From dreams to reality:
the plasma based accelerator project EuPRAXIA@SPARC_LAB.

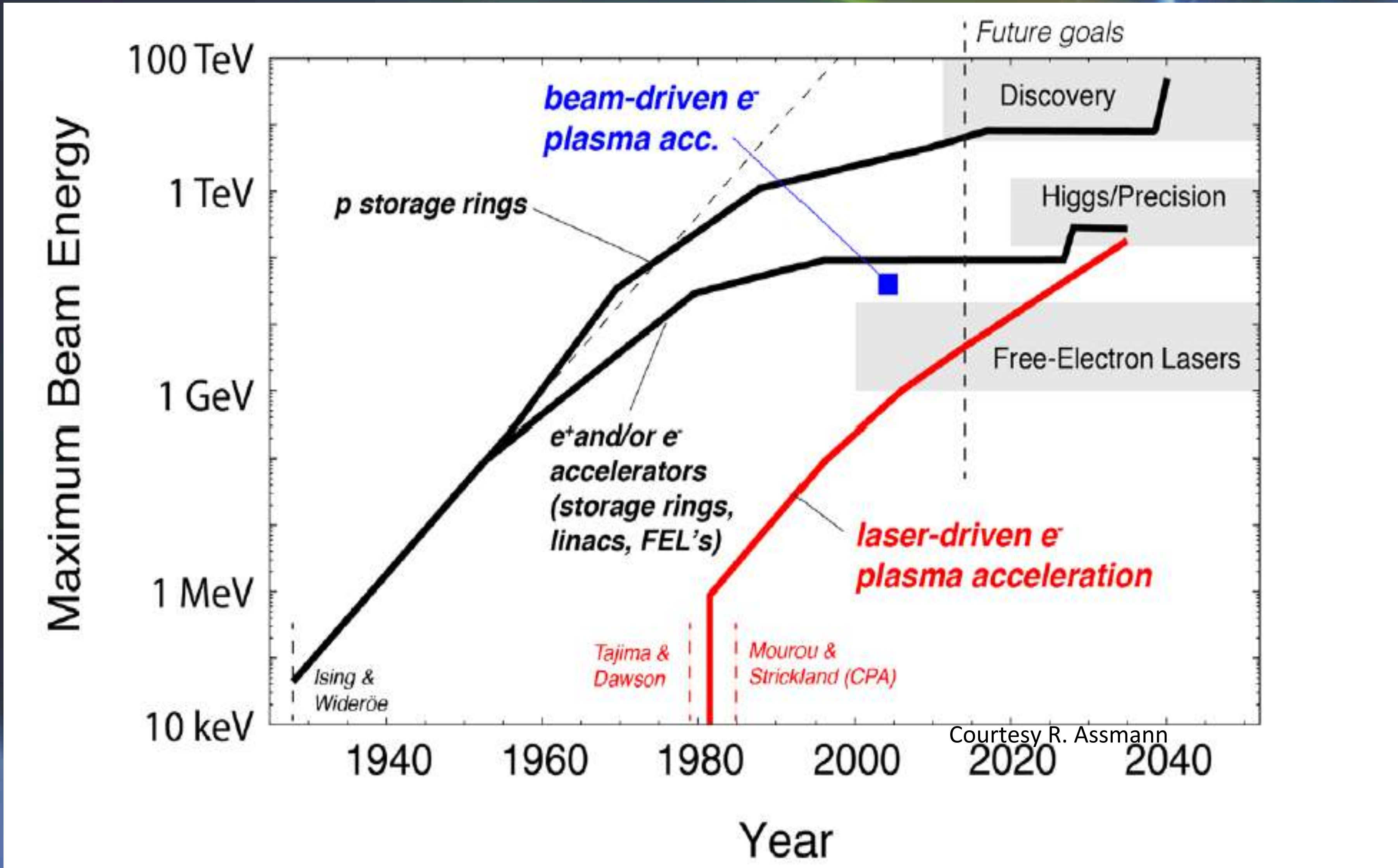
Massimo.Ferrario@lnf.infn.it

On behalf of the EuPRAXIA collaboration

Universita' la Sapienza, 12 Gennaio 2021, Zoom

Courtesy LBNL

Motivation: updated Livingston plot



Courtesy R. Assmann

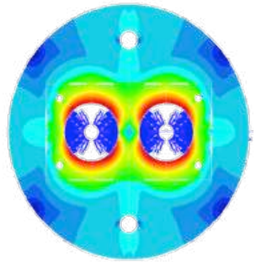
Options towards higher energies

Hadron (p) circular collider

$$p = e \cdot R \cdot B_y$$

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

Increase radius = size (FCC-hh)



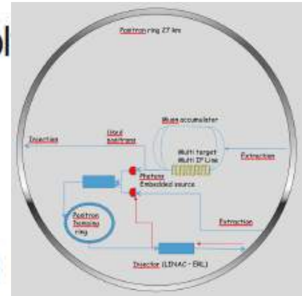
Lepton (e-,e+) circular collider

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

Increase supplied RF vol
(FCC-ee)

Increase mass of acc. particle (muon)

Increase radius = size (FCC-ee)



Lepton (e-,e+) linear collider

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

Increase length (ILC, CLIC)

Compact and Cost Effective....

Courtesy R. Assmann

Beam Quality Requirements

Future accelerators will require also high quality beams :

==> High Luminosity & High Brightness,

==> High Energy & Low Energy Spread

$$L = \frac{N_{e+} N_{e-} f_r}{4\pi\sigma_x\sigma_y}$$

- -N of particles per pulse => 10^9
- -High rep. rate f_r => bunch trains
- -Small spot size => low emittance

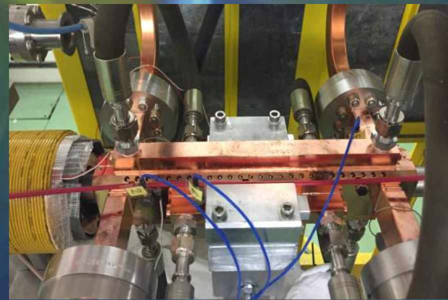
$$B_n \approx \frac{2I}{\varepsilon_n^2}$$

- -Short pulse (ps => fs)
- -Little spread in transverse momentum and angle => low emittance

High Gradient Linac Options

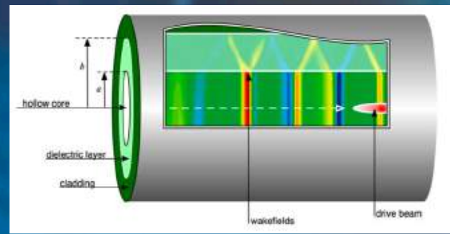
Metallic accelerating structures =>

100 MV/m < E_{acc} < 1 GV/m



Dielectrict structures, laser or particle driven =>

E_{acc} < 10 GV/m



Plasma accelerator, laser or particle driven =>

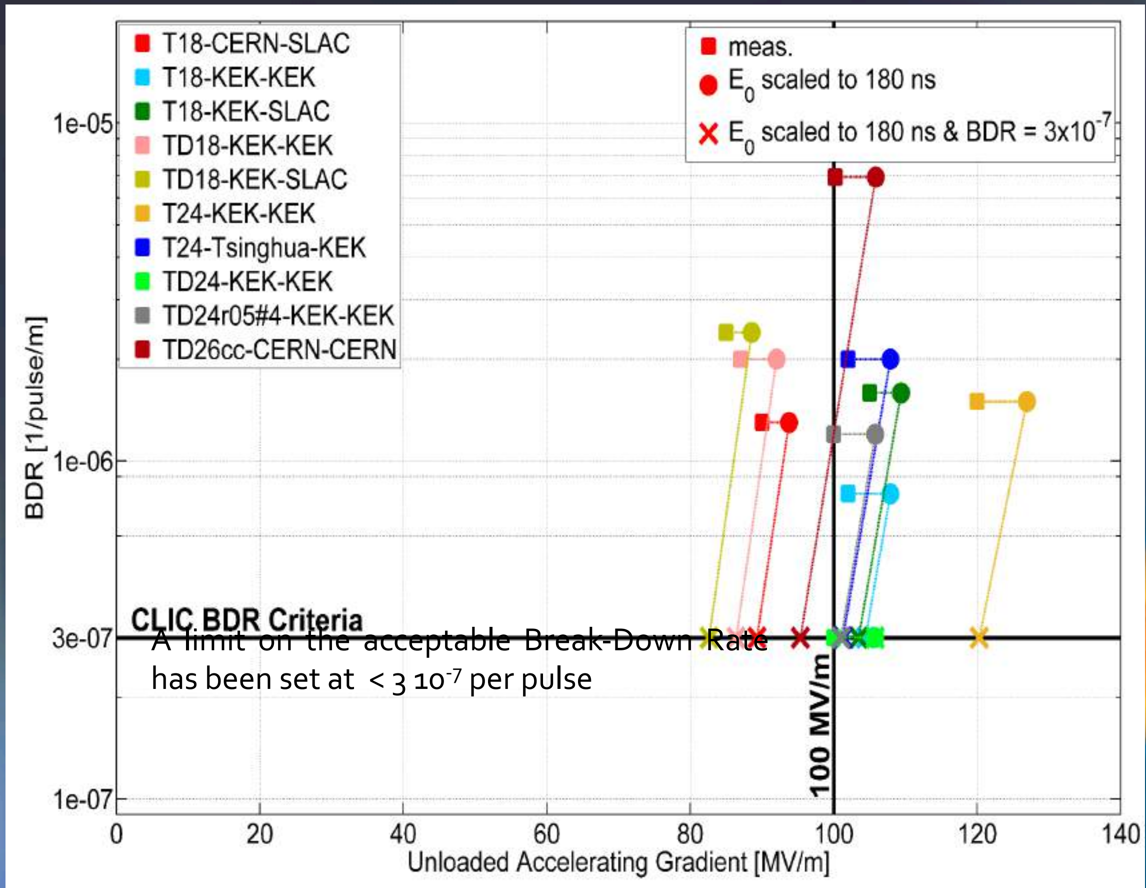
E_{acc} < 100 GV/m

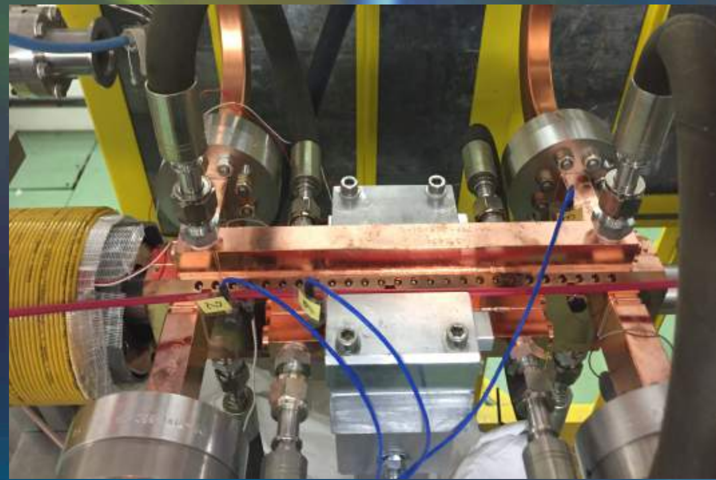
Related Issues: Power Sources and Efficiency, Stability, Reliability, Staging, Synchronization, Rep. Rate and short (fs) bunches with small (μm) spot to match high gradients

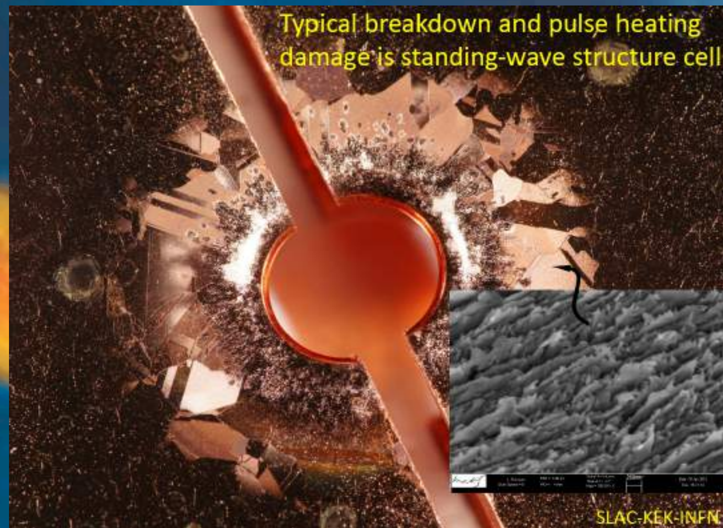
X-band RF structures – State of the Art

Max accelerating field: $\tau_{rf}^{-1/6}$

Stored energy: ν^{-3}

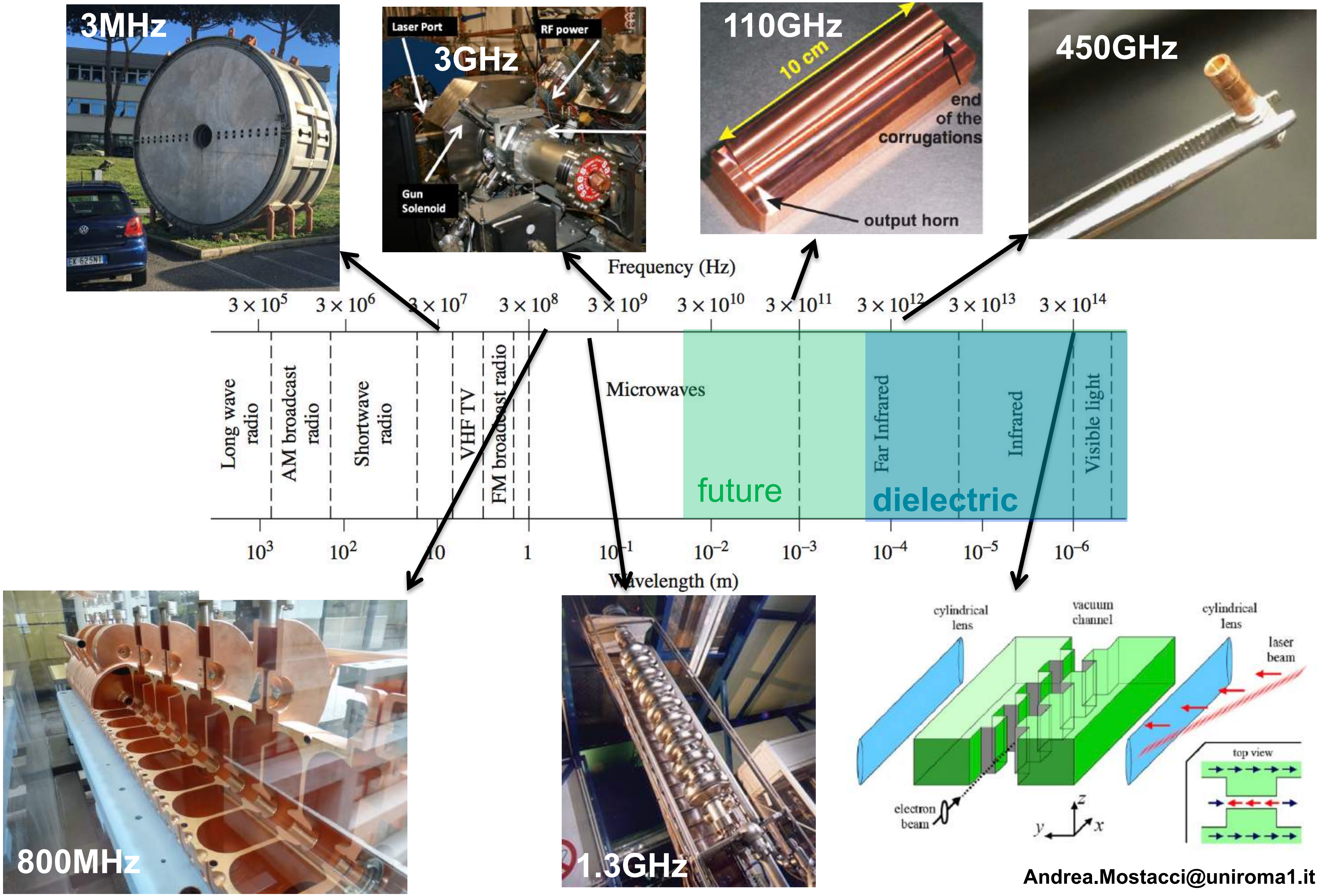






- Kilpatrick, W. D., Rev. Sci. Inst. 28, 824 (1957).
- *A. Grudiev et al, PRST-AB 12, 102001 (2009)*
- S. V. Dolgashev, et al. Appl. Phys. Lett. 97, 171501 2010.
- M. D. Forno, et al. PRAB. 19, 011301 (2016).

The E.M. Spectrum of Accelerating Structures



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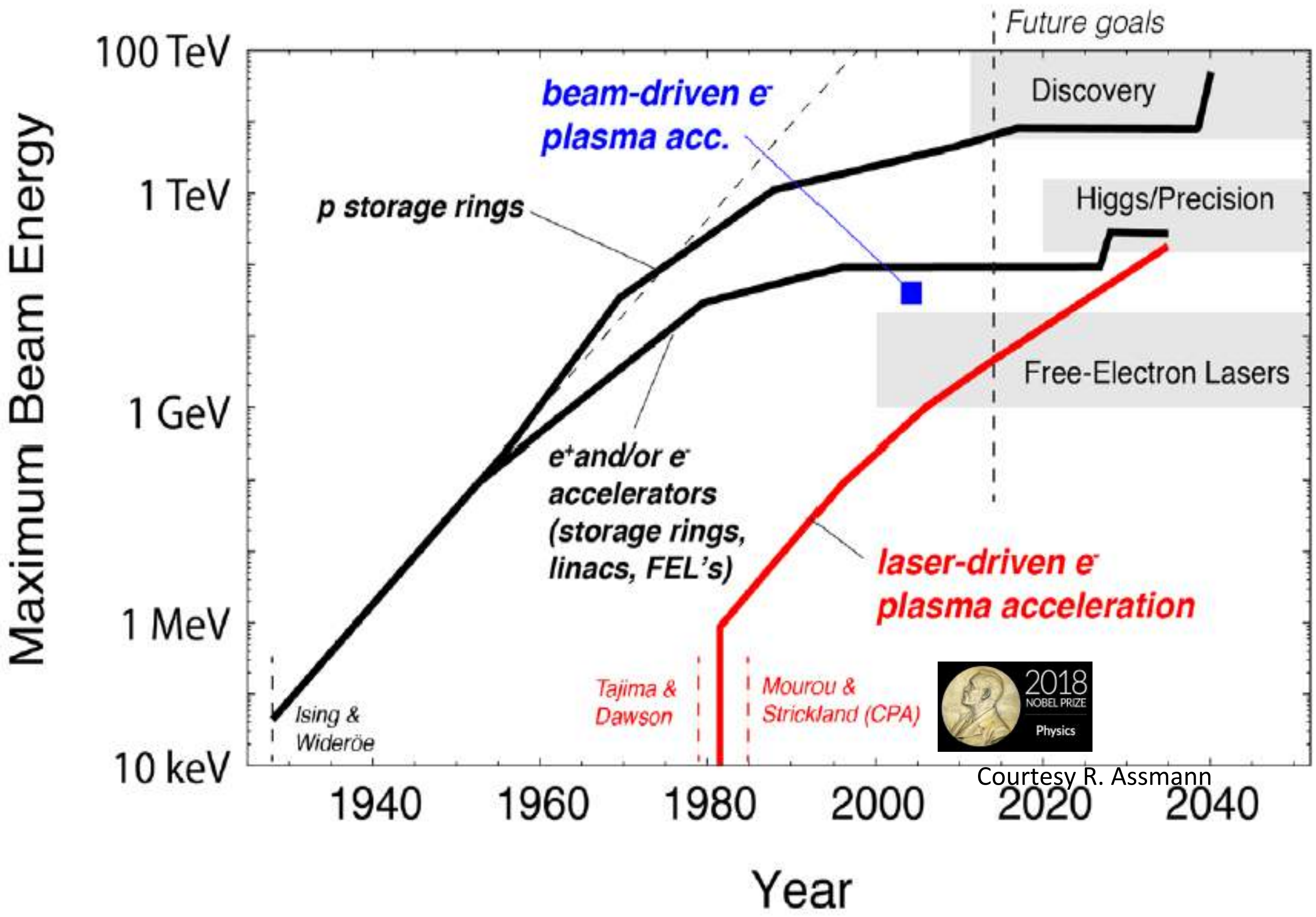


Courtesy R. Assmann

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.

VOLUME 54, NUMBER 7 PHYSICAL REVIEW LETTERS 18 FEBRUARY 1985

Acceleration of Electrons by the Interaction of a Bunched Electron Beam with a Plasma

Pisin Chen[a]
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

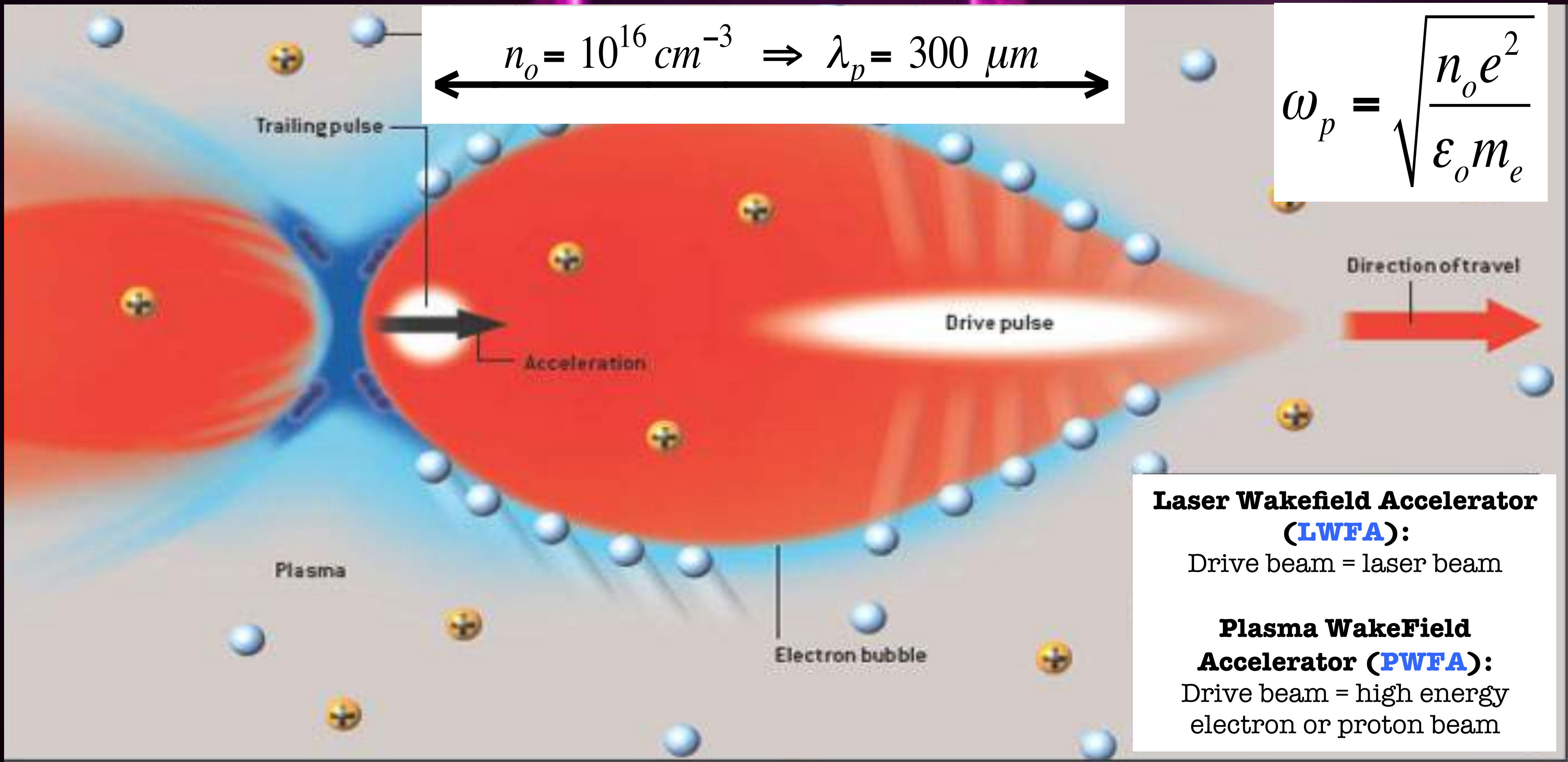
J. M. Dawson, Robert W. Huff, and T. Katsouleas
Department of Physics, University of California, Los Angeles, California 90024
(Received 20 December 1984)

A new scheme for accelerating electrons, employing a bunched relativistic electron beam in a cold plasma, is analyzed. We show that energy gradients can exceed 1 GeV/m and that the driven electrons can be accelerated from $\gamma_0 mc^2$ to $3\gamma_0 mc^2$ before the driving beam slows down enough to degrade the plasma wave. If the driving electrons are removed before they cause the collapse of the plasma wave, energies up to $4\gamma_0^2 mc^2$ are possible. A noncollinear injection scheme is suggested in order that the driving electrons can be removed.

Principle of plasma acceleration

$n_o = 10^{16}\ cm^{-3} \Rightarrow \lambda_p = 300\ \mu m$

$$\omega_p = \sqrt{\frac{n_o e^2}{\varepsilon_o m_e}}$$



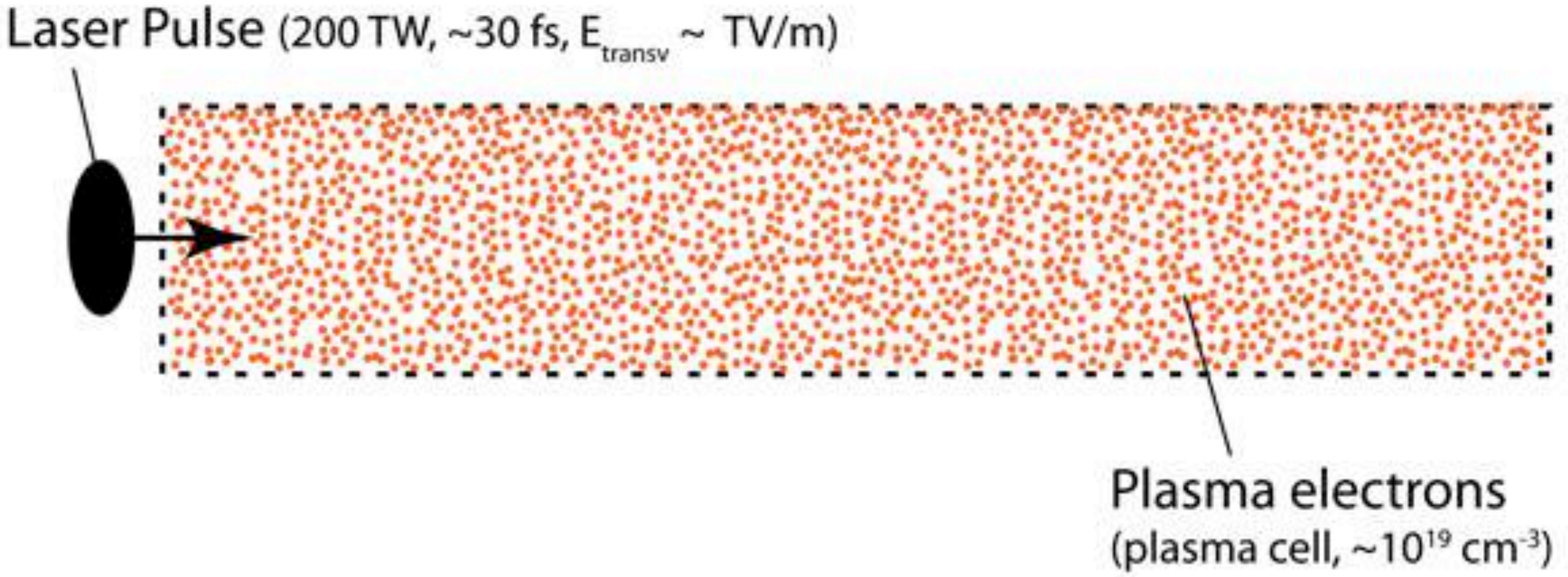
Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

Plasma WakeField Accelerator (PWFA):
Drive beam = high energy electron or proton beam

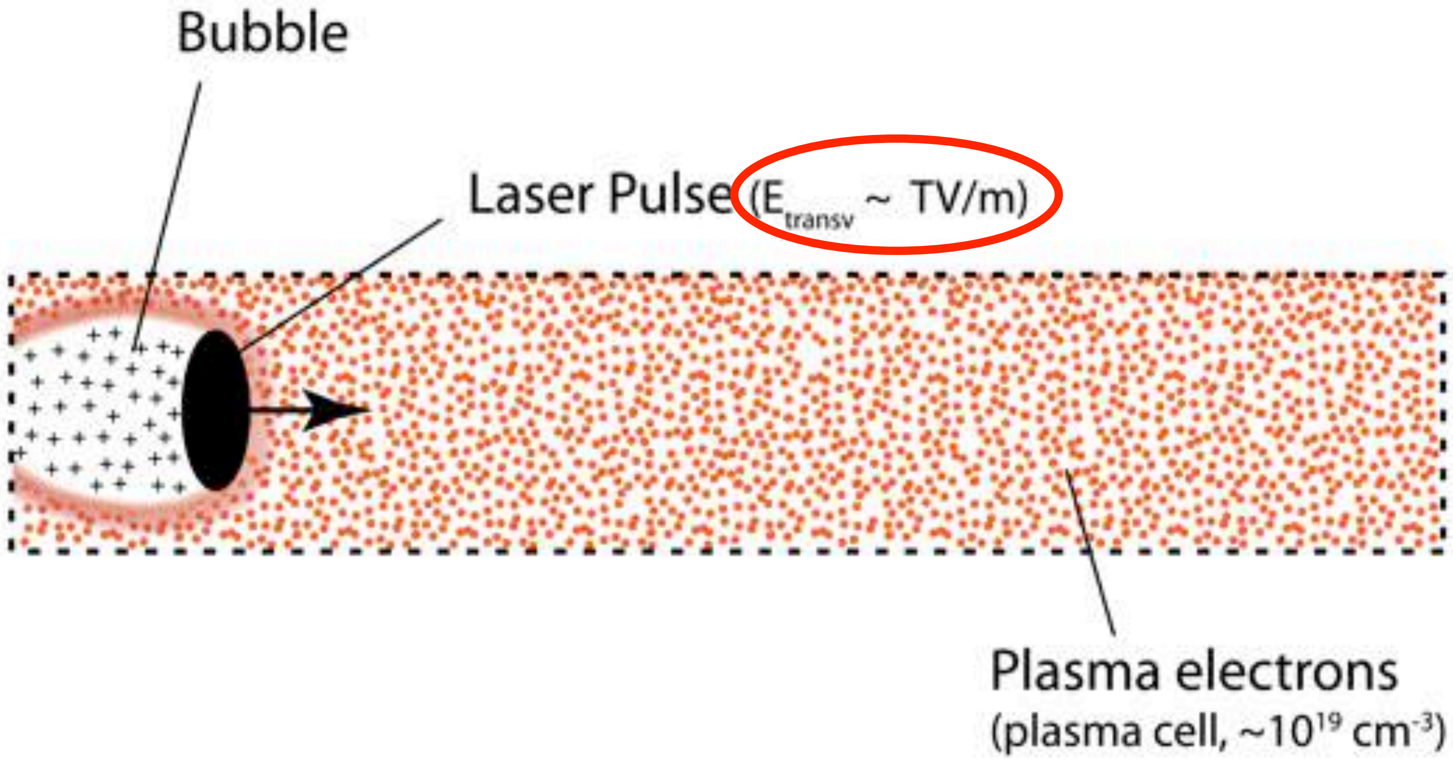
Break-Down Limit?
⇒ Wave-Breaking field:

$$E_{wb} \approx 100\left[GeV/m\right]\sqrt{n_o\left[cm^{-3}\right]}$$

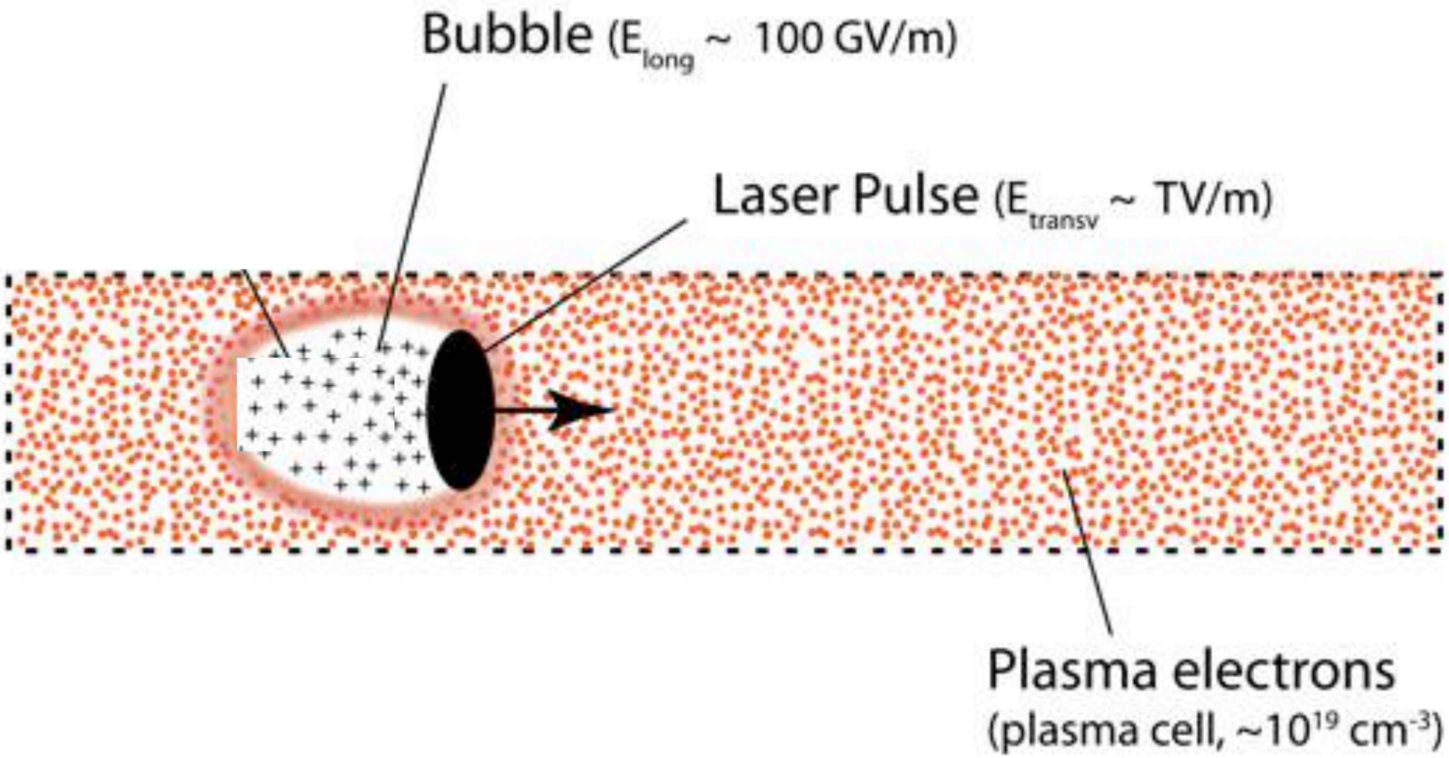
Plasma Wake-Acceleration



Plasma Wake-Acceleration

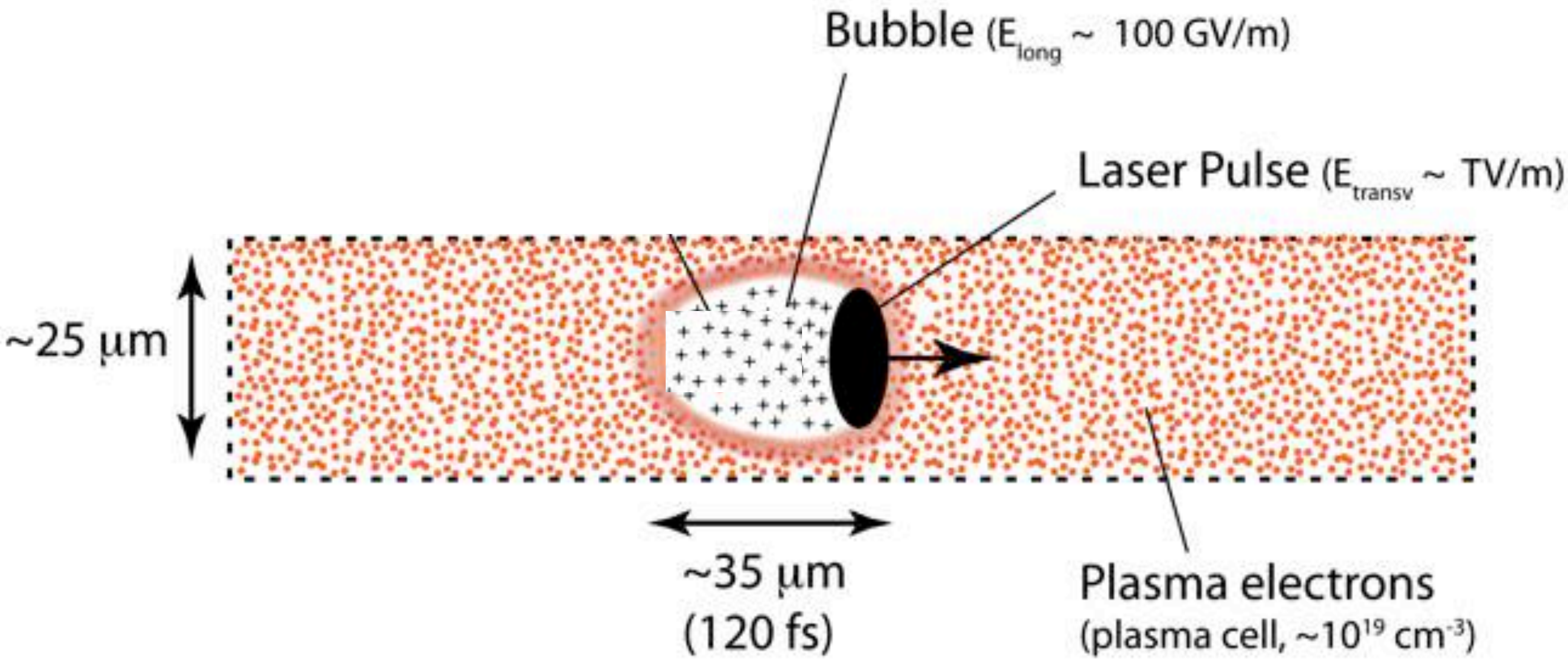


Plasma Wake-Acceleration



Plasma Wake-Acceleration

Horizon2020



This accelerator fits into a human hair!

Principle of plasma acceleration

Driven by Radiation Pressure

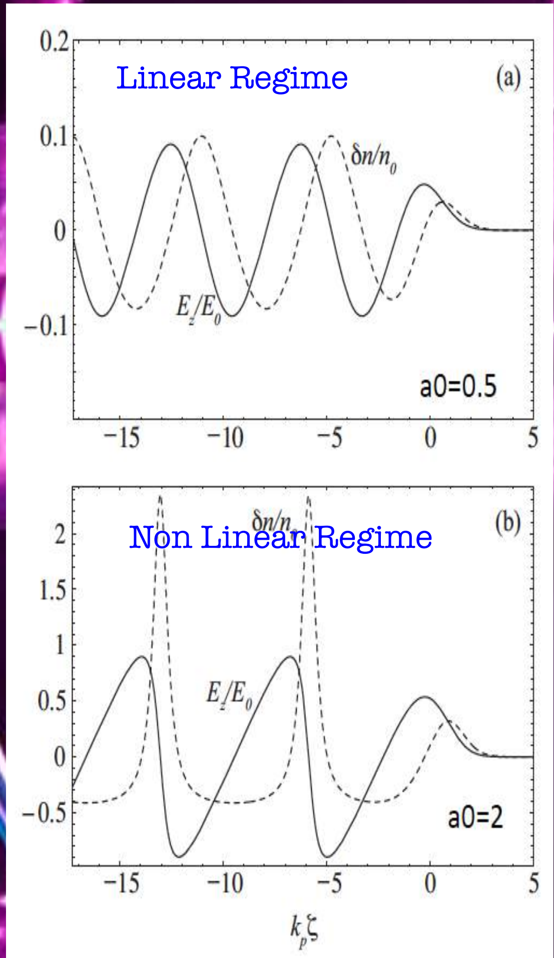
$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=c^2\nabla^2\frac{a^2}{2}$$

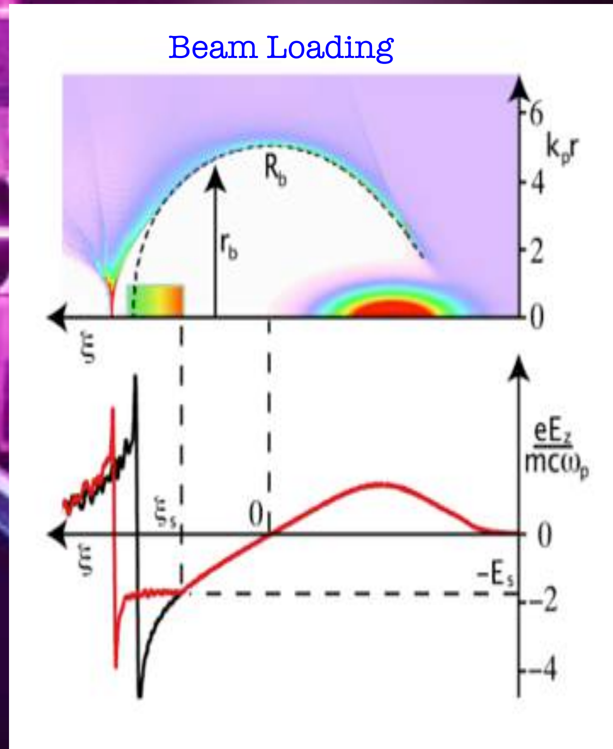
$$a=\frac{eA}{mc^2}\propto\lambda J^{1/2}$$

Driven by Space Charge

$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=-\omega_p^2\frac{n_{beam}}{n_o}$$

$$n_{beam}=\frac{N}{\sqrt{(2\pi)^3}\,\sigma_r^2\sigma_z}$$





LWFA limitations: Diffraction, Dephasing, Depletion

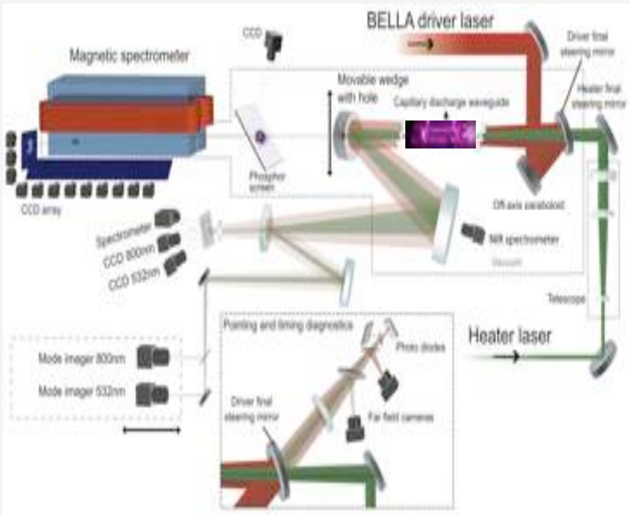
PWFA limitations: Head Erosion, Hose Instability

BELLA, Berkeley Lab, US

Laser Driven Plasma Wakefield Acceleration Facility: Today: PW laser!

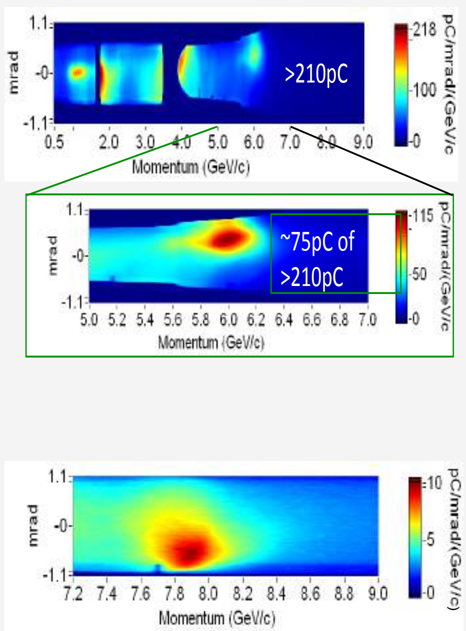
Petawatt laser guiding and electron beam acceleration to 8 GeV in a laser-heated capillary discharge waveguide

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



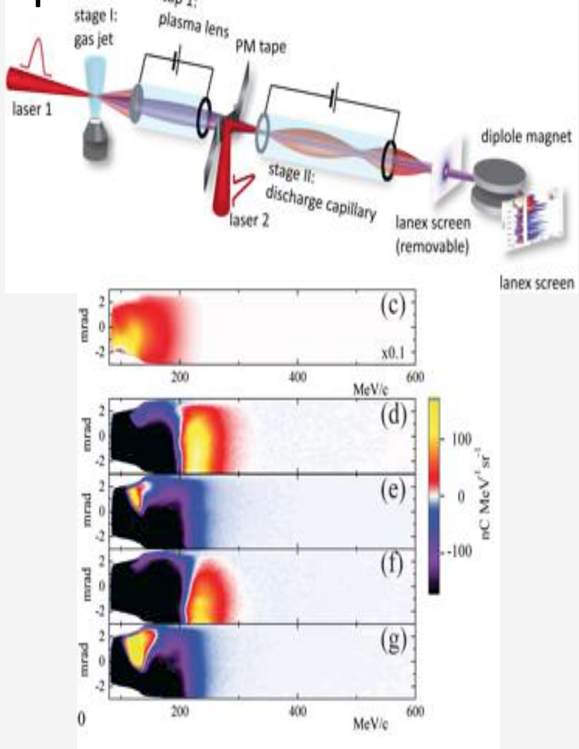
Laser heater added to capillary

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



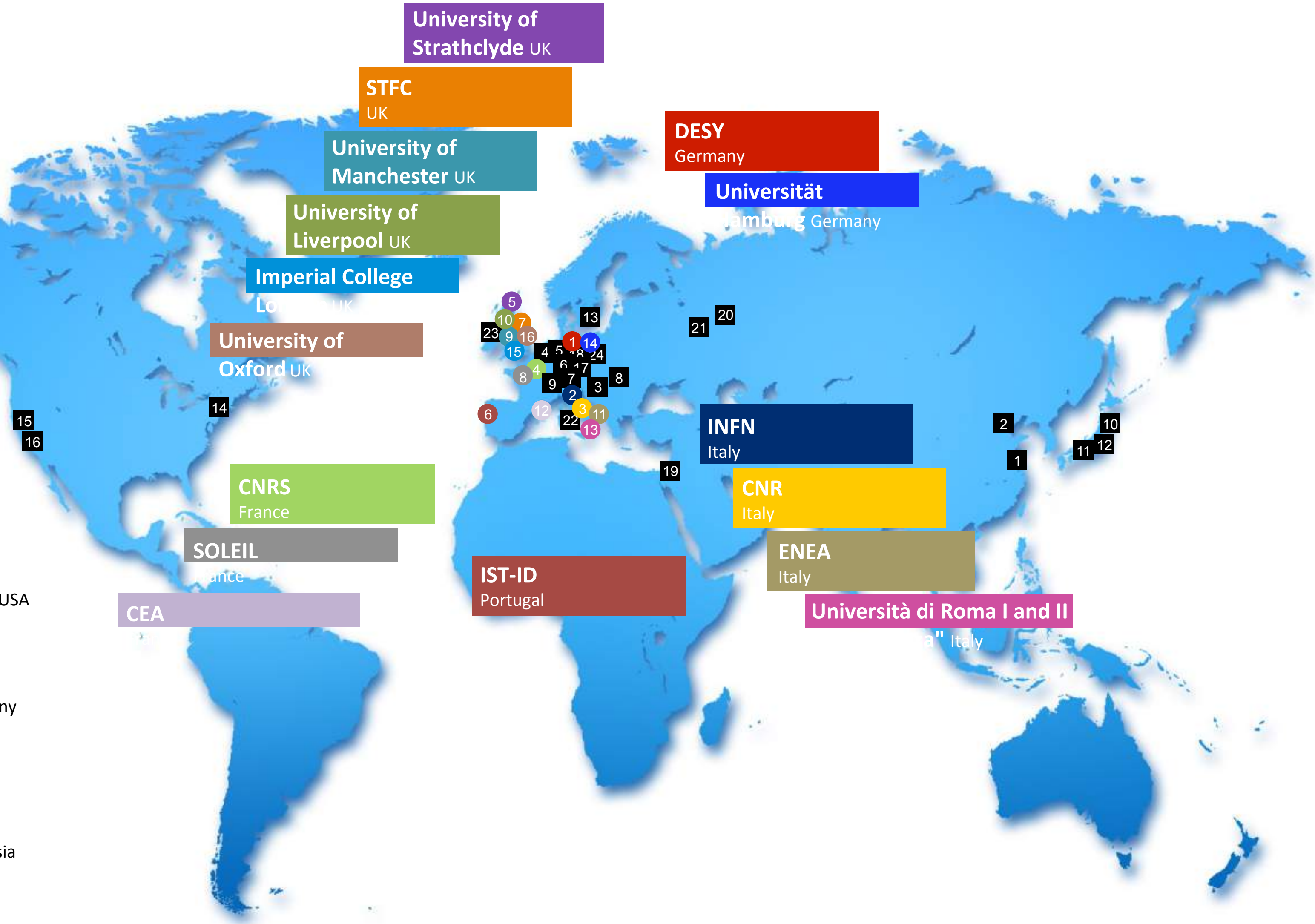
Staging demonstrated at 100 MeVs

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

Worldwide effort towards high quality plasma beams

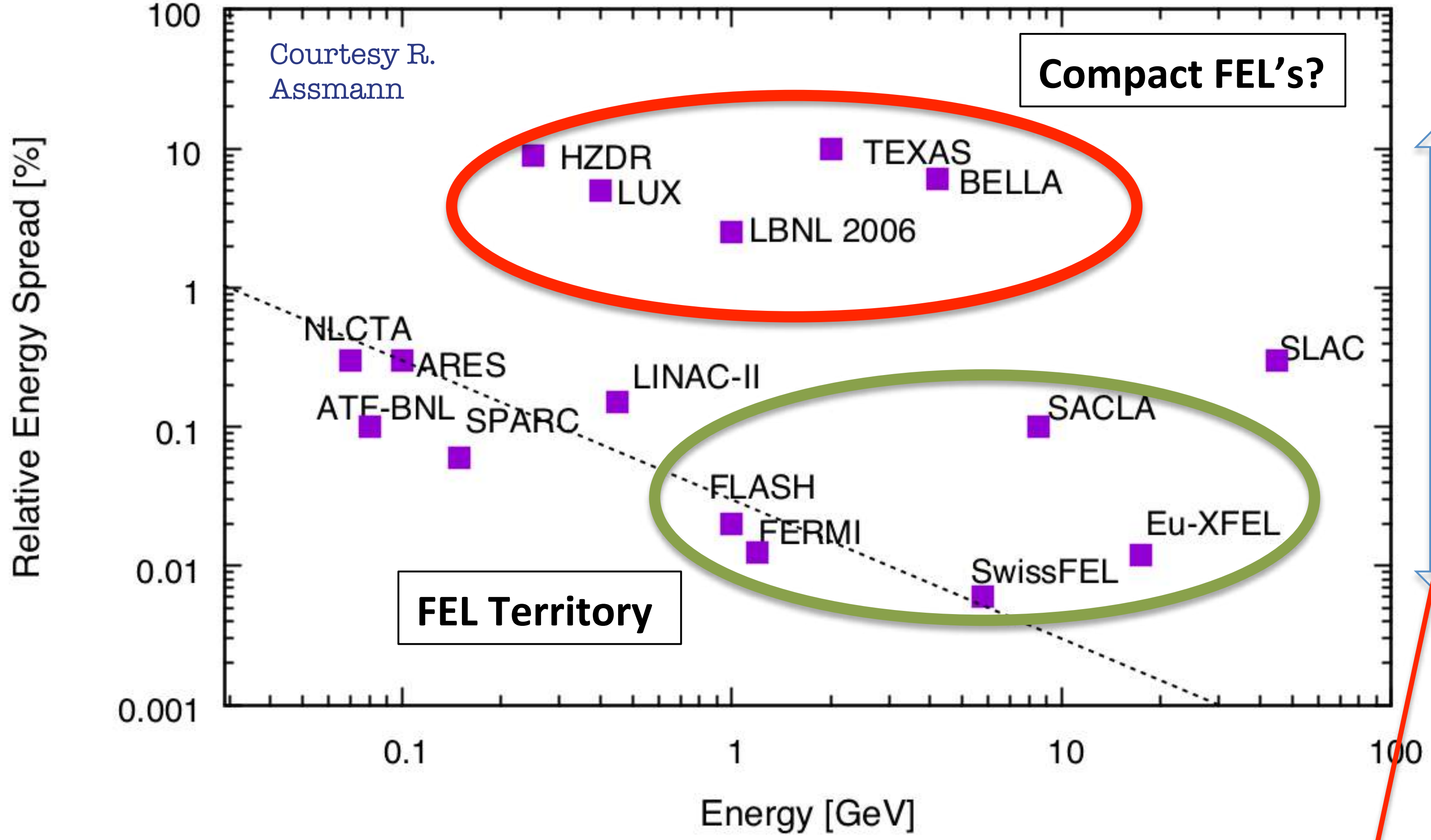
Associated Partners
(as of December 2017)

1. **Shanghai Jiao Tong-University**, China
2. **Tsinghua University Beijing**, China
3. **ELI Beamlines**, International
4. **PHLAM, Université de Lille,** France
5. **Helmholtz-Institut Jena**, Germany
6. **HZDR (Helmholtz)**, Germany
7. **LMU München**, Germany
8. **Wigner Fizikai Kutatóközpont**, Hungary
9. **CERN**, International
10. **Kansai Photon Science Institute**, Japan
11. **Osaka University**, Japan
12. **RIKEN SPring-8**, Japan
13. **Lunds Universitet**, Sweden
14. **Stony Brook University & Brookhaven NL**, USA
15. **LBNL**, USA
16. **UCLA**, USA
17. **Karlsruher Institut für Technologie**, Germany
18. **Forschungszentrum Jülich**, Germany
19. **Hebrew University of Jerusalem**, Israel
20. **Institute of Applied Physics**, Russia
21. **Joint Institute for High Temperatures**, Russia
22. **Università di Roma 'Tor Vergata'**, Italy
23. **Queen's University Belfast**, UK
24. **Ferdinand-Braun-Institut**, Germany



Quality: Example Energy Spread

Horizon 2020



Lower quality

Higher quality

$$\sigma_\gamma = \frac{\sqrt{3}}{2} k_p^2 \sigma_z^2$$

$$\sigma_{x,eq} = \sqrt[4]{\frac{2}{\gamma}} \sqrt{\frac{\varepsilon_n}{k_p}}$$

$$\varepsilon_{n,rms} = \sqrt{\langle \gamma^2 \rangle \left(\sigma_\gamma^2 \sigma_x^2 \sigma_{x'}^2 + \varepsilon_{rms}^2 \right)}$$

M. Migliorati et al, Physical Review Special Topics,Accelerators and Beams 16, 011302 (2013)
K. Floettmann, PRSTAB,6, 034202 (2003)

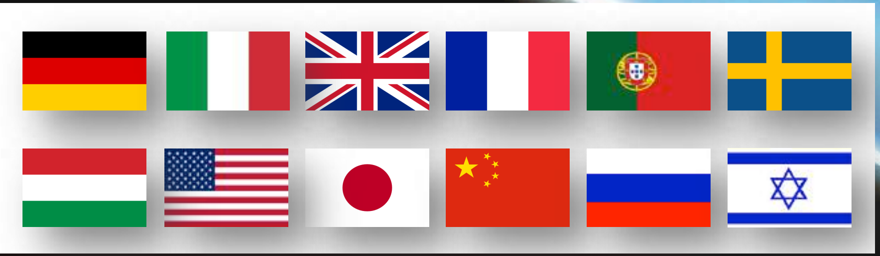
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on Novemebr 2015

Approved as HORIZON 2020 INFRADEV, 4 years, 3 M€

Coordinator: Ralph Assmann (DESY)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

http://eupraxia-project.eu

Motivations

Horizon2020

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

Courtesy R. Assmann

EuPRAXIA Conceptual Design: Complete

Conceptual design report submitted as planned to EU on November 1st

- **First ever international design of a plasma accelerator facility**
- Funded 2015-2019 by European Union (Horizon2020) with 3 Million Euro
- Coordinating lab: DESY (R. Assmann)
- Growing **consortium**: 32 → 41 labs, ELI, CERN, LBNL, Osaka, Shanghai, Russian labs
- **Industry**: Thales (France), Amplitude (France), Trumpf Scientific (Germany)

653 page CDR, 240 scientists contributed

http://www.eupraxia-project.eu/

EuPRAXIA Brings together European Actors in this Field…

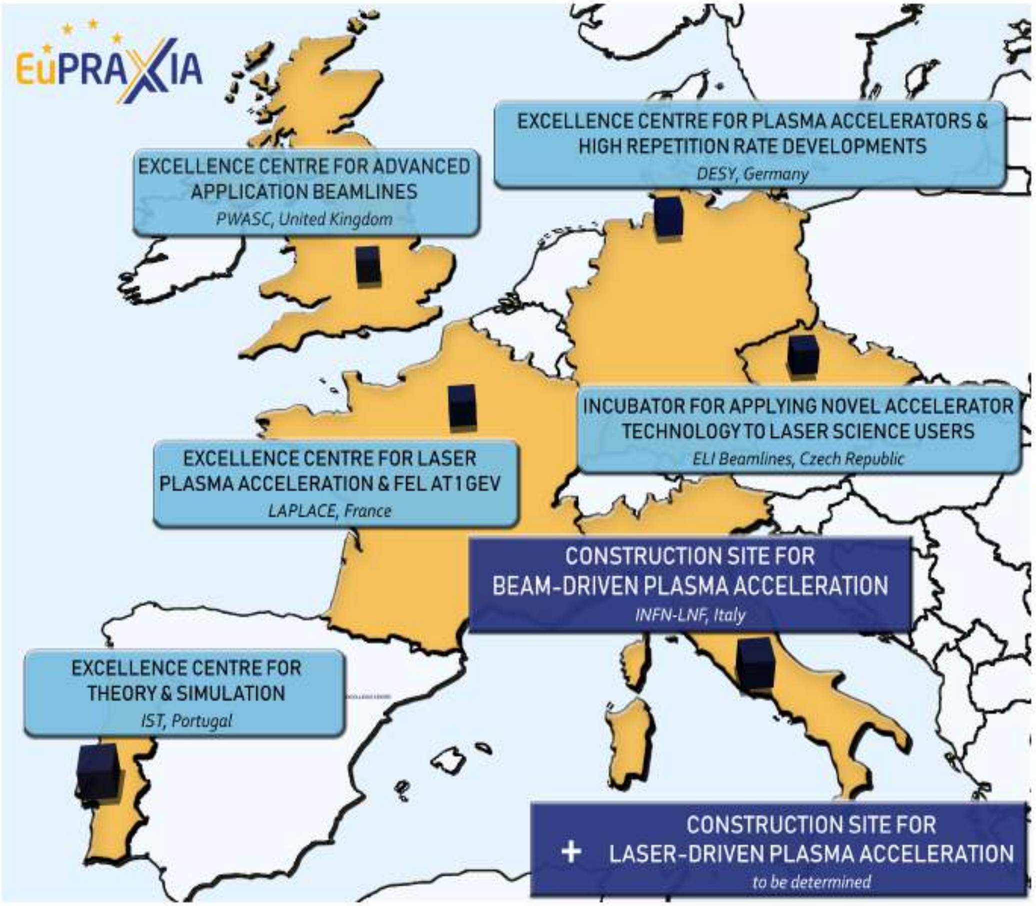
Position Europe as a Leader in the Global Context

- Avoid internal competition, **position Europe globally as lead player** in the compact accelerator "market", in innovative technology

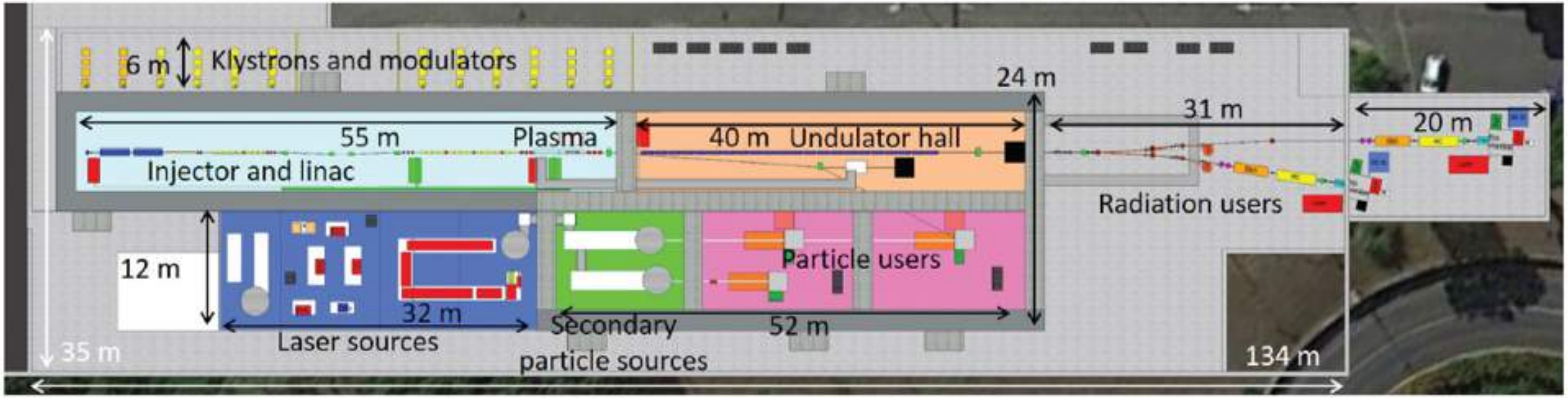
… and Builds a European Distributed Facility

Position Europe as a Leader in the Global Context

1. Lean overall **EuPRAXIA management**
2. **Ten clusters:** Collaborations of institutes on specific problems, developing solutions, technical designs, driving developments with EuPRAXIA generated funding → **expertise of Helmholtz centers required - opportunities**
3. **Five excellence centers** at existing facilities: Using pre-investment, support tests, prototyping, production with EuPRAXIA generated funding → **DESY excellence center**
4. **One or two construction sites** at existing facilities with EuPRAXIA generated funding:
   - **Beam-driven** at Frascati (Italy).
   - **Laser-driven** at CLF/STFC (UK), CNR/ INFN (Italy) or ELI-Beamlines.



Beam Driven EuPRAXIA Site at Frascati

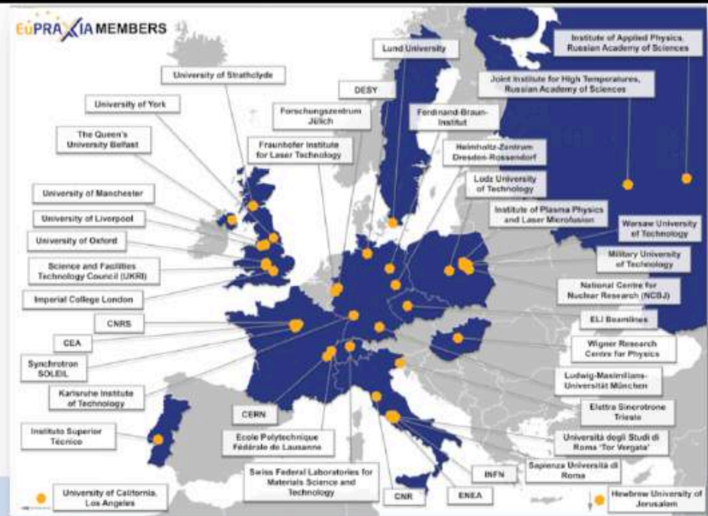


The **executive design of the building has officially started**, the delivery is expected by the end of February 2021.

ESFRI Proposal: Submitted on September 9

- EuPRAXIA strongly supported in European research landscape, it is **timely**, it offers **highly attractive opportunities** for innovation with industry, novel applications and pilot users.
- **Lead Country**: **Italy (LNF/INFN)**
  Political and financial support letter sent to ESFRI by Italian Ministry
- **Political support letters** (at least two needed from countries):
  - **Hungary**
  - **Portugal**
  - **Czech Republic** (ELI))
  - **UK**
- Note: All operational costs covered by host countries.

From political landscape it is seen that both Czech Republic and UK would be excellent sites for the second leg of EuPRAXIA, connecting to existing facilities with laser expertise and few 100 million € pre-invest.



Recent (November 4) message from ESFRI Policy Officer:
"We are glad to inform you that the proposal EuPRAXIA has been considered eligible and can now be assessed for entering the ESFRI Roadmap 2021."
Next steps:
- Invitation for the hearing with list of critical questions: February-March 2021
- Hearing: April-May 2021

EuPRAXIA@SPARC_LAB

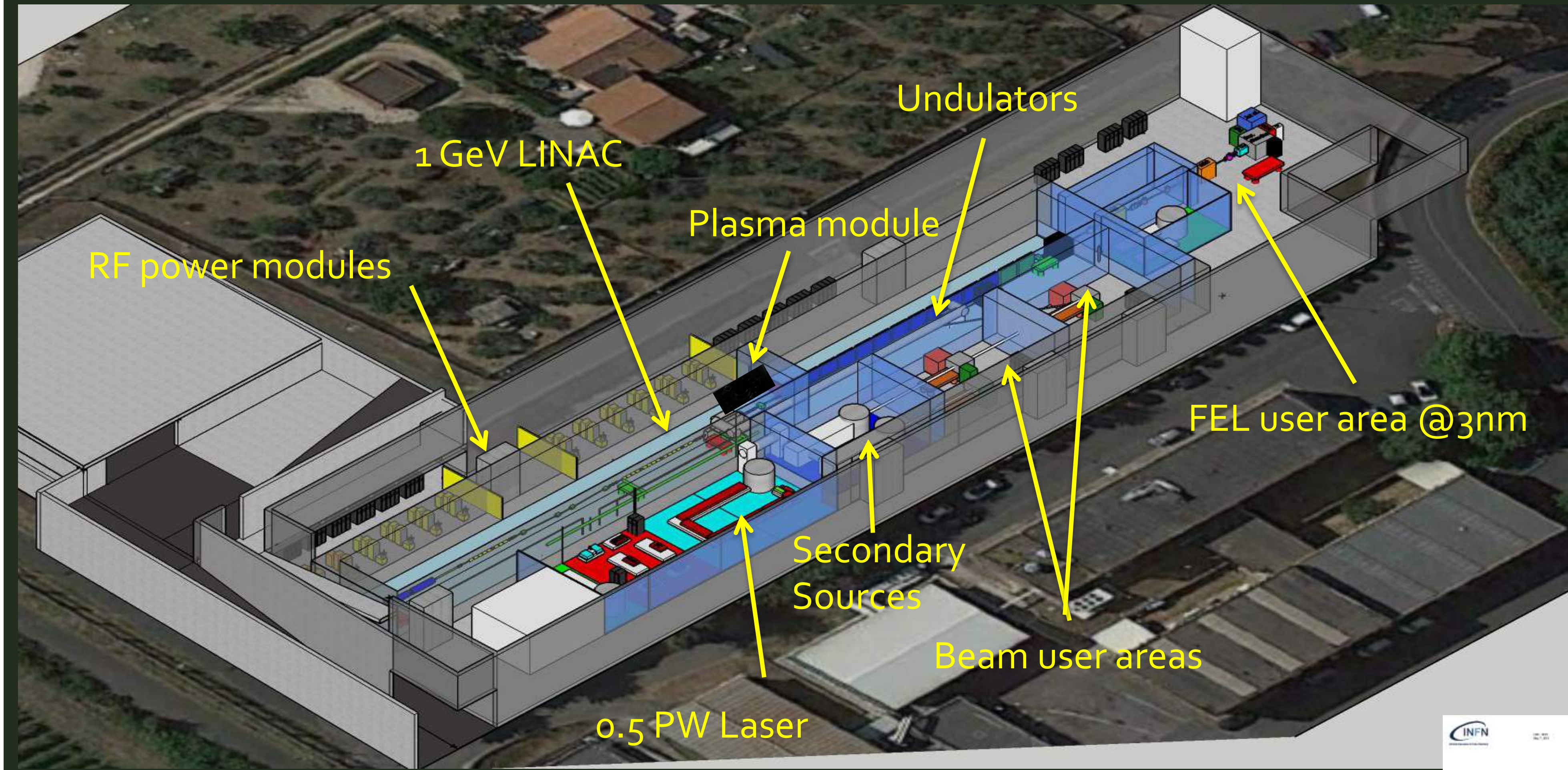

Courtesy Simona Incremona

INFN
Istituto Nazionale di Fisica Nucleare

EuPRAXIA@SPARC_LAB building _ render

Courtesy S. Incremona – U. Rotundo

EuPRAXIA@SPARC_LAB



http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

D. Alesini[a], M. P. Anania[a], M. Artioli[b], A. Bacci[c], S. Bartocci[d], R. Bedogni[a], M. Bellaveglia[a], A. Biagioni[a], F. Bisesto[a], F. Brandi[e], E. Brentegani[a], F. Broggi[c], B. Buonomo[a], P. Campana[a], G. Campogiani[a], C. Cannaos[d], S. Cantarella[a], F. Cardelli[a], M. Carpanese[f], M. Castellano[a], G. Castorina[g], N. Catalan Lasheras[h], E. Chiadroni[a], A. Cianchi[i], R. Cimino[a], F. Ciocci[f], D. Cirrincione[j], G. A. P. Cirrone[k], R. Clementi[a], M. Coreno[l], R. Corsini[h], M. Croia[a], A. Curcio[a], G. Costa[a], C. Curatolo[c], G. Cuttone[k], S. Dabagov[a], G. Dattoli[f], G. D'Auria[l], I. Debrot[c], M. Diomede[a,g], A. Drago[a], D. Di Giovenale[a], S. Di Mitri[l], G. Di Pirro[a], A. Esposito[a], M. Faiferri[d], M. Ferrario[a], L. Ficcadenti[g], F. Filippi[a], O. Frasciello[a], A. Gallo[a], A. Ghigo[a], L. Giannessi[f,l], A. Giribono[a], L. A. Gizzi[e], A. Grudiev[h], S. Guiducci[a], P. Koester[e], S. Incremona[a], F. Iungo[a], L. Labate[e], A. Latina[h], S. Licciardi[f], V. Lollo[a], S. Lupi[g], R. Manca[d], A. Marcelli[a,m,n], M. Marini[d], A. Marocchino[a], M. Marongiu[g], V. Martinelli[a], C. Masciovecchio[l], C. Mastino[d], A. Michelotti[a], C. Milardi[a], M. Migliorati[g], V. Minicozzi[i], F. Mira[g], S. Morante[i], A. Mostacci[g], F. Nguyen[f], S. Pagnutti[f], L. Palumbo[g], L. Pellegrino[a], A. Petralia[f], V. Petrillo[o], L. Piersanti[a], S. Pioli[a], D. Polese[d], R. Pompili[a], F. Pusceddu[d], A. Ricci[m], R. Ricci[a], R. Rochow[l], S. Romeo[a], J. B. Rosenzweig[p], M. Rossetti Conti[o], A. R. Rossi[c], U. Rotundo[a], L. Sabbatini[a], E. Sabia[f], O. Sans Plannell[a], D. Schulte[h], J. Scifo[a], V. Scuderi[k], L. Serafini[c], B. Spataro[a], A. Stecchi[a], A. Stella[a], V. Shpakov[a], F. Stellato[i], P. Tomassini[e], E. Turco[d], C. Vaccarezza[a], A. Vacchi[j], A. Vannozzi[a], G. Vantaggiato[e], A. Variola[a], S. Vescovi[a], F. Villa[a], W. Wuensch[h], A. Zigler[q], M. Zobov[a]

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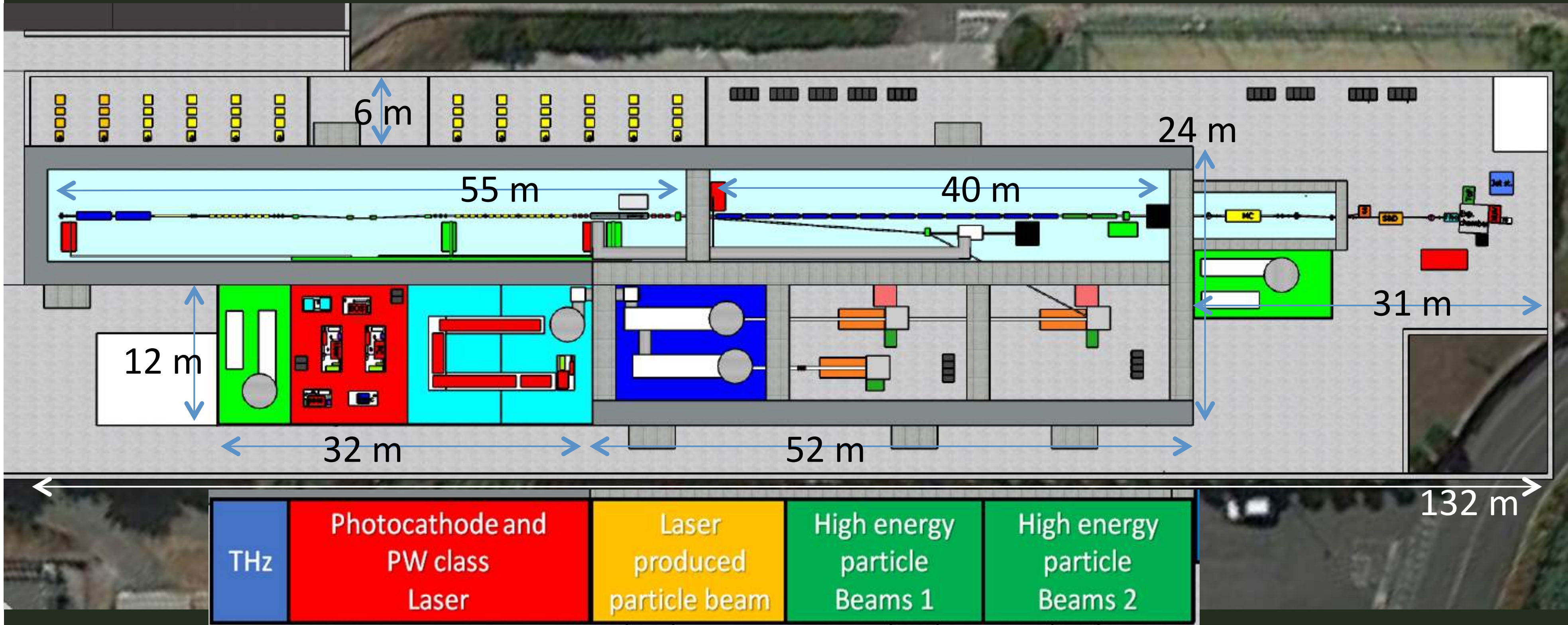
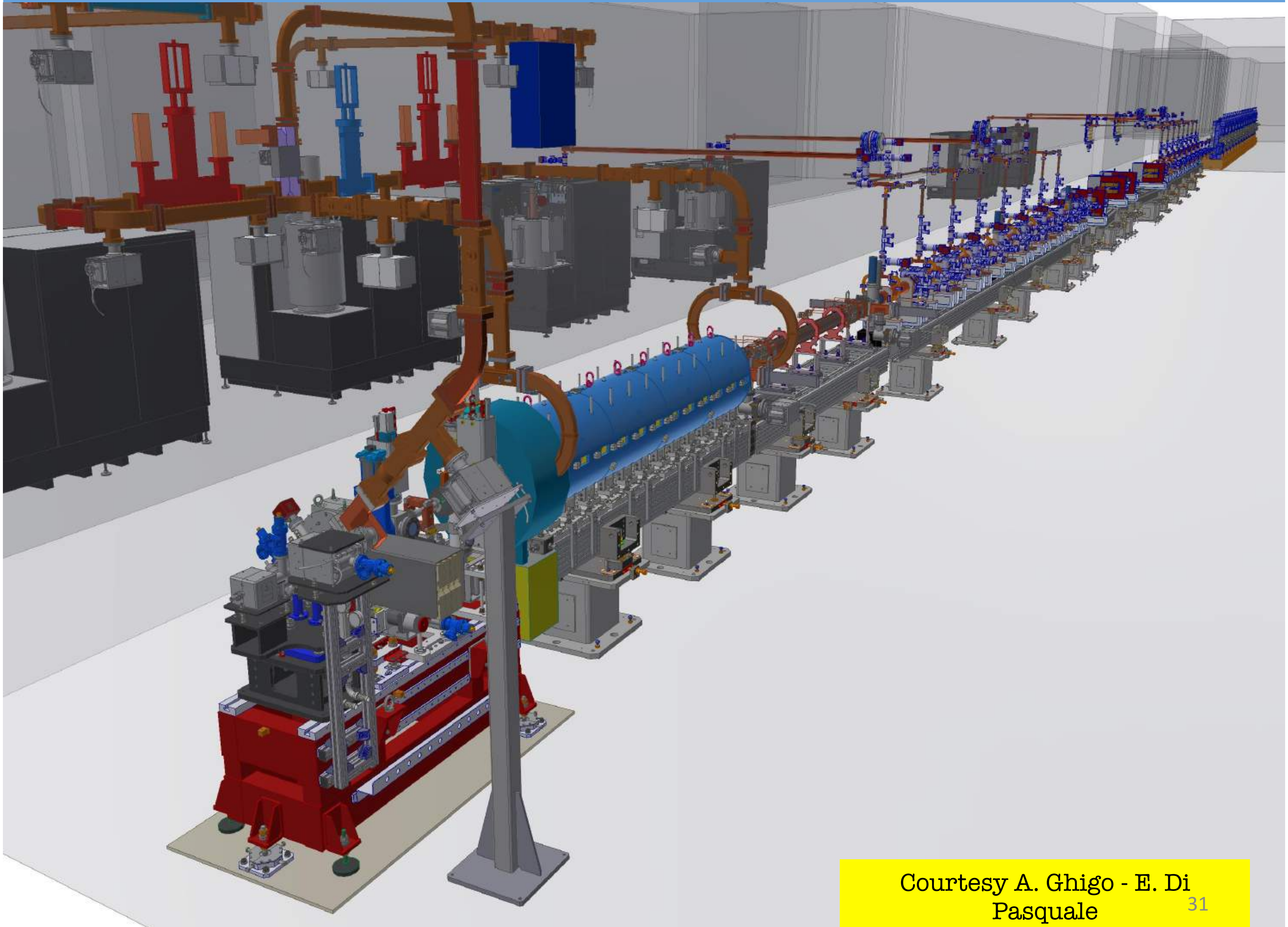
[q] *Racah Institute of Physics, The Hebrew University of Jerusalem, 91904 Jerusalem, Israel*

✓ Prepare LNF to host EuPRAXIA (1-5 GeV)

- FEL user facility (1 GeV – 3nm)
- Advanced Accelerator Test facility (LC) + CERN

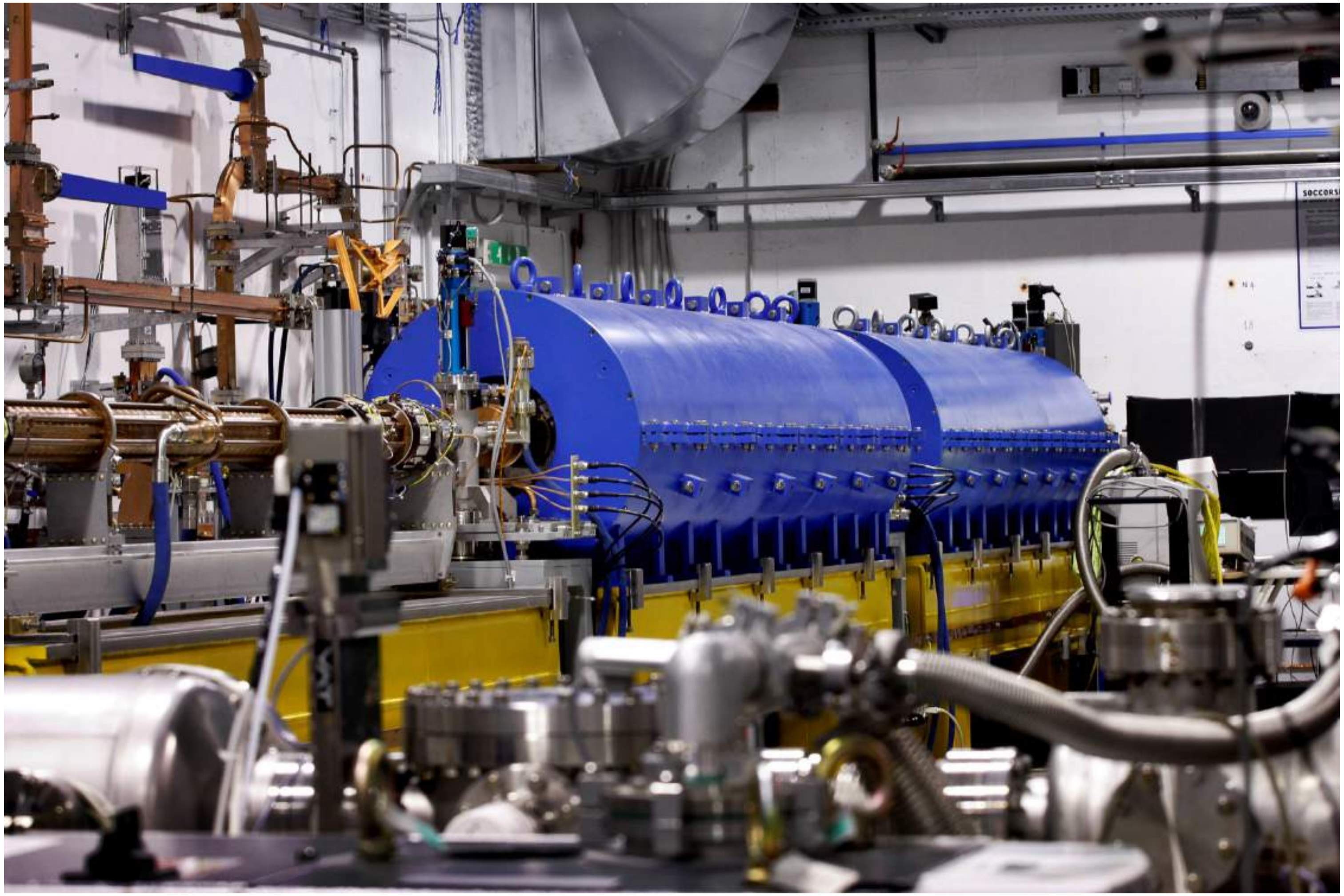


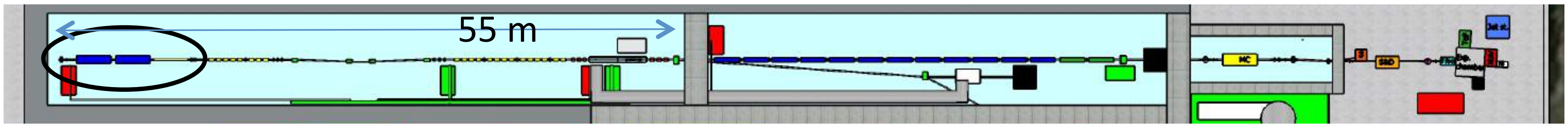
- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator



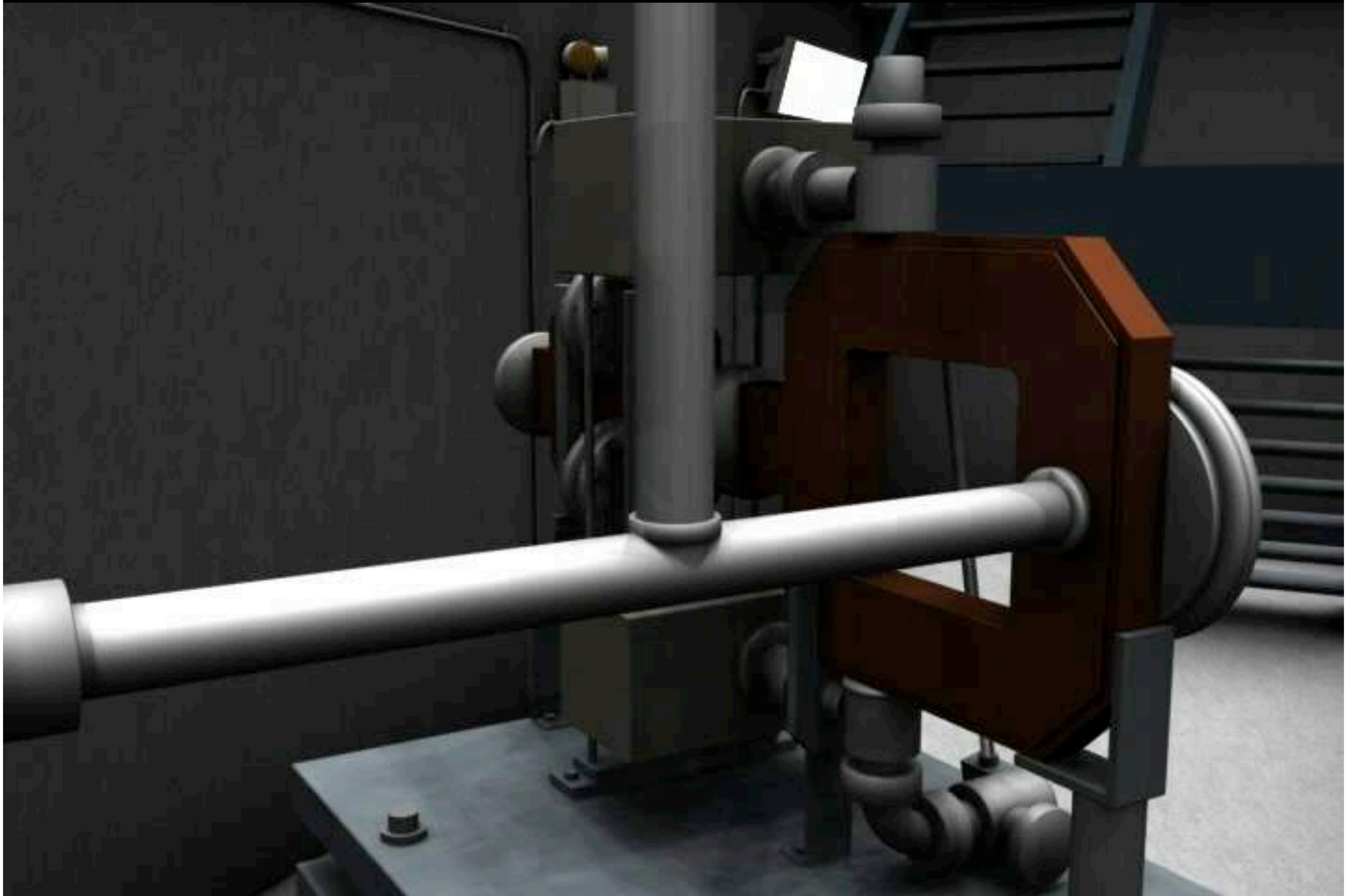
Courtesy A. Ghigo - E. Di Pasquale

SPARC_LAB HB photo- injector





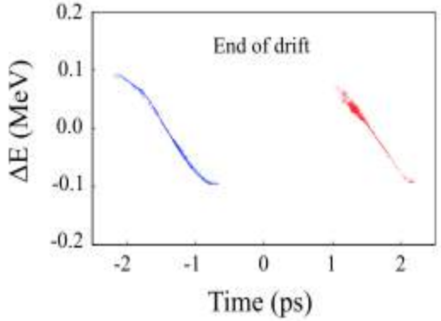
Electron source and acceleration

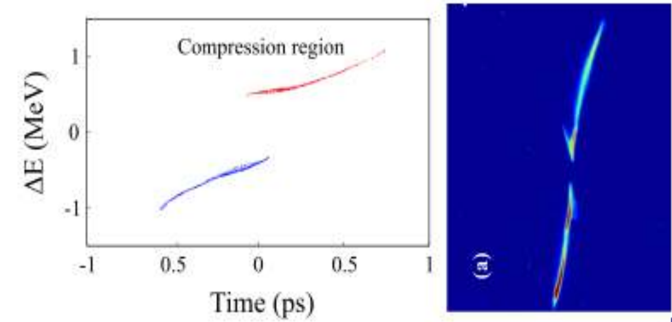


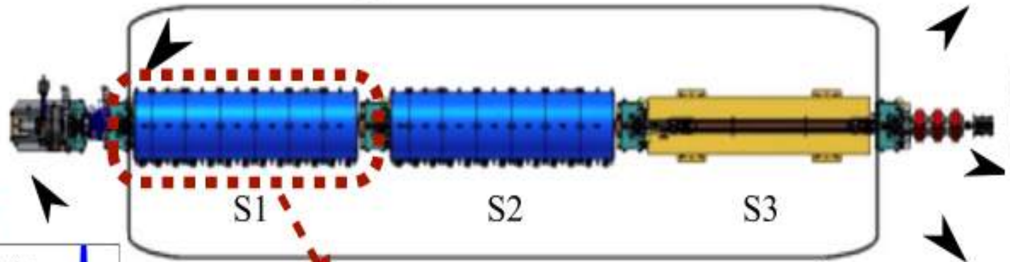
Generation of multi-bunch trains

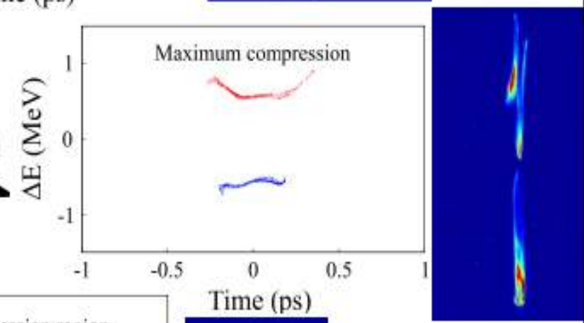
SPARC LAB

Sub-relativistic electrons ($\beta_c < 1$) injected into a traveling wave cavity at zero crossing move more slowly than the RF wave ($\beta_{RF} \sim 1$). The electron bunch slips back to an accelerating phase and becomes simultaneously accelerated and compressed.

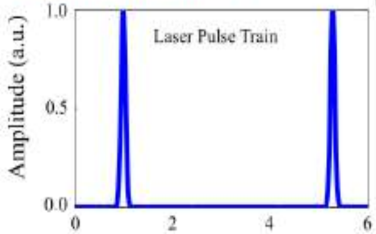




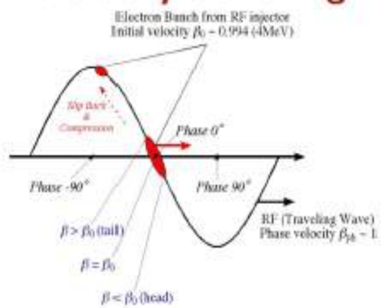


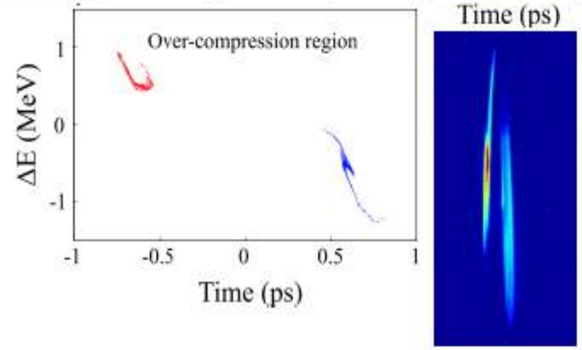


Comb-like laser

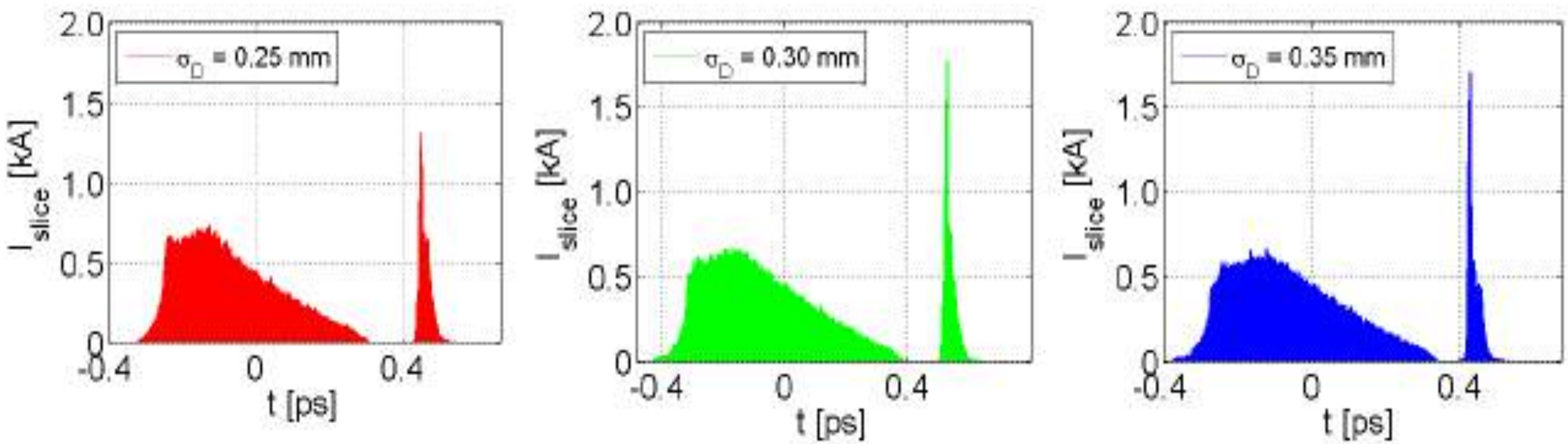


Velocity bunching





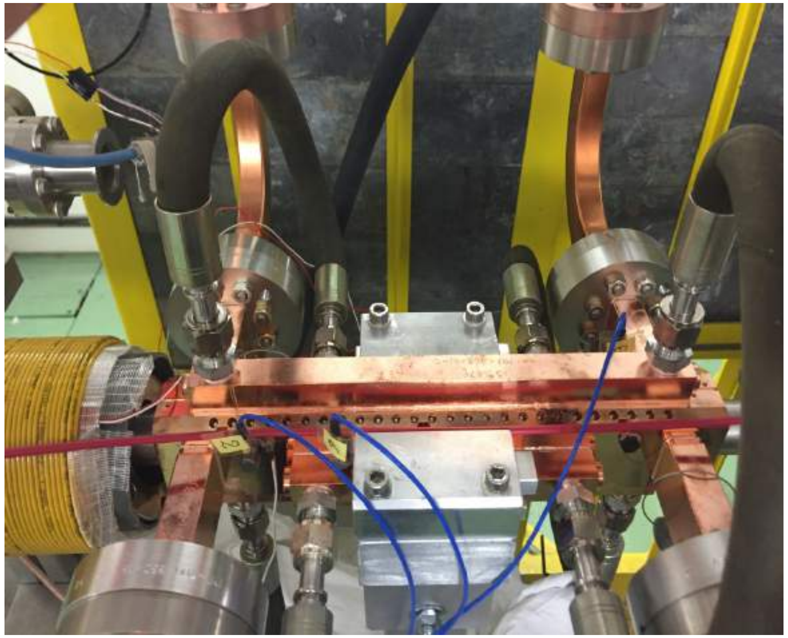
$$\Delta\phi_\infty = \frac{\sin\phi_0}{\sin\phi_\infty}\Delta\phi_0 + \frac{1}{2\alpha\gamma_0^2\sin\phi_\infty}\Delta\gamma_0 + \frac{1}{2}\left[\frac{\cos\phi_0}{\sin\phi_\infty} - \frac{\cos\phi_\infty\sin^2\phi_0}{\sin^3\phi_\infty}\right](\Delta\phi_0)^2.$$

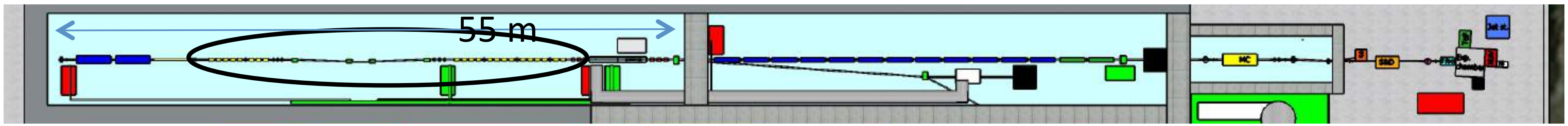


Parameter	Unit	Witness	Driver
Charge	pC	30	200
Energy	MeV	101.5	103.2
RMS energy spread	%	0.15	0.67
RMS bunch length	fs	12	20
RMS norm. emittance	mm mrad	0.69	1.95
Rep. rate	Hz	10	10

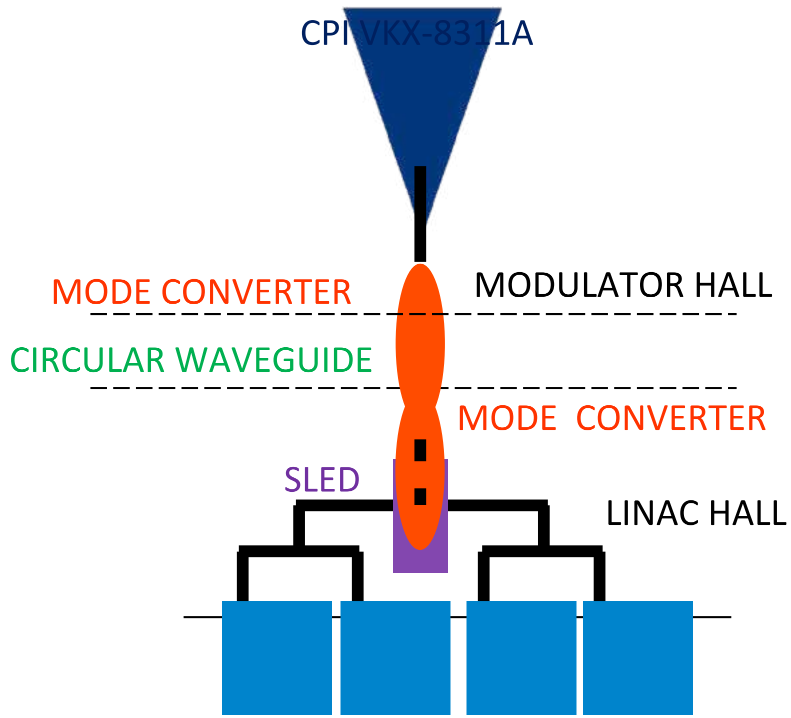
Table 7.2: Driver and witness beam parameters at the end of photo-injector.

X-band Linac





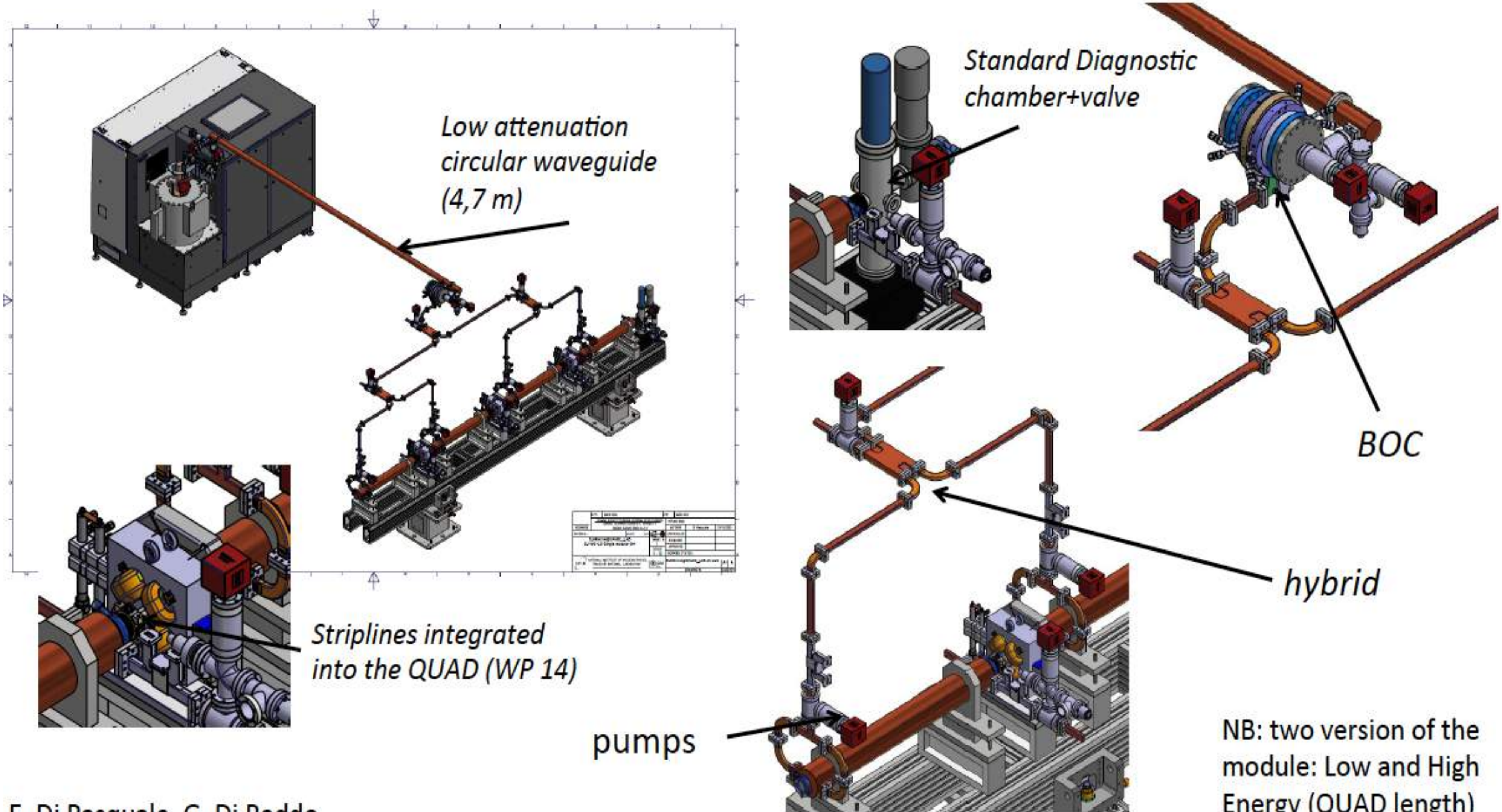
Compact



Parameter	Value
Frequency [GHz]	11.9942
RF pulse [μs]	1.5
Kly. power [MW]	50
Average iris radius <a>	3.5
Iris radius a [mm]	4.3-2.7
Average gradient <G> [MV/m]	65->60
Structure length L_s [m]	0.9
Linac active length L_{act} [m]	18
Unloaded SLED Q-factor Q_0	180000
External SLED Q-factor Q_E	23100
Shunt impedance R [MΩ/m]	85-117
Effective shunt Imp. R_s [MΩ/m]	356
Number of modules	5
Structures per module N_m	4
Klystron power per module Pk_m [MW]	43
Peak input power [MW]	74
Input power averaged over the pulse [MW]	48
Total number of structures N_{tot}	20
Total number of klystrons N_k	5

Courtesy M. Diomede

X BAND MODULE LAYOUT

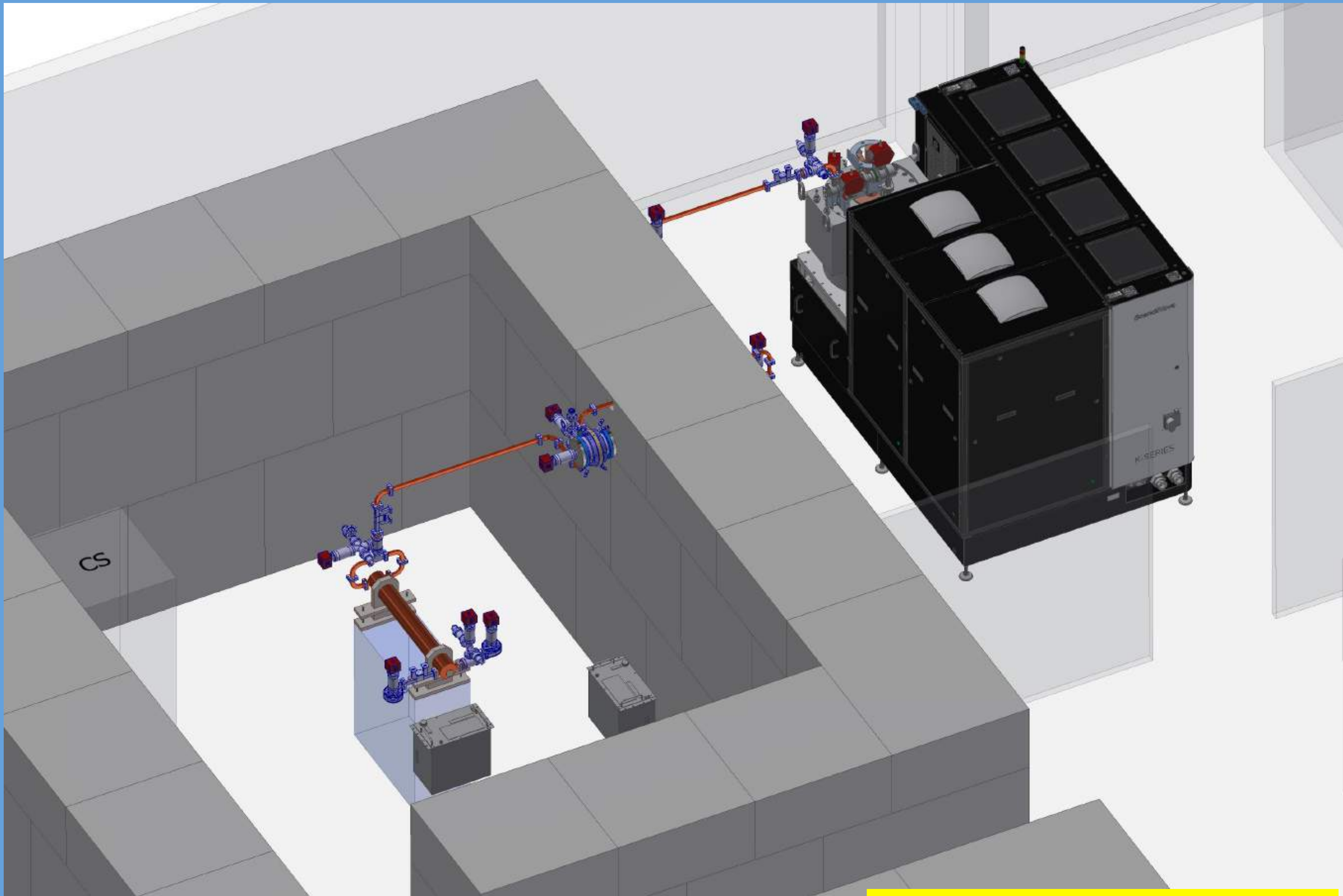


NB: two version of the module: Low and High Energy (QUAD length)

E. Di Pasquale, G. Di Raddo

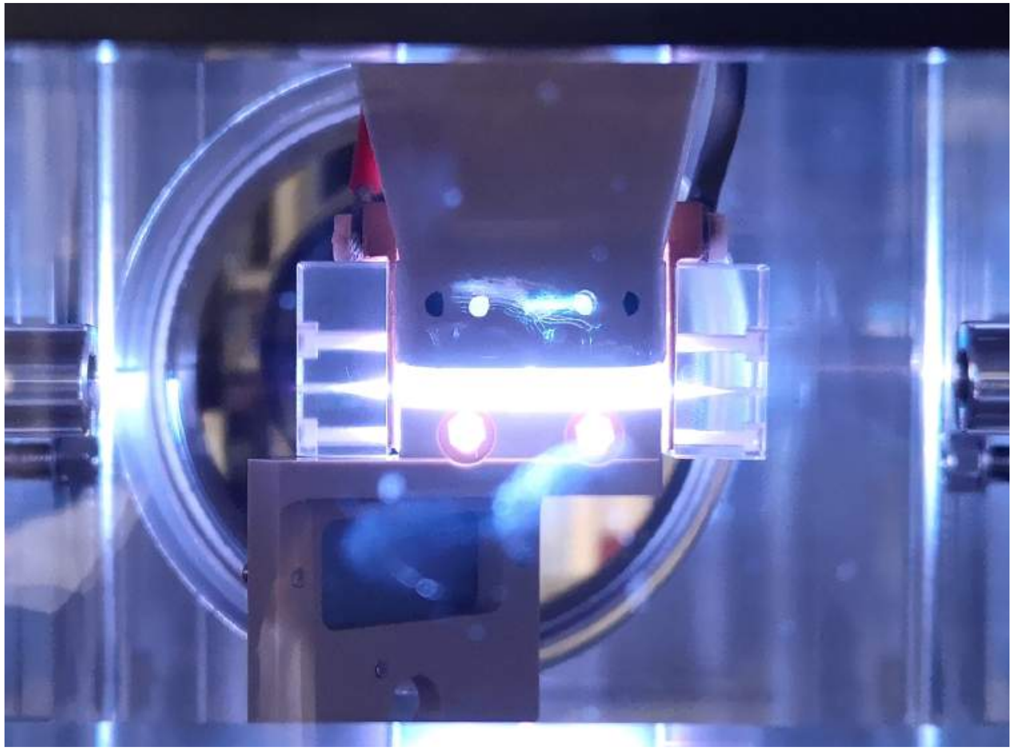
Courtesy D. Alesini

X-BOX@LNF

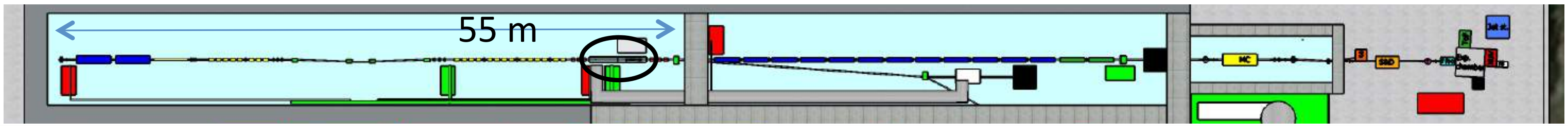


Courtesy E. Di Pasquale

Plasma WakeField Acceleration

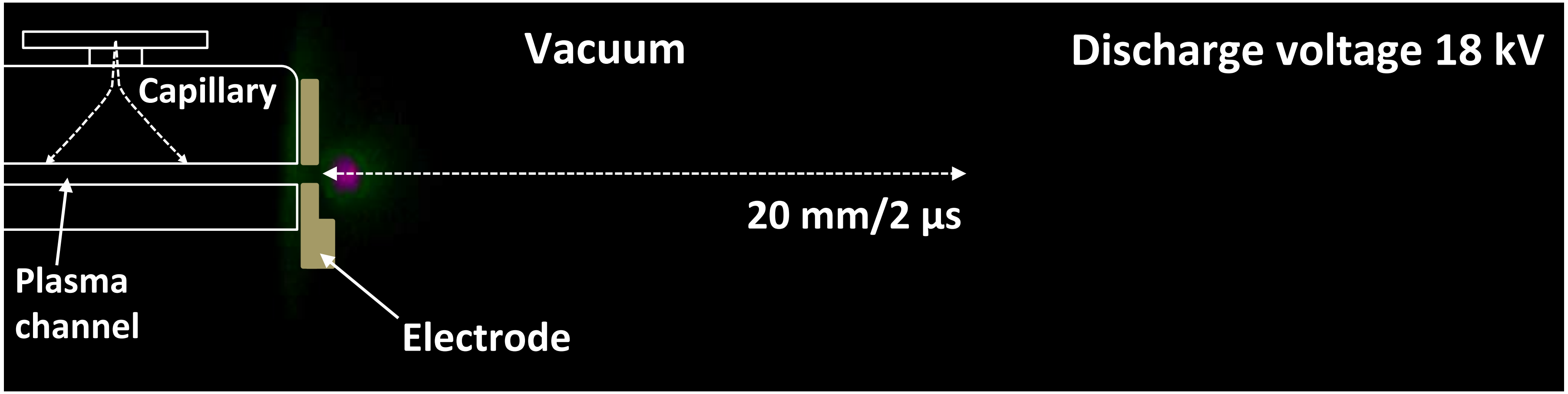


Capillary discharge at SPARC_LAB



Plasma plumes

- **20 images separated by 100 ns, so 2 µs of total observation time of the plasma plumes**
- **The ICCD camera area is 1024 x 256 pixel**

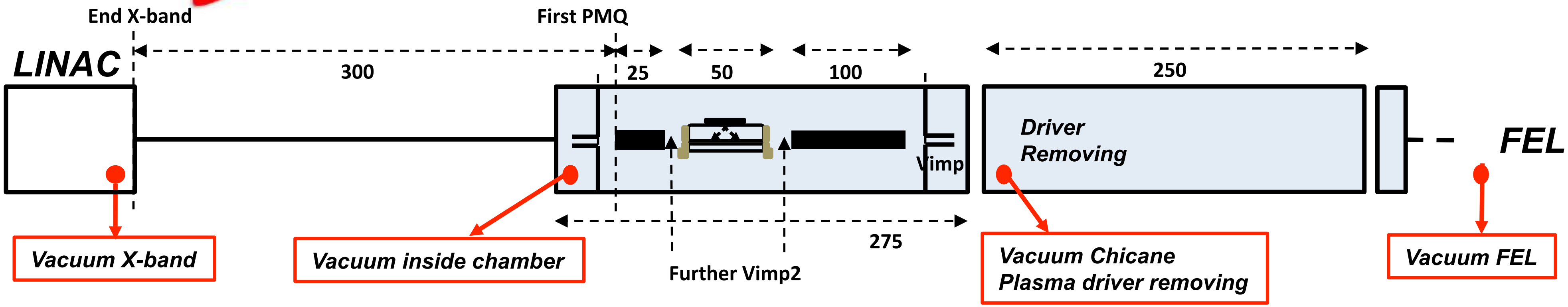


- Both plama plumes can reach a total expansion length around 40 mm (20 mm each one) that is comparable with the channel length of 30 mm, so they can strongly affect the beam properties that passes through the capillary

- Temperature, pressure and plasma density, inside and outside the gas-filled capillary plasma source, represent essential parameters that have to be investigated to understand the plasma evolution and how it can affect the electron beam.

Angelo.Biagioni@lnf.infn.it

Plasma module layout



1. *Chamber sizing depends on the vacuum constrains and capillary dimensions*
2. *Eupraxia chamber sizing starts from the current plasma chamber*
3. *Minimum length is 215 cm*
4. *Driver removing chamber properties depend on the technique used to remove the driver (Plasma or chicane)*
5. *Chamber/capillary factor is 5.5*
6. *New solutions will be studied to reduce the chamber/capillary factor by means of vacuum test and simulation*

3 cm-long capillary@ne = 10^{16} - 10^{17} cm^{-3}

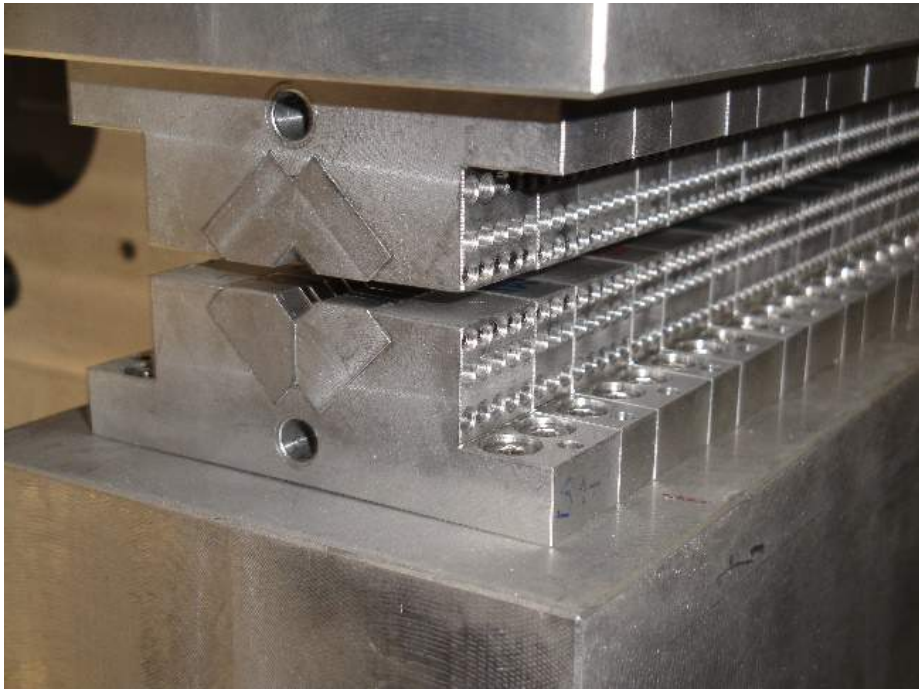
	Vgas (cm³)	*VimpEXT*	*VimpINT*	*Tpumps*	$V_{C\text{-}band}$	$V_{chamber}$	*Wtime*
1 Hz	0.0236	2 x 6mm/15cm	2 x 6mm/10cm	1780 l/s	10^{-7} mbar	10^{-8} mbar	No limits
10 Hz	0.236	2 x 6mm/15cm	2 x 6mm/10cm	1780 l/s	10^{-7} mbar	10^{-8} mbar	1 hour
100Hz	2.36						

50 cm-long capillary@ne = 10^{16} - 10^{17} cm^{-3}

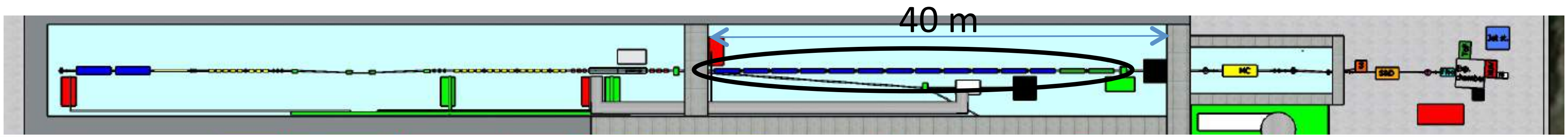
x15	*Vgas* (cm³)	*Vimp*	*Vimp2*	*Tpumps*	$V_{X\text{-}band}$	$V_{Chamber}$	*Wtime*
1 Hz	0.314	2 x 6mm/15cm	2 x 6mm/10cm	7000 l/s			
10 Hz	3.14	2 x 6mm/15cm	2 x 6mm/10cm	7000 l/s			
100Hz	31.4 *x100*						

Courtesy R. Pompili , A. Biagioni

Undulators



KYMA Δ udulator at SPARC_LAB: λ=1.4 cm, K1



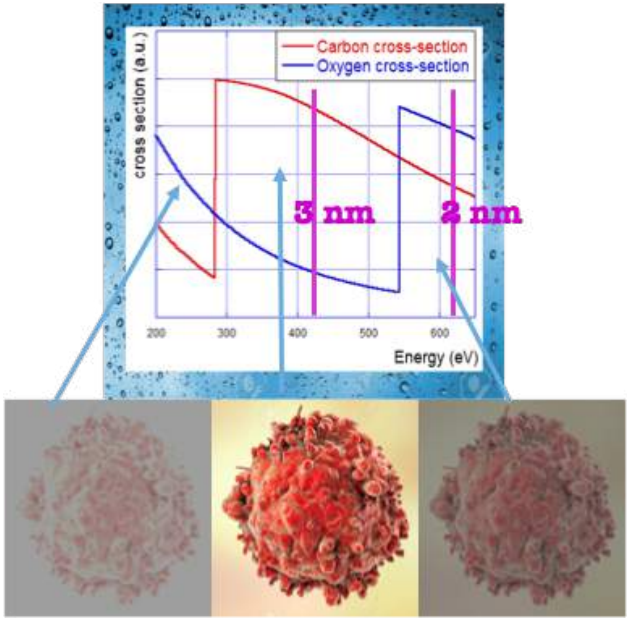
Undulators chain

Expected SASE FEL performances

	Units	Full RF case	Plasma case
Electron Energy	GeV	1	1
Bunch Charge	pC	200	30
Peak Current	kA	2	3
RMS Energy Spread	%	0.1	1
RMS Bunch Length	fs	40	4
RMS matched Bunch Spot	µm	34	34
RMS norm. Emittance	µm	1	1
Slice length	µm	0.5	0.45
Slice Energy Spread	%	0.01	0.1
Slice norm. Emittance	µm	0.5	0.5
Undulator Period	mm	15	15
Undulator Strength K		1.03	1.03
Undulator Length	m	12	14
Gain Length	m	0.46	0.5
Pierce Parameter ρ	x 10^{-3}	1.5	1.4
Radiation Wavelength	nm	3	3
Undulator matching β_u	m	4.5	4.5
Saturation Active Length	m	10	11
Saturation Power	GW	4	5.89
Energy per pulse	µJ	83.8	11.7
Photons per pulse	x 10^{11}	11	1.5

Table 2.1: Beam parameters for the EuPRAXIA@SPARC_LAB FEL driven by X-band linac or Plasma acceleration

Energy region between Oxygen and Carbon K-edge 2.34 nm – 4.4 nm (530 eV -280 eV)
Water is almost transparent to radiation in this range while nitrogen and carbon are absorbing (and scattering)

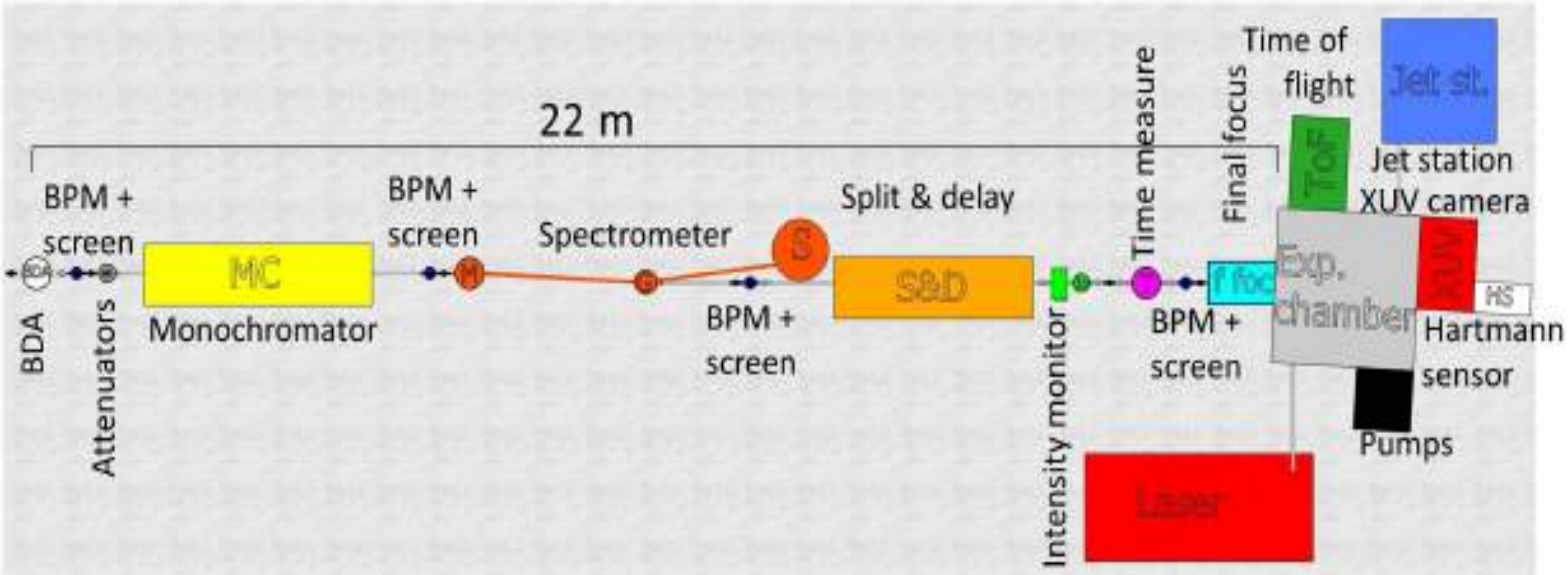


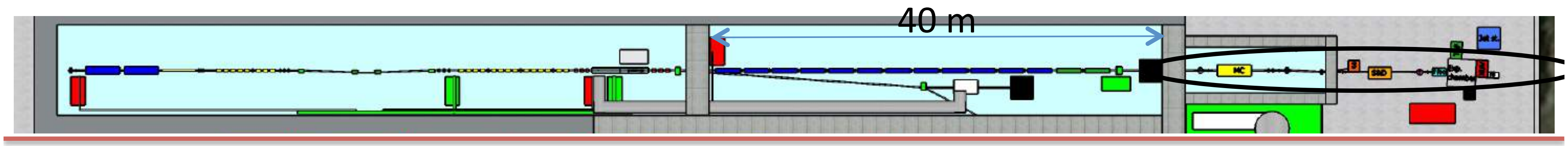
Coherent Imaging of biological samples
protein clusters, VIRUSES and cells
living in their native state
Possibility to study dynamics
~10^{11} photons/pulse needed

Courtesy F. Stellato, UniToV

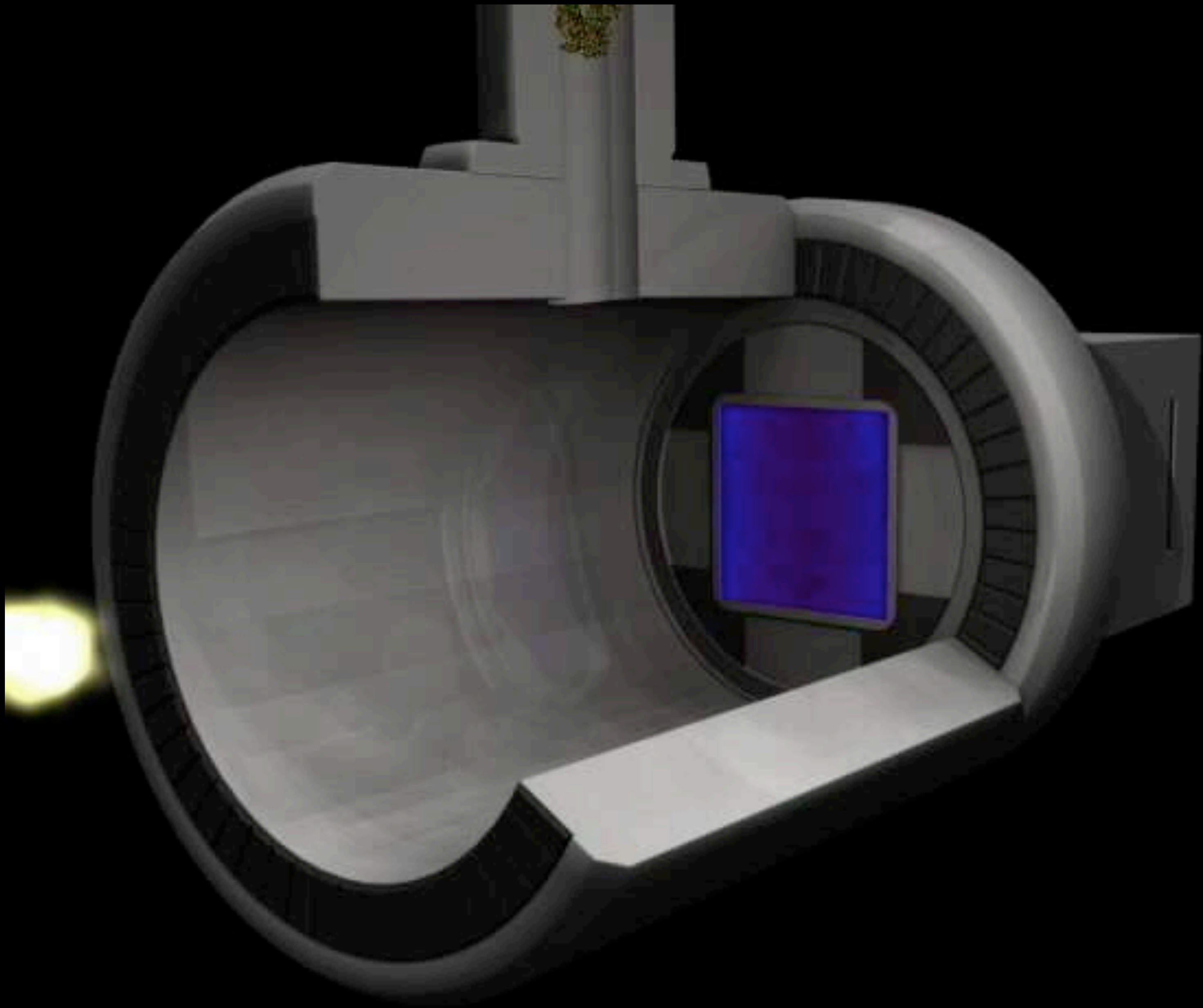
Beam separation

Photon beam line





Experimental hall (Single Protein Imaging)

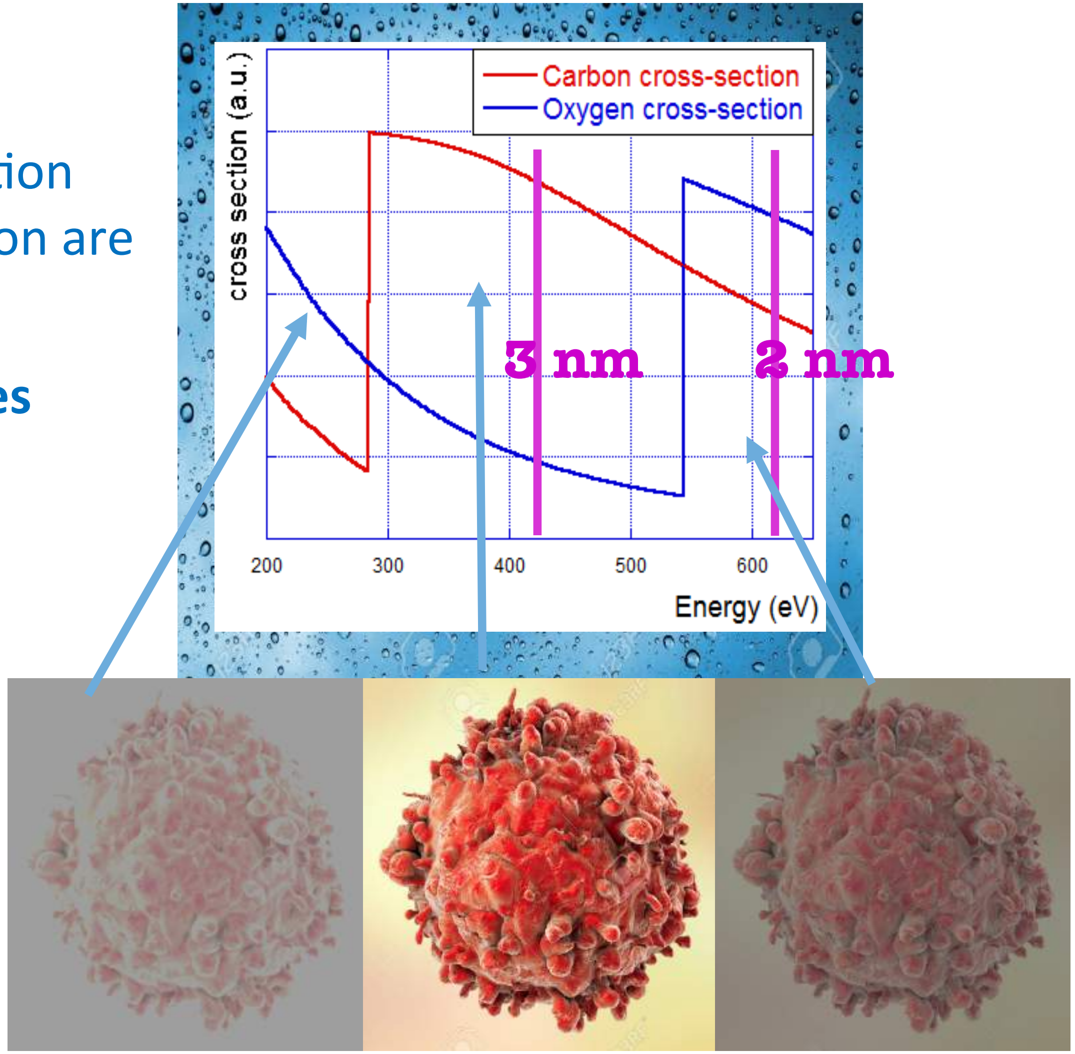


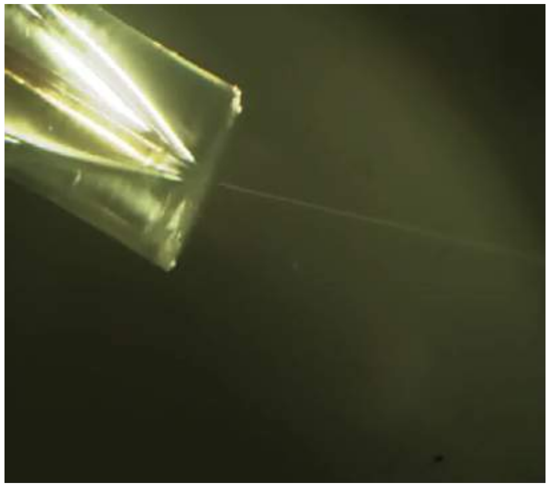
http://lcls.slac.stanford.edu/AnimationViewLCLS.aspx

Water Window Coherent Imaging

Energy region between Oxygen and
Carbon K-edge 2.34 nm – 4.4 nm
(530 eV -280 eV)
Water is almost transparent to radiation
in this range while nitrogen and carbon are
absorbing (and scattering)

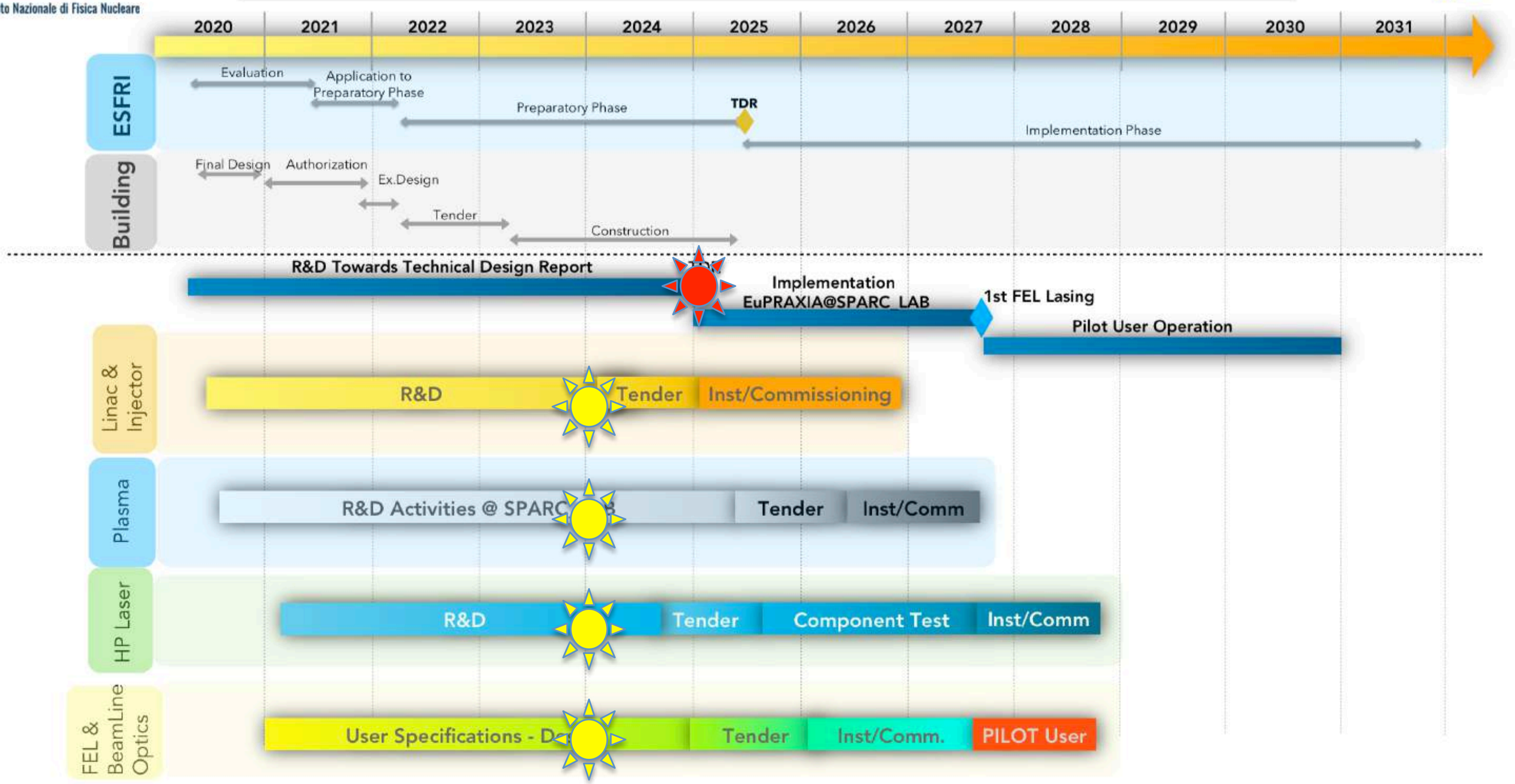
Coherent Imaging of biological samples
protein clusters, VIRUSES and cells
living in their native state
Possibility to study dynamics
~10 ^{11} photons/pulse needed





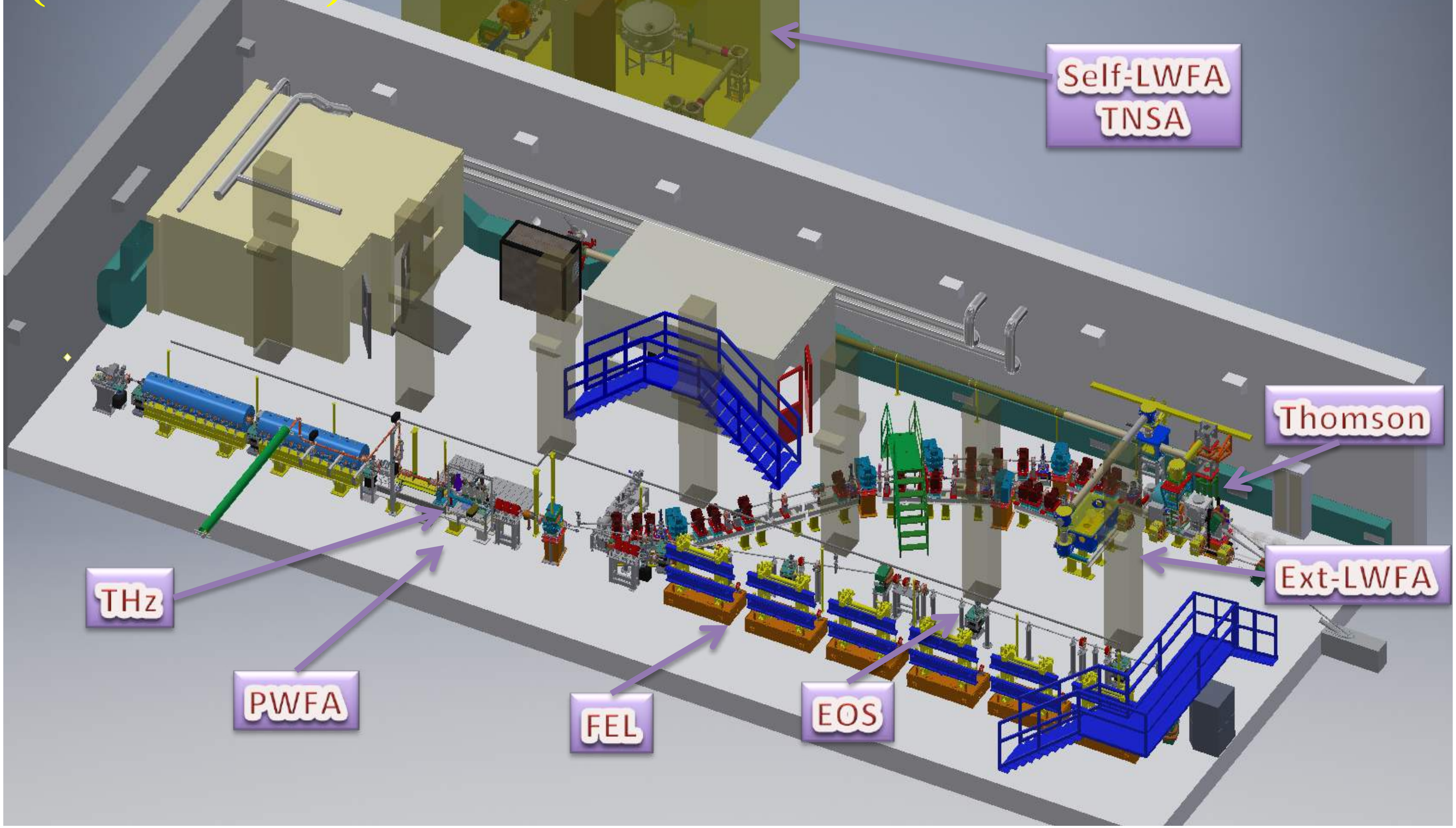
Courtesy F. Stellato, UniToV

EuPRAXIA @ SPARC_LAB Master Schedule

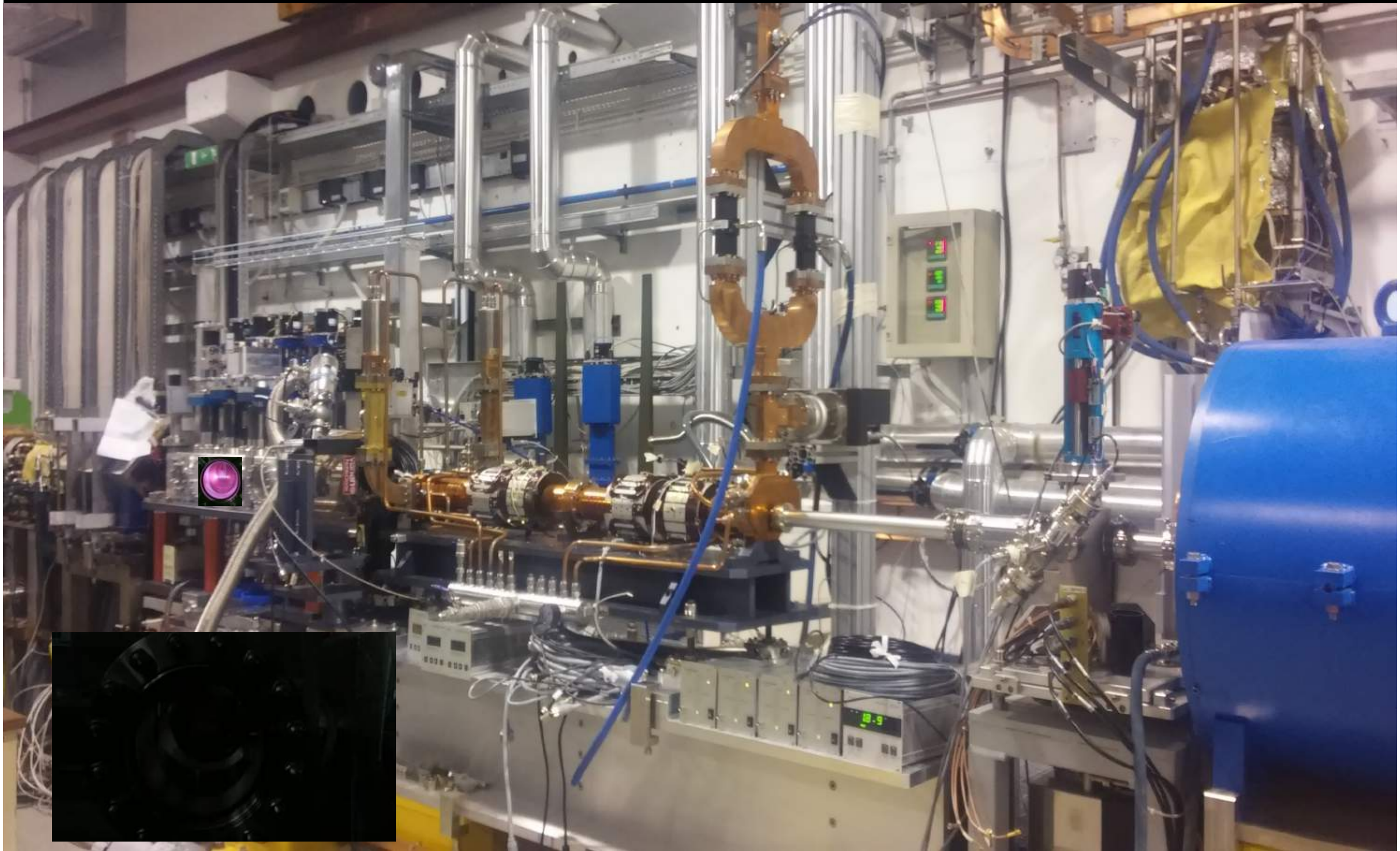


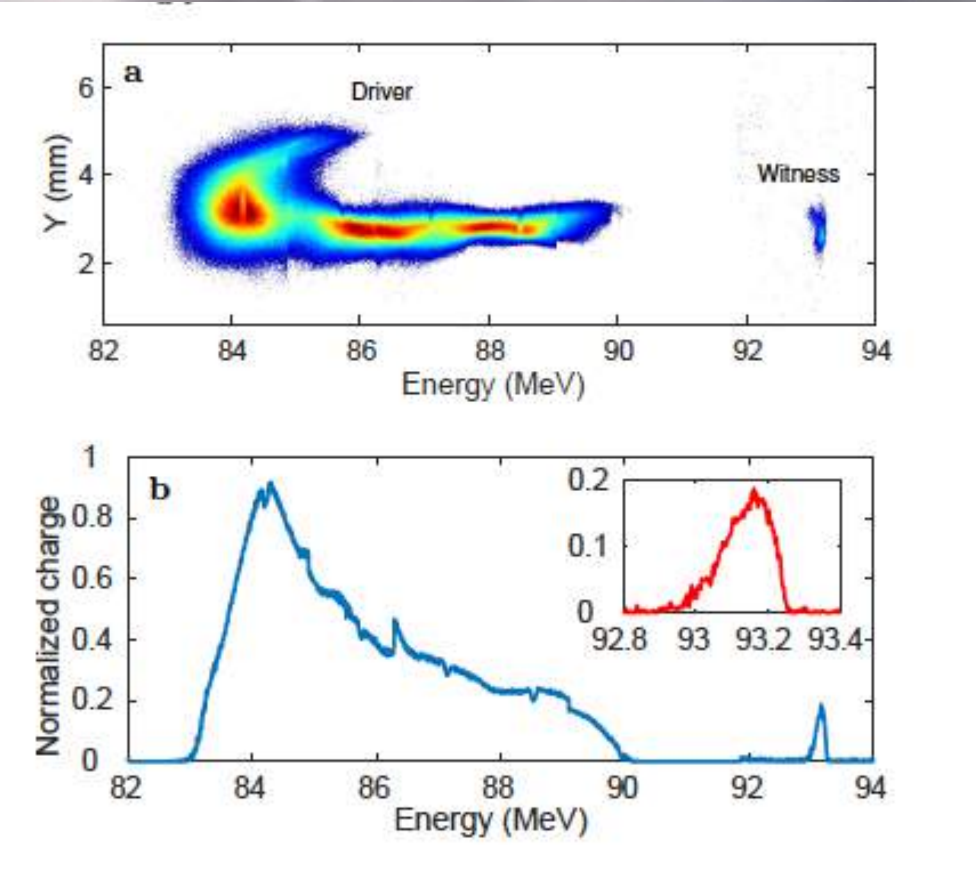
Courtesy A. Falone

SPARC_LAB is the test and training facility at LNF for Advanced Accelerator Developments (since 2005)



PWFA vacuum chamber at SPARC_LAB





Witness Energy Spread: 0.1 %

First results obtained with well-known WP 200+20 pC

Energy spread of witness (plasma OFF) is 0.2 MeV

The achieved acceleration is of ~4 MeV

- Corresponds to 130 MV/m

Energy jitter of the witness energy is 0.5 MeV

Energy spread after acceleration is 0.1 MeV, lower than the one with plasma off

http://w3.lnf.infn.it/primi-elettroni-accelerati-con-plasma-a-sparc_lab/

nature physics

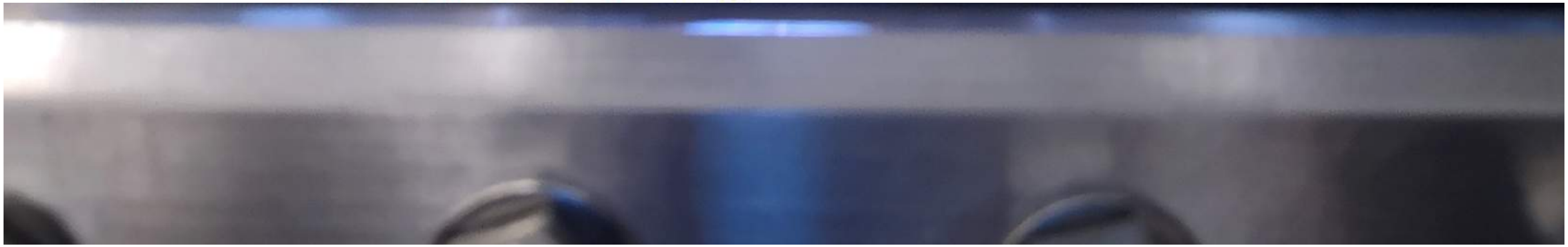
LETTERS

https://doi.org/10.1038/s41567-020-01116-9

Check for updates

Energy spread minimization in a beam-driven plasma wakefield accelerator

R. Pompili[1]✉, D. Alesini[1], M. P. Anania[1], M. Behtouei[1], M. Bellaveglia[1], A. Biagioni[1], F. G. Bisesto[1], M. Cesarini[1,2], E. Chiadroni[1], A. Cianchi[3], G. Costa[1], M. Croia[1], A. Del Dotto[1], D. Di Giovenale[1], M. Diomede[1], F. Dipace[1], M. Ferrario[1], A. Giribono[1], V. Lollo[1], L. Magnisi[1], M. Marongiu[1], A. Mostacci[2], L. Piersanti[1], G. Di Pirro[1], S. Romeo[1], A. R. Rossi[4], J. Scifo[1], V. Shpakov[1], C. Vaccarezza[1], F. Villa[1] and A. Zigler[1,5]



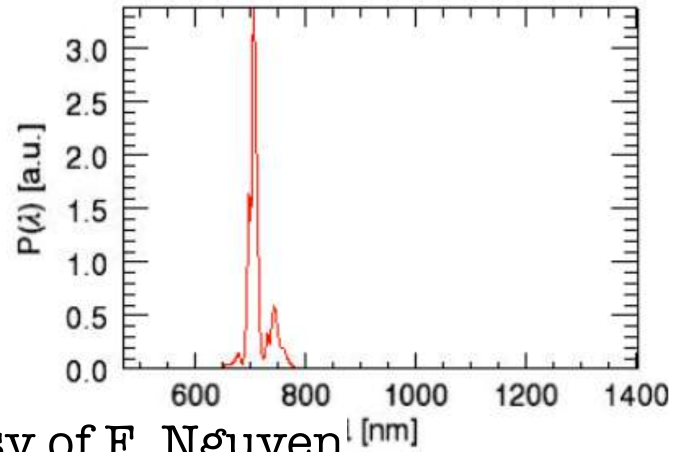
R&D Activities at SPARC_LAB
Expected FEL Results

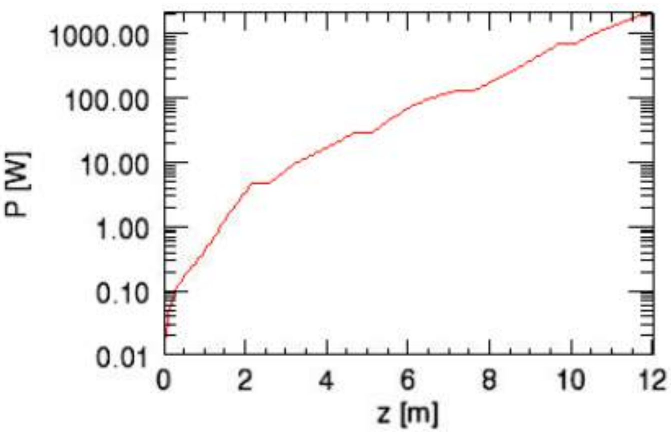
from measured accelerated beam parameters

The **experimental beam parameters**, as measured in the beam driven PWFA experiment, have been used as **input for a preliminary evaluation of FEL performances** by means of GENESIS 1.3 time-dependent simulations => **measurable growth of the FEL gain**

Witness beam parameters		Undulator parameters	
γ	174	λ_u (cm)	2.8
$\Delta E/E$ (%)	0.28*	K_{rms}	0.72
$\varepsilon_{nx,y}$(mm mrad)	3.5**	FODO β function (m)	1.6
Q (pC)	20	λ_r (nm)	700
I_{peak} (A)	214		

*It is the rms energy spread
**projected emittance





Courtesy of F. Nguyen

Energy Stability

$$\frac{\Delta\lambda}{\lambda} = \frac{1}{2}\frac{\Delta E}{E} \propto \rho \approx 10^{-3}$$

FEL requirement

$$\left.\frac{\Delta E}{E}\right|_{p} = \frac{\Delta n_p}{n_p}$$

Plasma density

$$\left.\frac{\Delta E}{E}\right|_{Q} = \frac{\Delta I_d}{2\left(I_d\right)} + \frac{\Delta I_w}{2\left(I_w\right)}$$

Bunch charge/length

$$\left.\frac{\Delta E}{E}\right|_{DW} = \frac{a\omega_p}{2\pi}\Delta t_{DW}$$

$$2 \le a \le 4$$

Driver/Witness separation

EuPRAXIA

Long-Term Scientific Program

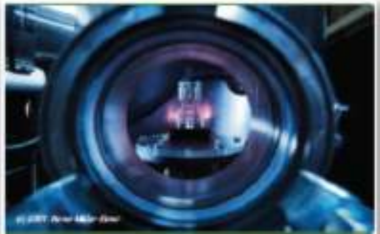
Horizon 2020

1. Reduced facility footprint

- *compact beamline components (undulators, magnets, etc.)*
- *compact diagnostics*
- *development of simplified, ultracompact prototype systems*

2. High power laser technology

- *high repetition rate*
- *high average power*
- *increased efficiency*
- *reduced footprint / cost*
- *robustness*



3. Accelerator technology

- *staging towards high energies*
- *advanced diagnostics*
- *hybrid plasma acceleration & other novel injection concepts*
- *beam control & quality*
- *ultrashort beams*

4. Plasma-based FEL

- *higher photon flux*
- *lower wavelength*
- *advanced undulator technologies*
- *ultrashort beams*
- *seeded FEL*

5. Method improvement for applications

- *medical imaging*
- *high-energy physics detectors*
- *material analysis (cargo scanning, structural analysis)*
- *positron generation and acceleration (plasma collider studies)*

Grazie per l'attenzione