FUTURE COLLIDERS PROJECTS
1ST PART

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ACKNOWLEDGEMENTS AND REMARKS

- Many thanks to **B. Holzer** for gave me the possibility to look at the current state of the art of many different concepts, in preparing these lectures
- This lecture is based on a collection of materials from many colleagues I would like to acknowledge:
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- For particle physics goals and experiments: Please see F. Simon and M. Klute lectures
- **Useful concepts introduced in other lectures**:
  - F. Asvesta : **particle accelerators and beam dynamics**
  - S. I. Bermudez: **accelerator technology challenges (part 1: magnet superconductivity)**
  - W. Venturini: **accelerator technology challenges (part 2: RF Superconductivity)**
  - F. Salvat: **accelerator technology challenges (part 3: accelerator operation and design challenges)**
- **Focus on EU projects**

OUTLINE

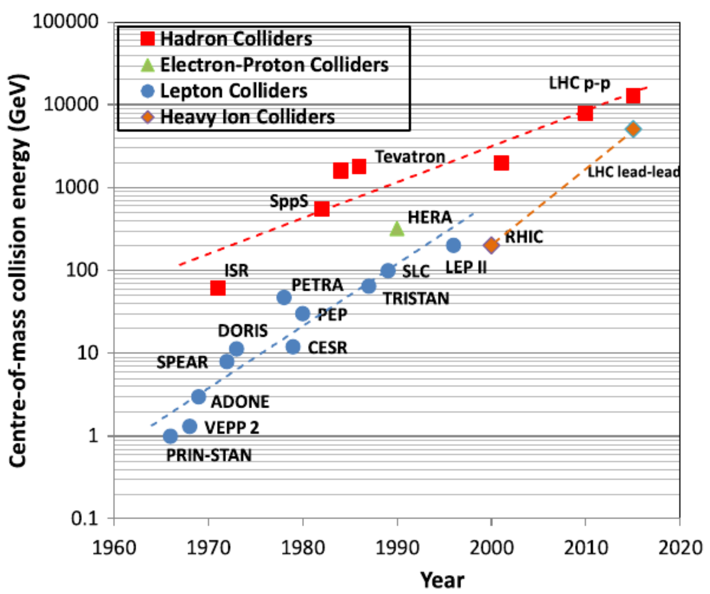
- European Strategy Update
- General Colliders Design Considerations
- Linear Colliders Projects
  - ILC
  - CLIC

PARTICLE ACCELERATORS

- Particle accellerators have been instrumental for scientific discoveries in high energy physics for more than half a century
  - Key for establishing the standard model in particle physics

- Technological innovation made it possible to increase energy at a much faster pace than the costs

- LHC has the highest energy among colliders built so far
  - Circular collider, designed to collide
    7 TeV protons and 5.5 TeV heavy ions (Pb-Pb)



"Livingstone plot" of collider energy vs time (source)

LHC PATH


QRL crisis 2004


Inner triplet crisis 2005

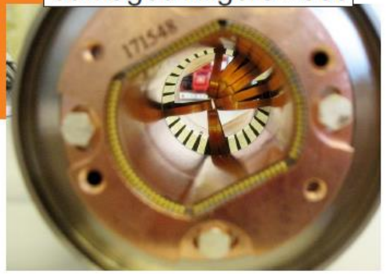
LHC timeline

L. Evans

• Preliminary conceptual studies	1984
• First magnet models	1988
• Start structured R&D program	1990
• Approval by CERN Council	1994
• Industrialization of series production	1996-1999
• DUP & start civil works	1998
• Adjudication of main procurement contracts	1998-2001
• Start installation in tunnel	2003
• Cryomagnet installation in tunnel	2005-2007
• Functional test of first sector	2007
• Commissioning with beam	2008
• Operation for physics	2010-?

F. Gianotti ICHEP 2022


September 2008

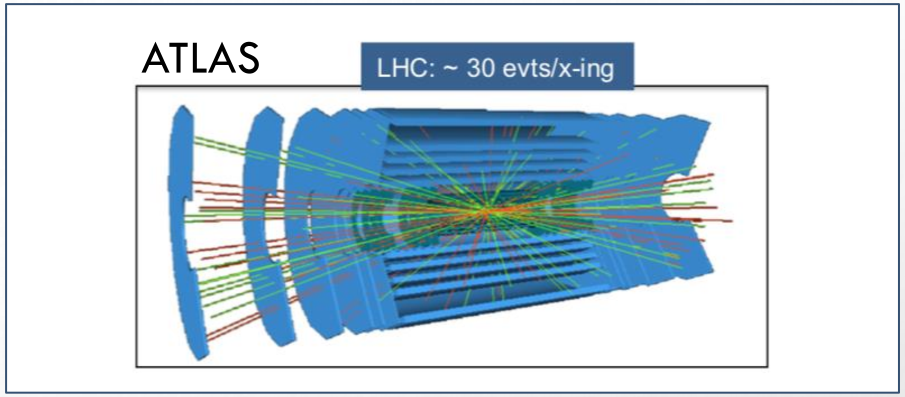

Plug-in module with damaged fingers 2008

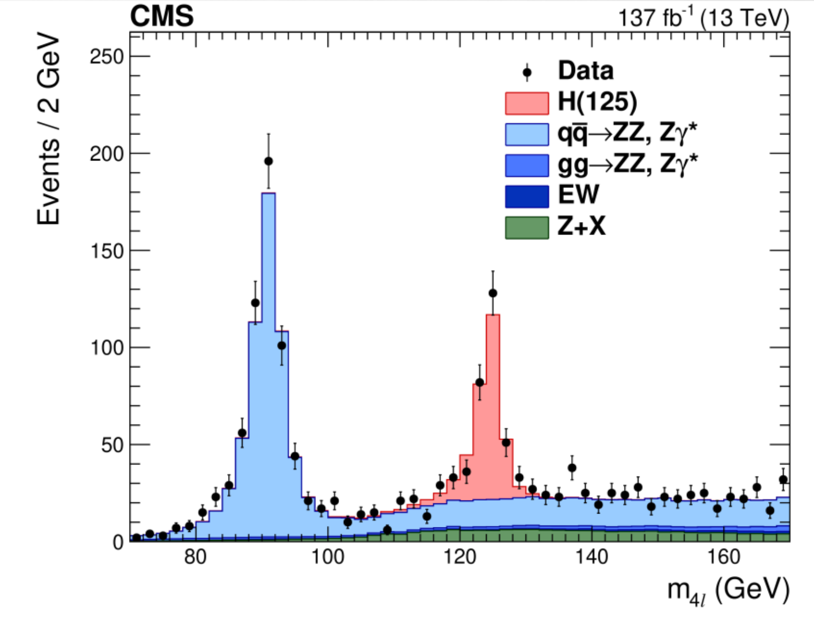
WHERE DO WE STAND

Higgs discovery (2012)

Open questions still remain:

- Naturalness
- Neutrino mass
- Asymmetry matter/antimatter
- Gravity
- Dark matter…





WHAT NEXT ?

- Common strategy worked out in Europe to guide future decision-making in field: "**European strategy for particle physics**" (endorsed by the CERN council)
  Based on bottom-up approach:
  - physics community is invited to submit proposals for near-term, mid-term and longer-term projects → community discussion in open symposium, [Physics briefing book]
  - Based on this input, the European Strategy Group* formulates the strategy

*consists of scientific delegates from CERN Member States, Associate Member States, directors of major European laboratories, representatives of various European organizations, some invitees from outside the European Community

2013

To stay at the forefront of particle physics, *Europe needs to be in a position to* ***propose an ambitious post-LHC accelerator*** *project at CERN* ***by the time of the next Strategy update***, *when physics results from the LHC running at 14 TeV will be available. CERN should* ***undertake design studies*** *for accelerator projects in a global context, with emphasis on proton-proton and electron- positron* ***high-energy frontier machines***. *These design studies should be* ***coupled to a vigorous accelerator R&D program***, *including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

2020

The successful completion of the high-luminosity upgrade …. should remain the focal point of European particle physics.

"An electron-positron Higgs factory is the highest-priority next collider"

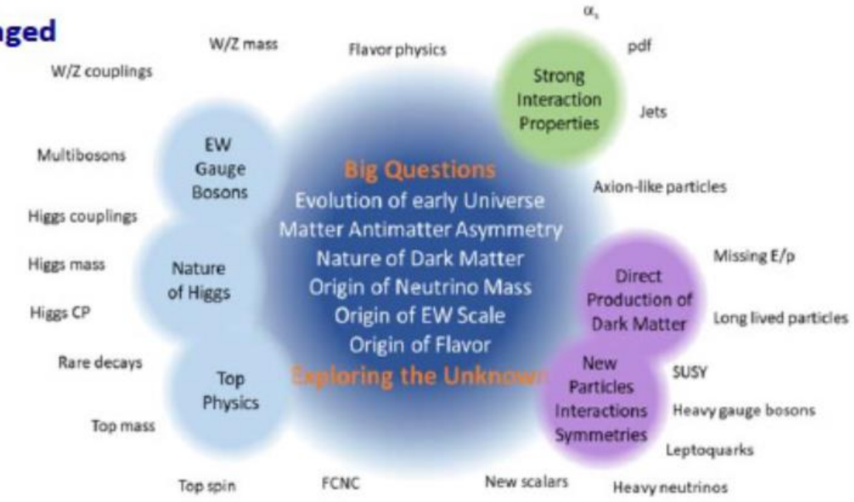
"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. "

"The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors"

SNOWMASS 2021

Energy Frontier (Message)

- **Compared to Snowmass 2013 the physics landscape has significantly changed**
  - The program of measuring the Higgs boson properties is well underway at the LHC with growing precision
  - A broad range of searches have explored multiple BSM scenarios without convincing evidence of new physics
  - The HL-LHC is an approved project
- **Without a robust support for the HL-LHC and a clearly defined path towards a Higgs factory we leave critically important physics unchecked and crucial questions unanswered**
- **The EF community should be prepared to explore a broad range of BSM phenomena at the 10 TeV mass scale**



The Energy Frontier community voices a strong support for

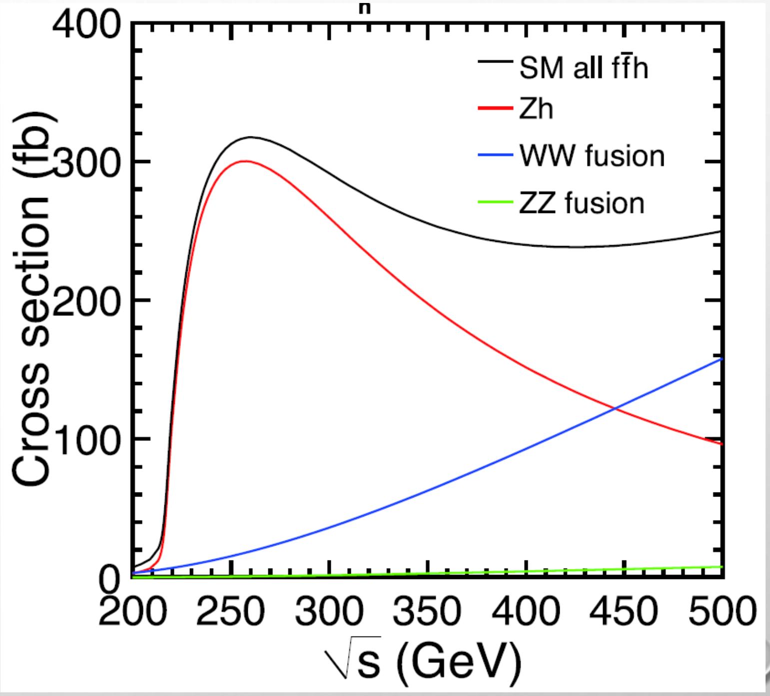
1. HL-LHC operations and 3 ab^{-1} physics program, including auxiliary experiments
2. The fastest path towards an e^+e^- Higgs factory (linear or circular) in a global partnership
3. A vigorous R&D program for a multi-TeV collider (hadron or muon collider)

LET'S GO BACK TO WORK

We want high energy and high luminosity (events Rate) $\frac{dR}{dt} = \sigma_{cs} \cdot L$

How do we get there? Several choices to be made:

- What to collide: lepton vs hadron
- How to collide:
  - fixed target or colliding beams
  - linear vs circular collider
- Acceleration technology
  - DC, RF, wakefield… (see lecture of W. Venturini)
- Magnet technology
  - Superconducting (what conductor?), normal conducting (see lecture of S. I. Bermudez)
- Acceptable cost of construction, **power consumption**, site

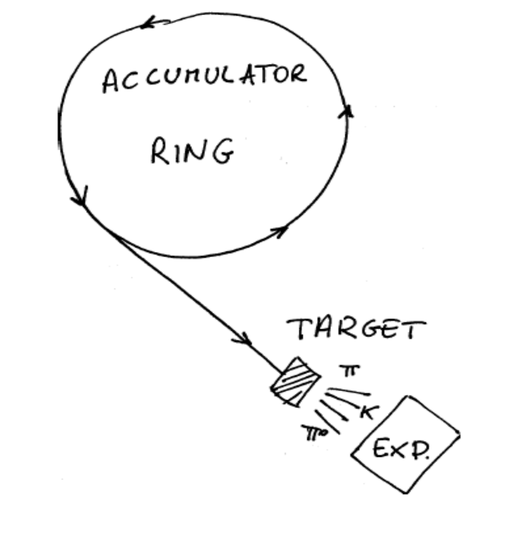


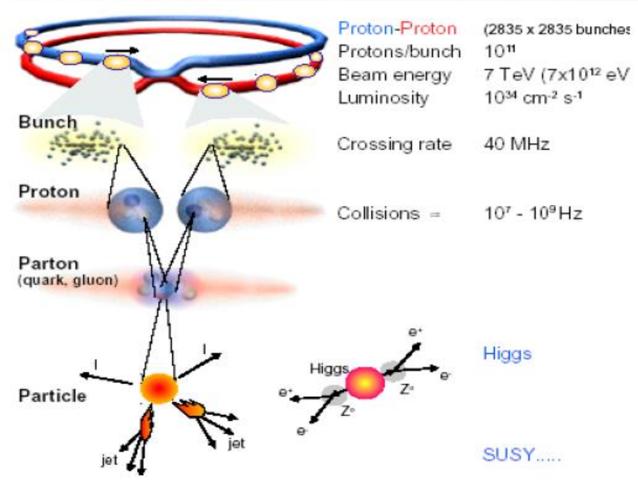
Example e+e- collision

Think about various limitations to energy and luminosity and how to overcome them

ENERGY REACH

- Fixed Target
- Collider





$$E_{CM} = \sqrt{(m_1^2 + m_2^2)c^4 + 2E_1 m_2 c^2} \quad \ll \quad E_{CM} = E_1 + E_2$$

To achieve the highest possible centre-of-mass energy, need a collider

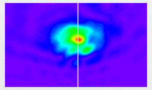
(See also F. Asvesta's Lecture)

LUMINOSITY AND BEAMS

beam size

$$\sigma(s) = \sqrt{\varepsilon_{rms}\beta(s)}$$

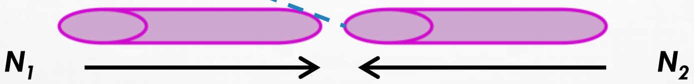
Beam quality



magnets

Luminosity

$$L = \frac{n_b N_1 N_2 f_{rep}}{4\pi\sigma_x\sigma_y}$$



event rate

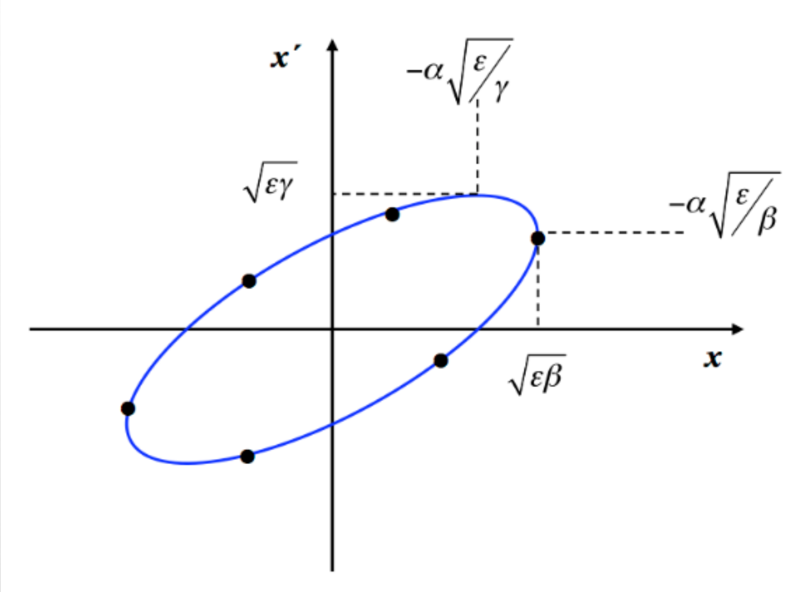
$$\frac{dR}{dt} = \sigma_{cs} \cdot L$$

n_b = number of bunches
N_1, N_2 = number of particles per bunch
f_{rep} = repetition frequency
σ_{cs} = cross section

ε_{rms} = beam emittance ⇒ phase space volume occupied by the beam

$\beta(s)$ = beta function ⇒ describes the focusing force along the beam transport system

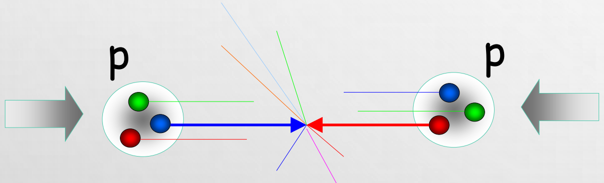
(See also F. Asvesta's Lectures)

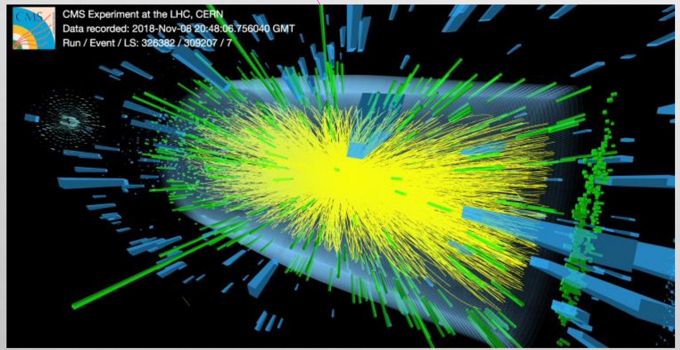


LEPTONS VS HADRONS

Hadrons (protons or ions)

- Mix of quarks, anti-quarks and gluons:
  - variety of processes
  - not all nucleon energy available in collision
  - Energy spread between partons – spread in collision energy
  - huge QCD background
- Can typically achieve highest collision energy
- Good for discoveries at the frontier of new physics

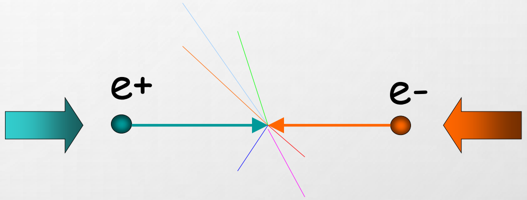




LHC Pb-Pb collision, CMS

Leptons (electrons, positrons, muons)

- Elementary particles colliding - very well defined centre-of-mass energy
- Low background
- Good for high-precision measurements
- Energy loss due to synchrotron radiation

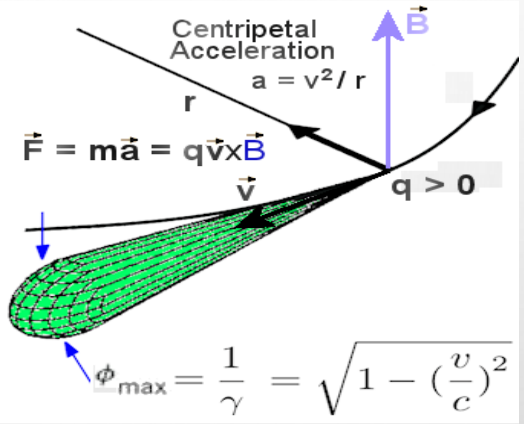


LEP II e+e- collision, DELPHI

SYNCHROTRON RADIATION

- Classical electrodynamics: an accelerating charge radiates
  - Radiation carries off energy, which is taken away from the kinetic energy
  - Radiated energy needs to be replenished by accelerating RF cavities => could lead to very **high power consumption**
  - Radiated photons impact on vacuum chamber
    => causes heating, maybe even damage for **high power loads**
    materials activation (i.e. radiation safety)

- Photon emission gives very small random ANGLE change => blowup, "quantum excitation" , which limits the minimum beam emittance (electrons)



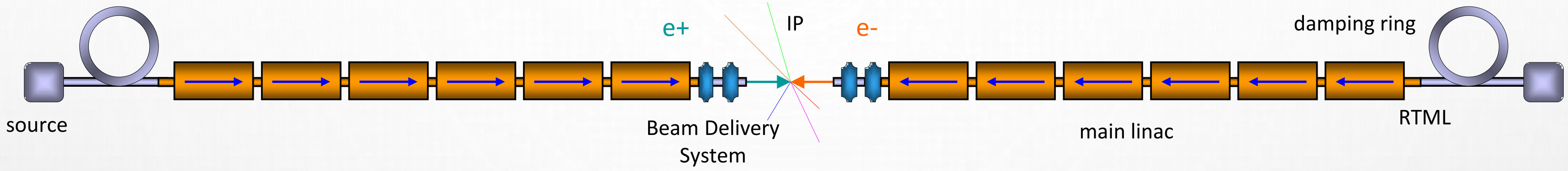
Radiated power

$$P = \frac{2}{3}\frac{e^2 c}{\rho^2}\beta^4\gamma^4$$

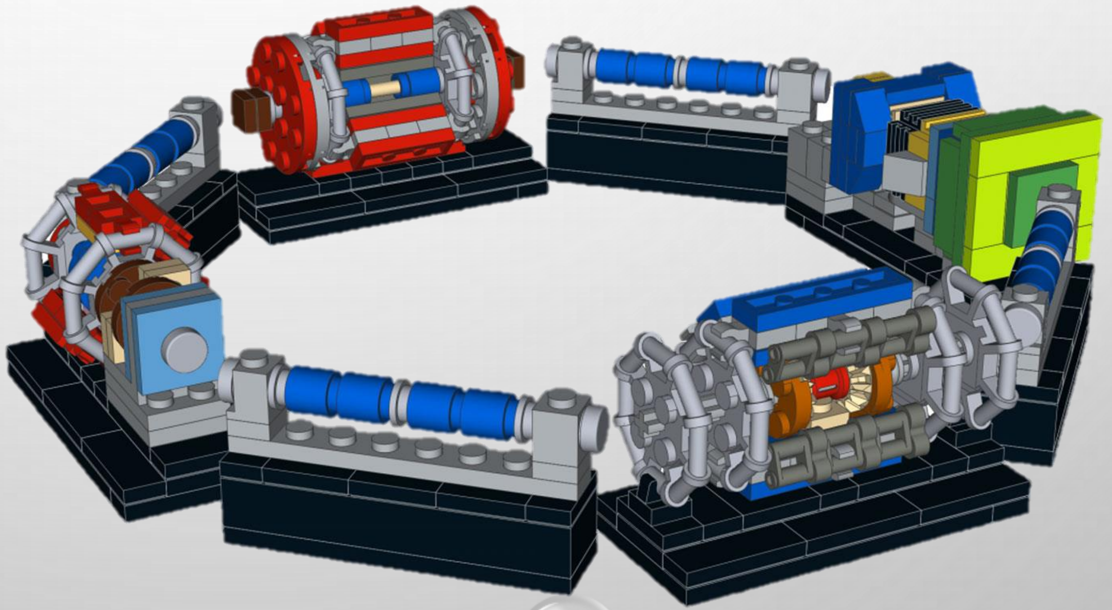
Energy loss

$$\Delta E \propto \left(\frac{E}{m}\right)^4 \frac{1}{R}$$

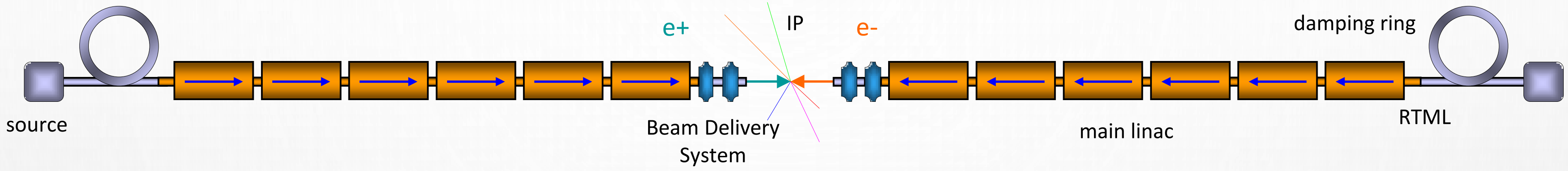
LINEAR AND CIRCULAR COLLIDERS



- electrons-positrons
- hadrons
- others



LINEAR COLLIDER



Linear Collider

- single pass => need to be very efficient
- few magnets, many accelerating cavities
- not limited by synchrotron radiation

Energy reach depends on:

- Accelerating gradient (RF technology)
- Plasma wakefield acceleration promises large advancement, but not yet mature to produce required beam quality
- Length (cost, site)

$$E_{cm} \approx L_{linac} G_{acc}$$

To push energy limit: improve technology (**RF gradient R&D**) and/or build a larger machine

CIRCULAR COLLIDER

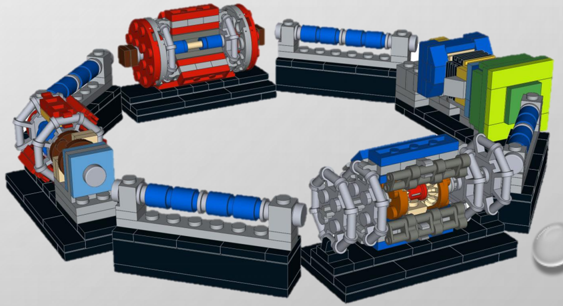
Circular collider

- Multi-pass => accelerate beam in many turns, let beam collide many times
- Many magnets, few accelerating cavities
- Bending of beam trajectory => synchrotron radiation losses
- Energy reach depends on:
  - Hadron beams: energy limited by ability of to keep particle on circular orbit
    - Maximum achievable dipole field (superconductor technology)
    - Radius of ring (cost, site)
  - Lepton beams: radiation losses
    - RF power consumption
    - Disposal of radiated power
    - Radius of ring (cost, site)

$$\frac{p}{q} = B\,\rho$$

$B\,\rho$ = **Beam rigidity**

(see F. Asvesta's Lectures)



To push energy limit: improve technology (**B-fields, RF-efficiency R&D**) and/or build a larger machine

LUMINOSITY LIMITATIONS

- Increase number of bunches k
- Increase single bunch intensity N

$\Rightarrow$ Limited by collective instabilities

$$L = \frac{kN^2 f\gamma}{4\pi\beta^* \varepsilon} \cdot F$$

- Reduce beam sizes (β^*, ε, σ)

$\Rightarrow$ Limited by optics design and magnets imperfections

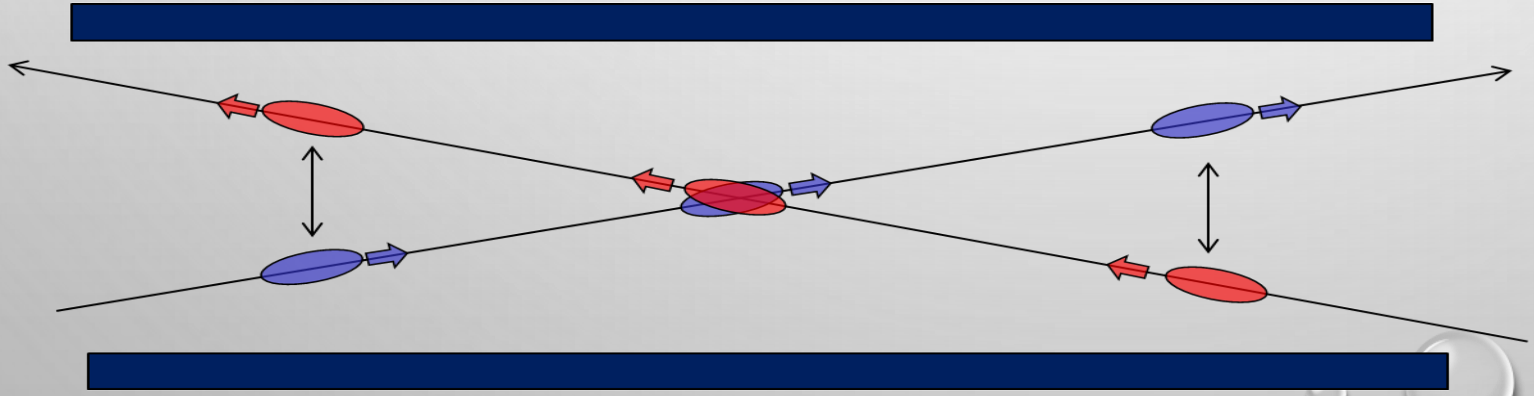
Round beams

- Maximize the geometric reduction Factor

$$\frac{1}{\sqrt{1 + \left(\frac{\sigma_s}{\sigma_x}\frac{\phi}{2}\right)^2}}$$

$\Rightarrow$ Compensation schemes

(see F. Asvesta's lectures)



$$L \propto \frac{kN^2 f\gamma}{4\pi\sigma_x^*\sigma_y^*} F$$

Elliptic beams

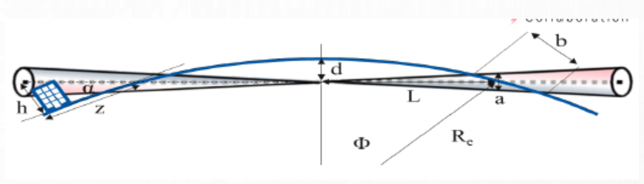
BEAM-BEAM LIMIT

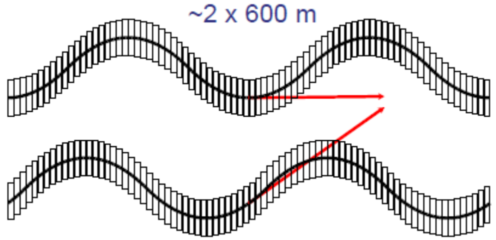
- **Beamstrahlung** and **Disruption** parameters in **Linear lepton colliders**
  - Strong field process, during beam beam interaction, leads to:
    - Strong focusing and consequent radiation losses (photon emission)
    - Enhance of luminosity but also broadening of the luminosity spectrum

- Beam –beam **in circular colliders**
  - The Strong focusing field in beam-beam interaction is linear (like quadrupoles) $\Rightarrow$ it produces a shift in the tune
  - But it generates a non-linear field component too (see F. Asvesta's lecture)
  - The beam-beam parameters for Gaussian **round** (Hadrons) beams and for **elliptic** (leptons) beams depends on key beam parameters

BEAM INDUCED BACKGROUND

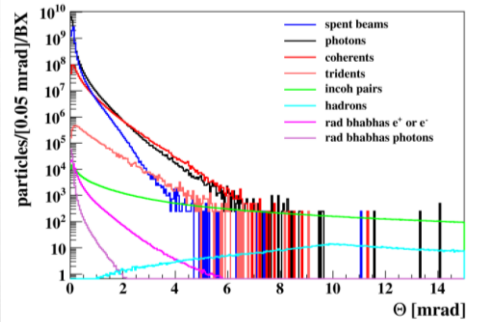
- Neutrinos and secondary particles radiation in muon colliders

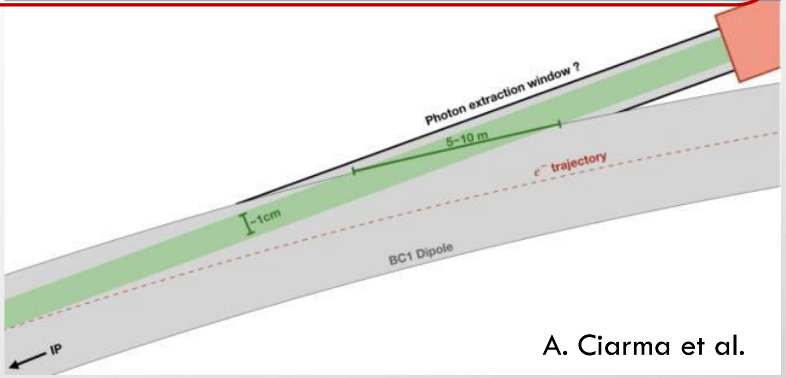




D. Schulte et al.

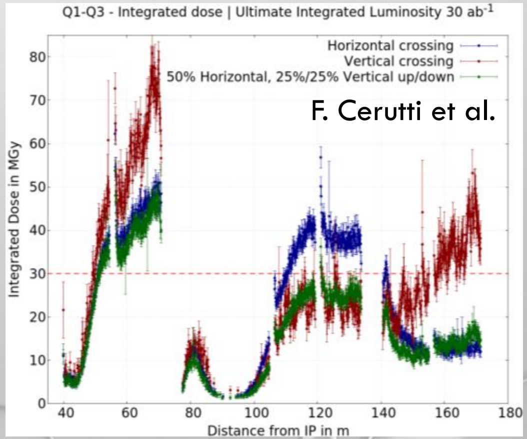
- Beamstrahlung photons and particles pairs in electrons circular and linear colliders





A. Ciarma et al.

- Beam-beam debris in hadron colliders
  - Energy deposition due to the debris produced in p-p non-elastic collisions in the first quadrupoles of the accelerator



F. Cerutti et al.

ASPECTS TO CONSIDER

D. Schulte

Physics potential	The collider energy The collider luminosity Particle type
Feasibility	The technical maturity The risk The schedule
Affordability	The collider cost The collider power consumption Availability of site

FUTURE HEP ACCELERATORS, CONCEPTS, IDEAS

FCC-ee

PERLE

HE-LHC

pEDM
storage ring

ILC

FCC-hh

$\mu\mu$ **collider**

LHeC

g-2
storage ring

CLIC

FCC-eh

Dielectric
laser acceleration

CEPC

HE-LHC

$\gamma\gamma$ **collider**

C^3

Factories

ReLiC

Plasma
acceleration

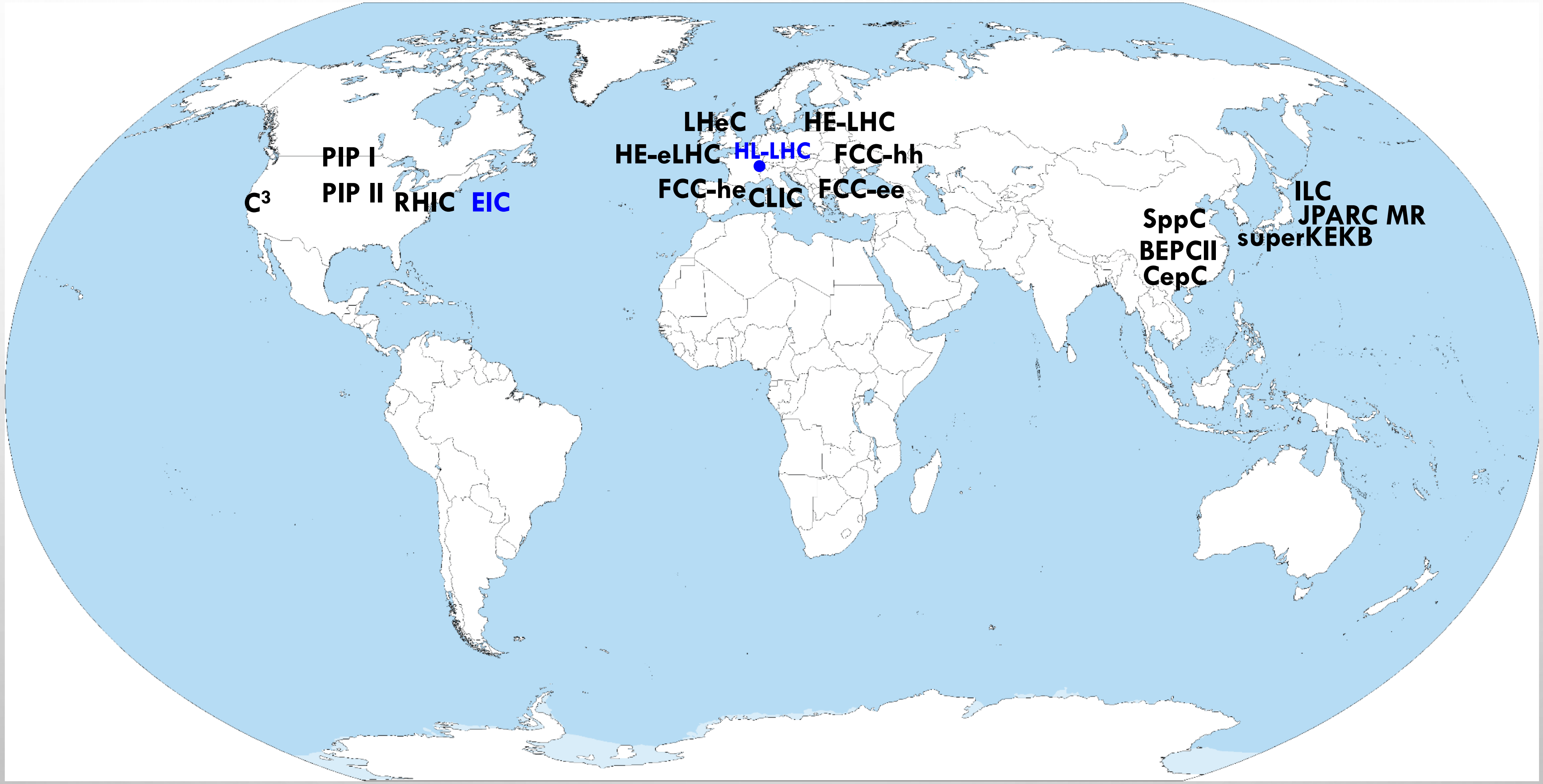
CPPC

Neutrino
factories

ERLC

W. Fischer ICHEP2022

FUTURE HEP ACCELERATORS



$\gamma\gamma$, Gamma Factory

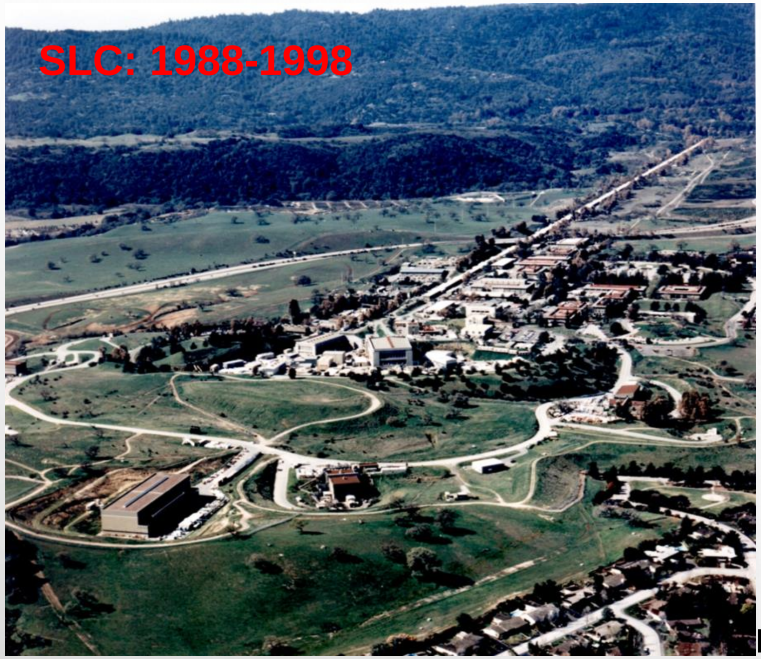
$\mu^+\mu^-$ colliders

charm-τ factory

plasma acceleration …..

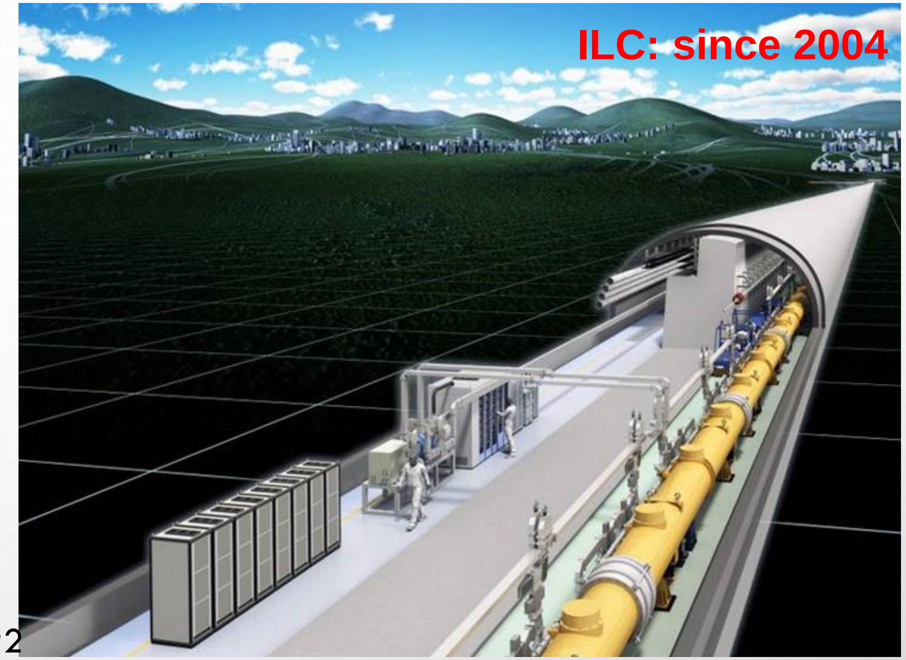
$\Rightarrow$ not shown

LINEAR COLLIDERS



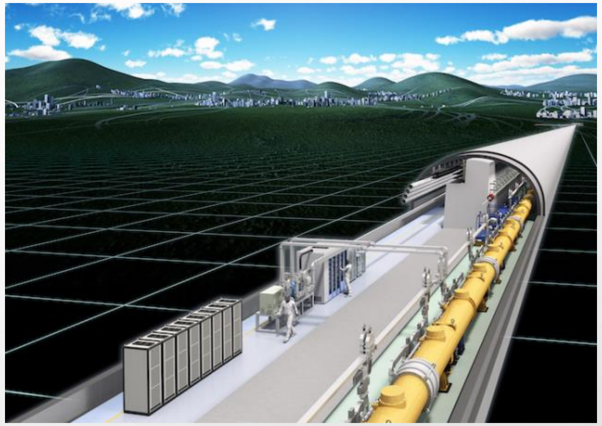
NLC
JLC
TESLA

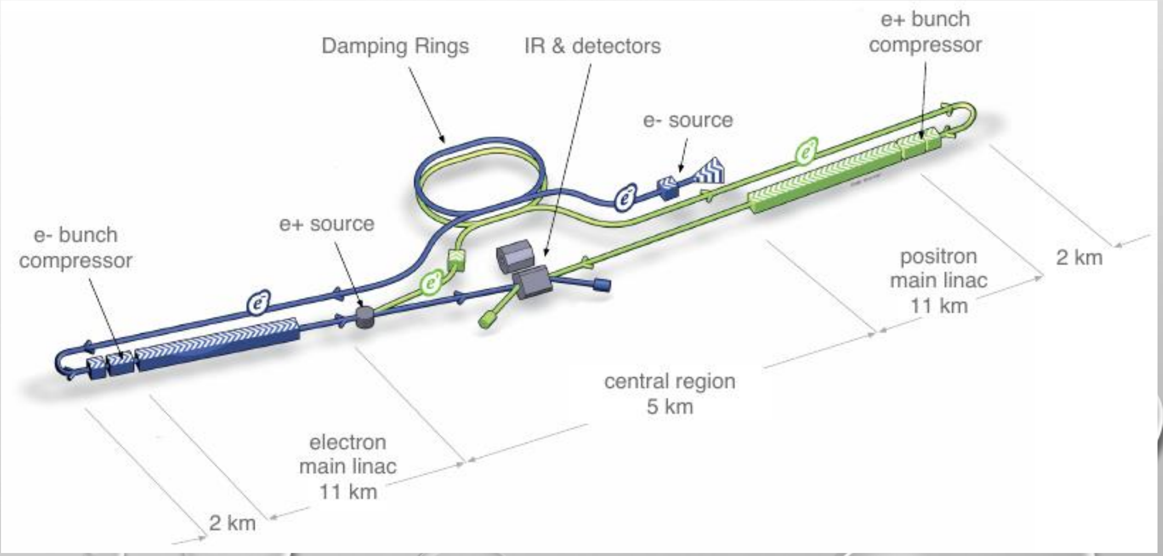
P. Burrows ICHEP2022



ILC CONCEPT

- first, create e- (photocathode dc gun)
- accelerate, send to circulate in 3.2 km damping ring
    - shrinking emittance under radiation damping
- e- sent to main linac, accelerate
- to create e+: electrons pass undulator – magnets with many periodic bends
    - radiated photons impact on a target, creating e+e- pairs.
    - capture e+, accelerate, send to damping ring
- send e+ to main linac, accelerate
- collide e+e- inside detector





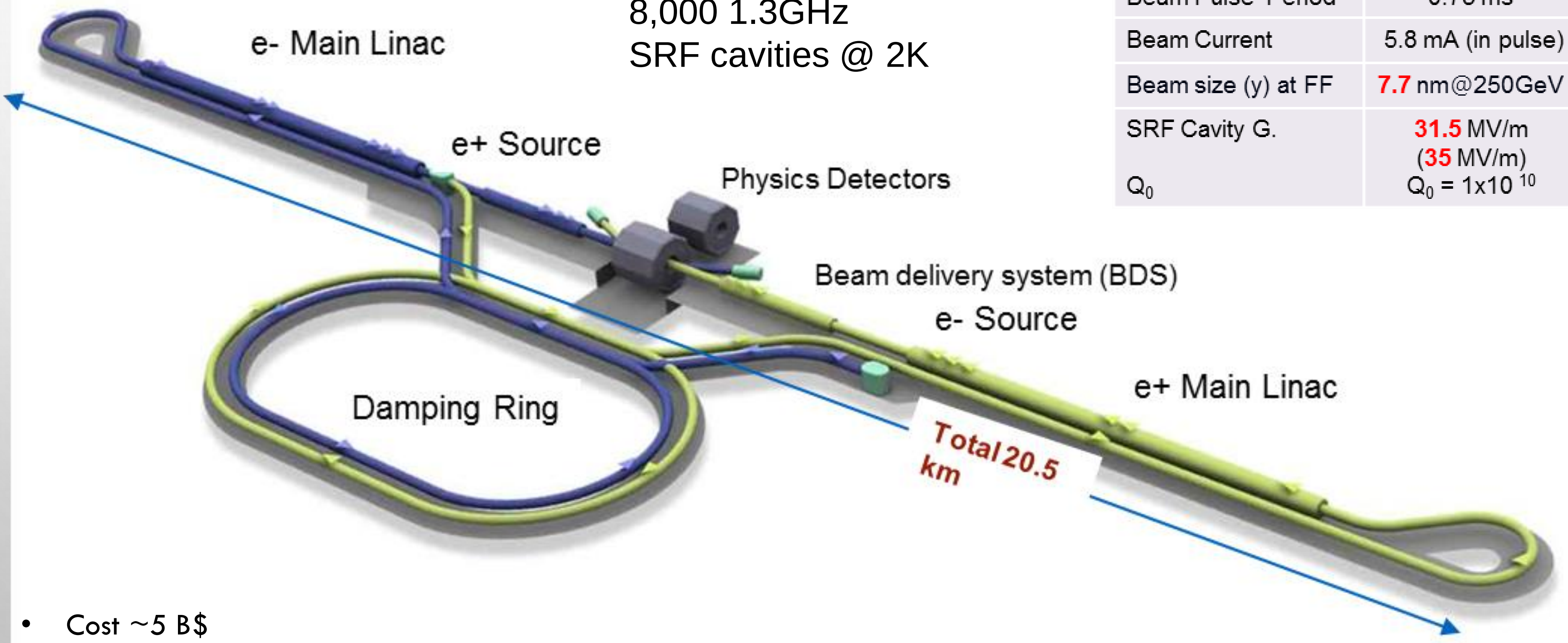
ILC TODAY

TDR (2013) exits for 500 GeV

Emphasis on Higgs precision Physics in the electroweak sector

8,000 1.3GHz SRF cavities @ 2K

Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G. Q_0	31.5 MV/m (35 MV/m) Q_0 = 1x10^{10}



- Cost ~5 B$

Compact LInear Collider

Compact: novel and unique two-beam accelerating technique based on high-gradient room temperature RF cavities:

first stage: **380 GeV, ~11km** long, 20,500 cavities

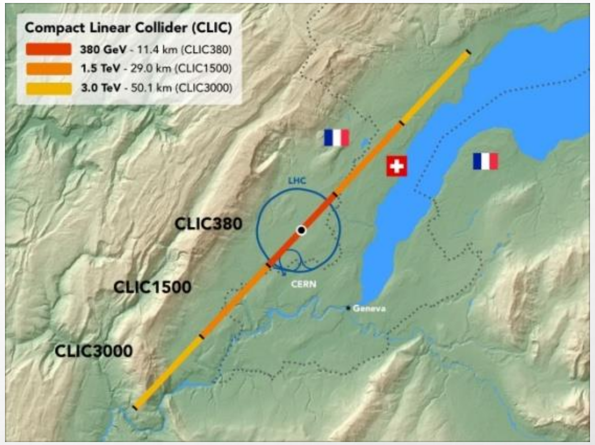
Expandable: staged collision energies from 380 GeV (Higgs/top) up to 3 TeV

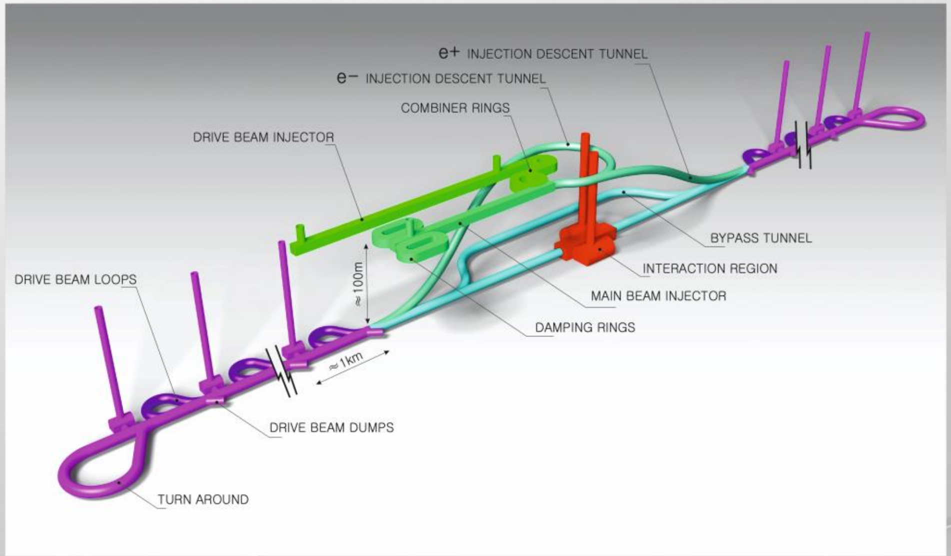
Conceptual design report published in 2012

Update on energy stage baseline in 2016

Project implementation plan released 2018

Cost: 5.9 BCHF for 380 GeV

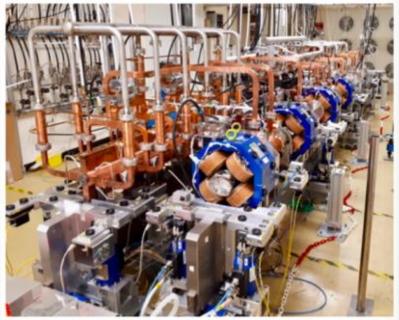




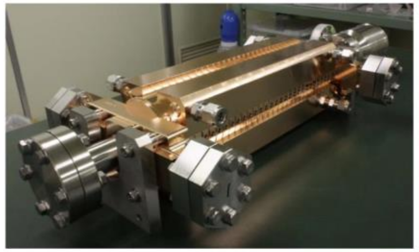
CLIC LAYOUT

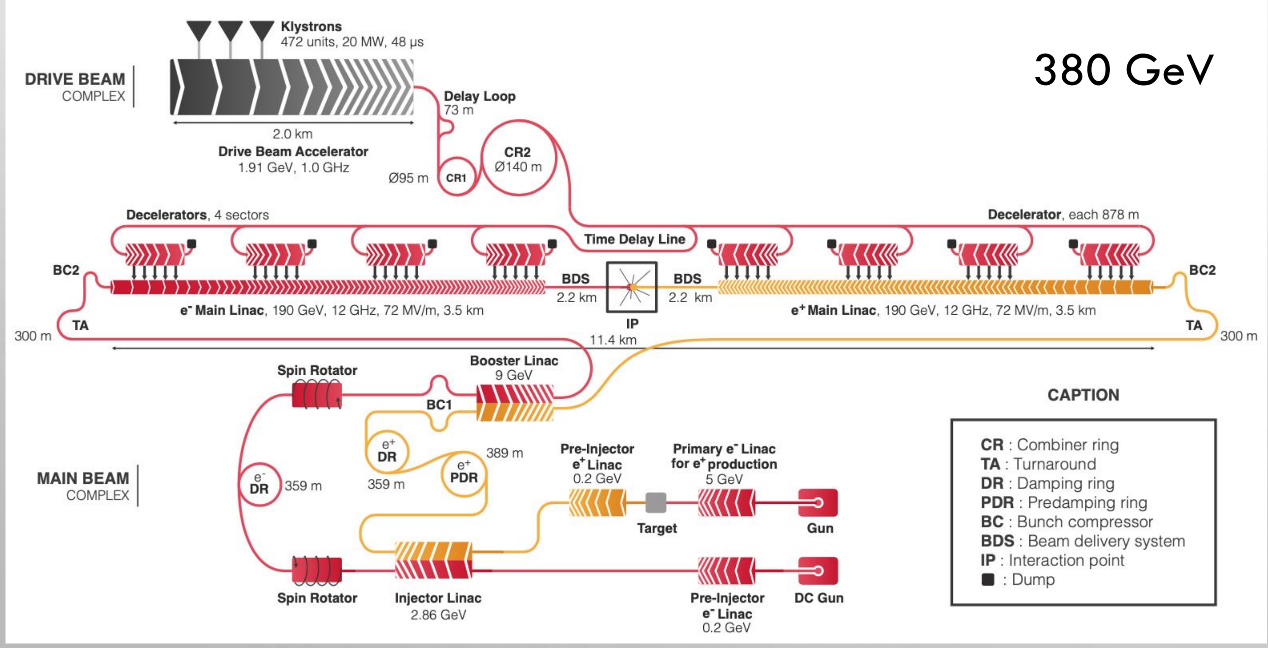
1. Drive beam accelerated to ~2 GeV using conventional klystrons
2. Intensity increased using a series of delay loops and combiner rings
3. Drive beam decelerated and produces high-RF
4. Feed high-RF to the less intense main beam using waveguides

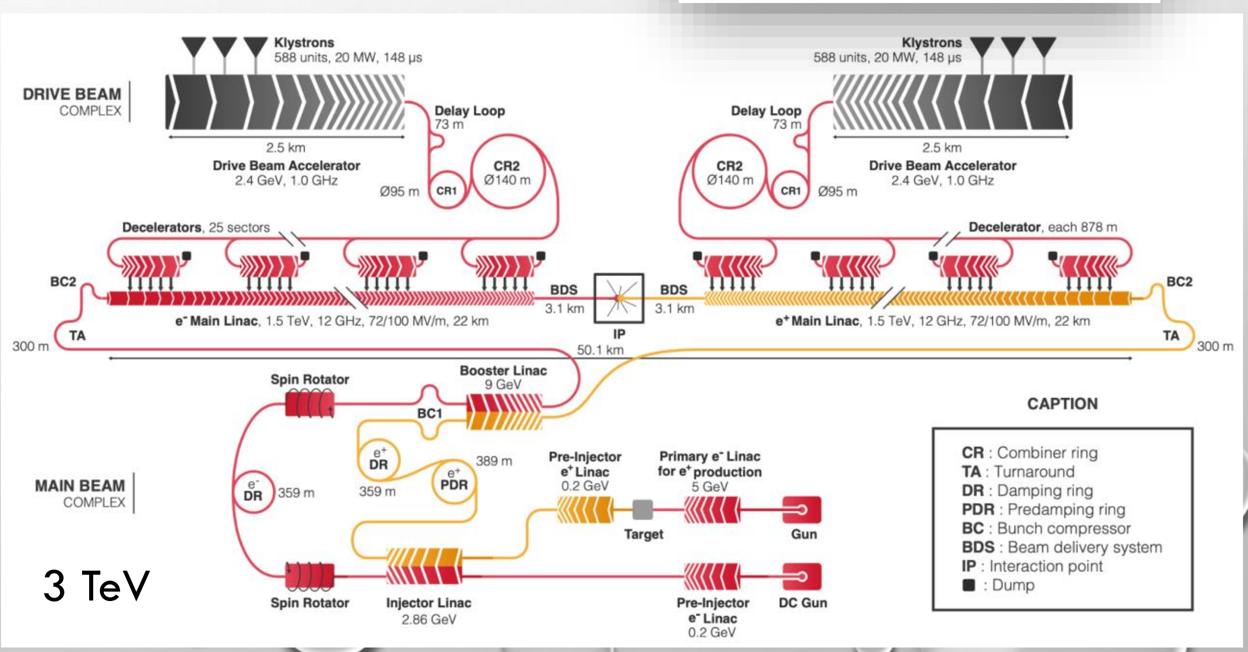
Extend by extending main linacs, increase drive beam pulse-length and power, and a second drive beam to get to 3 TeV



Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)



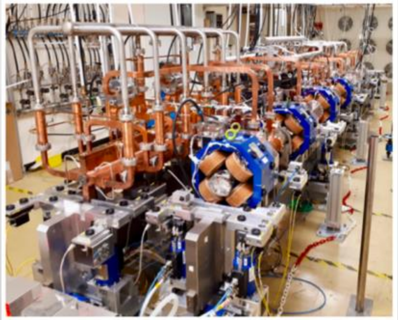


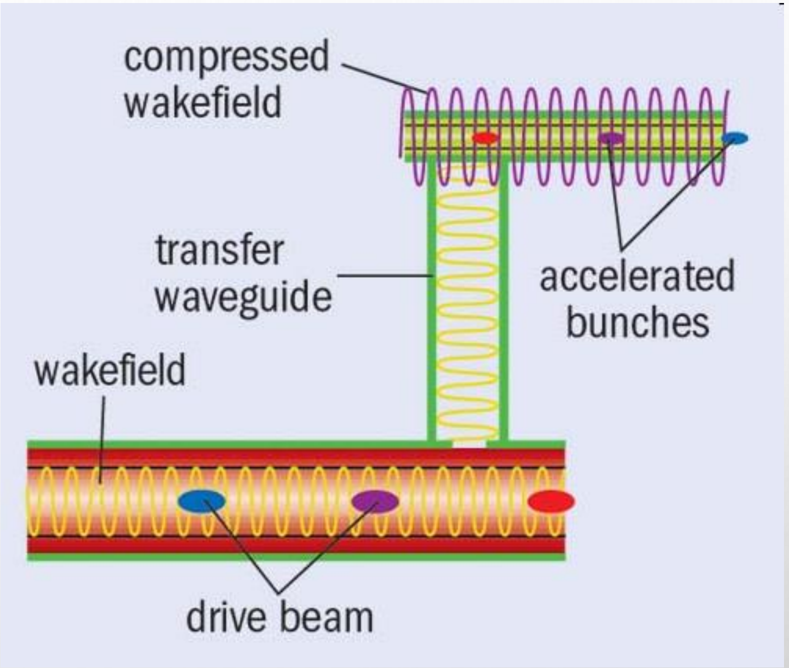


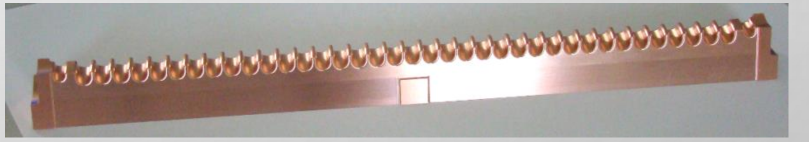
TWO BEAMS ACCELERATION SCHEME

- The high-current drive beam is decelerated in special power extraction structures (PETS)

- Generated EM field can be transferred in RF waveguides to the other beam => power is used to accelerate the main beam







CLIC PARAMETERS

Main beam dynamics challenges: generation and preservation of very small emittances along the accelerator

Table 1.1: Key parameters of the CLIC energy stages.

Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	1.3	1.4	2
Total int. lum. per year	fb^{-1}	276	444	708
Main linac tunnel length	km	11.4	29.0	50.1
Nb. of particles per bunch	1×10^{9}	5.2	3.7	3.7
Bunch length	μm	70	44	44
IP beam size	nm	149/2.0	~60/1.5	~40/1
Final RMS energy spread	%	0.35	0.35	0.35
Crossing angle (at IP)	mrad	16.5	20	20

PERFORMANCE OF FUTURE LINEAR COLLIDERS

- LINACS & BDS

Tuning: process to bring a system or several subsystems to the desired performance

Sources of performance degradation

- Static imperfections:
  - magnets displacements, roll, strength errors, etc…
- Dynamic imperfections:
  - ground motion, vibrations, beam jitter, etc…

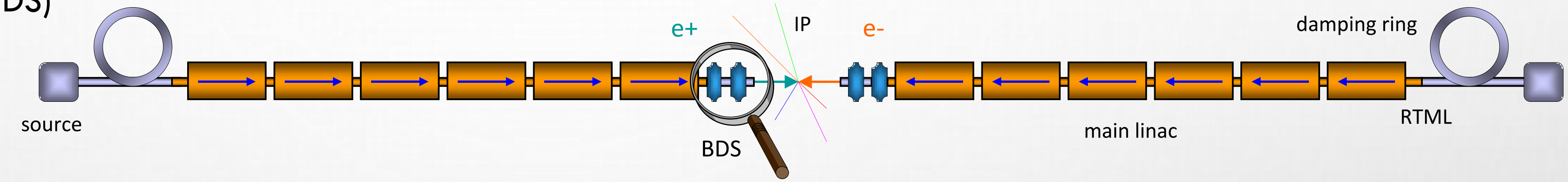
Definition of static corrections and feedbacks (dynamics variations) to recover known imperfections

- Choice of the algorithm, iteration, tolerances and of the figure of merit

Unknown

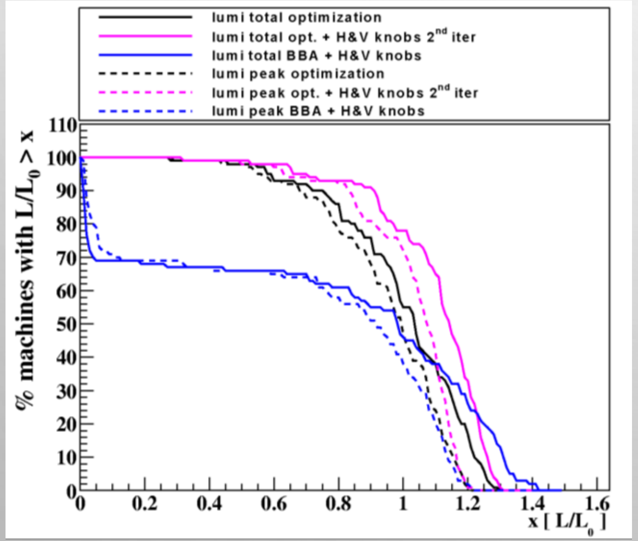
EXAMPLE OF TUNING TECHNIQUES

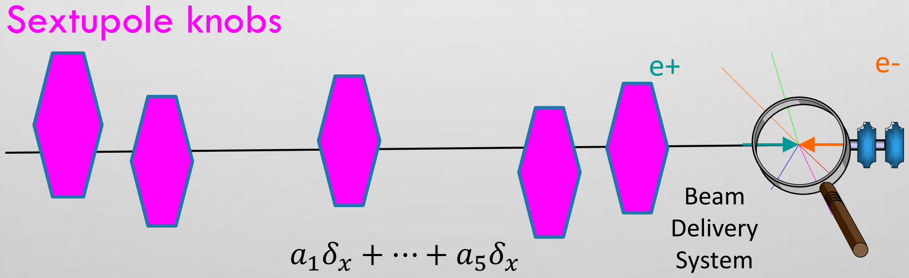
- High resolution bpms (sub- μm) coupled with sophisticated beam-based trajectory techniques
- Tight pre-alignment tolerances (~10 μm)
- Beam Delivery System (BDS)



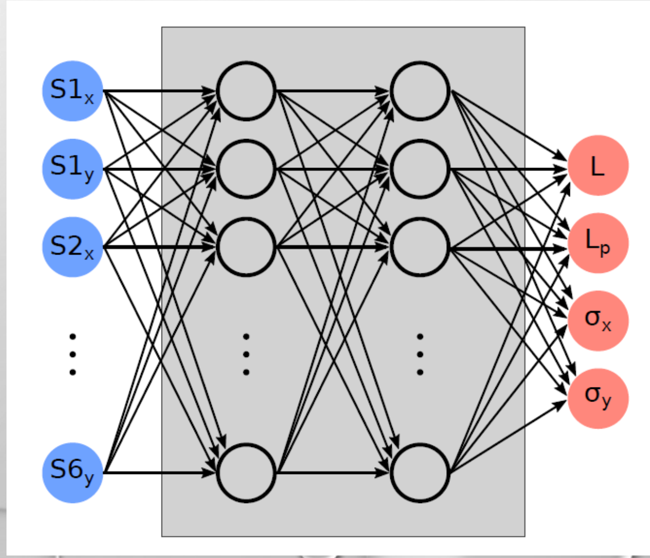
- Stabilization to suppress dynamic imperfections (sub-nm level)
- Tuning against static imperfections using sextupoles knobs, AI and a fast luminosity signal as figure of merit

B. Dalena et al., Phys. Rev. ST-AB, 15, 051006 (2012)





J. Ogren et al., JINST, 16, P05012 (2021)



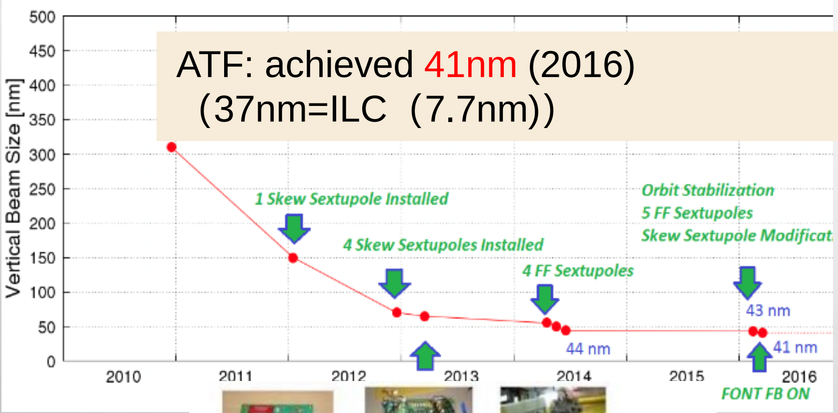
ILC/CLIC TEST FACILITY FOR NANO BEAMS

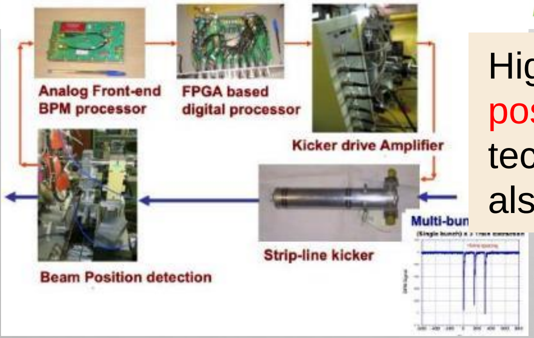
Tech. design completed
Spec. almost achieved

→

Detailed design
Stable operation
demonstration

ATF: achieved 41nm (2016)
(37nm=ILC (7.7nm))





High-speed beam position control technology was also demonstrated.

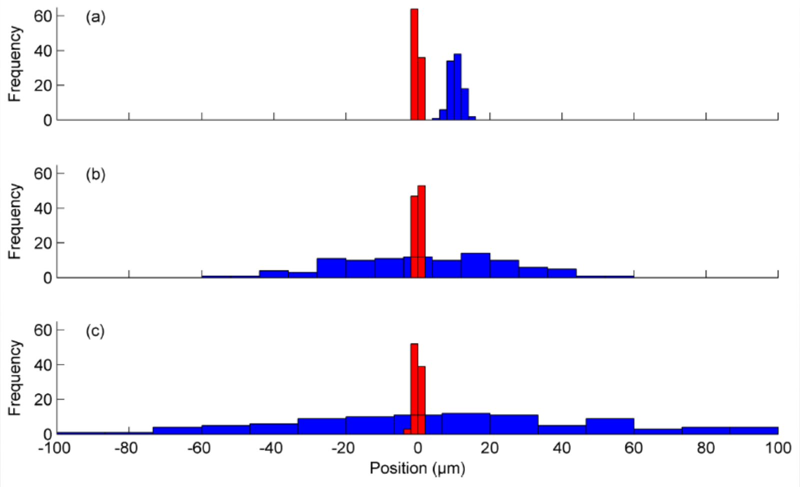
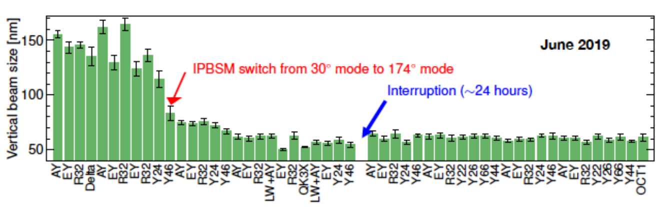


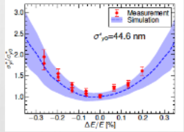
FIG. 19. Distributions of positions with feedback off (blue) and feedback on (red) for bunch 2 at P3 with incoming, uncorrected position jitters of (a) ~2 μm, (b) ~22 μm, and (c) ~45 μm.

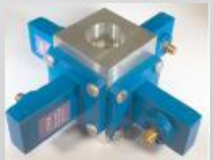
ATF International Review (Committee)*
-The committee highly evaluated the achievements of ATF so far.
-The committee pointed out the importance of continuing research to contribute to the detailed design of the ILC final convergence.

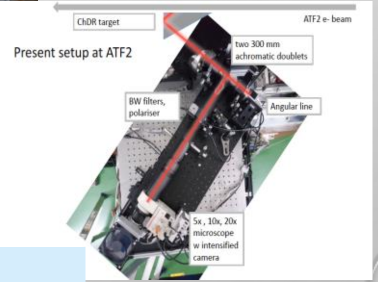
A. Faus Golfe and P. Burrows ICHEP 2022



Ultra low–β^* studies





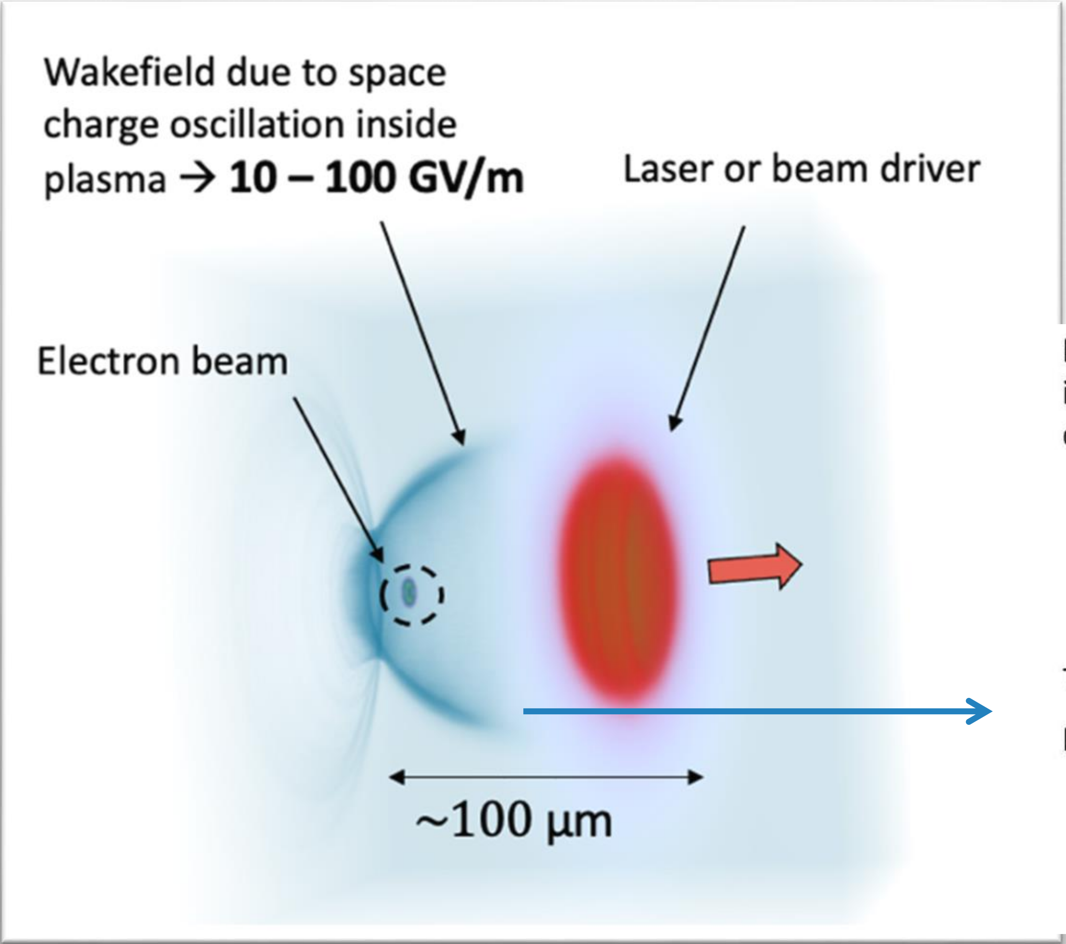


Modify the beam monitor system, etc. at ATF to demonstrate stable operation.

OUTLINE 2ND PART

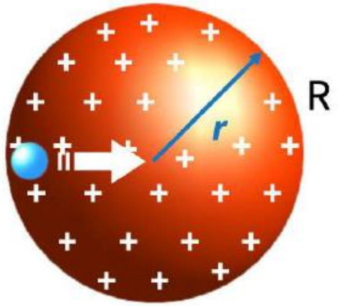
- Futures Circular Colliders Projects
    - HL-LHC
    - FCC-ee/FCC-hh
    - CepC/SppC

PLASMA WAKE ACCELERATORS PRINCIPLE



From Maxwell's equations, the electric field in a (positively) charged sphere with uniform density n_i at location **r** is

$$\vec{E}(r) = \frac{q_i n_i}{3\epsilon_0} r$$

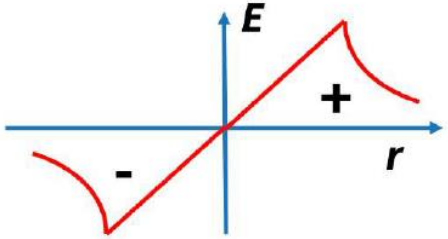


The field is **increasing** inside the sphere

Let's put some numbers

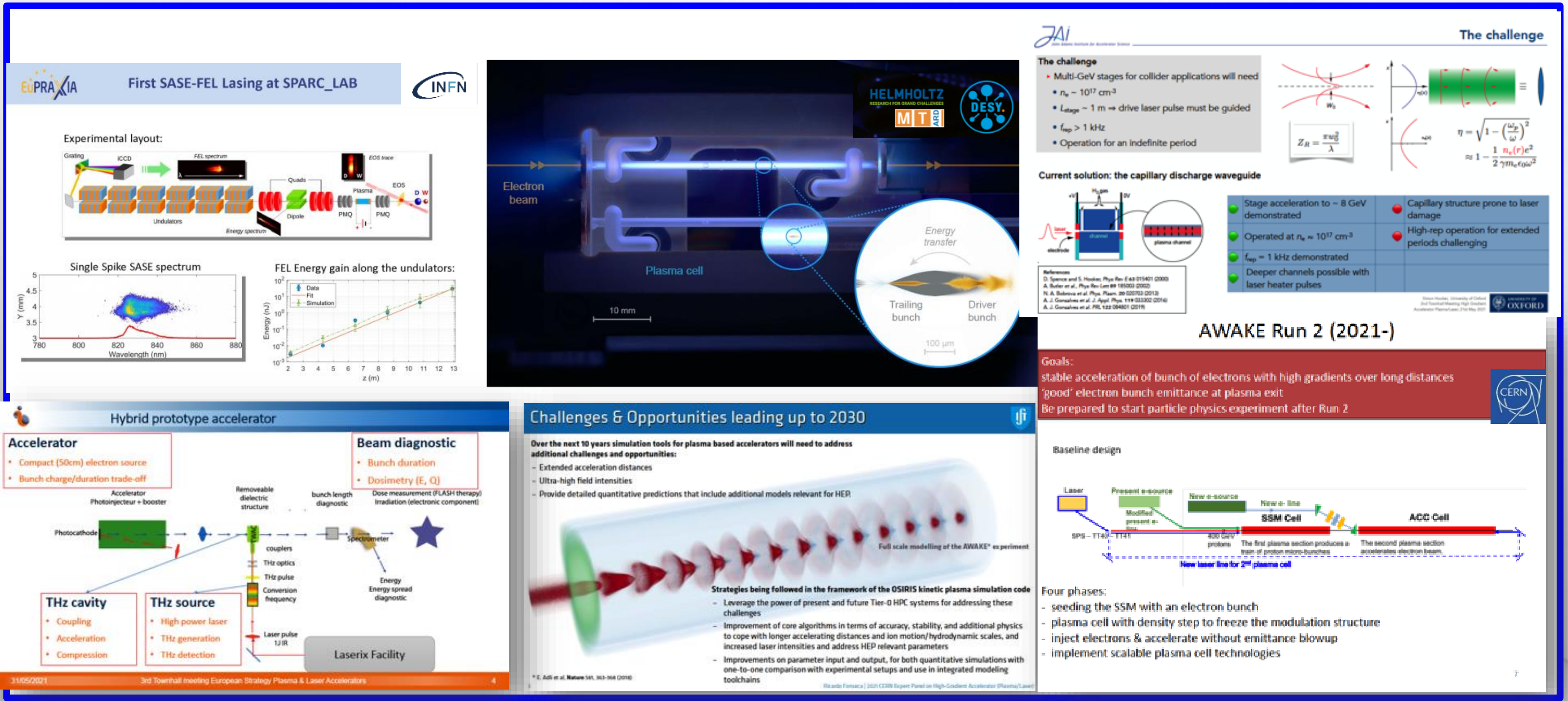
$n_i = 10^{16}\ cm^{-3}$

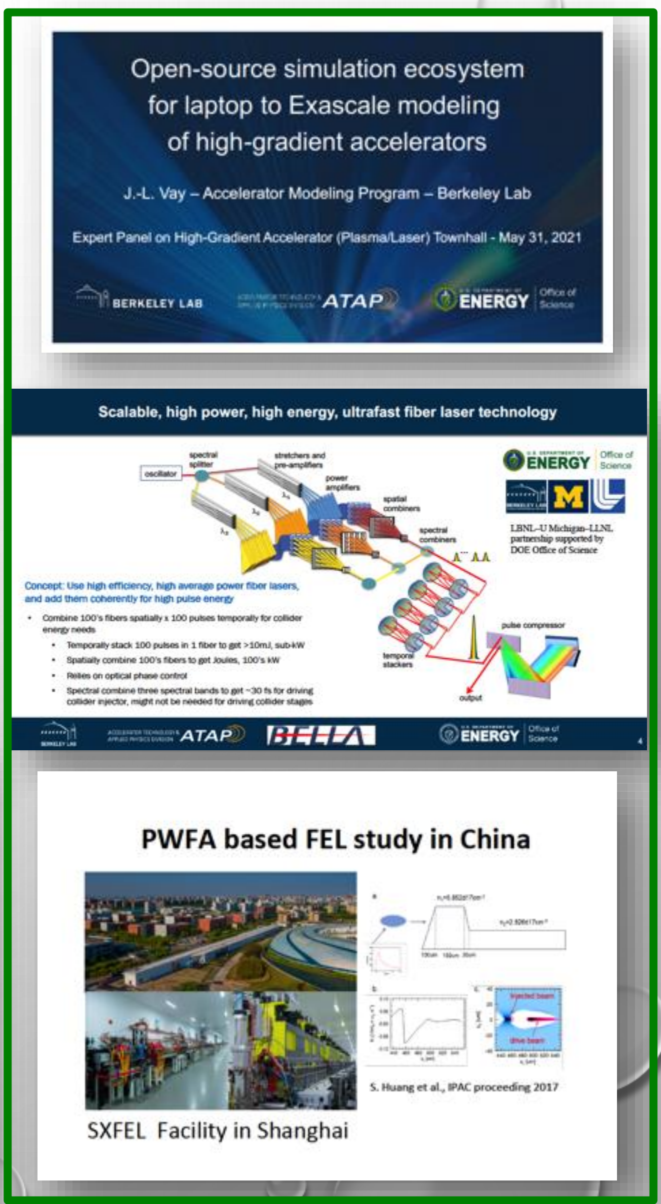
$R = 0.5\ \lambda_p = 150\ \mu m$ ⟹ $E \approx 10 \frac{GV}{m}$



PLASMA WAKEFIELD R&D

- Specific topics to be addressed:
  - Positron acceleration
  - Technological issue (efficiency, cooling, polarization,…)
- The world wide R&D focus on beam quality, beam stability, staging and continuous operation

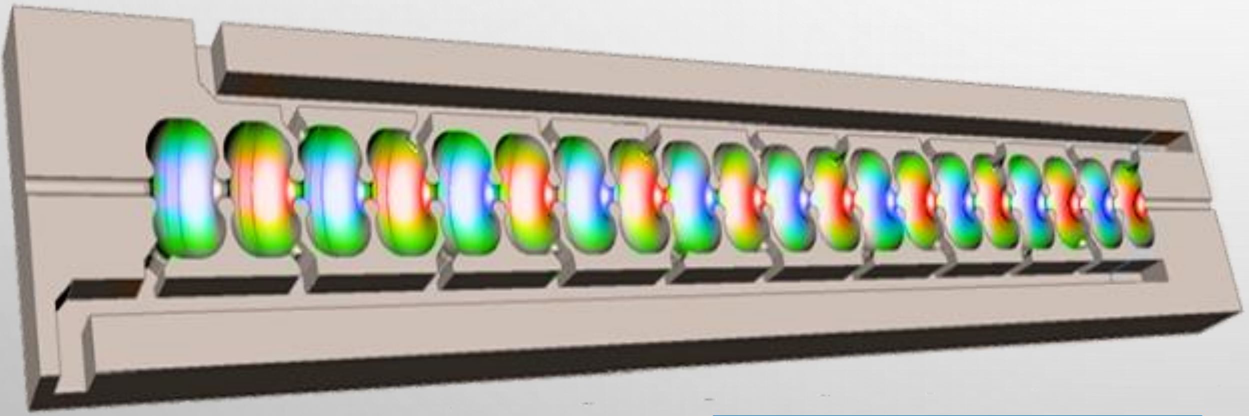




C³ (COOL COPPER COLLIDER)

250 GeV e+/e- initially
and upgrade to 550 GeV with ~8 km in length

Normal-Conducting Radio-Frequency (NCRF) C-band cavities cooled by liquid nitrogen reach ~120 MeV/m acc. gradient



Courtesy of F: Bordry, SLAC, CERN

L. Rossi ICHEP2022

C^3 : A "Cool" Route to the Higgs Boson and Beyond

Mei Bai, Tim Barklow, Rainer Bartoldus, Martin Breidenbach*, Philippe Grenier, Zhirong Huang, Michael Kagan, Zenghai Li, Thomas W. Markiewicz, Emilio A. Nanni*, Mamdouh Nasr, Cho-Kuen Ng, Marco Oriunno, Michael E. Peskin*, Thomas G. Rizzo, Ariel G. Schwartzman, Dong Su, Sami Tantawi, Caterina Vernieri*, Glen White, Charles C. Young

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INFN-LNF, Frascati, Rome 00044, Italy

Vladimir Shiltsev

Fermi National Accelerator Laboratory, Batavia IL 60510-5011

ABSTRACT

We present a proposal for a cold copper distributed coupling accelerator that can provide a rapid route to precision Higgs physics with a compact 8 km footprint. This proposal is based on recent advances that increase the efficiency and operating gradient of a normal conducting accelerator. This technology also provides an e^+e^- collider path to physics at multi-TeV energies. In this article, we describe our vision for this technology and the near-term R&D program needed to pursue it.

ArXiv 2110.15800 (2021)

ILC UPGRADES OPTIONS

Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ^*_{z}	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ^*_{x}	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	138	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [26]. *): For operation at the Z-pole additional beam power of 1.94/3.88 MW is necessary for positron production.

ILC KEY TECHNOLOGIES: SRF CAVITIES

Cavity

- Huge global interest in ILC-like SC RF systems: European XFEL, LCLS-II, Shanghai XFEL …
- Nb cavity performance advancements made at many labs.

New surface treatments and improved fabrication techniques → major improvements in gradient, Q, yield, cost

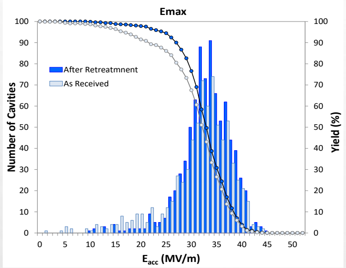
N-infusion:
45 MV/m @ Q ~ 2 x 10**10

ILC spec:
31.5 MV/m @ Q ~ 1x 10**10

(for Q see W. Venturini lecture)

Yield evaluation of cavities based on TDR

The mass production of European XFEL has reached ≥ 83% of the ILC specification yield (90%).



European XFEL: 29 ± 5.1 MV/m

Cryomodule

Eng. design

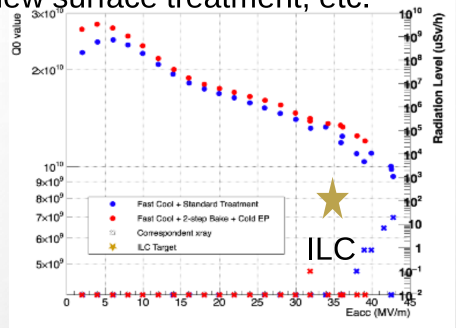
Euro-XFEL Operation (Europe)
~800 cavities/
~100 Modules

LCLS-II Construction (USA)
~280 cavities/
~35 Modules

Realized through international cooperation and procurement

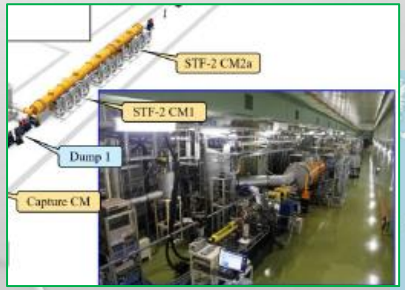
High performance and cost reduction

US-Japan: high performance with new surface treatment, etc.



Germany-Japan: Improving Efficiency in Cavity Manufacturing.

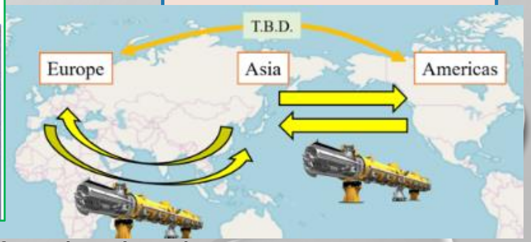
Module assembly



France-Japan: Automation of cavity cleaning

Cavity manufacturing, performance demonstration (Yield demonstration in three areas)

Demonstration of cryomodule assembly, transfer, and performance



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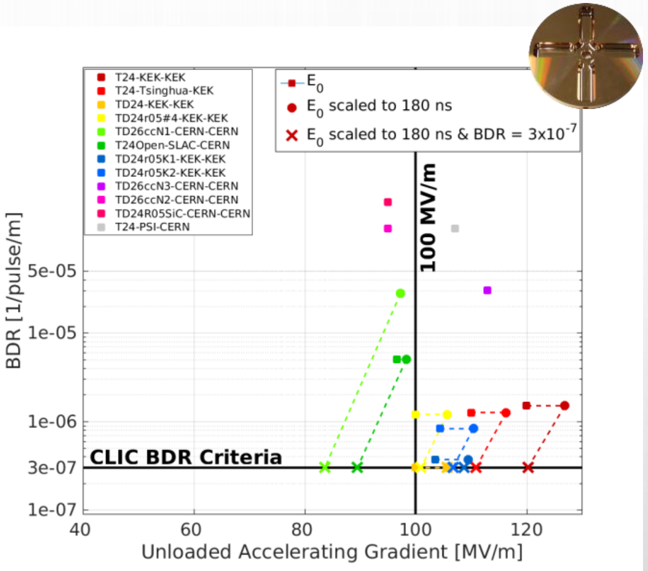
CLIC ON GOING ACCELERATOR STUDIES


X-band technology:
- Design and manufacturing of X-band structures and components
- Study structures breakdown limits and optimization, operation and conditioning
- Baseline verification and explore new ideas
- Assembly and industry qualification



Technical and experimental studies, design and parameters:
- Module studies
- Beamdynamics and parameters: Nanobeams (focus on beam-delivery), pushing multi TeV region (parameters and beam structure vs energy efficiency)
- Tests in CLEAR (wakefields, instrumentation) and other facilities (e.g. ATF2)
- High efficiency klystrons
- Injector studies suitable for X-band linacs (coll. with Frascati)

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Application of X-band technology (examples):
- A compact FEL (CompactLight: EU Design Study 2018-21)
- Compact Medical linacs (proton and electrons)
- Inverse Compton Scattering Source (SmartLight)
- Linearizers and deflectors in FELs (PSI, DESY, more)
- 1 GeV X-band linac at LNF
- eSPS for light dark matter searches (within PBC)

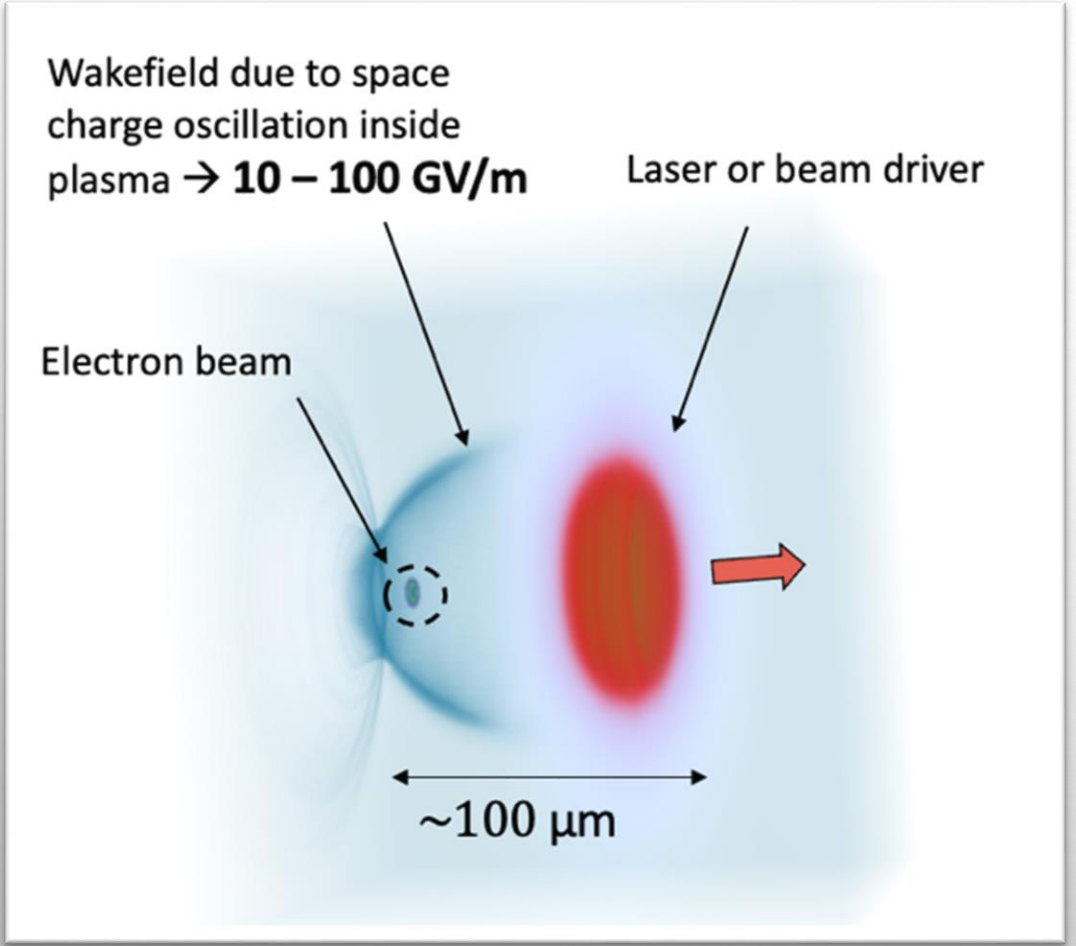
More information: [CLIC mini week (1.10.2020)]

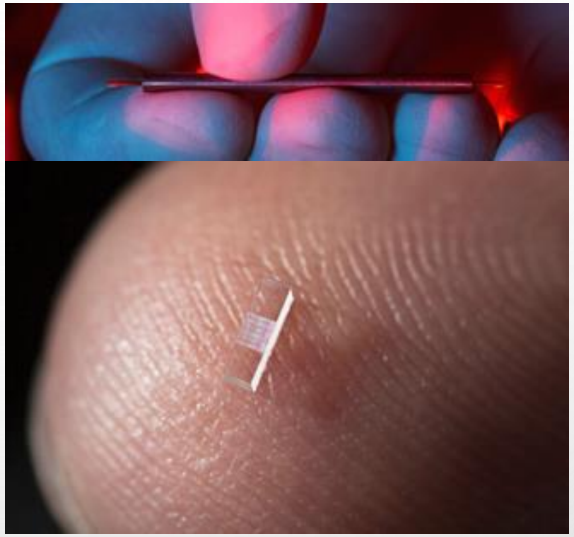
Sostituire con slides di Phi

PLASMA WAKE ACCELERATORS PRINCIPLE

Damage limits for metallic walls in RF cavities limit accelerating fields→ replace metal with plasmas or dielectric materials → advance into the many GV/m regime → shorter acc. lengths → reduced cost?

Illustration from EuPRAXIA, A. Ferran Pousa et al





Lasers or THz pulses or e- beams drive dielectric structures (e.g. Silicium)

"Accelerator on a Chip" grant Moore foundation: Stanford, SLAC, University Erlangen, DESY, University Hamburg, PSI, EPFL, University Darmstadt, CST, UCLA

AXSIS ERC Synergy Grant: DESY, Arizona SU

Options for driving plasma and dielectric structures (no klystrons at those frequencies):

- **Lasers:** Industrially available, steep progress, path to low cost
  Limited energy per drive pulse (up to **50 J**)
- **e- bunch:** Short bunches (need mm) available, need long RF accelerator
  More energy per drive pulse (up to **500 J**)
- **p+ bunch:** Only long (inefficient) bunches, need very long RF accelerator
  Maximum energy per drive pulse (up to **100,000 J**)

R. Assmann EPS-HEP 2021