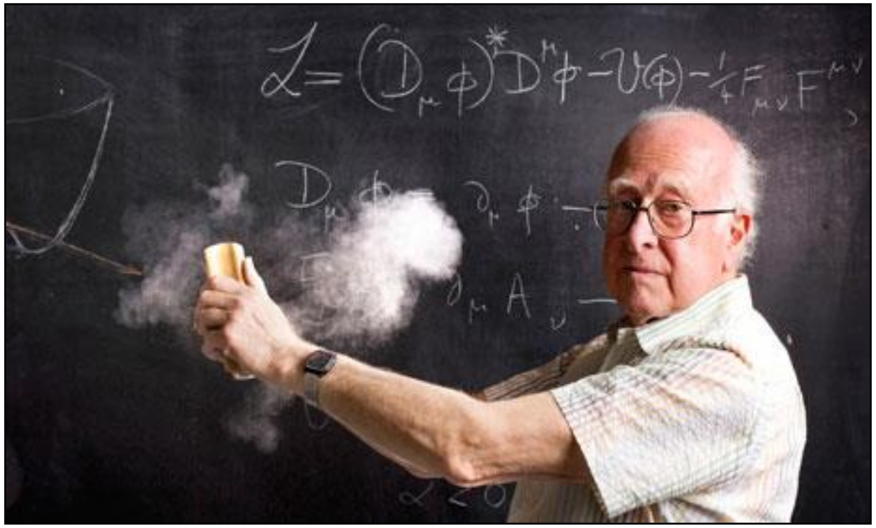
Future High Energies Linear Colliders

Louis Rinolfi

CERN

General physics context today

ATLAS and CMS announced on 4th July 2012 the discovery of a Higgs boson at 126 GeV



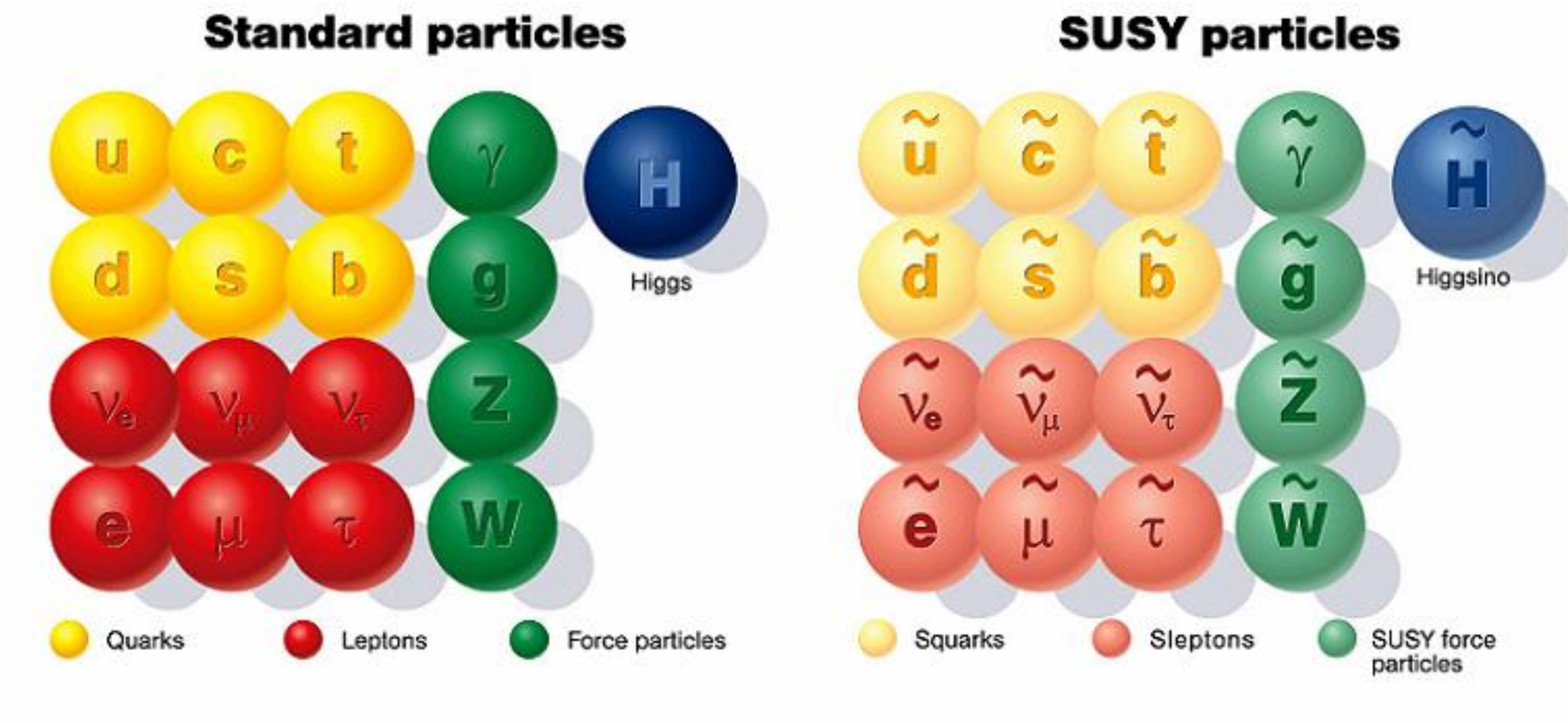
Peter Higgs

With this discovery, the Standard Model is now complete.

Do we need other high energy colliders ?

The answer is "yes", but at which Energy ?

SUSY or Super Symétrie

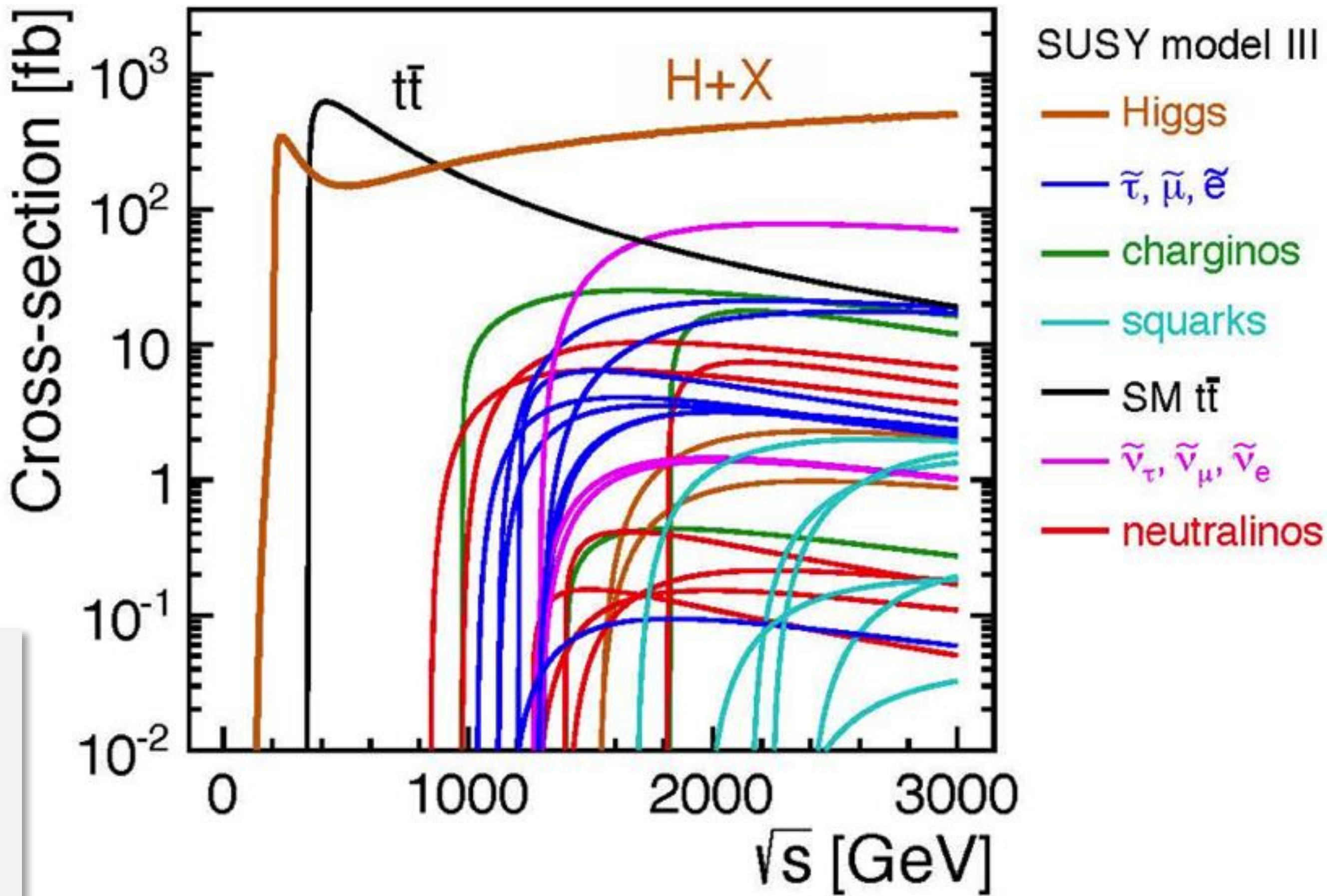


* **Each particle could have a super symmetric particle**

Physics context with Super Symmetry

Energy-frontier model for leptons collisions,

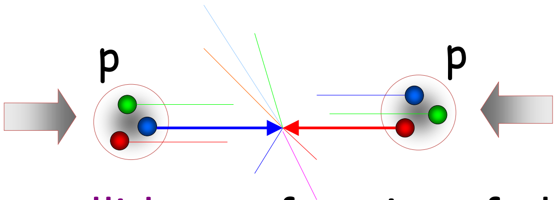
New physics from LHC ?



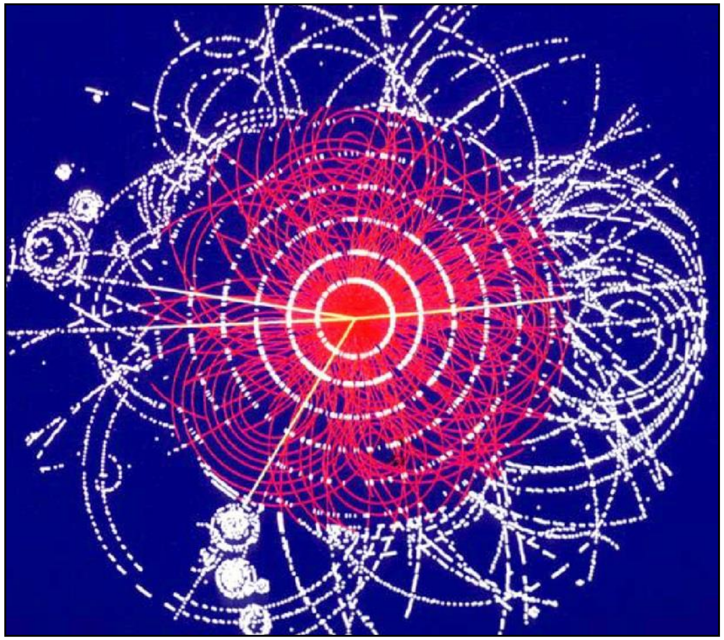
- Higgs physics (SM and non-SM)
- SUSY
- Extra dimensions
- ?

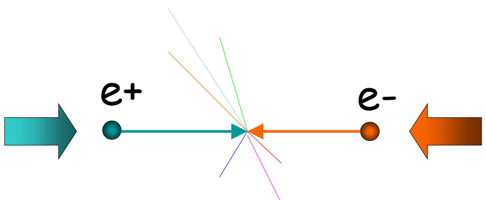
How do we build the optimal machine given a physics scenario ?

Hadrons versus leptons colliders

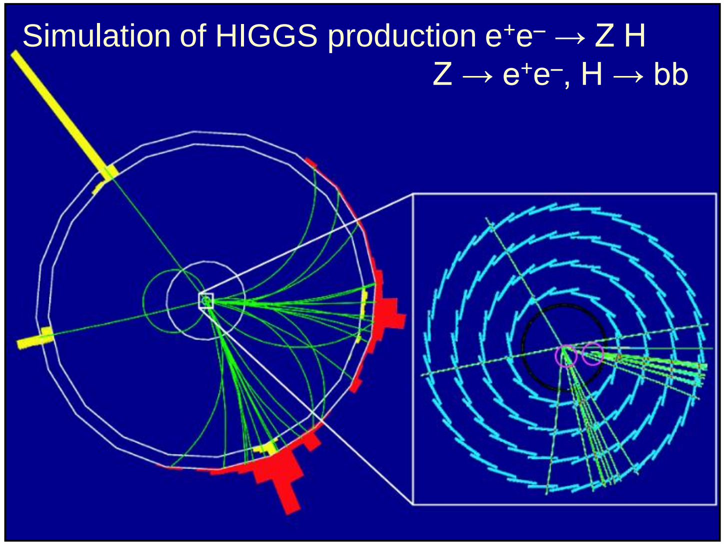


- hadron collider => frontier of physics
  - discovery machine
  - quarks collisions
  - huge background
  - not all nucleon energy available in collision

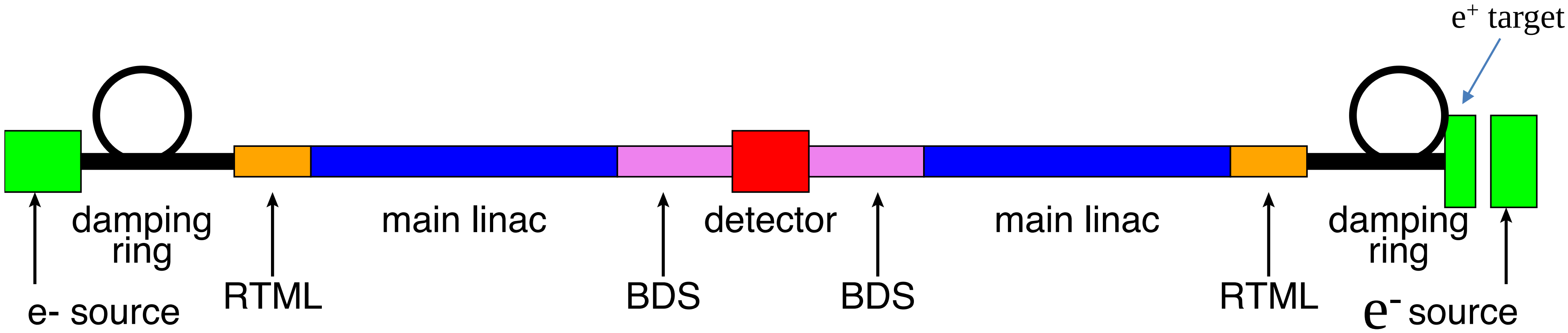




- lepton collider => precision physics
  - study machine
  - elementary particles collisions
  - well defined CM energy
  - polarization possible

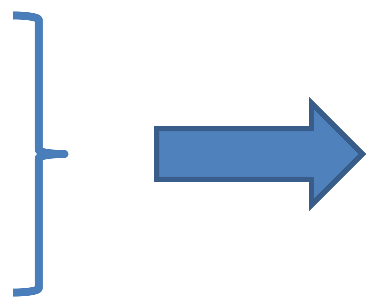


Linear Collider Challenges



Reach the highest collision energy

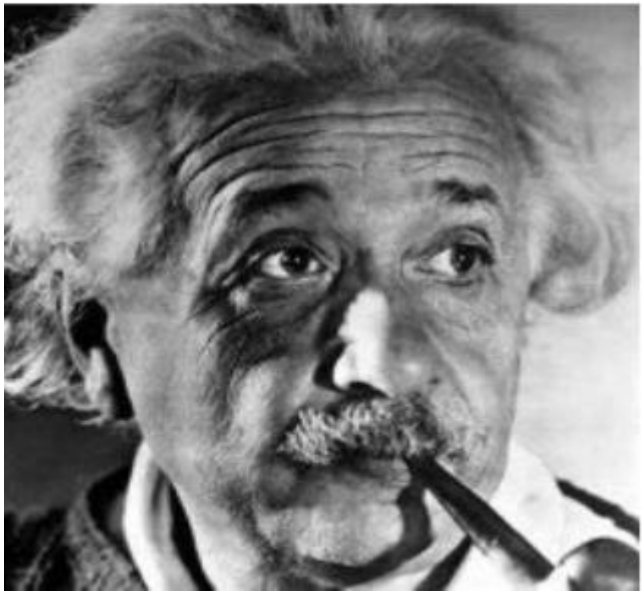
Reach the highest luminosity



With a reduced power consumption and a minimum cost

BDS = Beam Delivery System
RTML = Return To Main Linac

Energy



$$E = mc^2$$

Well known !

<u>Particles</u>

W   80 GeV

Z   91 GeV

H   126 GeV

t   171 GeV

<u>Futures machines ?</u>

380 GeV

500 GeV

1 TeV

3 TeV

5 TeV

100 TeV

… PeV

Luminosity

The number of events for a particular type of event is given by:

Number of events = L x σ_{event}

σ_{event} ***is the probability of producing a particular event***
L is a measure of the total number of interactions

The unit of the cross-section (σ_{event}**) is the barn (1 barn =** 10^{-28} m^2**)**
=> 1fb = 10^{-43} m^2

If the cross-section to produce a given event is 1fb then we would need $1fb^{-1}$ of data to get 1 event!!

$$L = N_{events} / \sigma_{event}$$

Major parameters for linear colliders

Energy (center of mass) $$E_{cm} = 2\, F_{fill}\, L_{linac}\, G_{RF}$$

E_{cm}: MeV; L_{linac}: m; G_{RF}: MV/m

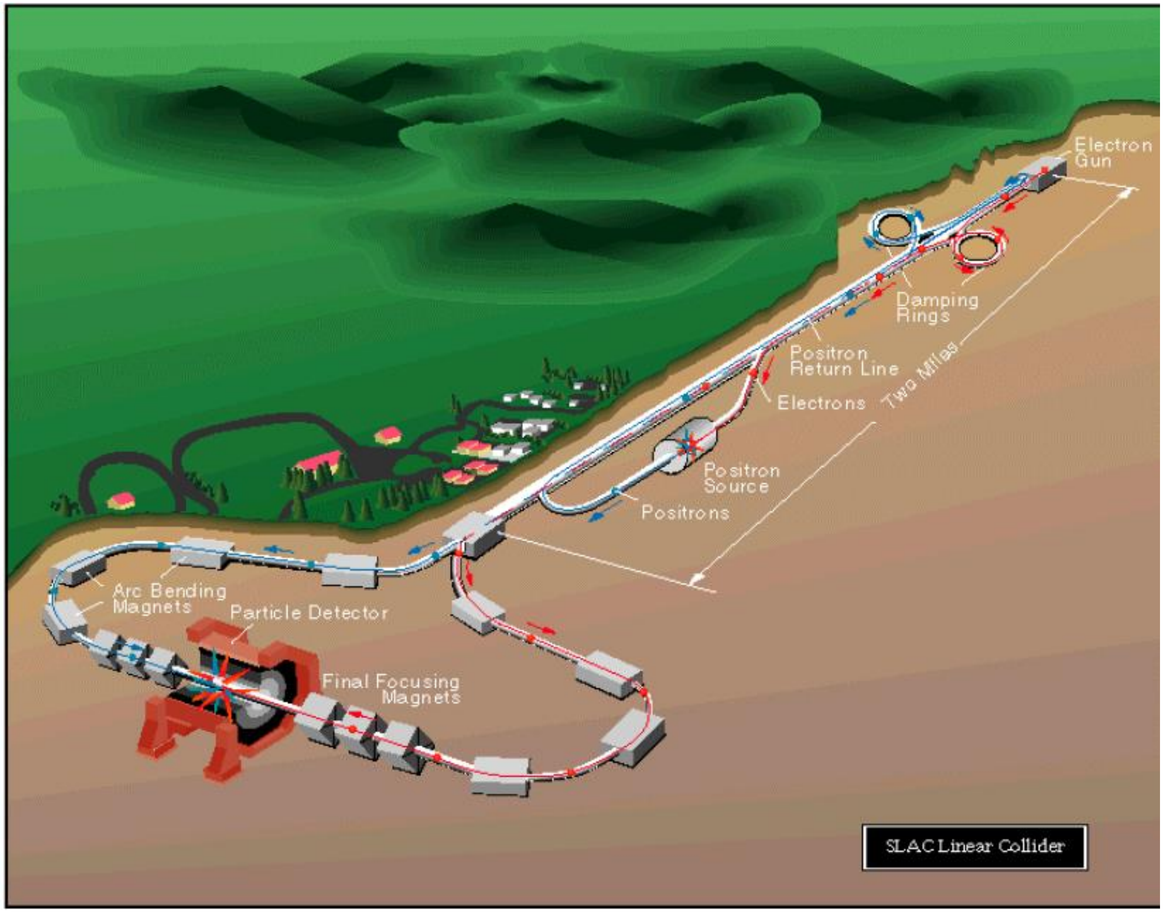
Luminosity (basic) $$L = \frac{n_b\, N^+ N^-\, f_{rep}}{4\pi\, \sigma_x\, \sigma_y}$$

L: cm^{-2} s^{-1}; f_{rep}: Hz; σ_x, σ_y: cm

F_{fill} = Filling factor of the Linac; L_{linac} = Length of the linac; G_{RF} = accelerating gradient

n_b = number of bunches; N = number of particles per bunch; σ_x, σ_y = beam size parameters

SLC (Stanford Linear Collider) – California - USA



2 experiments: MARK II, SLD
Energy: 92 GeV
Peak Luminosity: $2x10^{30}cm^{-2}s^{-1}$

The only Linear Collider who was running with a beam (up to now)

Operation: 1989-1998

Brief history of CLIC (Compact Linear Collider $e^+ e^-$)

1985: **CLIC = CERN Linear Collider**

CLIC Note 1: “Some implications for future accelerators” by J.D. Lawson => first CLIC Note

1995: **CLIC = Compact Linear Collider**

=> 6 Linear colliders studies (TESLA, SBLC, JLC, NLC, VLEPP, CLIC)

2004: International Technology Recommendation Panel selects the Superconducting RF technology (TESLA based) versus room temperature technology (JLC/NLC based)

=> ILC at 1.3 GHz for the TeV scale and CLIC study at 30 GHz continues for the multi-TeV scale

2007: **Major parameters changes:** 30 GHz => **12 GHz** and 150 MV/m => **100 MV/m**

2012 : July: Higgs boson discovery at LHC
CERN Council Strategy group for Particle Physics (Krakow September 2012)
Publication of CLIC - CDR (Conceptual Design Report)

2017: Rescaling of the CLIC energy at 380 GeV for the first phase

Physics at CLIC

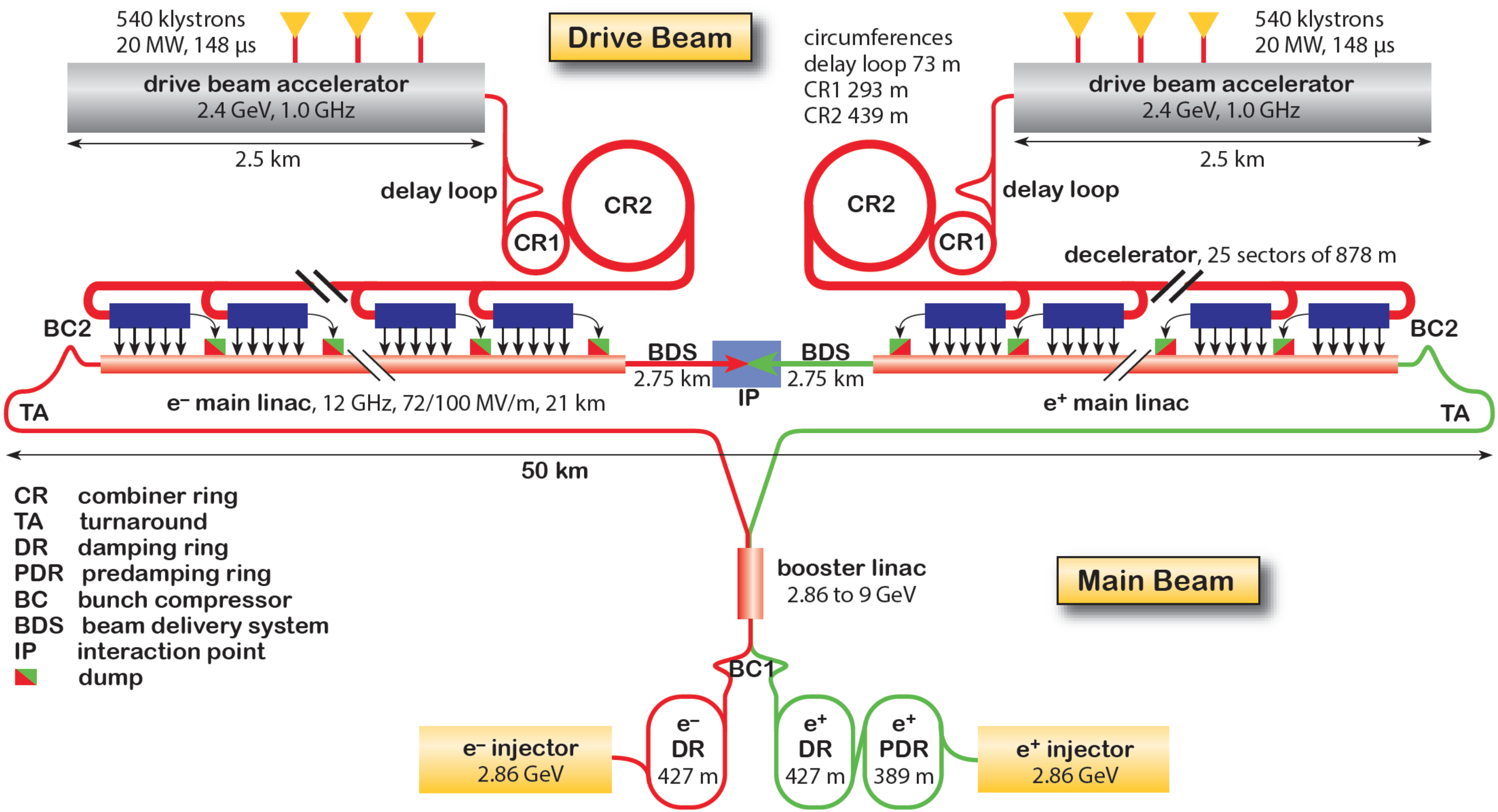
Seminar by Lucie Linssen (CERN)

24^{th} January 2017

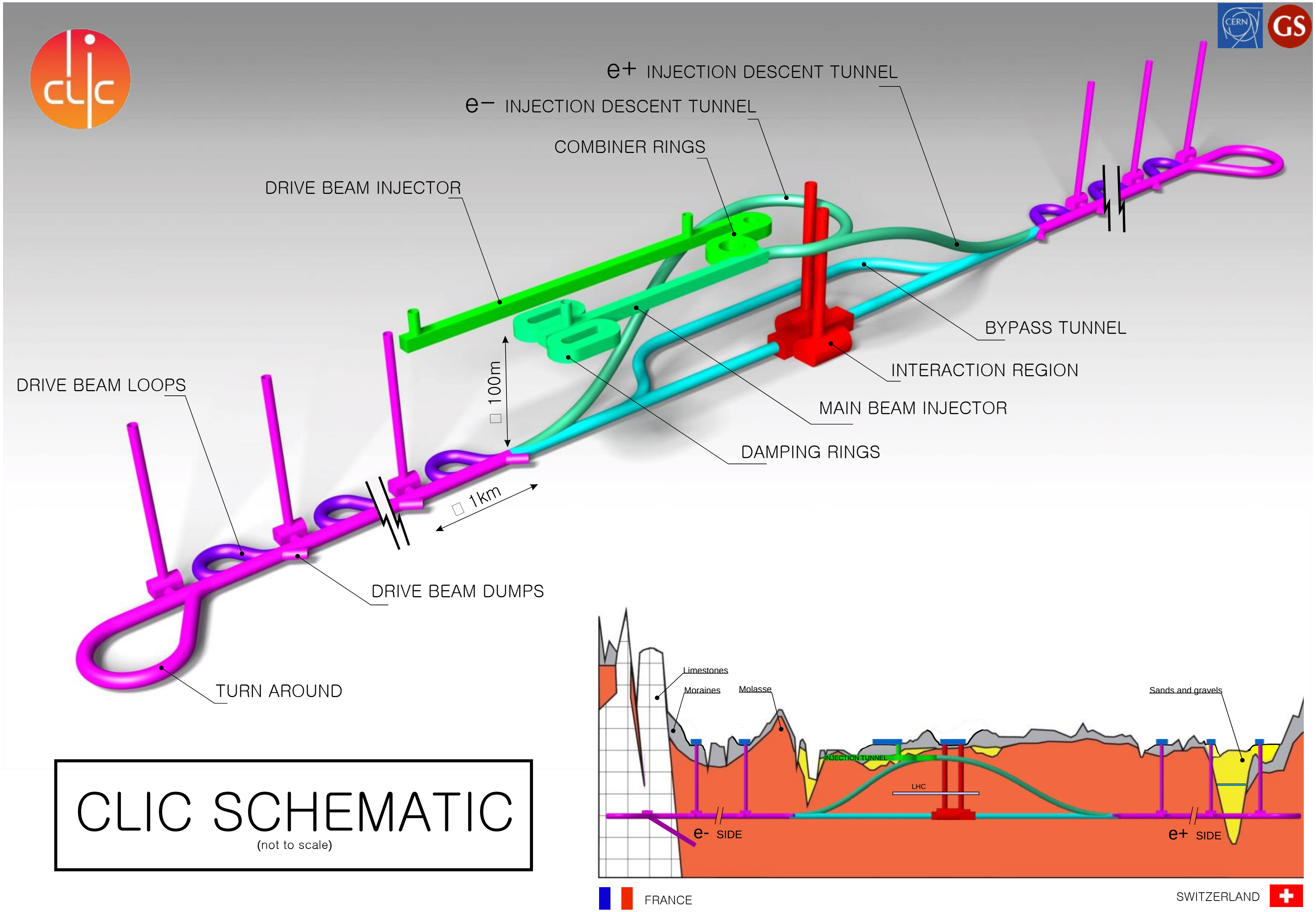
Following the discovery of the Higgs boson, the CLIC potential for precision Higgs measurements is addressed for several centre-of-mass energies

https://indico.cern.ch/event/571073/

CLIC Layout (3 TeV) $e^+ e^-$



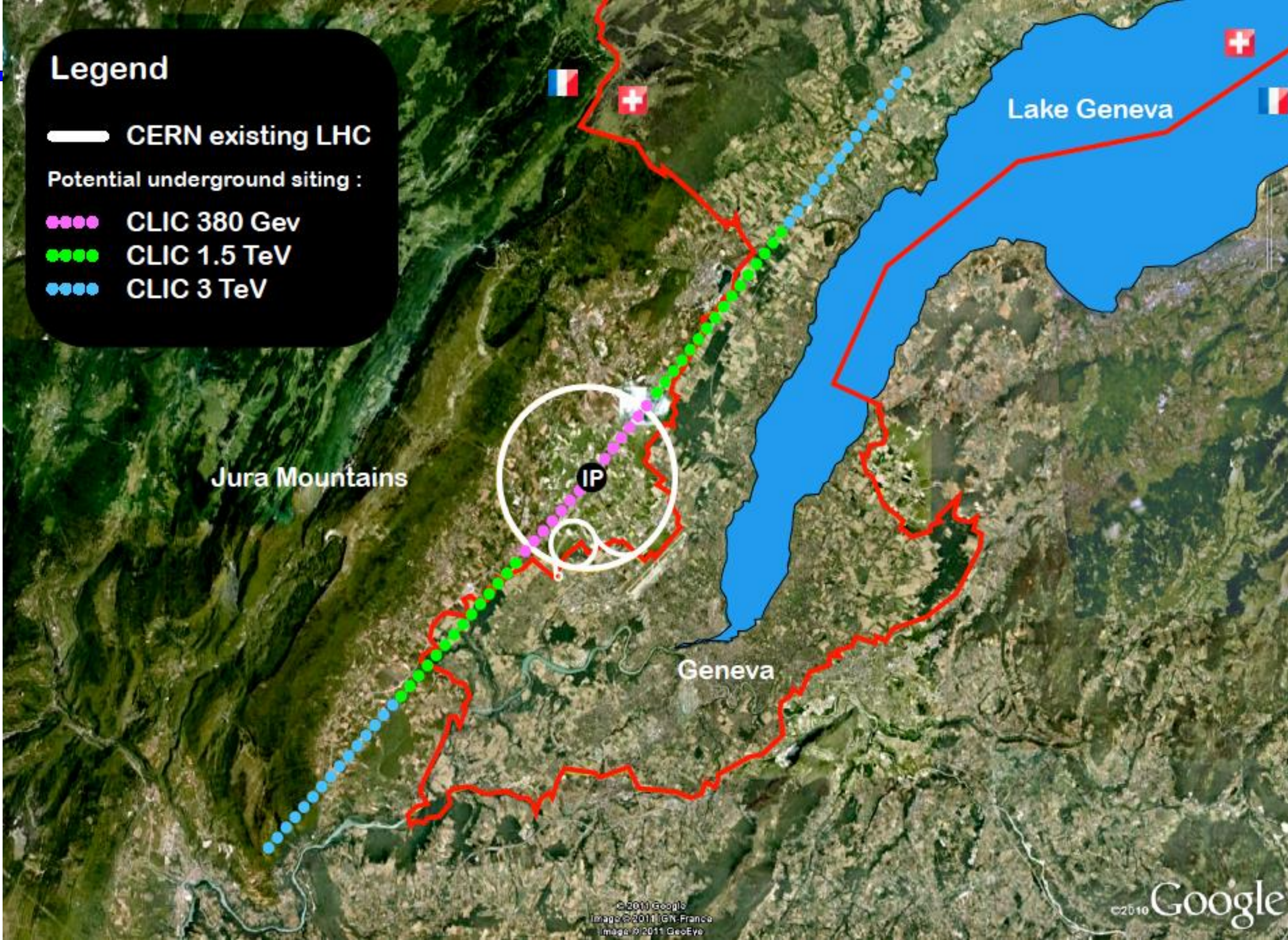
CLIC Tunnel layout



CLIC staging parameters

Parameter	380 GeV	1.5 TeV	3 TeV
Luminosity L ($10^{34}cm^{-2}sec^{-1}$)	1.5	3.7	5.9
L above 99% of $\sqrt{s}$ ($10^{34}cm^{-2}sec^{-1}$)	0.9	1.4	2.0
Accelerator gradient (MV/m)	72	72/100	72/100
Site length (km)	11.4	29	50
Repetition frequency (Hz)	50	50	50
Bunch separation (ns)	0.5	0.5	0.5
Number of bunches per train	352	312	312
Beam size at IP σ_x/σ_y (nm)	150/2.9	~60/1.5	~40/1
Beam size at IP σ_z (μm)	70	44	44
Estimated power consumption* (MW)	252	364	589

**scaled from CDR, with room for improvement*



Legend
CERN existing LHC
Potential underground siting :
CLIC 380 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva
©2011 Google
Image ©2011 IGN-France
Image ©2011 GeoEye
©2010 Google

A tremendous amount of challenging parameters

Accelerating gradient (G = 100 MV/m)

Very low break down rate in the accelerating cavities (BDR < 10^{-7})

Beam emittance production and preservation ($\gamma\varepsilon_n$ = 5 nm.rad at Damping ring exit)

Ground motion and stability requirements

Positron flux (1.1 10^{14} e^+/s => 20 times more than the SLC machine produced)

Beam size at IP (σ_y = 1 nm)

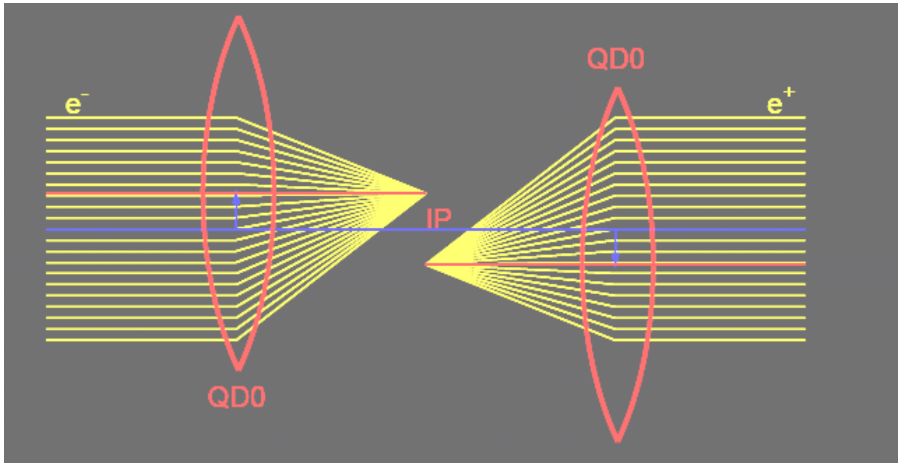
Power consumption (~ 600 MW)

Cost (several billions of €, $, CHF,…..)

+ many others; none will be discussed in this seminar; only the beam size at IP is illustrated in the next slide

Challenges at the Interaction Point: beam size

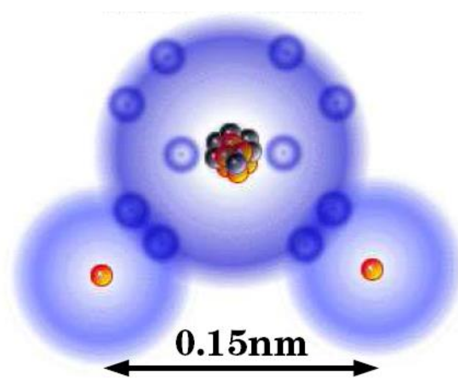
Vertical spot size at IP is 1 nm



Stability requirements (> 4 Hz) for a 2% loss in luminosity

Magnet	Horizontal jitter	Vertical jitter
Linac (2600 quads)	14 nm	1.3 nm
Final Focus (2 quads) QD0	4 nm	0.15 nm

H_2O molecule



CLIC Timeline

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

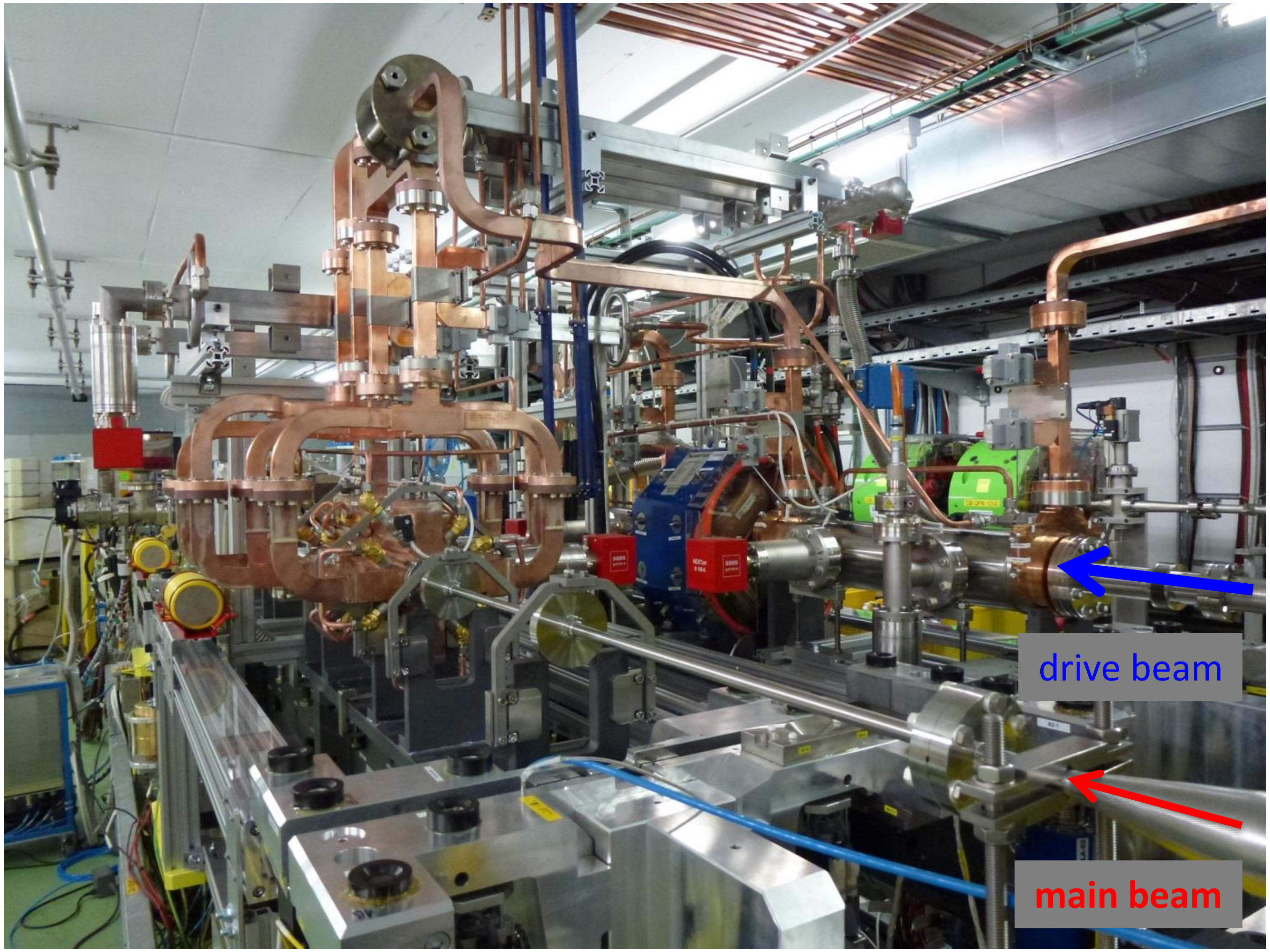
2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

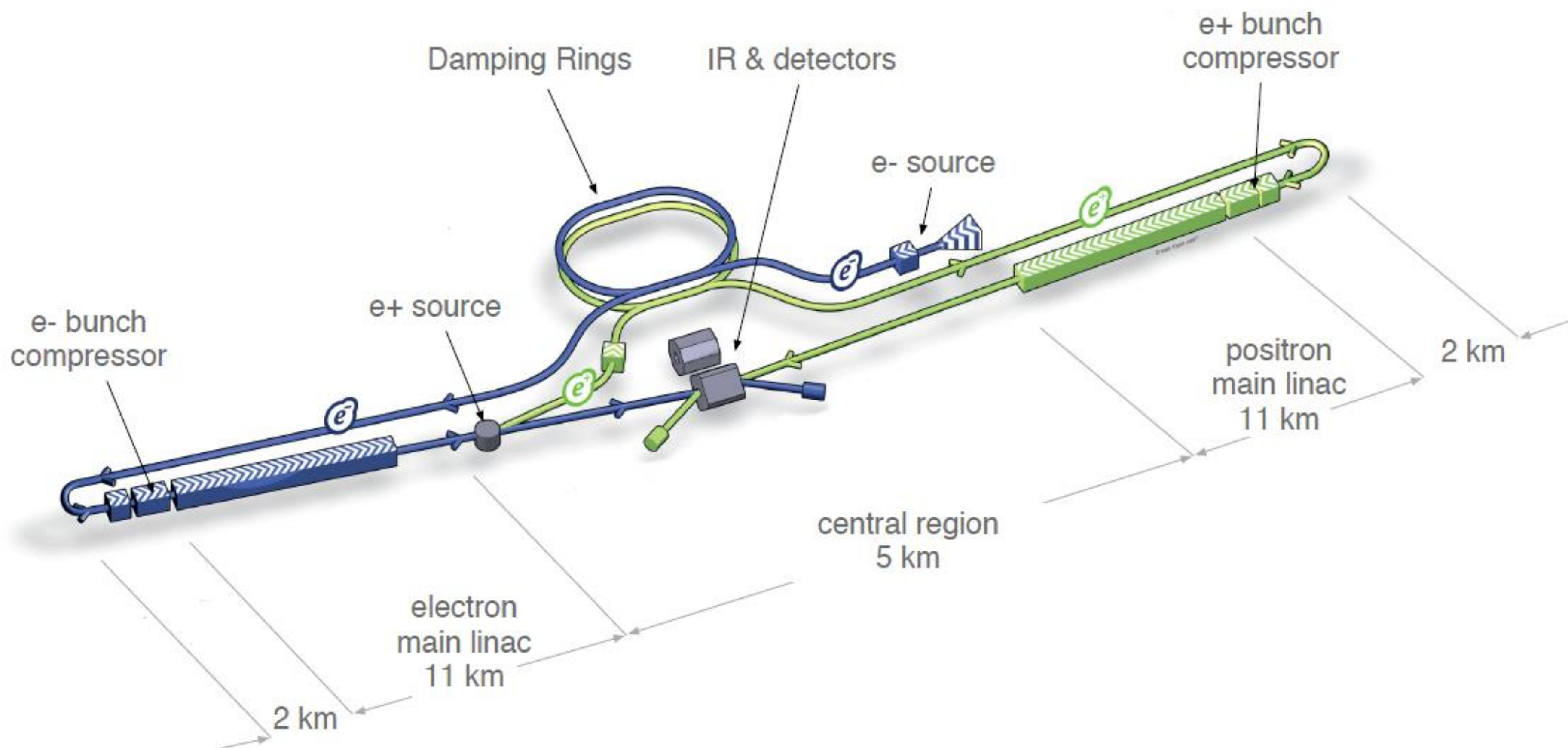
CTF3 (CLIC Test facility)



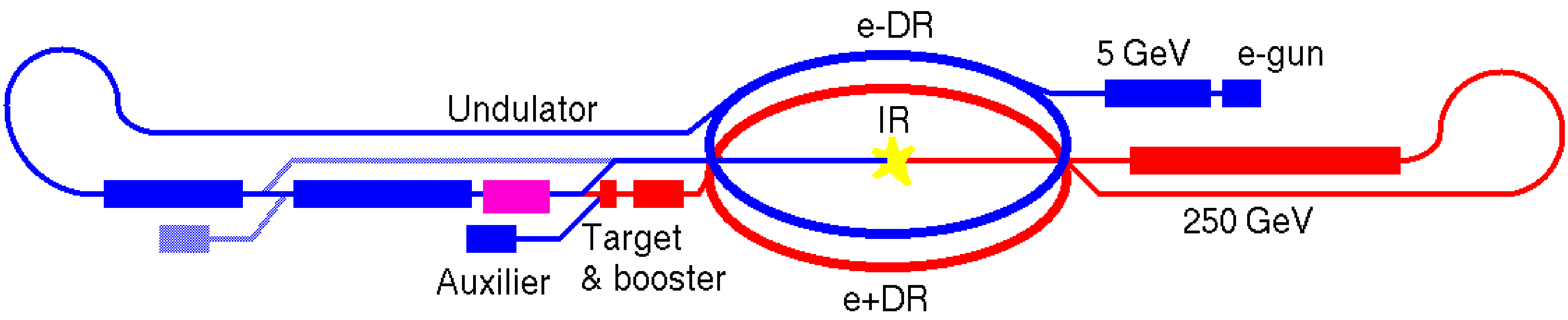
CTF3 successfully demonstrated a two-beam acceleration up to a gradient of 145 MV/m

A new facility starts operating in 2017 (based on the CFT3 main beam). It's called:
CLEAR, Cern Linear Electron Accelerator for Research

ILC (International Linear Collider) $e^+ e^-$



ILC accelerator overview

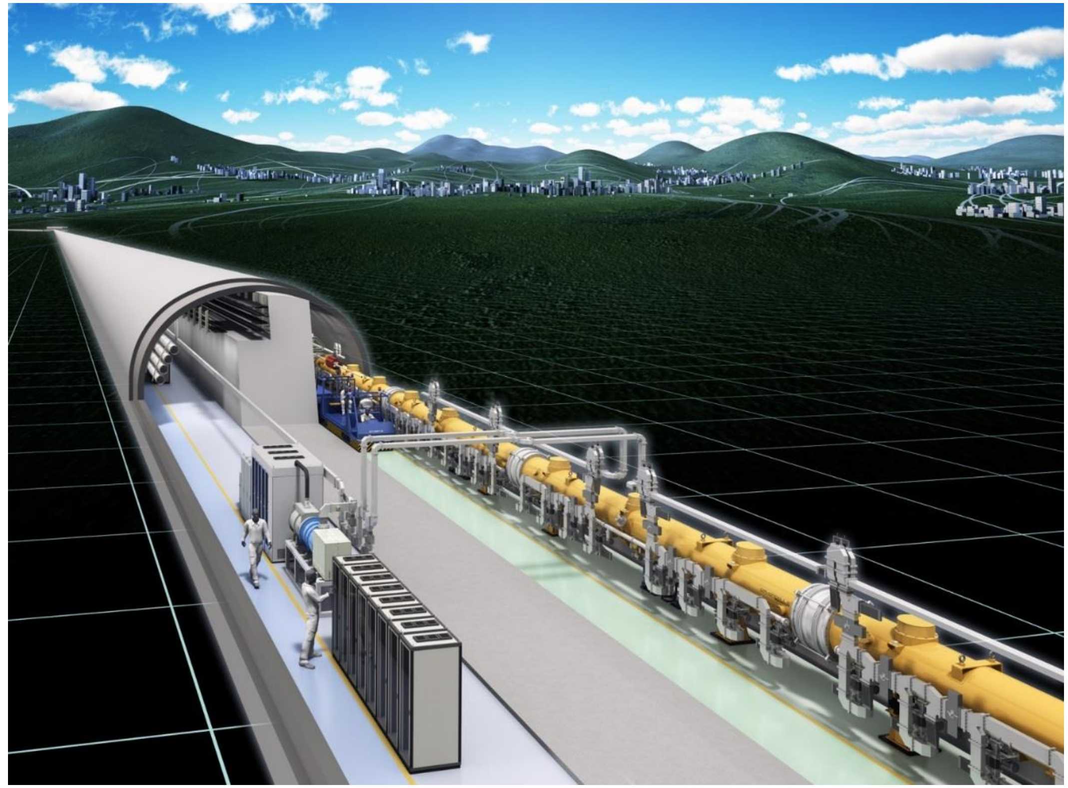


- High gradient acceleration with super-conducting accelerator. G = 31.5 MV/m
- High luminosity is obtained with the high aspect ratio beam made up with Damping ring and final focus. $L = 1.8\ 10^{34}\ cm^{-2}s^{-1}$
- Polarized electron.
- Potential polarization of positron. $3.9\ 10^{14}\ e^{+}/s$

ILC parameters

Parameter	Symbol	ILC	Unit
Center of mass energy	E_{cm}	500	GeV
Main Linac RF Frequency	f_{RF}	1.3	GHz
Luminosity	**L**	**2**	**10^{34} cm^{-2} s^{-1}**
Luminosity (in 1% of energy)	$L_{99\%}$	**1**	10^{34} cm^{-2} s^{-1}
Linac repetition rate	f_{rep}	5	Hz
No. of particles / bunch	N_b	20	10^9
No. of bunches / pulse	k_b	1312	
Overall two linac length	l_{linac}	22	km
Proposed site length	**l_{tot}**	**31**	**km**
Beam power / beam	P_b	10.8	MW
Wall-plug power to beam efficiency	$\eta_{wp\text{-}rf}$	9.4	%
Total site AC power	**P_{tot}**	**230**	**MW**
Transverse horizontal emittance	$\gamma\varepsilon_x$	8000	nm rad
Transverse vertical emittance	$\gamma\varepsilon_y$	40	nm rad
Horizontal IP beam size before pinch	σ^*_x	640	nm
Vertical IP beam size before pinch	σ^*_y	5.7	nm
Beamstrahlung energy loss	δ_B	2.4	%

ILC in Japan ?



A tremendous amount of challenging parameters

Accelerating gradient in SC cavities (G = 31 MV/m)

Beam emittance production and preservation ($\gamma\varepsilon_n$ = 10 nm.rad at Damping ring exit)

Ground motion and stability requirements

Positron flux (3.9 10^4 e^+/s => 70 times more than the SLC machine produced)

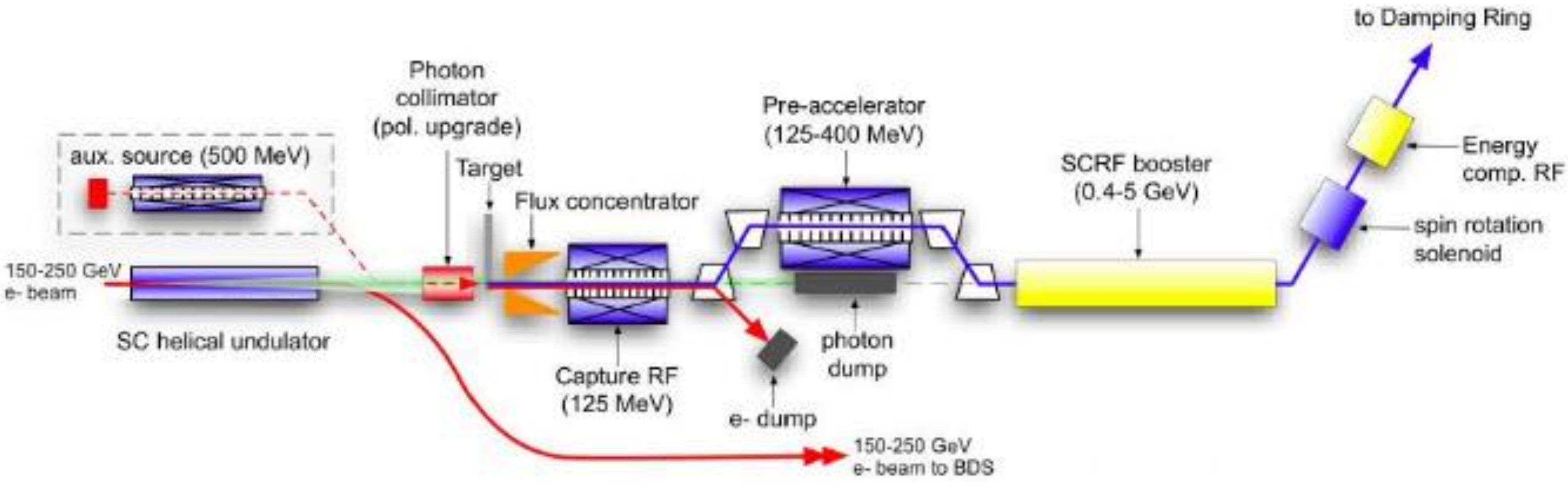
Beam size at IP (σ_y = 6 nm)

Power consumption (~ 230 MW)

Cost (several billions of €, $, CHF,…..)

+ many others; none will be discussed in this seminar; only the e^+ source is illustrated in the next slide

Challenge to produce e^+



Driven by > 125 GeV => The main electron beam should go through a SC helical undulator to produce polarized photons

Advantage => Polarized positrons (30 to 60 %) are produced
=> Powerful tool for Physics

Issues and questions

- Positron production at low energy.
- How important is polarization?
- How interesting is gamma-gamma?

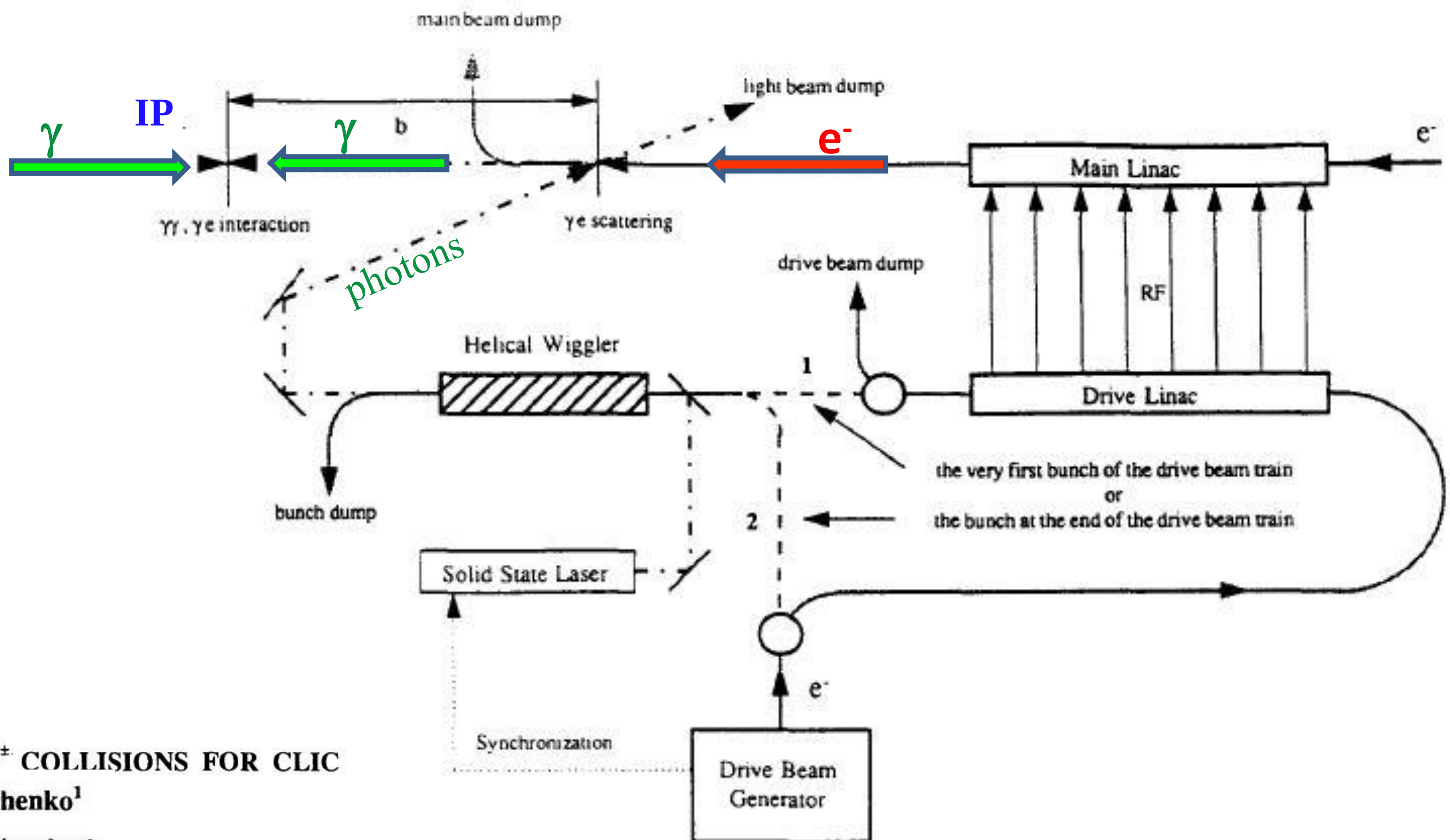
LCWS
Linear Collider Workshop
Morioka - Japan
December 2016

Link to LCWS 2016:

https://agenda.linearcollider.org/event/7371/timetable/#all.detailed

γγ collider from CLIC

- Based on e^-e^- collider
- But collide electron beam with laser beam just before the IP (at small angle α)
- Hard backscattered photons move almost in direction of initial electron (angle ~1/γ)
- Photons collide



CLIC Note 254
15/12/94

THE FEASIBILITY OF γγ, γe[±] COLLISIONS FOR CLIC

R. Corsini, A. Mikhailichenko[1]

CERN, CH 1211, Geneva, Switzerland

Other possible future linear colliders

LPA = Laser Plasma Accelerator

PWFA = Plasma Wake Field Accelerator

DLA = Dielectric Laser Accelerator

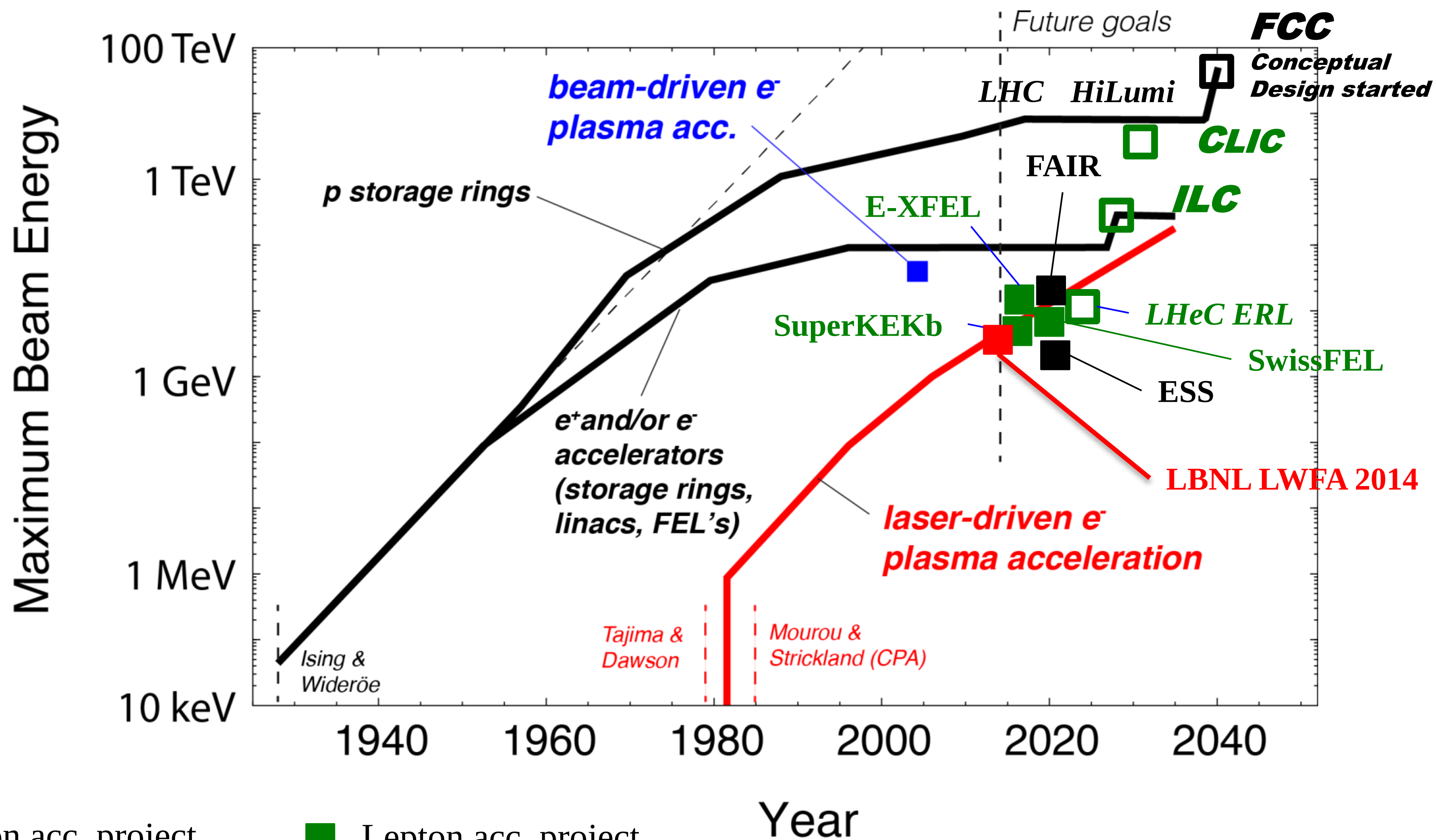
JUAS Seminar on The future of particle accelerators (European context) 12th January 2017 by M. Vretenar /CERN

JUAS Seminar on Laser Plasma Accelerator 1st February 2017 by R. Aßmann / DESY

EAAC workshop – Elba - Italy

Future of accelerators

R. Assmann, EAAC 2015, 9/2015



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

Laser-driven Plasma Accelerator

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 051301 (2012)

Beamstrahlung considerations in laser-plasma-accelerator-based linear colliders

C. B. Schroeder, E. Esarey, and W. P. Leemans
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
(Received 23 November 2011; published 4 May 2012)

ature
article

44 March 2009 Physics Today

Laser-driven plasma-wave electron accelerators

Wim Leemans and Eric Esarey

Surfing a plasma wave, a bunch of electrons or positrons can experience much higher accelerating gradients than a conventional RF linac could provide.

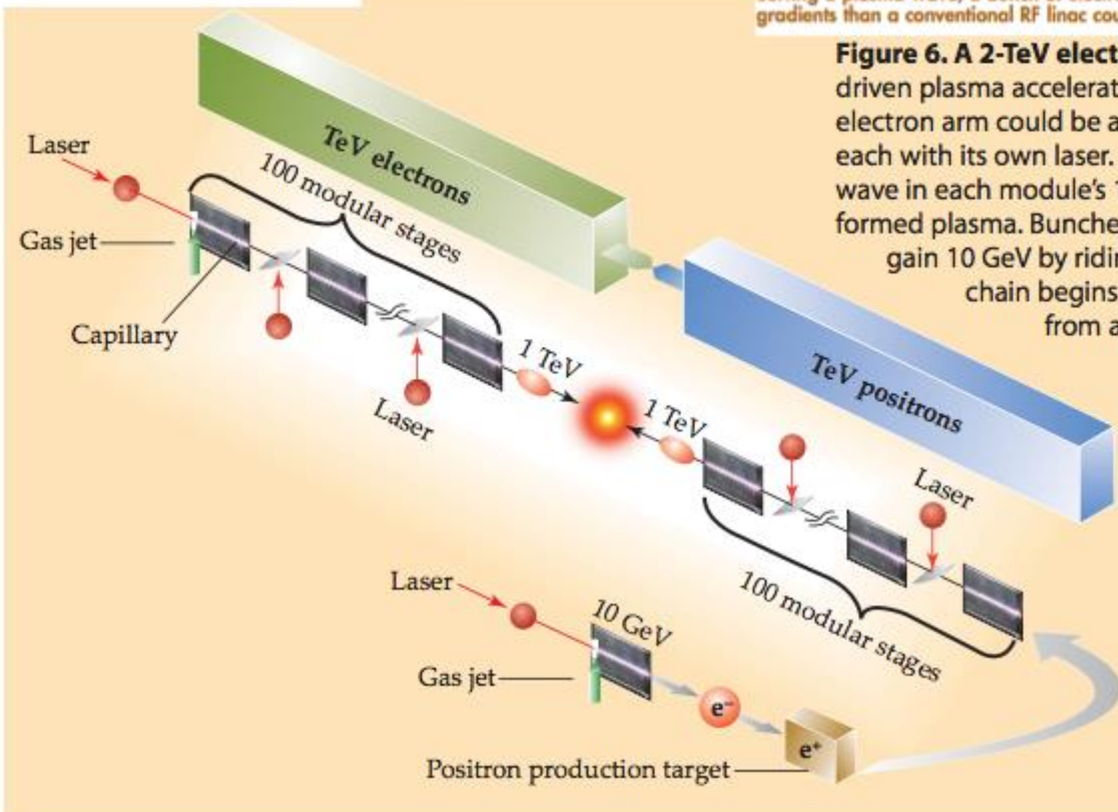


Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first module's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.

An European project

Acc

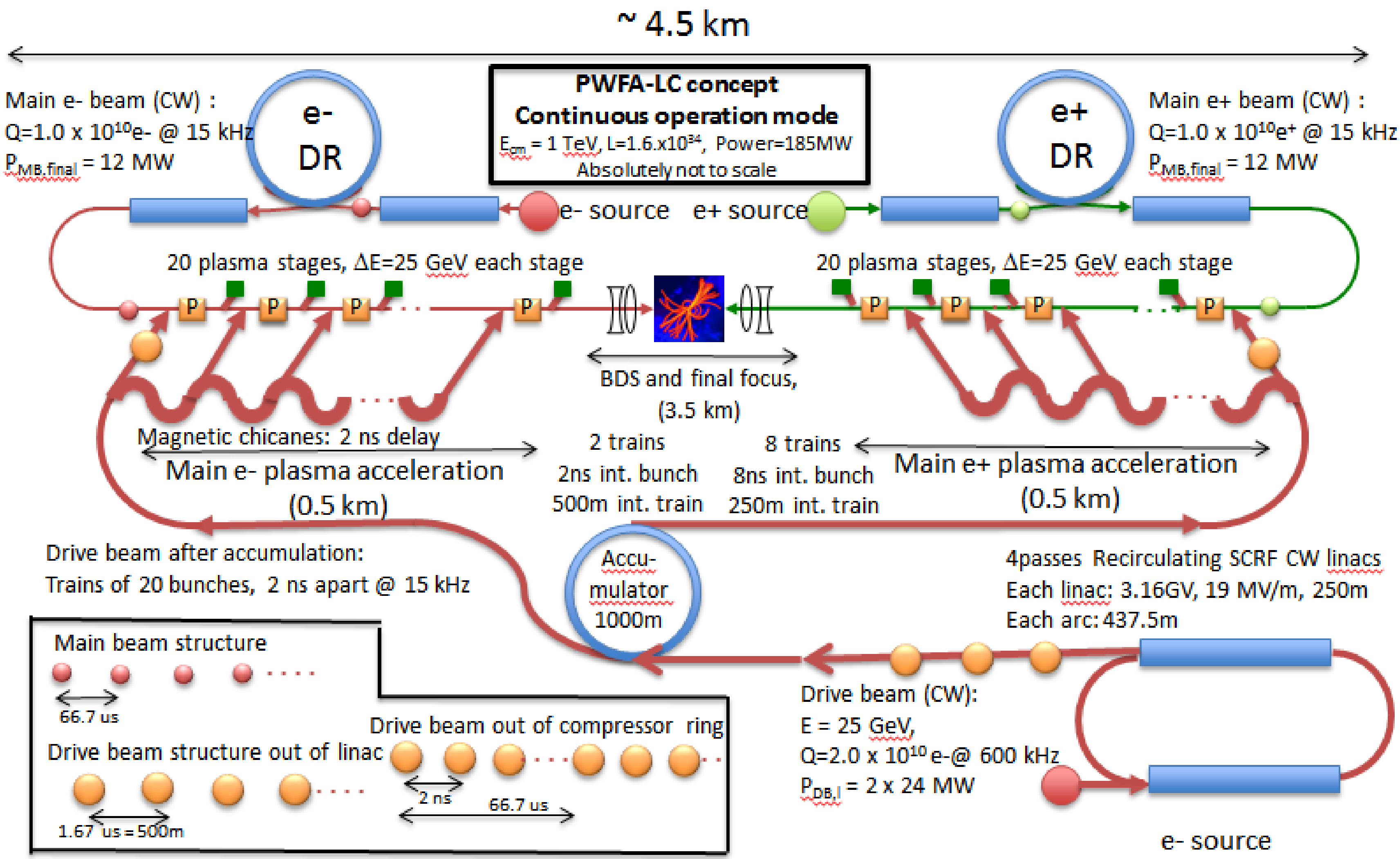
Compact modern accelerators for big science

By Carsten Welsch(UNILIV)

On 1 November 2015 a new European Design Study called EuPRAXIA ("European Plasma Research Accelerator with eXcellence In Applications") started. 3 M€ of funding has been awarded to 16 laboratories and universities from 5 EU member states within the European Union's Horizon 2020 programme. They will be joined by 18 *associated partners* that make additional in-kind contributions.

EuPRAXIA will produce a conceptual design report for the worldwide first 5 GeV plasma-based accelerator with industrial beam quality and user areas. EuPRAXIA is the required intermediate step between proof-of-principle experiments and ground-breaking, ultra-compact accelerators for science, industry, medicine or the energy frontier ("plasma linear collider"). The study will design accelerator

PWFA as Linear Collider



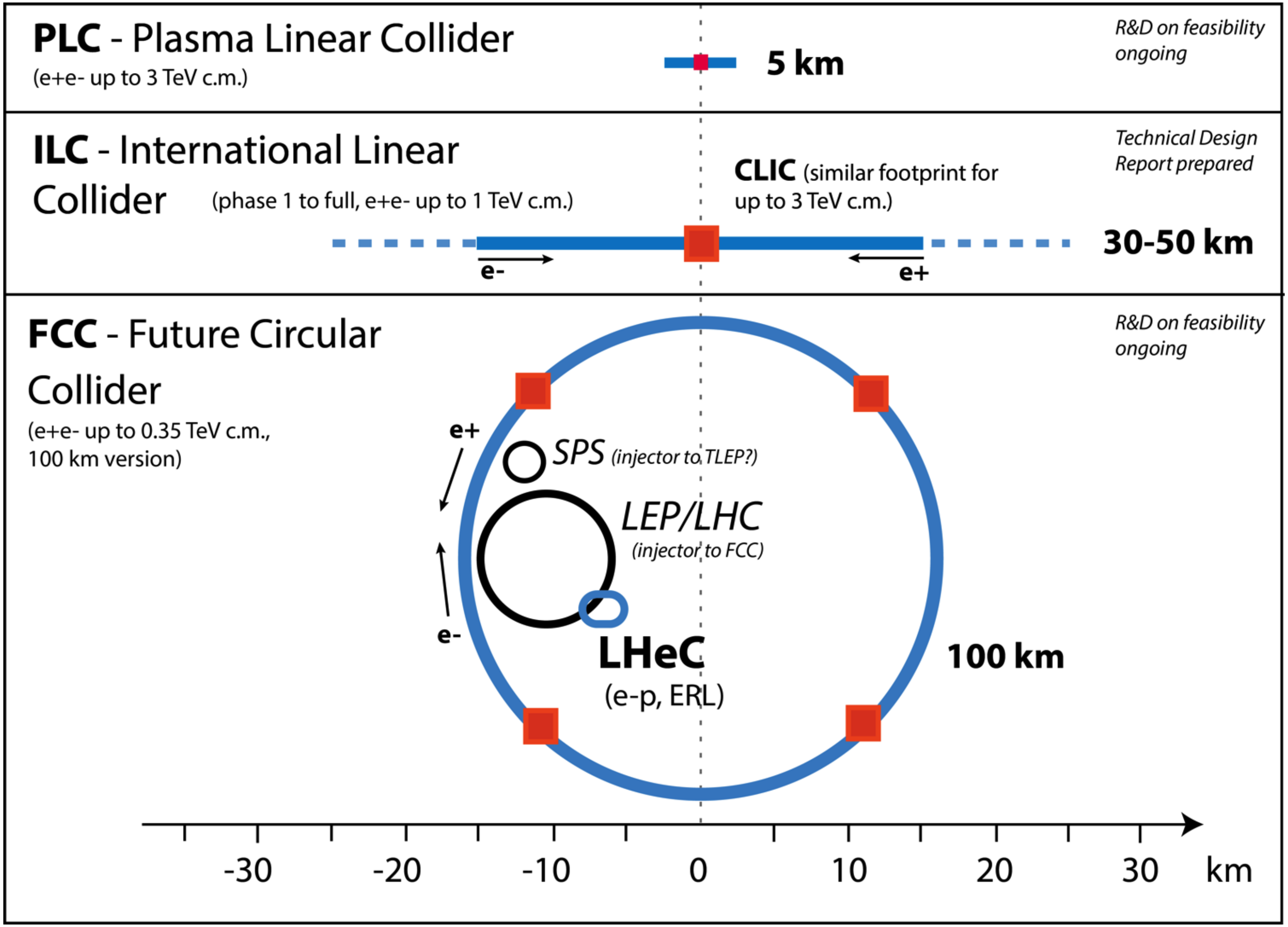
Concept for PWFA-LC layout for 1TeV. Based on earlier work from 2009 by Raubenheimer et al.

E. Adli et al., "A beam driven Plasma Wake-Field Linear Collider", CSS2013 and arXiv:1308.1145

Main beam parameters

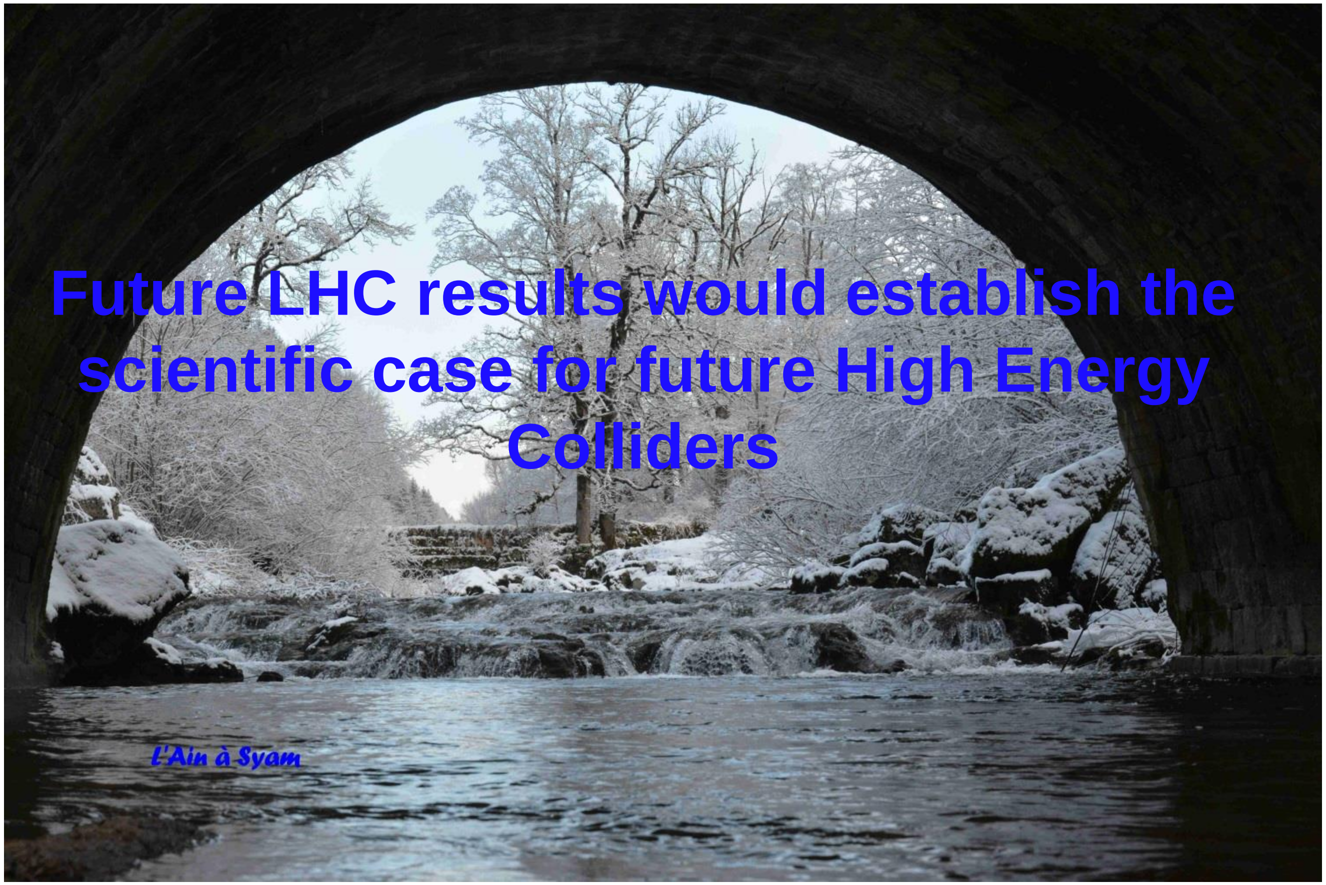
Parameter	Symbol [unit]	ILC	CLIC	LPA	PWFA
CMS energy	E_{cm} [GeV]	500	3000	1000	3000
Luminosity	L [$10^{34}cm^{-2}s^{-1}$]	1.8	6	2.0	6.3
Lum. in peak	$L_{0.01}$ [$10^{34}cm^{-2}s^{-1}$]	1	2	(0.74)	2.5
Beam power	[MW]	10.5	28	9.6	48
Eff. gradient	G [MV/m]	21	80	5000	1000
Particl./bunch	N [10^9]	20	3.72	4	10
Bunch length	σ_z [μm]	300	44	1	20
IP beam size	$\sigma_{x,y}$ [nm/nm]	474/6	40/1	10/10	194/1.1
Emittances	$\varepsilon_{x,y}$ [nm]	10^4/35	660/20	100/100	10^4/35
Bunches/train	n_b	1312	312	1	1
Bunch dist.	Δz [ns]	554	0.5	66.7×10^3	10^5
Rep. rate	f_r [Hz]	5	50	15×10^3	10^4

Plasma Linear Collider



Future

LHC continues to investigate what physics is behind the Higgs boson and what energy scale should be considered.



Many fundamental questions remain open

What is the origin of the mass of the particles ?

Why there is no antimatter in the space ?

What was the state of the matter just after the Big-Bang ?

Why our existing models explain only 4% of the Univers estimated mass ?

And many more ……

Future is very exciting ……

Conclusion

JUAS students are the future machine builders …..

…. for future high energy particle accelerators !