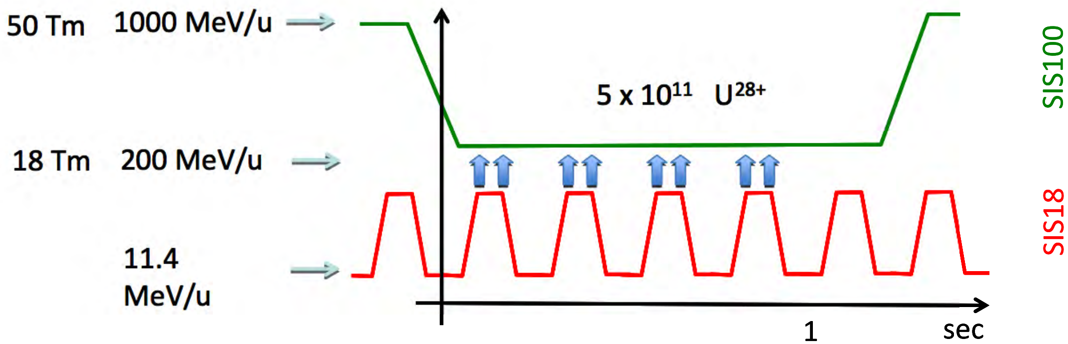
Fast ramped magnets (synchrotrons) dipole and multipoles



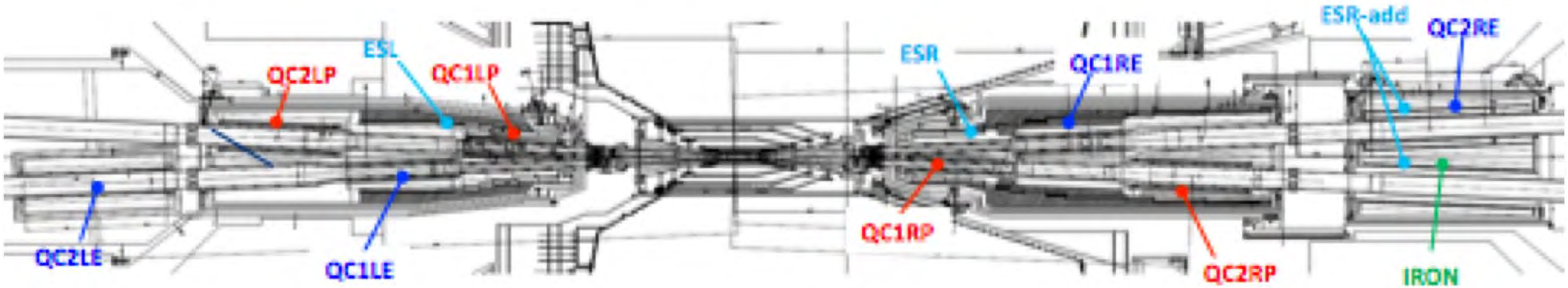
- Dynamic load and AC heat losses
  Bρ= 100 Tm - Bmax= 1.9 T - dB/dt= 4 T/s
  Quench propagation, eddy currents on ramp
- High field quality, low multipole strength
  → Field calculations, mechanical analysis



1.9T dipoles with 4 T/s ramping for FAIR



S.C. magnets in SuperKEKB IR



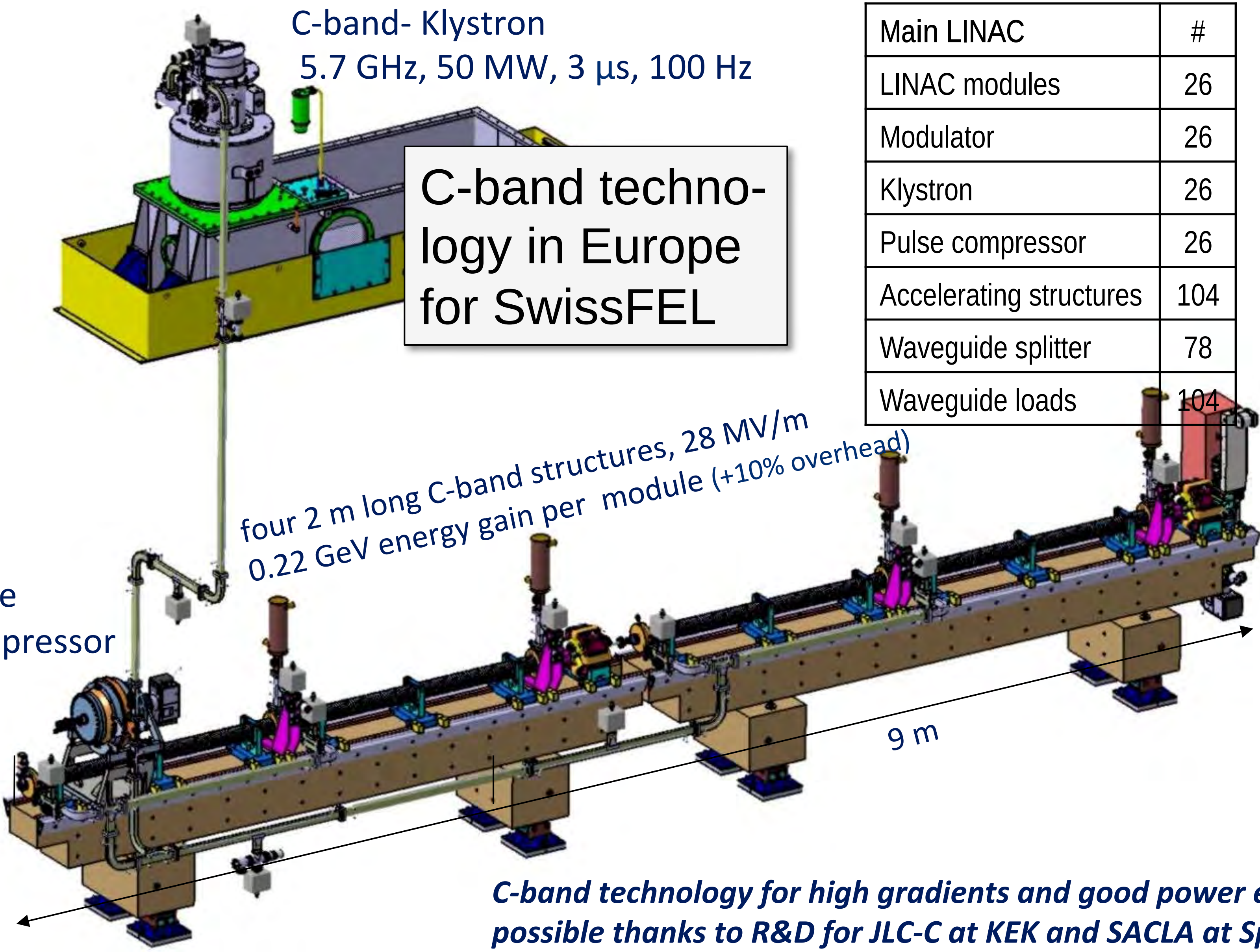
	Integral field gradient, (T/m)·m Solenoid field, T	Magnet type	Z pos. from IP, mm	θ, mrad	ΔX, mm	ΔY, mm
QC2RE	13.58 [32.41 T/m × 0.419m]	Iron Yoke	2925	0	-0.7	0
QC2RP	11.56 [26.28 × 0.410]	Permendur Yoke	1925	-2.114	0	-1.0
QC1RE	26.45 [70.89×0.373]	Permendur Yoke	1410	0	-0.7	0
QC1RP	22.98 [68.89×0.334]	No Yoke	935	7.204	0	-1.0
QC1LP	22.97 [68.94×0.334]	No Yoke	-935	-13.65	0	-1.5
QC1LE	26.94 [72.21×0.373]	Permendur Yoke	-1410	0	+0.7	0
QC2LP	11.50 [28.05 × 0.410]	Permendur Yoke	[illegible]	[illegible]	0	-1.5
QC2LE	15.27 [28.44×0.537]	Iron Yoke	[illegible]	[illegible]	+0.7	0

Up to 72 T/m quadrupoles in SuperKEKB IR

C) The Room-Temperature RF Frontier

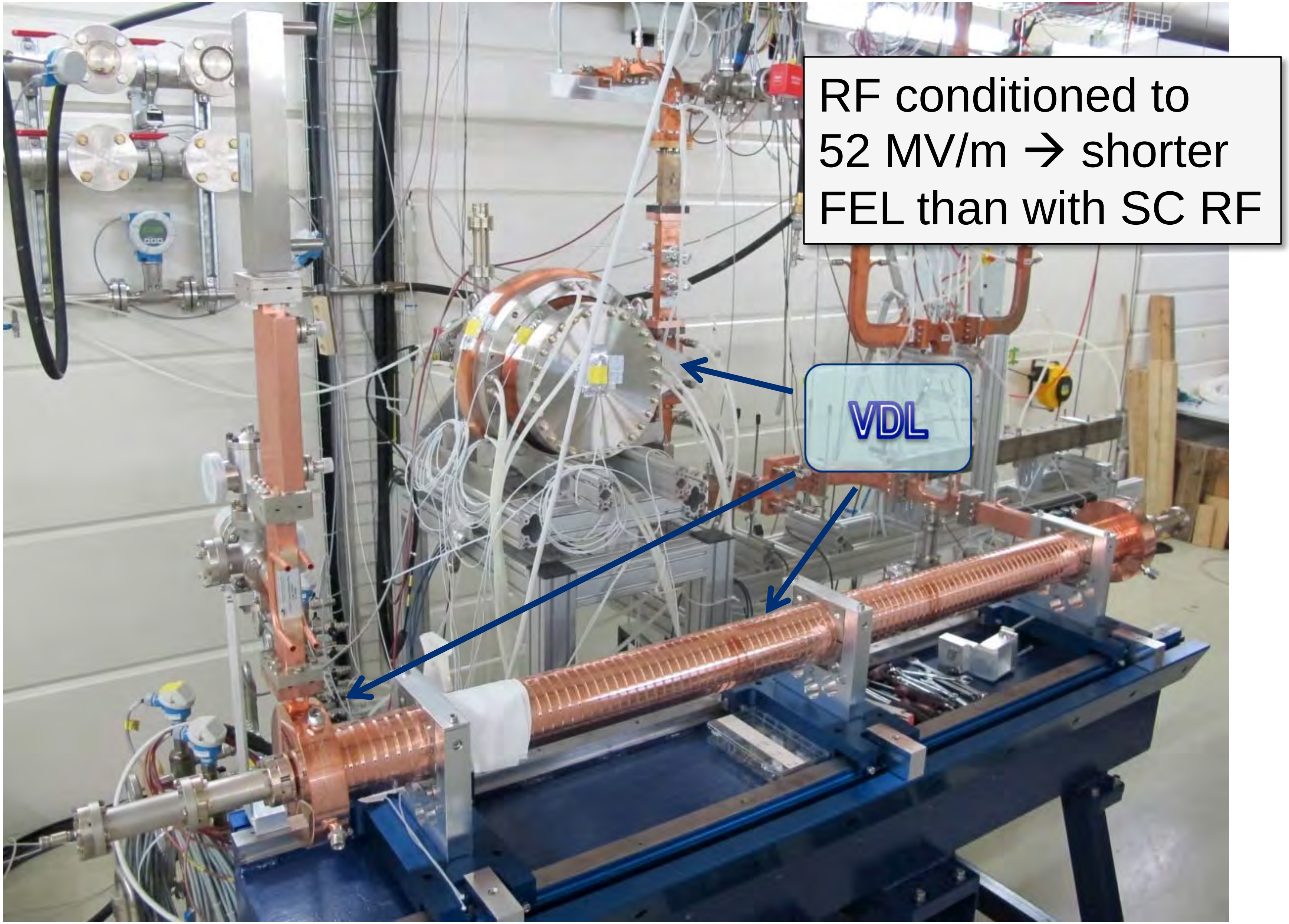
SwissFEL Main Linac building block

Main LINAC	#
LINAC modules	26
Modulator	26
Klystron	26
Pulse compressor	26
Accelerating structures	104
Waveguide splitter	78
Waveguide loads	104



C-band technology for high gradients and good power efficiency possible thanks to R&D for JLC-C at KEK and SACLA at Spring8

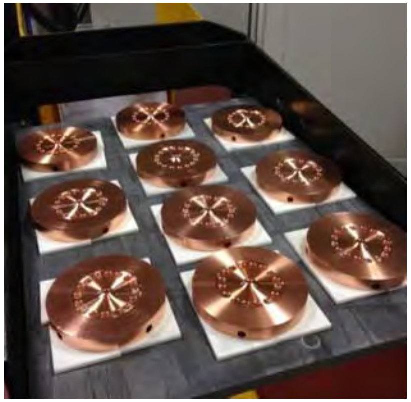
High power test of nominal C-band Structure and BOC, Rf-conditioned to 52 MV/m (nominal 28MV/m)!

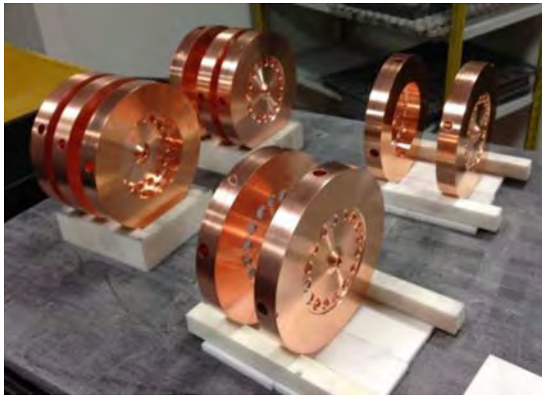


Main activities

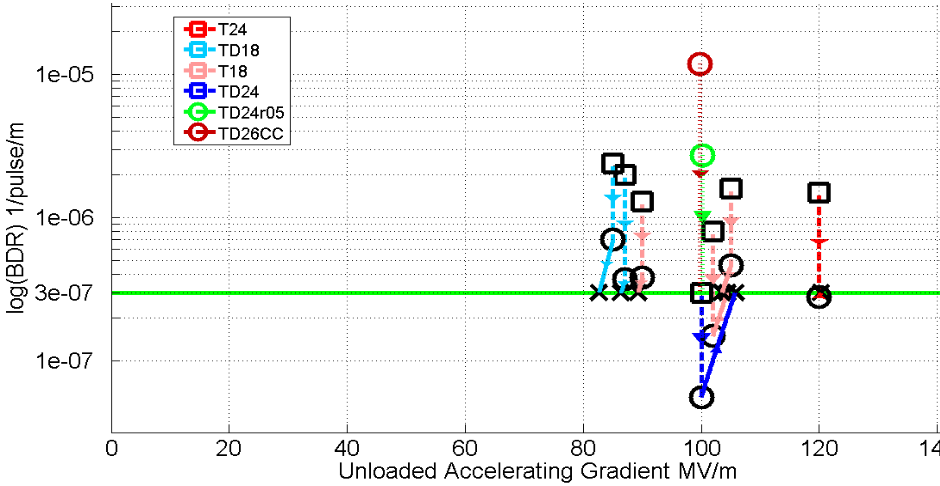
Parameters, Design and Implementation:
- Integrated Baseline Design and Parameters
- Cost and power optimisation in design and technological developments, optimal stages
- Links to experimental programme and integrate experimental results

X-band Technologies
- High gradient structures and high eff RF
- New X-band High power Testing Facilities (x3)
- Use of Xband technologies for FELs





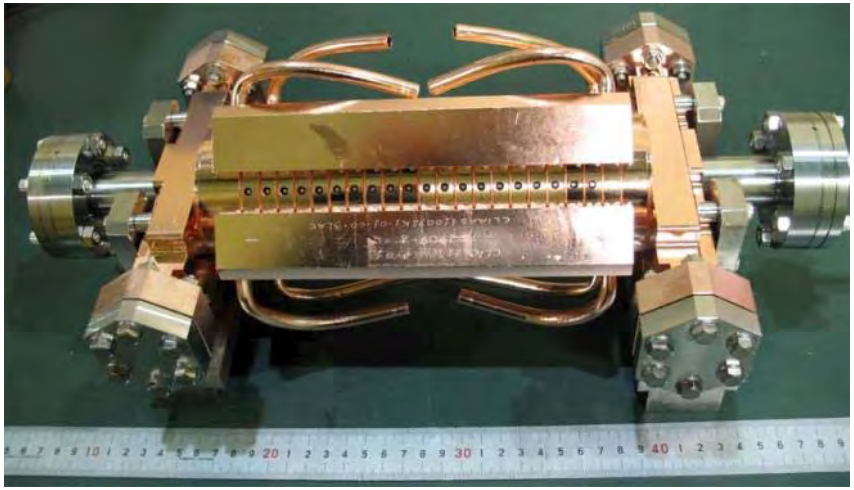
Xband disk, Xband teststand

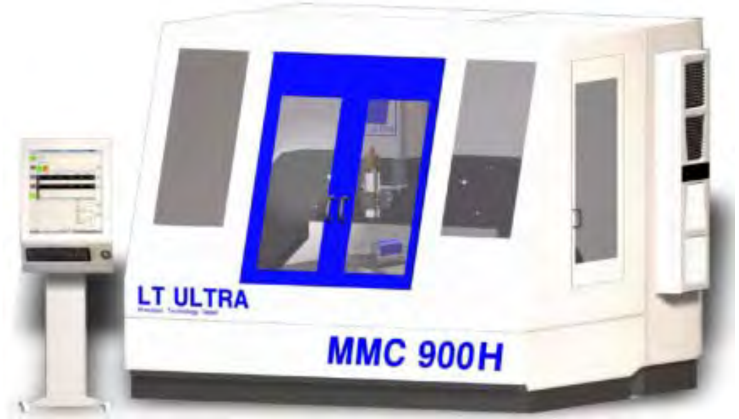


Institute	Structure	Status
KEK	Long history – latest TD26CC	Mechanical design
Tsinghua	T24 - VDL machined, Tsinghua assembled, H bonding, KEK high-power test	At KEK
	CLIC choke	manufacturing tests
SINAP	XFEL structure, KEK high-power test	rf design phase
	T24, CERN high-power test	Agreement signed
	Four XFEL structures	H2020 proposal
CIEMAT	TD24CC	
PSI	Two T24 structures made at PSI using SwissFE production line including vacuum brazing	
VDL	XFEL structure	
SLAC	T24 in milled halves	
CERN	Structures and Test-stands	
	KT (Knowledge Transfer) funded medical linac	machining

100 MV/m with X-band technology and low breakdown rate for CLIC
→ even shorter linacs

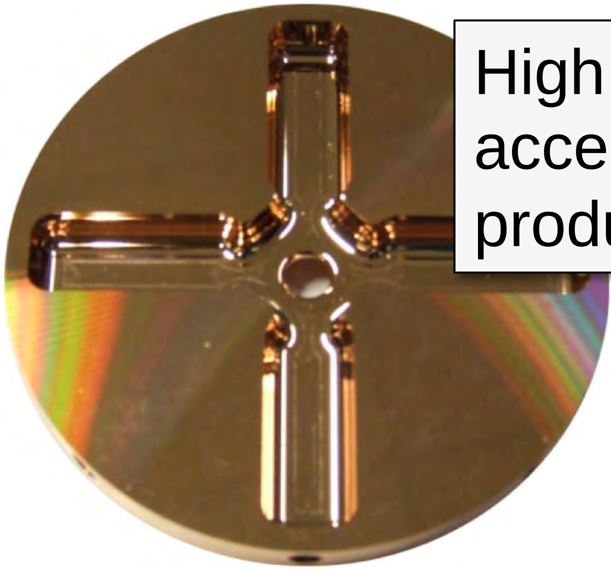
Micron-precision manufacture

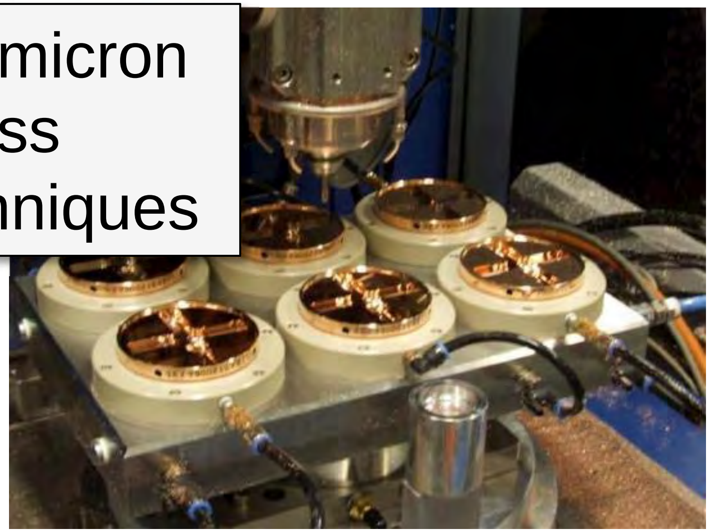




Commercial micron-precision turning and milling.

High precision micron accelerator mass production techniques



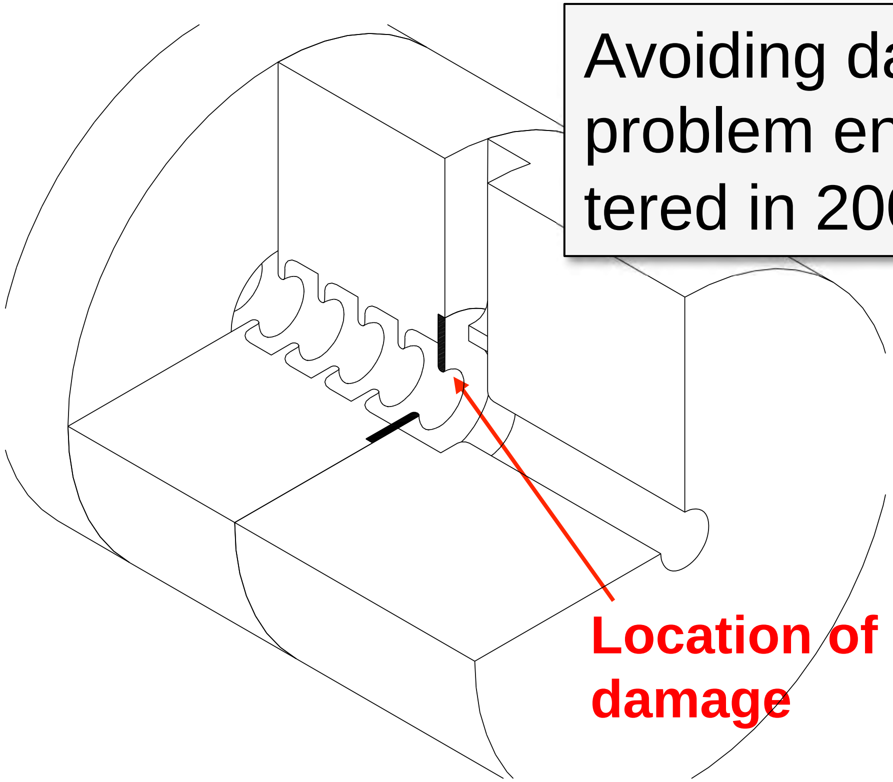


Single point diamond turned and milled disk

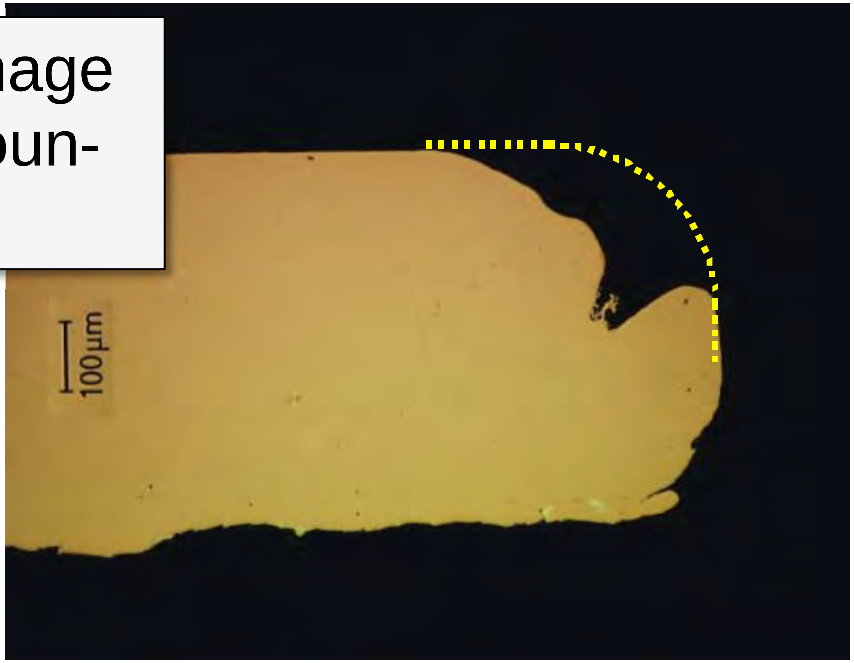
Towards mass production

If Accelerating Gradients Pushed too High (30 GHz)…

Avoiding damage problem encoun-tered in 2002



Single feed power coupler
30 GHz, 16 ns,
66 MV/m local accelerating gradient



W. Wuensch 2002

Major success for X-band: mastering of breakdown problem without damage.

Limitation for much higher gradients than 100 MeV/m!

D) The High Luminosity Challenge

Achieved Beam Sizes with New Optics Scheme in ATF2

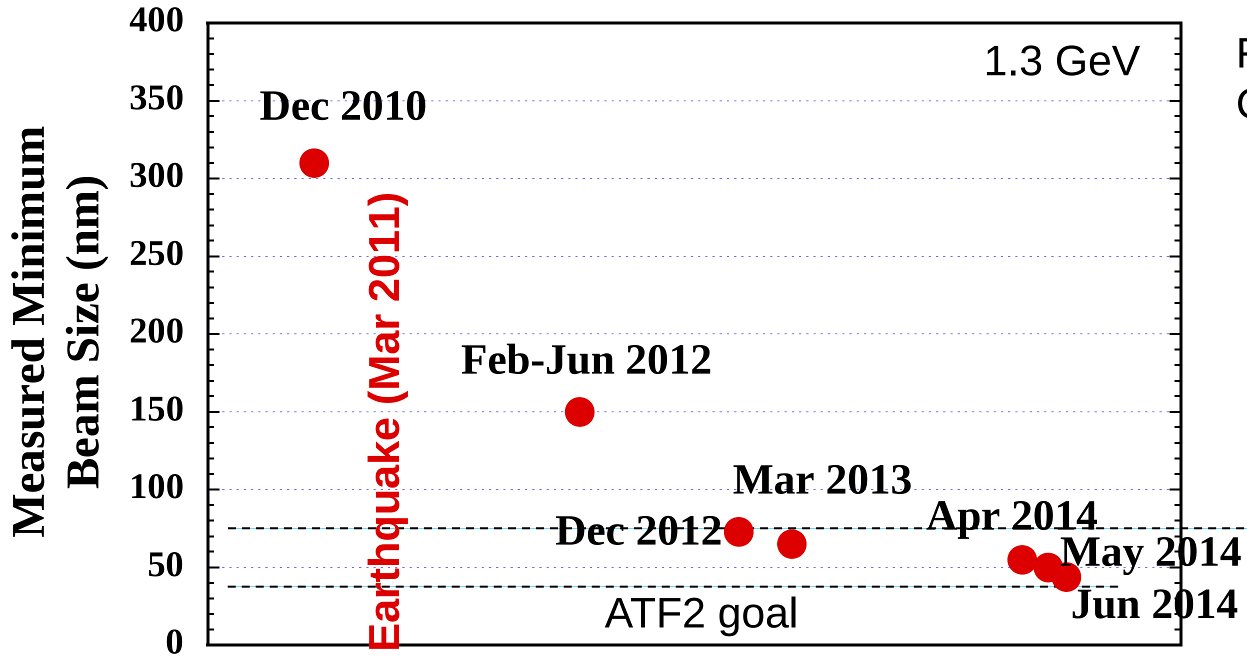


Figure by ATF2 coll.
Courtesy N. Walker

Previous HEP accelerator **world record** from 1994 with 46.6 GeV at SLAC

Note: Scanning Transmission Electron Micro-scopes achieve sub-nm spot size!

Note:

Adiabatic emittance damping → means that physical emittance shrinks with 1/Energy → Beam size shrinks with 1/ SQRT(Energy) → 37 nm corresponds to 2.7 nm at 250 GeV.

Higher energy means less sensitivity to perturbations like wakefields with higher currents!

New record 40 nm beam size at ATF2 → towards ILC

Achieved beam sizes at IP

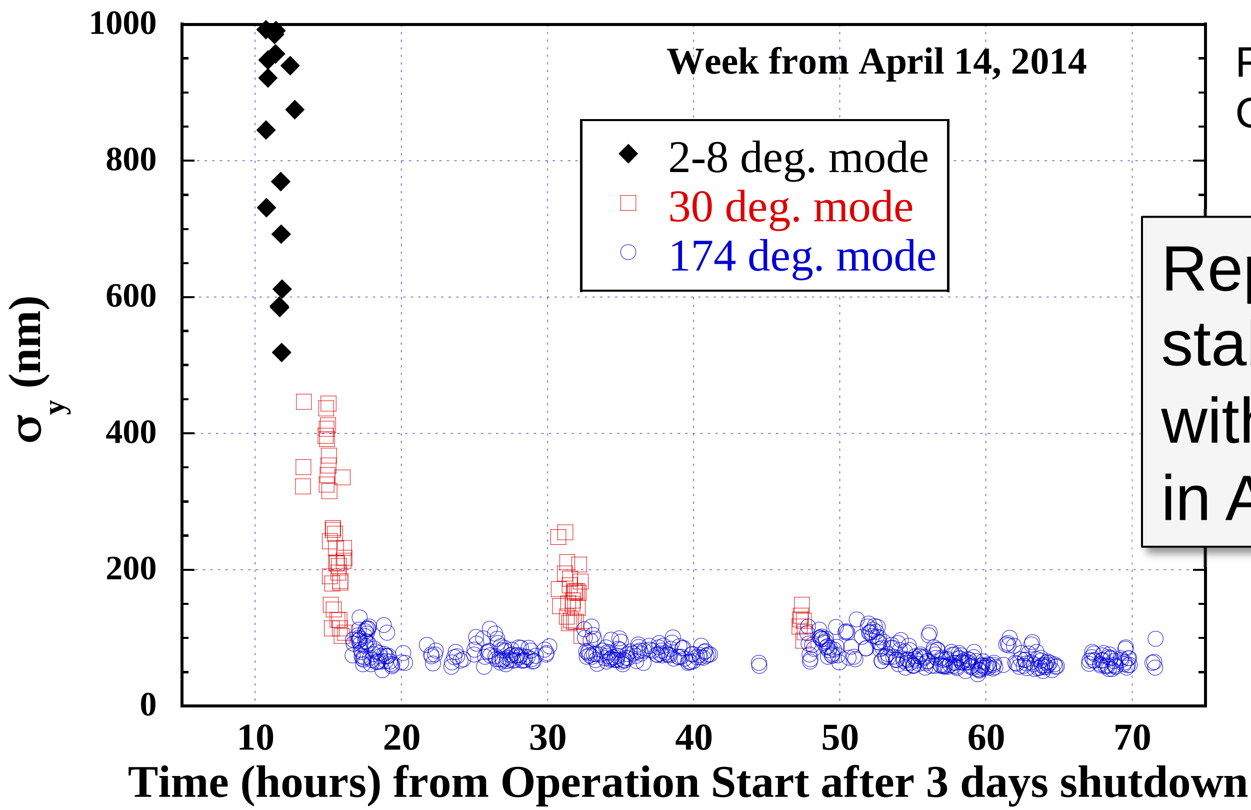


Figure by ATF2 coll.
Courtesy N. Walker

Reproducible and stable operation with nanobeams in ATF2

Current run: ATF2 now routinely achieves <50nm in ~1 day of tuning (starting with ~1 um)

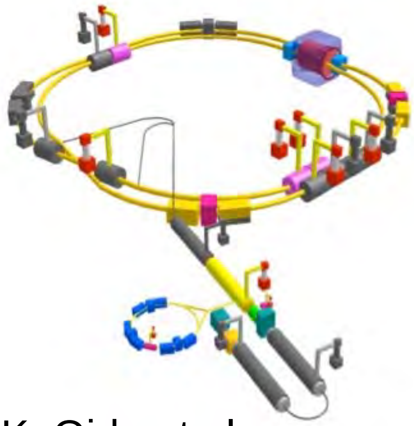
(caveat: only at low bunch charge: impedance effects under investigation)

SuperKEKB (in construction for beam commissioning in 2016)

Table 1: Main Machine Parameters of SuperKEKB.

	LER(e^+)	HER(e^-)	units
Beam energy	4	7.007	GeV
Circumference	3016.315		m
Crossing angle: full	83		mrad
Horizontal emittance	3.2	4.6	nm
Vertical emittance	8.64	11.5	pm
Coupling	0.27	0.28	%
β^*_x / β^*_y	32 / 0.27	25 / 0.30	mm
Vert. beam size at IP	48	62	nm
Energy spread	8.10	6.37	10^{-4}
Beam current	3.60	2.60	A
Number of bunches	2500		
Energy loss/turn	1.86	2.43	MeV
RF frequency	508.9		MHz
RF voltage	9.4	15.0	MV
Bunch length	6.0	5.0	mm
Vert. b-b param.	0.088	0.081	
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$

Sub mm beta* in SuperKEKb upgrade



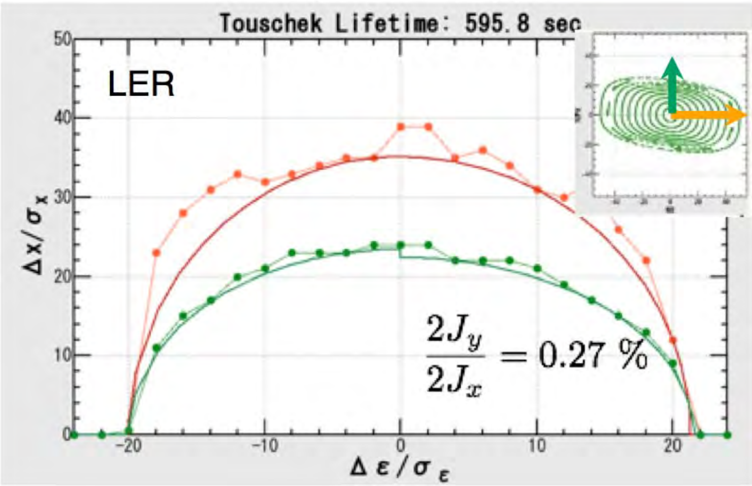
K. Oide et al

Will break into new territory for e+e- colliders!

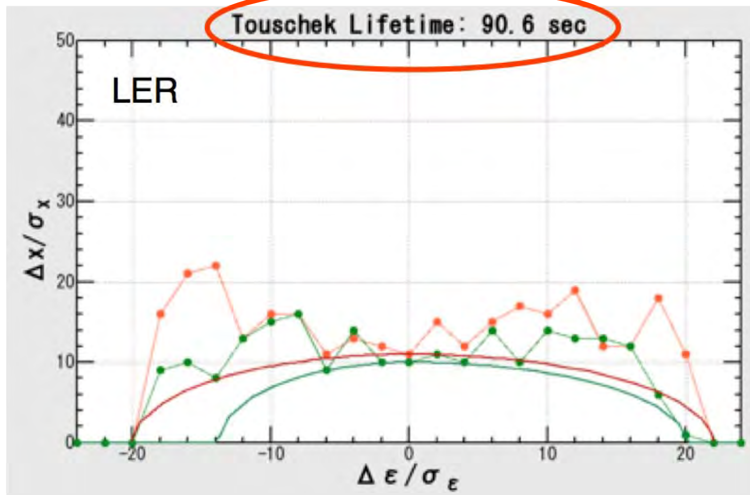
nano-beam scheme

Reduction of dynamic aperture due to beam-beam

w/o beam-beam

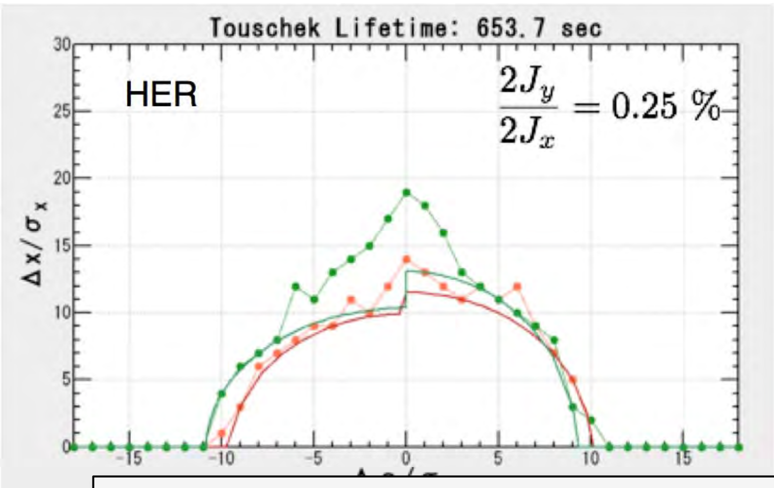


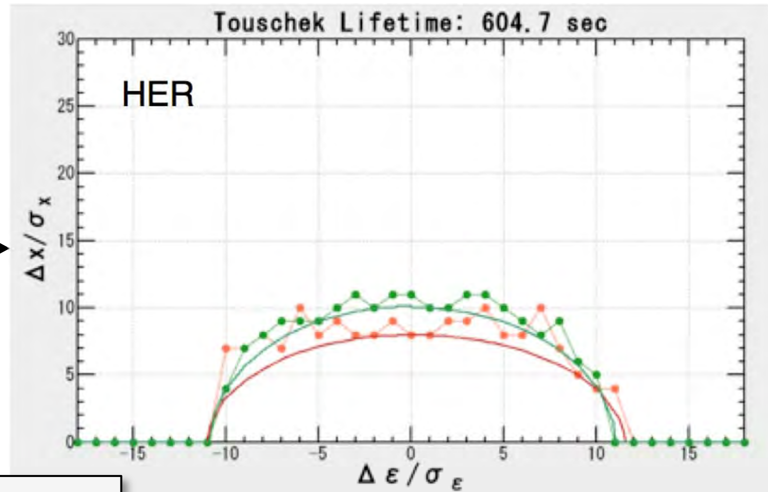
with beam-beam



$$\Delta p/p = \pm 1.4\%$$

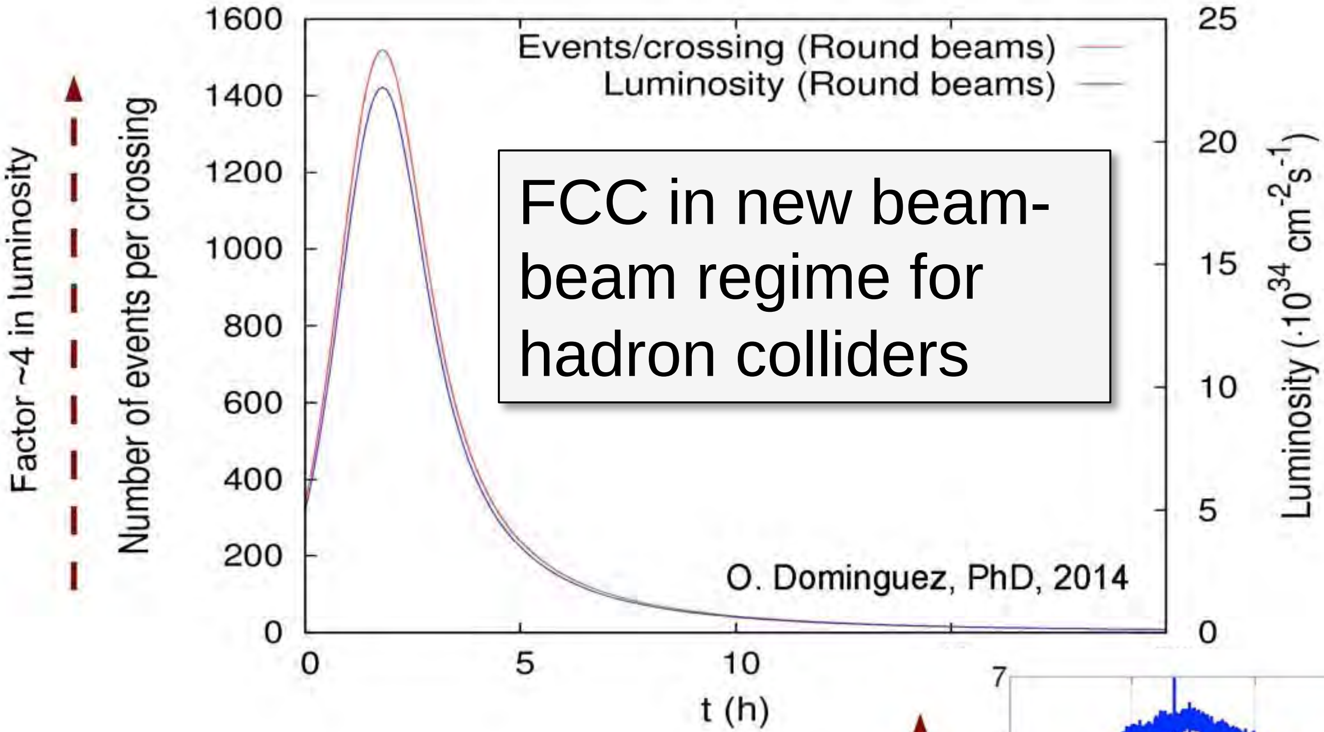
Transverse aperture reduces significantly.





Y. Ohnishi, A. Morita, H. Sugimoto, H. Koiso

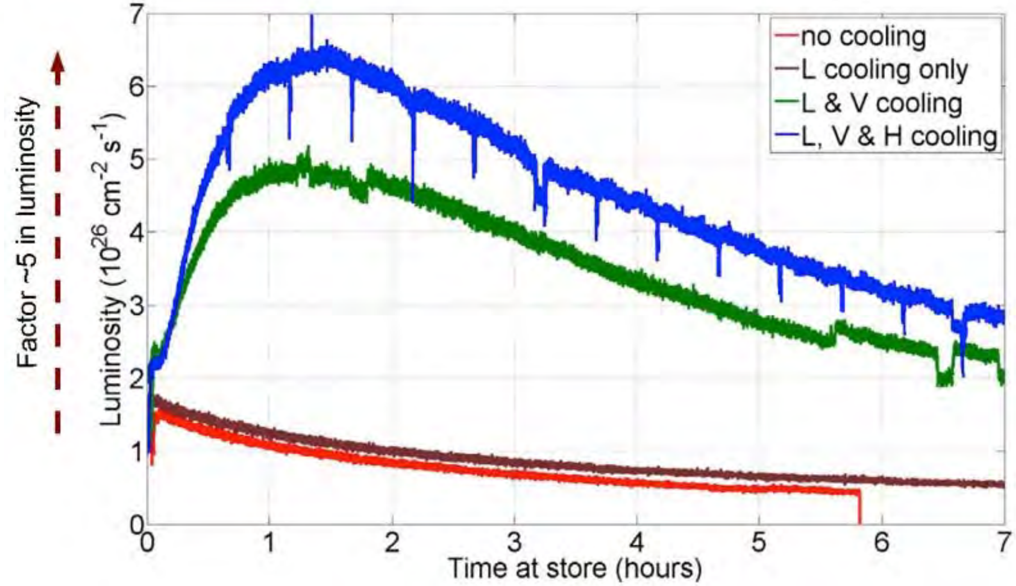
luminosity evolution w rad damping



emittance control by noise excitation

O. Domiguez

M. Blaskiewicz et al.



extremely similar to RHIC operation with stochastic cooling

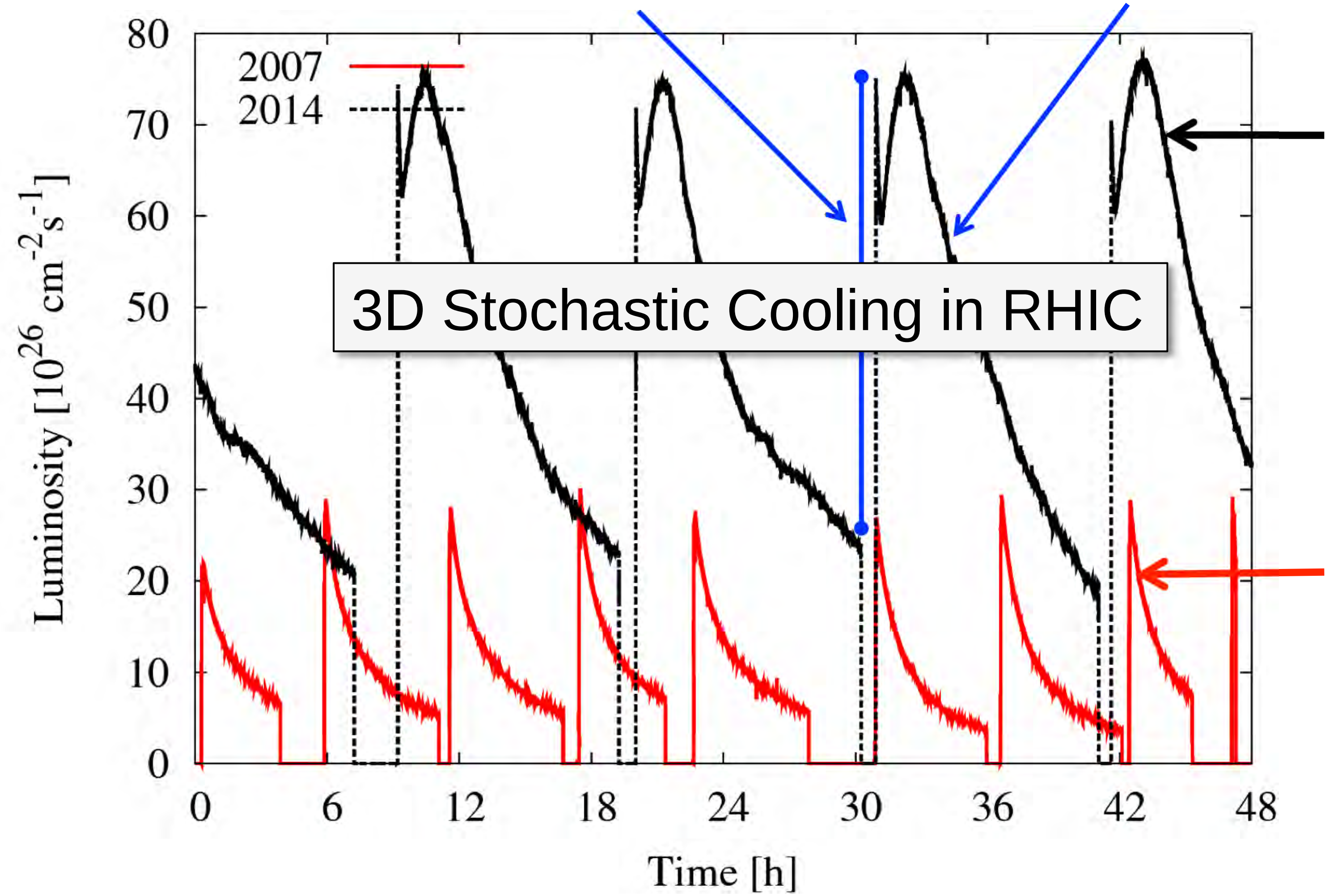
R. Tomas

RHIC Run-14 Au+Au

Delivering RHIC-II luminosity

Increase in initial luminosity
result of larger bunch intensity

Increase in luminosity lifetime
result of **3D stochastic cooling**, >90% burn-off



2014, End of
RHIC-II upgrade
25x design luminosity

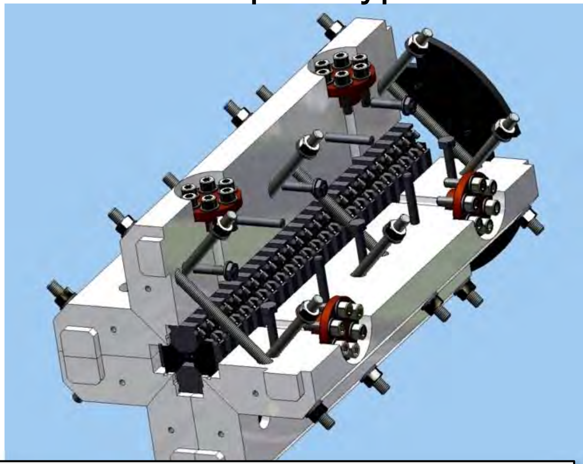
2007, Beginning
of RHIC-II upgrade
6x design luminosity

Stochastic cooling: M. Blaskiewicz, J. M. Brennan, and K. Mernick, PRL 105, 094801 (2010).

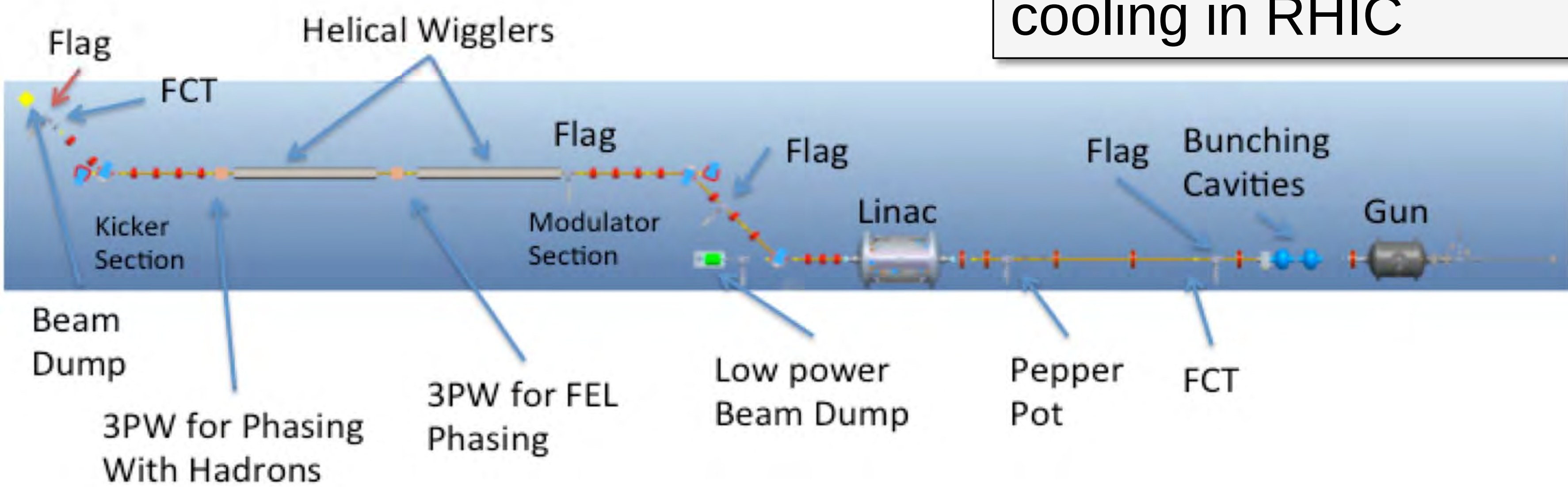
Coherent electron Cooling

- Idea proposed by Y. Derbenev in 1980, novel scheme with full evaluation developed by V. Litvinenko
- Fast cooling of high energy hadron beams
- Made possible by high brightness electron beams and FEL technology
- ~ 20 minutes cooling time for 250 GeV protons → 10x reduced proton emittance gives high eRHIC luminosity
- Proof-of-principle demonstration planned with 40 GeV/n Au beam in RHIC
- Micro-bunching test also planned with same set-up

Helical wiggler prototype



Towards demonstrating coherent electron cooling in RHIC



The Success of Project-Driven R&D

- **Breakthrough achievements** in the various projects presented before: *40 nm beam size, sub-mm beta*, 20T HTS dipole goal, 4T/s ramping magnets, >25 MV/m SC RF, 52 MV/m C-Band, 100 MV/m X-Band, cooling, CW beams, …*
- Apologies that many great results could not be shown in the time available.
- Project-driven accelerator R&D **opens new science and research opportunities**.
- The available techniques allow for various **future HEP projects to be envisaged technically**: ILC, FCC. Challenges from practical limitations.
- **Users play a very important role in this success of project-driven accelerator R&D** → they ensure focus on the directions to take and feedback on required quality and parameters!
- Something that is not as evident in generic accelerator R&D → there we also need to get users involved...

Outline

1. Project-Driven Accelerator R&D
2. **R&D towards a New Kind of Accelerators**
3. Conclusion

Plasma Accelerators as Future Technology

Successful accelerator technologies approach physical and practical limits → advances slow down.

Plasma accelerators produce the same energy gain as conventional accelerators in 1/1000 of acceleration length.

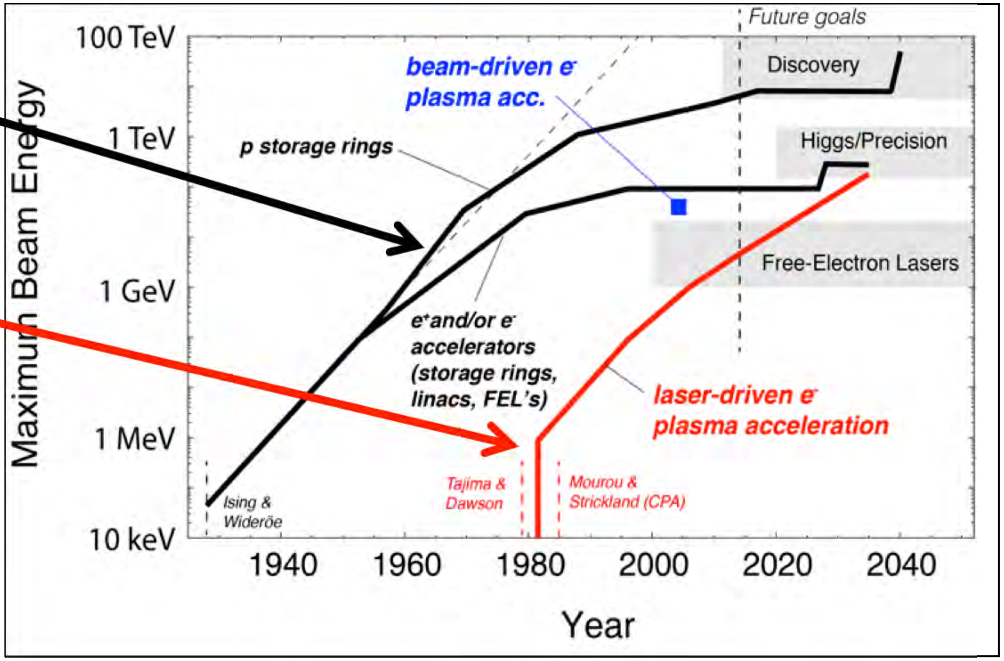
The required high power lasers become more and more compact. Rapid laser development and progress!

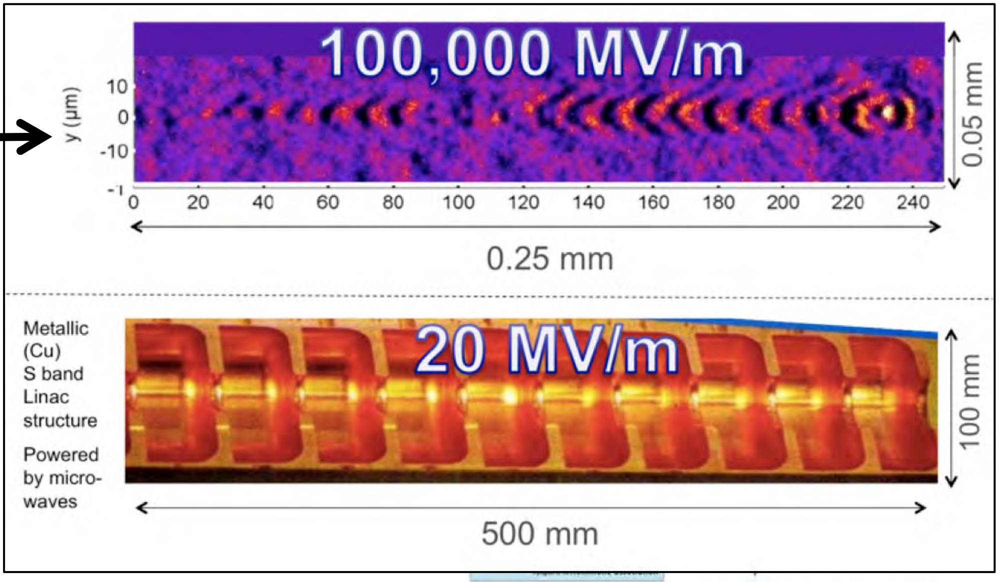
Beams (e- and p) can also drive wakefields

Potential for ultra-compact accelerators of e^-, p and ions. Reduced size & cost(?).

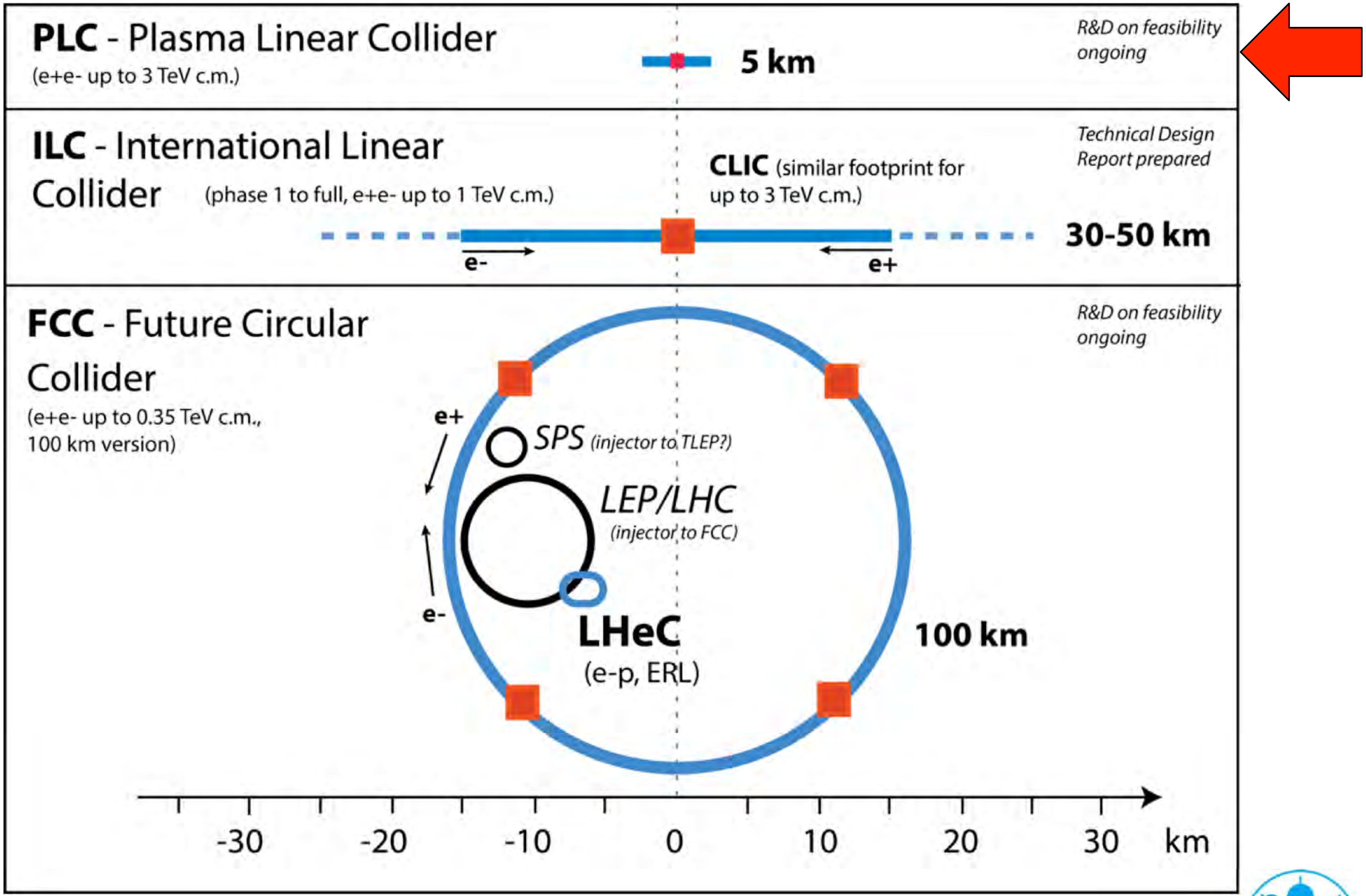
Challenge:

Usability – Stability – Quality



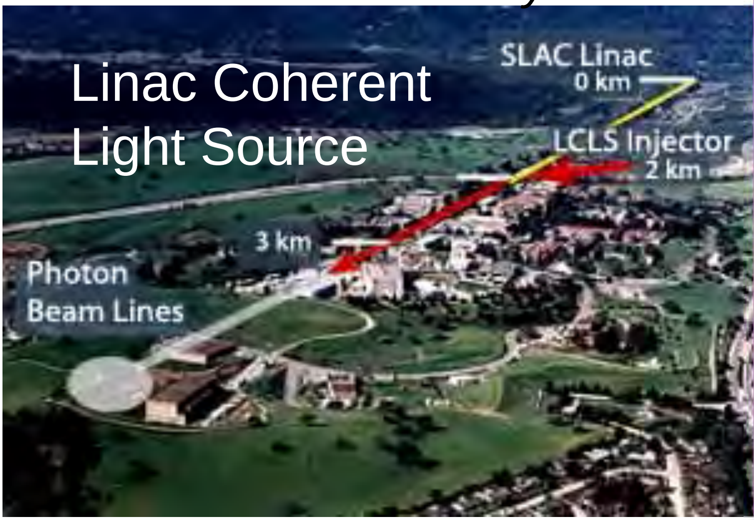


Long-Term Application 1: Compact linear collider

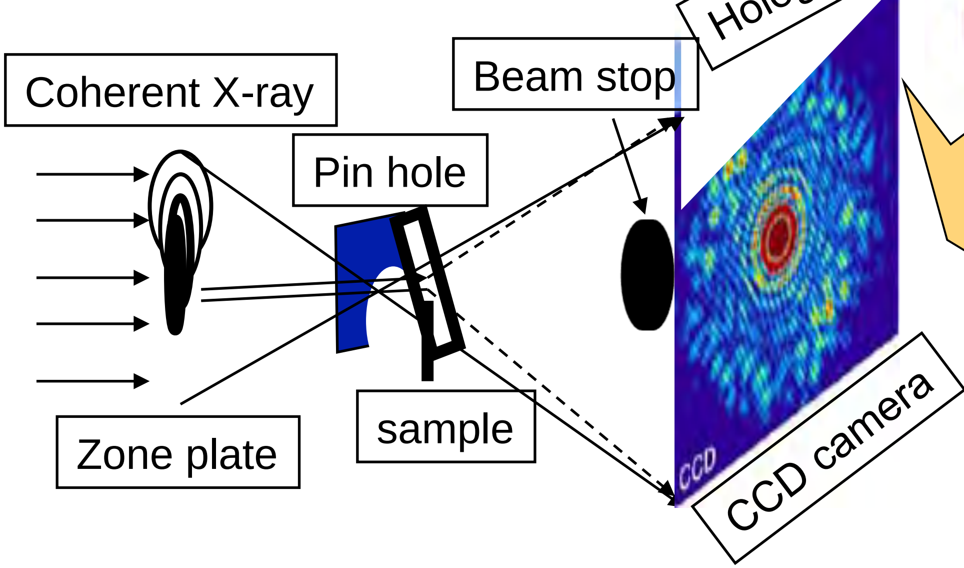


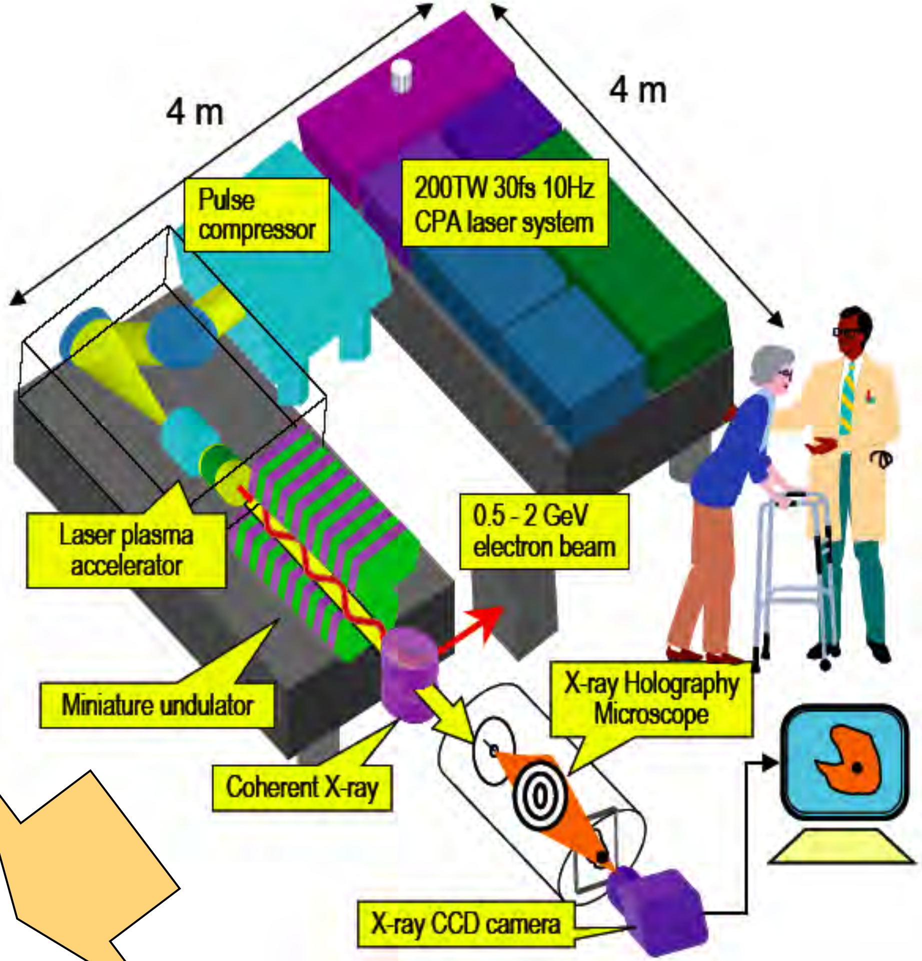
Long-Term Application 2: Laser-driven compact X-ray FEL

Kilometer-scale X-ray FEL



X-ray Holography Microscope

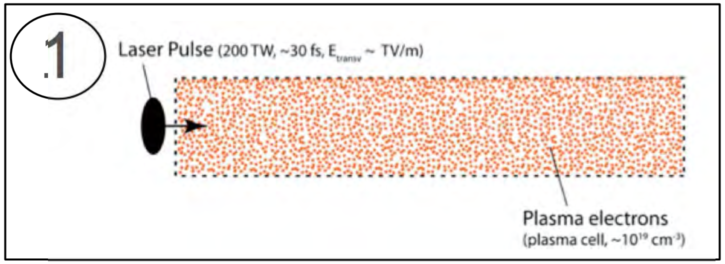


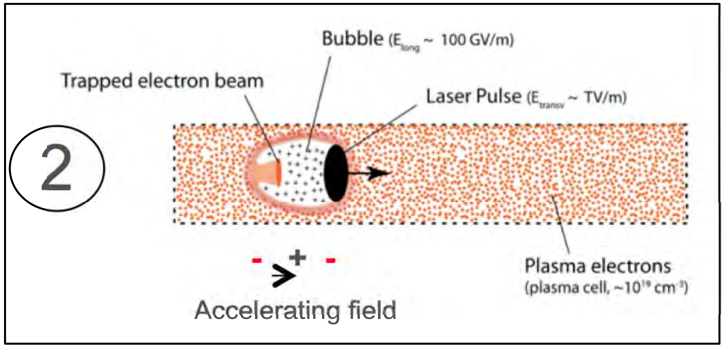


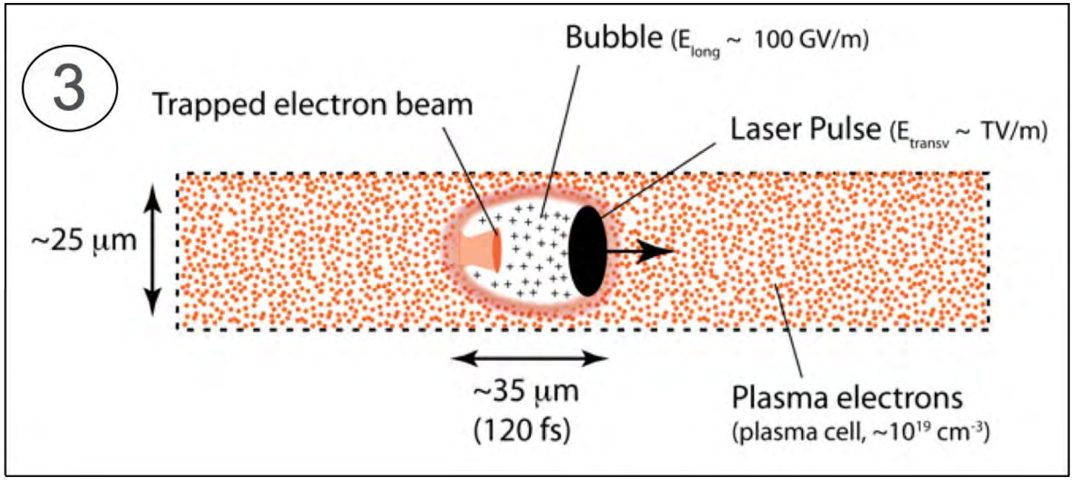
Visualization by
T. Tajima, 2010

Physics of Plasma Acceleration on 1 Slide

Modern lasers have transverse fields of **1.000.000 MV/m**! Can we use these fields to accelerate charged particles?







Electrons can also be produced externally and injected into the plasma accelerator!

This accelerator fits in principle into a human hair!
Of course: Lasers are of substantial size but progressing rapidly (reduced size, higher power, better quality, ...).

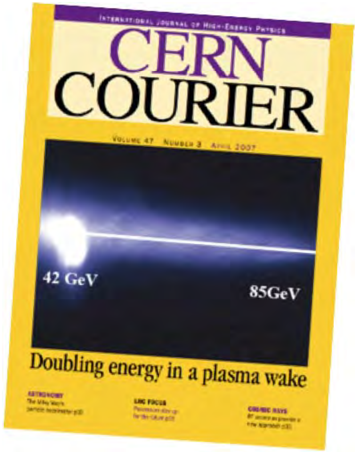


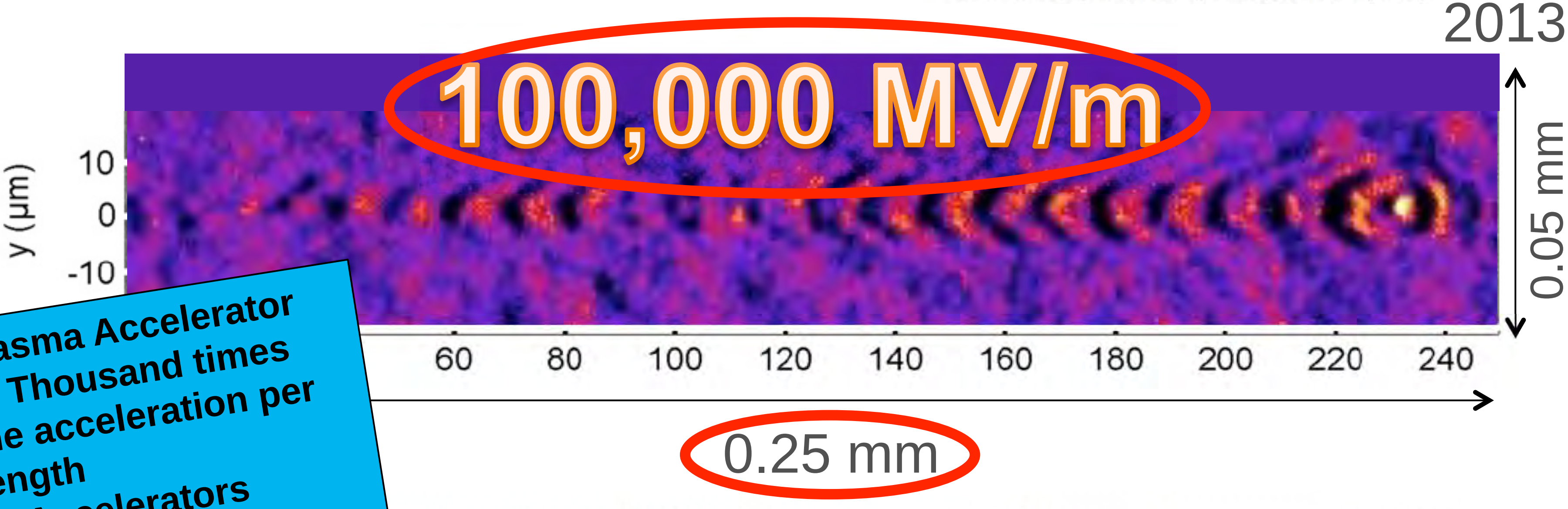
Photo Laser-Plasma Accelerator

APPLIED PHYSICS LETTERS 103, 191118 (2013)

Few-cycle optical probe-pulse for investigation of relativistic laser-plasma interactions

M. B. Schwab,[1,a)] A. Sävert,[1] O. Jäckel,[1,2] J. Polz,[1] M. Schnell,[1] T. Rinck,[1] L. Veisz,[3] M. Möller,[1] P. Hansinger,[1] G. G. Paulus,[1,2] and M. C. Kaluza[1,2]
[1]Institut für Optik und Quantenelektronik, Max-Wien-Platz 1, 07743 Jena, Germany
[2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany
[3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

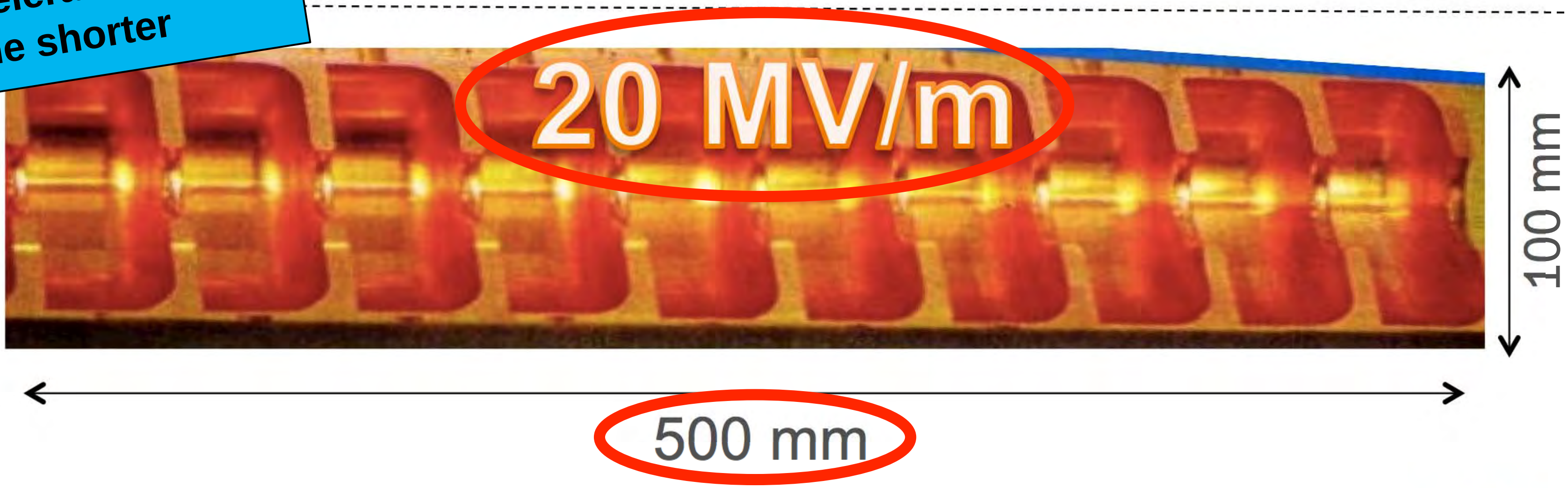
2013



Plasma Accelerator
→ Thousand times the acceleration per length
→ Accelerators become shorter

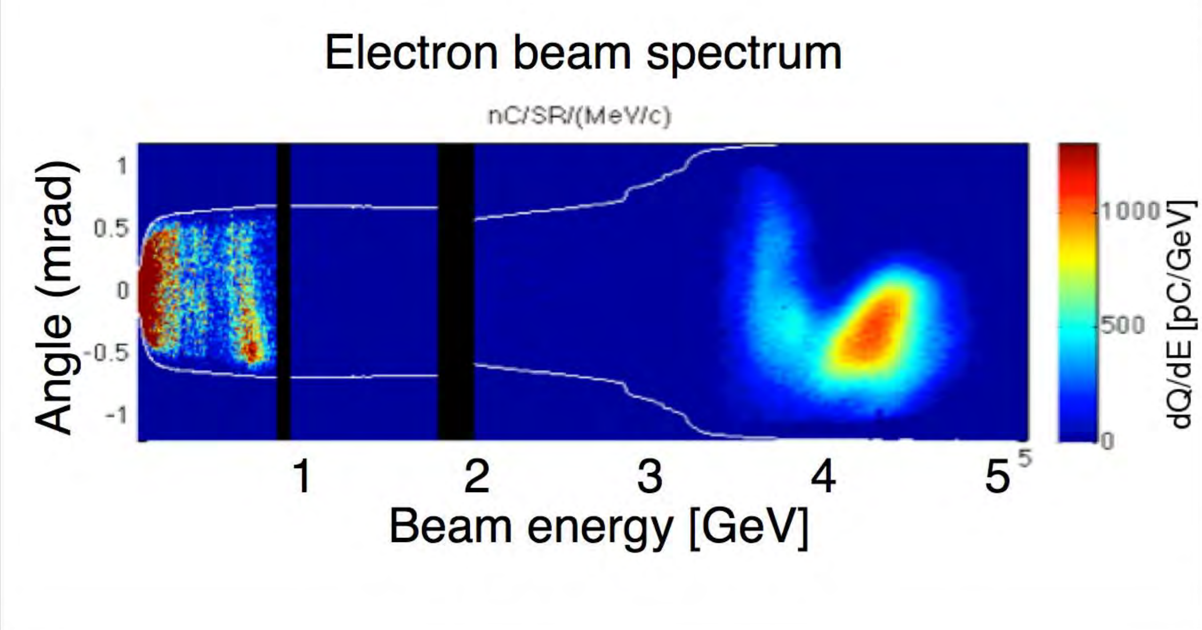
Me
(Copper)
S band
Linac
Structure

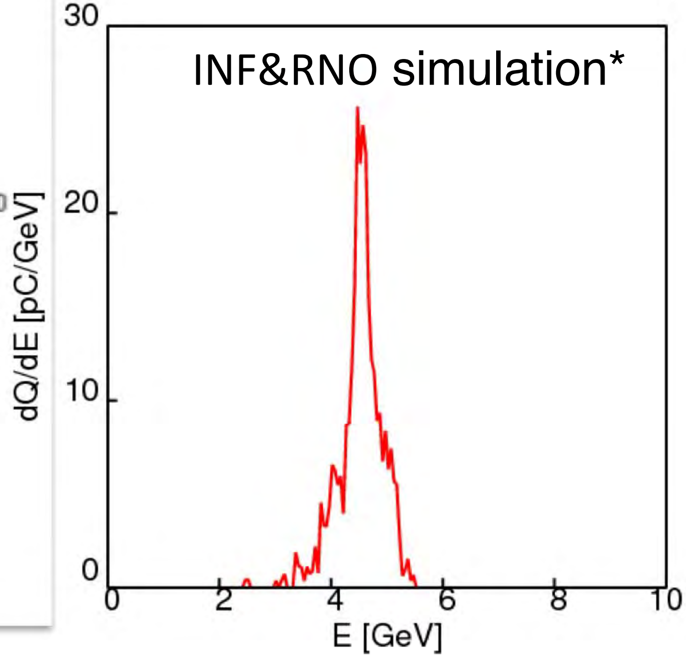
Powered by micro-waves



4.25 GeV beams have been obtained from 9 cm plasma channel powered by 310 TW laser pulses **(15 J)**

*C. Benedetti et al., proceedings of AAC2010, proceedings of ICAP2012





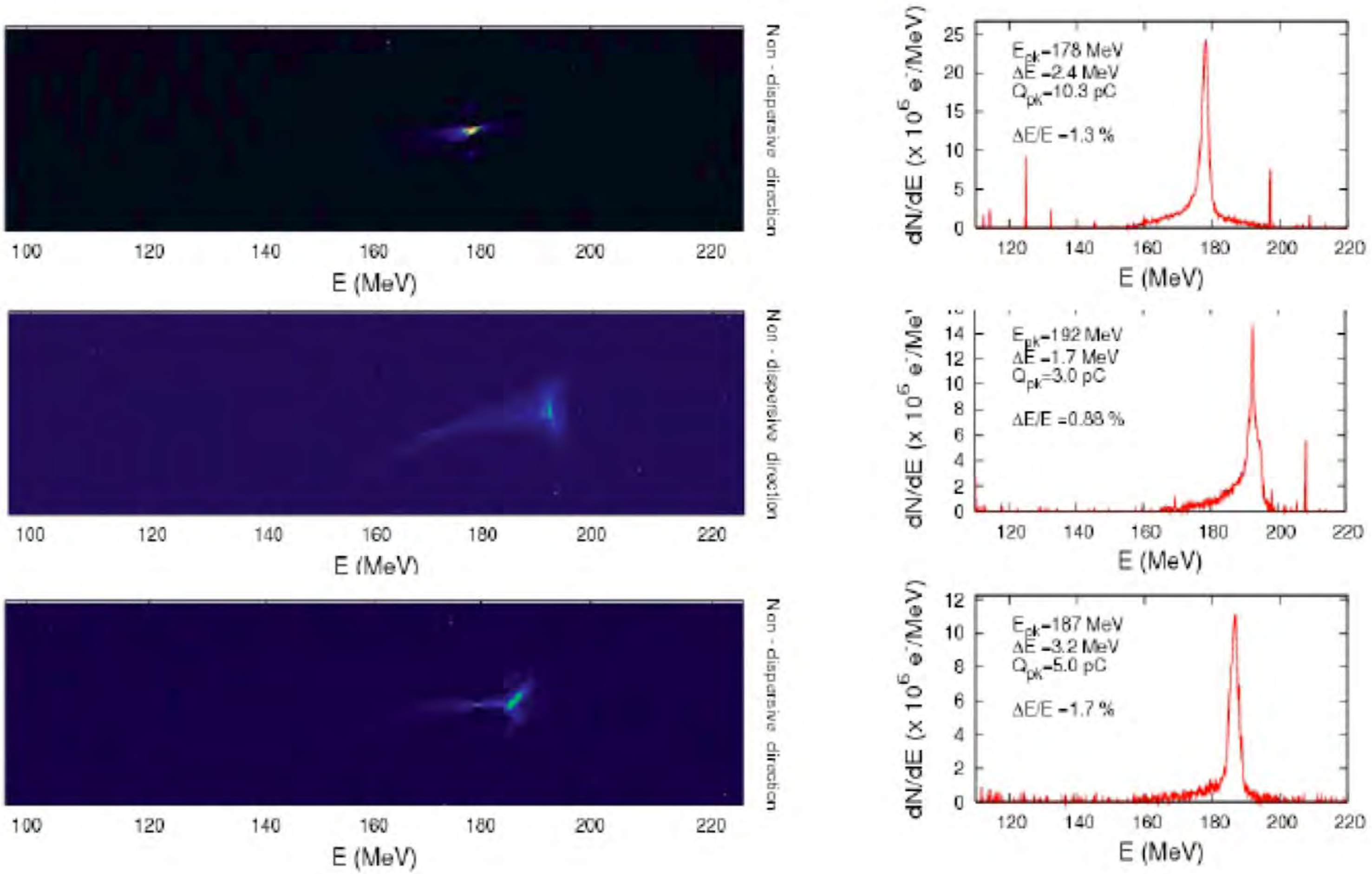
- **Laser** (E=15 J):
  - Measured longitudinal profile (T_0= 40 fs)
  - Measured far field mode (w_0=53 μm)
- **Plasma:** parabolic plasma channel (length 9 cm, n_0~$6x10^{17}$ cm^{-3})

	Exp.	Sim.
Energy	4.25 GeV	4.5 GeV
ΔE/E	5%	3.2%
Charge	~20 pC	23 pC
Divergence	0.3 mrad	0.6 mrad

W.P. Leemans et al.,PRL 2014, in print

1% relative energy spread

Slide by V. Malka

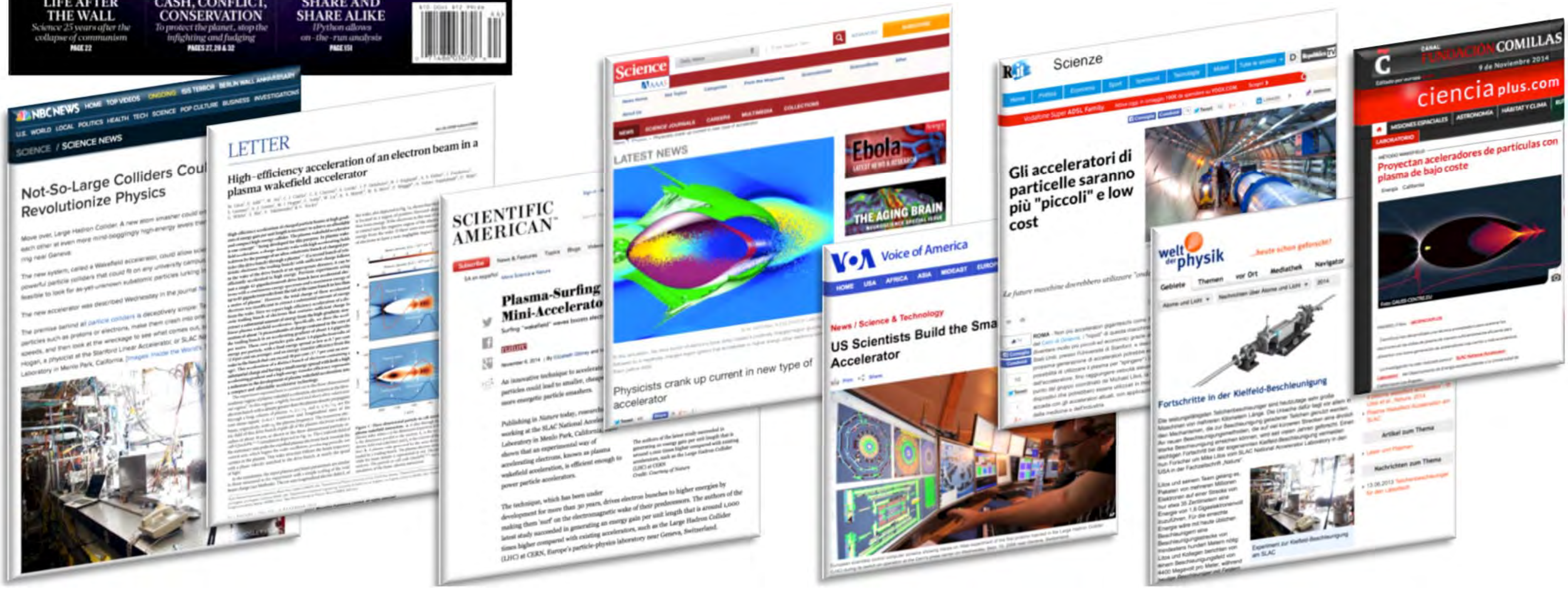


C. Rechatin *et al.*, Phys. Rev. Lett. **102**, 194804 (2009)

FACET: *A National User Facility based on high-energy beams and their interaction with plasmas and lasers*

UCLA SLAC

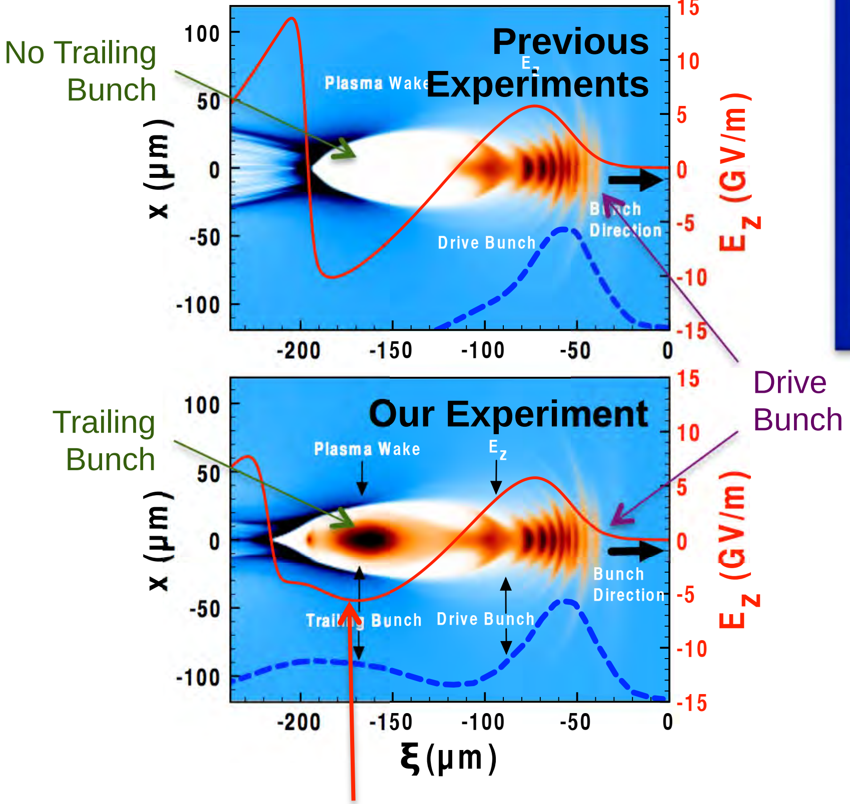
- Facility hosts more than 150 users, 25 experiments
- One high profile result a year
- Priorities balanced between focused plasma wakefield acceleration research and diverse user programs with ultra-high fields



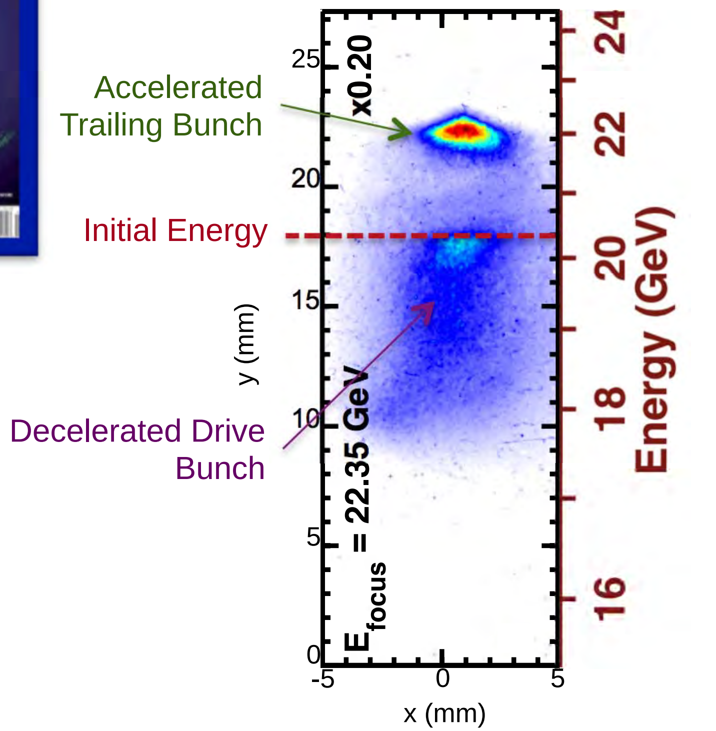
High-Efficiency Acceleration of an Electron Bunch in a Plasma Wakefield Accelerator

UCLA SLAC

Simulations



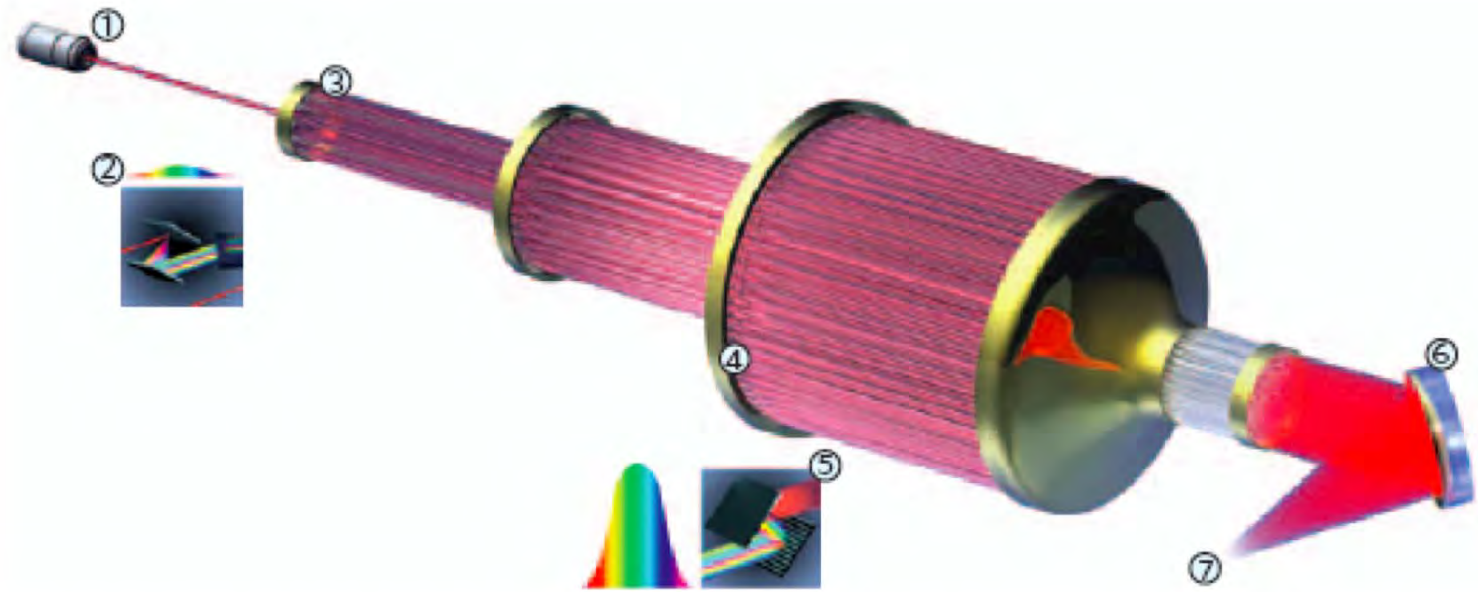
Energetically Dispersed Beam After Plasma (**Data**)



- Electric field in plasma wake is loaded by presence of trailing bunch
- Allows efficient energy extraction from the plasma wake

This result is important for High Energy Physics applications that require very efficient high-gradient acceleration

Work on Laser Efficiency: Towards 30% Efficiency



ICAN

Coherent Amplification Network

Figure 1 | Principle of a coherent amplifier network. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of >10 J at a repetition rate of ~10 kHz (7).

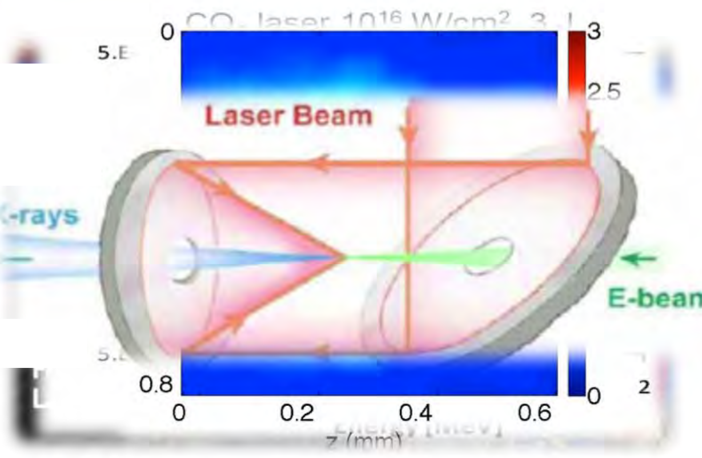
The future is fibre accelerators

Gerard Mourou, Bill Brocklesby, Toshiki Tajima and Jens Limpert

Could massive arrays of thousands of fibre lasers be the driving force behind next-generation particle accelerators? The International Coherent Amplification Network project believes so and is currently performing a feasibility study.

Picosecond CO_2 gas laser

a tool for exploring
novel methods of particle acceleration
and radiation sources.



CO_2 (λ=10 μm) advantages
as compared to solid-state ($\lambda \approx$1 μm) lasers:

#1 favorable scaling of accelerating structures, better electron phasing into the field

#2 100 times stronger ponderomotive effects at the same laser intensity

#3 10 times more photons per Joule

#4 100 times lower critical plasma density

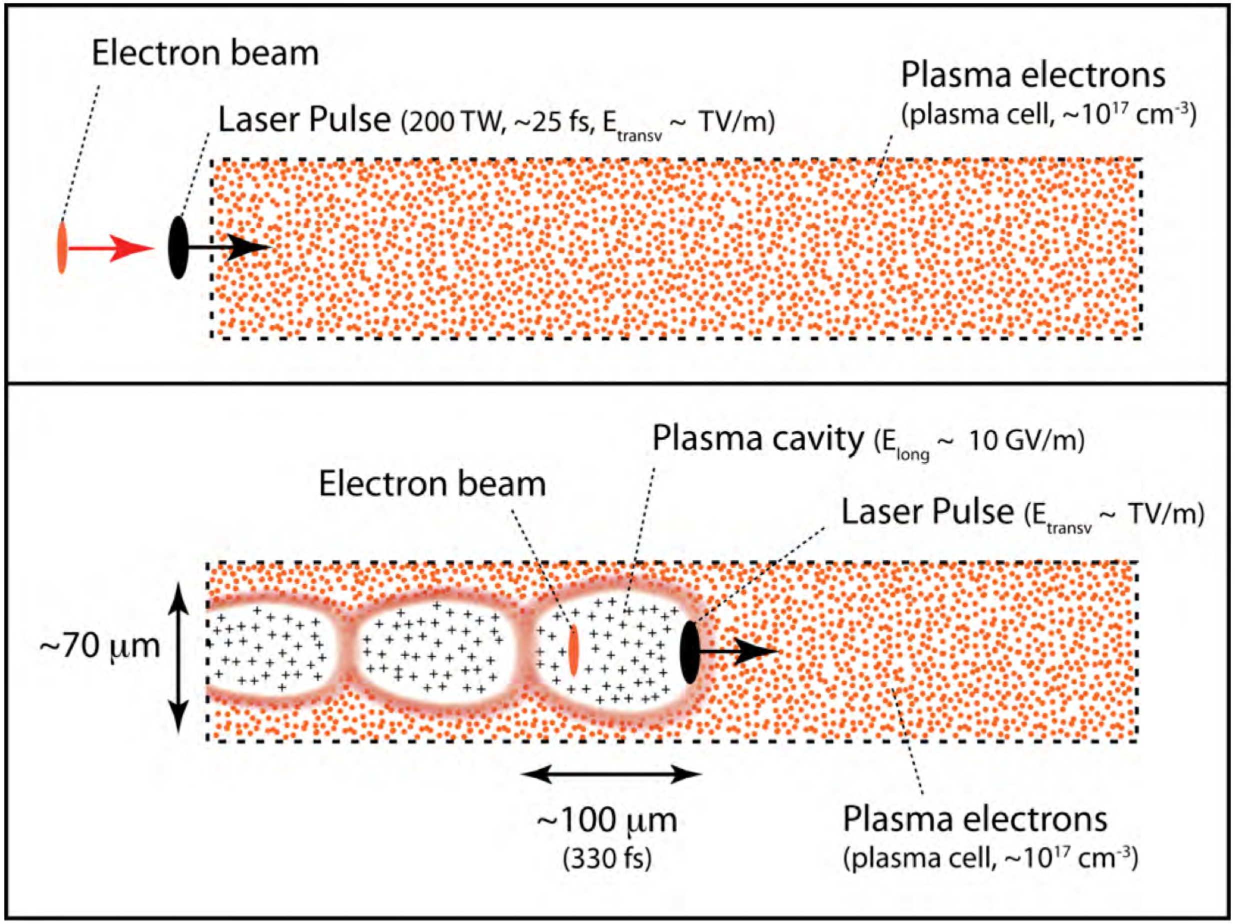
Critical, Missing Step: Make it Useful for Something...

> Stability in plasma accelerators still insufficient. At the same time no fundamental limit on stability is know.

> **Modular Ansatz:**

- A known e-beam is injected → **external injection**.
- Hybrid: DESY „Best in Class“ accelerator + laser + plasma.
- Reduced complexity!
- Allows placing several accelerating plasma structures behind each other (“Staging”).

> Not shown so far!

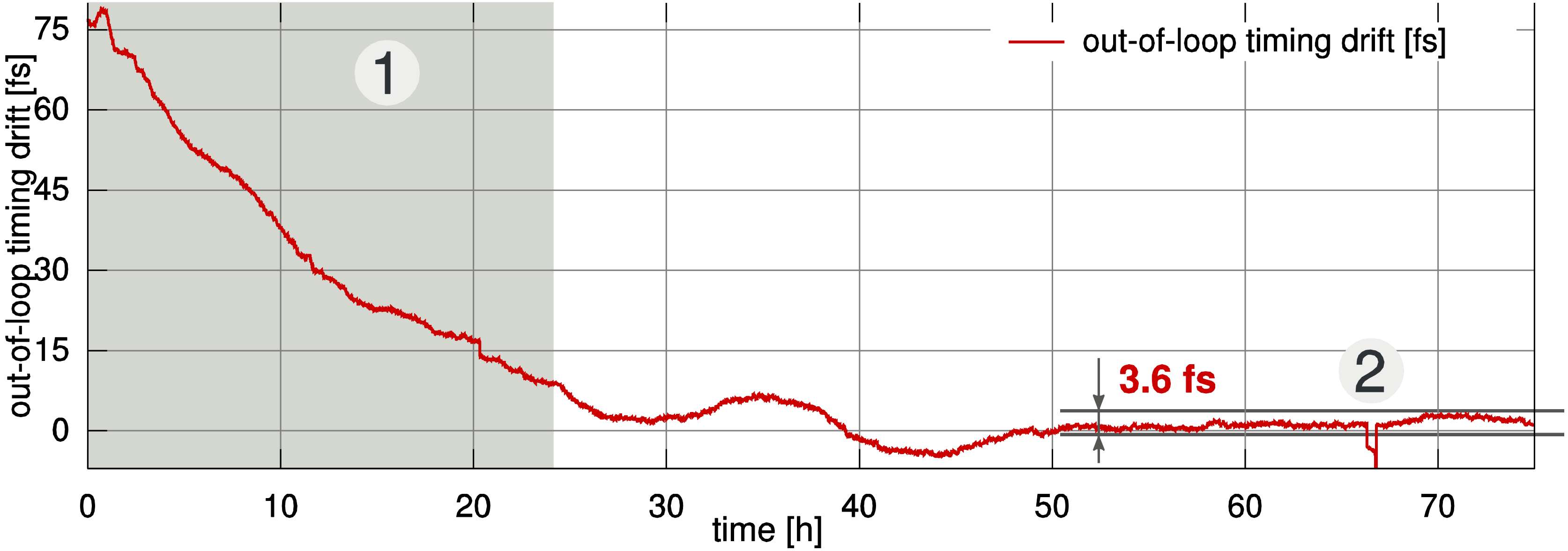


Accelerator Builder's Challenge *(simplified to typical values)*

- Match into and out of plasma with **beam size around 1 μm** (about 1 mm beta function).
  - *See ATF2 results: 40 nm for beam size. See SuperKEKB: < 1mm beta in circular coll.*
- Control **offsets** between the wakefield driver (laser or beam) and the accelerated electron bunch at **1 μm level**.
- Use **short bunches (few fs)** to minimize energy spread.
- Achieve **synchronization stability of few fs** from injected electron bunch to wakefield (energy stability and spread).
- Control the **charge and beam loading** to compensate energy spread.
- Develop and demonstrate **user readiness of a 5 GeV plasma accelerated beam**.

Accelerator Builder's Challenge – Feasible?

> Difficult but we believe solutions can be found. Will not come for free…



Femtosecond Precision in Laser-to-RF Phase Detection

(from H. Schlarb, T. Lamb, E. Janas et al. Report on DESY Highlights 2013).

> Again: **No fundamental limit here, but strong technical challenges!**

Accelerator Builder's Challenge – Feasible?

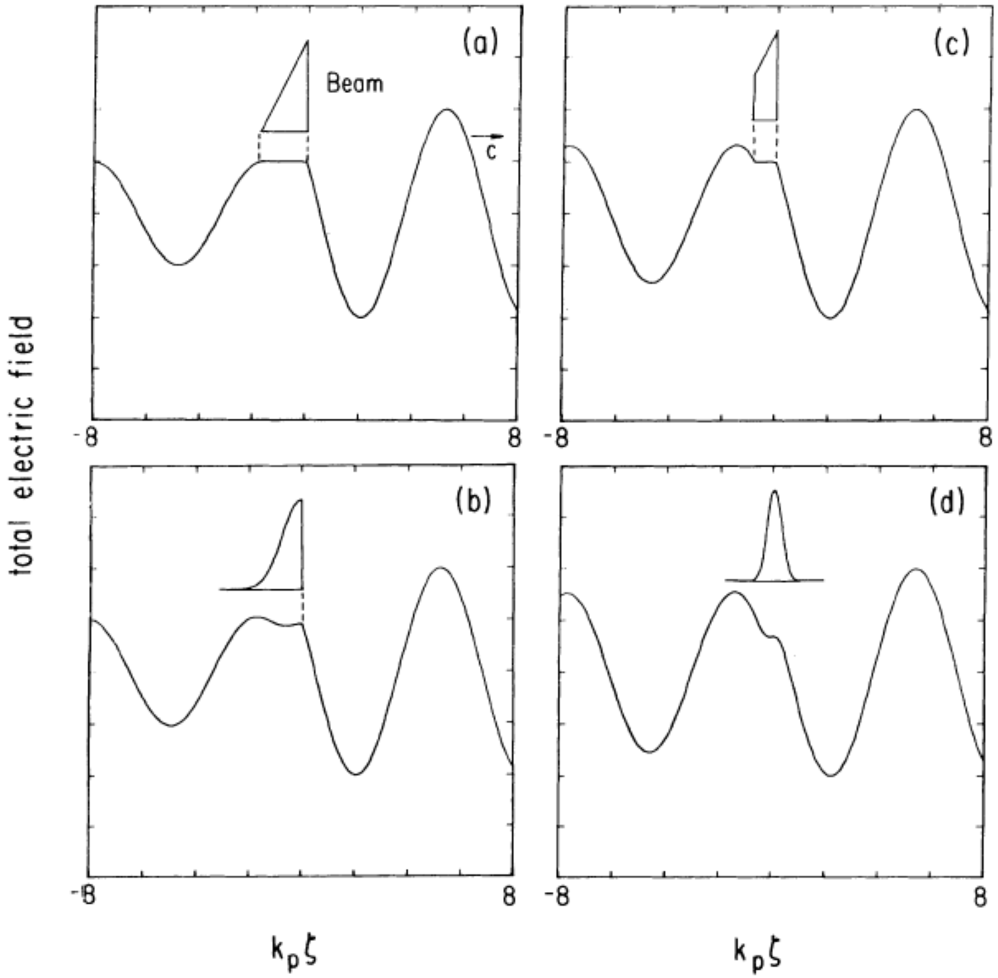
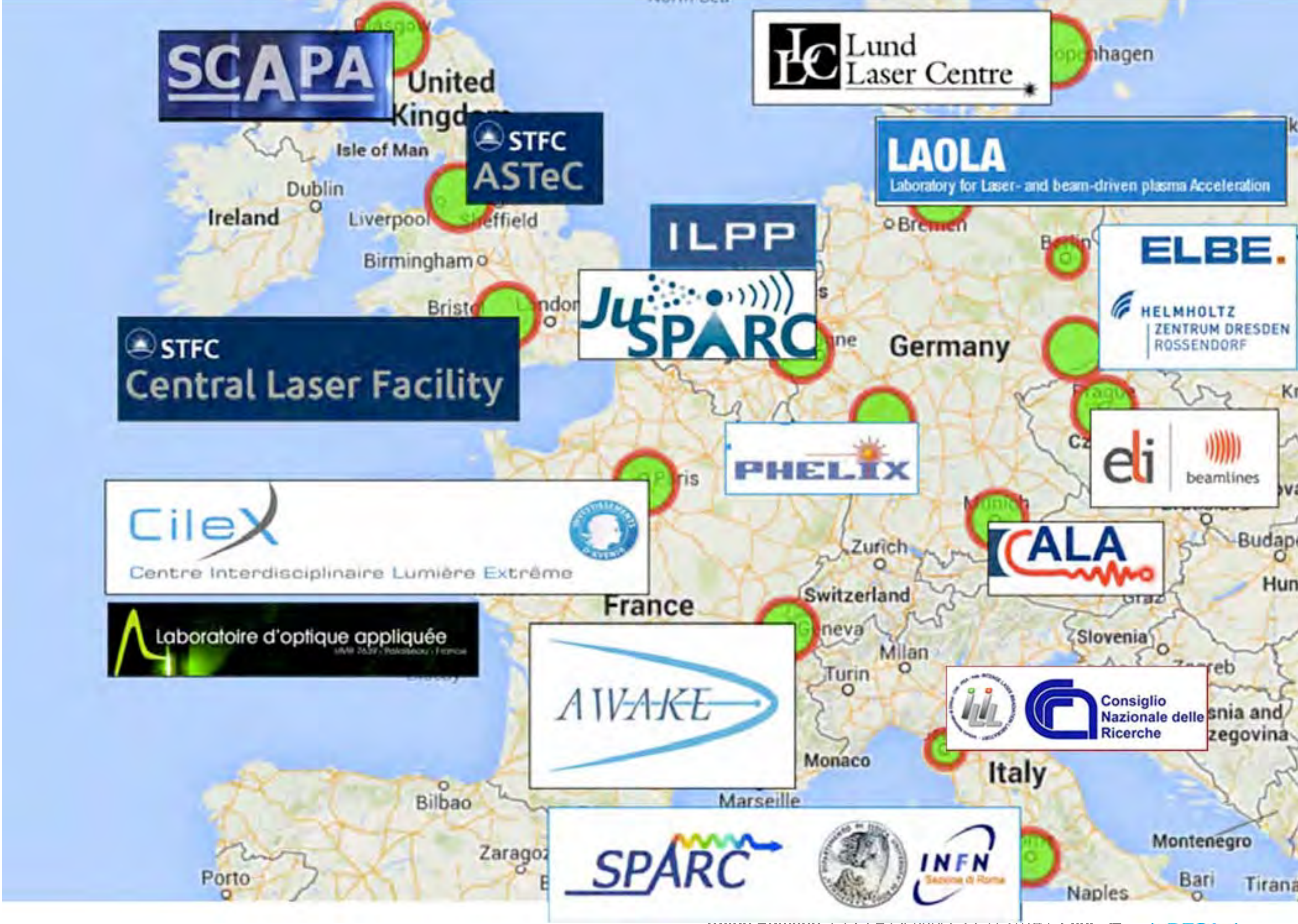


FIGURE 4 Total electric field for various beam shapes: (a) triangle [Eq. (22), $N = 3N_0/4$, $k_p\zeta_0 = \pi/3$), (b) half-Gaussian of same number of particles, (c) truncated triangle ($N = 9N_0/16$), and (d) Gaussian of same number as (c).

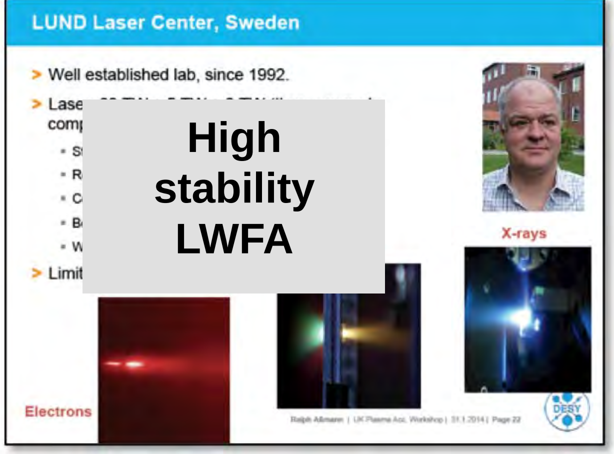
- > **Idea**: Beam Loading to Flatten Wakefield
- > Author: **Simon van der Meer** – CLIC Note No. 3, CERN/PS/85-65 (AA) (1985).
- > Shape the electron beam to get optimized fields in the plasma, e.g. minimize energy spread.
- > Study: Tom Katsouleas.

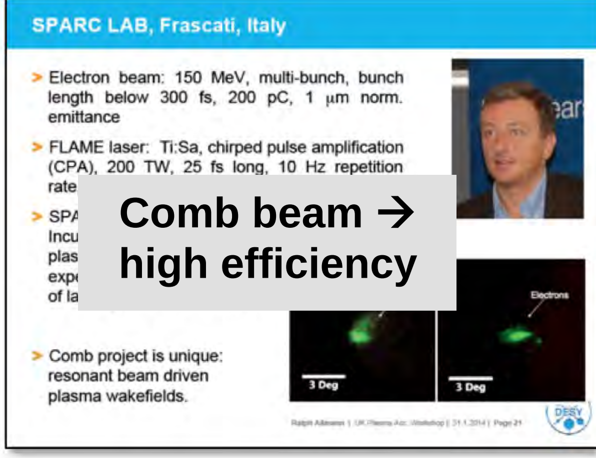
Katsouleas, T., et al. Beam Loading in Plasma Accelerators. Particle Accelerators, 1987, Vol. 22, pp. 81-99 (1987)

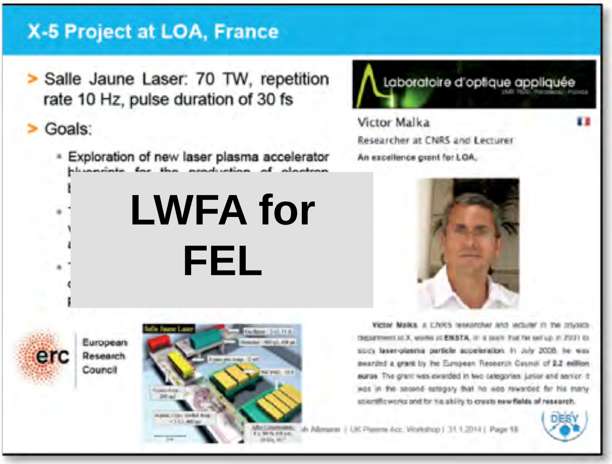
DESY

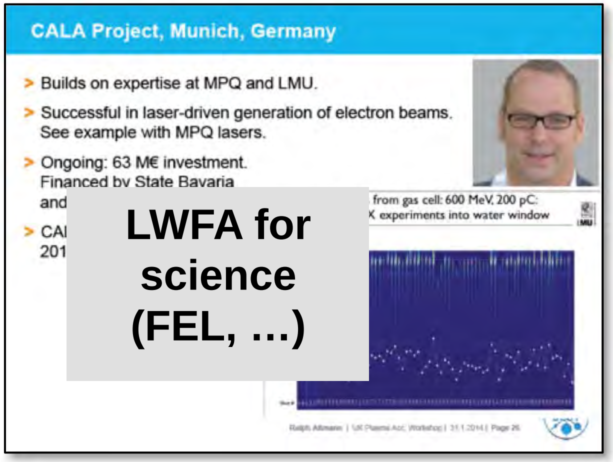

SCAPA
United
Isle of Man
Dublin
Ireland
Liverpool
Birmingham
STFC
ASTeC
Lund
Laser Centre
LAOLA
Laboratory for Laser- and beam-driven plasma Acceleration
ILPP
JuSPARC
Germany
ELBE.
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF
STFC
Central Laser Facility
PHELIX
eli
beamlines
Cilex
Centre Interdisciplinaire Lumière Extrême
CALA
Zurich
Switzerland
France
Laboratoire d'optique appliquée
AWAKE
Slovenia
Milan
Turin
Consiglio
Nazionale delle
Ricerche
Monaco
Italy
Bilbao
Marseille
Zaragoz
Porto
SPARC
INFN
Montenegro
Bari
Naples

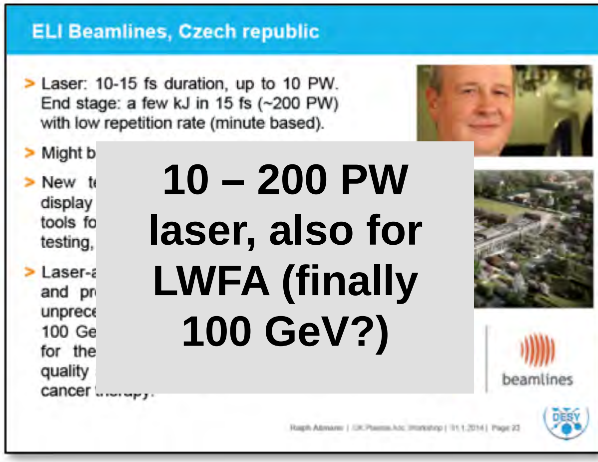

CILEX Project, Plateau de Saclay, France
The big French project.
5 PW laser and LWFA area
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 17

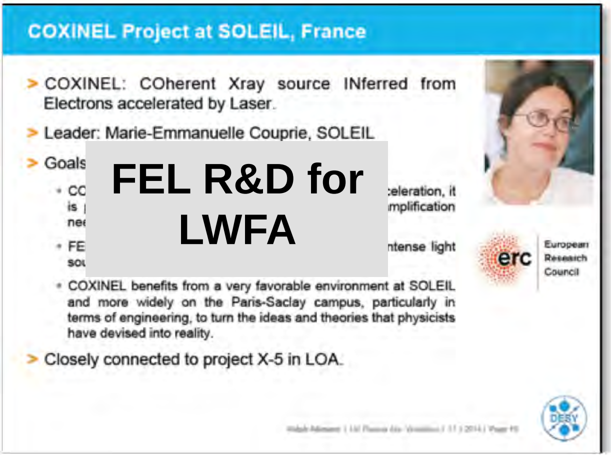

LUND Laser Center, Sweden
Well established lab, since 1992.
High stability LWFA
X-rays
Electrons
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 22

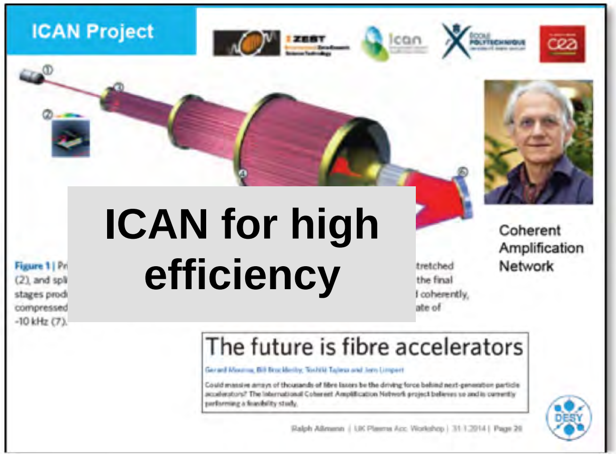

SPARC LAB, Frascati, Italy
Electron beam: 150 MeV, multi-bunch, bunch length below 300 fs, 200 pC, 1 µm norm. emittance
FLAME laser: Ti:Sa, chirped pulse amplification (CPA), 200 TW, 25 fs long, 10 Hz repetition rate
Comb beam → high efficiency
Comb project is unique: resonant beam driven plasma wakefields.
3 Deg
3 Deg
Electrons
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 21

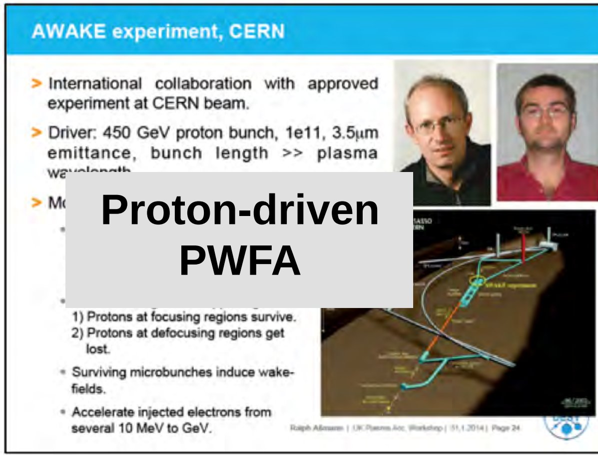

X-5 Project at LOA, France
Salle Jaune Laser: 70 TW, repetition rate 10 Hz, pulse duration of 30 fs
Goals:
Exploration of new laser plasma accelerator
Laboratoire d'optique appliquée
Victor Malka
Researcher at CNRS and Lecturer
An excellence grant for LOA.
LWFA for FEL
erc European Research Council
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 18


CALA Project, Munich, Germany
Builds on expertise at MPQ and LMU.
Successful in laser-driven generation of electron beams. See example with MPQ lasers.
Ongoing: 63 M€ investment.
Financed by State Bavaria
from gas cell: 600 MeV, 200 pC;
X experiments into water window
LWFA for science (FEL, …)
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 20

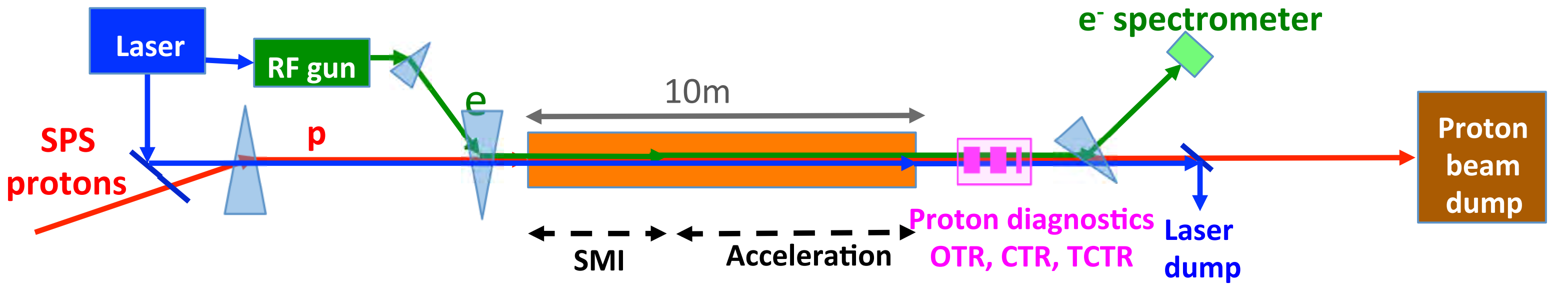

ELI Beamlines, Czech republic
Laser: 10-15 fs duration, up to 10 PW. End stage: a few kJ in 15 fs (~200 PW) with low repetition rate (minute based).
10 – 200 PW laser, also for LWFA (finally 100 GeV?)
beamlines
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 23


COXINEL Project at SOLEIL, France
COXINEL: COherent Xray source INferred from Electrons accelerated by Laser.
Leader: Marie-Emmanuelle Couprie, SOLEIL
FEL R&D for LWFA
erc European Research Council
COXINEL benefits from a very favorable environment at SOLEIL and more widely on the Paris-Saclay campus, particularly in terms of engineering, to turn the ideas and theories that physicists have devised into reality.
Closely connected to project X-5 in LOA.
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 19

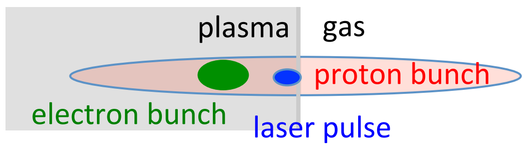

ICAN Project
ICAN for high efficiency
Coherent Amplification Network
The future is fibre accelerators
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 25

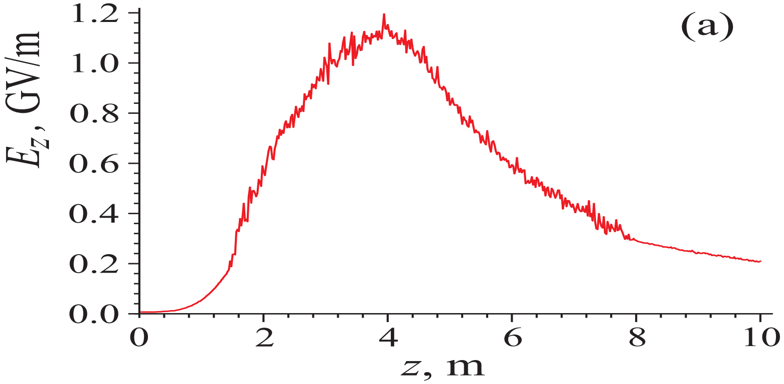

AWAKE experiment, CERN
International collaboration with approved experiment at CERN beam.
Driver: 450 GeV proton bunch, 1e11, 3.5µm emittance, bunch length >> plasma wavelength
Proton-driven PWFA
1) Protons at focusing regions survive.
2) Protons at defocusing regions get lost.
Surviving microbunches induce wake-fields.
Accelerate injected electrons from several 10 MeV to GeV.
Ralph Aßmann | UK Plasma Acc. Workshop | 31.1.2014 | Page 24

AWAKE First Experimental Goals

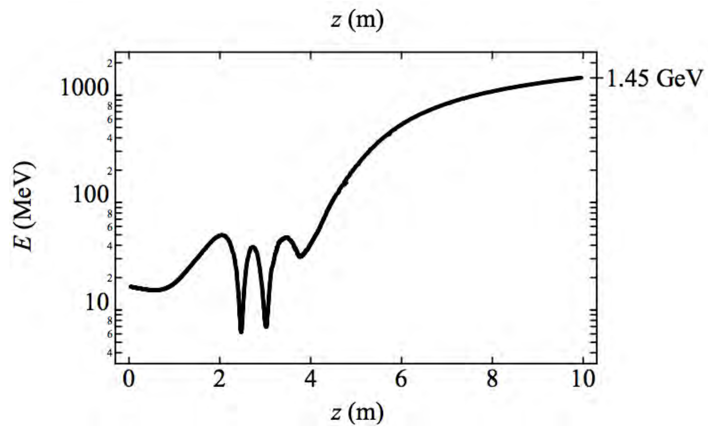


- Laser and proton beam synchronized at the **100 ps level**.
- Laser and electron beam synchronized at the **< 1 ps level**.
- Plasma density uniformity better than **0.2%**

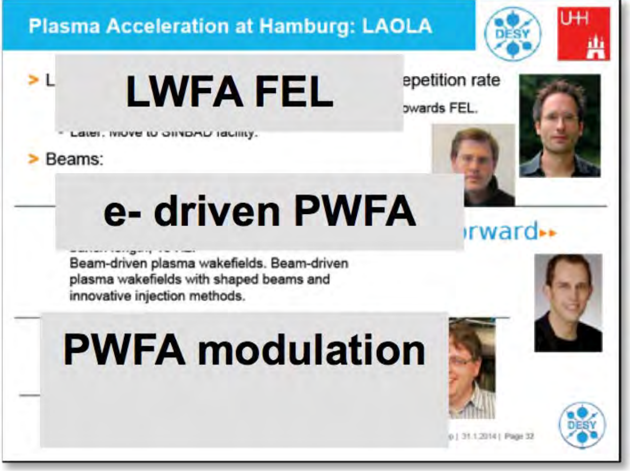


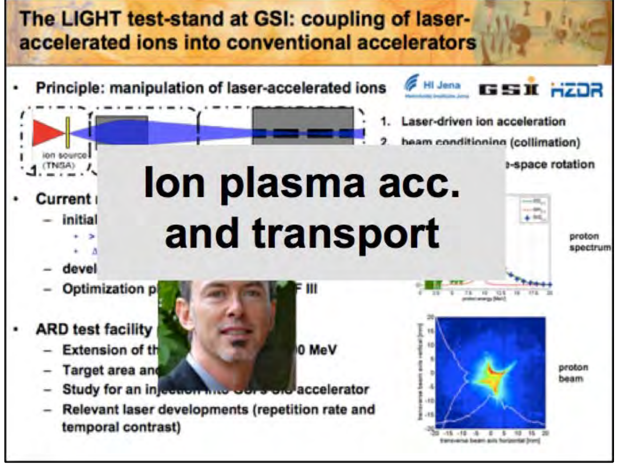


Maximum amplitude of the **accelerating field E_z** as a function of position along the plasma.

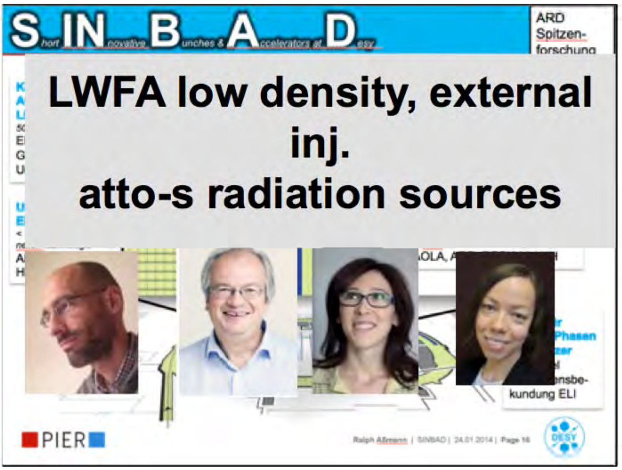


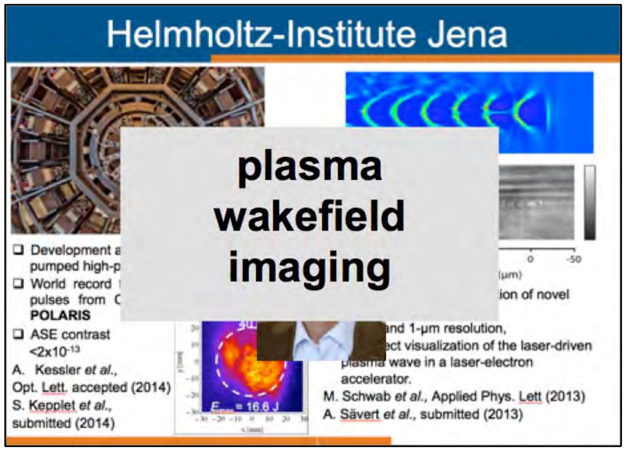
Energy of the electrons gained along the 10 m long plasma cell.

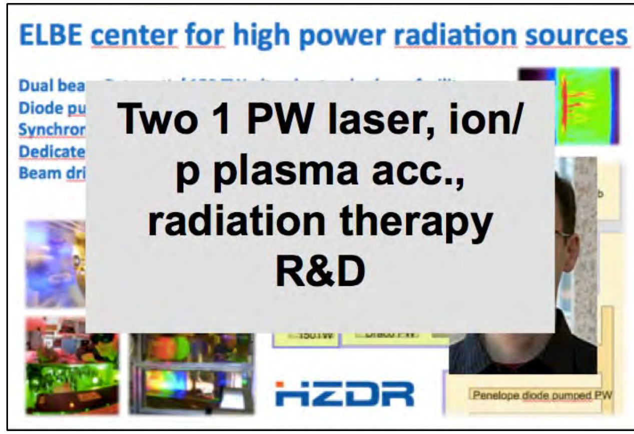

Plasma Acceleration at Hamburg: LAOLA
LWFA FEL
Beams:
e- driven PWFA
Beam-driven plasma wakefields. Beam-driven plasma wakefields with shaped beams and innovative injection methods.
PWFA modulation

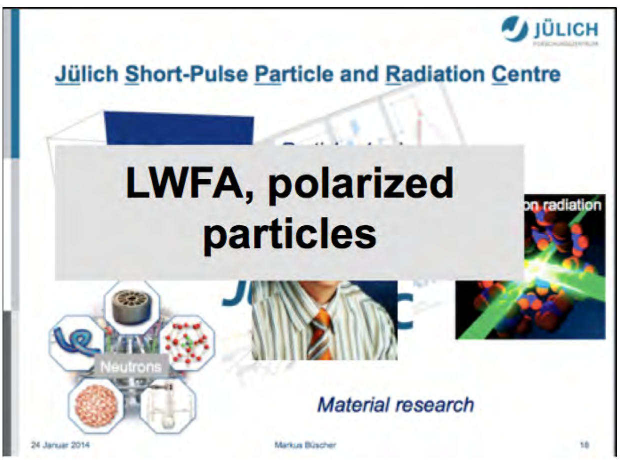

The LIGHT test-stand at GSI: coupling of laser-accelerated ions into conventional accelerators
Principle: manipulation of laser-accelerated ions
1. Laser-driven ion acceleration
2. beam conditioning (collimation)
Ion plasma acc. and transport
ARD test facility
Relevant laser developments (repetition rate and temporal contrast)
proton spectrum
proton beam


Cockcroft Institute and CLARA Project
Cockcroft Institute: Universities of Lancaster, Liverpool and Manchester,
FEL, industrial applications, PWFA
Training.
J. Clarke
C. Welsch
S. Smith

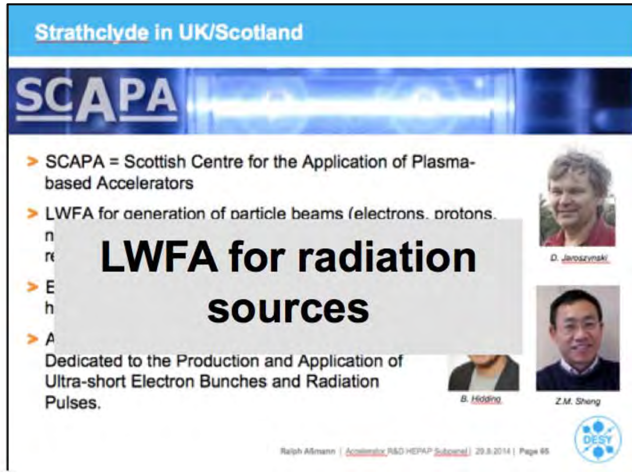

SINBAD
ARD Spitzen-forschung
LWFA low density, external inj.
atto-s radiation sources
PIER


Helmholtz-Institute Jena
plasma wakefield imaging
POLARIS
ASE contrast
A. Kessler et al., Opt. Lett. accepted (2014)
S. Keppler et al., submitted (2014)
accelerator.
M. Schwab et al., Applied Phys. Lett (2013)
A. Sävert et al., submitted (2013)

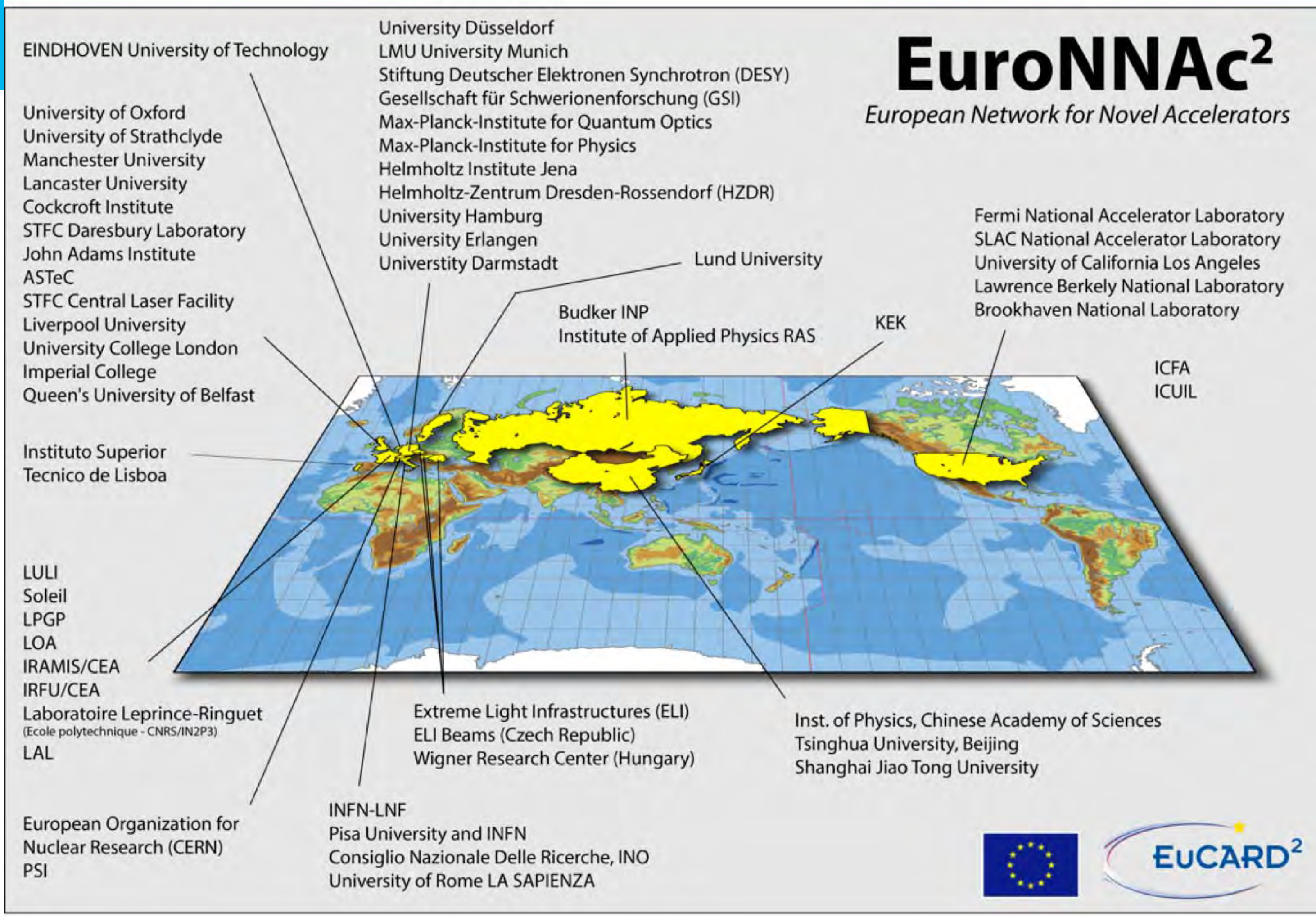

ELBE center for high power radiation sources
Two 1 PW laser, ion/ p plasma acc., radiation therapy R&D
HZDR
Penelope diode pumped PW


JÜLICH
Jülich Short-Pulse Particle and Radiation Centre
LWFA, polarized particles
Neutrons
Material research
24 Januar 2014
Markus Büscher


STFC – CLF and John Adams Institute in UK
STFC Central Laser Facility used also for LWFA.
LWFA, medical imaging, training
Training of accelerator specialists, also in advanced methods.
S. Hooker
Z. Najmudin
A. Seryi
R. Walczak

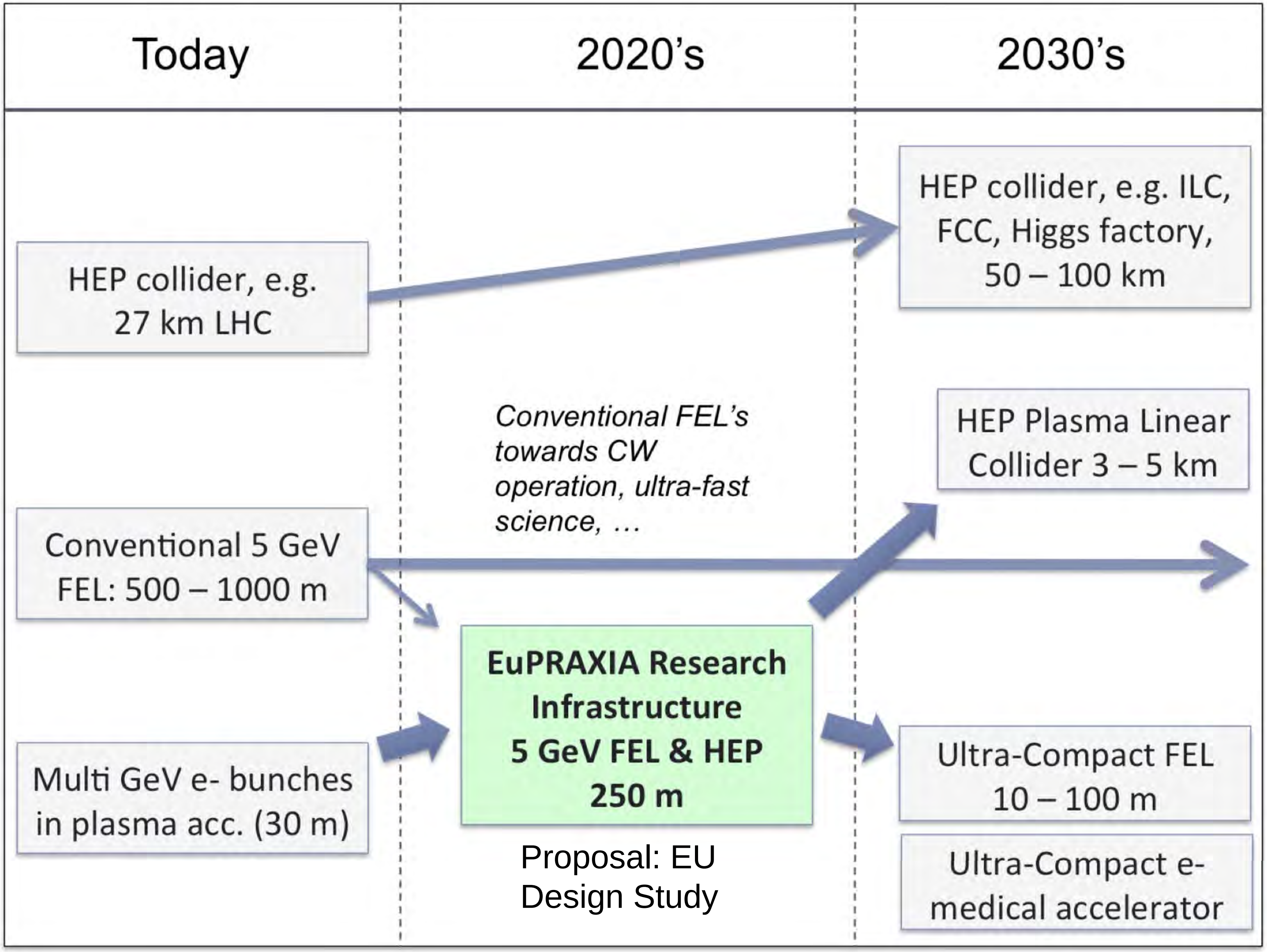

Strathclyde in UK/Scotland
SCAPA
SCAPA = Scottish Centre for the Application of Plasma-based Accelerators
LWFA for radiation sources
Dedicated to the Production and Application of Ultra-short Electron Bunches and Radiation Pulses.
D. Jaroszynski
B. Hidding
Z.M. Sheng

EU Funded Network on Novel Accelerators



1st European Advanced Accelerator Workshop EAAC2013

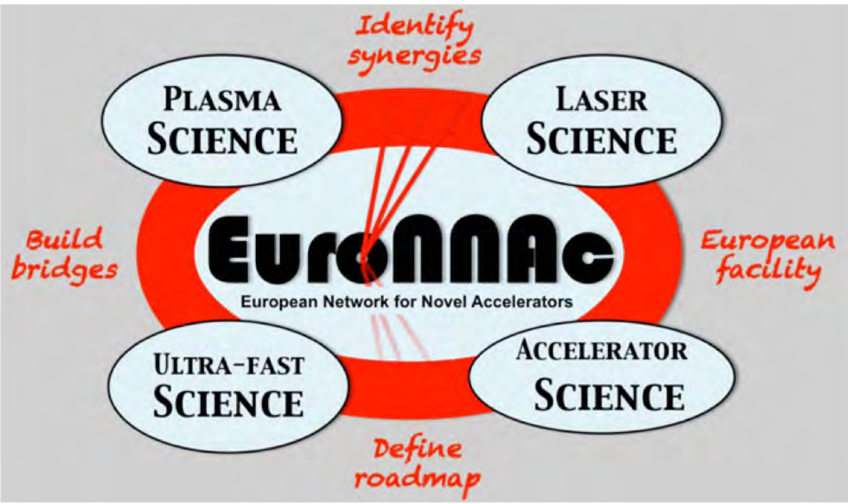
Strategy European Network Novel Accelerators

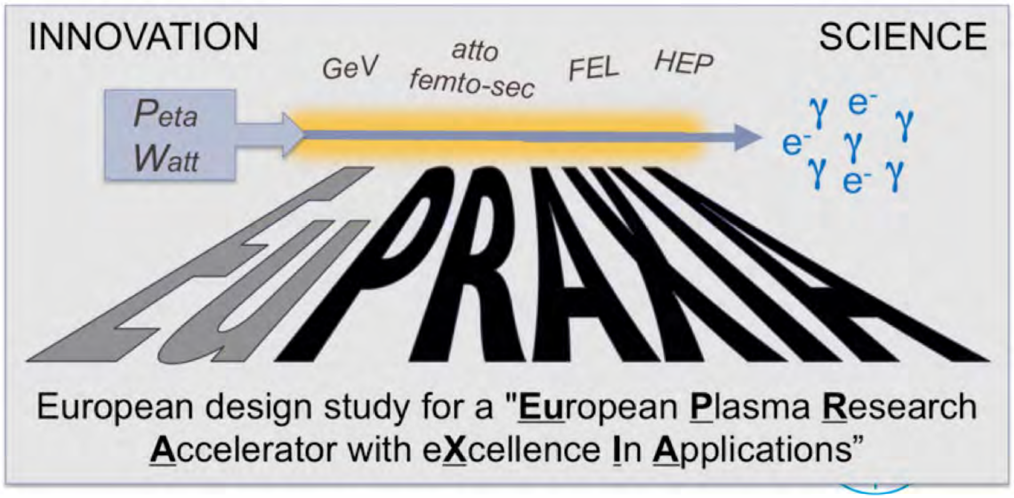


Proposal for a H2020 Design Study “European Plasma Research Accelerator with eXcellence In Applications“ (EuPRAXIA*)

Collaborative Project

* In Greek mythology, Eupraxia was the personification of well-being. In medicine the term Eupraxia describes the normal ability to perform coordinated movements.





EuPRAXIA – Connected Labs and Institutes

List of participants:

Participant no.	Participant organisation name	Short name	Country
1 (Coordinator)	Stiftung Deutsches Elektronen Synchrotron	DESY	Germany
2	Istituto Nazionale di Fisica Nucleare	INFN	Italy
3	Consiglio Nazionale delle Ricerche	CNR	Italy
4	Centre National de la Recherche Scientifique	CNRS	France
5	University of Strathclyde	USTRAH	UK
6	Instituto Superior Técnico	IST	Portugal
7	Science & Technology Facilities Council	STFC	UK
8	Synchrotron SOLEIL – French National Synchrotron	SOLEIL	France
9	University of Manchester	UMAN	UK
10	University of Liverpool	ULIV	UK
11	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenible	ENEA	Italy
12	Commissariat à l'Énergie Atomique et aux énergies alternatives	CEA	France
13	Sapienza Universita di Roma	UROM	Italy
14	Universität Hansestadt Hamburg	UHH	Germany
15	University of Oxford	UOXF	UK
16	Imperial College London	ICL	UK

16 beneficiaries from 5 EU member states

plus 18 associated partners

Associated partner organisation name	Short name	Country
Jiaotong-Universität Shanghai	JUS	China
Tsingua University Beijing	TUB	China
Extreme Light Infrastructures - Beams	ELI-B	Czech Repu
Lille University	PHLAM	France
Helmholtz Institute Jena	HIJ	Germany
Helmholtz-Zentrum Dresden-Rossendorf	HZDR	Germany
Ludwig-Maximillians-Universität München	LMU	Germany
Wigner Research Center of the Hungarian Academy of Science	WIGNER	Hungary
European Organization for Nuclear Research	CERN	IEIO[1]
High Energy Accelerator Research Organization	KEK	Japan
Kansai Photon Science Institute, Japan Atomic Energy Agency	KPSI-JAEA	Japan
Osaka University	OU	Japan
RIKEN SPring-8 Center	RSC	Japan
Lund University	LU	Sweden
Center for Accelerator Science and Education at Stony Brook U & BNL	CASE	USA
Lawrence Berkeley National Laboratory	LBNL	USA
SLAC National Accelerator Laboratory	SLAC	USA
University of California, Los Angeles	UCLA	USA

EuPRAXIA – Support

European Steering Group for Accelerator R&D, 2014

EuPRAXIA

Producing high acceleration gradients is a critical issue for particle accelerators, as highlighted by the European Strategy for Particle Physics. The feasibility of large acceleration gradient (up to 100 GV/m) within exited plasma channels is demonstrated since several decades. More recently, it has been shown that appropriate beam properties (low emittance and beam energy dispersion as well as acceptable bunch charge) can be obtained. Europe is at the forefront of this research. Based on these achievements, the realization of accelerators with appropriate beam characteristics for user-communities is now credible and highly desirable.

The vast majority of accelerators operating in the world are relatively low energy (<~10 GeV) facilities including light sources, medical and industrial applications. However these infrastructures remain complex to develop and operate and necessitate relatively large footprints.

The EuPRAXIA proposal aims at establishing the design of a 1 to 5 GeV electron accelerator with pilot applications for the Free Electron Laser user community as well as the community developing state-of-the-art particle detectors.

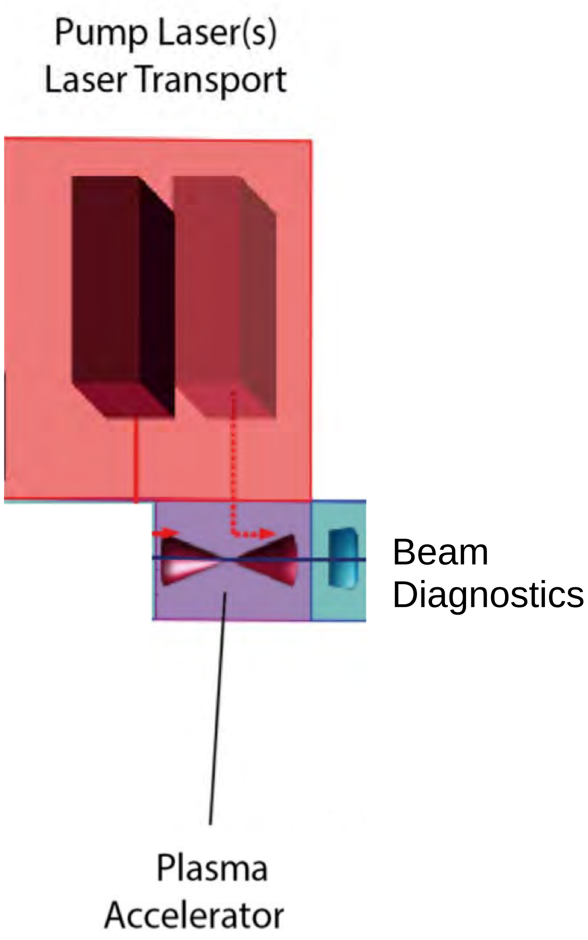
The proposal is technically strong and federates the major European competences and institutes required to accomplish the needed tasks.

"… the realization of accelerators with appropriate beam characteristics for user-communities is now credible and highly desirable."

competition from CERN FCC and ESS neutrino upgrade DS proposals

Letters from industry (Thales, Amplitude) removed from this version.

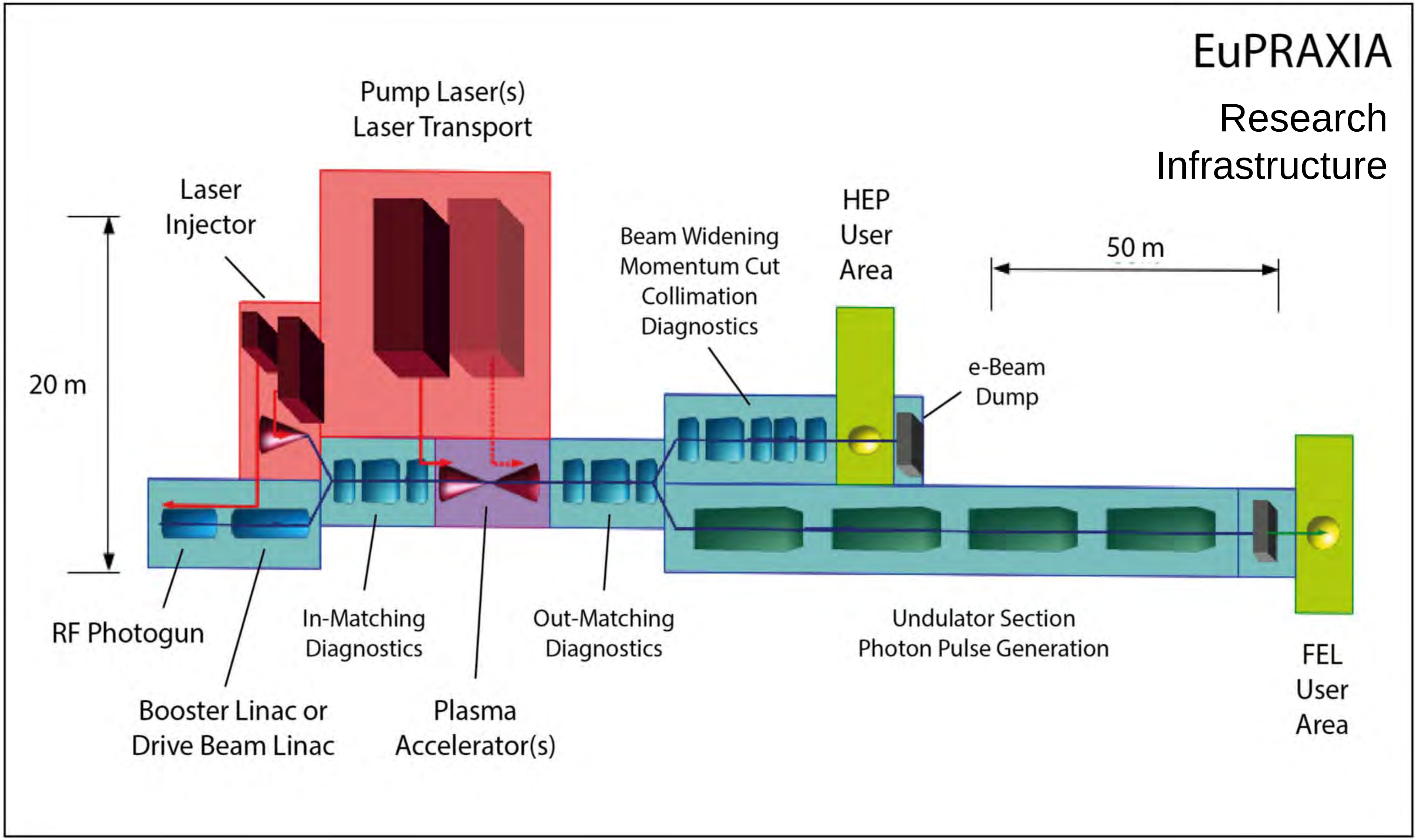
Schematic Layout EuPRAXIA Research Infrastructure



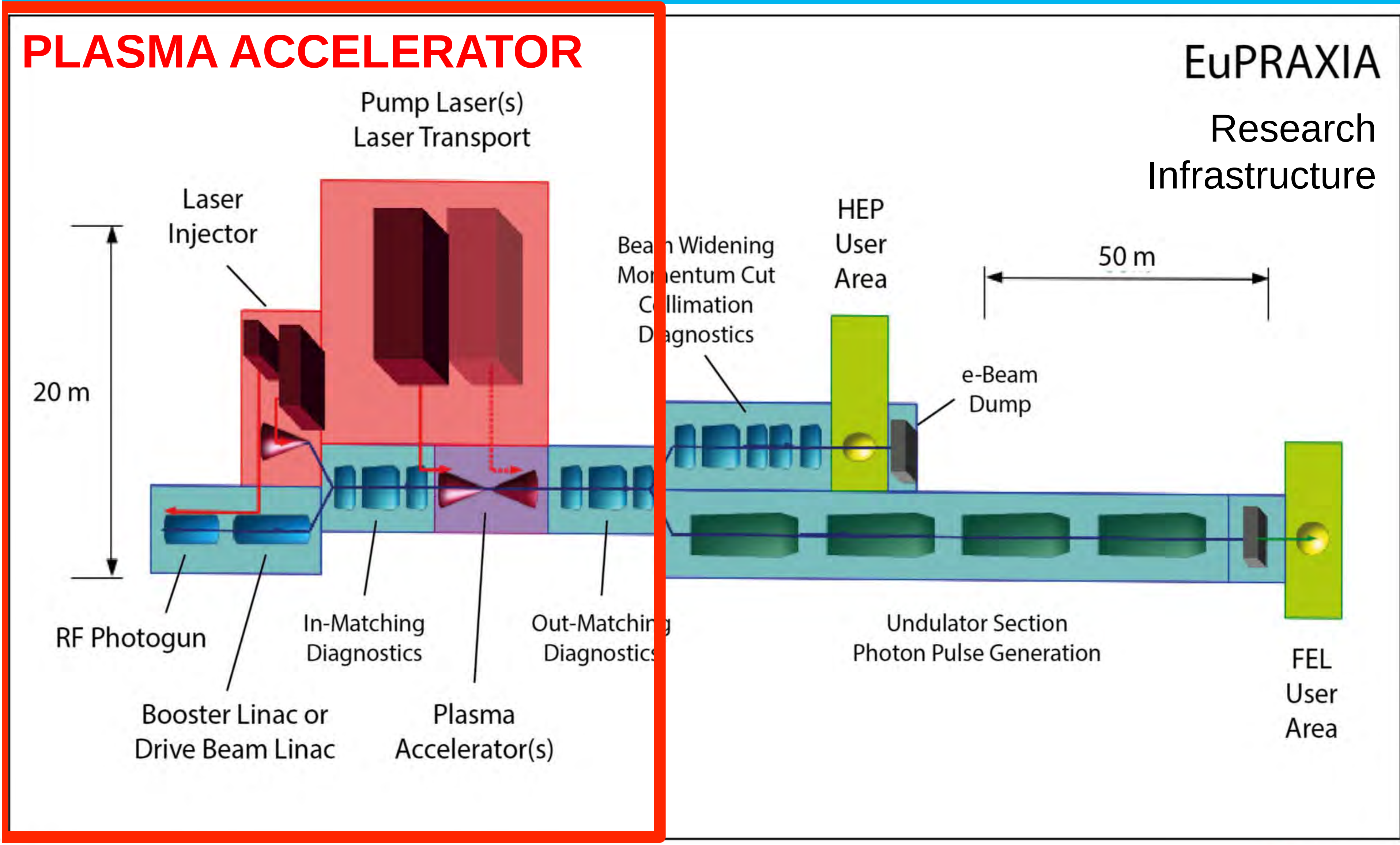
Present Laser Plasma Accelerators

Up to 4.25 GeV electron beams

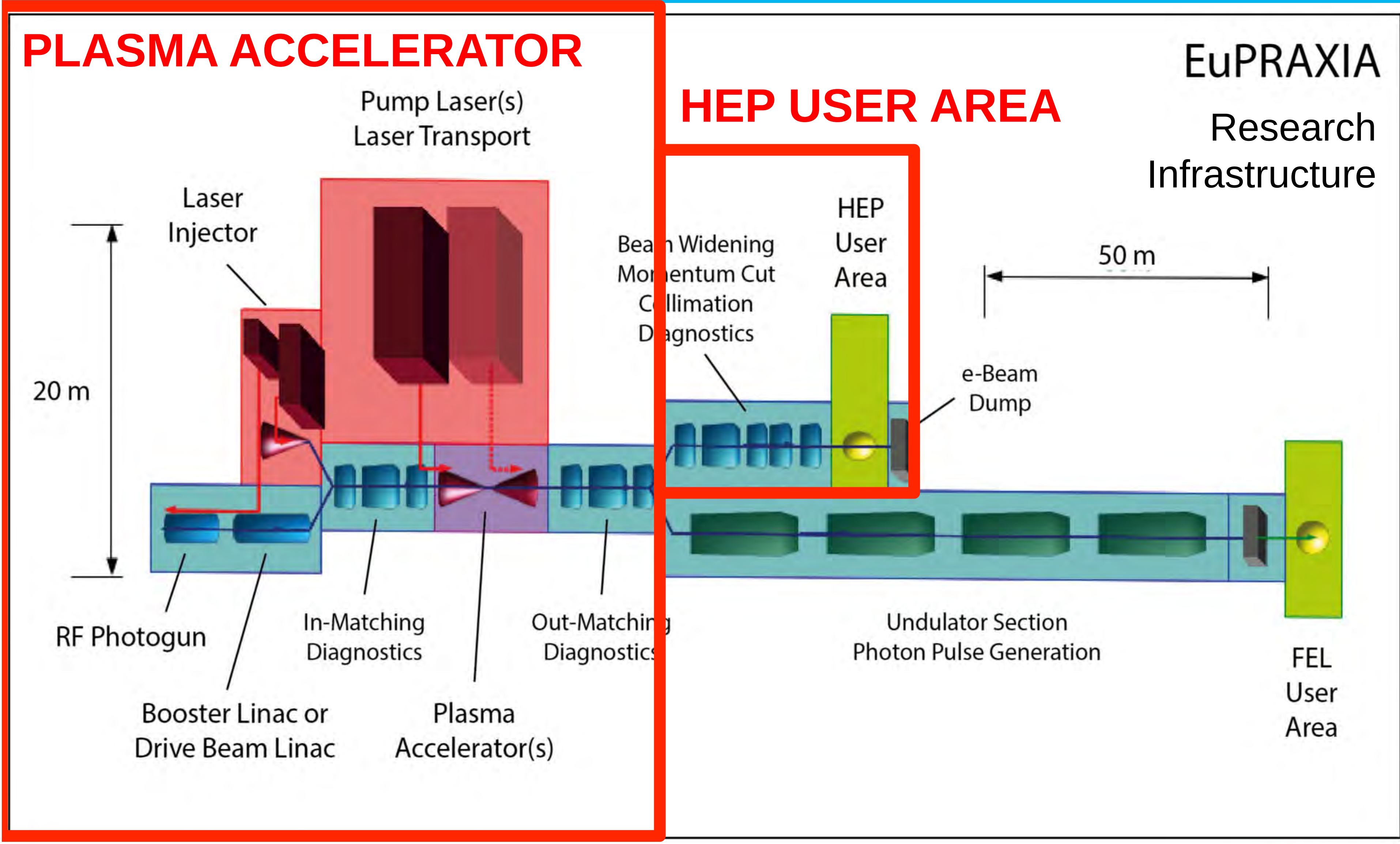
Schematic Layout EuPRAXIA Research Infrastructure



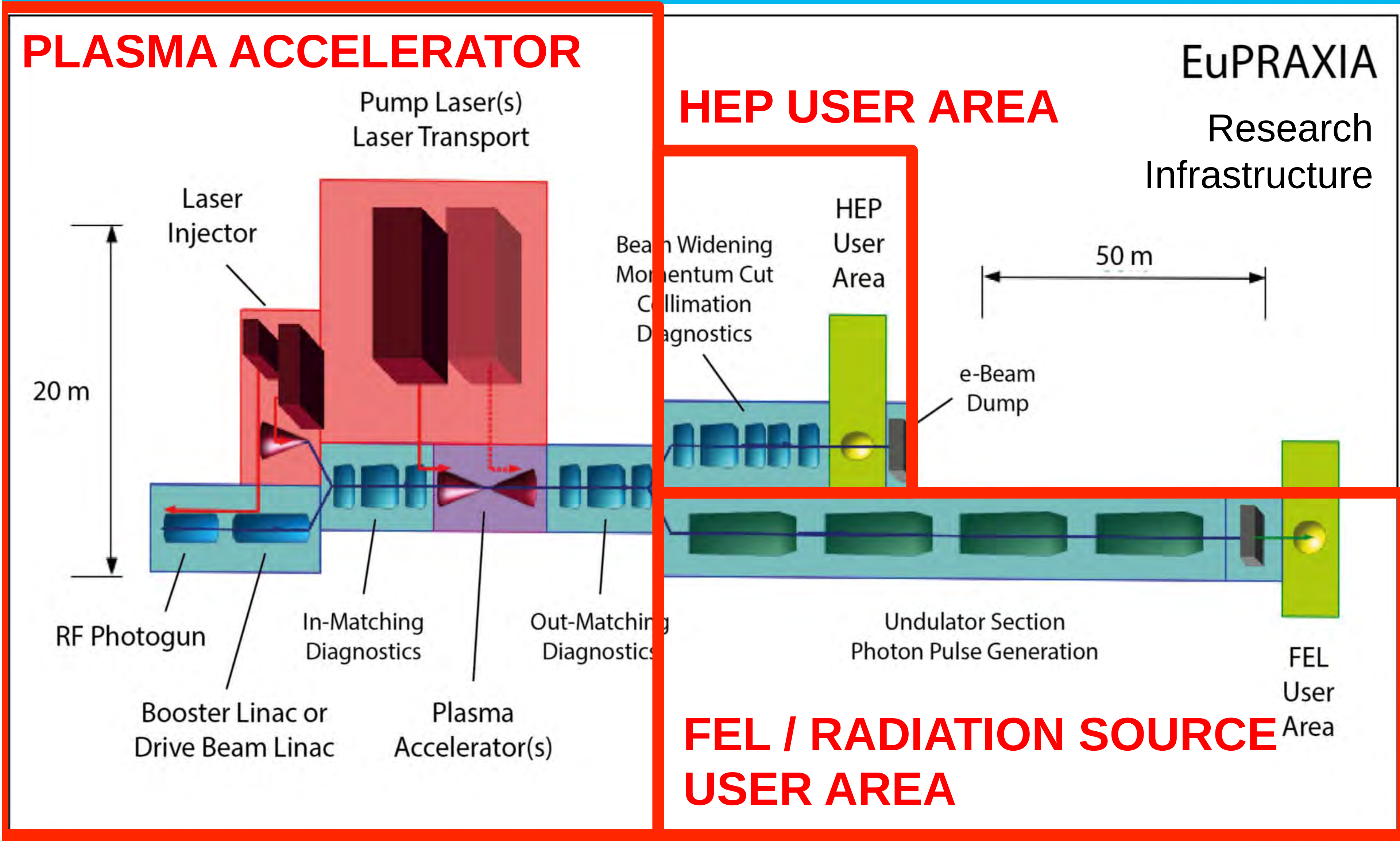
Schematic Layout EuPRAXIA Research Infrastructure



Schematic Layout EuPRAXIA Research Infrastructure



Schematic Layout EuPRAXIA Research Infrastructure



EuPRAXIA Research Infrastructure Goal Parameters

Beam Parameter	Unit	Value
Particle type	-	Electrons
Energy	GeV	1 – 5
Charge per bunch	pC	1 – 50
Repetition rate	Hz	10
Bunch duration	fs	0.01 - 10
Peak current	kA	1 – 100
Energy spread	%	0.1 – 5
Norm. emittance	mm	0.01 – 1

Envisaged Implementation

> Goal is to design one operational facility at one location.

> Resources will be distributed to all partners:

- Model of big particle physics detector: Many institutes team up to build one detector at one place, each contributing a part.

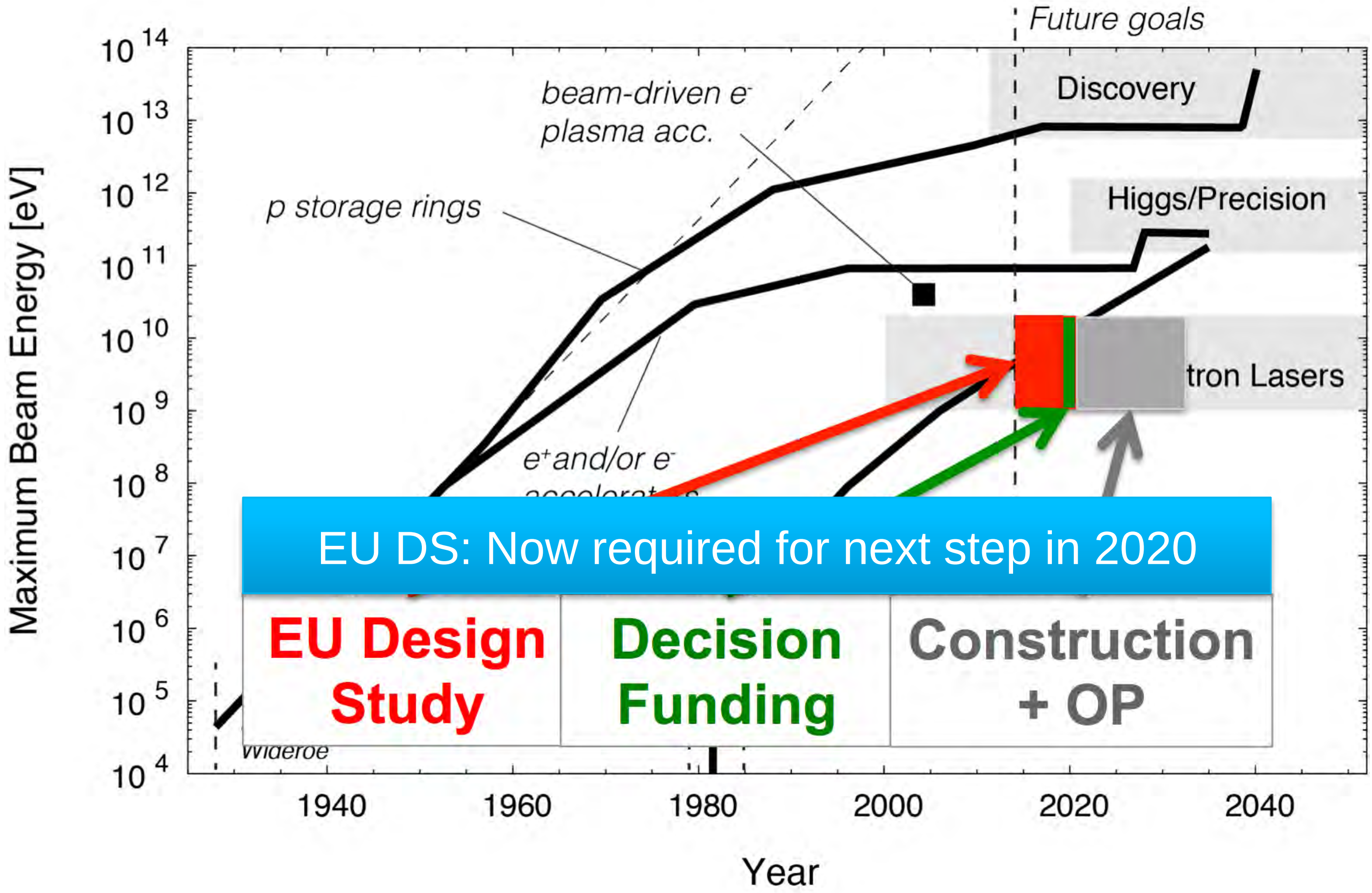
> Site study with the goal to propose the best site:

- Existing infrastructure, host lab support, scientific user community, support from funding agency, …

> Facility will be devoted to provide for pilot users:

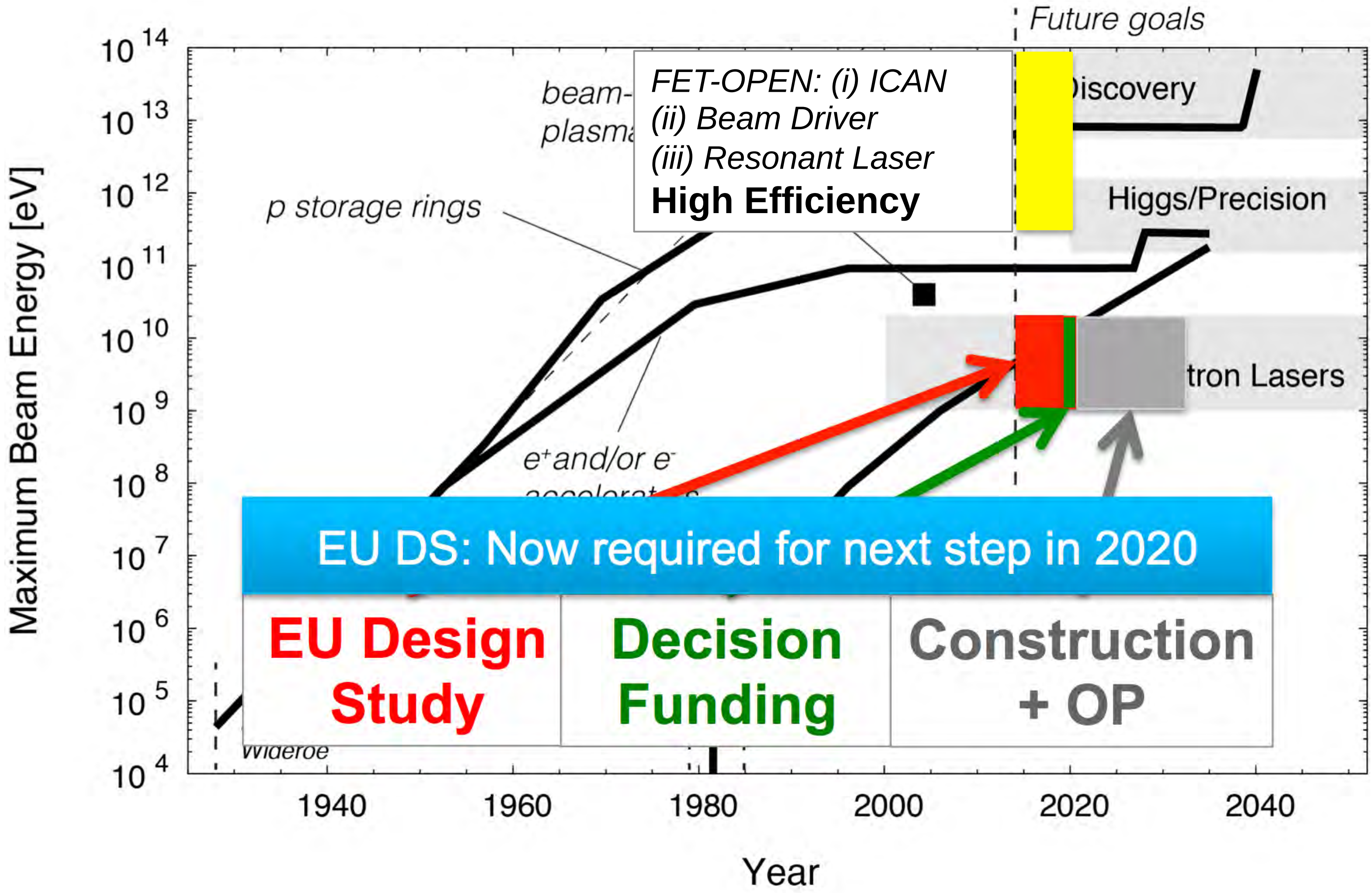
- Ultra-compact X-ray FEL
- Ultra-compact GeV electron source for HEP detector development

Timelines



R. Assmann, EuroNNAc @ ICAN, 4/2014

Timelines



R. Assmann, EuroNNAc @ ICAN, 4/2014

Research field Matter in the Helmholtz Association

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

JÜLICH
FORSCHUNGSZENTRUM

+ Helmholtz Institutes Jena and Mainz

Karlsruher Institut für Technologie

Hamburg and Zeuthen

HZB Helmholtz Zentrum Berlin

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

since 2011

(Total Helmholtz: 18 centers, 6 research fields, ~3B€ yearly budget)

HELMHOLTZ (Germany) – Research Field Matter: new programme structure, starting 1.1.2015

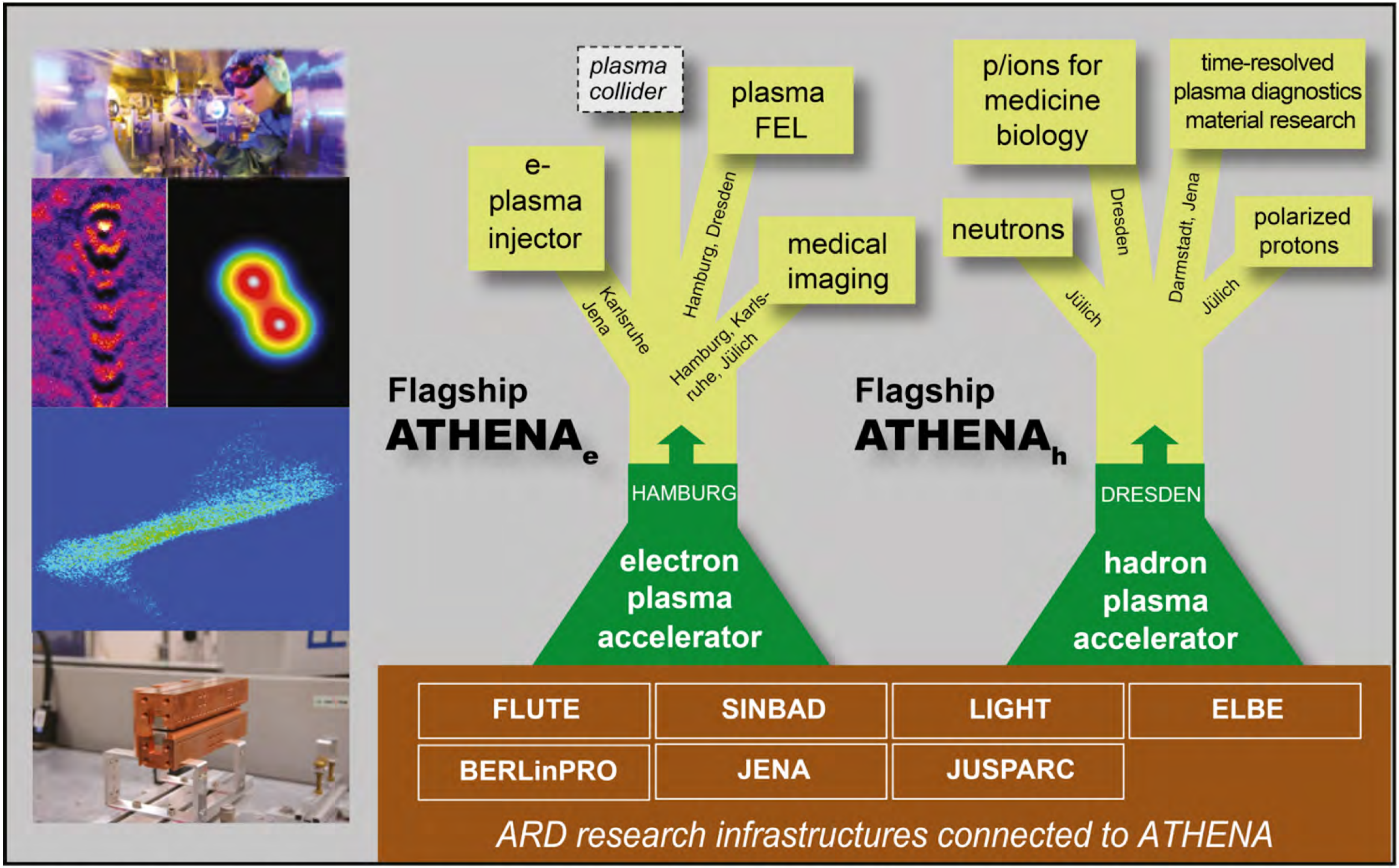
Matter and the Universe	From Matter to Materials and Life	Matter and Technologies
Fundamental Particles and Forces	In-House Research on the Structure, Dynamics and Function of Matter at Large Scale Faciltities	Accelerator Research and Development
Cosmic Matter in the Laboratory	Facility Topic: Research on Matter with Brilliant Light Sources	Detector Technologies and Systems
Matter and Radiation from the Universe	Facility Topic: Neutrons for Research on Condensed Matter	
	Facility Topic: Physics and Materials Science with Ion Beams	
	Facility Topic: Research at Highest Electromagnetic Fields	

ARD

ATHENA =
Accelerator Technology
HElmholtz iNfrAstructure

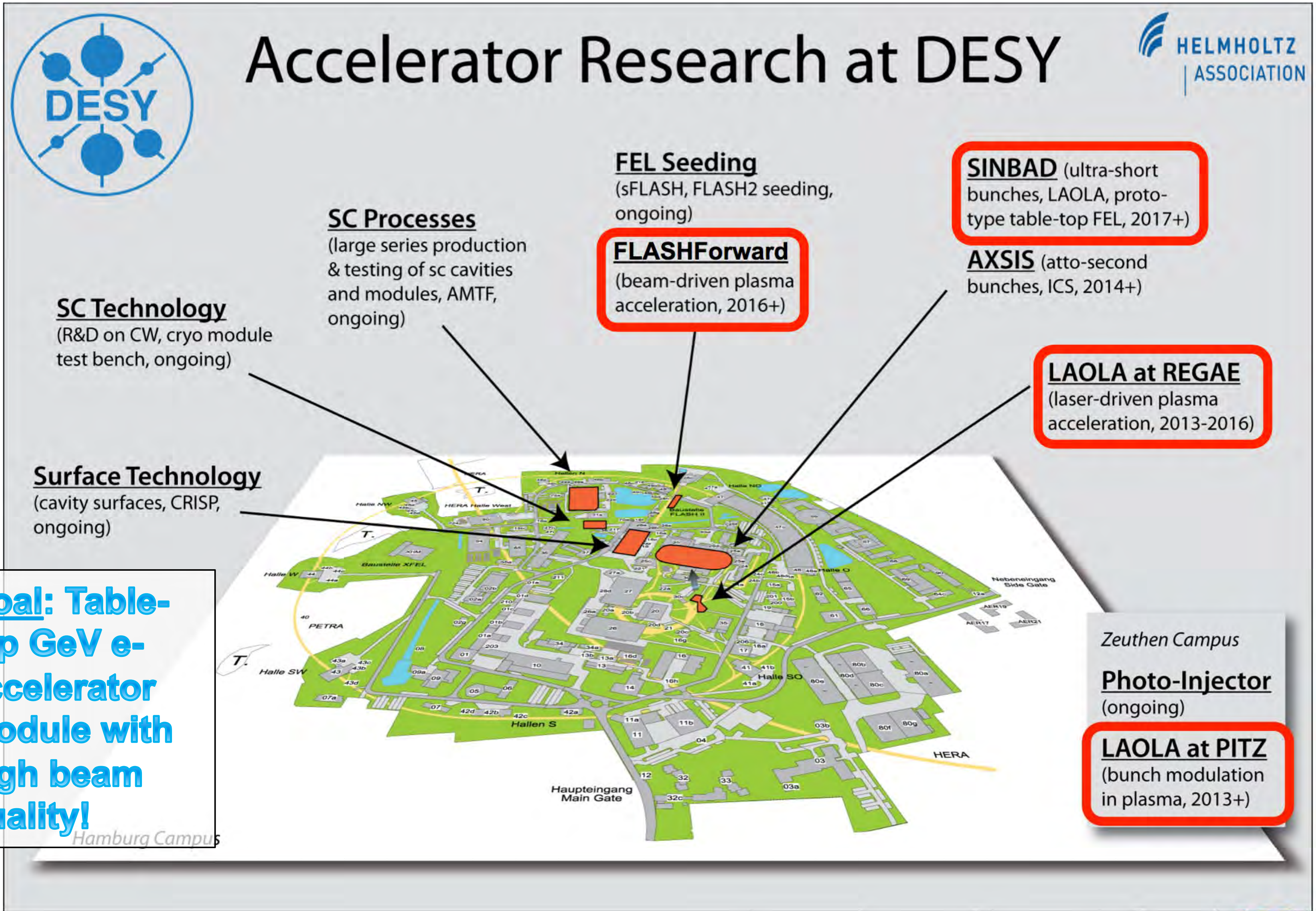
LK II
„performance category II"
= user operation of large scale facilities


Details on included facilities see presentations on the Helmholtz ARD web site or contact PI's!
SINBAD Short INnovative Bunches & Accelerators at DESY
Kompakte Atto-Sekunden Lichtquelle
50 as, ICS
ERC Synergy Grant, DESY, Uni HH, Arizona
Ultrakurzer Elektronenpuls
< 1 fs mit konventio-neller Technologie
ARD, DESY, Uni HH, KIT
Raum für weitere Phasen und Nutzer
Drittmittel Interessensbe-kundung ELI
PIER
Coordinating PI
bERLinPro centre for high power cw beams in sc accelerators
bERLinPro = Berlin Energy Recovery Linac Project
100 mA / low emittance technology demonstrator
bERLinPro
Helmholtz-Zentrum Berlin
beam dump
6.5 MeV, 100 mA = 650 kW
booster
4.5 MeV
linac module
44 MeV
srf-gun
1.5-2 MeV
merger
dogleg
high virtual beam power zone
microwave instability driven radiation generation)
50MeV, 100mA, 2ps (5 MW of virtual beam power)
50MeV, 10mA, <100fs (500kw of virtual beam power)
both modes normalized emittance < 1mm mrad
JÜLICH
Jülich Short-Pulse Particle and Radiation Centre
Particle physics
Synchrotron radiation
JuSPARC
Material research
Markus Büscher
Hanover
Bielefeld
Brunswick
Magdeburg
Büren
Halle
Riesa
Essen
Dusseldorf
Germany
Leipzig
Chemnitz
Dresden
Zwickau
Frankfurt
Nuremberg
Stuttgart
Tübingen
Ulm
Augsburg
Munich
Passau
ELBE center for high power radiation sources
Dual beam Petawatt / 150 TW ultrashort pulse laser facility
Diode pumped Petawatt laser development
Synchronized operation with ELBE accelerator
Dedicated shielded target areas (~1000m² laser lab space)
Beam driven sources (THz, FEL, ...) at ELBE
ELBE
150TW
Draco PW
HZDR
The LIGHT test-stand at GSI: coupling of laser-accelerated ions into conventional accelerators
Principle: manipulation of laser-accelerated ions
HI Jena
GSI
HZDR
1. Laser-driven ion acceleration
2. beam conditioning (collimation)
3. drift line and phase-space rotation
Current results:
proton spectrum
proton beam
FLUTE: ARD-Forschung am KIT
KIT
Ultrakurze Elektronenpulse (1 fs bis 300 fs)
Grosser Bereich an Ladungen (1 pC bis 3 nC)
Kohärente Strahlung für Materialwissenschaften und biologische Anwendungen
Entwicklung/Tests von Kurzpuls-Strahldiagnose und Instrumentierung
Kooperation KIT, PSI, DESY
Ferninfrarot Linac-
FLUTE
FLUTE, a Linac-Based THz Source at KIT
Helmholtz-Institute Jena
relative z-position (µm)
Development and application of novel plasma diagnostics:
few-fs and 1-µm resolution,
first direct visualization of the laser-driven plasma wave in a laser-electron accelerator.
M. Schwab et al., Applied Phys. Lett (2013)
A. Sävert et al., submitted (2013)



ATHENA: 2018 – 2021, proposal to be submitted, 6 centers + 1 institute + universities + international collaborators, using infrastructures together, 2 future technologies for the Helmholtz strategy, high relevance for applications in many centers.

DESY Accelerator R&D



Goal: Table-top GeV e- accelerator module with high beam quality!

LAOLA Collaboration (Plasma)

>**Laser:** Ti:Sa 200 TW, 25 fs pulse length, 5 Hz repetition rate

- *Initially: Laser-driven wakefields in REGAE. LUX exp. towards FEL*
- *Later: Move to SINBAD facility.*

A. Maier

F. Grüner

Beams:

- **REGAE**: *5 MeV, fC, 7 fs bunch length, 50 Hz*

- **FLASH**: *1.25 GeV, 20 – 500 pC, 20 - 200 fs bunch length, 10 Hz.*
  Beam-driven plasma wakefields. Beam-driven plasma wakefields with shaped beams and innovative injection methods. Helmholtz VI with UK collaboration.

FLASHForward

J. Osterhoff

- **PITZ**: *25 MeV, 100 pC, 20 ps bunch length, 10 Hz.*
  Beam modulation experiment in a plasma cell, preparation to CERN experiment AWAKE

F. Stephan

- **SINBAD**: dedicated R&D, multi purpose, *150 MeV, 0.01 – 3 pC, down to < 1 fs bunch length, pulse rate 10 – 1000 Hz*
  → Home of AXSIS ERC Synergy Grant
  → Home of ATHENA$_e$

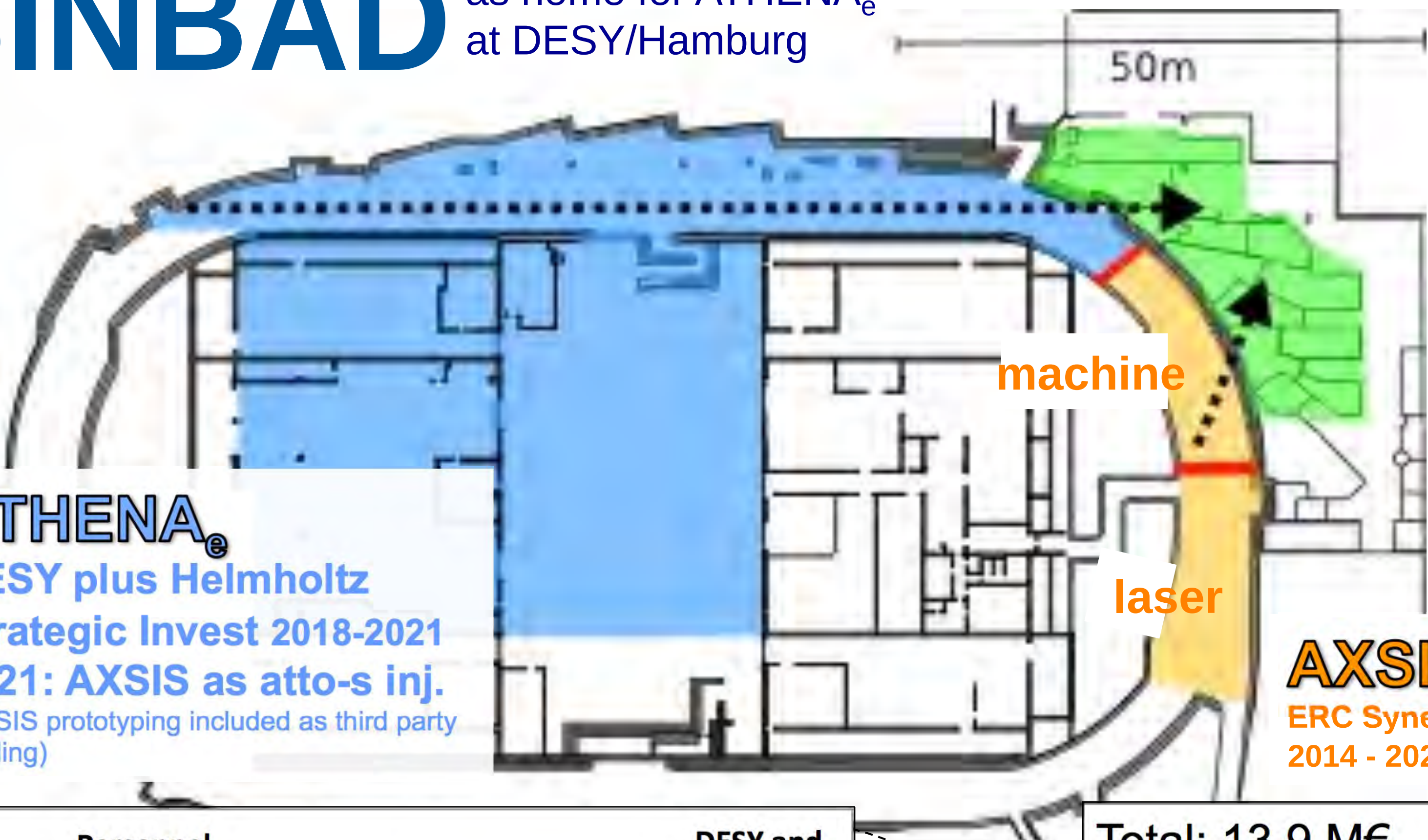
U. Dorda

B. Marchetti

J. Grebenyuk

Similarly strong teams in other Helmholtz centers!

SINBAD as home for ATHENA$_e$ at DESY/Hamburg



Users Photon Science

initially AXSIS

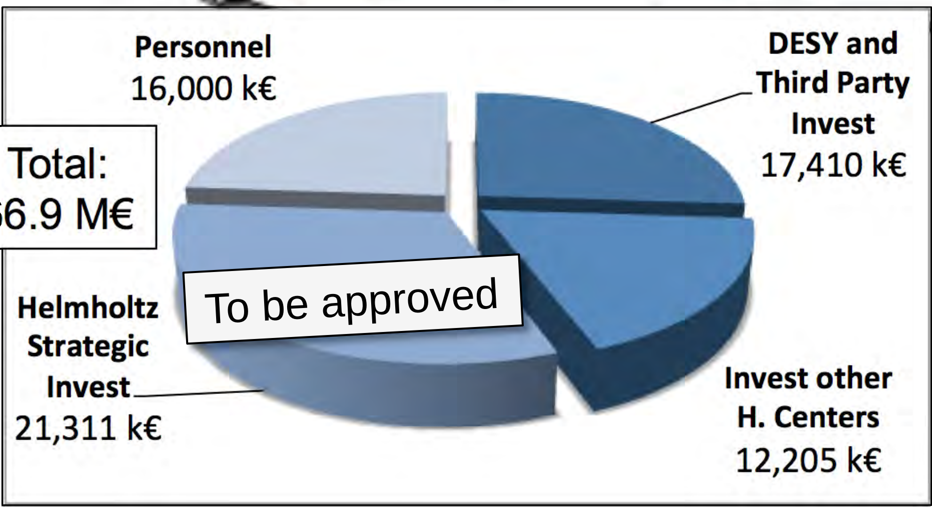
European Research Council
Established by the European Commission

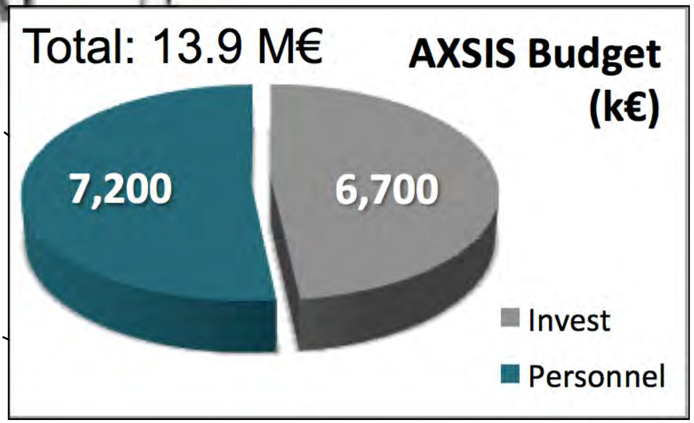
ATHENA$_e$

DESY plus Helmholtz Strategic Invest 2018-2021
2021: AXSIS as atto-s inj.
(AXSIS prototyping included as third party funding)

AXSIS
ERC Synergy Grant 2014 - 2020

Total: 66.9 M€





Accelerator Research and Development ARD
HELMHOLTZ GEMEINSCHAFT

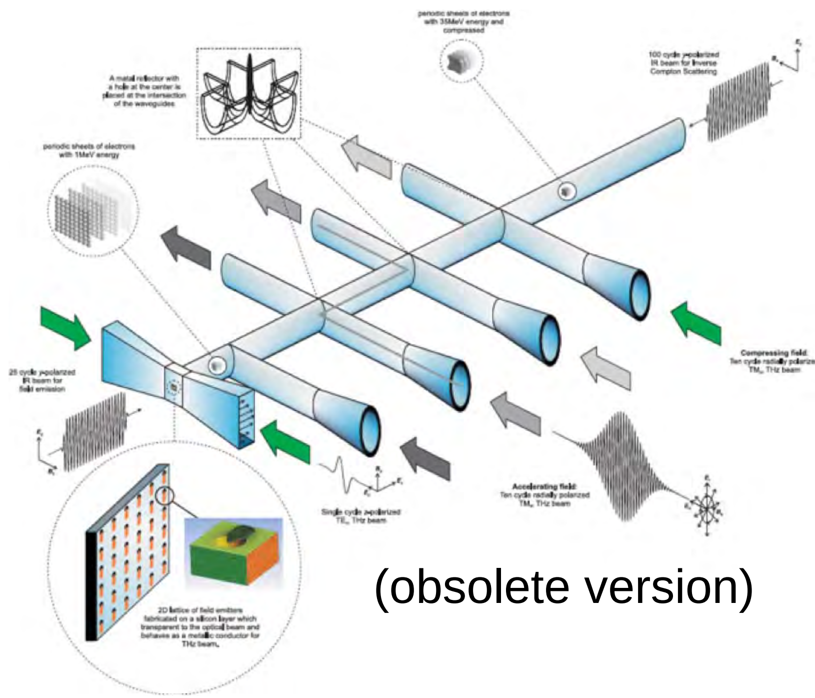
Compact Atto-Second Light Source

European Research Council
Established by the European Commission

> **Compact atto-second light source**, based on new, laser-driven accelerator technology (dielectric structures). Research on the photo-system. AXSIS.

> **Interdisciplinary team with strong user component:**

- Laser science (F. Kärtner, DESY/Uni HH)
- Spectroscopy light sources (H. Chapman, DESY/Uni HH)
- Biology (P. Fromme, Uni Arizona)
- Accelerator science (R. Aßmann, DESY)



(obsolete version)

> Only accelerator-related ERC synergy grant 14 M€ over 6 years (2014 – 2020)

> Will be set up at DESY in the context of the multi-purpose accelerator research facility SINBAD (part of the Distributed ARD test facility).

Conclusions I

- **Short overview was given on accelerator research** activities performed around the globe by many colleagues:
  - Apologies that not all important topics could be covered in the available time.
- **New ideas, technologies, concepts, talents are developing and maturing**, even if it sometimes takes half a century from idea to large scale implementation, sometimes only a decade.
- **Several acceleration technologies** (SC, C-band, X-band) are ready to be used in a next HEP project.
- **SC RF technology is at the moment the technique of choice for many high power applications** (SNS, XFEL, ESS, ILC, …). Together with the energy recovery linac concept, efficiency is much improved.
- The **discovery of the Higgs boson has removed uncertainty about the target energy for a future HEP project** → exciting time for the accelerator field with new ideas and concepts entering discussion.

Known Higgs Boson Energy → e+e- Higgs Factory Design…

Some IPAC2013 Papers

STATUS OF THE EXPLORATION OF AN ALTERNATIVE CLIC FIRST ENERGY STAGE BASED ON KLYSTRONS

D. Schulte, A. Grudiev, Ph. Lebrun, G. McMonagle, I. Syratchev, W. V
CERN, Geneva, Switzerland

A MUON COLLIDER AS A HIGGS FACTORY*

D. Neuffer#, M. Palmer, Y. Alexahin, Fermilab, Batavia IL 60510, USA, C. Ankenbrandt, Muons, Inc., Batavia IL 60510, USA, J. P. Delahaye, SLAC, Menlo Park, CA 94025 USA

PRELIMINARY DESIGN OF A HIGGS FACTORY $\mu^+\mu^-$ STORAGE RING*

A.V. Zlobin#, Y.I. Alexahin, V.V. Kapin, V.V. Kashikhin, N.V. Mokhov, I.S. Tropin, FNAL, Batavia, IL 60510, U.S.A.

OPTIMIZATION PARAMETER DESIGN OF A CIRCULAR e^+e^- HIGGS FACTORY*

D. Wang#, J. Gao, M. Xiao, H. Geng, S. Xu, Y. Guo, N. Wang, Y. An, Q. Qin, G. Xu, S. Wang, IHEP, Beijing, 100049, China

THE LHeC AS A HIGGS BOSON FACTORY

F. Zimmermann, O. Brüning, CERN, Geneva, Switzerland; M. Klein,

CONSIDERATIONS FOR A HIGGS FACILITY BASED ON LASER WAKEFIELD ACCELERATION

S. Hillenbrand, KIT, Karlsruhe, Germany and CERN, Geneva, Switzerland
A.-S. Müller, KIT, Karlsruhe, Germany
Assmann*, D. Schulte, CERN, Geneva, Switzerland

TLEP: A HIGH-PERFORMANCE CIRCULAR e^+e^- COLLIDER TO STUDY THE HIGGS BOSON

M. Koratzinos, A.P. Blondel, U. Geneva, Switzerland; R. Aleksan, CEA/Saclay, France; O. Brunner, A. Butterworth, P. Janot, E. Jensen, J. Osborne, F. Zimmermann, CERN, Geneva, Switzerland; J. R. Ellis, King's College, London; M. Zanetti, MIT, C

SIMULATED BEAM-BEAM LIMIT FOR CIRCULAR HIGGS FACTORIES

K. Ohmi, KEK-ACCL, 1-1 Oho, Tsukuba, 305-0801, Japan
F. Zimmermann, CERN-ABP, Geneva, CH-1211, Switzerland

DESIGN OF A TeV BEAM DRIVEN PLASMA WAKEFIELD LINEAR COLLIDER*

E. Adli†, University of Oslo, Norway
J.P. Delahaye, S.J. Gessner, M.J. Hogan, T. Raubenheimer, SLAC, Stanford, USA
W. An, W. Mori, C. Joshi, UCLA, Los Angeles, USA, P. Muggli, MPP, Munich, Germany

DESY

Conclusions II

- **Breakthrough results plasma acceleration**. User applications in reach!
- Europe: **Increased investments in novel accelerator R&D**. Accelerator R&D in Germany recognized as **independent research area**. Conventional and novel acc. R&D together. HEP and photon science acc. R&D together.
- Europe: **≈15 significant projects** in plasma acceleration. Best lasers produced in Europe and used at LBNL for record result.
- EuroNNAc: exchange info, develop common plans.
- Right time is now to spend time and efforts on **developing plasma accelerator technology to user readiness**.
- Efforts on **grouping our European efforts**: EuPRAXIA proposal, CILEX, Helmholtz Distributed ARD Test Facility, …
- We hope that our efforts will be supported also by ECFA and supported by sufficient funding to develop it into a **plan B for HEP in the 2030's**.

Wideröe 1992 at age 90

After all, **plans can only be made for those accelerators which can realistically be built with the means available, and obviously, these means are limited**.

Ideas are not subject to any such considerations. The **limitations are set only by the intellect of human beings themselves**.

The **theoretical possibilities** with regard to accelerating particles by electromagnetic means (i.e. within the scope of the Maxwell equations which have been known since the 19th century), **are nowhere near being exhausted**, and technology surprises us almost daily with innovations which in turn allow us to broach new trains of thought.

…there are yet **more fundamental breakthroughs** to be made. They could allow us to advance to **energies unimaginable today**.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