AAC Sessions Summary for LCWS2024

Mark J. Hogan / Senior Staff Scientist / FACET and Test Facilities Division Director

July 11, 2024

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

U.S. DEPARTMENT OF ENERGY

A Fun and Interesting Week

Tue 09/07

09:00	**HALHF: Current Status, Optimisation, and Future Plans**	*Richard D'Arcy*	*1320 (CHANGED), Science building n.4*	09:00 - 09:20
	Physics Considerations for 10-30 TeV e^+e^-, $\gamma\gamma$, and $\mu^+\mu^-$ Colliders	*Michael Peskin*	*1320 (CHANGED), Science building n.4*	09:20 - 09:40
	Luminosity Spectra of Multi-TeV PWFA Gamma-Gamma Colliders	*Tim Barklow*	*1320 (CHANGED), Science building n.4*	09:40 - 10:00
10:00	**Preliminary Investigation of a Higgs Factory based on Proton-Driven Plasma Wakefield Acceleration**	*John Patrick Farmer*		
	Betatron radiation diagnostic systems for a plasma wakefield-based linear collider	*James Rosenzweig*	*1320 (CHANGED), Science building n.4*	10:20 - 10:40

Wed 10/07

14:00	**Application of laser-plasma accelerators to future linear colliders**	*Carl Schroeder*	*1320, Science building n.4 (CHANGED)*	14:00 - 14:15
	Simulation studies towards HEP applications of plasma accelerators	*Maxence Thévenet*	*1320, Science building n.4 (CHANGED)*	14:15 - 14:30
	Advanced structures R&D for structure wakefield acceleration at the Argonne Wakefield Accelerator	*Xueying Lu*	*1320, Science building n.4 (CHANGED)*	14:30 - 14:45
	Progress of research on corrugated wakefield structures in PAL working group.	*Hyung-sup Kong*	*1320, Science building n.4 (CHANGED)*	14:45 - 15:00
15:00	**Advancements in Beam Delivery Systems: CLIC Innovations and Plasma Collider Applications**	*Vera Cilento*	*1320, Science building n.4 (CHANGED)*	15:00 - 15:15
	High energy plasma injector for future electron-positron collider	*Shiyu Zhou*	*1320, Science building n.4 (CHANGED)*	15:15 - 15:30

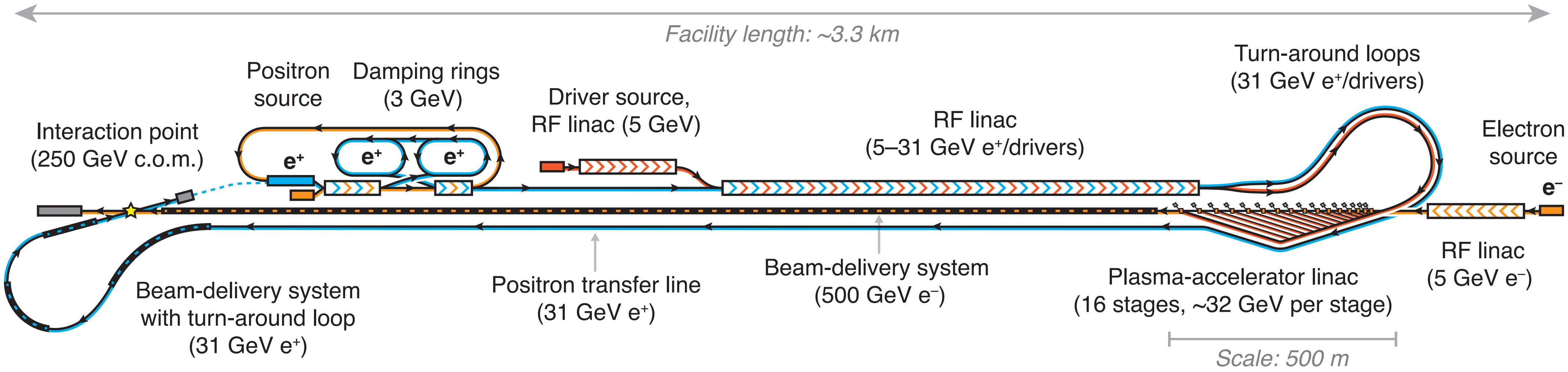
From email sent to session participants July 3rd:

> "As a final note, I have been asked to give a 10 minute summary of the working group on Thursday morning so please send me a single slide encapsulating the import message(s) from your talk so that I can piece together a summary."

The event rate recorded in my INBOX detector was quite low, so please forgive any omissions

John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD



HALHF: A Hybrid, Asymmetric, Linear Higgs Factory

Current Status, Optimisation, and Future Plans

Richard D’Arcy

University of Oxford

Brian Foster, Carl A. Lindstrøm

University of Oxford/DESY & University of Oslo

9th July 2024 | International Workshop on Future Linear Colliders (LCWS2024)

Summary

Making great strides toward a plasma-based collider design

> **The HALHF concept proposes a compact, cheaper, greener, possibly quicker Higgs factory**
>
> > HALHF benefits from maximal asymmetry: energy — charge — emittance

> **A collaboration of experts has been assembled to identify issues requiring more R&D** and help guide design decisions towards HALHF 2.0
>
> > **Many physics issues have been ironed out since 2023:** getting close to self-consistency
>
> > **A powerful optimization framework implemented:** currently improving cost model accuracy

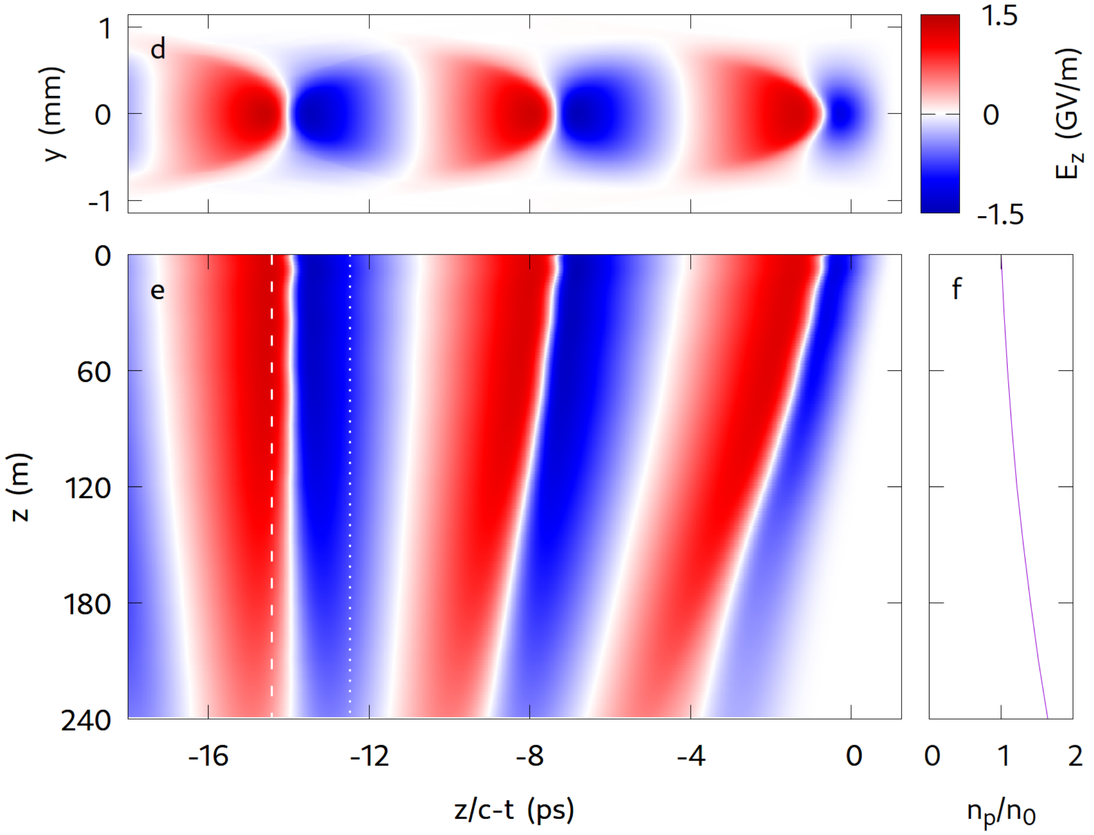
> **Upgrade path to higher energy, output, and integration:** not just a one-trick pony!

> **Continued community engagement required to conclude on the path forward towards a pre-CDR and input to ESPP update**

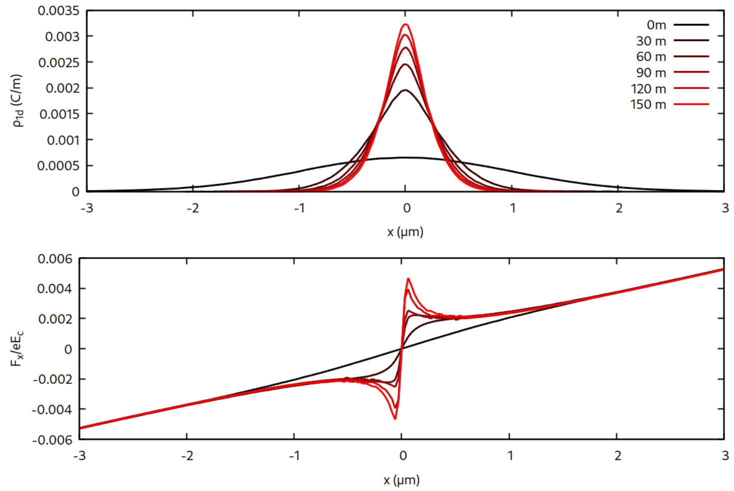
Preliminary Investigation of a Higgs Factory based on Proton-Driven Plasma Wakefield Acceleration

J. Farmer, A. Caldwell, and A. Pukhov

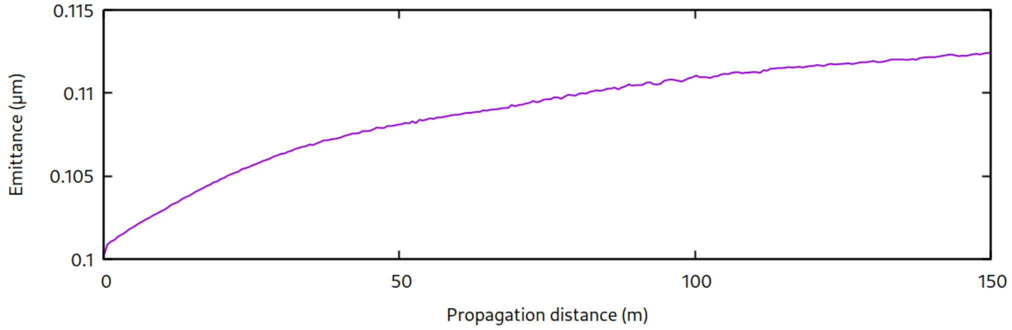
https://doi.org/10.48550/arXiv.2401.14765



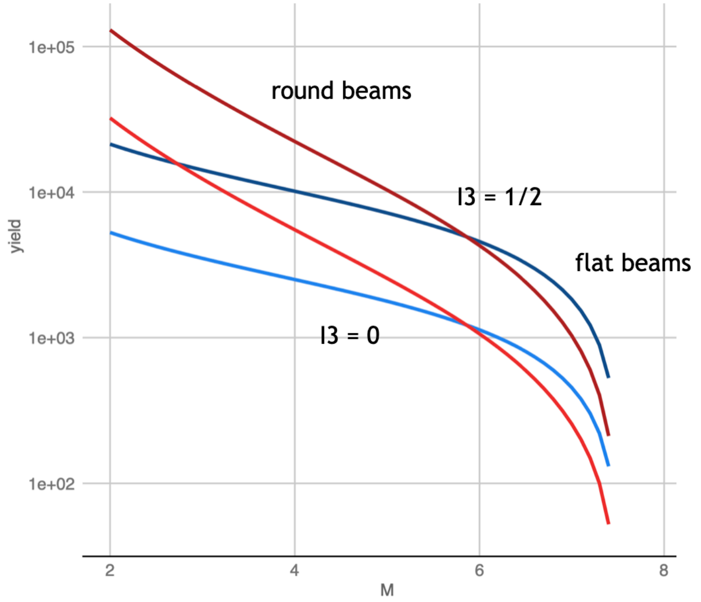
Short driver + plasma density gradient prevents dephasing, allows acceleration to Higgs-relevant energies <u>in a single plasma stage</u>.



Adiabatic focussing of electron witness during acceleration leads to ion motion (lithium). Slow evolution allows witness to self-match, <u>minimal emittance growth</u>.



Physics Considerations for 10-30 TeV e+e-, γγ, and μ+μ- Colliders



Michael Peskin
LCWS 2024
July 2024

thanks to Kalyan Narayanan and to the SLAC-LBNL working group on 10 TeV physics organized by Spencer Gessner.

For future colliders, the next major step in energy will be to the 10 TeV parton energy scale. This is the goal of FCC-hh, SPPS, muon colliders, plasma wakefield electron colliders.

Today, there are no reasonable solutions to reach this energy scale:

High-field dipoles for pp colliders have cost/m >> NbTi LHC magnets.

Muon cooling is unproven; phase space compression of 10^6 is needed.

Plasma wakefield accelerators are not yet at the stage of consistent, reproducible operation.

Major R&D programs are needed to have such colliders in operation, even 30 years from now.

Still, it is likely that lepton colliders will win out and will be "energy frontier" or "discovery" machines in the usual sense.

In the meantime, we ought to discuss the physics motivation for these machines. As high-energy physicists, we feel that "exploration" is sufficient reason. However, for a multi - $B collider, we should have a more definite target.

We have a need for new fundamental interactions, and new particles, to give a physical model of electroweak symmetry breaking.

Before the LHC, the most attractive models of EWSB involved new particles with few-hundred GeV masses. Integrating these out gave the Higgs potential, unstable at the origin. Such models seem to be excluded by LHC searches. Still, there is room for more complex models with multiple stages of symmetry breaking. Such models are more complex, but there are actual models in this class. The alternative are less well formed ideas — anthropic arguments, appeals to cosmology, or other accidents of nature.

Thus, it is important to continue the search for pair production of new particles, and the search for s-channel resonances, even to the 10 TeV range of masses.

One further note:

It is doubtful that the beam-beam physics in Guinea-Pig and CAIN is actually a precise prediction. The treatment of nonlinear QED processes and beamstrahlung is based on the assumption of a constant background field. This is strongly violated in cases with large disruption (ie. in all cases of 10 TeV colliders).

It is my belief (hope?) that a proper treatment of nonlinear QED will lead to smaller beamstrahlung effects and energy spread.

The laboratory for nonlinear QED available now is electron-laser scattering (SLAC-320 and LUXE at DESY). We need to follow this program very carefully.

Simulations Luminosity Spectra of Multi-TeV PWFA $\gamma\gamma$ Colliders

Advanced Accelerator Concepts LCWS2024

Tim Barklow

July 09, 2024

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

U.S. DEPARTMENT OF ENERGY

Summary

Working with a fixed, specific set of round electron beam parameters (varying only the beam energy as needed):

- Not surprisingly, it is not straightforward to extrapolate a Compton $\sqrt{s}=125$ GeV $\gamma\gamma$ collider to 10 or 15 TeV
- A value of $x=4.8$ requires e^-e^- E_{cm}=18.2 TeV for E_{cm}=15 TeV $\gamma\gamma$ and has very broad lumi spectrum
- A value $x=$ 40 requires e^-e^- E_{cm}=15.6 TeV for E_{cm}=15 TeV $\gamma\gamma$. But when coherent processes are considered, EM fields produced by the tightly focused e^- beams lead to significant coherent beamstrahlung and e^+e^- pair-production for moderate values of x This is excaberated by the produced e^+ which pinch the e^- beams leading to even higher EM fields. These effects serve to diminish the $\gamma\gamma$ luminosity in the top 20% of the $\sqrt{\hat{s}}$ distribution. The mean number of pileup events is 26.2 (defined to include all events down to $\pi\pi$ threshold of $\sqrt{\hat{s}}=0.3$ GeV).
- A multi-TeV $\gamma\gamma$ collider with extremely large values of $x\approx 10^5$, corresponding to soft x-ray Compton scattering, does not suffer as much from coherent processes. This is due to a larger number of trident processes $e^-\gamma \to e^-e^+e^-$ It also gives the largest top 20% luminosity among the configurations considered so far, and has an e^+e^-/XCC-like luminosity spectrum with a relatively narrow peak near the maximum center-of-mass energy. The mean number of pileup events is 22.5 (defined to include all events down to $\pi\pi$ threshold of $\sqrt{\hat{s}}=0.3$ GeV).

Application of laser-plasma accelerators to future linear colliders

Carl Schroeder, C. Benedetti, J. Osterhoff, K. Nakamura, E. Esarey
Lawrence Berkeley National Laboratory

LCWS2024 International Workshop on Future Linear Colliders

Wednesday July 10, 2024
University of Tokyo, Japan

Work supported by the U.S. DOE, Office of Science, Office of High Energy Physics, under Contract No. DE-AC02-05CH11231

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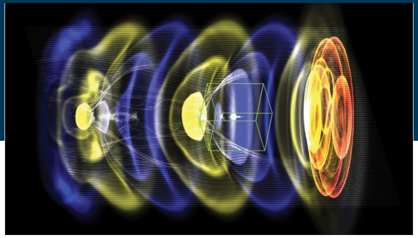
Berkeley UNIVERSITY OF CALIFORNIA

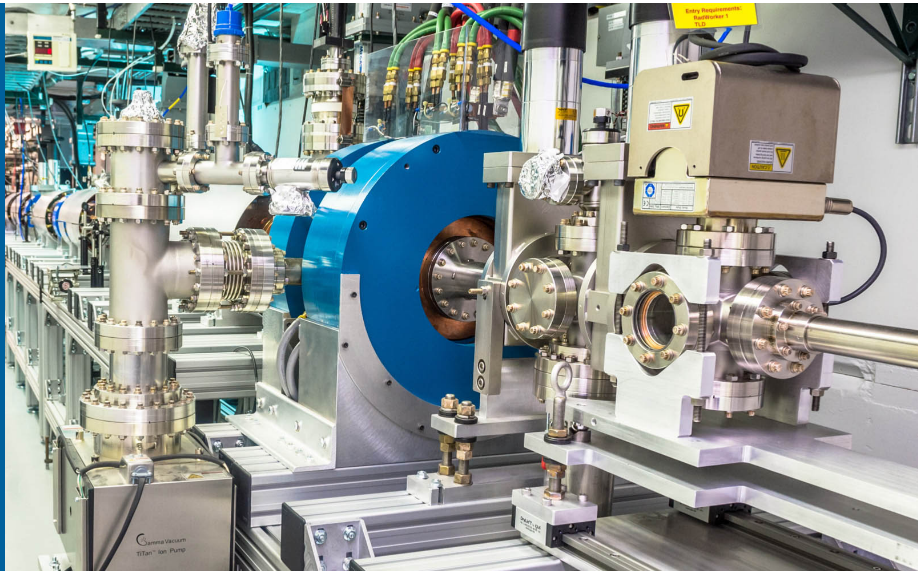
Conclusions



- Linacs based on staging plasma accelerators: ~1 TeV/km geo. gradient
  - Proper beamloading and tapering: low energy spread (0.1%), high efficiency (>40%), high gradient
  - Minimal emittance growth (<nm) owing to scattering in plasma (due to strong focusing)
  - Synchrotron emission low ($dE/E \sim 10^{-3}$) for collider-relevant emittances (<100nm)
  - Hosing suppressed via coherent ion motion
  - Ion motion results in horizontal-vertical coupling and round beams
- Laser-plasma-based collider:
  - Positron acceleration is a challenge, requires R&D and demonstrations of new concepts
  - Gamma-gamma (or e-e-) colliders are promising option with demonstrated wakefield technology
    - Scattering using 0.33um (~10J laser) with 5TeV beam, yields x~300>>4.82
  - Collider sub-systems (BDS, damping, injector, etc.) require development
- High average power laser system R&D required
  - coherent combination of fiber lasers promising path to high average, high peak power, and high efficiency short-pulse lasers

LCWS2024 International Workshop on Future Linear Colliders

Advanced Structures R&D For Structure Wakefield Acceleration at Argonne Wakefield Accelerator



Xueying Lu

Northern Illinois University (NIU)
& Argonne National Laboratory (ANL)

July 10, 2024
The University of Tokyo, Japan

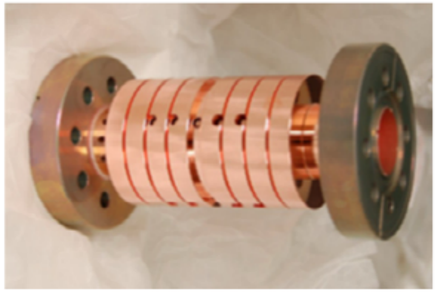
Argonne NATIONAL LABORATORY

NIU Northern Illinois University

Advanced structures R&D is at the core of SWFA research

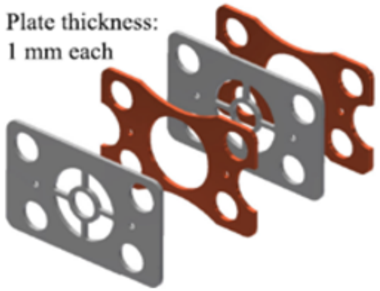
Advanced wakefield structures

Metallic

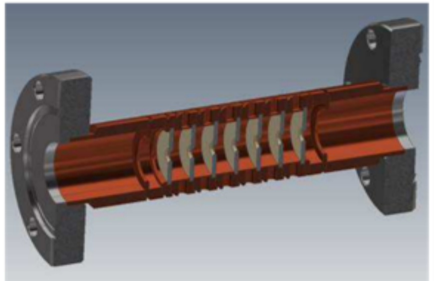


Dielectric

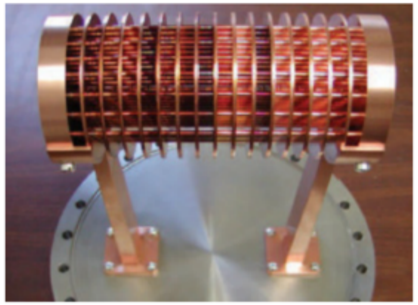
Metamaterial



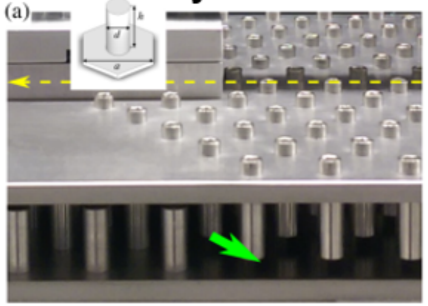
Dielectric disk structure



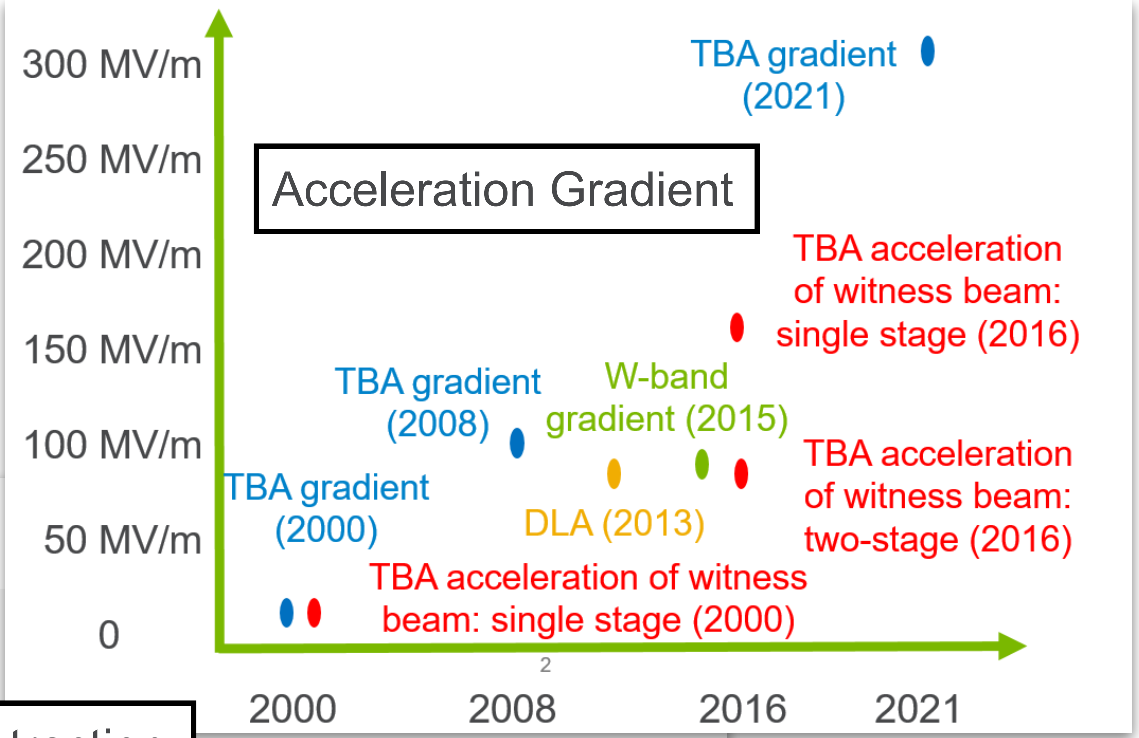
Photonic band-gap

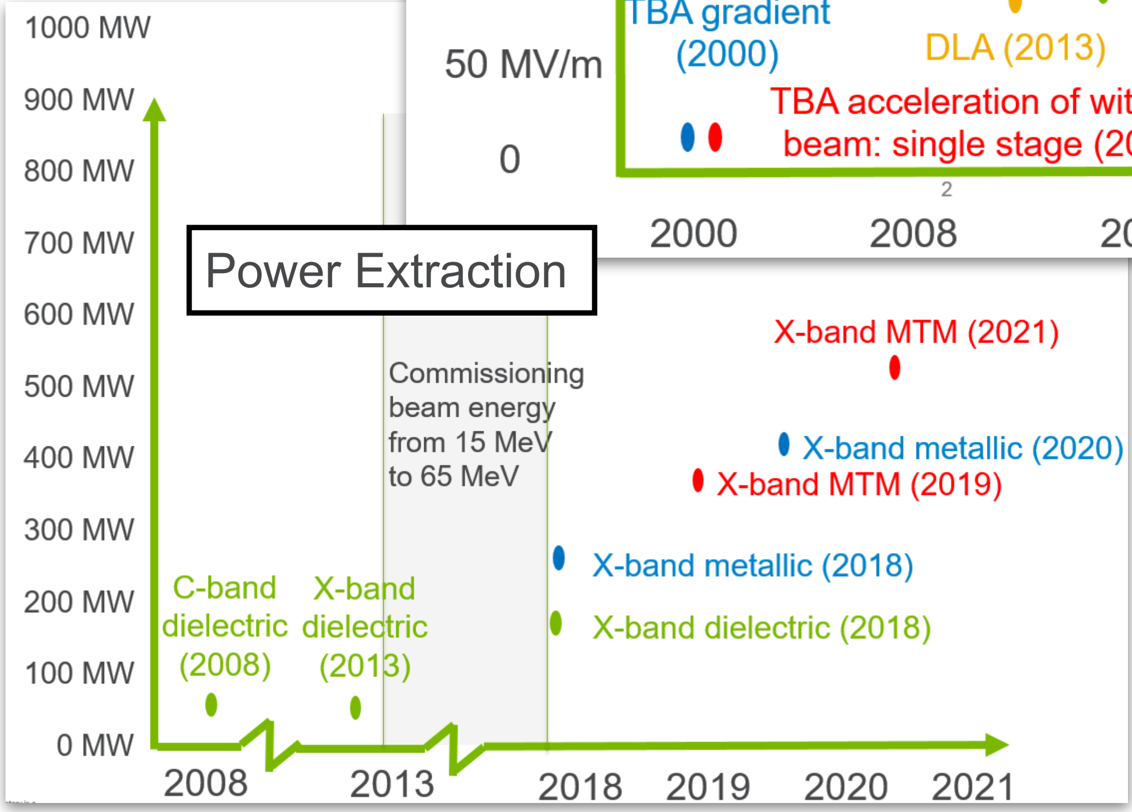


Photonic topological crystals

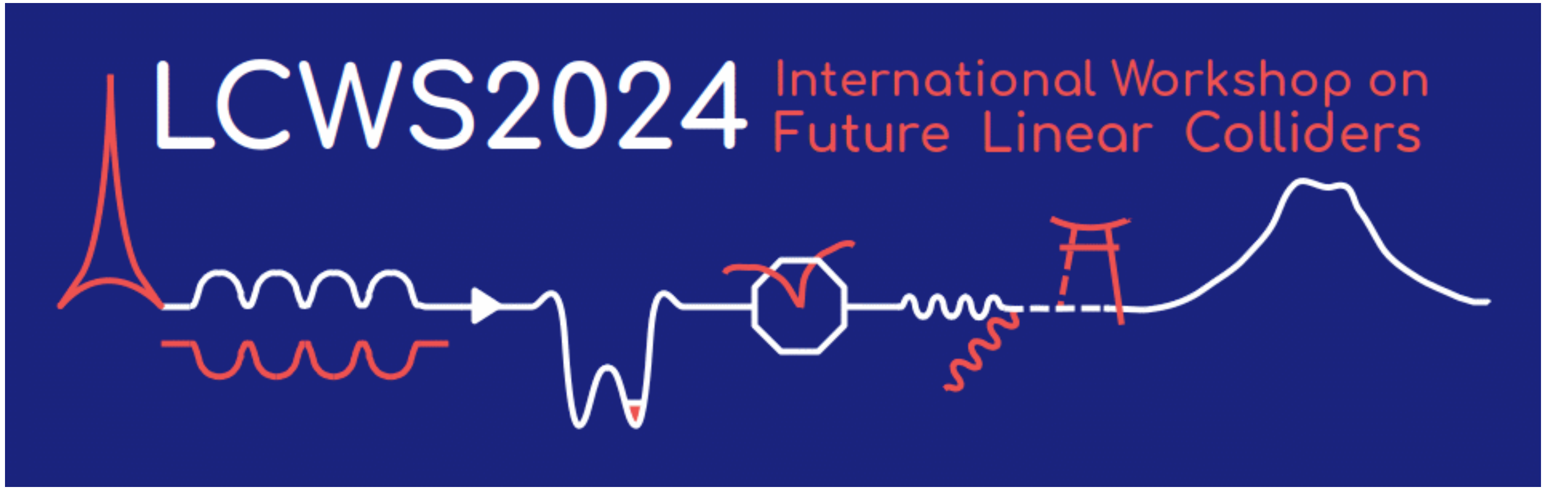


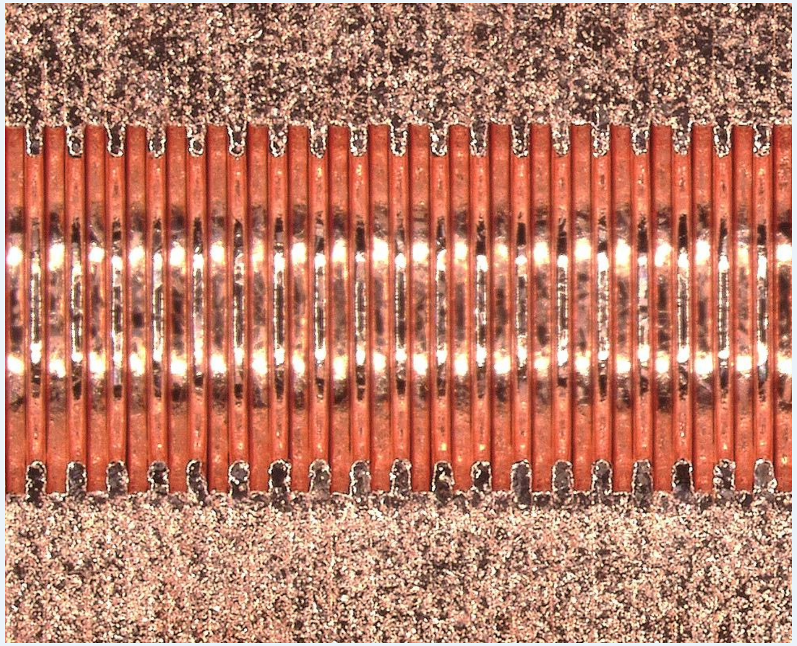
Recent Progress in X-band structures for TBA





Progress of research on corrugated wakefield structures in PAL working group





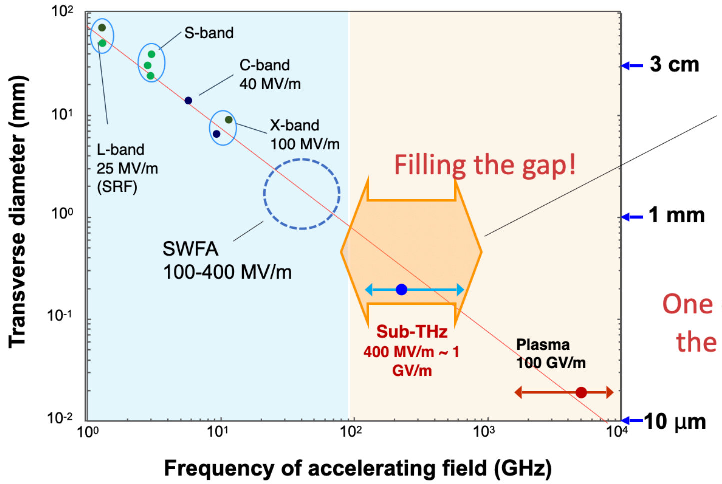
2024. 07. 10

POHANG ACCELERATOR LABORATORY

Summary

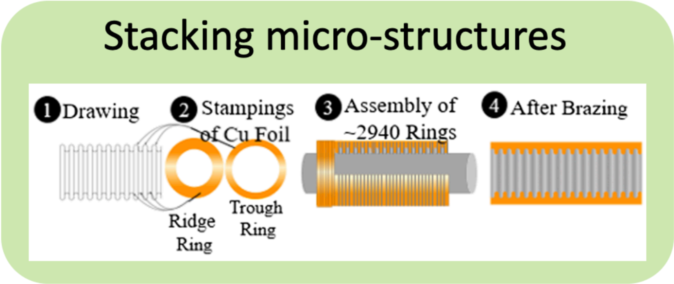
- Pohang Accelerator Laboratory developed a method to fabricate sub-THz structure.

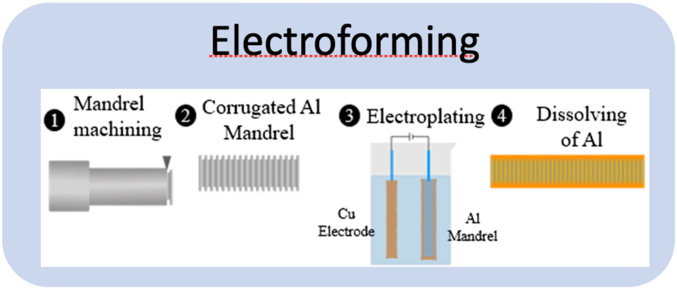
Accelerator Size ⌚ Accelerating Gradient ⌚ RF Frequency



Could be…
- Higher gradient than GHz-SWFA
- Higher stability than plasma
- Compatible with nC charges

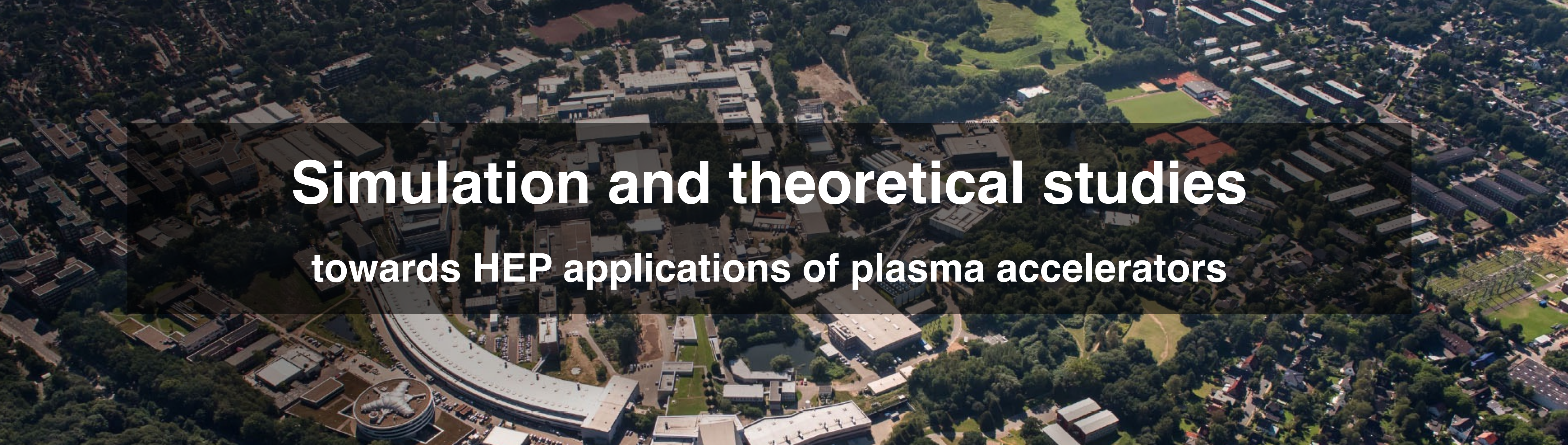
One of major challenges is the fabrication of micro-structures





Siy, A., et al. "Fabrication and testing of corrugated waveguides for a collinear wakefield accelerator." *Physical Review Accelerators and Beams* 25.2 (2022): 021302.

- The fabricated structure was characterized by electron beam-based measurement and showed good agreement with simulations.
- Collaboration (PAL, Korea University, NIU, Argonne) developing THz-TBA technology
- Demonstration for high-power generation is underway.
- Structure is being fabricated, and the beam-based test is planned in early September.



Simulation and theoretical studies

towards HEP applications of plasma accelerators

Maxence Thévenet – DESY

10.07.2024, LCWS24

The University of Tokyo, Japan

- A plasma injector for Petra IV
- Flat beams in plasma accelerators

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Conclusion

- **We propose a plasma injector for Petra IV.**

  6 GeV, < 0.3% energy deviation, 2.6 nC/s

  Reliable 6 GeV LPA + energy compression beamline for energy spread & jitter reduction

  CDR to be published soon

- **Accelerating a flat beam in a plasma accelerator poses significant challenges.**

  Emittance is transferred from the large to the small direction, degrading quality

  This is caused by particles falling in a resonance

  Avoiding the resonance might mitigate this effect

Resonant emittance mixing of flat beams in plasma accelerators

S. Diederichs,[1,2] C. Benedetti,[3] A. Ferran Pousa,[1] A. Sinn,[1] J. Osterhoff,[1,3] C. B. Schroeder,[3,4] and M. Thévenet[1,*]

[1]*Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany*
[2]*CERN, Espl. des Particules 1, 1211 Geneva, Switzerland*
[3]*Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley, California 94720, USA*
[4]*Department of Nuclear Engineering, University of California, Berkeley, California 94720, USA*

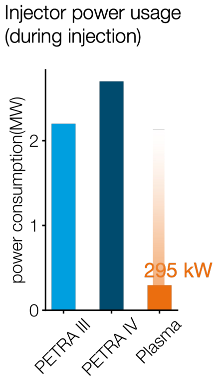
(Dated: March 12, 2024)

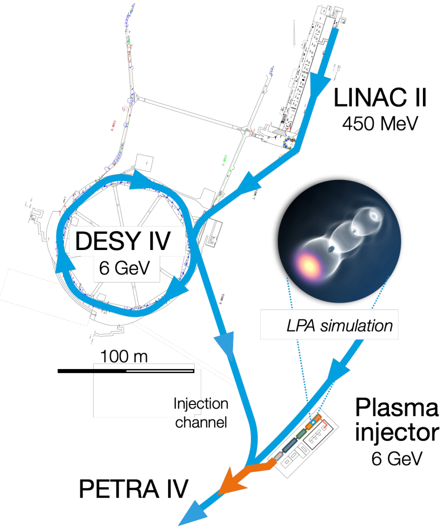
arXiv

- **Full-physics realistic simulations are *very* affordable.**

- **Compact –** Laser-plasma acc. + beamline: < 50 m
- **Cost-effective –** Power consumption: < 500 kW
- **Competitive –** Full PETRA IV operation (fill + top-up)

Key challenges
- Energy gain **6 GeV**
- Energy spread and jitter: **< 0.3 %**
  to maximize charge throughput and stability
- Charge injection rate: **> 2.6 nC/s**
  to fill the ring in < 10 minutes
- Availability: **> 98%**
  for users' satisfaction





Thank you for your attention

High energy plasma injector for future electron-positron collider

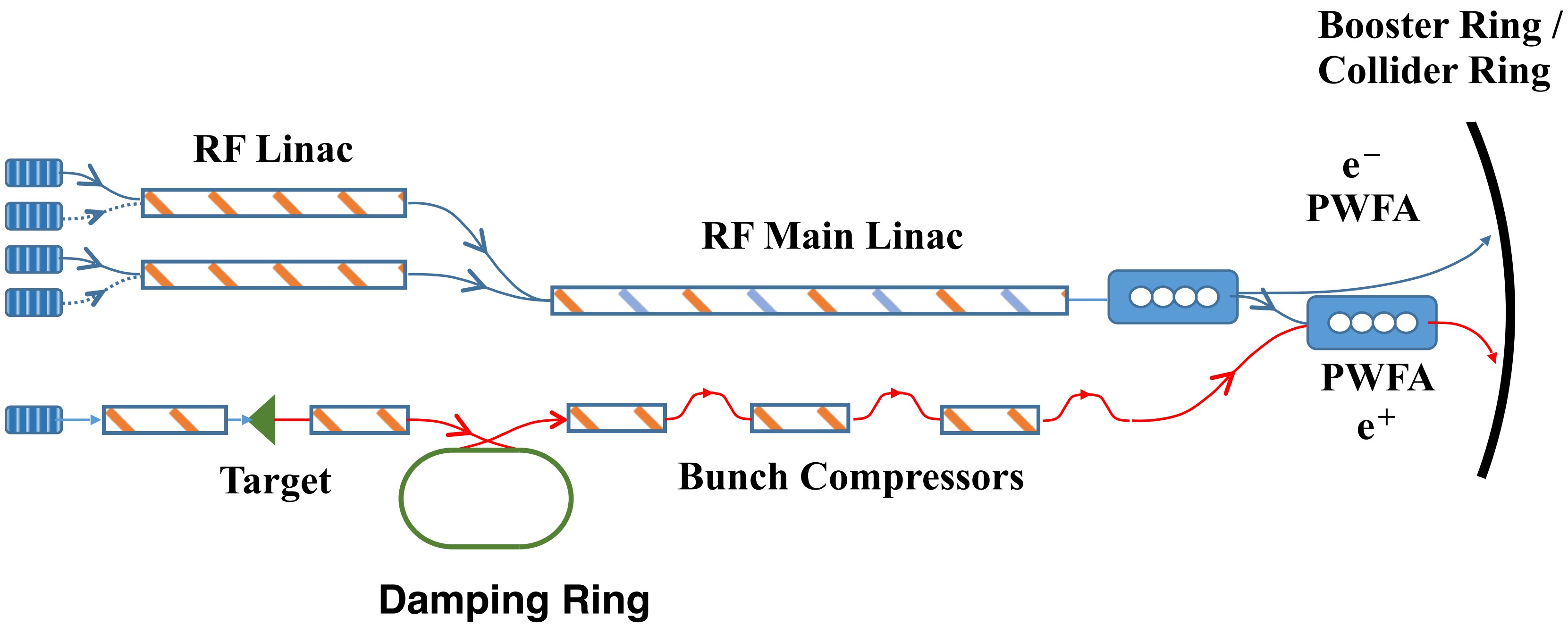
CEPC Plasma Injector Study Group

Shiyu Zhou
Department of Engineering Physics, Tsinghua University

International Workshop on Future Linear Colliders, 2024

清華大學 Tsinghua University
北京師範大學 BEIJING NORMAL UNIVERSITY
中國科學院高能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences
UCLA

Summary of CEPC plasma injector



Parameter	Unit	
e^-/e^+ beam energy	GeV	30
e^-/e^+ bunch charge	nC	> 1.0
Energy spread (e^-/e^+)	%	0.2
Emittance (e^-/e^+)	mm·mrad	< 200

- Parameter design and tolerance analysis for electron acceleration show high feasibility.
- Baseline design for positron acceleration arm is done.
- Results from PIC simulations fulfill the requirements of booster.
- Overall design has already been published as the appendix of CEPC TDR.
- The concept of plasma injector can be applied to other circular collider and demonstrate the key issues for the future plasma based linear collider.

CEPC, CDR (2018)
CEPC, TDR (2023)

Concluding Thoughts

- I came to SLAC in 1998 as the SLC was winding down
- The SLC produced an amazing legacy – in hardware, beam dynamics, techniques for making multi-km linacs perform, and most importantly in people!
- The next HEP machine (Higgs factory) after HL-LHC is not certain
- The best option for 10TeV is even less certain
- This creates an opportunity for Advanced Accelerator Concepts to mature our technologies and refine our concepts (next slide)
- On the way there are many opportunities for AAC to be impactful with compact XFELs, possible injectors to storage rings…
- We have enjoyed engaging with the broader LC community at LCWS and looking forward to the years ahead

Thank you!

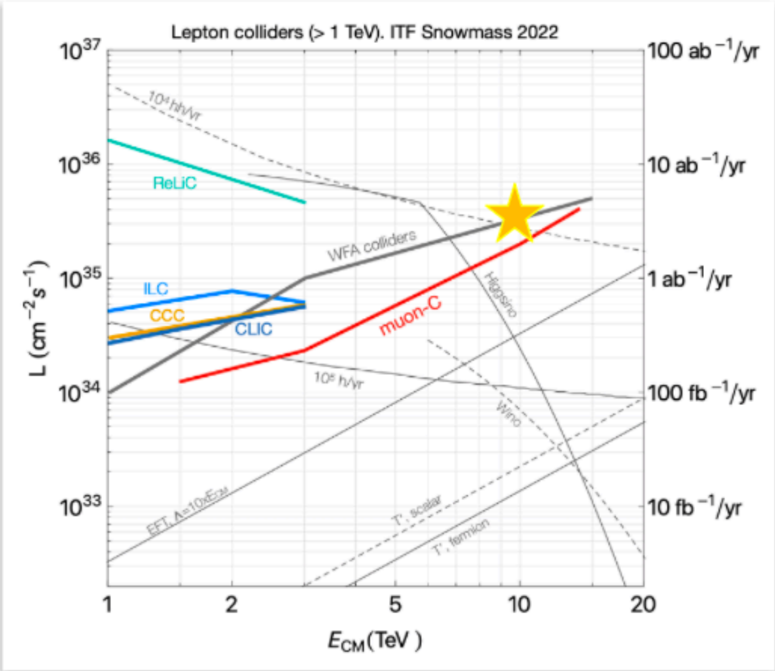
Design Study for a 10 TeV Wakefield Accelerator Collider

The P5 Report recommends:

Vigorous R&D toward a cost-effective 10 TeV pCM collider based on proton, muon, or possible wakefield technologies. . .

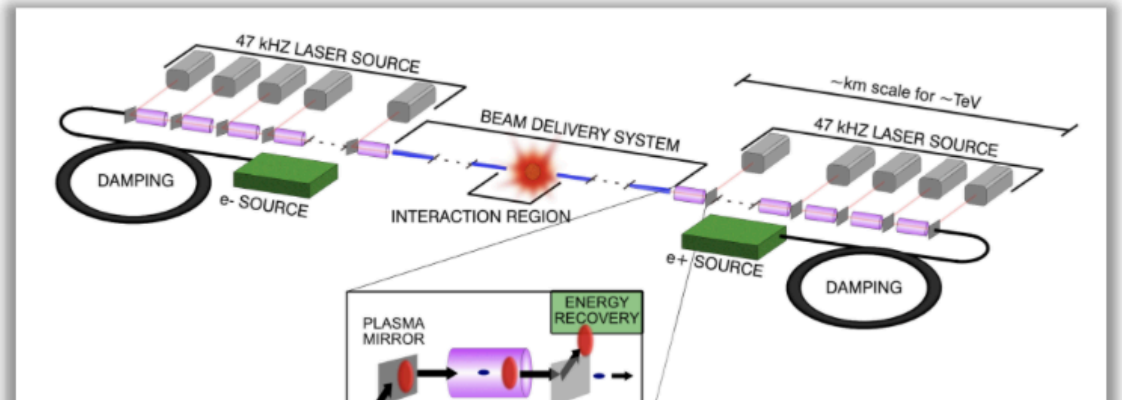
And requests a design study on wakefield colliders:

A critical next step is the delivery of an end-to-end design concept, including cost scales, with self-consistent parameters throughout.



The US Advanced Accelerator Community will pursue an end-to-end design of a 10 TeV Wakefield Collider. We aim to engage with our colleagues worldwide in this process.

Working groups, timelines, and deliverables will be announced at the AAC24 Workshop in July.



Laser-Plasma Linear Collider
C.B. Schroeder et al JINST 2023