John Adams Institute for Accelerator Science
Imperial College London
Royal Holloway University of London
UNIVERSITY OF OXFORD

Conventional and Advanced Concepts in the Designs of Plasma-based Colliders
(con preludio e coda)

Andrei Seryi

EAAC workshop

26 Sep 2017

Abstract

- **In this talk we will discuss the present concepts of plasma-based colliders, and in particular will discuss the sub-systems of the design, reviewing the assumptions and exploring if conventional sub-systems can be replaced, in some cases, by advanced designs**

- **Before discussing this may topic I would like to briefly describe experience on development of conventional LC concepts and designs**
  - **This experience may be useful for development of plasma-based LC concepts and design**

Road to the next collider

We of course do not know what is between our present location and the desired goal, what else we will find on the way and where exactly we will end up…

SSC => …

LEP => Z, W   LHC => H

TESLA => XFEL

CLIC, ILC => ?   FCC => ?   AWAKE => ?   LPWA =>?

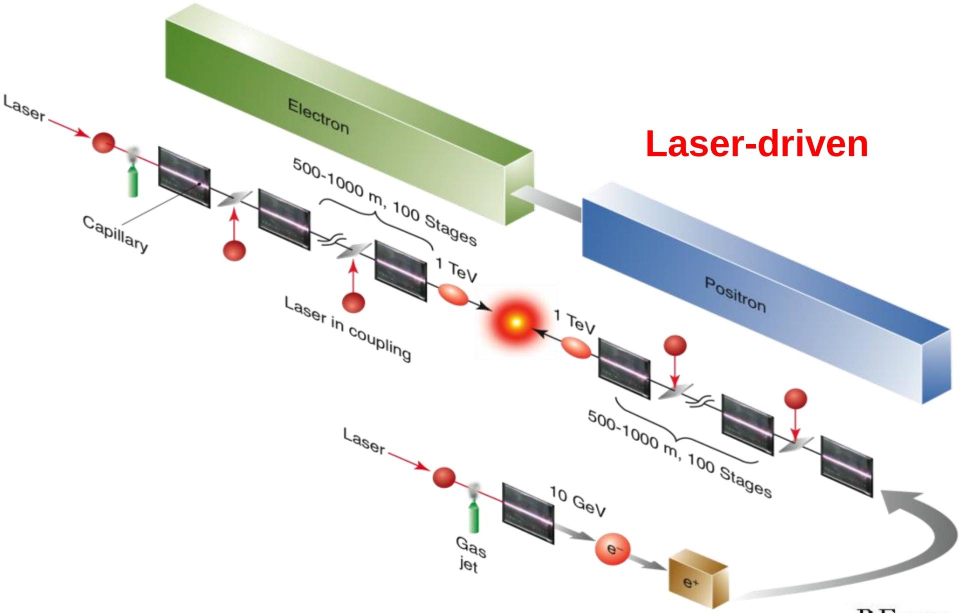
The path to collider

- There are concepts of plasma-based colliders
- Key R&D is ongoing
- Community is building roadmaps
- Advanced and Novel Accelerators for High Energy Physics Roadmap (ANAR) workshops starting to help in world-wide coordination

- Is this sufficient?
- How one can streamline the path?

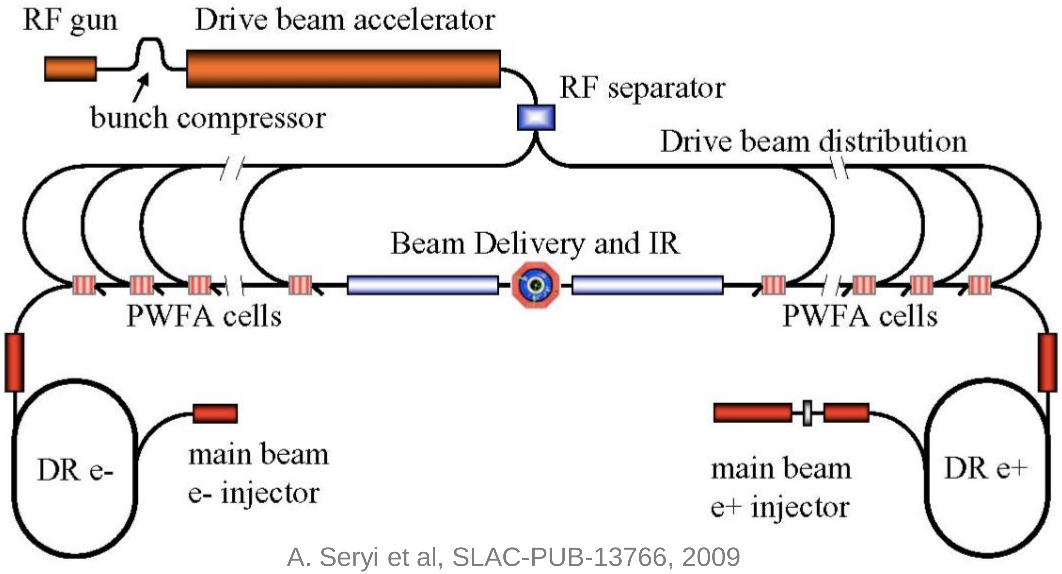
Concepts of plasma acceleration based colliders

Laser-driven



Esarey et al, Rev. Mod. Phys. (2009)

Beam-driven

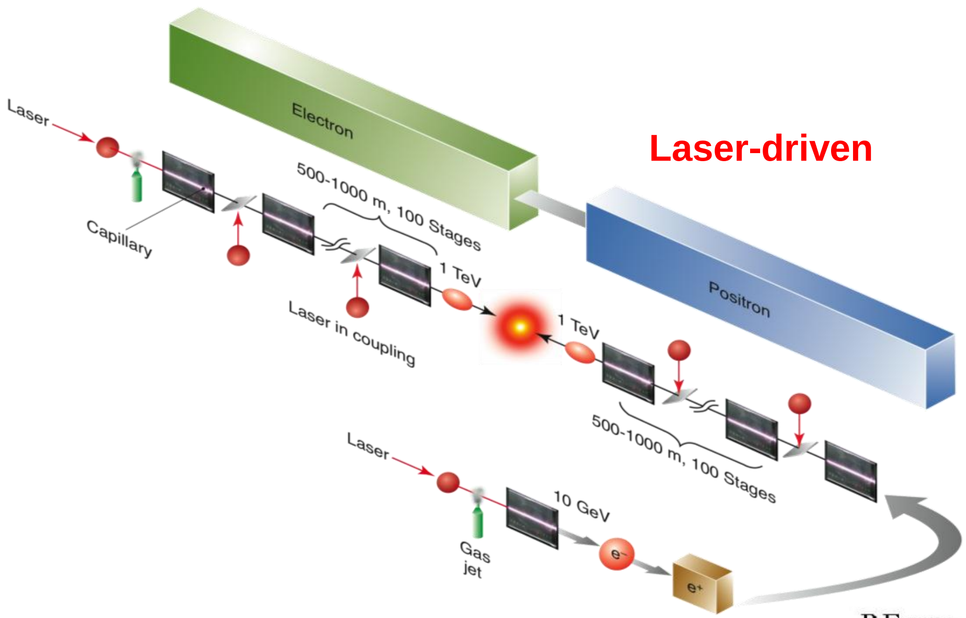


A. Seryi et al, SLAC-PUB-13766, 2009

Advanced accelerator community developing roadmaps toward plasma-based collider in 2040

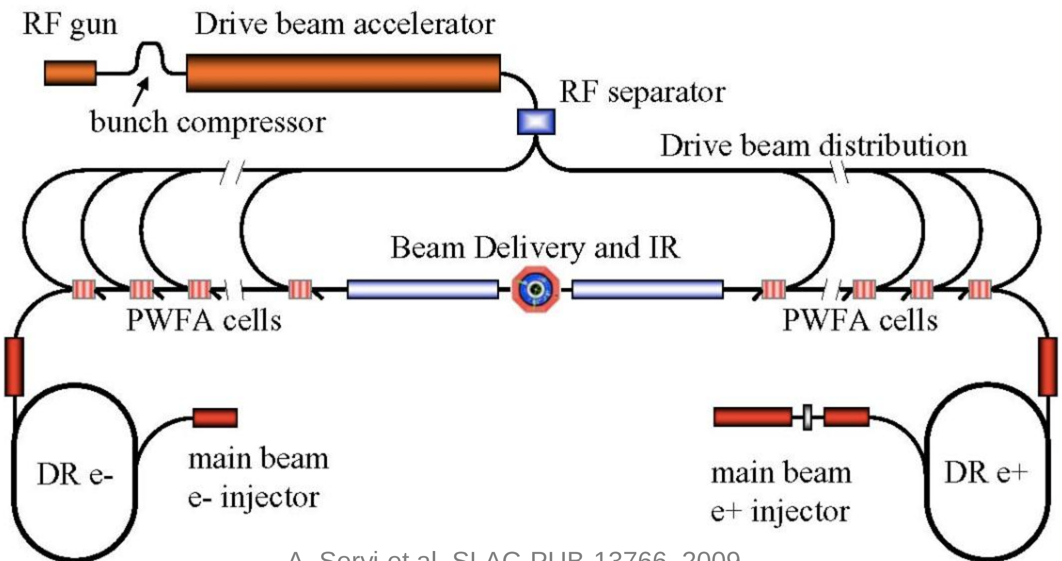
Concepts of plasma-based colliders

Laser-driven



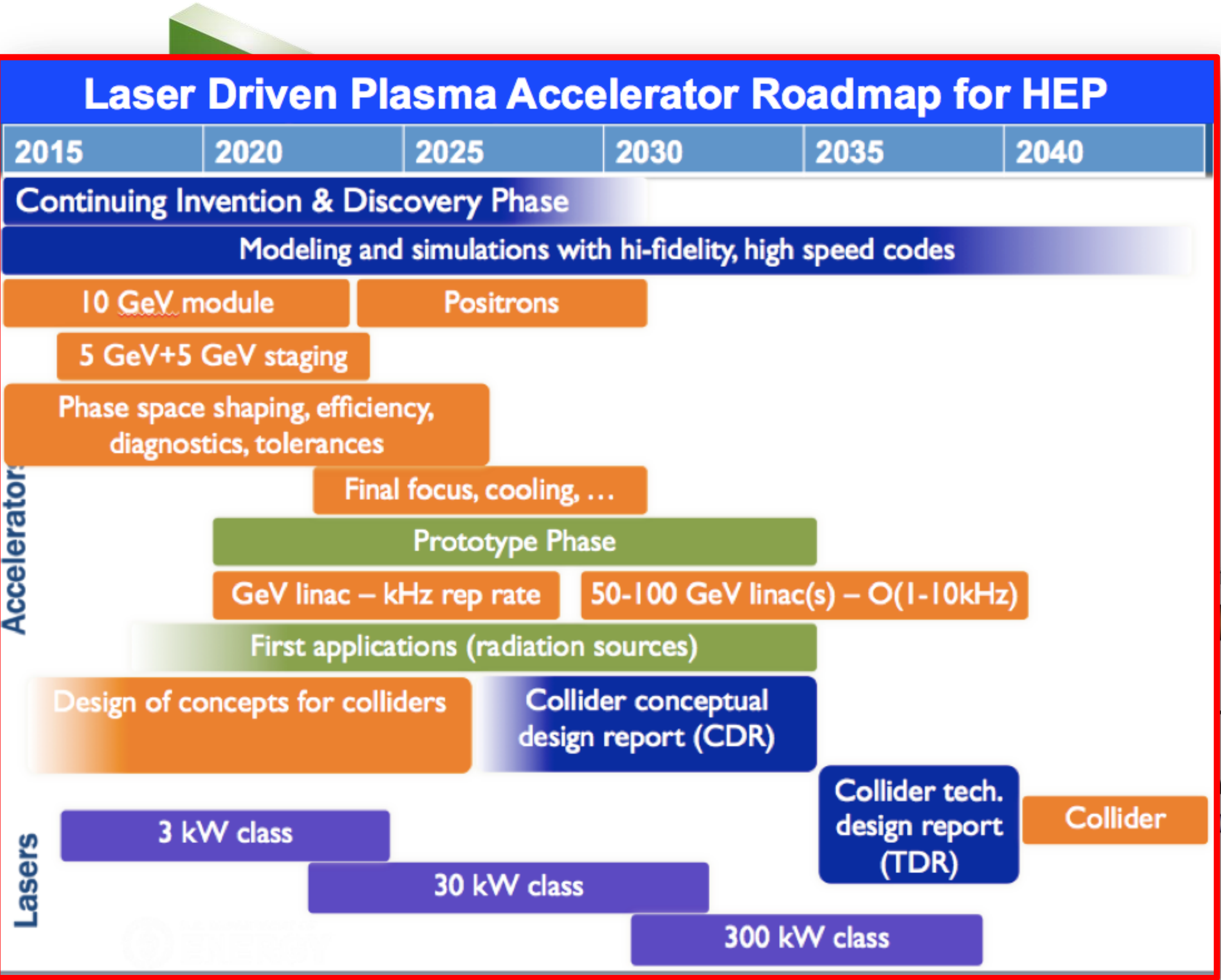
Esarey et al, Rev. Mod. Phys. (2009)

Beam-driven



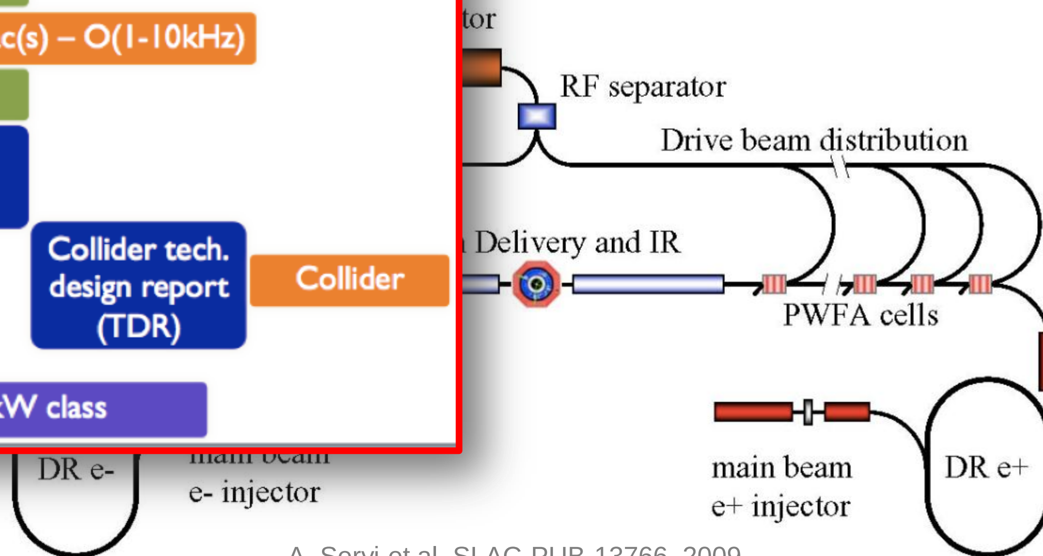
A. Seryi et al, SLAC-PUB-13766, 2009

Advanced accelerator community developing roadmaps toward plasma-based collider in 2040



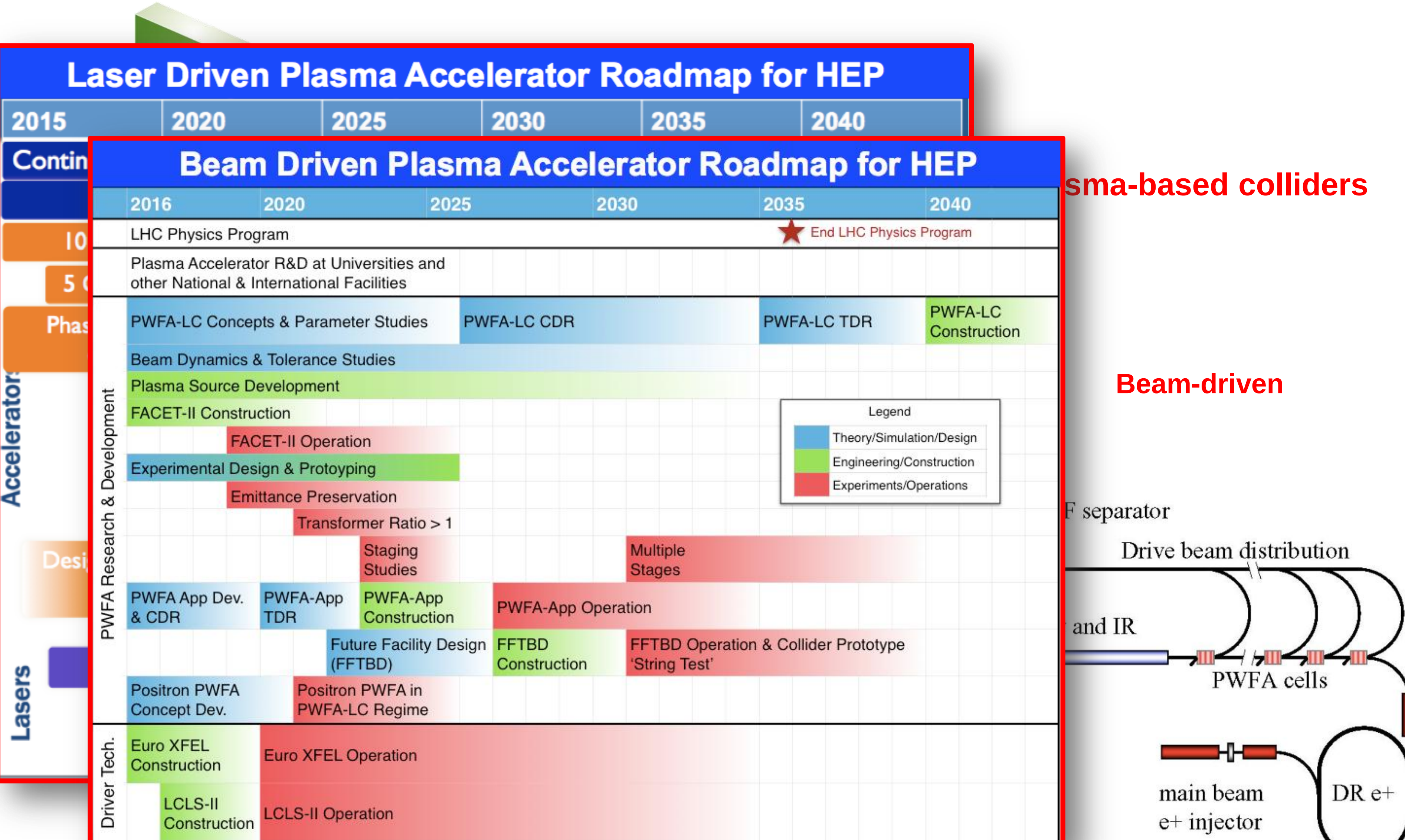
of plasma-based colliders

Beam-driven



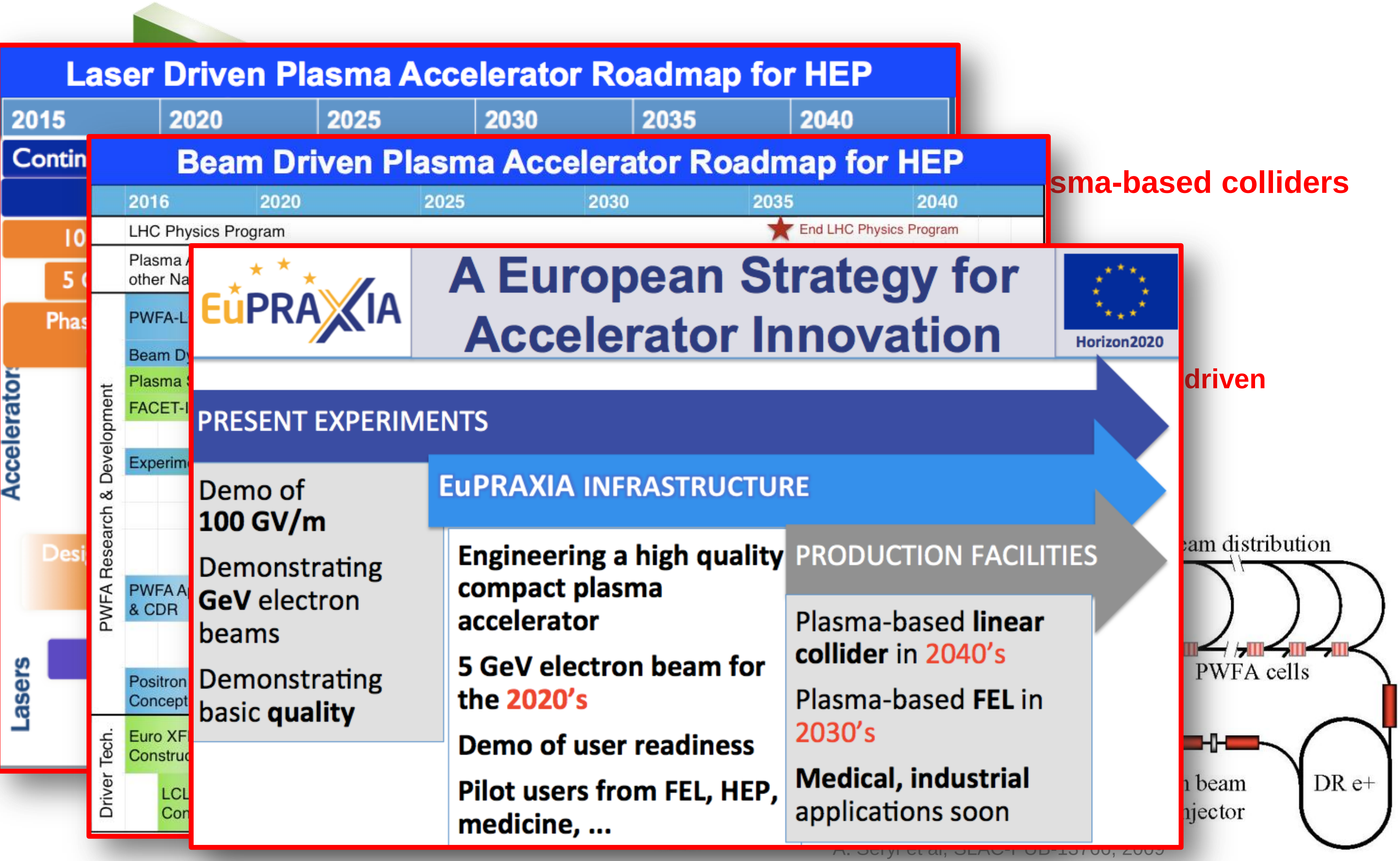
A. Seryi et al, SLAC-PUB-13766, 2009

Advanced accelerator community developing roadmaps toward plasma-based collider in 2040



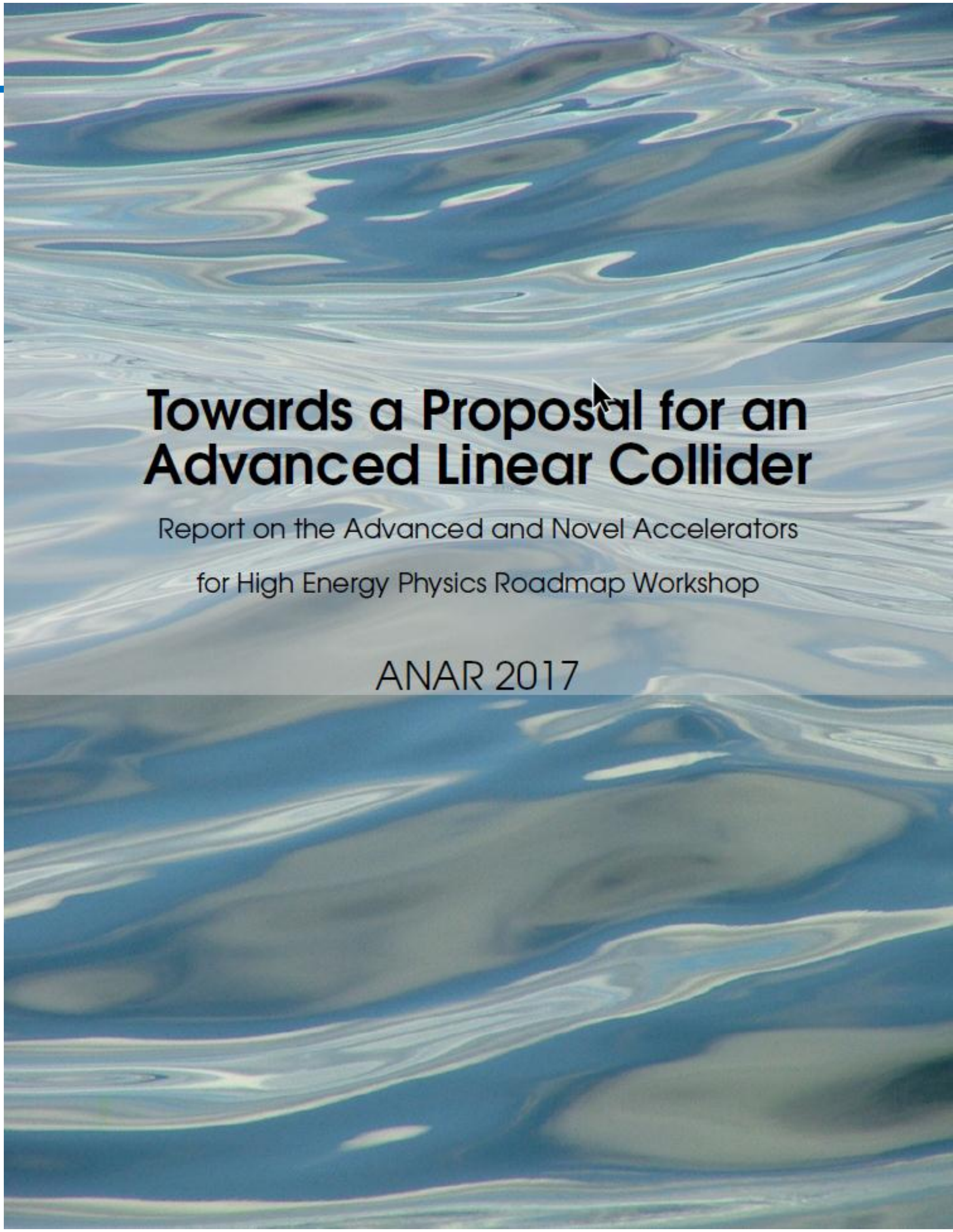
A. Seryi et al, SLAC-PUB-13766, 2009

Advanced accelerator community developing roadmaps toward plasma-based collider in 2040



ANAR

- **Advanced and Novel Accelerators for High Energy Physics Roadmap (ANAR) workshop**
- **Report for ICFA Advanced and Novel Accelerators Panel**
- **Potential for increased world-wide coordination role**



Towards a Proposal for an Advanced Linear Collider

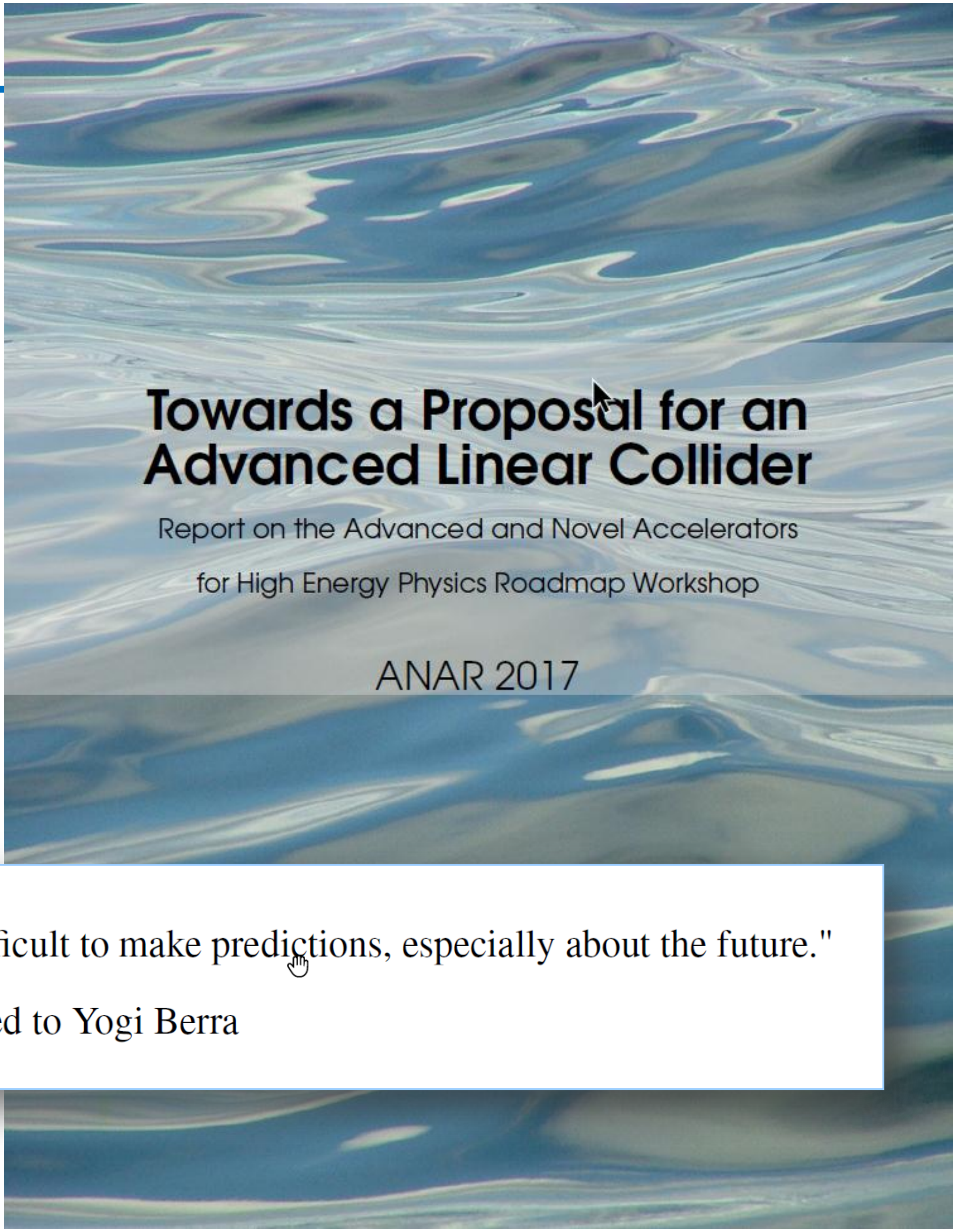
Report on the Advanced and Novel Accelerators for High Energy Physics Roadmap Workshop

ANAR 2017

http://www.lpgp.u-psud.fr/icfaana/ana-publications-2017

ANAR

- **Advanced and Novel Accelerators for High Energy Physics Roadmap (ANAR) workshop**
- **Report for ICFA Advanced and Novel Accelerators Panel**
- **Potential for increased world-wide coordination role**



"It is difficult to make predictions, especially about the future."

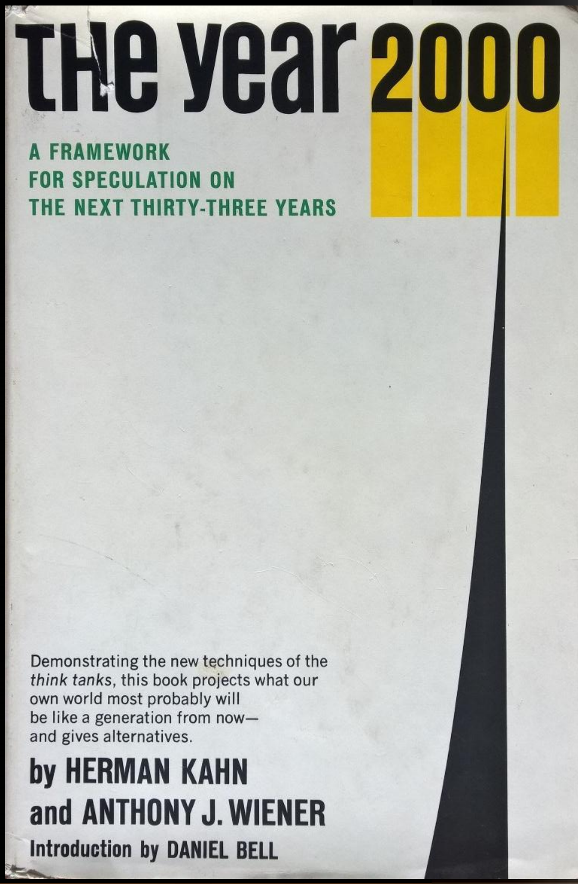
Attributed to Yogi Berra

http://www.lpgp.u-psud.fr/icfaana/ana-publications-2017

We would like to predict how our field will look like in close to the middle of 21 century

Can we learn from past efforts to make it more reliable and efficient?

Predictions made in 1968 for the year 2000

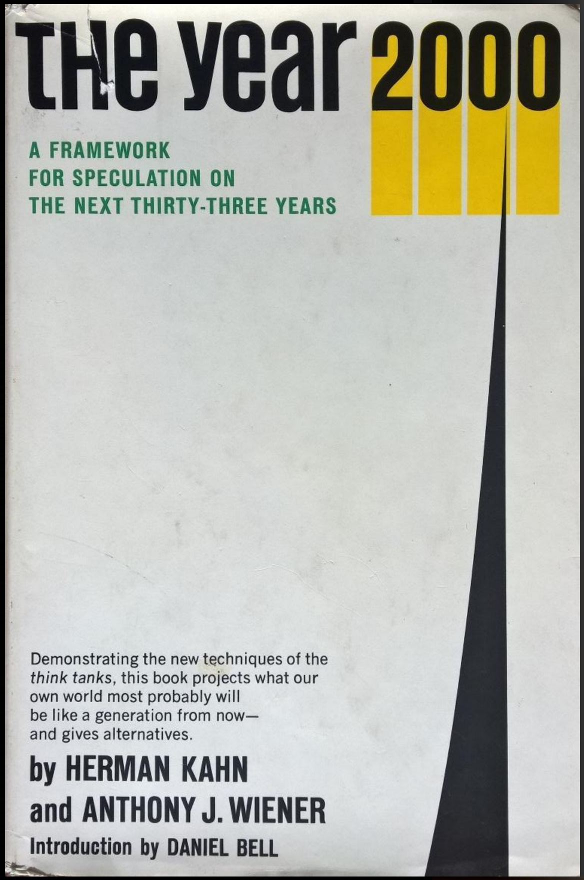


"The Year 2000", 1968
K. Herman, A. Wiener
ISBN 978-0025604407

We would like to predict how our field will look like in close to the middle of 21 century

Can we learn from past efforts to make it more reliable and efficient?

Predictions made in 1968 for the year 2000


THE year 2000

A FRAMEWORK
FOR SPECULATION ON
THE NEXT THIRTY-THREE YEARS

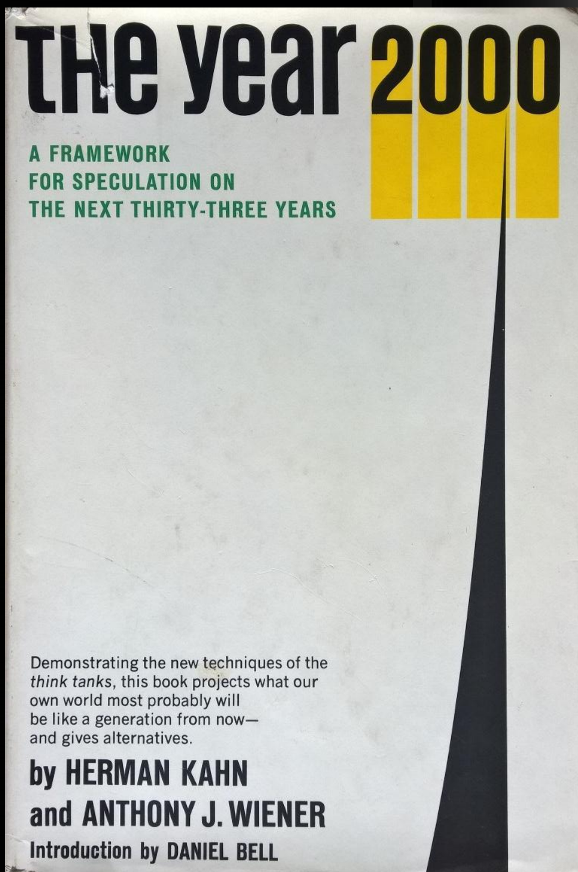
Demonstrating the new techniques of the *think tanks*, this book projects what our own world most probably will be like a generation from now—and gives alternatives.

by HERMAN KAHN
and ANTHONY J. WIENER
Introduction by DANIEL BELL

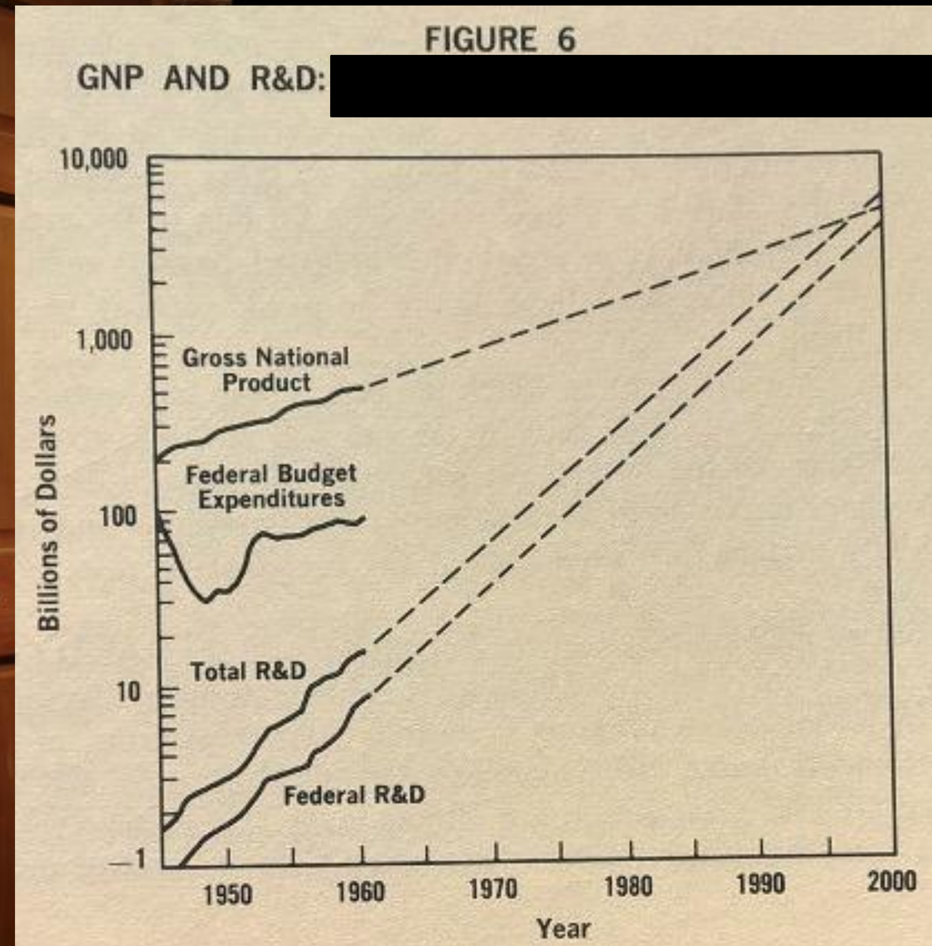
"The Year 2000", 1968
K. Herman, A. Wiener
ISBN 978-0025604407

Importance of rigorous methodology of predictions is very important

Predictions made in 1968 for the year 2000

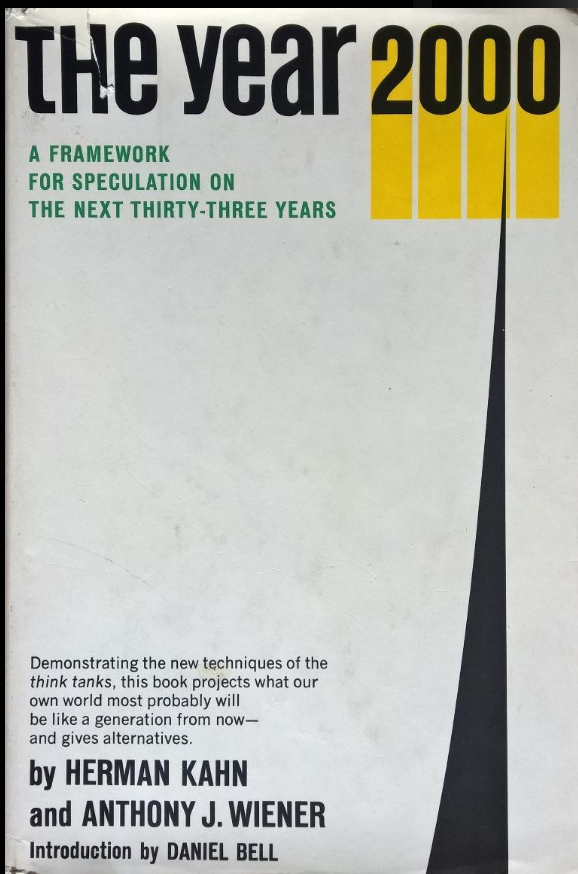


F
U
T
U
R
E



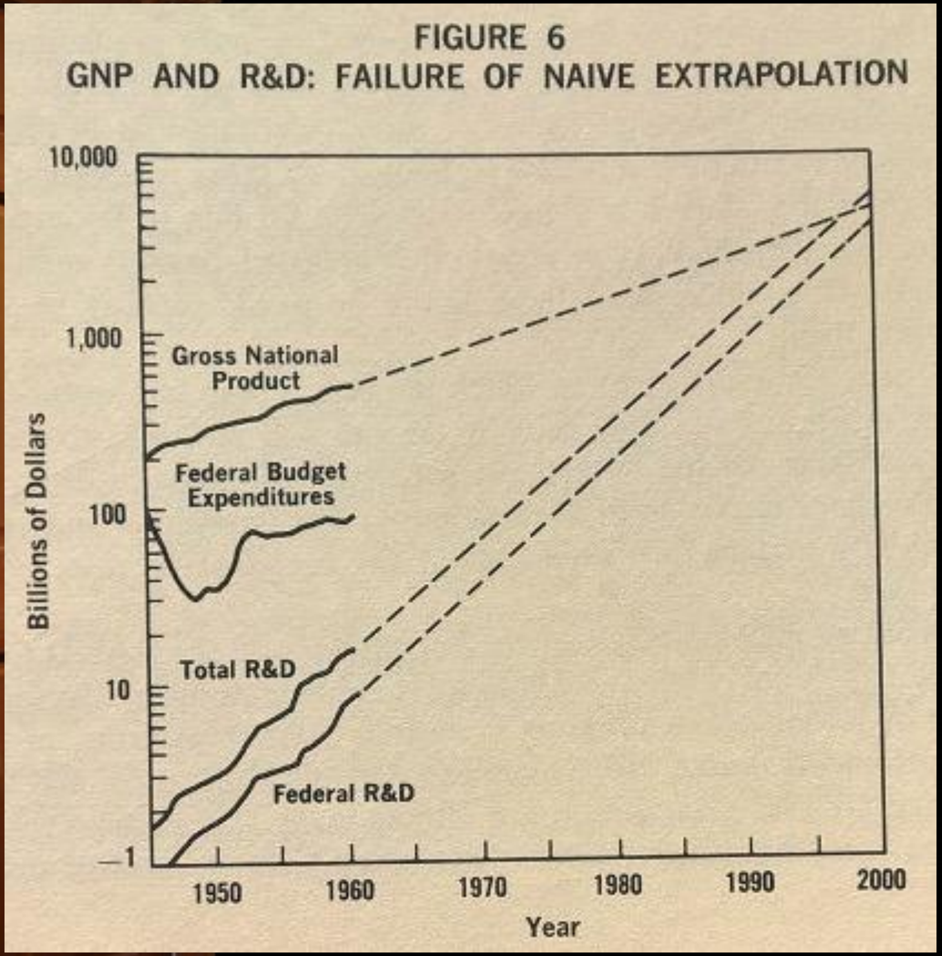
"The Year 2000", 1968
K. Herman, A. Wiener
ISBN 978-0025604407

Predictions made in 1968 for the year 2000



"The Year 2000", 1968
K. Herman, A. Wiener
ISBN 978-0025604407

F U T U R E



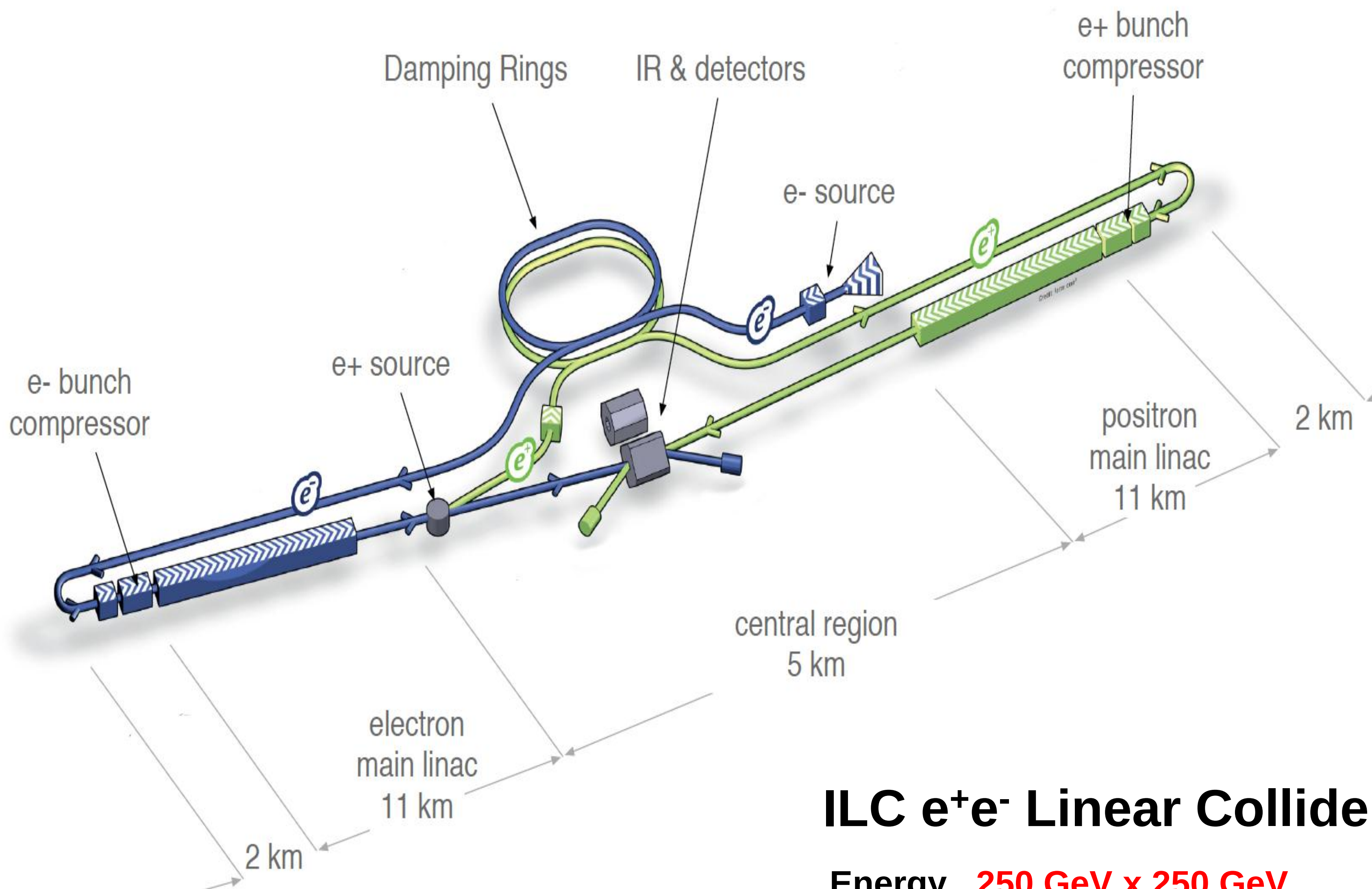
Avoid naïve extrapolations

To make viable predictions and efficient R&D plan for plasma-based collider:

Absorb the ~20 years experience of development of conventional LC concepts to technical designs

...and also look around, across different disciplines, to imagine where other areas of science and technology are dreaming and planning to be in the middle of 21 century

Path to ILC – how was it done?



ILC e^+e^- Linear Collider

Energy **250 GeV x 250 GeV**

Path to ILC – how was it done?

- LC state in ~1990 – many and many linear collider concepts
- Yearly meeting of LC accelerator designers
  - Obviously, this is essential for plasma LC too
- Yearly meetings of LC detector/physics community
  - Maybe less obvious, but this is needed too (despite that physics studied done, detectors designed) since the Machine Detector Interface (MDI) design, background, etc., could be quite different for the plasma-based LC

Path to ILC – how was it done?

- **Essential – periodic review of the design readiness by the community appointed committee**
- **Greg Loew's committee**
  - **A year long process, with a lot of work by many**
  - **All system analysed**
  - **Problems and risks ranked and recorded**
  - **Review Report of 1995**
  - **Review Report of 2003**

Gregory A. Loew

From 1995 LC Technical Review Report

- **Working groups**
  - All systems analysed
  - Look across similar systems despite different technologies (NC, SC, two-beam acc)
  - R&D steps needed in the next years identified

Structure and Members of the Technical Review Committee

Steering Group:
G. Loew, Chairman
T. Weiland, Secretariat

Reading Committee:
B. Aune, V. Balakin, H. Edwards, K. Hübner, E. Paterson, A. Sessler, K. Takata, G. Vignola, G. Voss, B. Wiik

Working Groups:

1) Injection Systems and Pre-Accelerators
M. Yoshioka, Chair
A. Mikhailichenko, Deputy Chair
H. Braun, J.P. Delahaye (CLIC), K. Flöttmann, J. Frisch, R. Miller, C. Pagani, L. Rinolfi, J. Rosenzweig, H. Tang, C. Travier, D.A. Yeremian

2) Damping and Compression Systems
J. Rossbach (SBLC), Chair
J. Urakawa, Deputy Chair
S. Chattopadyhay, A. Mikhailichenko, J.P. Potier, T. Raubenheimer

3) Linac Technology
P. Wilson (NLC), Chair
D. Proch, Deputy Chair
N. Holtkamp, Deputy Chair
G. Caryotakis, T. Higo, H. Mizuno, W. Namkung, H. Padamsee, R. Palmer, N. Solyak (VLEPP), G. Westenskow, I. Wilson

4) Beam Dynamics
K. Yokoya (JLC), Chair
A. Mosnier, Deputy Chair
G. Guignard, R. Ruth, R. Wanzenberg

5) Beam Delivery
R. Brinkmann (TESLA), Chair
V. Telnov, Deputy Chair
A. Dragt, J. Irwin, O. Napoly, K. Oide, A. Sery, B. Zotter

6) Experimentation
R. Settles, Chair
T. Markiewicz, Deputy Chair
S. Bertolucci, S. Kawabata, D. Miller, R. Orava, F. Richard, T. Tauchi, A. Wagner

International Linear Collider Technical Review Committee Report, 1995, SLAC-R-471
https://www.osti.gov/scitech/biblio/220447

From 1995 LC Technical Review Report

Table 1.1

Linear Colliders: Overall and Final Focus Parameters – 500 GeV (c.m.)

	TESLA*	SBLC	JLC (S)	JLC (C)	JLC (X)	NLC	VLEPP	CLIC
Initial energy (c.of .m.) (GeV)	500	500	500	500	500	500	500	500
RF frequency of main linac (GHz)	1.3	3	2.8	5.7	11.4	11.4	14	30
Nominal Luminosity (10^{33} cm^{-2}s^{-2})†	2.6	2.2	5.2	7.3	5.1	5.3	12.3	0.7-3.4
Actual luminosity (10^{33} cm^{-2}s^{-2})†	6.1	3.75	4.3	6.1	5.2	7.1	9.3	1.07-4.8
Linac repetition rate (Hz)	10	50	50	100	150	180	300	2530-1210
No. of particles/bunch at IP (10^{10})	5.15	2.9	1.44	1.0	.63	.65	20	.8
No. of bunches/pulse	800	125	50	72	85	90	1	1-10
Bunch separation (nsec)	1000	16.0	5.6	2.8	1.4	1.4	–	.67
Beam power/beam (MW)	16.5	7.26	1.3	2.9	3.2	4.2	2.4	.8-3.9
Damping ring energy (GeV)	4.0	3.15	2.0	2.0	2.0	2.0	3.0	2.15
Main linac gradient, unloaded/loaded††(MV/m)	25/25	21/17	31/–	40/32	73/58	50/37	100/91	80/78
Total two-linac length (km)	29	33	22.1	18.8	10.4	15.6	7	8.8
Total beam delivery length (km)	3	3	3.6	3.6	3.6	4.4	3	2.4
$\gamma\epsilon_x/\gamma\epsilon_y$ (m-$rad \times 10^{-8}$)	2000/100	1000/50	330/4.8	330/4.8	330/4.8	500/5	2000/7.5	300/15
β_x^*/β_y^* (mm)	25/2	22/0.8	10/0.1	10/0.1	10/0.1	10/0.1	100/0.1	10/0.18
σ_x^*/σ_y^* (nm) before pinch	1000/64	670/28	260/3.0	260/3.0	260/3.0	320/3.2	2000/4	247/7.4
σ_z^* (μm)	1000	500	120	120	90	100	750	200
Crossing Angle at IP (mrad)	0	3	6.4	6.0	6.1	20	6	1
Disruptions D_x/D_y	0.56/8.7	.36/8.5	.29/25	.20/18	.096/8.3	.07/7.3	.4/215	0.29/9.8
H_D	2.3	1.8	1.6	1.4	1.4	1.34	2.0	1.42
Upsilon sub-zero	.02	.037	.20	.14	.12	.089	.059	0.07
Upsilon effective	.03	.042	.22	.144	.12	.090	.074	.075
δ_B (%)	3.3	3.2	12.7	6.5	3.5	2.4	13.3	3.6
n_γ (no. of γ's per e)	2.7	1.9	2.2	1.5	.94	.8	5.0	1.35
N_{pairs}(p_T^{min}=20 MeV/c,θ_{min}=0.15)	19.0	8.8	31.6	10.3	2.9	2.0	1700	3.0
$N_{hadrons}$/crossing	0.17	0.10	0.98	0.23	0.05	0.03	45.9	0.05
$N_{jets} \times 10^{-2}$ (p_T^{min}=3.2 GeV/c)	0.16	0.14	3.4	0.66	0.14	0.08	56.4	0.10

International Linear Collider Technical Review Committee Report, 1995, SLAC-R-471

https://www.osti.gov/scitech/biblio/220447

From 1995 LC Technical Review Report

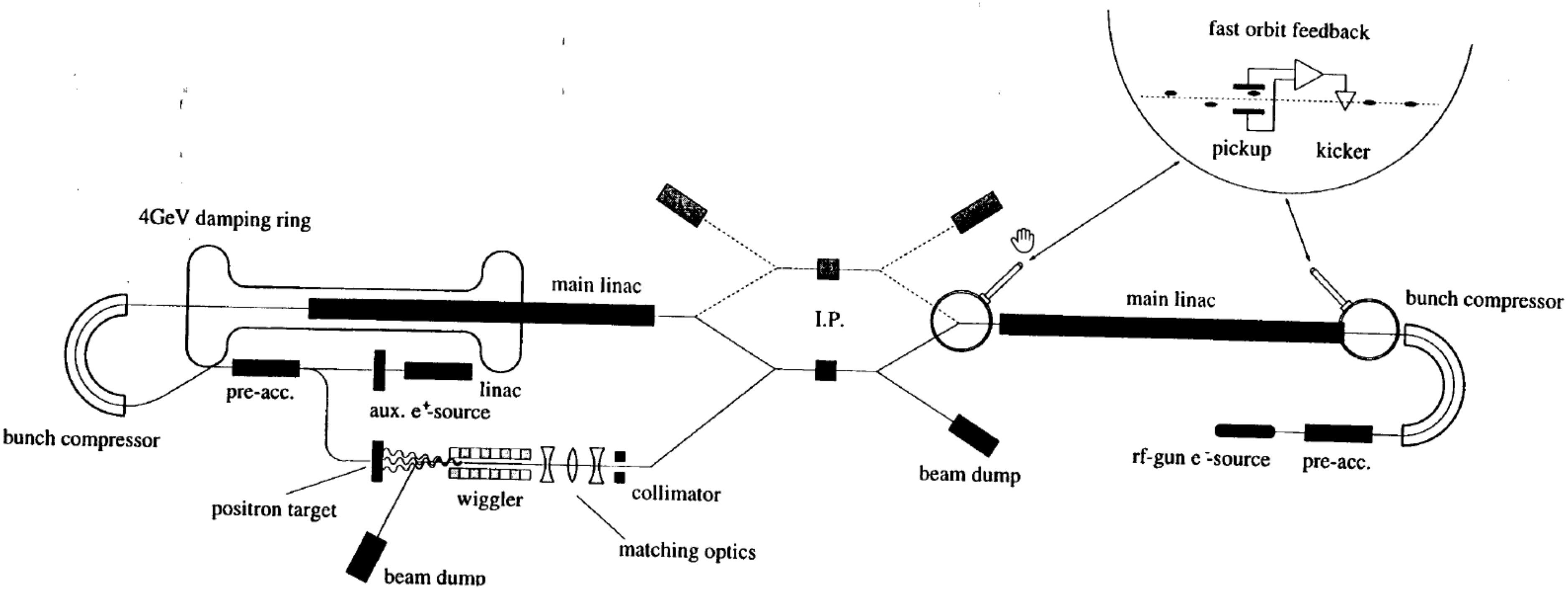


Fig.1.1 Overall TESLA layout.

International Linear Collider Technical Review Committee Report, 1995, SLAC-R-471
https://www.osti.gov/scitech/biblio/220447

From 1995 LC Technical Review Report

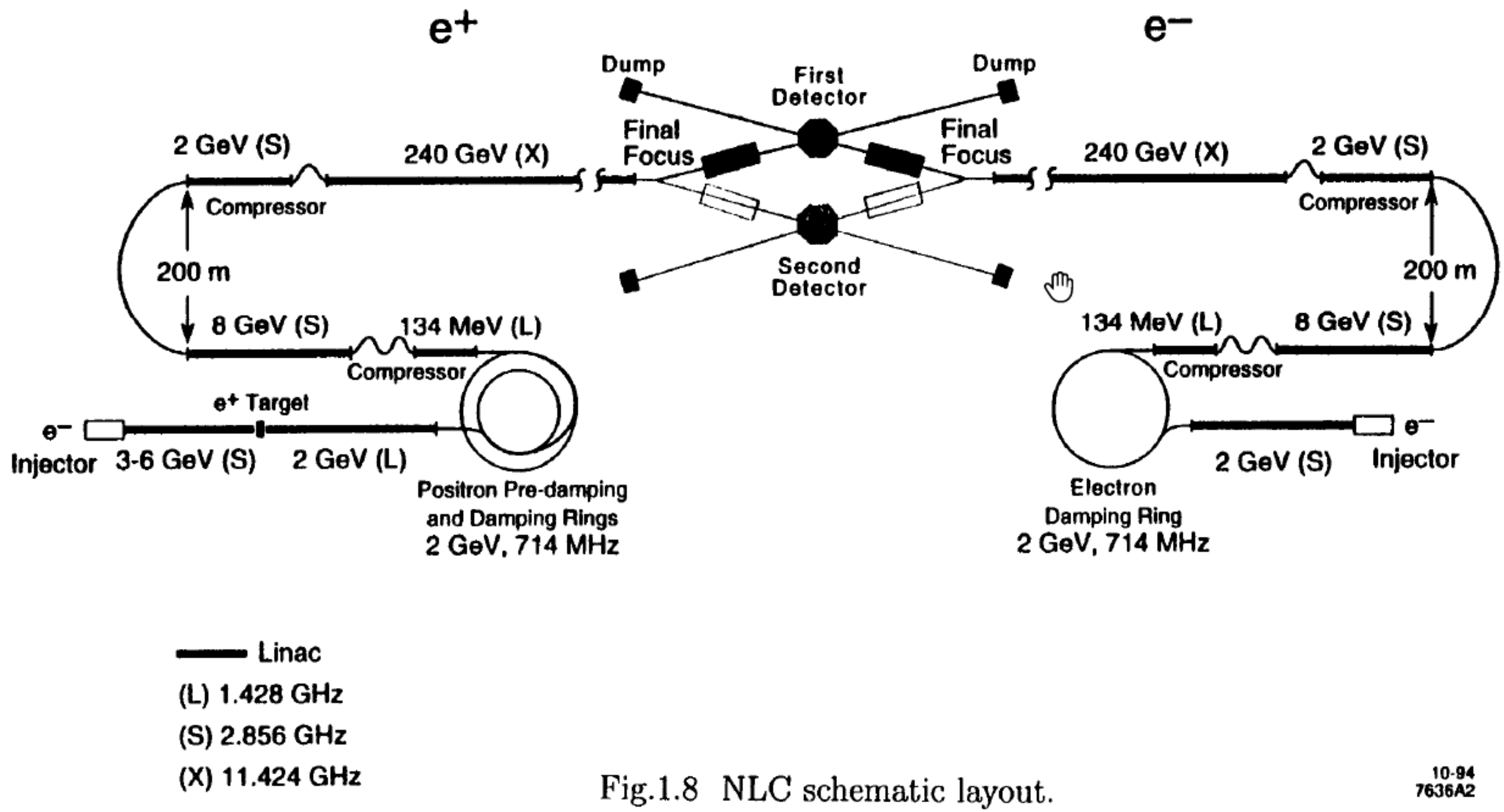


Fig.1.8 NLC schematic layout.

International Linear Collider Technical Review Committee Report, 1995, SLAC-R-471
https://www.osti.gov/scitech/biblio/220447

From 1995 LC Technical Review Report

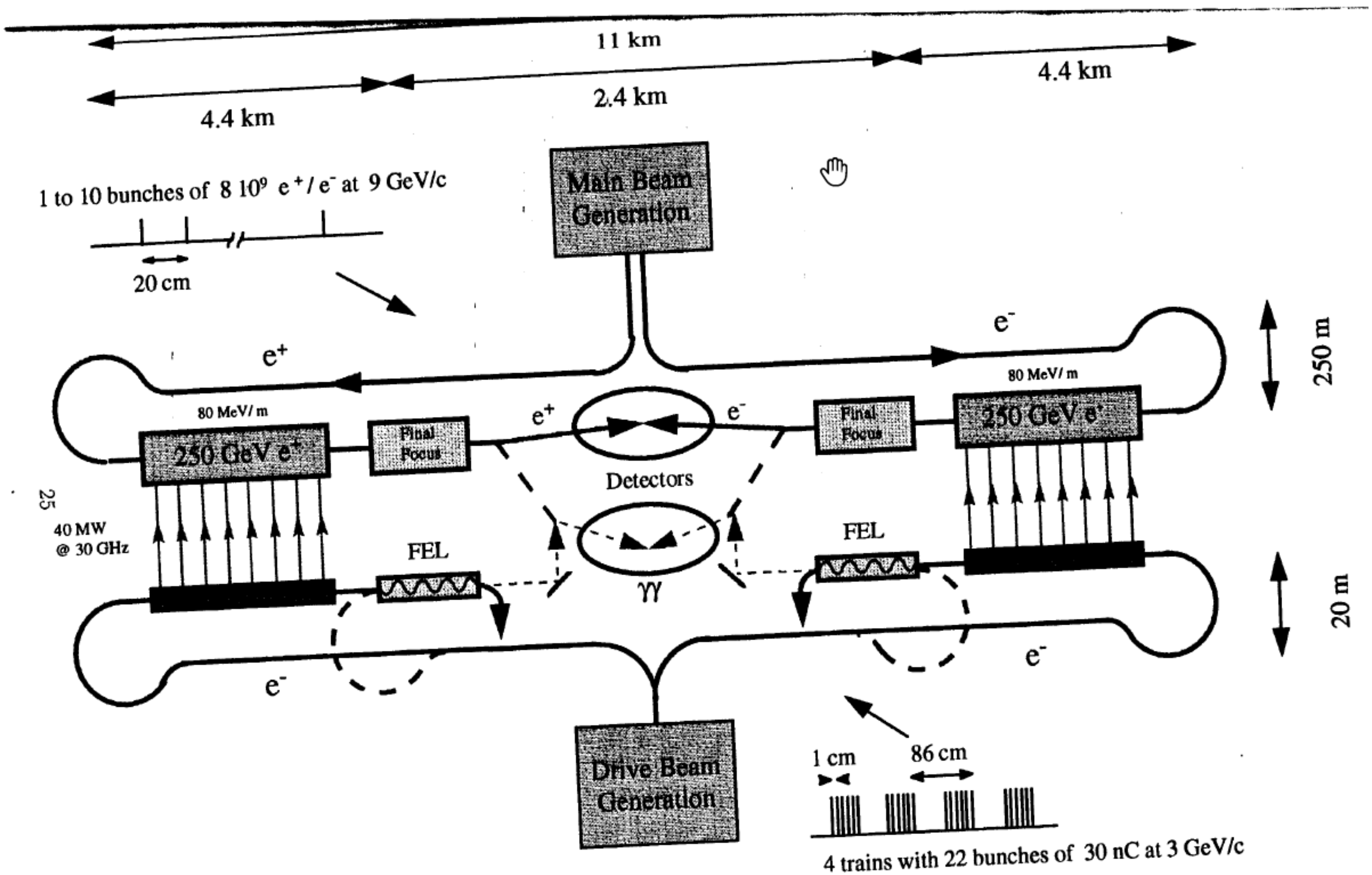


Fig.1.14 CLIC general layout.

International Linear Collider Technical Review Committee Report, 1995, SLAC-R-471
https://www.osti.gov/scitech/biblio/220447

From 2003 LC Technical Review Report

TABLE 2: Summary of Machine Parameters

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
Center of mass energy [GeV]	500	800	500	1000	500	1000	500	3000
RF frequency of main linac [GHz]	1.3		5.7	5.7/11.4[b]	11.4		30	
Design luminosity [10^{33} cm^{-2}s^{-1}]	34.0	58.0	14.1	25.0	25.0 (20.0)	25.0 (30.0)	21.0	80.0
Linac repetition rate [Hz]	5	4	100		150 (120)	100 (120)	200	100
Number of particles/bunch at IP [10^{10}]	2	1.4	0.75		0.75		0.4	
$\gamma\varepsilon_x^* / \gamma\varepsilon_y^*$ emit. at IP [m·rad × 10^{-6}]	10 / 0.03	8 / 0.015	3.6 / 0.04		3.6 / 0.04		2.0 / 0.01	0.68 / 0.01
β_x^* / β_y^* at IP [mm]	15 / 0.40	15 / 0.40	8 / 0.20	13 / 0.11	8 / 0.11	13 / 0.11	10 / 0.05	16 / 0.07
σ_x^* / σ_y^* at IP before pinch[c] [nm]	554 / 5.0	392 / 2.8	243 / 4.0	219 / 2.1	243 / 3.0	219 / 2.1	202 / 1.2	60 / 0.7
σ_z^* at IP [μm]	300		200	110	110		35	
Number of bunches/pulse	2820	4886	192		192		154	
Bunch separation [nsec]	337	176	1.4		1.4		0.67	
Bunch train length [μsec]	950	860	0.267		0.267		0.102	
Beam power/beam [MW]	11.3	17.5	5.8	11.5	8.7 (6.9)	11.5 (13.8)	4.9	14.8
Unloaded/loaded gradient[d] [MV/m]	23.8 / 23.8[e]	35 / 35	41.8/31.5	41.8/31.5 / 70/55	65 / 50		172 / 150	
Total number of klystrons	572	1212	4276	3392/4640	4064	8256	448	
Number of sections	20592	21816	8552	6784/13920	12192	24768	7272	44000
Total two-linac length [km]	30	30	17.1	29.2	13.8	27.6	5.0	28.0
Total beam delivery length [km]	3		3.7		3.7		5.2	
Proposed site length [km]	33		33		32		10.2	33.2
Total site AC power[f] [MW]	140	200	233	300	243 (195)	292 (350)	175	410
Tunnel configuration[g]	Single		Double		Double		Single	

International Linear Collider Technical Review Committee Second Report, 2003

http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/PAPERS/TRC03PR.PDF

From 2003 LC Technical Review Report

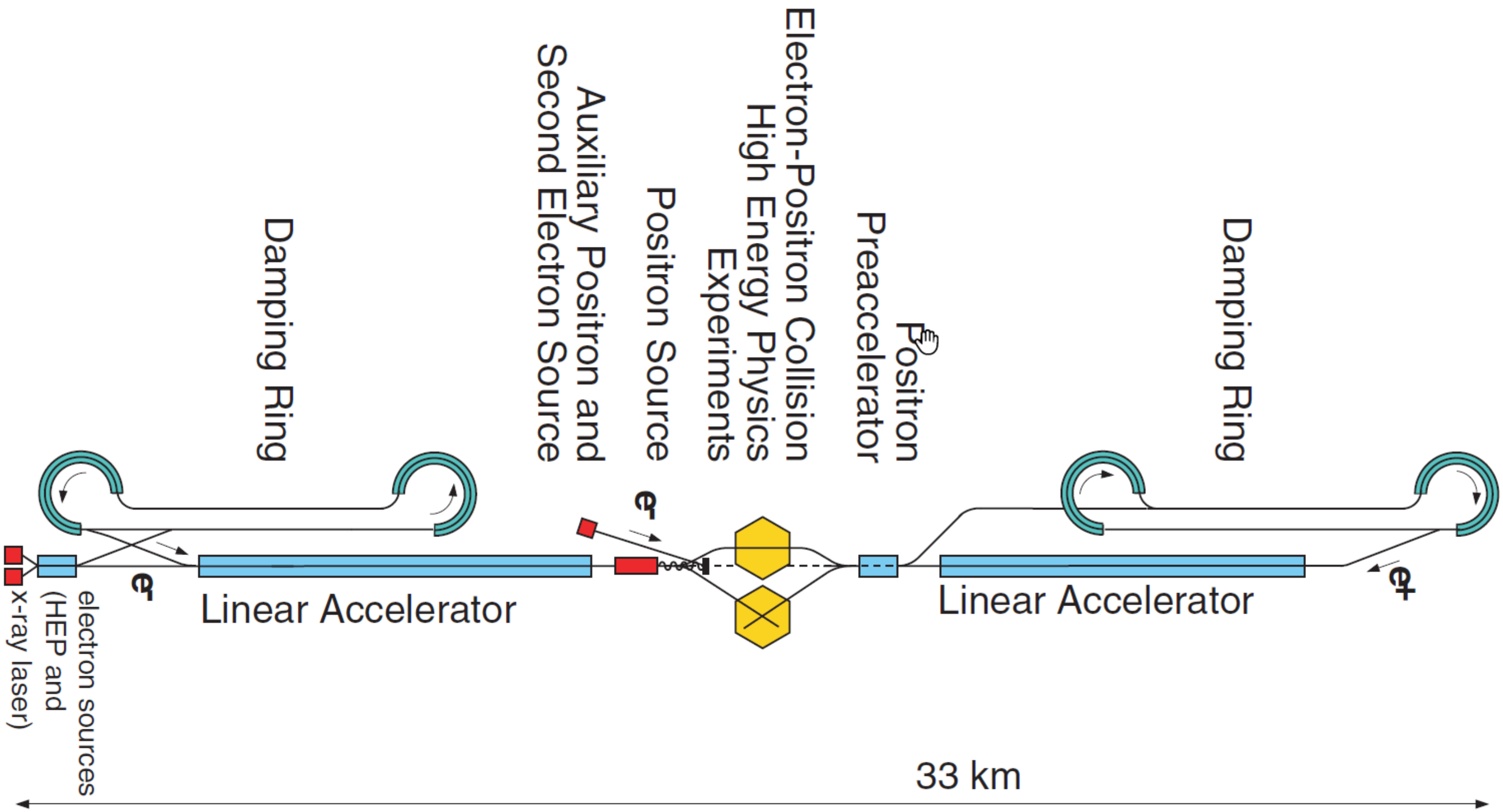


FIGURE 1. TESLA layout

International Linear Collider Technical Review Committee Second Report, 2003
http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/PAPERS/TRC03PR.PDF

From 2003 LC Technical Review Report

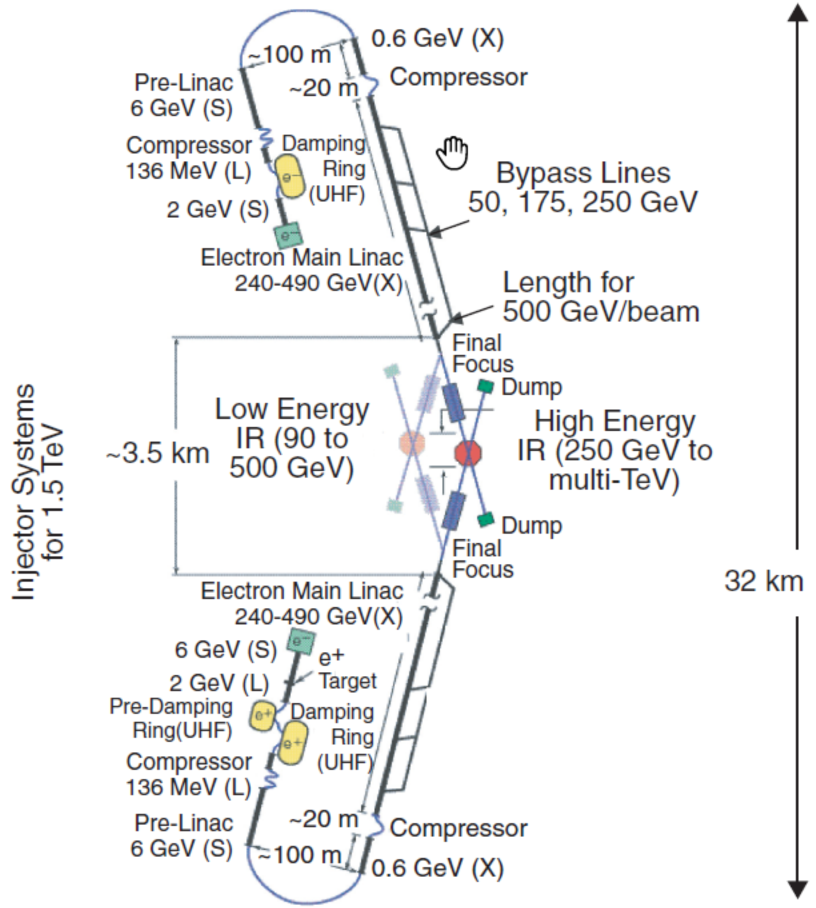


FIGURE 5. JLC-X/NLC layout

International Linear Collider Technical Review Committee Second Report, 2003

http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/PAPERS/TRC03PR.PDF

From 2003 LC Technical Review Report

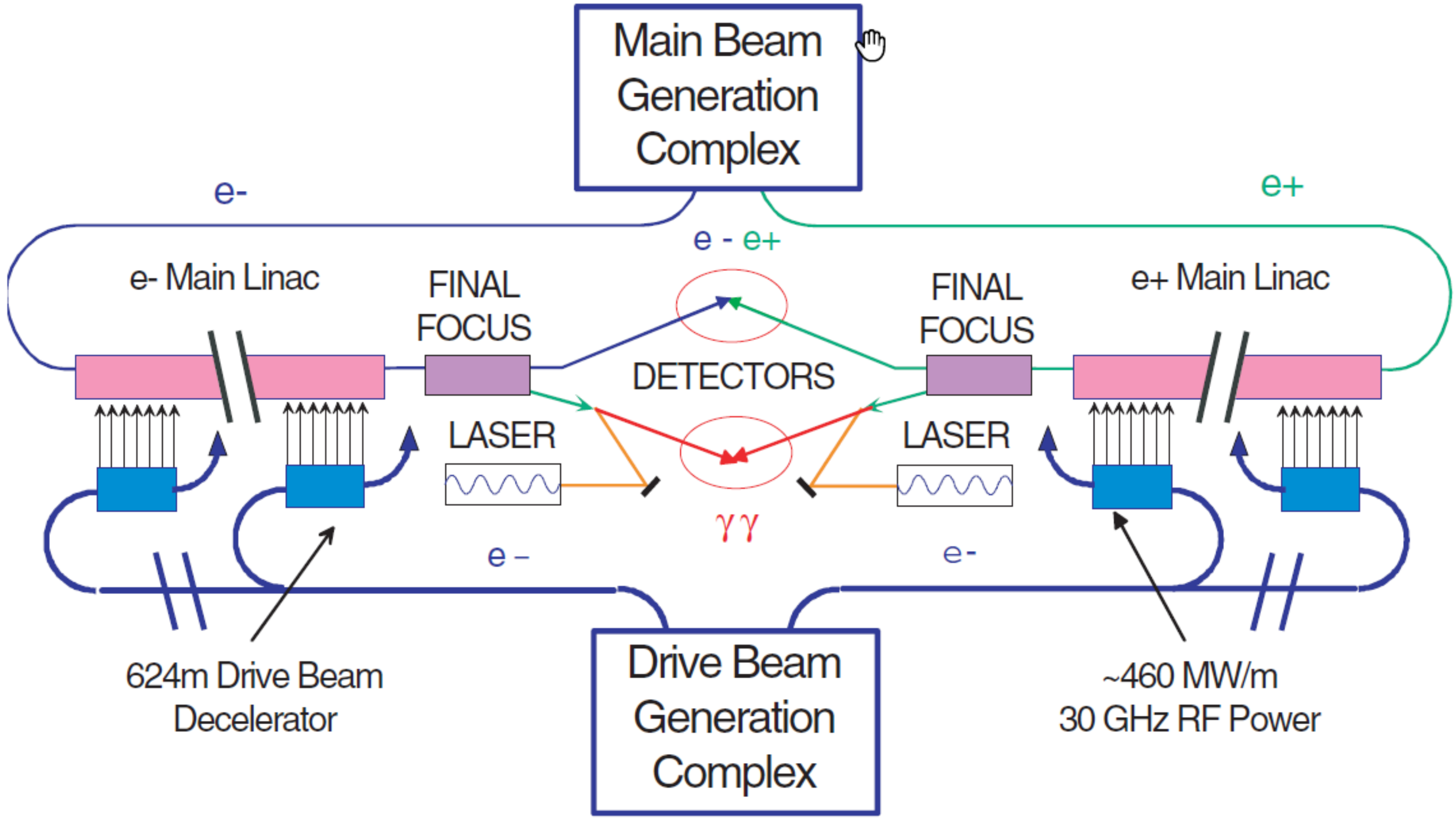


FIGURE 7. CLIC layout (two-linac length at 500 GeV c.m. is 5 km)

International Linear Collider Technical Review Committee Second Report, 2003
http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/PAPERS/TRC03PR.PDF

From 2003 LC Technical Review Report

Ranking 1: R&D needed for feasibility demonstration of the machine

The objective of these R&D items is to show that the key machine parameters are not unrealistic. In particular, a proof of existence of the basic critical constituents of the machines should be available upon completion of the Ranking 1 R&D items.

Ranking 2: R&D needed to finalize design choices and ensure reliability of the machine

These R&D items should validate the design of the machine, in a broad sense. They address the anticipated difficulties in areas such as the architecture of the subsystems, beam physics and instabilities, and tolerances. A very important objective is also to examine the reliability and operability of the machine, given the very large number of components and their complexity.

Ranking 3: R&D needed before starting production of systems and components

These R&D items describe detailed studies needed to specify machine components before construction and to verify their adequacy with respect to beam parameters and operating procedures.

Ranking 4: R&D desirable for technical or cost optimization

In parallel to the main stream of R&D needed to build a linear collider, there should be other studies aimed at exploring alternative solutions or improving our understanding of the problems encountered. The results of the Ranking 4 R&D items are likely to be exploited for improved technical performance, energy upgrades, or cost reduction.

International Linear Collider Technical Review Committee Second Report, 2003

http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/PAPERS/TRC03PR.PDF

1-st conclusion:

> 20 years experience of development of conventional LC concepts to technical designs, with community driven periodic reviews, applicable to plasma collider

...and also look around, across different disciplines, to imagine where other areas of science and technology are dreaming and planning to be in the middle of 21 century

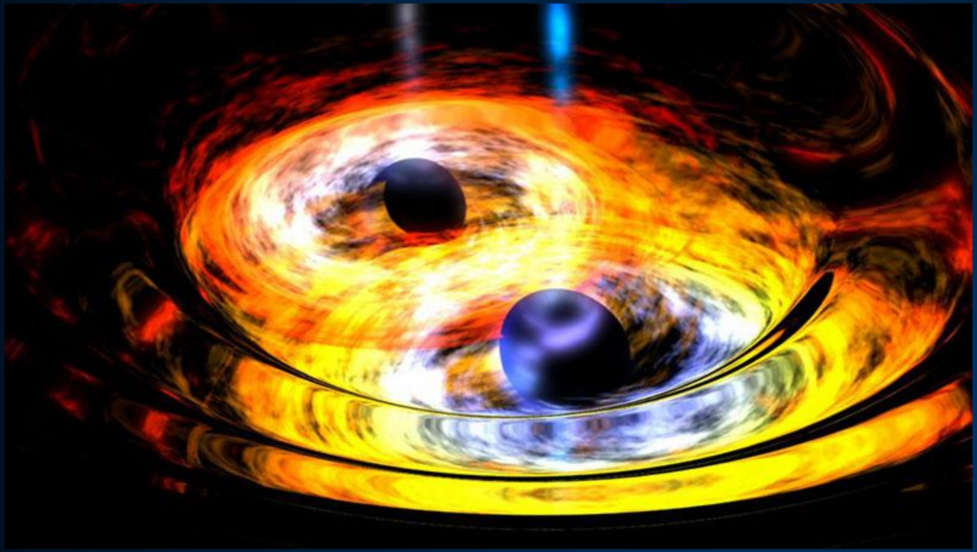
1-st conclusion:

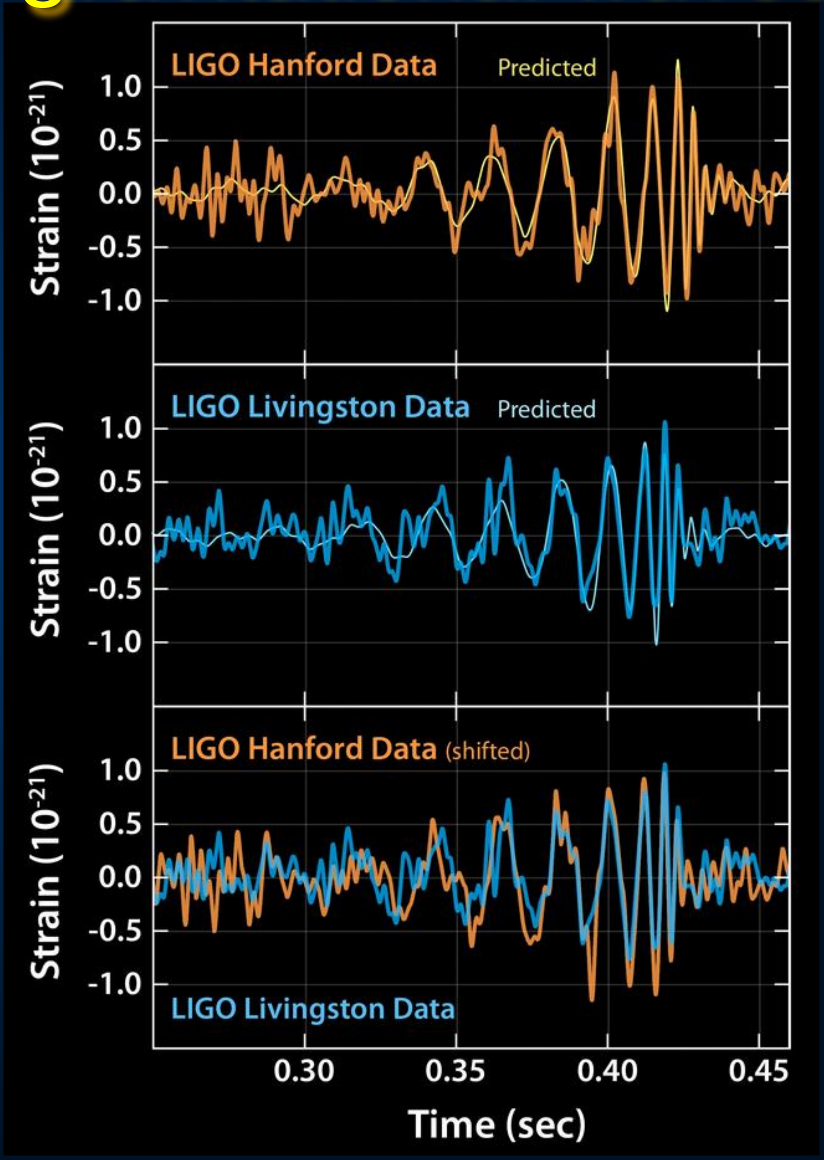
> 20 years experience of development of conventional LC concepts to technical designs, with community driven periodic reviews, applicable to plasma collider

F U T U R E

...and also look around, across different disciplines, to imagine where other areas of science and technology are dreaming and planning to be in the middle of 21 century

2016 Special Breakthrough Prize in Fundamental Physics – gravitational waves

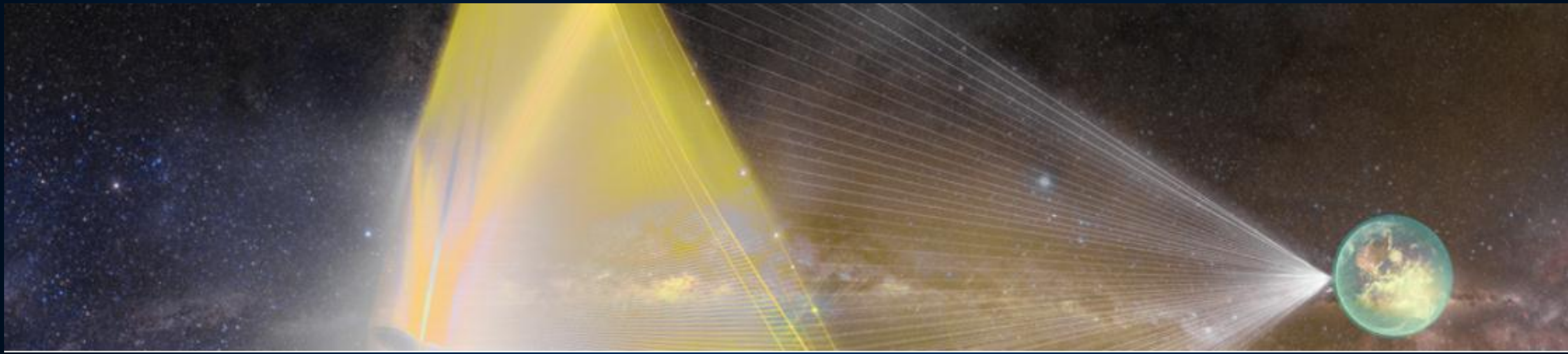




Why is this shown in this talk? Next slide will explain.

Image: Caltech/MIT/LIGO Lab

Breakthrough challenge 3 - Starshot



Nano-space-ship with light-sail (2g total mass) propelled by laser to 20% of speed of light, to reach Alfa Centauri within a generation (and to take photos and send them back)

Enormous number of challenges!
Multi-year R&D is funded (M100$)

What are reasonable intermediate steps?

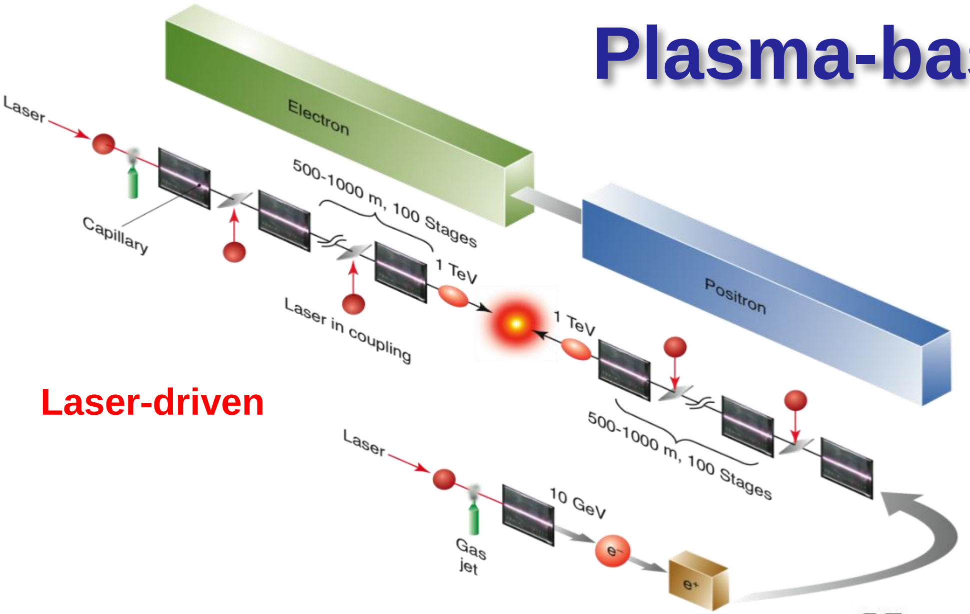
Board of
Breakthrough Starshot:

Stephen Hawking
Yuri Milner
Mark Zuckerberg

How this R&D will push lasers, in terms of their power, controllability, stability, in application to plasma acceleration? NB: "light sail"

https://breakthroughinitiatives.org/Challenges/3

Plasma-based colliders



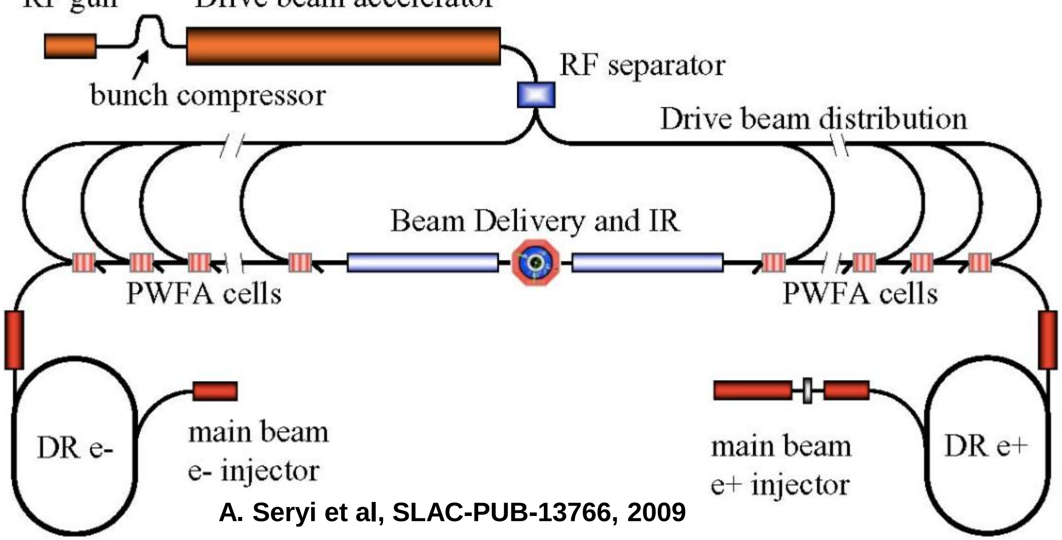
Laser-driven

E. Esarey et al, Rev. Mod. Phys. (2009)

One of the main difficulties of both of these concepts:

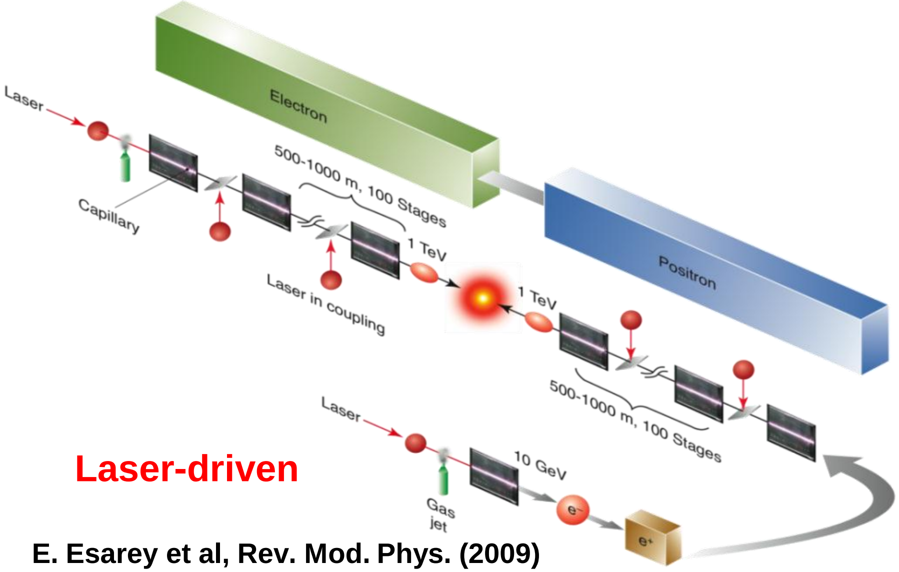
Combination of traditional technology with new

Beam-driven



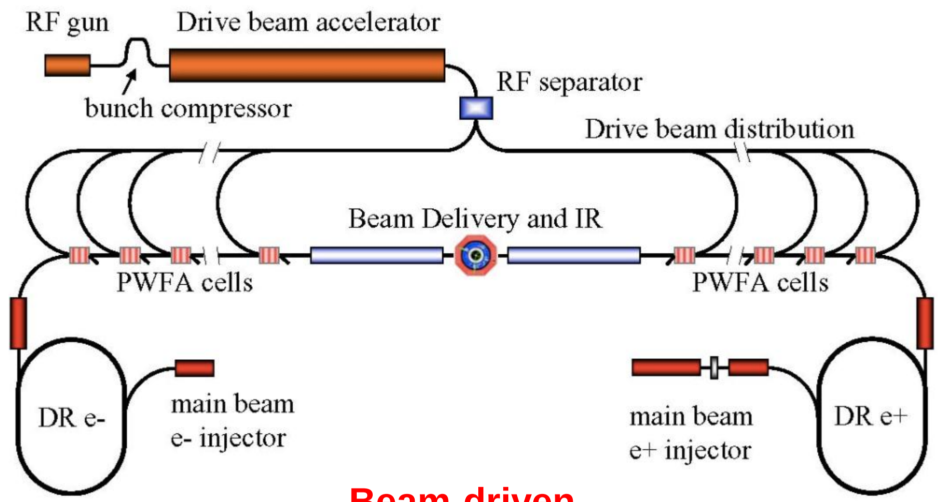
A. Seryi et al, SLAC-PUB-13766, 2009

The approaches should be modified – aim to use only new technologies



Laser-driven

E. Esarey et al, Rev. Mod. Phys. (2009)

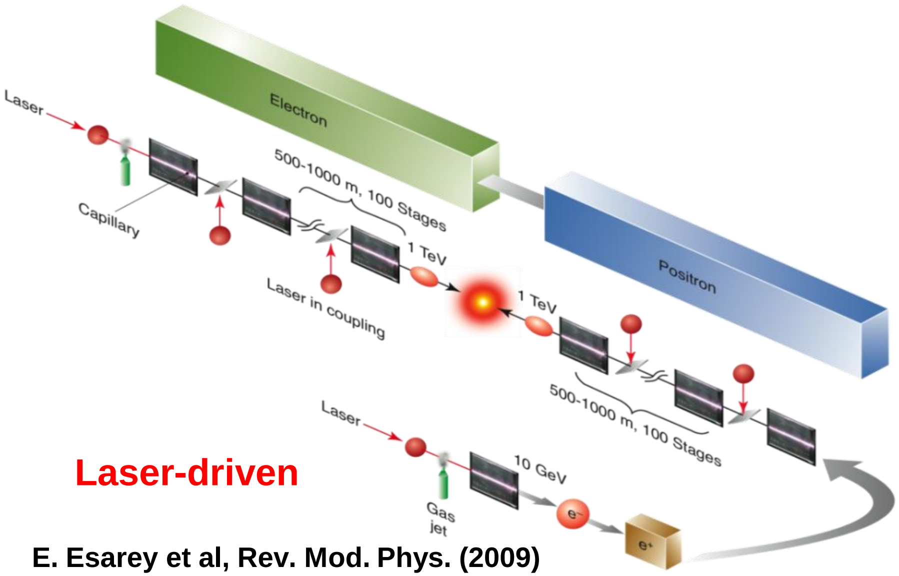


Beam-driven

A. Seryi et al, SLAC-PUB-13766, 2009

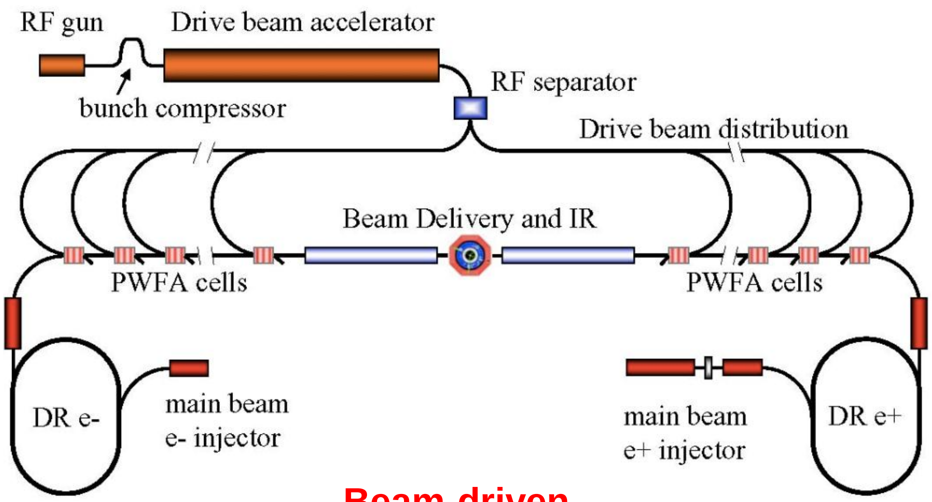
Taking all the above into account – how should these concepts evolve, aiming at mid of 21 century?

- **Remove conventional systems, e.g.:**
  - **Remove 4km final focus, assume emittance so small that strong focusing at IP not needed**
  - **Cooling (if needed for e+) is in linear system**
  - **Could p-drive beam be useful, as a driver, produced by a single-cycle laser pulse?**



Laser-driven

E. Esarey et al, Rev. Mod. Phys. (2009)



Beam-driven

A. Seryi et al, SLAC-PUB-13766, 2009

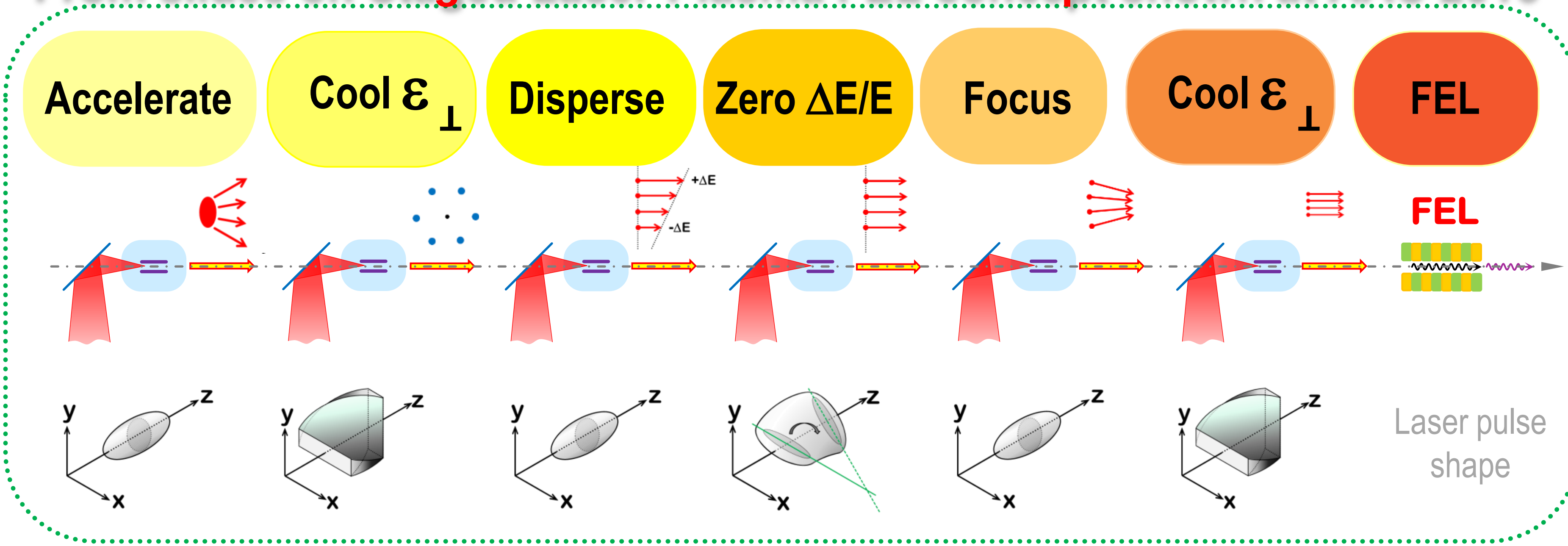
Taking all the above into account – how should these concepts evolve, aiming at mid of 21 century?

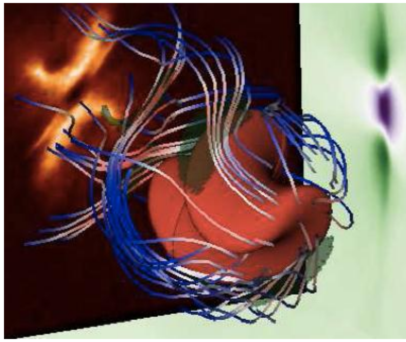
- **Rely on progress in lasers, also due to:**
  - **Progress driven by commercial applications**
  - **Progress driven by XCAN fiber combination project**
  - **Progress driven by Starshot challenge**

    - **And proactively help this progress!**

Linear cooling system?

From slides on Staged Laser-Plasma FEL concept shown at AAC 2016

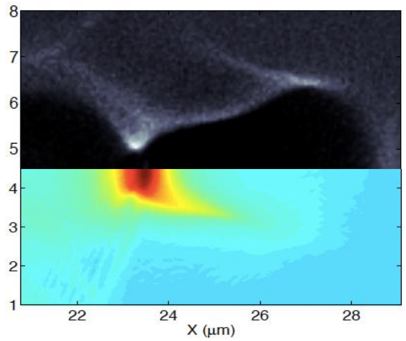




Screw-shaped laser pulse and trajectories of electrons - left

Bubble shape (top) and solenoidal field map (bottom) - right

A. Seryi, et al

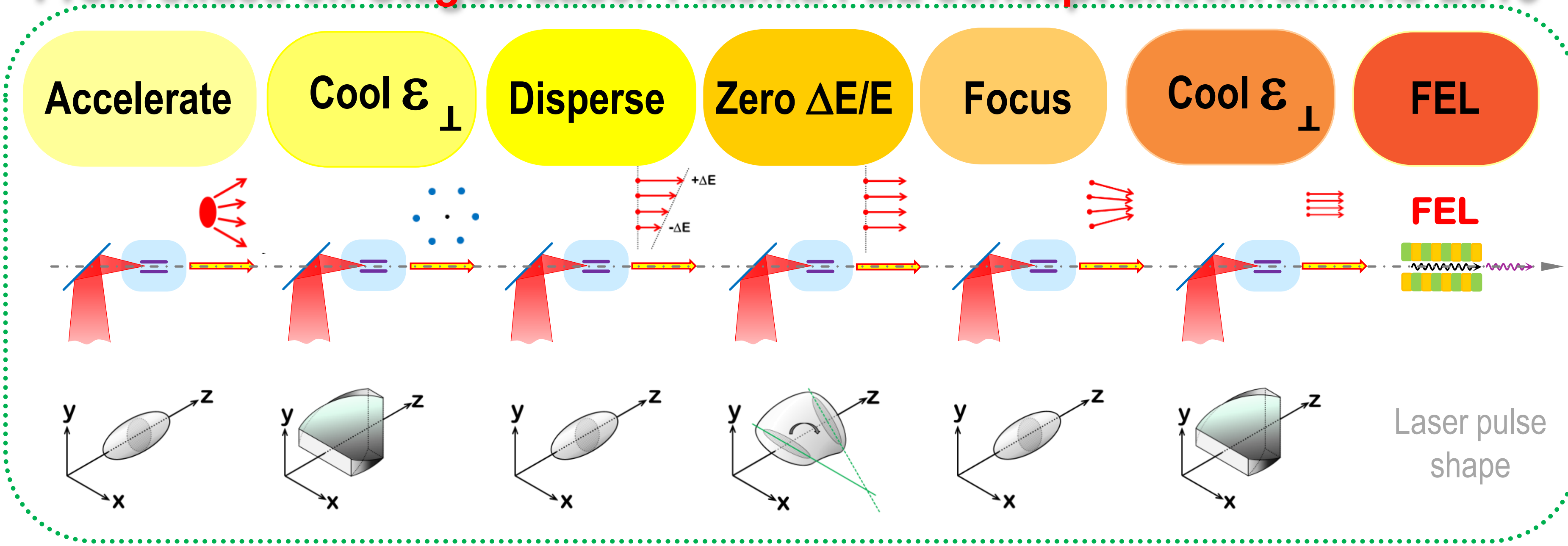


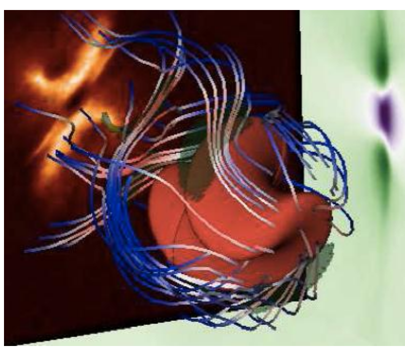
Spiral-shaped laser pulse => Giga-gauss solenoidal field in plasma bubble => Fast SR cooling of transverse DOF=> new approach to design laser-plasma FEL or collider

Further studies have shown that the cooling rate has been significantly overestimated. This approach is not viable at present technologies.

Linear cooling system?

From slides on Staged Laser-Plasma FEL concept shown at AAC 2016

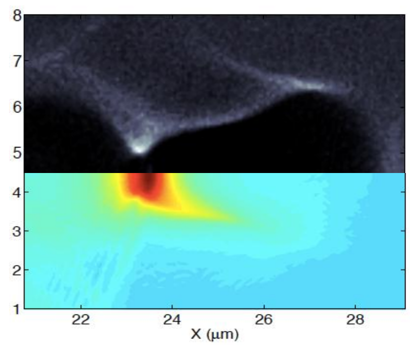




Screw-shaped laser pulse and trajectories of electrons - left

Bubble shape (top) and solenoidal field map (bottom) - right

A. Seryi, et al

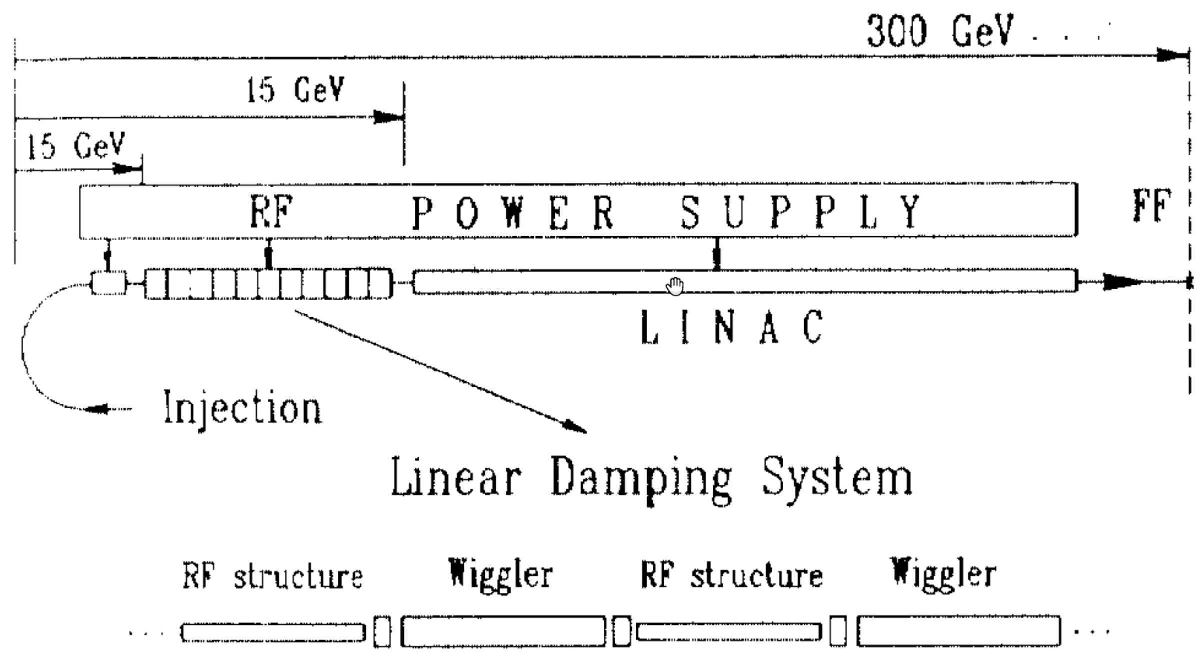


Spiral-shaped laser pulse => Giga-gauss solenoidal field in plasma bubble => ~~Fast SR cooling of transverse DOF~~=> ~~new approach to design laser-plasma FEL or collider~~

Further studies have shown that the cooling rate has been significantly overestimated. This approach is not viable at present technologies.

Linear cooling systems – other ideas

- **Straightline cooling system –chain of wigglers interleaved with RF acc sections**
- **Advantage – no x-dispersion (unlike in Damping Rings), => no quantum excitation of x-motion => much smaller emittance of the cooled beam**
- **Difficulties (that time) – challenging requirements for fields and gradient**



"Straightline cooling system for obtaining beams of electrons and positrons with minimal emittance", N. Dikansky, A. Mikhailichenko,
Preprint Budker INP, 1988-009, Novosibirsk 1988 (in Russian).
http://www.inp.nsk.su/activity/preprints/files/1988_009.pdf
And also in proceedings of EPAC 1992.


ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

Н.С. Диканский, А.А. Михайличенко

ПРЯМОЛИНЕЙНАЯ ОХЛАЖДАЮЩАЯ СИСТЕМА ДЛЯ ПОЛУЧЕНИЯ СГУСТКОВ ВЫСОКОЭНЕРГИЧНЫХ e^+, e^- С ПРЕДЕЛЬНО МАЛЫМ ФАЗОВЫМ ОБЪЕМОМ

ПРЕПРИНТ 88-9

НОВОСИБИРСК

Linear cooling systems – follow-ups

"Potential of Non-standard Emittance Damping Schemes for Linear Colliders", H.H. Braun, M. Korostelev, F. Zimmermann, CLIC Note 594 (2004)

"Linear Damping System for the International Linear Collider", G. Dugan, in Proc of PAC 2005

Summary and Issues

The parameters of the linear damping systems discussed above are presented in Table 1.

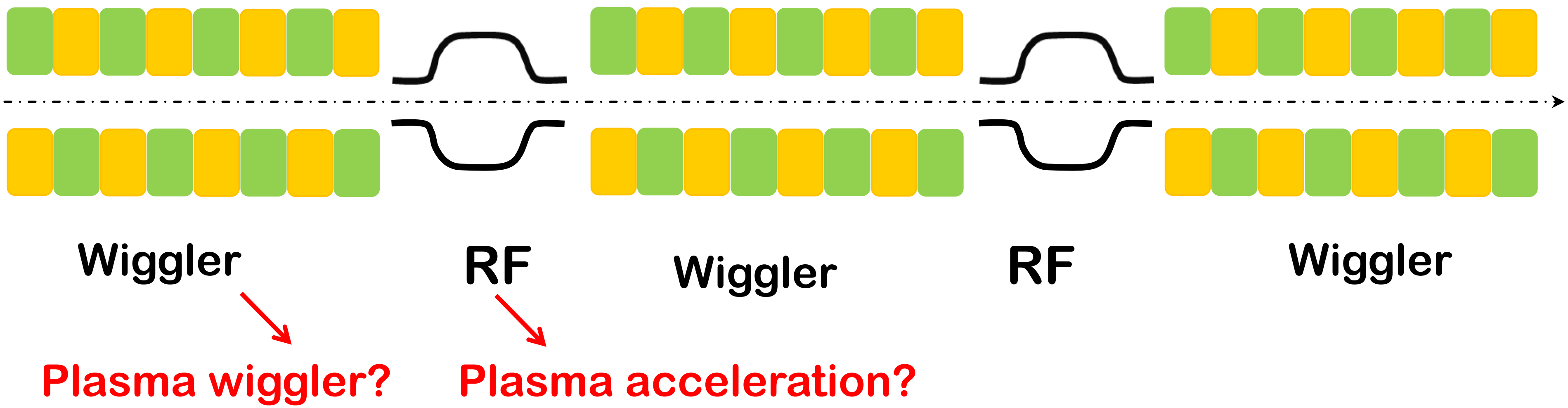
There are a number of major issues in the implementation of these linear damping schemes. The technological challenge of building many kilometers of high-field, short period wigglers is daunting. Small beta functions and ultra-small dispersion functions are required throughout the wigglers (see Table 1). This will result in very tight tolerances on the alignment of the wigglers and the quadrupoles required for transverse focusing. The relatively large energy spread of the damped beam makes bunch compression very difficult to do subsequent to the linear dampers. Bunch compression prior to the dampers leads to high peak currents in the wigglers, which may present stability problems.

Table 1: Linear damping examples for ILC applications. β = 2 m, and the radiated power is calculated for the nominal ILC current.

Application	B_0 [T]	E_0 [GeV]	N_{damp}	L [km]	λ_u [cm]	$(\gamma_0\epsilon_h)_f$ [μm]	$\frac{\sigma_{\gamma,f}}{\gamma_{0,i}}$ [$\times 10^{-3}$]	η_{pk} [μm]	$\langle \frac{dP}{ds} \rangle$ [kW/m]
Electron damper	10	23.5	7.6	10.2	11	8.1	6.6	39	1.58
Positron damper	10	23.5	13.5	18.1	11	8.1	6.6	39	1.58
Positron predamper	15	5	5.9	9.1	13.5	41	3.7	275	0.160
Afterdamper	5	47	2.3	6.2	31	8.0	6.6	9.7	1.58

Linear cooling systems – plasma?

- **Is it conceivable to replace wigglers and RF acceleration with plasma?**



- **Can be studied**
- **Issues to watch for:**
  - **Transverse position tolerances**
  - **Impact on the overall efficiency of the collider (wall-plug)**
  - **Etc.**

Now let's look at Final Focus

- **Assumption:**
  - **plasma acceleration allows to make very short linacs ☺**
- **But:**
  - **"CLIC Final Focus is 3km long" ☹**
- **How to use advantages of plasma acceleration?**

- **Why FF of conventional LC is 3km?**
- **How the requirements to detectors (physics reach or precision) need to be modified to take full advantage of the new technology and to devise a compact plasma-based collider?**

- ***In the following slides, will make significant simplifications of the issues***

Why 3km for CLIC FF?

- First of all, 3km is entire BDS (beam delivery), and FF is a short fraction of BDS
- BDS includes – beam diagnostics, coupling correction section, betatron collimation, energy collimation, final focus.
- In CLIC the longest components of BDS are E-collimation and FF
- Let's ignore other systems and consider, very approximately, only the two main:

E-collimation (2.3km)	FF (0.7km)

Why 3km for CLIC FF?

- **First of all, 3km is entire BDS (beam delivery), and FF is a short fraction of BDS**
- **BDS includes – beam diagnostics, coupling correction section, betatron collimation, energy collimation, final focus.**

- **In CLIC the longest components of BDS are E-collimation and FF**

- **Let's ignore other systems and consider, very approximately, only the two main:**

E-collimation (2.3km)	FF (0.7km)

Where the requirements for the length are coming from?

They are coming not really from the optics, but really originates from requirements from detectors, e.g. physics reach

CLIC FF length – what defines it?

E-collimation (2.3km)	FF (0.7km)

- Collimation system – defined by the requirement from detector to cut all beam tails beyond certain number of sigmas (e.g. 10)

- The collimation system is thus ensures that there are no losses closer than few hundred meters from the IP – maintain clean background-free conditions in the detector

CLIC FF length – what defines it?

E-collimation (2.3km)	FF (0.7km)

- Collimation system – defined by the requirement from detector to cut all beam tails beyond certain number of sigmas (e.g. 10)
- The collimation system is thus ensures that there are no losses closer than few hundred meters from the IP – maintain clean background-free conditions in the detector

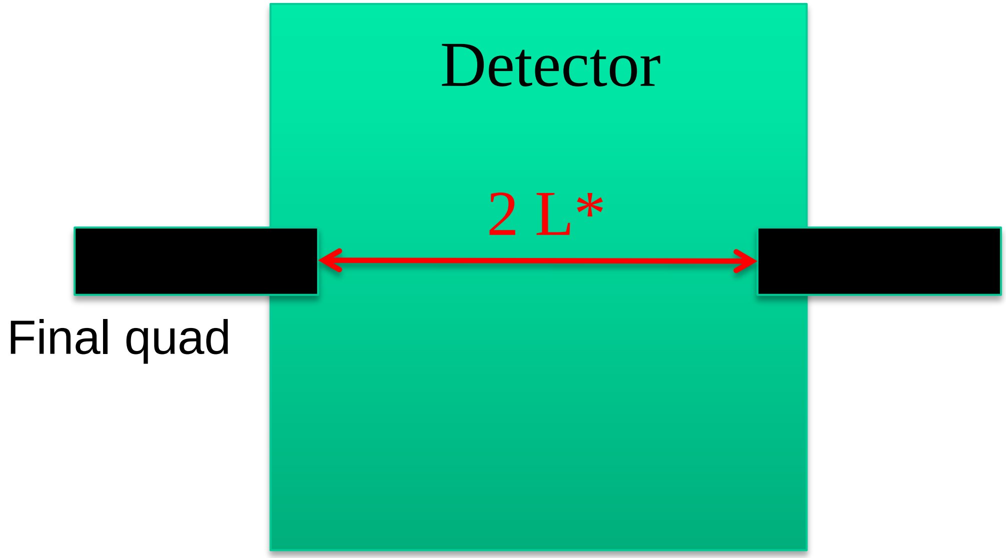
The length of the collimation system, maybe surprisingly, is primarily defined by machine protection system requirements – the collimators should be able to survive a full mis-steered train

(In ILC, where bunch separation is much longer, collimators have to survive just two bunches, as the rest of the train can be diverted)

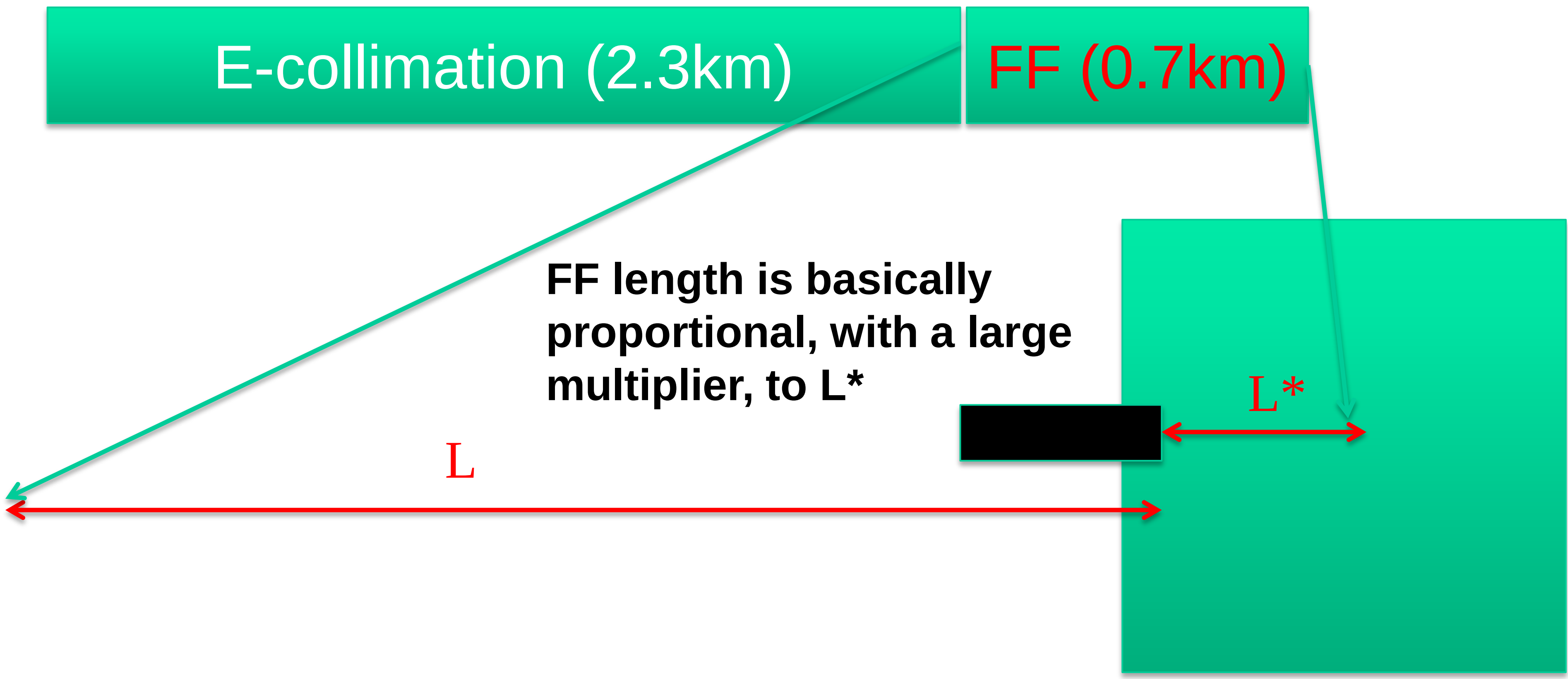
CLIC FF length – what defines it?

E-collimation (2.3km) | FF (0.7km)

Final focus – defined by 1) the requirement from detector to have the L* longer than certain value, to avoid interference with accelerator; and 2) push for lowest beta* to minimize beam size



CLIC FF length – what defines it?



To derive very rough scaling assume that chromaticity of final lenses (which is L*/beta*) dominates. This gives

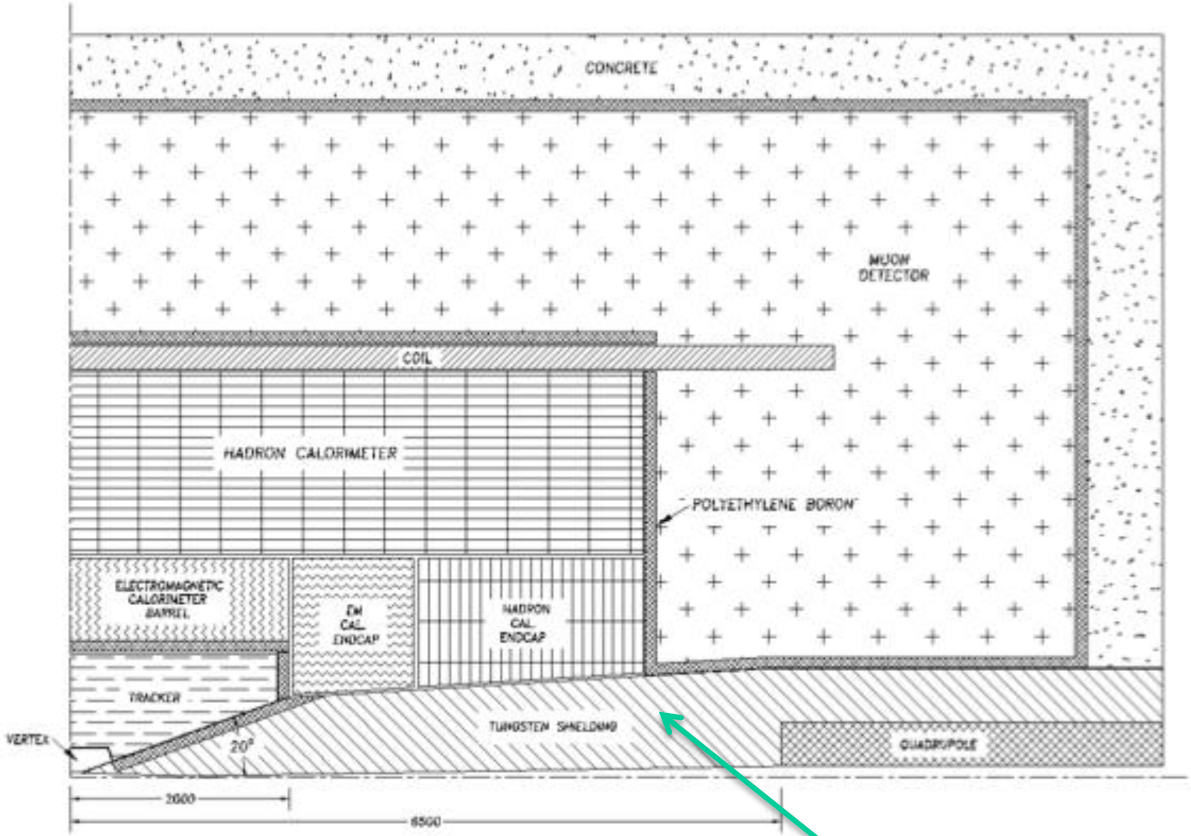
$$L \sim L^* \; (L^* / \beta^*) \; \Delta E/E$$

Assume L*=5m, beta*=0.1mm, deltaE/E=0.2% => L~ 500m

FF and collimations

- **Conclusions for plasma collider**
  - **To take advantage of plasma technology, have to modify detector requirements (and thus work with HEP on a possible detector, background and event reconstructions)**
  - **Such a work and detector design modification, due to requirements from the technology, is not unique**
  - **Look, for example, how muon collider technology proponents adjusted their detector concept to take into account the fact that muons decay and give background on the detector axis – see next slide**

Strawman Detector Concept for a Muon Collider



Dec 11, 2008 S. Kahn -- Muon Collider Detector Backgrounds 7

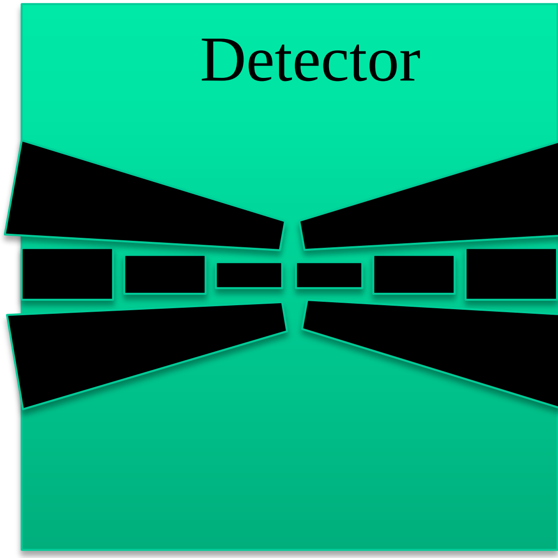
Tungsten shielding cone

A possible FF / IR approach for plasma collider

– for discussion

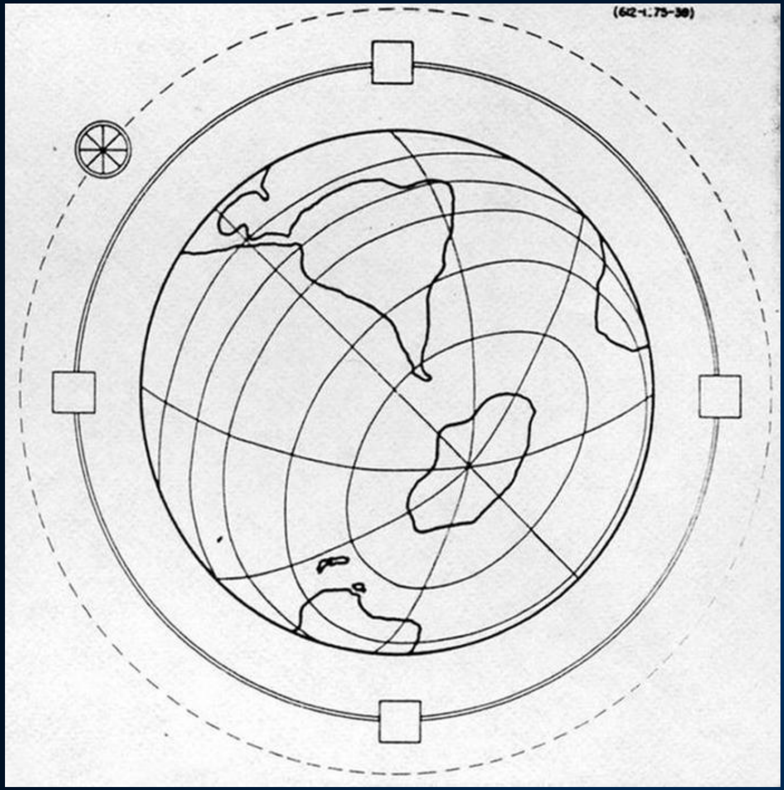
- Radically reduce L* - then the FF is very short and adiabatic focusing with short L* have large energy acceptance
(Maybe use plasma focusing)

- May have to have shielded exclusion cone in the detector



- Collimation – assume no dedicated stand-alone collimation system to start with
- Explore incorporating some collimation in drifts between accelerating stages

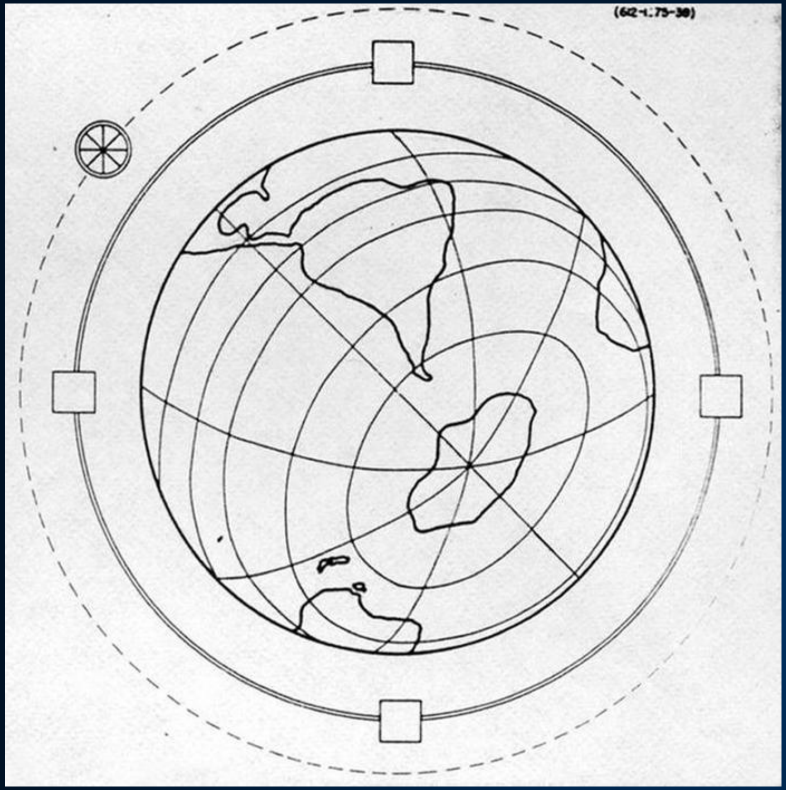
Evolution of accelerators



In 1954 Enrico Fermi presented, in his lecture, a vision of an accelerator that would encircle the Earth, and would attain highest possible energies

Would this be indeed a natural evolution of accelerators?

Evolution of accelerators



Enrico Fermi Earth accelerator, 1954

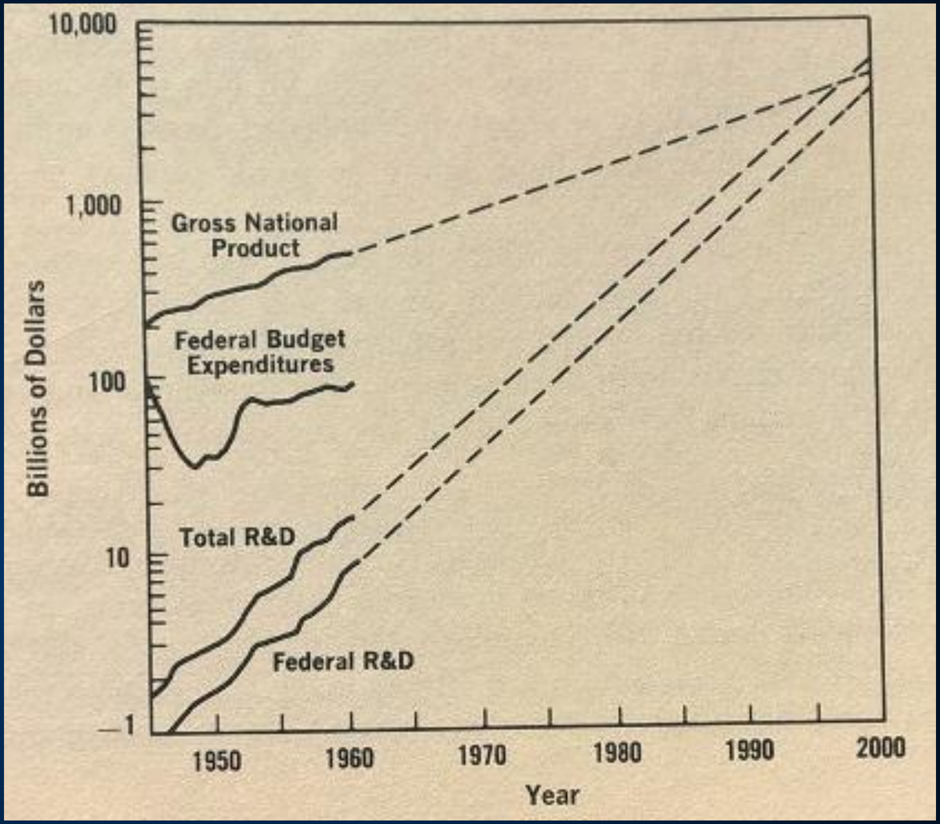
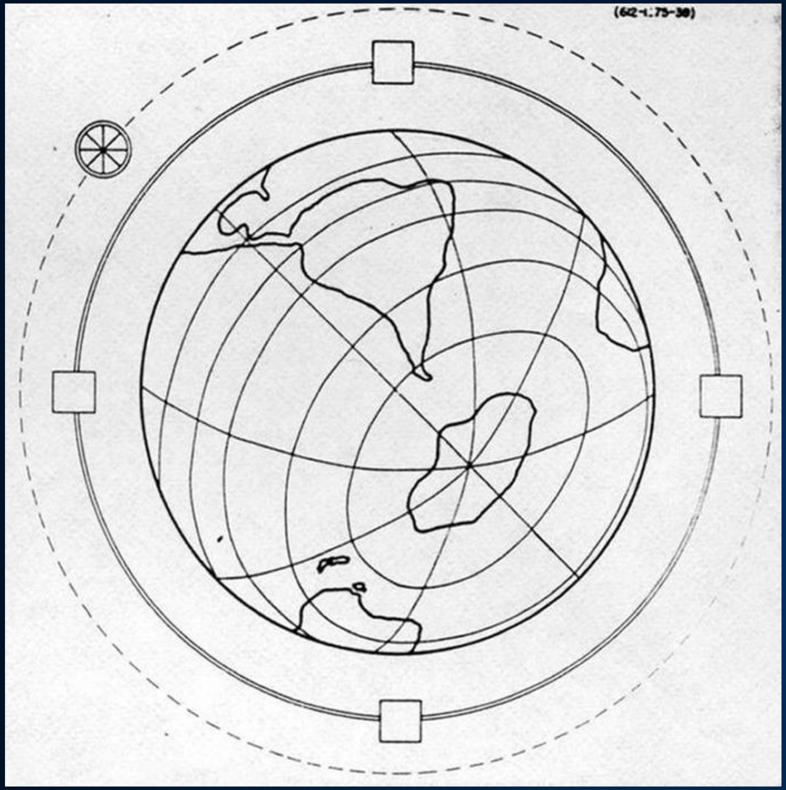


Fig 6, GNP and R&D: Failure of naïve extrapolation.
"The Year 2000", 1968, K. Herman, A. Wiener

Would this be indeed a natural evolution of accelerators?

No. And not only because R&D budget is now not growing faster than GDP

Evolution of accelerators



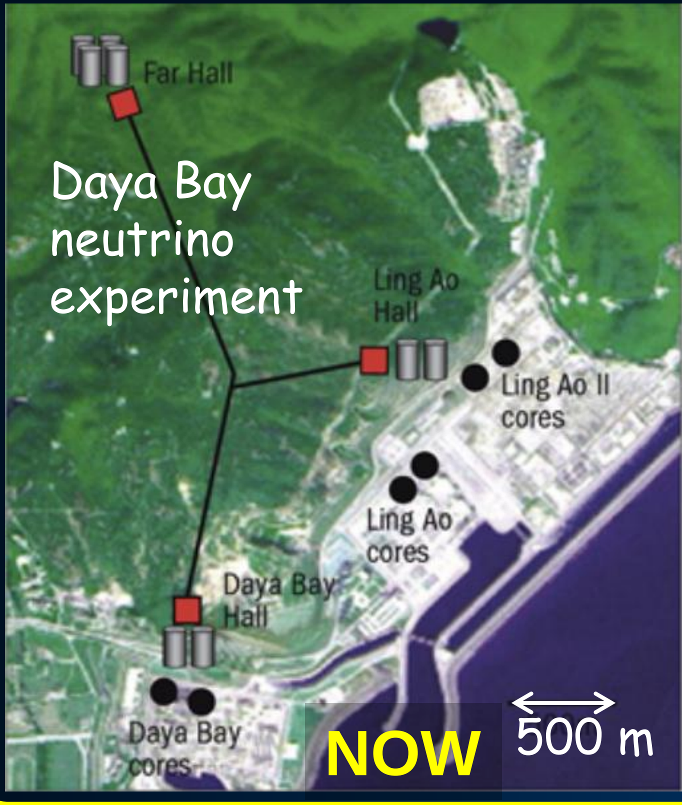
Enrico Fermi Earth accelerator, 1954

Would this be indeed a natural evolution of accelerators?

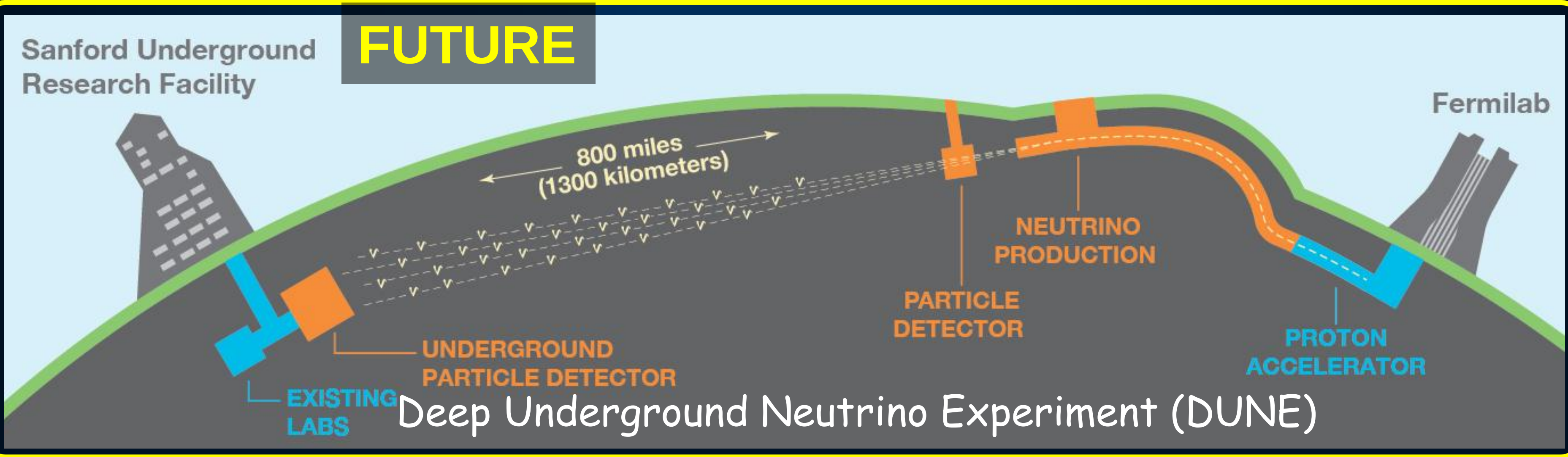
No.

Increasing the size or base of the experiment, to increase precision, with proportional or event faster increase of the cost, would unlikely be accepted by governments and society

Evolution of neutrino experiments



Increasing the size or base of the experiment, to increase precision, <u>without</u> proportional increase of the cost – good chance to be accepted by society & governments



Evolution of neutrino

Far Hall

UK signs £65m science partnership agreement with US

20 September 2017

The UK is investing £65million in a flagship global science project based in the United States that could change our understanding of the universe. The investment, made under a new UK-US Science and Technology agreement, further secures the UK's position as the international research partner of choice.

Today, UK Universities and Science Minister Jo Johnson signed the agreement with the US Energy Department to invest the sum in the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE). DUNE will study the properties of mysterious particles called neutrinos, which could help explain more about how the universe works and why matter exists at all.

This latest investment is part of a long history of UK research collaboration with the US, and is the first major project of the wider UK-US Science and Technology agreement.

Jo Johnson (UK Minister of State for Universities, Science, Research and Innovation) and Judith G. Garber (U.S. Acting Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs) signed the U.S.-UK Science and Technology Agreement on Sept. 20 in Washington, D.C.
(Credit: FCO)

PARTICLE DETECTOR

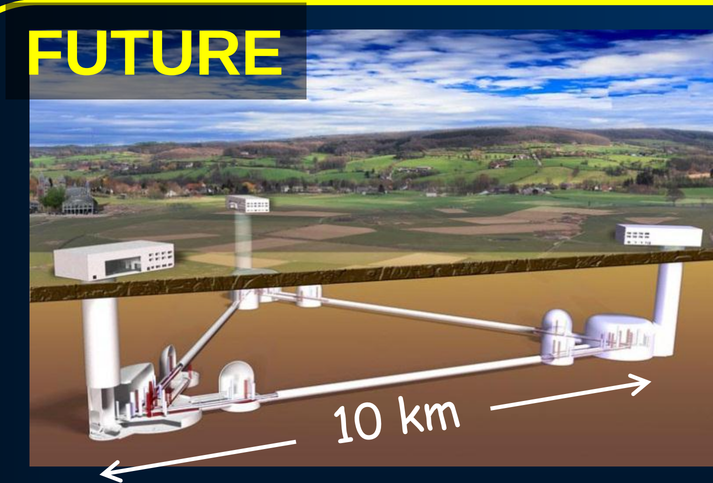
EXISTING LABS

ACCELERATOR

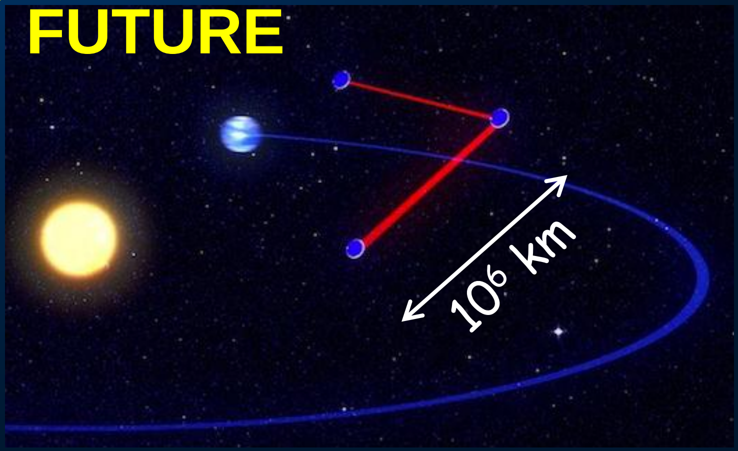
Deep Underground Neutrino Experiment (DUNE)

Evolution of gravitational wave detectors

Increasing the size or base of the experiment, to increase precision, without proportional increase of the cost – good chance to be accepted by society & governments

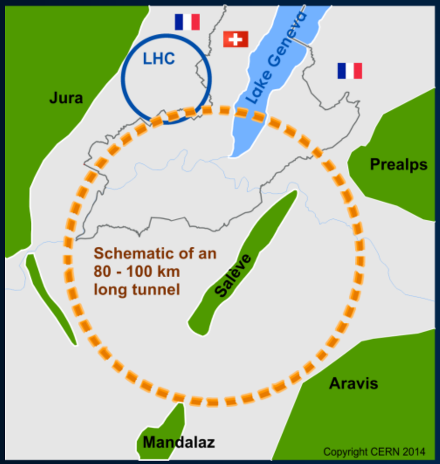


Einstein telescope



eLISA

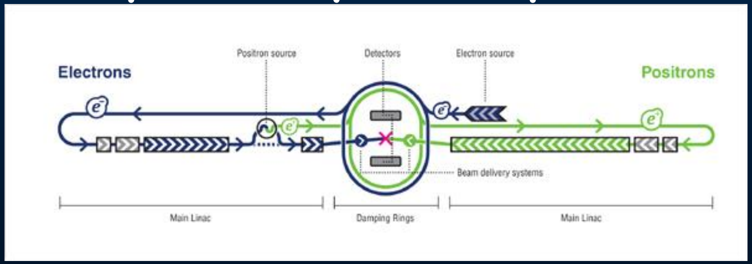
From that point of view – can next big conventional collider be built (accepted by government & society)?



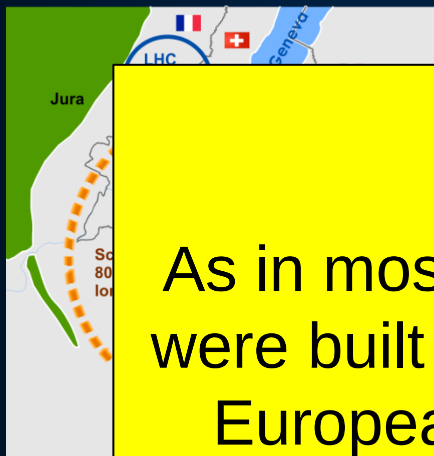
Circular collider FCC (CERN)

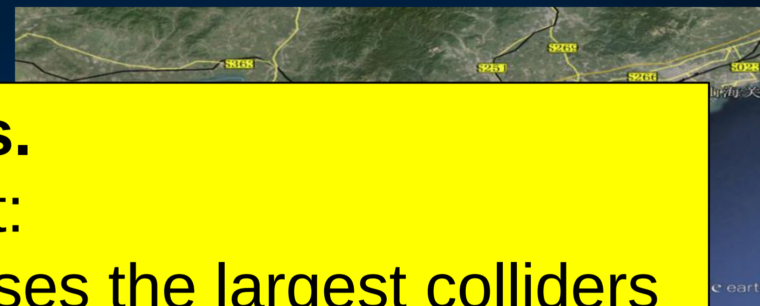
Circular collider CEPC (China)

Linear collider
ILC
(possibly in Japan)



From that point of view – can next big conventional collider be built (accepted by government & society)?





Yes.

But:

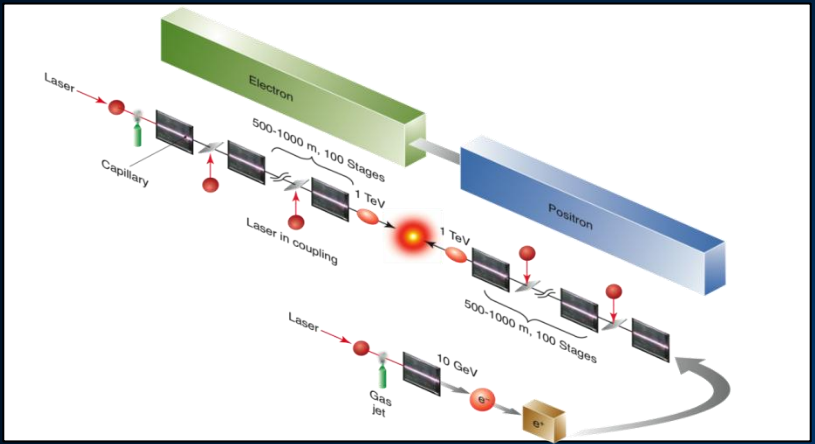
As in most of previous cases the largest colliders were built as mostly regional efforts (e.g. primarily European funding for LHC), building ~3 times larger and more expensive collider perhaps can be done but only with all world efforts combined.

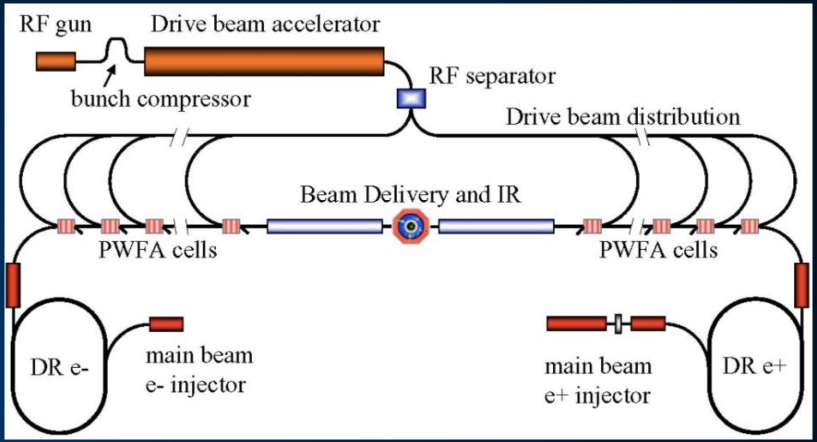
I.e. only once more.

This is then really the limit.

(Assuming that the motivations for the collider are still the same – fundamental science)

What is then the role and plan for plasma collider?





Obvious: make a better and competitive design

Thank you for your attention!