



FUTURE COLLIDERS PROJECTS

1ST PART

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ACKNOWLEDGEMENTS AND REMARKS

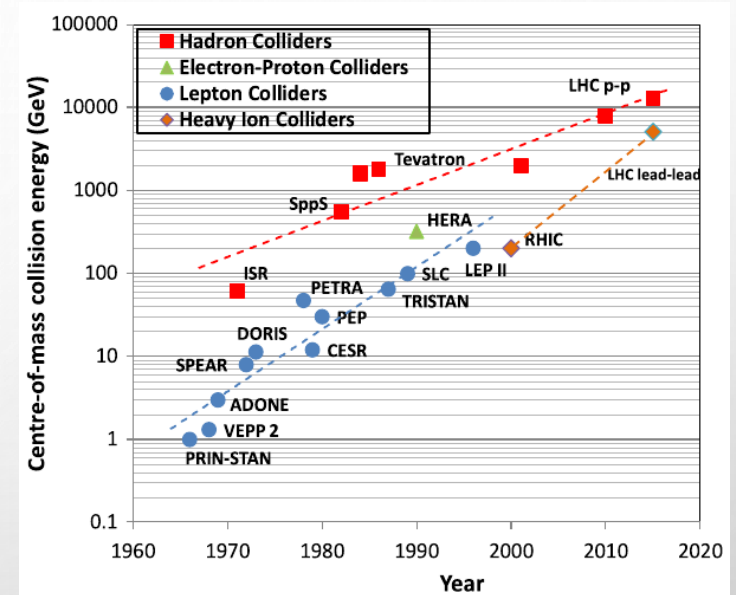
- Many thanks to **B. Holzer** for gave me the possibility to look at the current state of the art of many different concepts, in preparing these lectures
- This lecture is based on a collection of materials from many colleagues I would like to acknowledge:
 - R. Bruce (last year lectures), D. Schulte, W. Bartmann, M. Benedict, M. Boscolo, H. Burkhardt, P. Burrows, R. Corsini, R. De Maria, O. Etisken, A. Faus Golfe, F. Gianotti, M. Giovannozzi, B. Holzer, M. Hofer, J. Jowett, R. Kersevan, W. Kaabi, M. Lamont, T. Pieloni, S. Redaelli, L. Rossi, M. Schaumann, J. Wenninger, F. Zimmermann, S. Stapnes, G. Sterbini, R. Assmann, J-P. Delahaye, L. Linssen, S. Doebert, A. Grudiev, F. Tecker, W. Wuensch, R. Kersevan, and many others I might have forgotten
- For particle physics goals and detector: Please see F. Simon lectures
- **Useful concepts introduced in other lectures:**
 - M.Schaumann: **particle accelerators and beam dynamics**
 - H. Felice: **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
 - PLASMA WAKE ACCELERATORS

PARTICLE COLLIDERS

- Particle colliders 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 heavy ions



“Livingstone plot” of collider energy vs time ([source](#))

LHC PATH



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-?



Plug-in module with damaged fingers 2008



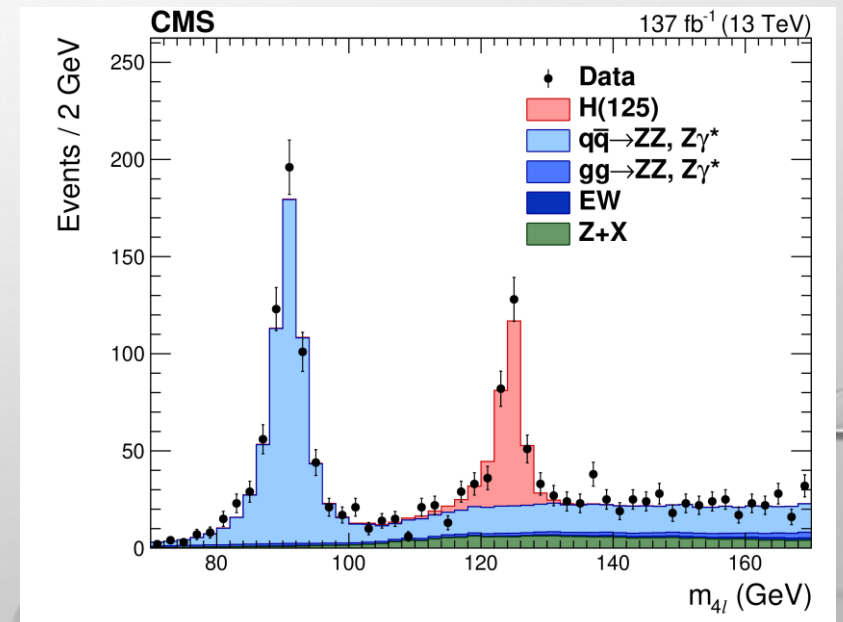
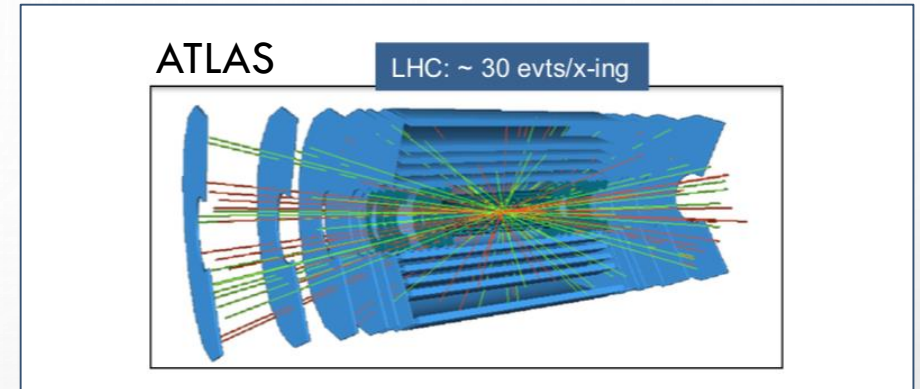
F. Gianotti ICHEP 2022

WHERE DO WE STAND

Higgs discovery (2012)

Open questions still remain (see F. Simon Lecture):

- 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”

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

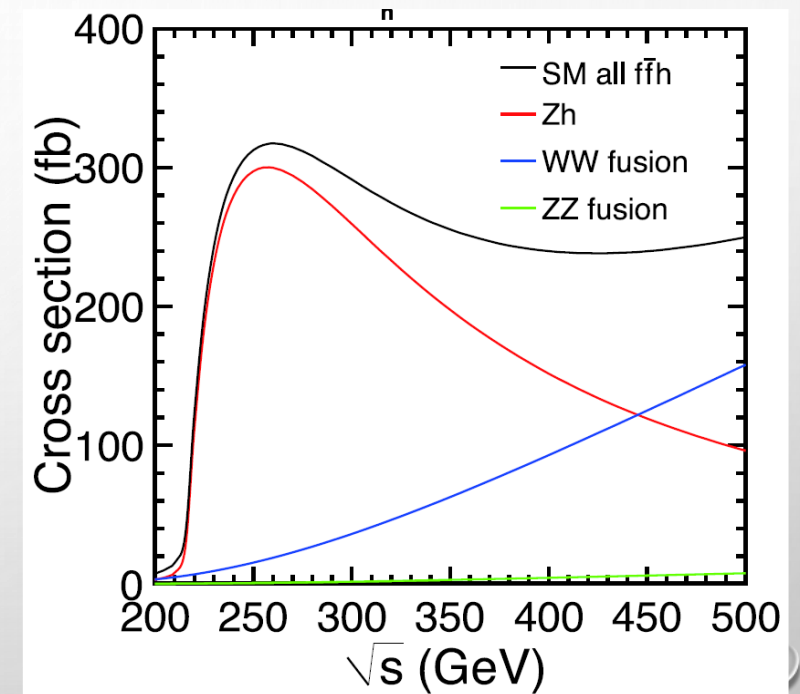
Acceleration technology

DC, RF, wakefield... (see lecture of W. Venturini)

Magnet technology

Superconducting (what conductor?), normal conducting
(see lecture of H. Felice)

Acceptable cost of construction, **power consumption**, site



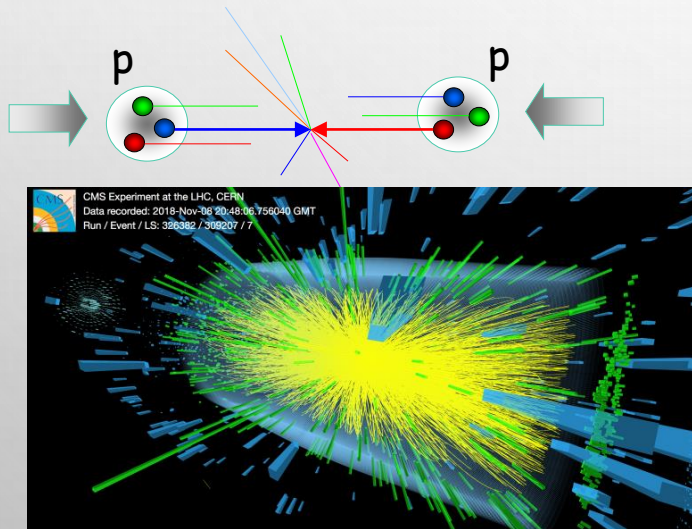
Example e^+e^- collision

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

LEPTONS VS HADRONS

Hadrons (protons or ions)

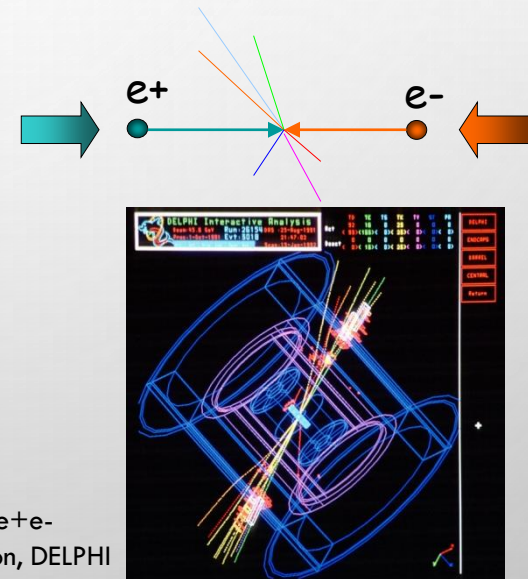
- Mix of quarks, anti-quarks and gluons:
 - variety of processes
 - not all nucleon energy available in collision
 - Energy spread between partons – spread in collision energy
 - huge QCD background
- Can typically achieve highest collision energy
- Good for discoveries at the frontier of new physics



LHC Pb-Pb collision, CMS

Leptons (electrons, positrons, muons)

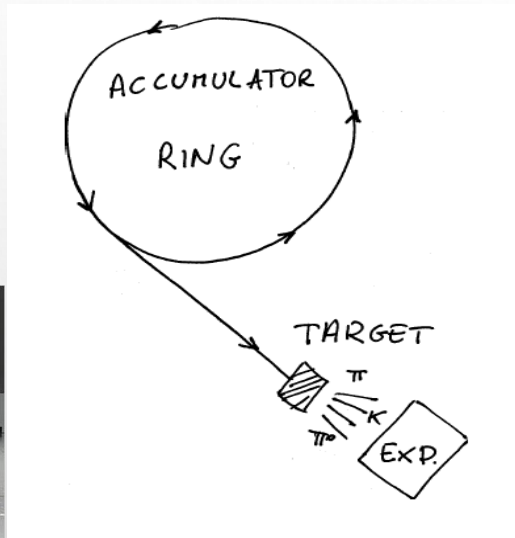
- Elementary particles colliding - very well defined centre-of-mass energy
- Low background
- Good for high-precision measurements
- Energy loss due to synchrotron radiation



LEP II e^+e^- collision, DELPHI

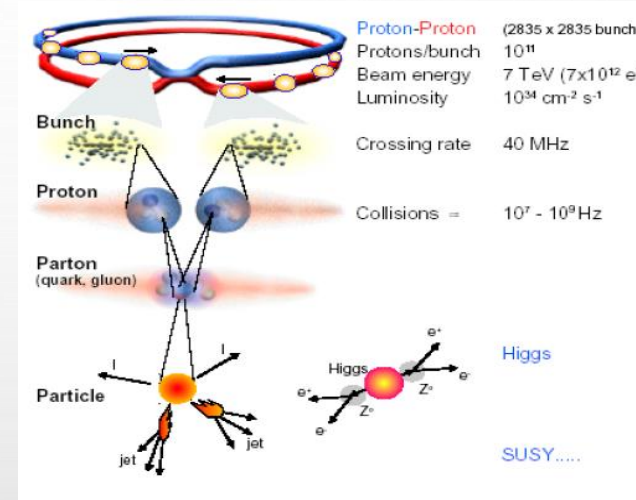
ENERGY REACH

- Fixed Target



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

- Collider



$$\ll E_{CM} = E_1 + E_2$$

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

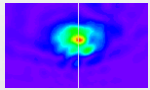
(See M. Schaumann's Lecture)

LUMINOSITY AND BEAMS

beam size

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

Beam quality



magnets



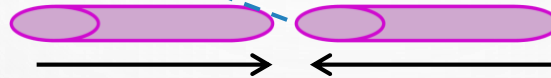
Luminosity

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

event rate

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

N_1



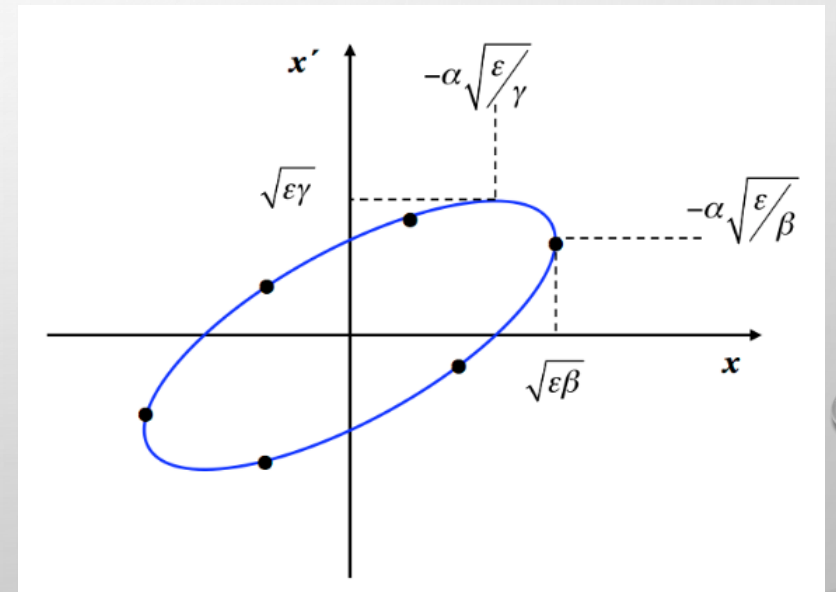
N_2

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 \Rightarrow phase space volume occupied by the beam

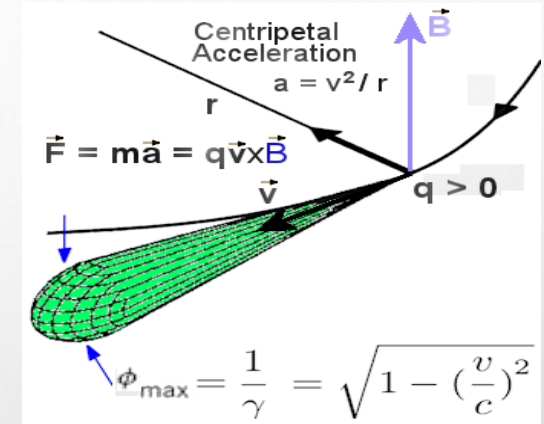
$\beta(s)$ = beta function \Rightarrow describes the focusing force along the beam transport system

(See M. Schaumann Lecture)



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



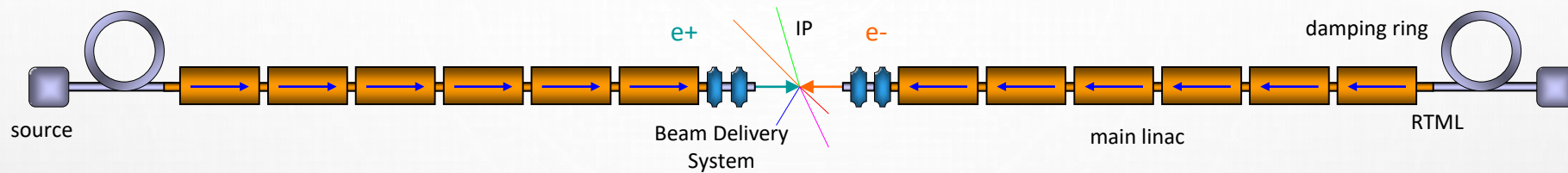
Radiated power

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

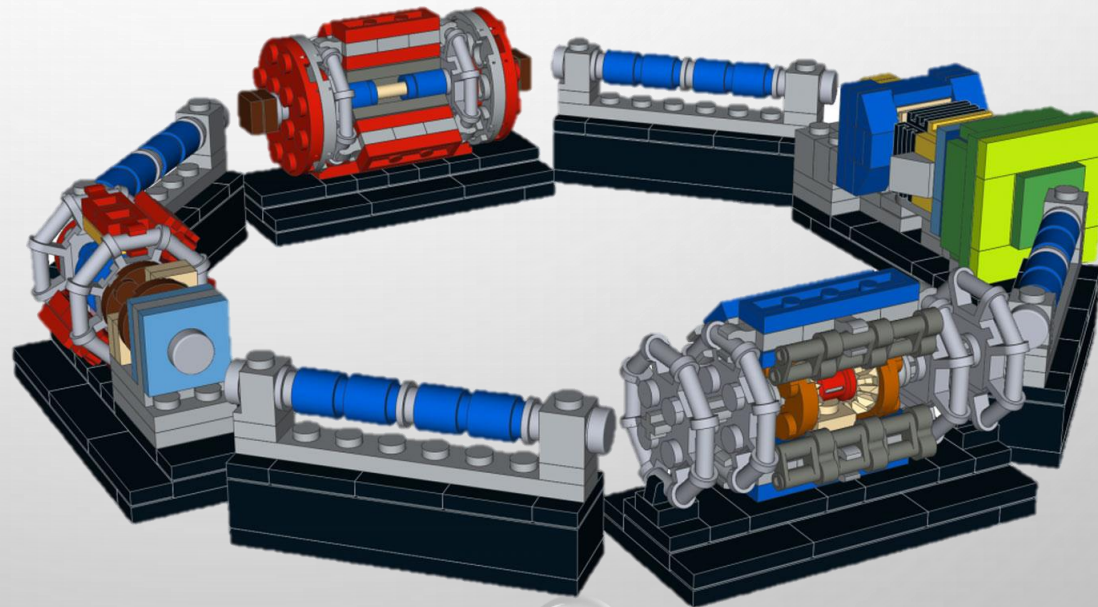
Energy loss

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

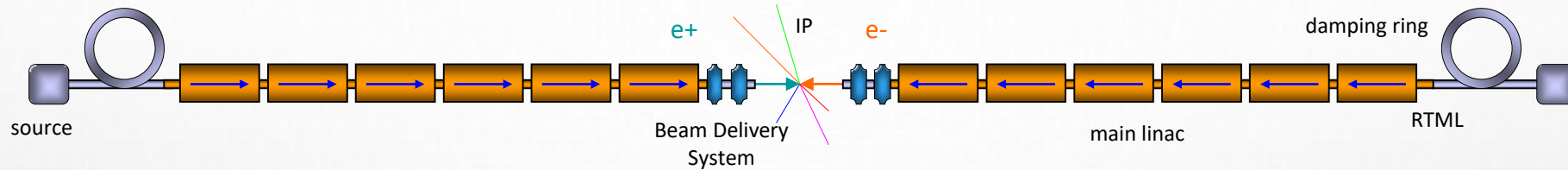
LINEAR AND CIRCULAR COLLIDERS



- 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

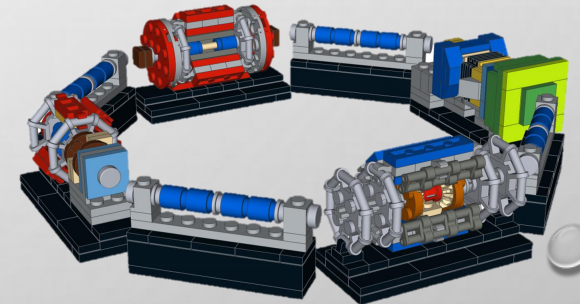
Circular collider

- 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 lecture M. Schaumann)



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

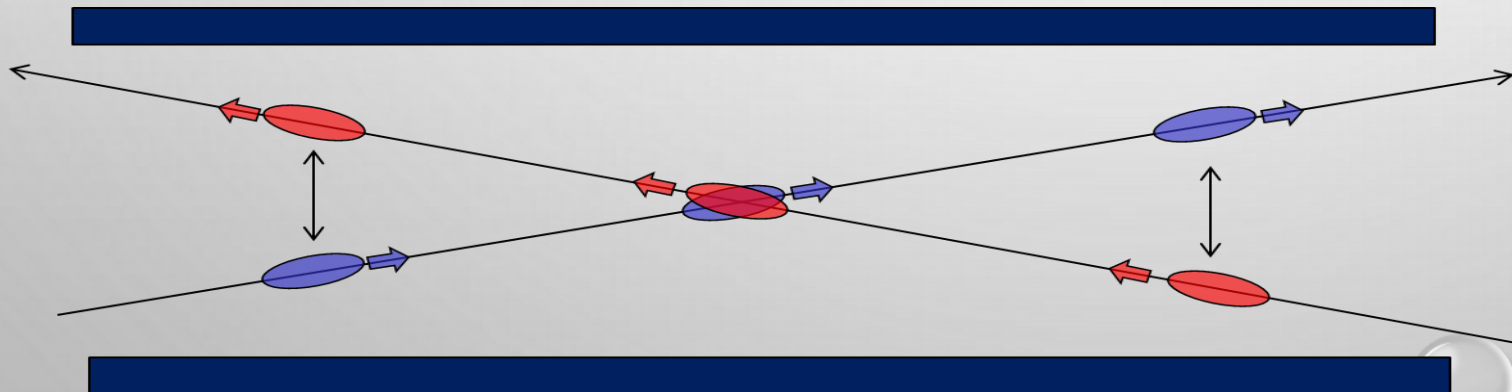
LUMINOSITY LIMITATIONS

- Increase number of bunches k
- Increase single bunch intensity N \Rightarrow Limited by collective instabilities
- Reduce beam sizes (β^* , ε , σ) \Rightarrow Limited by optics design and magnets imperfections

- Maximize the geometric reduction Factor

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

\Rightarrow Compensation schemes



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

Round beams

(see lecture M. Schaumann)

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

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

- **Beam** – **beam** tune shift in **circular colliders**

- The Strong focusing field in beam-beam interaction is linear (like quadrupoles) \Rightarrow it produces a shift in the tune (see M. Schaumann lecture)
- The beam-beam parameters for Gaussian **round** (Hadrons) beams and for **elliptic** (leptons) beams depends on key accelerator parameters

$$\langle \Upsilon \rangle = \frac{5}{6} \frac{\gamma N r_e^2}{\alpha \sigma_z (\sigma_x + \sigma_y)}$$

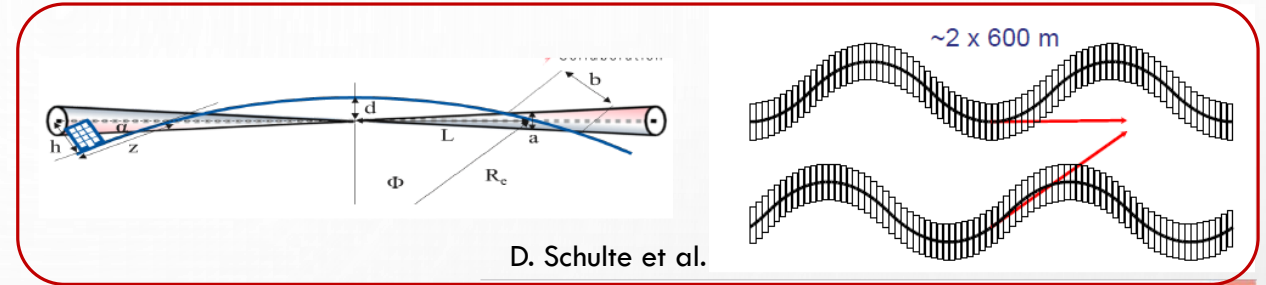
$$D_{x,y} = \frac{2 N r_e \sigma_z}{\gamma \sigma_{x,y} (\sigma_x + \sigma_y)}$$

$$\xi = \frac{N r_0 \beta^*}{4 \pi \gamma \sigma^2}$$

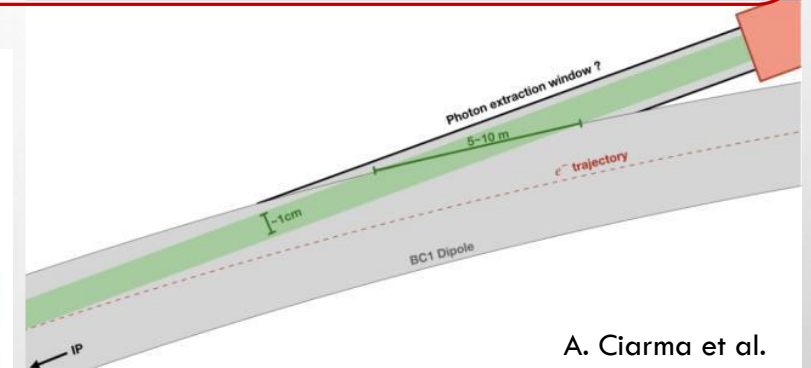
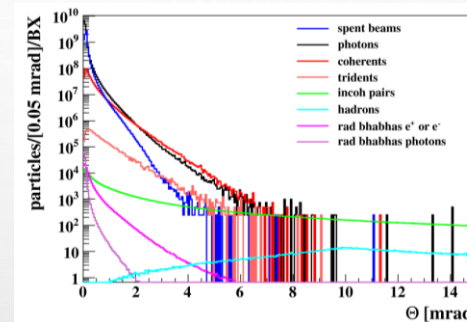
$$\xi_{x,y} = \frac{N r_0 \beta_{x,y}^*}{2 \pi \gamma \sigma_{x,y} (\sigma_x + \sigma_y)}$$

BEAM INDUCED BACKGROUND

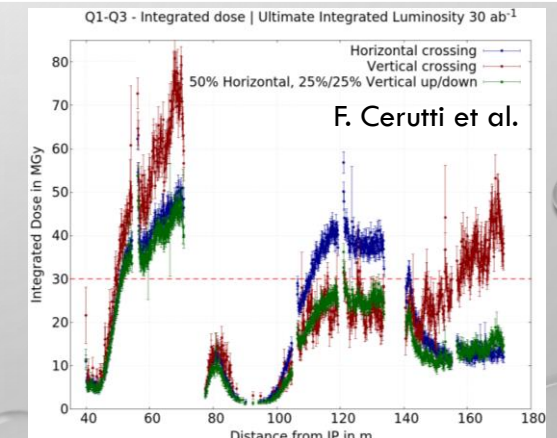
- Neutrinos and secondary particles radiation in muon colliders



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



- 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



ASPECTS TO CONSIDER

D. Schulte

Physics potential

The collider energy
The collider luminosity
Particle type

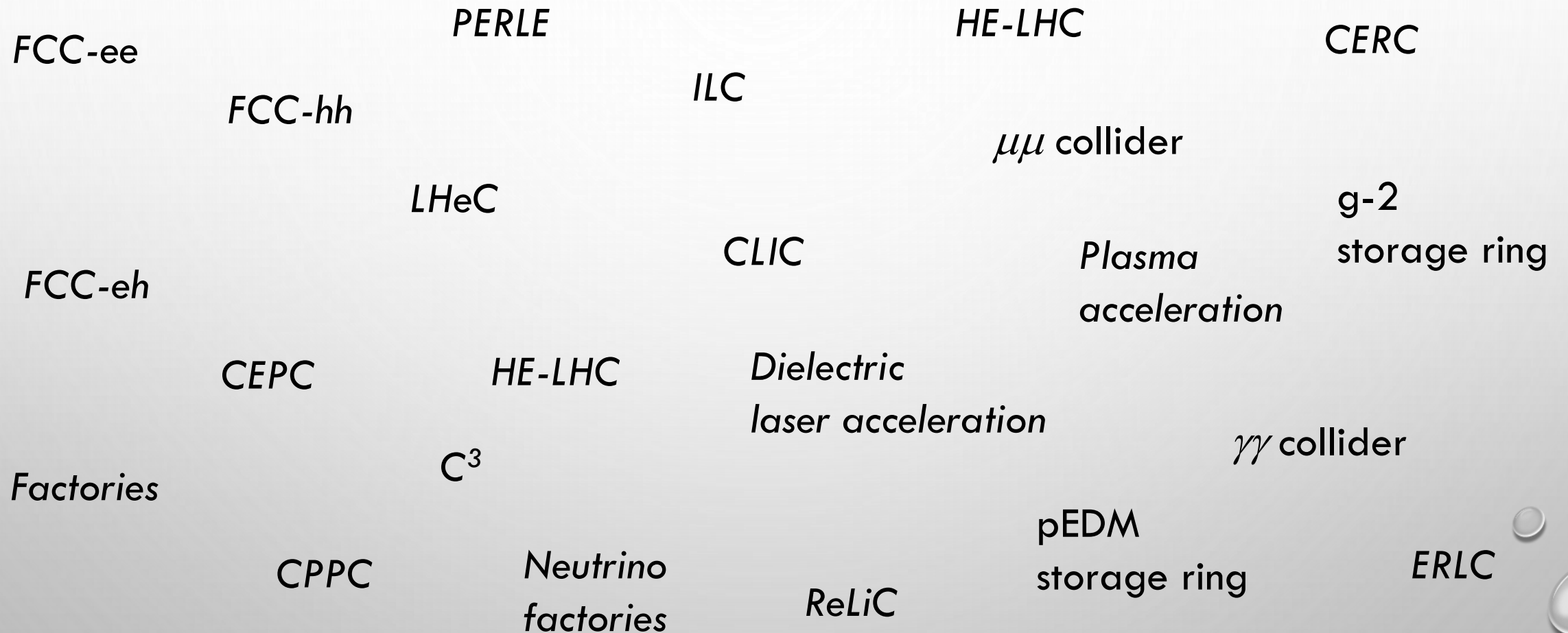
Feasibility

The technical maturity
The risk
The schedule

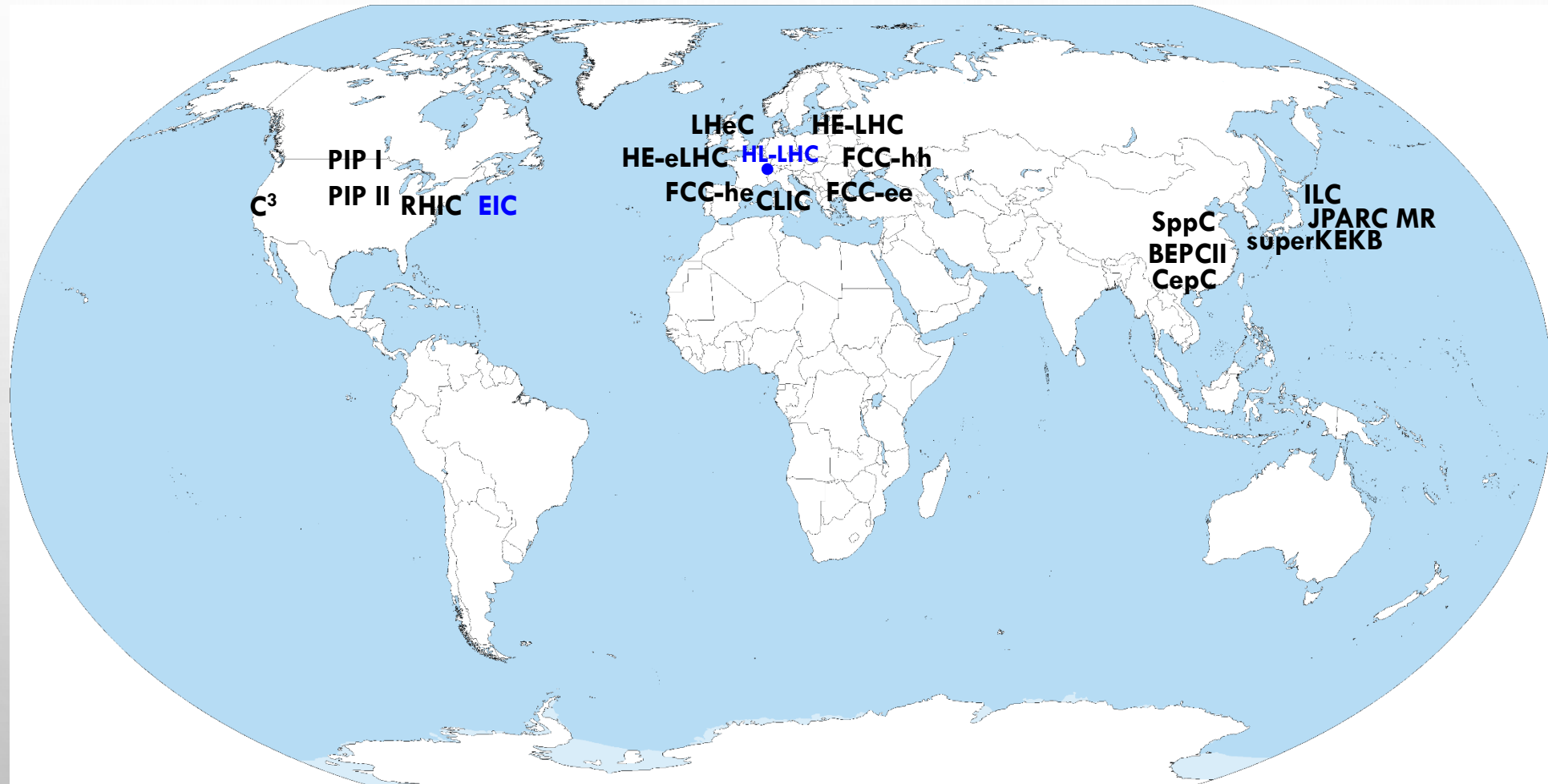
Affordability

The collider cost
The collider power consumption
Availability of site

FUTURE HEP ACCELERATORS, CONCEPTS, IDEAS



FUTURE HEP ACCELERATORS

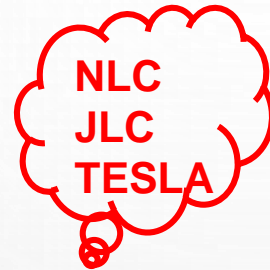


$\gamma\gamma$, Gamma Factory
 $\mu^+\mu^-$ colliders

charm- τ factory
 plasma acceleration

\Rightarrow not shown

LINEAR COLLIDERS



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ILC TODAY

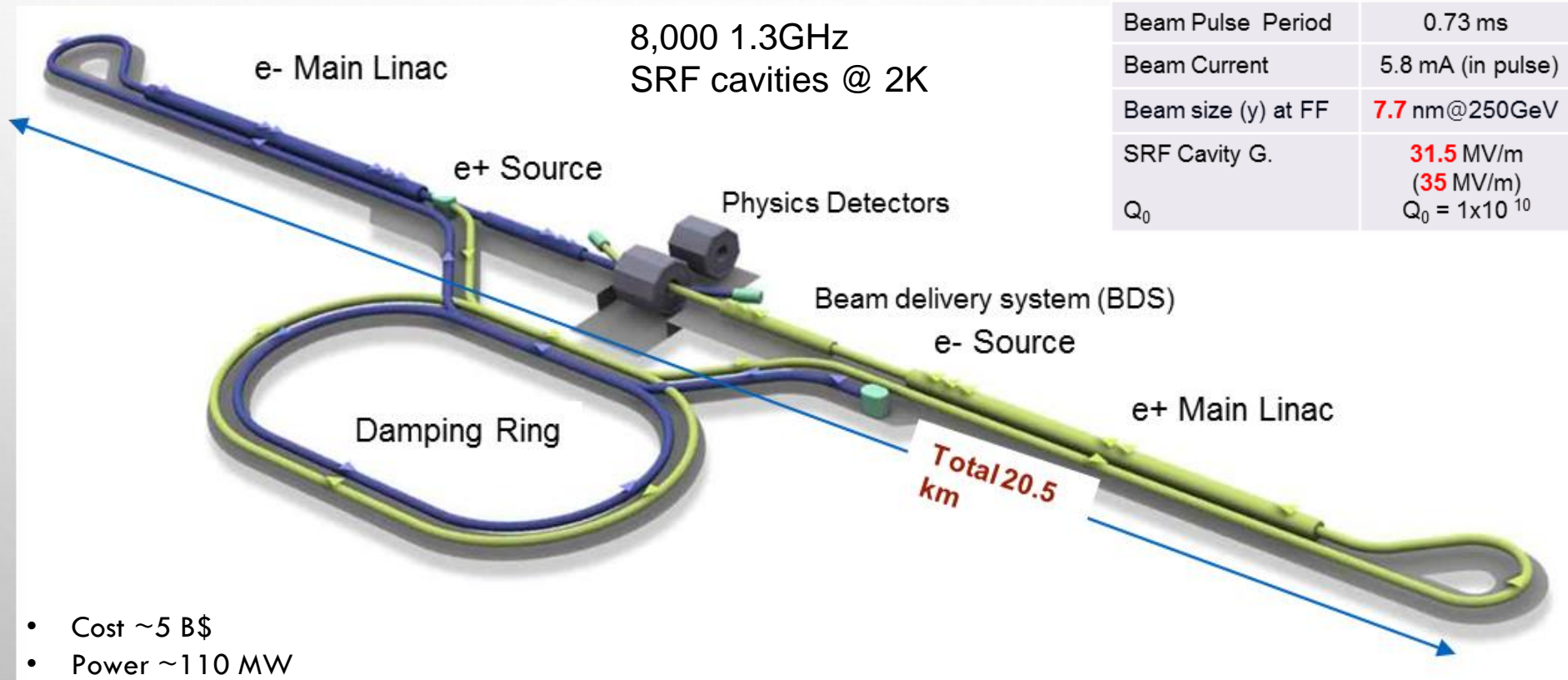
TDR (2013) exits for 500 GeV

Emphasis on Higgs precision Physics in the electroweak sector



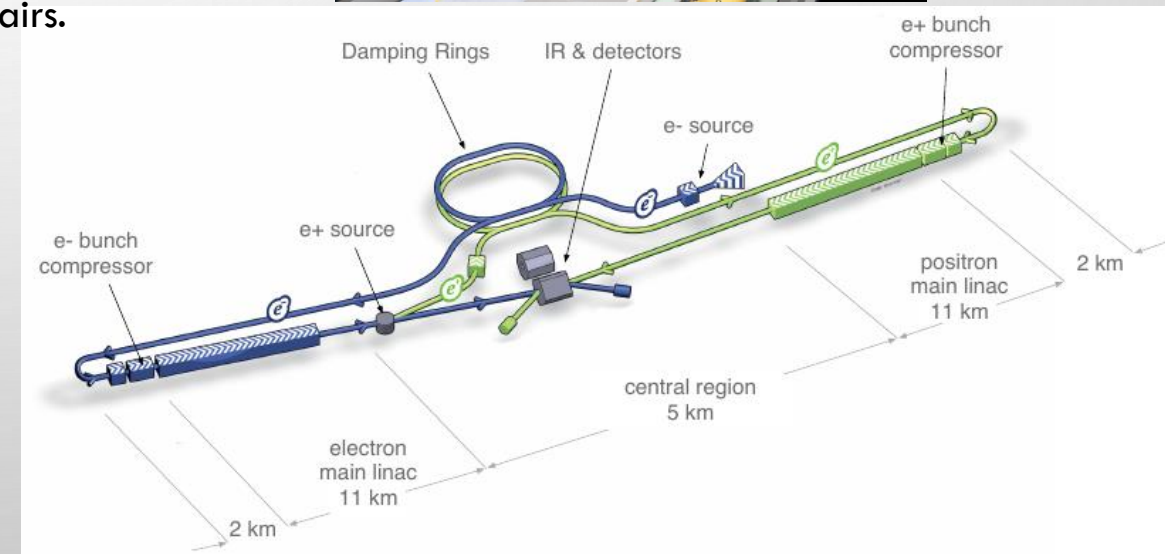
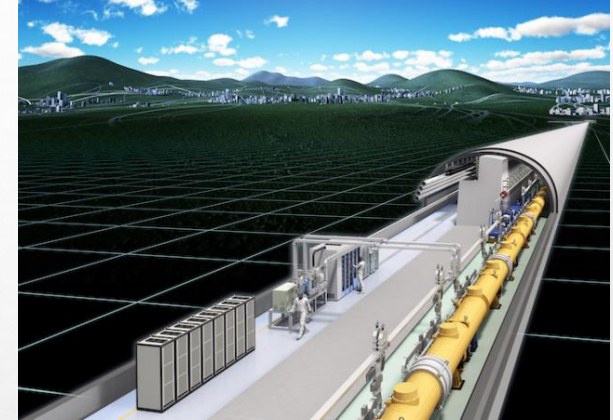
8,000 1.3GHz
SRF cavities @ 2K

Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	$1.35 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
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.	31.5 MV/m (35 MV/m)
Q_0	$Q_0 = 1 \times 10^{10}$



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 ti-alloy target, creating e^+e^- pairs.
 - capture e^+ , accelerate, send to damping ring
- send e^+ to main linac, accelerate
- collide e^+e^- inside detector



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}	$10^{34} \text{cm}^{-2} \text{s}^{-1}$	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	$\gamma\epsilon_x$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_y$	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 $5.4 \cdot 10^{34} \text{cm}^{-2} \text{s}^{-1}$ [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

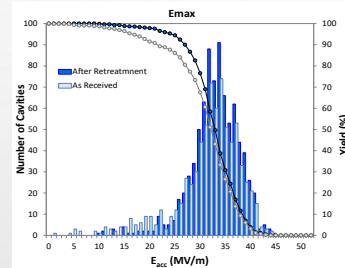
N-infusion:
45 MV/m @ $Q \sim 2 \times 10^{10}$

ILC spec:
31.5 MV/m @ $Q \sim 1 \times 10^{10}$

(for Q see W. Venturini lecture)

Yield evaluation of cavities based on TDR

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



European XFEL: 29 ± 5.1 MV/m

Cryomodule

Eng. design



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

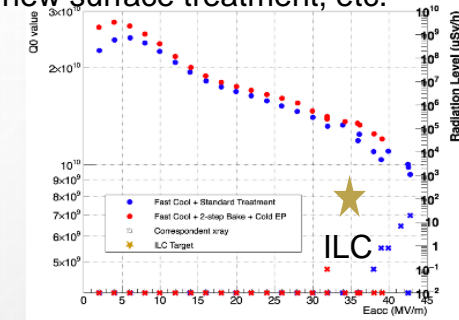


LCLS-II Construction (USA)
~280 cavities/
~35 Modules

Realized through international cooperation and procurement

High performance and cost reduction

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



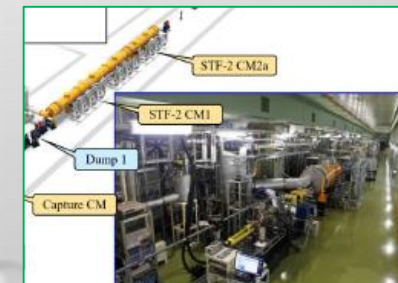
Germany-Japan: Improving Efficiency in Cavity Manufacturing.

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



Demonstration of cryomodule assembly, transfer, and performance

Module assembly



France-Japan: Automation of cavity cleaning

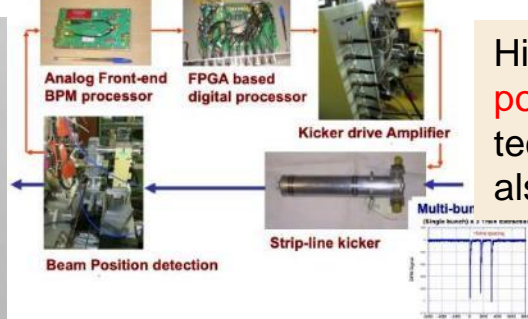
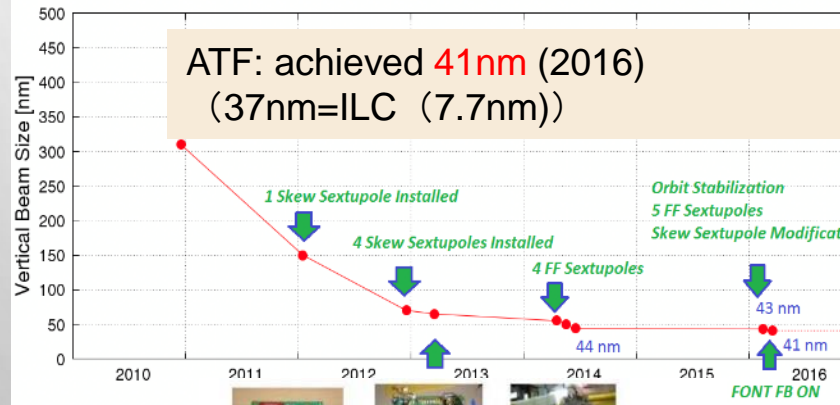


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ILC KEY TECHNOLOGIES: NANO BEAMS

Tech. design completed
Spec. almost achieved

Detailed design
Stable operation
demonstration



High-speed beam
position control
technology was
also demonstrated.

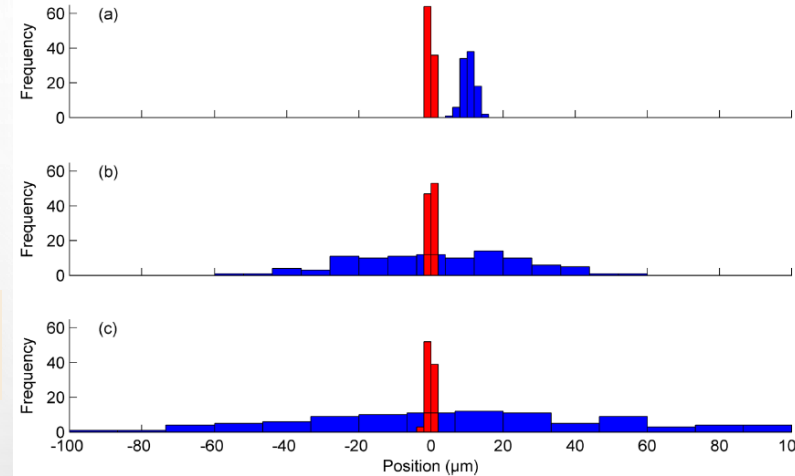
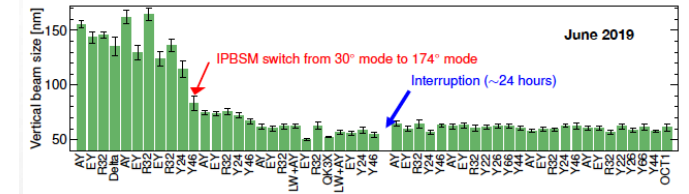


FIG. 19. Distributions of positions with feedback off (blue) and feedback on (red) for bunch 2 at P3 with incoming, uncorrected position jitters of (a) $\sim 2 \mu\text{m}$, (b) $\sim 22 \mu\text{m}$, and (c) $\sim 45 \mu\text{m}$.

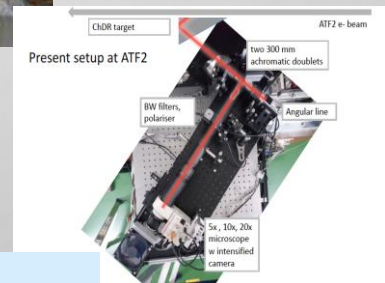
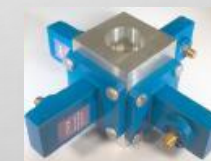
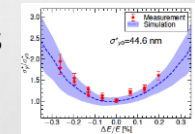
ATF International Review (Committee)*

- 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.

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Ultra low- β^* studies



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

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

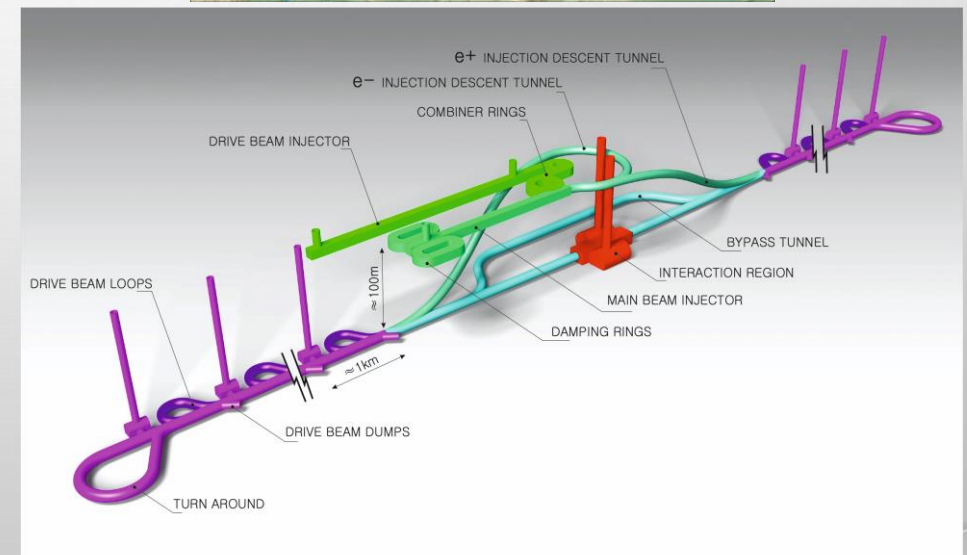
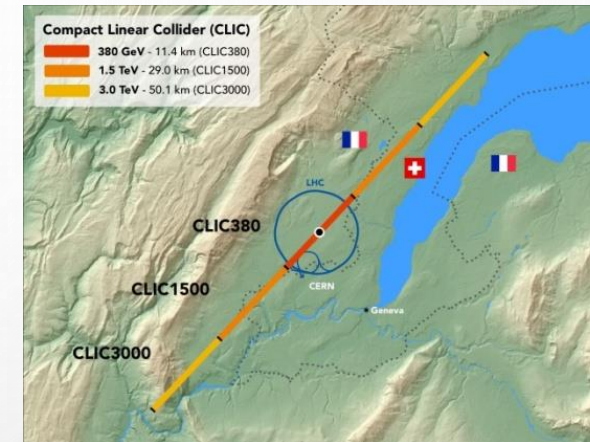
Conceptual design report published in 2012

Update on energy stage baseline in 2016

Project implementation plan released 2018

Cost: 5.9 BCHF for 380 GeV

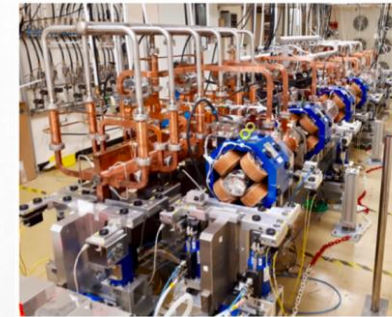
Power: 168 MW at 380 GeV



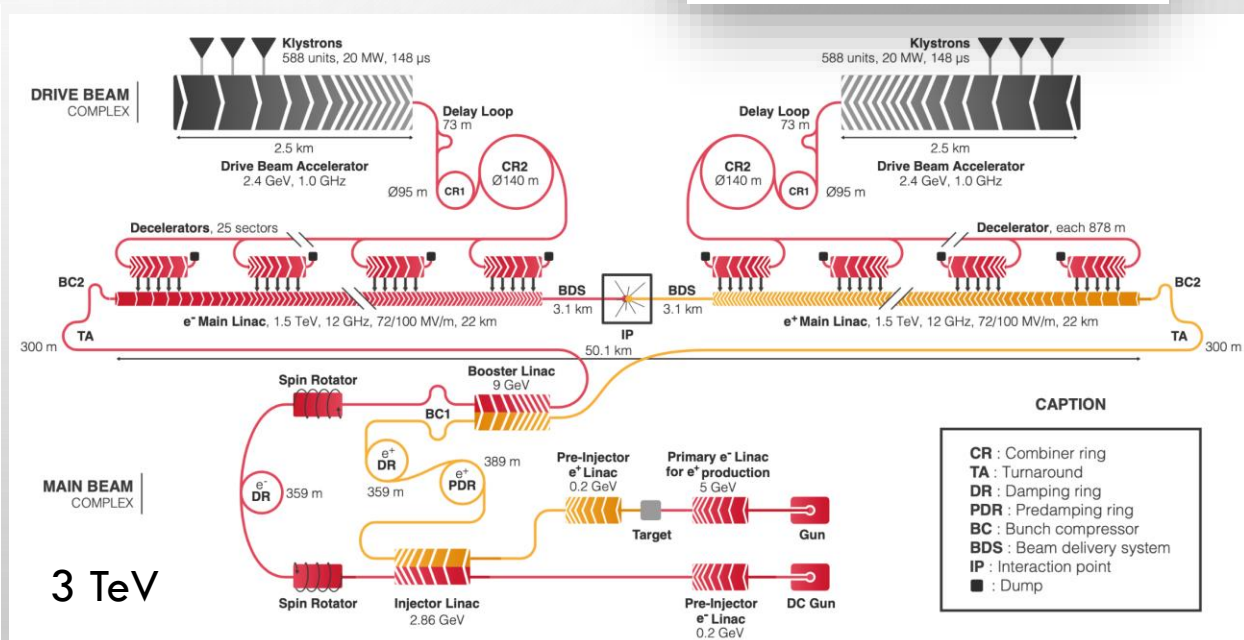
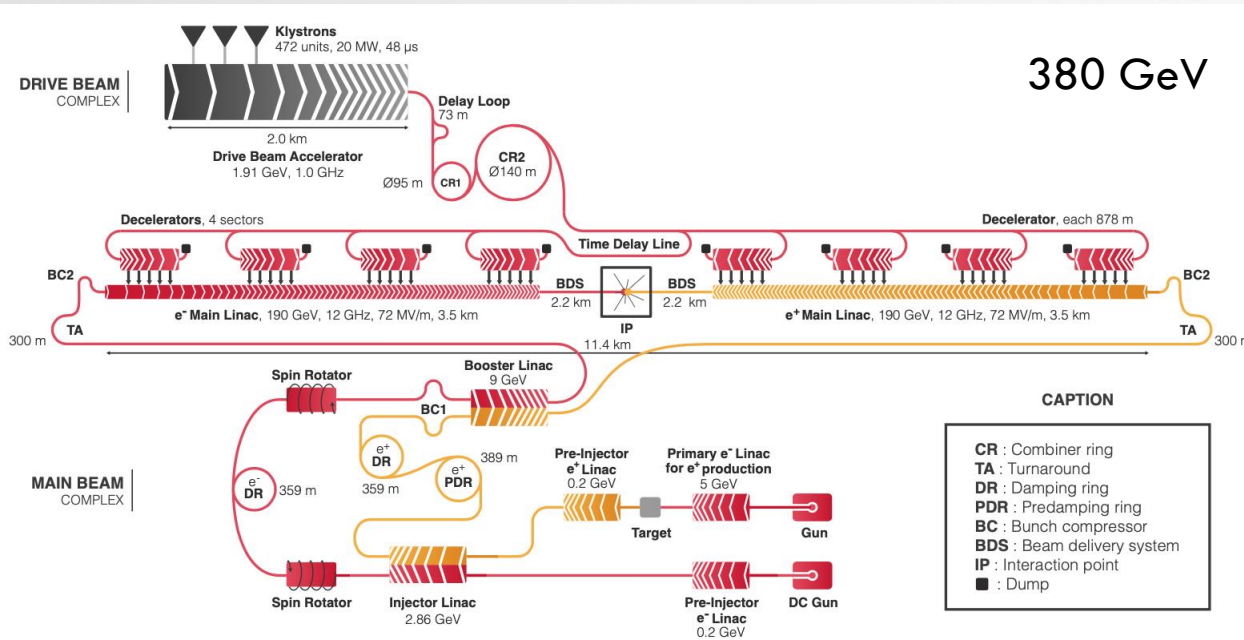
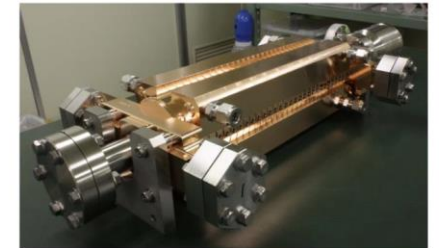
CLIC LAYOUT

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

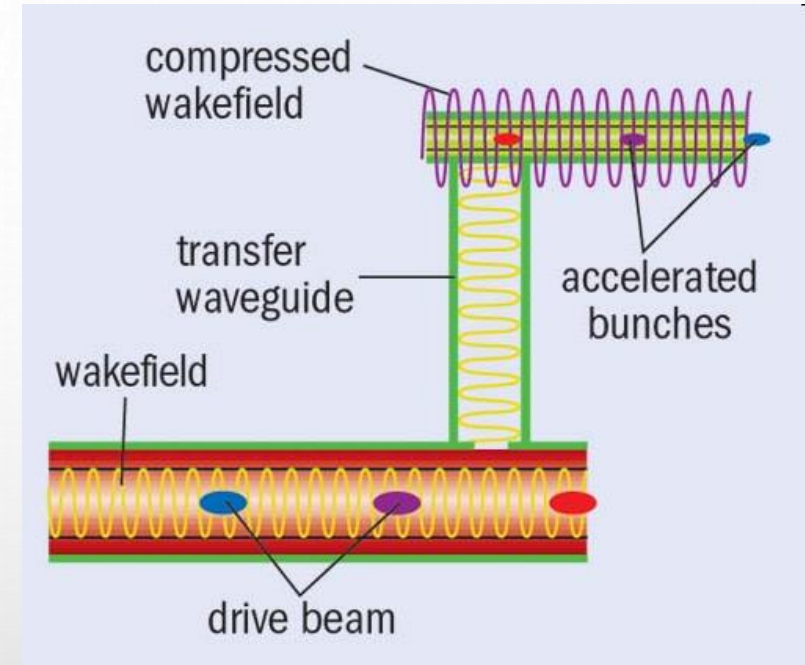
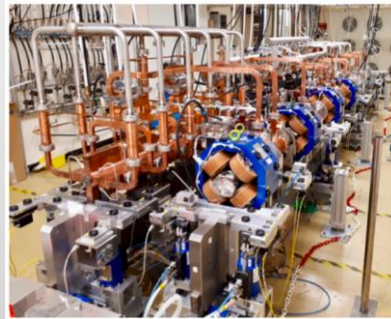


Accelerating structure prototype for CLIC: 12 GHz ($L \sim 25$ cm)



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

- Tight pre-alignment tolerances (10 μm)
- Stabilization to suppress dynamic imperfections (sub-nm level)
- High resolution BPMs (sub- μm) coupled with sophisticated beam-based trajectory techniques
- Mitigation of Wakefield due to high current

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	$1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	2.3	3.7	5.9
Lum. above 99 % of \sqrt{s}	$1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	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	$\sim 60/1.5$	$\sim 40/1$
Final RMS energy spread	%	0.35	0.35	0.35
Crossing angle (at IP)	mrad	16.5	20	20

CLIC ON GOING ACCELERATOR STUDIES



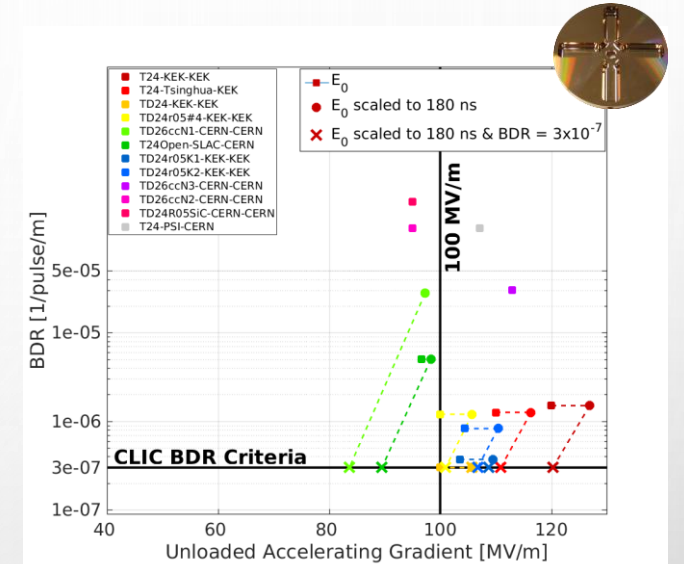
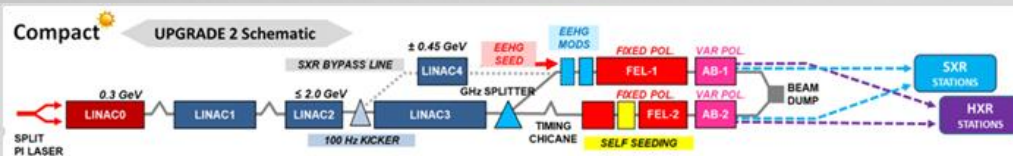
X-band technology:

- 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
- Beam dynamics 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)

P. Burrows ICHEP2022



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 \(1.10.2020\)](#)

PLASMA WAKE ACCELERATORS PRINCIPLE

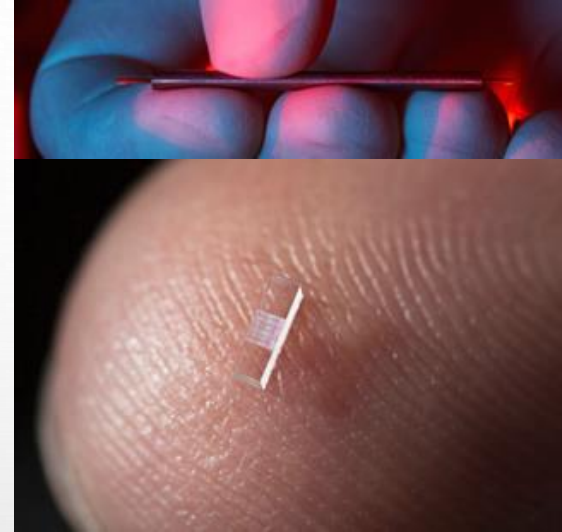
Damage limits for metallic walls in RF cavities limit accelerating fields → replace metal with plasmas or dielectric materials → advance into the many GV/m regime → shorter acc. lengths → reduced cost?

Wakefield due to space charge oscillation inside plasma → **10 – 100 GV/m**

Laser or beam driver

Electron beam

~100 μm



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

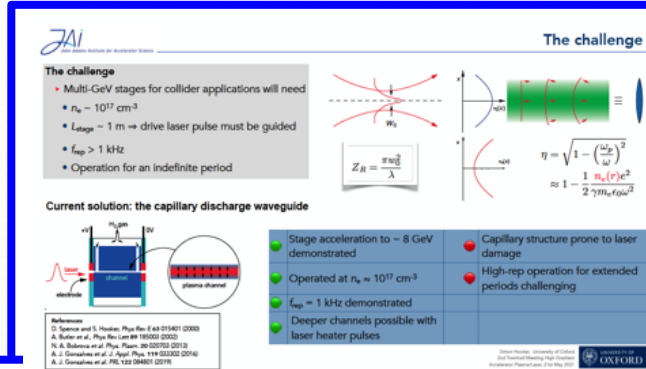
AXSIS ERC Synergy Grant: DESY, Arizona SU

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**)

PLASMA WAKEFIELD R&D

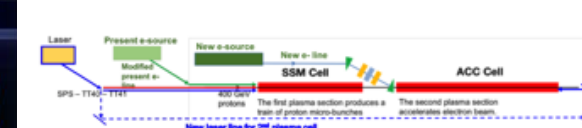
- Specific topics to be addressed:
 - Positron acceleration
 - Technological issue (efficiency, cooling, polarization,...)
- The world wide R&D focus on beam quality, beam stability, staging and continuous operation



AWAKE Run 2 (2021-)

Goals:
stable acceleration of bunch of electrons with high gradients over long distances
'good' electron bunch emittance at plasma exit
Be prepared to start particle physics experiment after Run 2

Baseline design



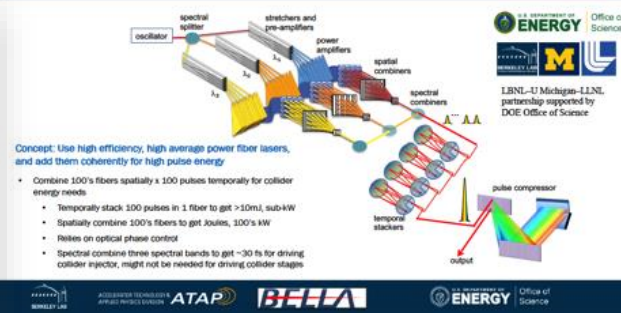
Four phases:

- seeding the SSM with an electron bunch
- plasma cell with density step to freeze the modulation structure
- inject electrons & accelerate without emittance blowup
- implement scalable plasma cell technologies

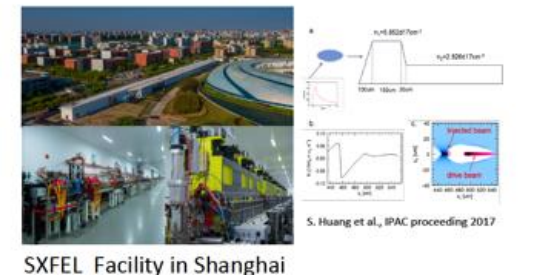
Research Roadmaps



Scalable, high power, high energy, ultrafast fiber laser technology



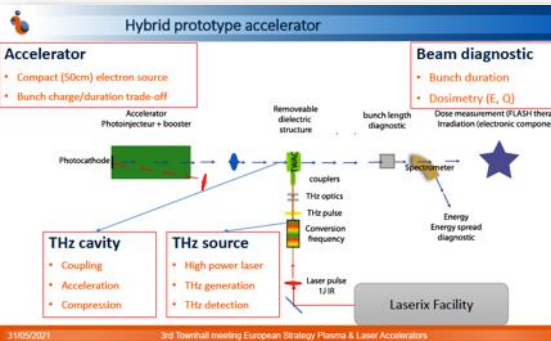
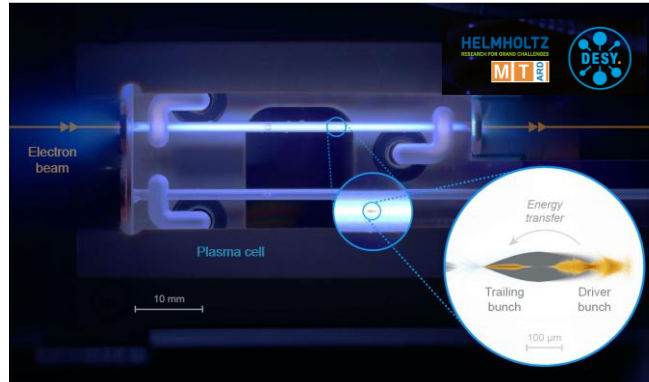
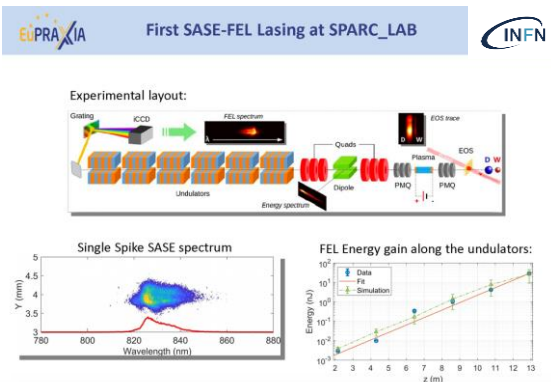
PWFA based FEL study in China



Open-source simulation ecosystem for laptop to Exascale modeling of high-gradient accelerators

J.-L. Vay – Accelerator Modeling Program – Berkeley Lab

Expert Panel on High-Gradient Accelerator (Plasma/Laser) Townhall – May 31, 2021



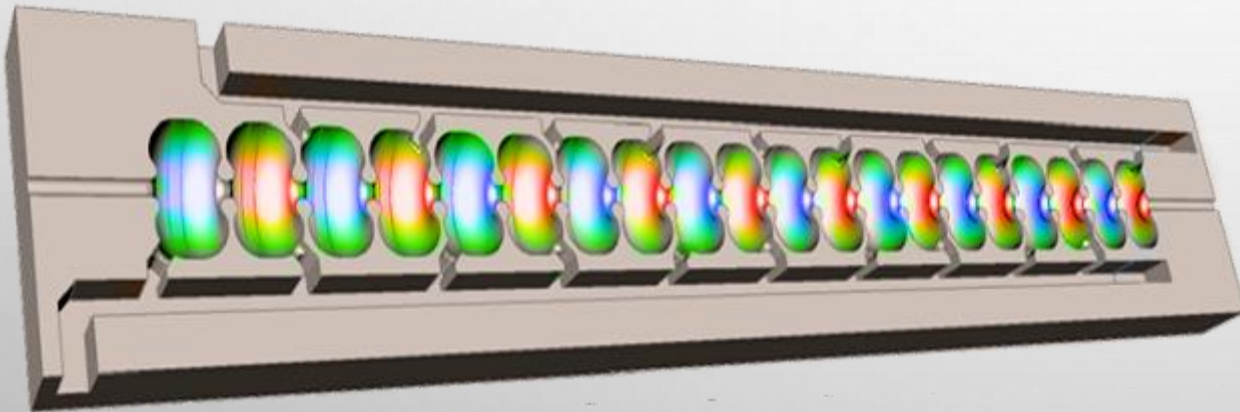
OUTLINE 2ND PART

- Futures Circular Colliders Projects
 - HL-LHC
 - FCC-ee/FCC-hh
 - CepC/SppC
 - LHeC/FCC-eh
 - Muons colliders

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

C³ : A “Cool” Route to the Higgs Boson and Beyond

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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 \(2021\)](https://arxiv.org/abs/2110.15800)