Futuri acceleratori
$e^+ - e^-$ colliders

ALESSANDRO VARIOLA
INFN LNF
INFN EU STRATEGY MEETING,
ROMA .5-6 SETTEMBRE 2018

Leptons Colliders, EU strategy

LISBONA - 2006

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology ….*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientifi c opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

8. Flavour physics and precision measurements at the high luminosity frontier at lower energies complement our understanding of particle physics and allow for a more accurate interpretation of the results at the high-energy frontier; *these should be led by national or regional collaborations, and the participation of European laboratories and institutes should be promoted.*

UPDATE - 2013

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

ALL this has been taken into account, and many results achieved, by the international accelerator community. Circular colliders appeared, strategy to be defined.

Future lepton colliders projects

- Linear colliders

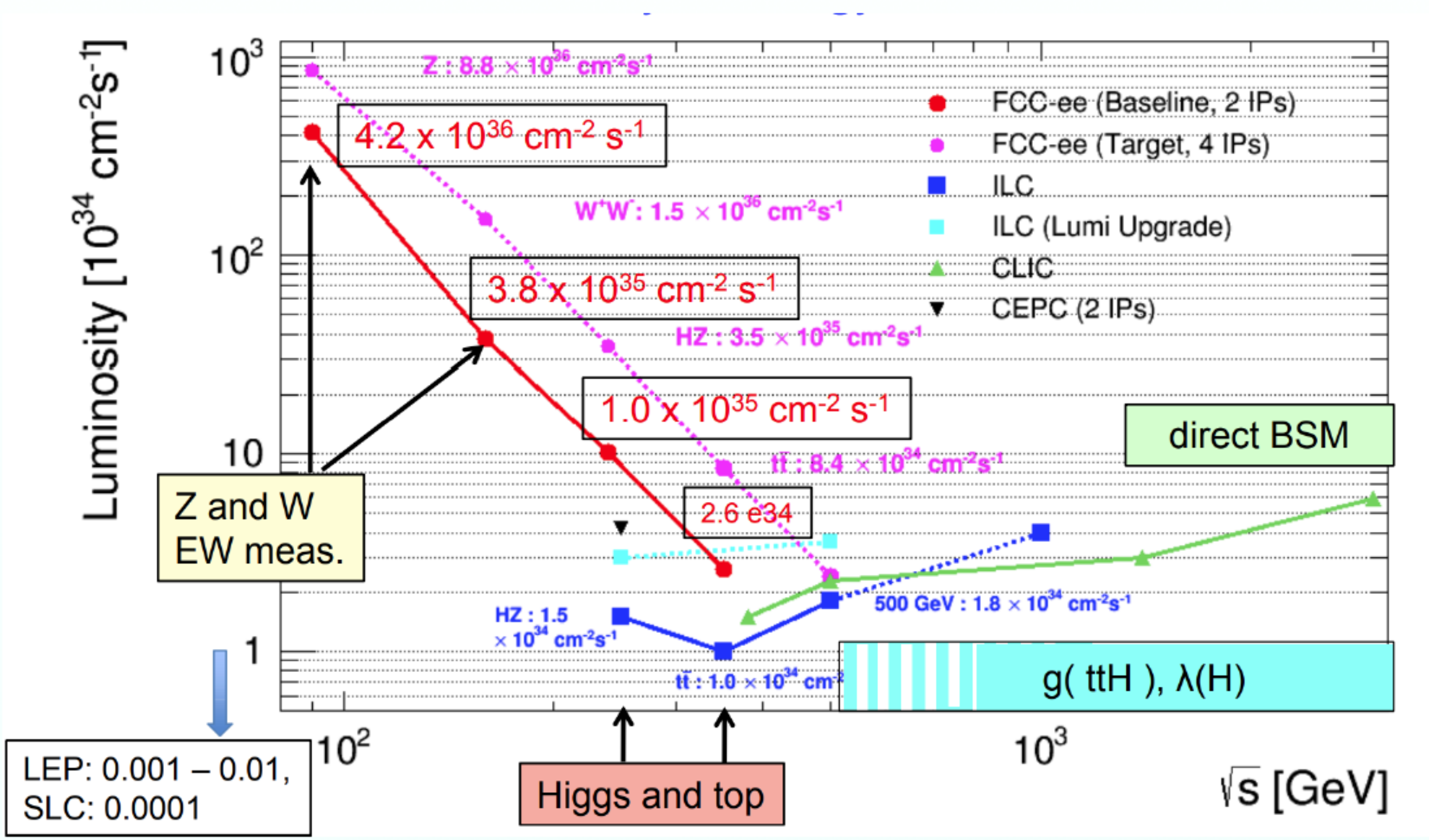
ILC, CLIC

- Circular colliders

Fcc-ee, CEPC Energy sector

Super Tau Charm factory (BINP) Precision sector

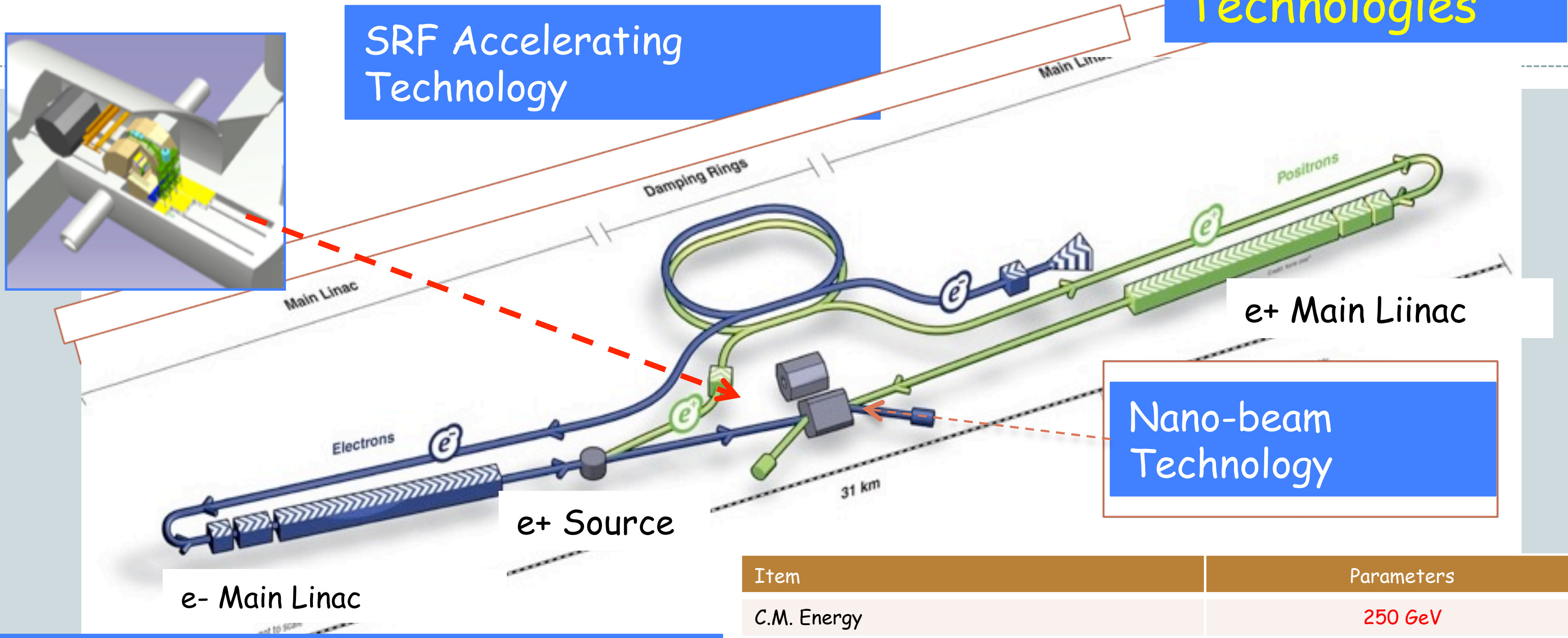
Luminosity vs Energy



- PROJECTS: LINEAR ACCELERATORS

ILC

ILC



Item	Parameters
C.M. Energy	250 GeV
Length	20.5 km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Integrated Luminosity	$2ab^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm
SRF Cavity G.	31.5~35 MV/m@Q_0 = 1 ~ 1.6x10^{10}
AC Power	120 ~ 130 MW
Beam polarization	30/80 %

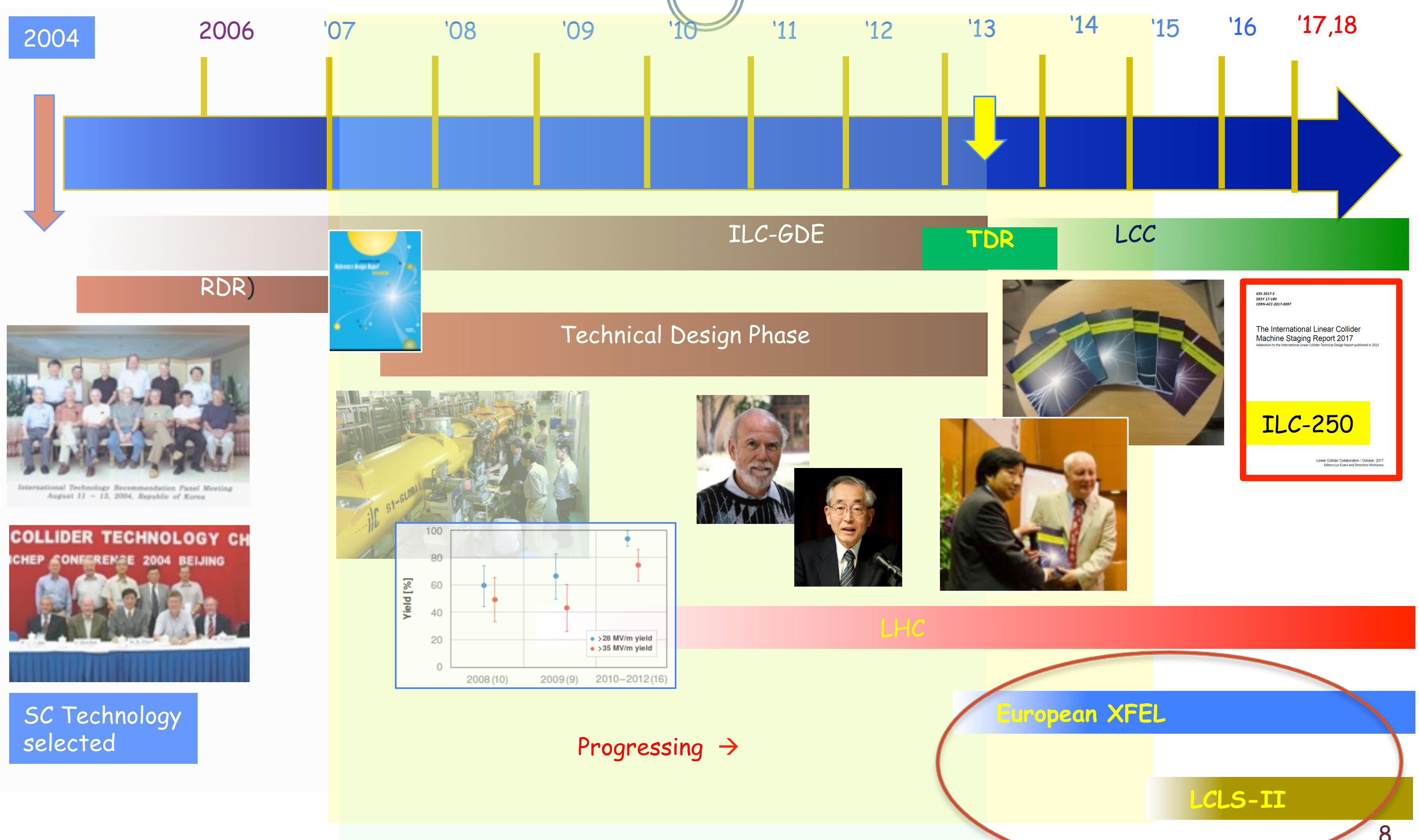
Key element : positron source

TDR baseline 500

Centre-of-mass energy	E_{CM}	GeV	200	230	250	350	500
Luminosity pulse repetition rate		Hz	5	5	5	5	5
Positron production mode			10 Hz	10 Hz	10 Hz	nom.	nom.
Estimated AC power	P_{AC}	MW	114	119	122	121	163
Bunch population	N	$\times 10^{10}$	2	2	2	2	2
Number of bunches	n_b		1312	1312	1312	1312	1312
Linac bunch interval	Δt_b	ns	554	554	554	554	554
RMS bunch length	σ_z	μm	300	300	300	300	300
Normalized horizontal emittance at IP	$\gamma\epsilon_x$	μm	10	10	10	10	10
Normalized vertical emittance at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35
Horizontal beta function at IP	β_x^*	mm	16	14	13	16	11
Vertical beta function at IP	β_y^*	mm	0.34	0.38	0.41	0.34	0.48
RMS horizontal beam size at IP	σ_x^*	nm	904	789	729	684	474
RMS vertical beam size at IP	σ_y^*	nm	7.8	7.7	7.7	5.9	5.9
Vertical disruption parameter	D_y		24.3	24.5	24.5	24.3	24.6
Fractional RMS energy loss to beamstrahlung	δ_{BS}	%	0.65	0.83	0.97	1.9	4.5
Luminosity	L	$\times 10^{34}$ $cm^{-2}s^{-1}$	0.56	0.67	0.75	1.0	1.8
Fraction of L in top 1% E_{CM}	$L_{0.01}$	%	91	89	87	77	58
Electron polarisation	P_-	%	80	80	80	80	80
Positron polarisation	P_+	%	30	30	30	30	30
Electron relative energy spread at IP	$\Delta p/p$	%	0.20	0.19	0.19	0.16	0.13
Positron relative energy spread at IP	$\Delta p/p$	%	0.19	0.17	0.15	0.10	0.07

from ILC500 to ILC250

1980' ~ : Basic Study



STATUS
Design frozen
Looking for budget

KEK 2017-3
DESY 17-180
CERN-ACC-2017-0097

The International Linear Collider
Machine Staging Report 2017

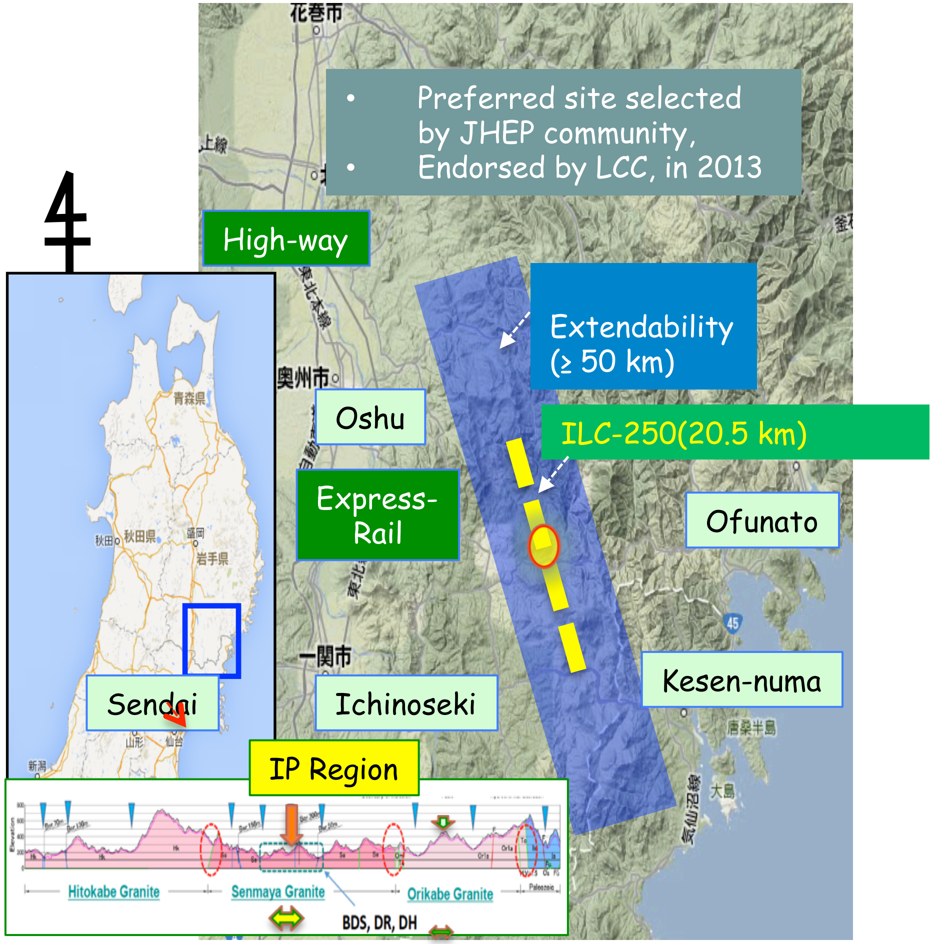
Addendum to the International Linear Collider Technical Design Report published in 2013

Linear Collider Collaboration / October, 2017
Editors:Lyn Evans and Shinichiro Michizono

Table 5-1: New beam parameters optimized for ILC250GeV.

			TDR		New
Center-of-mass energy	E_{CM}	GeV	250	500	250
Bunch population	N	e10	2	2	2
Bunch separation		ns	554	554	554
Beam current		mA	5.78	5.78	5.78
Number of bunches per pulse	Nb		1312	1312	1312
Collision frequency		Hz	5	5	5
Electron linac rep rate		Hz	10	5	5
Beam power (2 beams)	P_B	MW	5.26	10.5	5.26
r.m.s. bunch length at IP	σ_z	mm	0.3	0.3	0.3
relative energy spread at IP (e−)	σ_E/E	%	0.188	0.124	0.188
relative energy spread at IP (e+)	σ_E/E	%	0.15	0.07	0.15
Normalized horizontal emittance at IP	ε_{nx}	μm	10	10	5
Normalized vertical emittance at IP	ε_{ny}	nm	35	35	35
Beam polarization (e−)		%	80	80	80
Beam polarization (e+)		%	30	30	30
Beta function at IP (x)	β_x	mm	13	11	13
Beta function at IP (y)	β_y	mm	0.41	0.48	0.41
r.m.s. beam size at IP (x)	σ_x	nm	729	474	516
r.m.s. beam size at IP (y)	σ_y	nm	7.66	5.86	7.66
r.m.s. beam angle spread at IP (x)	θ_x	μr	56.1	43.1	39.7
r.m.s. beam angle spread at IP (y)	θ_y	μr	18.7	12.2	18.7
Disruption parameter (x)	Dx		0.26	0.26	0.51
Disruption parameter (y)	Dy		24.5	24.6	34.5
Upsilon (average)	Υ		0.020	0.062	0.028
Number of beamstrahlung photons	n_γ		1.21	1.82	1.91
Energy loss by beamstrahlung	δ_{BS}	%	0.97	4.50	2.62
Geometric luminosity	Lgeo	$e34/cm^2s$	0.374	0.751	0.529
Luminosity	L	$e34/cm^2s$	0.82	1.79	1.35

https://arxiv.org/abs/1711.00568



Site proposed

ILC-250 Status

Science:

- Scientifi … sing,
- ILC rede … 0 GeV, and
- Energy e

Technolo

- SRF tec … with functioni
- Nano-be … equivalent to that (
- Cost red … echnology.

Toward

- Progress … (JP) to provide t
- Int'l disc … ERN, EU, EJADE,
- The due- … ed.

ILC Status & Recent Activities

ICFA

- Project under serious consideration by the Japanese Government
  - Statement/Decision expected by the end of 2018
  - Japan is aware of the urgency and milestones (e.g., upcoming European Strategy Update)
- High level advisory panel and working groups were formed; studies completed and reports generated
  - Science Council of Japan will finalize extensive technical reviews in the coming 2-3 months.
- Encouraging interactions of Japanese Officials with agencies/ governments in the US and in Europe have taken place
- Strong ongoing efforts in Japan with outreach to public, media, science community and industry

Technical achievements - Progress in FF Beam Size and Stability at ATF2

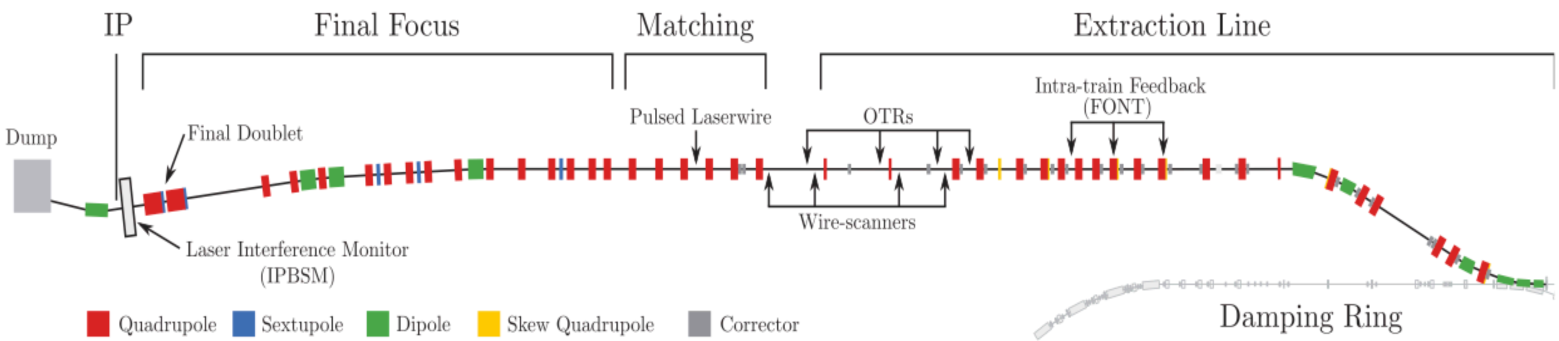
Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

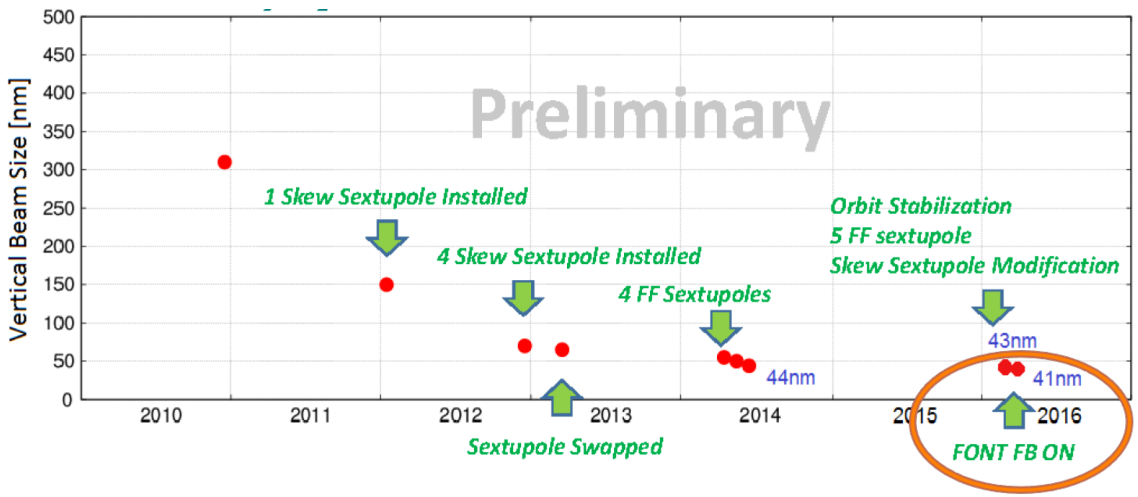
- ATF2 Goal : 37 nm → 6nm @ILC500GeV

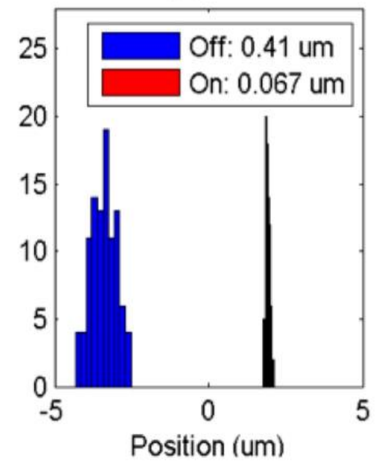
  7.7nm@ILC250GeV
  - Achieved **41 nm** (2016)

Goal 2: Develop a few nm position stabilization for the ILC collision

- **FB latency 133 nsec achieved**
  (target: < 300 nsec)
- **positon jitter at IP: 410 → 67 nm (2015)**
  (limited by the BPM resolution)

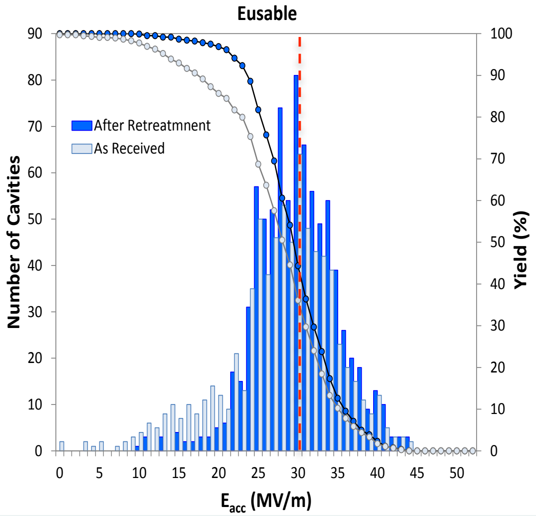




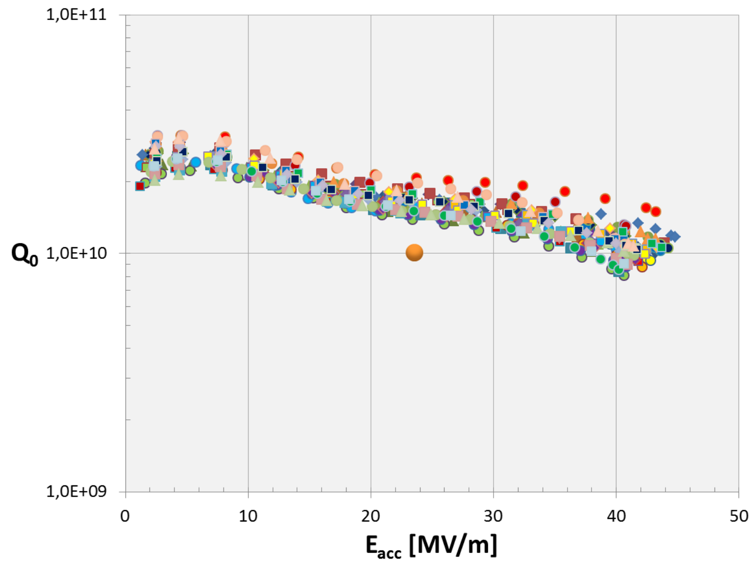


Nano-meter stabilization at IP

SRF MODULES : European XFEL (% of ILC):



>10 % (47/420, RI) cavities exceeding 40 MV/m



After Retreatment:
E-usable: 29.8 ± 5.1 [MV/m]
(RI): E usable 31.2 ± 5.2 [MV/m]), w/ 2nd EP
(EZ): E usable 28.6 ± 4.8 [MV/m]) , w/ BCP (instead of 2nd EP)

- FNAL recently demonstrated a new treatment, which utilizes **"nitrogen infusion"**, achieving **45.6 MV/m** with **Q ~ 2x10^{10}**
- FNAL has now successfully applied it on three nine cell cavities

ongoing:

- Jlab, KEK have reproduced similar results on single cell cavities with Q >2e10 at 35 MV/m
- R&D work towards:
  - Best recipe for higher Q at high G
  - Robustness of process

INFN contributions

- SRF
- Damping rings

LASA Superconducting RF Cavities for Electron Accelerators

C. Pagani, Università degli Studi di Milano & INFN Milano – LASA.
M. Bertucci, A. Bignami, A. Bosotti, J. Chen, C. Maiano, P. Michelato, L. Monaco, R. Paparella, P. Pierini, D. Sertore, INFN Milano - LASA

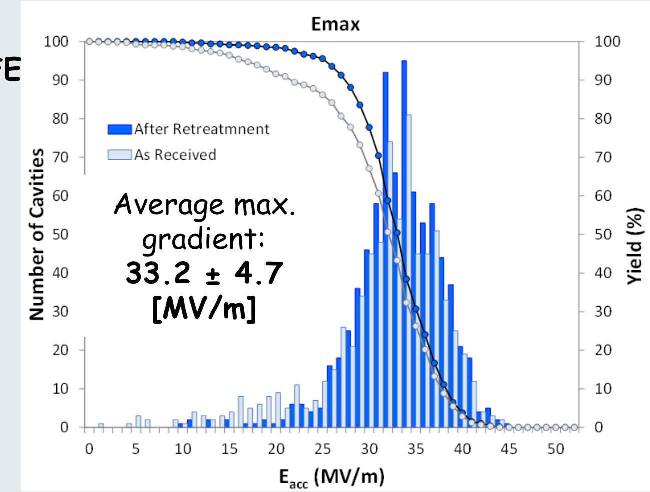
LASA designed, fabricated and tested many cavities for several research projects.
Deep synergies in the SRF cavity community (DESY, FNAL, CEA, INFN, In2p3, KEK …..)

The TESLA type SC cavity

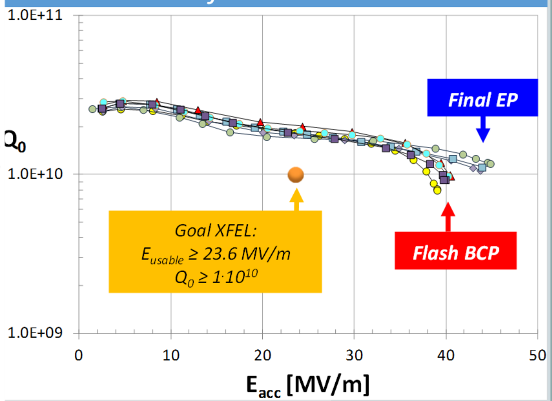
1.3 GHz TESLA cavities
Many projects worldwide
- TESLA / TTF / FLASH / ILC / E-XFEL

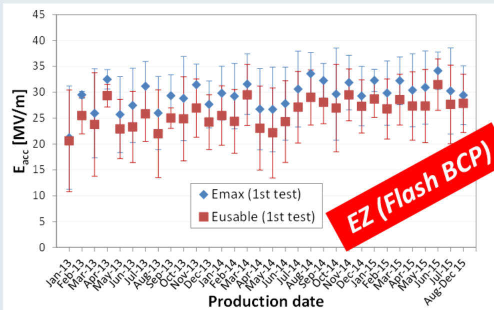
Many different contributions:
- Cryostats / Cryomodules
  - Design, blue prints and fabrication (training Industry)
  - Diagnostic and Assembly
  - Wire Position Monitors

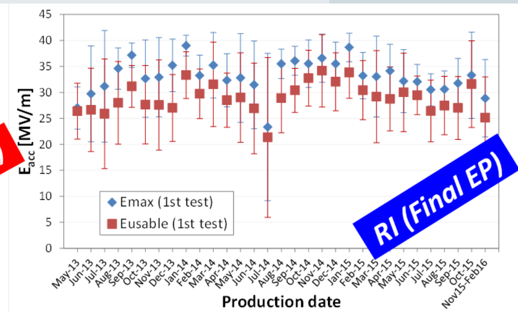
- Superconducting 9-cell cavities :
  - Participation to the design
  - Fabrication procedure ("build-to-print") and tools with industry
  - Responsibility of the 50% of the 800 cavity delivery for the E-XFEL



Best Performance Cavities







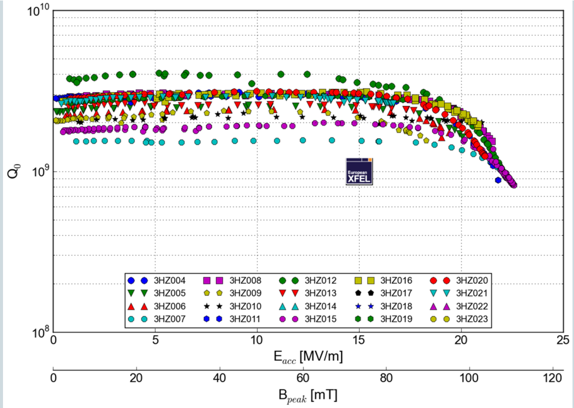
Quality control of on going-production (test at the arrival)

P.Michelato

3.9 GHz E-XFEL cavities

3rd Harmonic E-XFEL Injector Cryomodule:

- 3.9 GHz, 9-cell, Cavities: design, fabrication and tests
- Cryomodule and cryogenics
- Cavity tuning systems (Blade-tuner type)



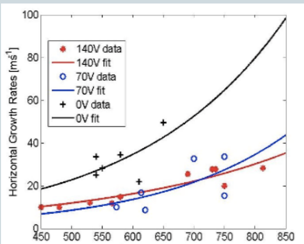
LASA provided all the steps

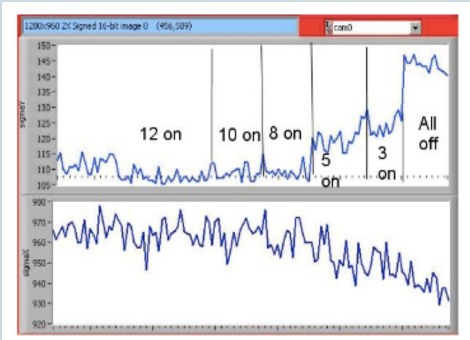
- Design, prototyping, RF measurements at RT
- Definition of surface treatments to be done at industry
- Cleaning and cavity preparation at the LASA Class 10 clean-room
- Qualification in a vertical cryogenic test at 2.0 K
- Assembly of cavity string into cryomodule

INFN-LNF activity for the ILC Damping Rings (DR)

S. Guiducci, D. Alesini, M. Biagini, R. Boni, R. Cimino, T. Demma, A. Drago, A. Gallo, F. Marcellini, P. Raimondi

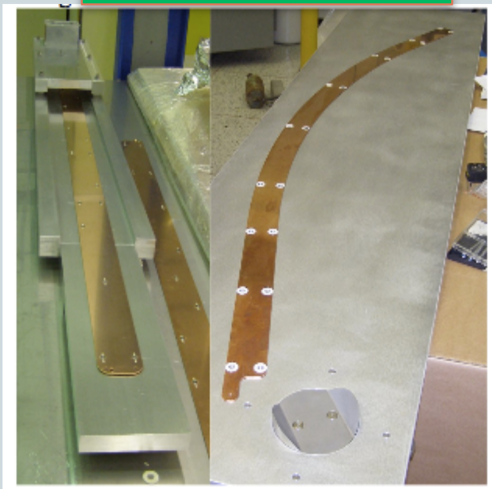
- LNF has been leading DR working group activity for the RDR
  in 2007 and for the TDR in 2013
- R&D on DR systems based on tests at DAFNE
  - Lattice design and parameters definition
  - Mitigation of e-cloud instability
  - Fast stripline kickers
  - Bunch-by-bunch feedbacks systems





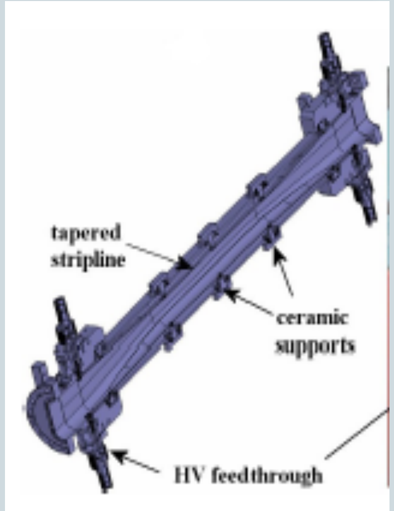
The growth rate of the e-cloud instability is substantially reduced when turning on the clearing electrodes at 70 and 140 V
TUOBC03 IPAC12

DAFNE clearing electrodes



Beam dimension (in mm) at the SLM increase, due to e-clod instability, when turning off progressively all clearing electrodes
TUOBC03 IPAC12

DAFNE Fast Stripline kickers



Low coupling impedence, good field uniformity, both rise and fall time of the pulse below 6 ns
TU6RFP082 PAC09

http://www.linearcollider.org/ILC/Publications/Reference-Design-Report
http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

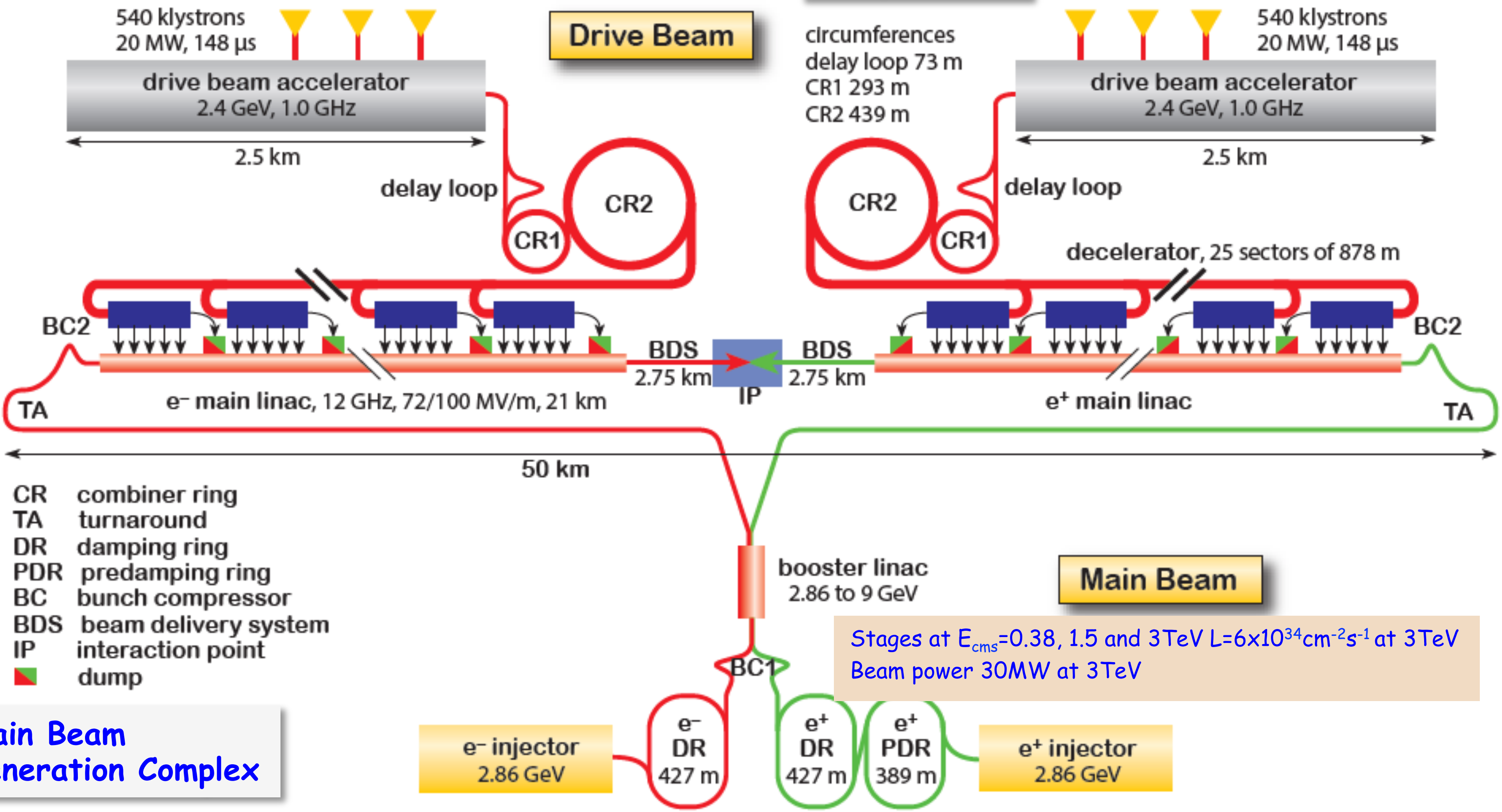
CLIC

CLIC 3 TeV Layout

Goal: Lepton energy frontier

CLIC at 3TeV

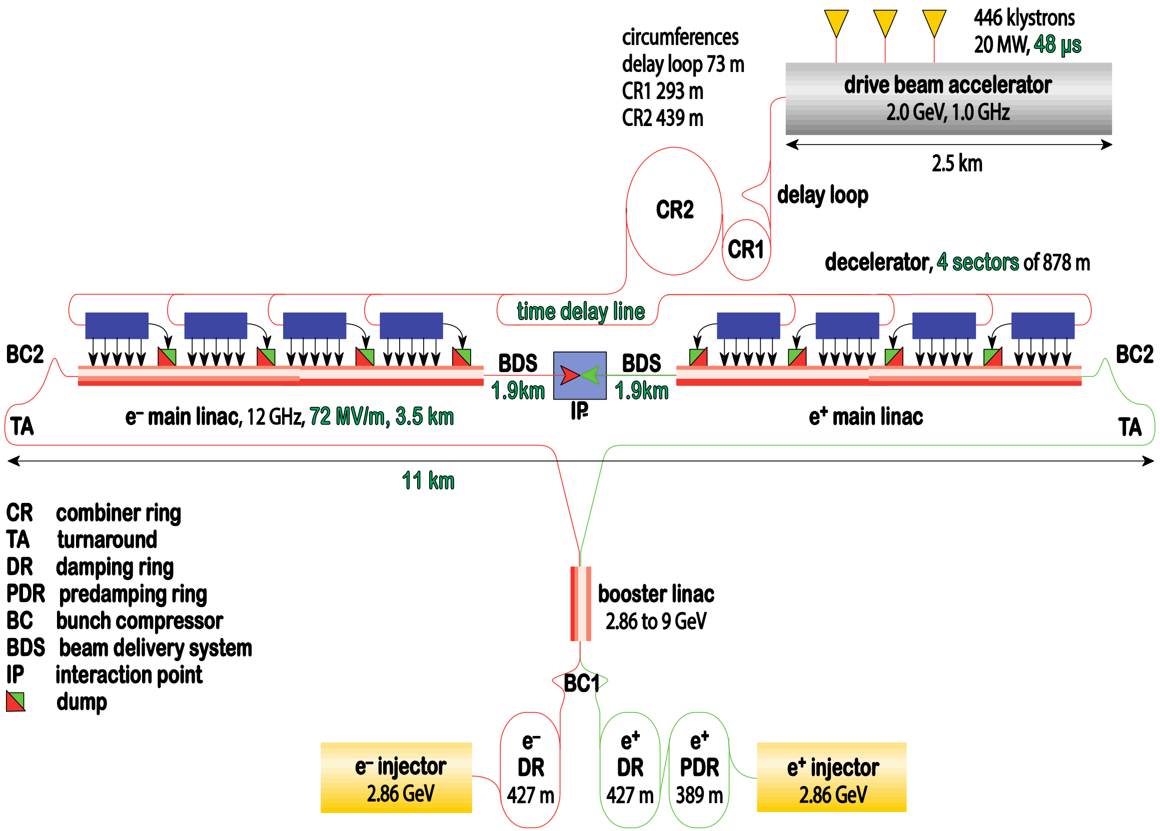
Drive Beam Generation Complex



Stages at E_{cms}=0.38, 1.5 and 3TeV $L=6\times10^{34}cm^{-2}s^{-1}$ at 3TeV
Beam power 30MW at 3TeV

Main Beam Generation Complex

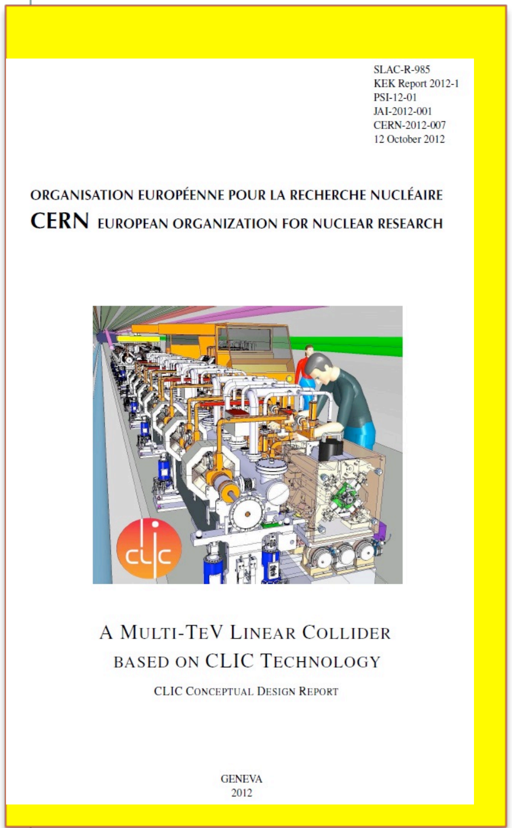
STAGE 1- CLIC @380 GeV



Parameter	Symbol [unit]	CLIC	CLIC
CMS energy	E_{cm} [GeV]	380	3000
Luminosity	L [10^{34} $cm^{-2}s^{-1}$]	1.5	6
Gradient	G [MV/m]	72	100
Repetition rate	f_r [Hz]	50	50
Bunches/train	n	352	312
Particles/bunch	N [10^9]	5.2	3.72
Bunch spacing	ns	0.5	0.5
Bunch length	σ_z [μm]	70	44
Energy spread	[%]	0.35	0.35
Emittances	$\varepsilon_{x,y}$ [nm]	950/30	660/20
IP beam size	$\sigma_{x,y}$ [nm/nm]	149/3	40/1
Beta-functions	$b_{x,y}$[mm]	8/0.1	6/0.07
Assumed eff. running time	[10^7 s/year]	1.08	1.08

STATUS, 2012 CDR…….

CLIC aims to provide **multi-TeV electron-positron** collisions with high luminosity at affordable cost and power consumption


SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A MULTI-TEV LINEAR COLLIDER BASED ON CLIC TECHNOLOGY
CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

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)

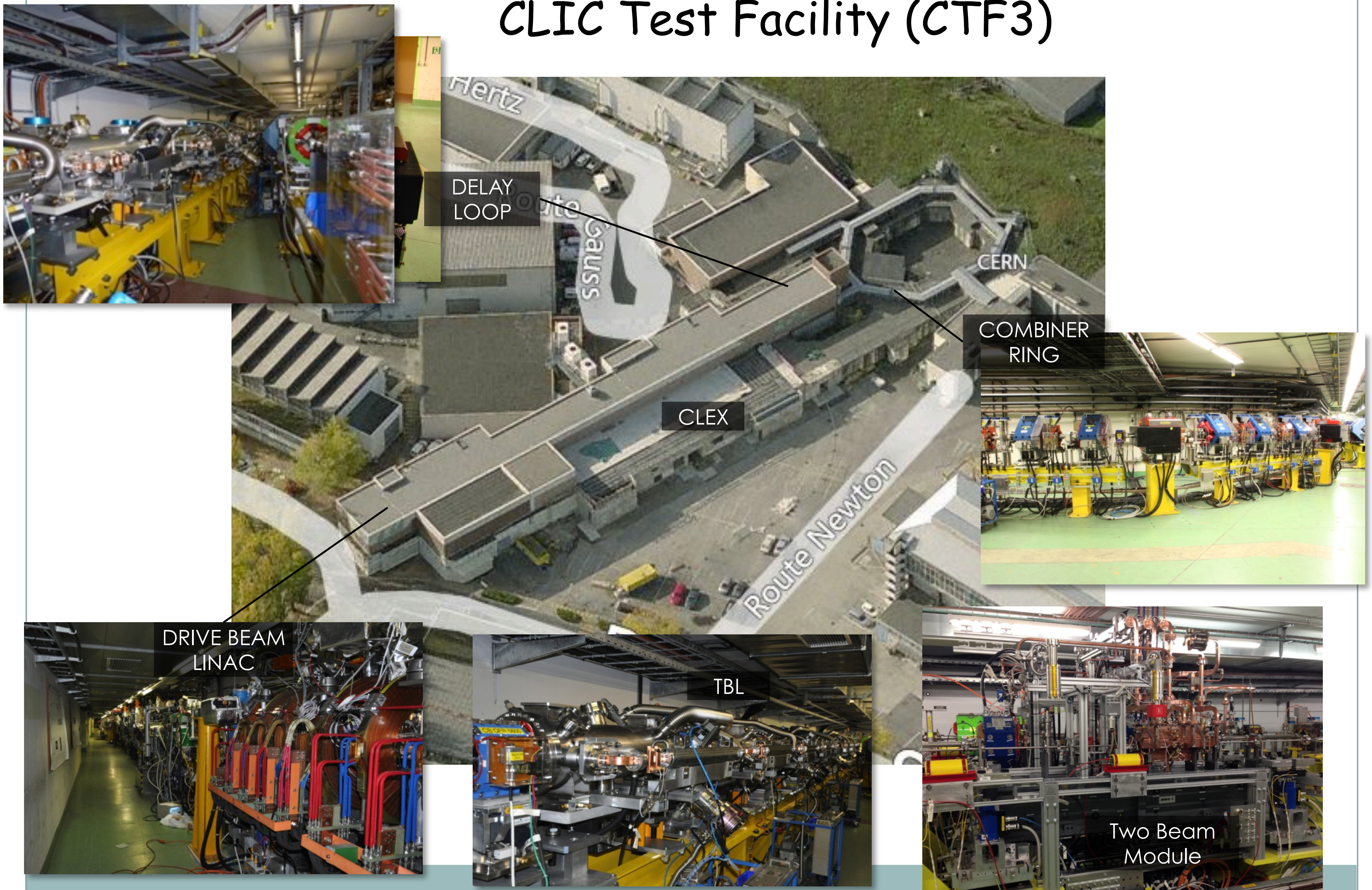
2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

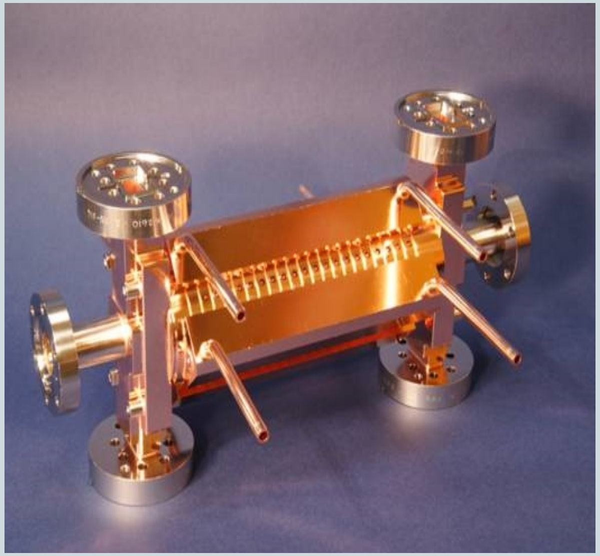
Getting ready for data taking by the time the LHC programme reaches completion

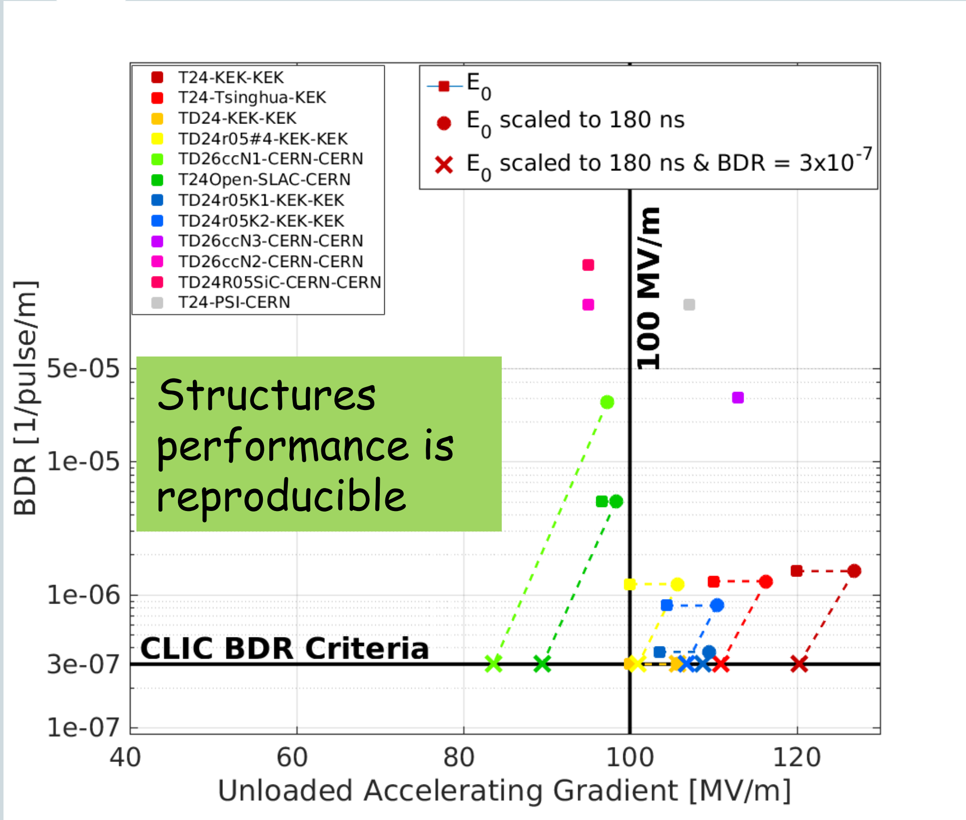
Technical achievements:
CLIC Test Facility (CTF3)



Technical achievements : CLIC Structure Development

Several klystron-based test stands exist that test structures (X-boxes)



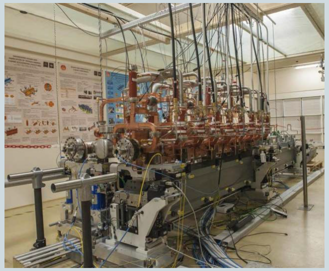


Need industrialization and final configuration (SiC)

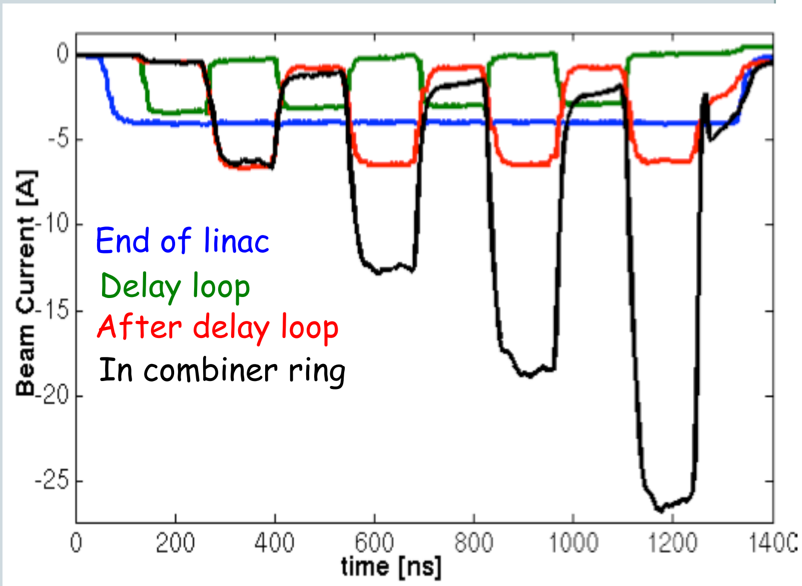
Drive Beam Combination in CTF3

Note: Efficiencies
RF to drive beam >95%
Drive beam to RF >95%

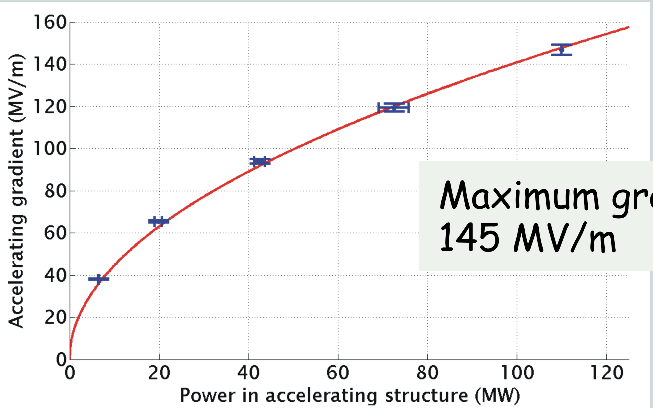
Total efficiency wall plug
to main beam is about 10%



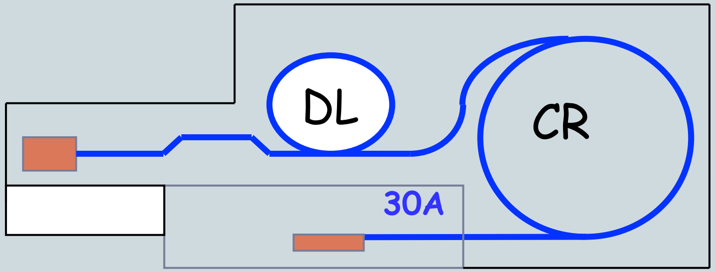
Parameter	CLIC goal	CTF3 measured
Arrival time	50 fs	50 fs
Current after linac	0.75×10^{-3}	$0.2\text{-}0.4 \times 10^{-3}$
Energy	1.0×10^{-3}	0.7×10^{-3}



Measured accelerating gradient



Maximum gradient
145 MV/m



30A!

INFN contributions and strategy

- DR studies (international collaboration)
- Recombinations ring, RF Deflectors, delay loops

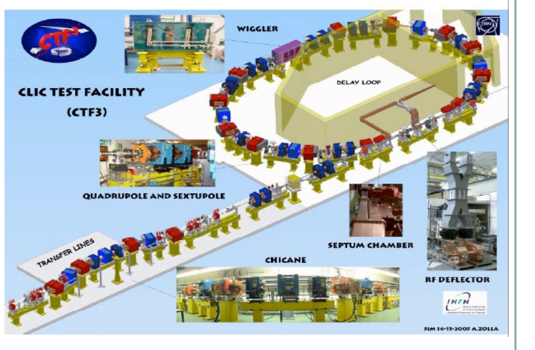
- Future Xlab (with CERN)
- Coatings e.m characterization (with CERN)
- Linear colliders schemes (ELI NP)

INFN-LNF contribution to the CLIC Test Facility

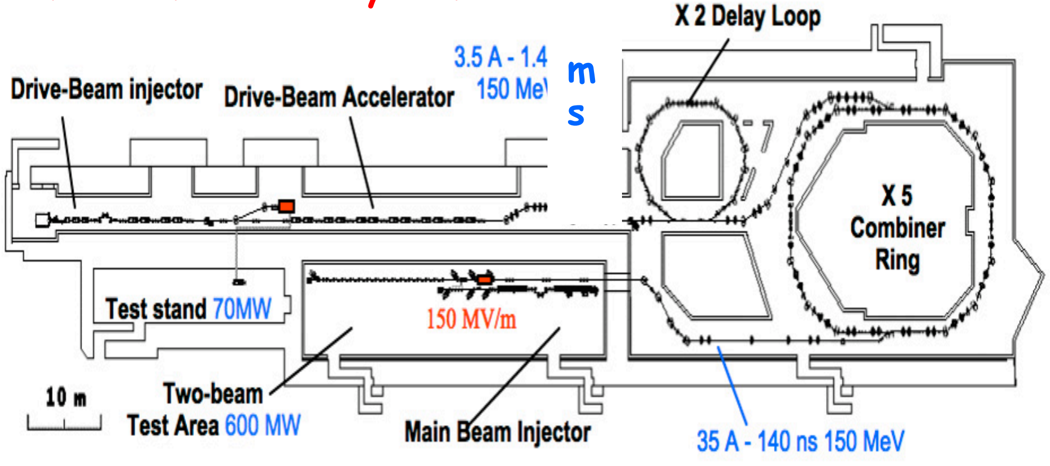
D.Alesini, C.Biscari, R.Boni, B.Buonomo, M.Castellano, A.Clozza, A.Drago, D.Filippetto, A.Gallo, A.Ghigo (resp.), F.Marcellini, C.Milardi, M.Petrarca, B.Preger, M.A.Preger, R.Ricci, C.Sanelli, M.Serio, F.Sgamma, A.Stella, C.Vicario, M.Zobov

- Drive Beam recombination system design
- Delay loop and Combiner Ring lattice design
- Full responsibility on the Delay Loop construction
- Contribution to the Combiner Ring realization
- RF deflectors, vacuum chambers, diagnostics, magnets
- Contribution to the commissioning of the entire complex
- Full Specs achieved

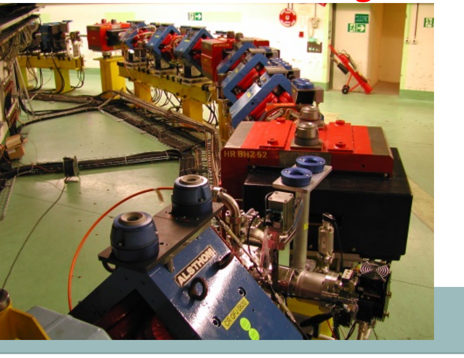
CTF3 Delay Loop



Beam recombination system

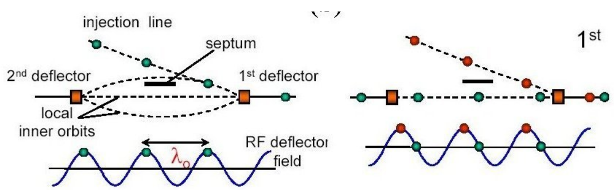


CTF3 Combiner Ring

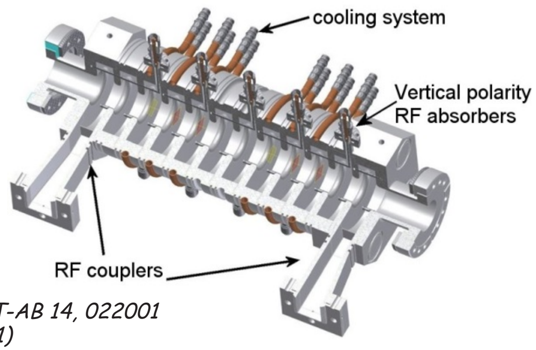


RF DEFLECTORS FOR THE CTF3 COMBINER RING AND DELAY LOOP (INFN LNF)

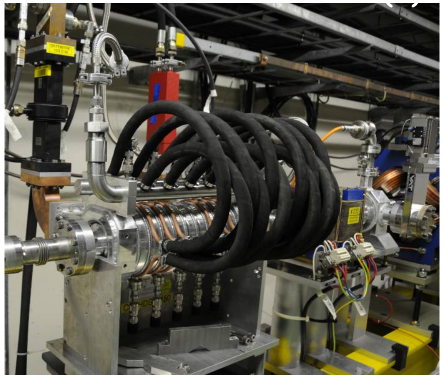
The **RFDs are the crucial components** for the recombination process in the DL and CR of CLIC. They have been designed, fabricated and tested at full power with beam in CTF3 demonstrating the possibility to recombine the train of bunches.

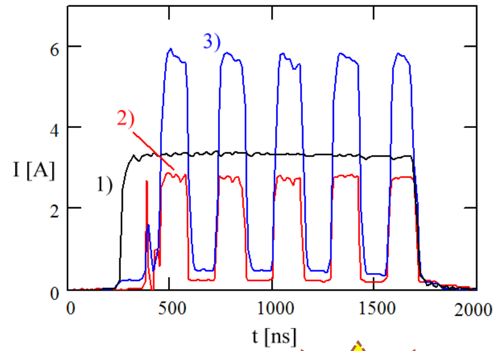


RFD of the CR



PRST-AB 14, 022001 (2011)





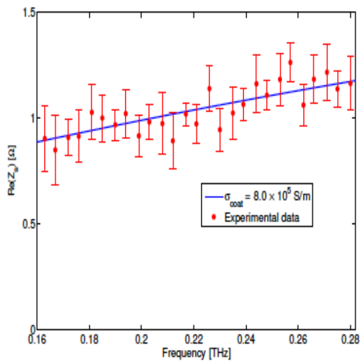
A novel methodology for the electromagnetic characterization of **Coating materials in Sub-THz range. (INFN Na)**

A. Passarelli, A. Andreone, H. Bartosik, O. Boine-Frankenheim, C. Koral, M.R. Masullo, G. Rumolo, V.G. Vaccaro

CERN Synergy

➢Implementation of a new waveguide technique for high-frequency (100-500 GHz) surface impedance measurements of coated materials. Study (analytical and numerical) and measurements of the electromagnetic properties of Non-Evaporated Getter (NEG) in high frequency range. *Study connected with CLIC damping rings.*

The proposed method is based on time domain measurements inside a specifically designed waveguide, which has a thin central copper slab where the material under test is deposited on both sides.
Different coated samples have been measured !



Surface impedance of 3.68 mm NEG coated slab

The waveguide

D.Alesini, M.R Masullo

THE FRASCATI X BOX – COMPACT LIGHT (LNF)
CERN IS INTERESTED IN OUTSOURCE PART OF THE ACTIVITY!!!

⇒ The **duplication of one of CERN X-boxes** at LNF is a perfect opportunity to **gain experience** and **expertise** in handling and operating X-band structures and power plants in view of the EuPRAXIA@SPARC_LAB project.

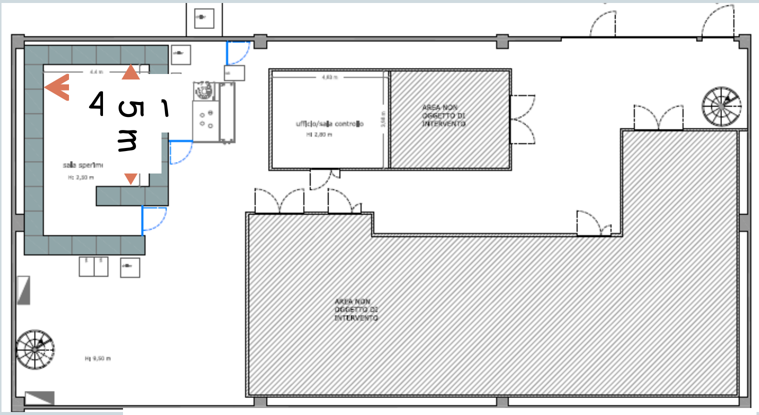
⇒ This activity is in **strong synergy** and collaboration with **CERN (CLIC group)**.

⇒ The LNF X Box will be located in LNF (building #7), very close to the SPARC_LAB area, formerly used for testing and conditioning of the DAFNE RF power plants and cavities.

CERN Synergy

Scandinova Pulsed Modulator

LNF X Box area



EuPRAXIA@SPARC_LAB
X-band accelerating module preliminary layout

X-band CPI klystron

Open challenges for linear colliders

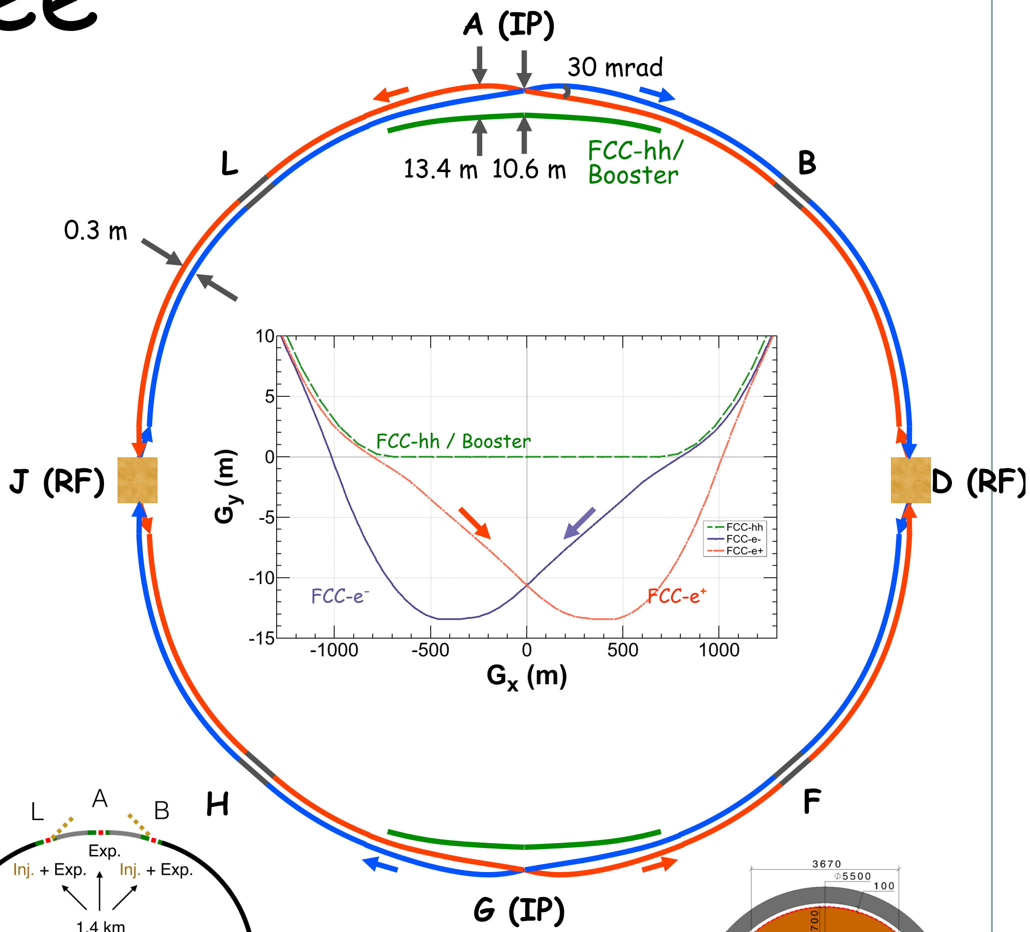
- Nanobeam
- Alignment and stability (local and global)
- Sources: positrons and polarization. Targets
- Polarization and polarization dynamics
- Industrialization

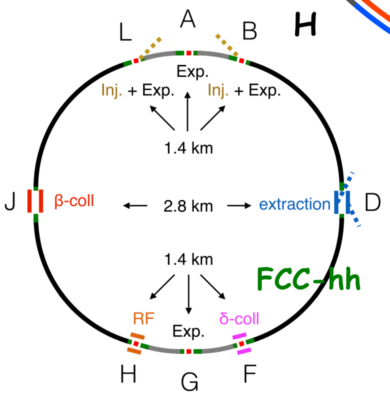
CIRCULAR ACCELERATORS

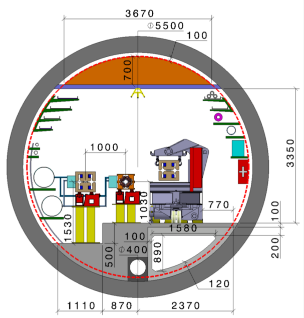
FCC-ee

Layout of FCC-ee collider

- **2-ring** e⁺e⁻ collider, following **FCC-hh footprint** (apart from IPs)
- **2 IPs** with **crab-waist** scheme, large horizontal x-angle of 30 mrad.
- Flexible optics design with **common lattice for all energies**
- **Top-up injection** to maintain current/ luminosity through a **full-energy Booster** synchrotron (same tunnel)
- **Synchrotron radiation power** of **50 MW/beam** at all energies.
- Beamstrhalung dominated at high energy







Parameters

FCC-ee parameters		Z	W^+W^-	ZH	ttbar	
Beam energy	**GeV**	**45.6**	**80**	**120**	**175**	**182.5**
Luminosity / IP	**10^{34} cm^{-2} s^{-1}**	**230**	**28**	**8.5**	**1.8**	**1.55**
Beam current	mA	1390	147	29	6.4	5.4
Bunches per beam	#	16640	2000	328	59	48
Average bunch spacing	ns	19.6	163	994	2763	3396
Bunch population	10^{11}	1.7	1.5	1.8	2.2	2.3
Horizontal emittance e_x Vertical emittance e_y	nm pm	0.27 1.0	0.84 1.7	0.63 1.3	1.34 2.7	1.46 2.9
b_x^* / b_y^*	**m / mm**	**0.15 / 0.8**	**0.2 / 1.0**	**0.3 / 1.0**	**1.0 / 1.6**	
beam size at IP: s_x^* / s_y^*	mm / nm	6.4 / 28	13 / 41	13.7 / 36	36.7 / 66	38.2/68
Energy spread: SR / total (w BS)	%	0.038 / 0.132	0.066 / 0.131	0.099 / 0.165	0.144 / 0.196	0.15 / 0.192
Bunch length: SR / total	mm	3.5 / 12.1	3 / 6.0	3.15 / 5.3	2.75 / 3.82	1.97 / 2.54
Energy loss per turn	GeV	0.036	0.34	1.72	7.8	9.2
RF Voltage /station	GV	0.1	0.75	2.0	4/5.4	4/6.9
Longitudinal damping time	turns	1273	236	70.3	23.1	20.4
Acceptance RF / energy (DA)	%	1.9 / ±1.3	2.3 / ±1.3	2.3 / ±1.7	3.5/ (-2.8; +2.4)	3.36 / (-2.8; +2.4)
Rad. Bhabha/ actual Beamstr. Lifetime	min	68 / > 200	59 / >200	38 / 18	37/ 24	40 / 18
Beam-beam parameter x_x / x_y		0.004 / 0.133	0.01 / 0.141	0.016 / 0.118	0.088 / 0.148	0.099 / 0.126
Interaction region length	mm	0.42	0.85	0.9	1.8	1.8

STATUS :Conceptual Design Report

1 – PHYSICS

Physics opportunities across all scenarios

2 Hadron Collider Summary

3 – Hadron Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experimen t
- eh

4 Lepton Collider Summary

5 – Lepton Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment

6 High Energy LHC Summary

7 – High Energy LHC Comprehensive

- Accelerator
- Injectors
- Infrastructure

Refs to FCC-hh, HL-LHC, LHeC

CDR summary volumes will be available by end 2018, as input for European Strategy Update 2019/20

INFN contributions and strategy

- MDI
- Instabilities and impedances
- Collaborations on the feedback systems for circular colliders and storage rings (ILC-damping rings, FCC-ee, CEPC).
- FCC pp R&D for electron cloud

CERN
Synergy

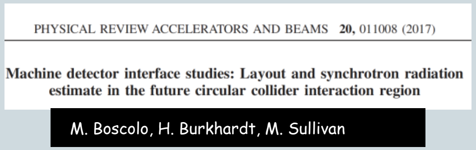
FCC-ee Machine Detector Interface

MDI group: convener: M. Boscolo (machine-side, LNF);
co-convener: N. Bacchetta (detector-side, INFN-Pd)

- The task is to study the integration of beams, machine elements and detectors able to produce/exploit the very high luminosities expected at FCC-ee at the IR. The group is charged to come up with a plausible design and, if needed, a set of necessary technical R&D or measurements.
- International group CERN, INFN, KEK, BINP, SLAC, Univ. Geneva, ..

- Accelerator-born backgrounds
- Synchrotron radiation and masking

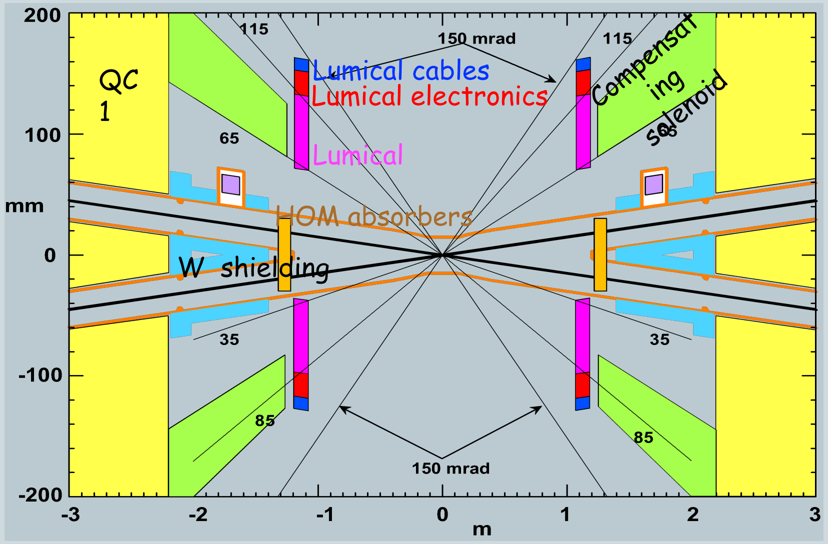
-SR
-luminosity monitor
-solenoid compensation scheme
-trapped modes
-High Order Modes absorber design


PHYSICAL REVIEW ACCELERATORS AND BEAMS 20, 011008 (2017)

Machine detector interface studies: Layout and synchrotron radiation estimate in the future circular collider interaction region

M. Boscolo, H. Burkhardt, M. Sullivan

- Detector aspects and layout
- Luminosity measurements
- Solenoid field compensation
- L* and links to optics, coupling corrections
- Technical infrastructure requirements and interfaces
- Effect of synchrotron radiation on particle detectors
- Integration of magnetic systems



All this work is being described in the CDR

Impedances and instabilities

FCC ee Convener: M. Migliorati, INFN LNF , Roma1, La Sapienza

- Impedance and single beam instabilities in FCC-ee:
  - Evaluation of the machine impedance budget. Contribution of:
  - Resistive wall, RF cavities and tapers, synchrotron radiation absorbers, collimator, beam position monitors, RF shielding.
- Effects of impedance on beam dynamics:
  - Microwave instability, transverse mode-coupling instability, multi-bunch instabilities
  - Bunch-by-bunch feedback requirements
- Interaction region: impedance budget, resistive wall, synchrotron radiation masks, trapped modes
- Electron cloud: electron density threshold for the single bunch head-tail instability

PHYSICAL REVIEW ACCELERATORS AND BEAMS **21,** 041001 (2018)

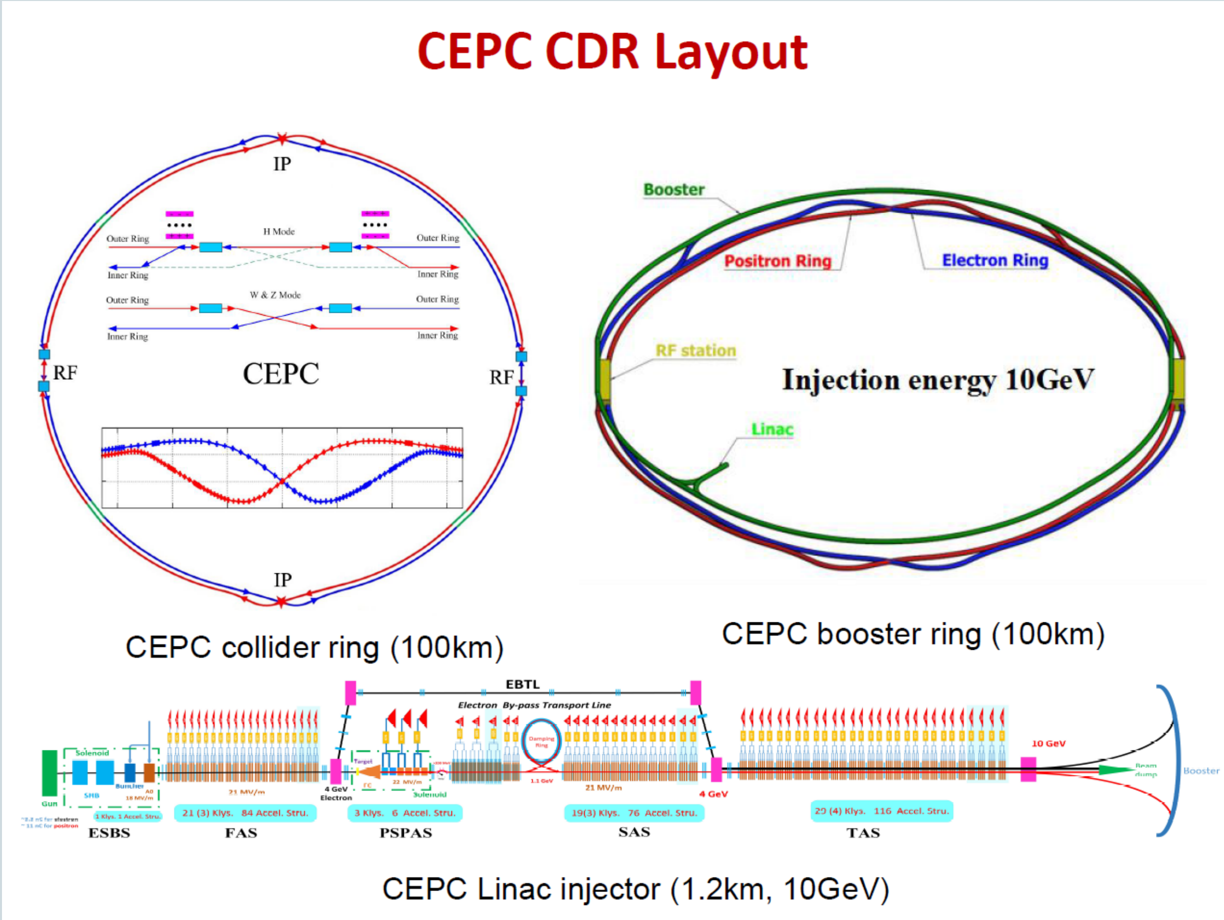
Impact of the resistive wall impedance on beam dynamics in the Future Circular e^+e^- Collider

E.Belli, M. Migliorati, M. Zobov

CEPC

- In time the project develop design very close to FCC ee

CEPC Layout

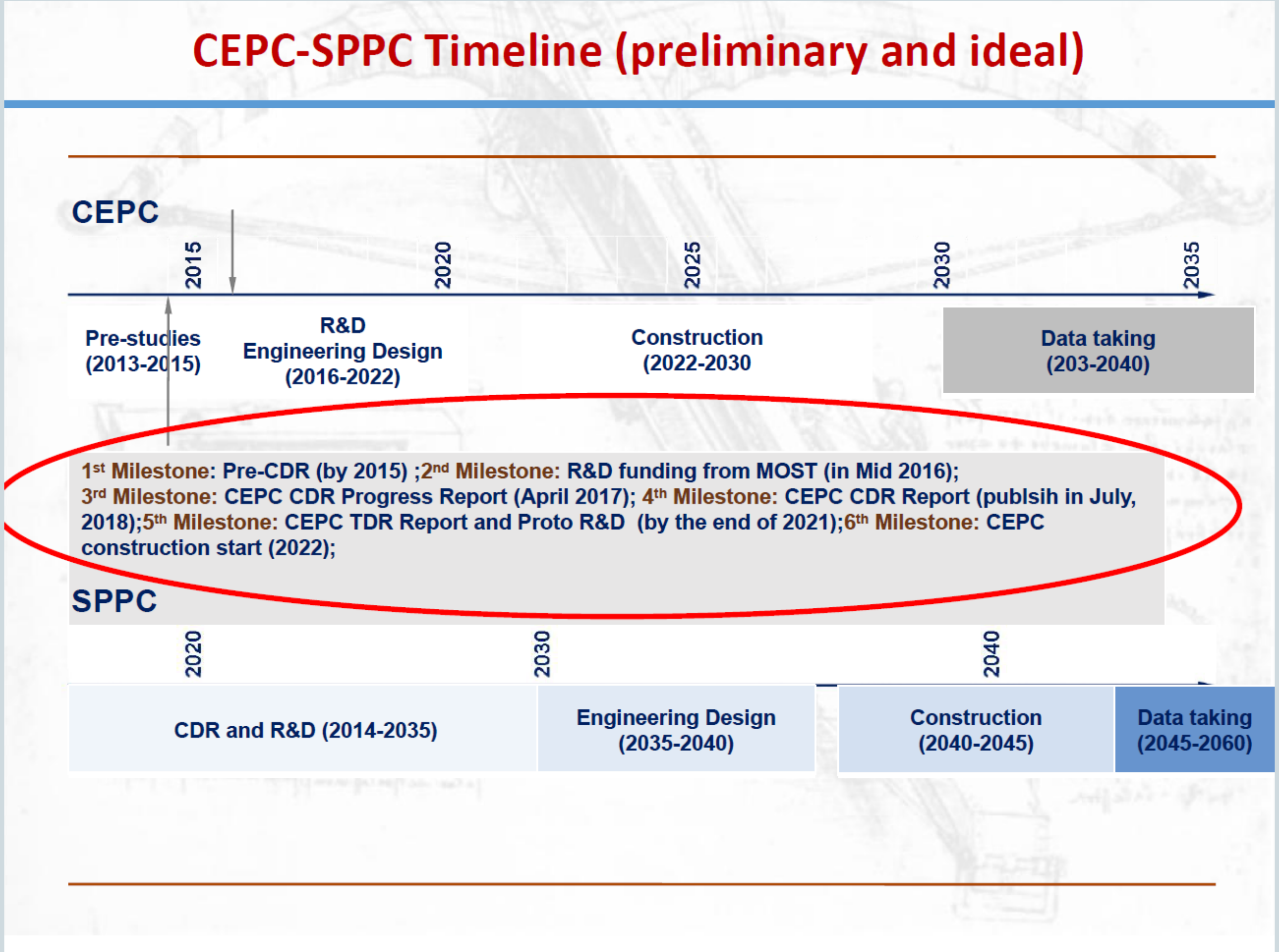

CEPC CDR Layout
IP
H Mode
W & Z Mode
Outer Ring
Inner Ring
RF
CEPC
RF
IP
CEPC collider ring (100km)
Booster
Positron Ring
Electron Ring
RF station
Injection energy 10GeV
Linac
CEPC booster ring (100km)
EBTL
Electron By-pass Transport Line
10 GeV
4 GeV
ESBS
FAS
PSPAS
SAS
TAS
21 (3) Klys. 84 Accel. Stru.
3 Klys. 6 Accel. Stru.
19(3) Klys. 76 Accel. Stru.
29 (4) Klys. 116 Accel. Stru.
Booster
CEPC Linac injector (1.2km, 10GeV)

Main parameters

CEPC CDR Parameters

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP L (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

STATUS

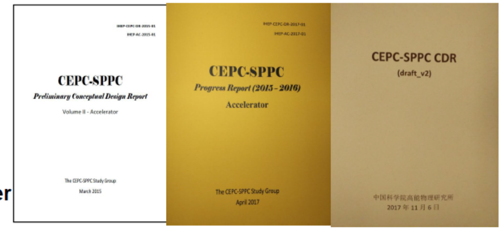

CEPC-SPPC Timeline (preliminary and ideal)
CEPC
2015
2020
2025
2030
2035
Pre-studies (2013-2015)
R&D Engineering Design (2016-2022)
Construction (2022-2030
Data taking (203-2040)
1st Milestone: Pre-CDR (by 2015) ;2nd Milestone: R&D funding from MOST (in Mid 2016);
3rd Milestone: CEPC CDR Progress Report (April 2017); 4th Milestone: CEPC CDR Report (publsih in July, 2018);5th Milestone: CEPC TDR Report and Proto R&D (by the end of 2021);6th Milestone: CEPC construction start (2022);
SPPC
2020
2030
2040
CDR and R&D (2014-2035)
Engineering Design (2035-2040)
Construction (2040-2045)
Data taking (2045-2060)

STATUS

CEPC Accelerator from Pre-CDR to CDR

CEPC accelerator CDR completed in June 2018 (to be printed in July 2018)

- **Executive Summary**
  1. **Introduction**
  2. **Machine Layout and Performance**
  3. **Operation Scenarios**
  4. **CEPC Collider**
  5. **CEPC Booster**
  6. **CEPC Linac**
  7. **Systems Common to the CEPC Linac, Booster and Collider**
  8. **Super Proton Proton Collider**
  9. **Conventional Facilities**
  10. **Environment, Health and Safety**
  11. **R&D Program**
  12. **Project Plan, Cost and Schedule**
- Appendix 1: CEPC Parameter List
- Appendix 2: CEPC Technical Component List
- Appendix 3: CEPC Electric Power Requirement
- Appendix 4: Advanced Partial Double Ring
- Appendix 5: CEPC Injector Based on Plasma Wakefield Accelerator
- Appendix 6: Operation as a High Intensity γ-ray Source
- Appendix 7: Operation for e-p, e-A and Heavy Ion Collision
- Appendix 8: Opportunities for Polarization in the CEPC
- Appendix 9: International Review Report



March 2015 | April 2017 | Draft CDR for Mini International Review in Nov. 2017

CDR Version for International Review June 2018

CDR Complete,
With R&D phase
well defined

Conclusions

- The study path from CEPC Pre-CDE to CEPC CDR baseline and alternative choice has been overviewed
- CEPC Accelerator CDR has been completed with all systems reaching the CDR design goals with new ideas beyond CDR
- CEPC hardware design and key technologies' R&D plan are ready for full TDR phase

Open Challenges for Circular colliders

DESIGN:

- Beamstrahlung dominated at high energy
- Large energy range (FCC ee)
- Large SR energy loss
- Short beam lifetime and consequences (top up)
- Impedances and new instabilities from beam-beam interaction
- Asymmetric IR optics to control SR in the IR (at all energies)
- Strong sawtooth effect, tapering of magnet strength
- IP momentum acceptance
- Bootstrapping injection
- Polarization (FCC ee)

No evident Showstopper at present.

CEPC CDR Technical R&D

- **· SRF Key Technology R&D (2016-2020, IHEP, MOST & PAPS)**
- — High Q & high gradient cavity with **N-doped Nb** & **Fe-based** superconductor
- — Very high power variable input coupler with low heat load (300 kW CW)
- — High power coaxial HOM coupler and wideband HOM absorber
- **· Cryomodule Prototyping (2019-2022, PAPS, etc.)**
- — **Collider cryomodules**: 650 MHz 2 x 2-cell and full scale 6 x 2-cell (11 m)
- — **Booster cryomodules**: 1.3 GHz 2 x 9-cell and full scale 8 x 9-cell (12 m)
- — High Q operation (clean assembly, magnetic hygiene and flux

parameters for FCC and CEPC

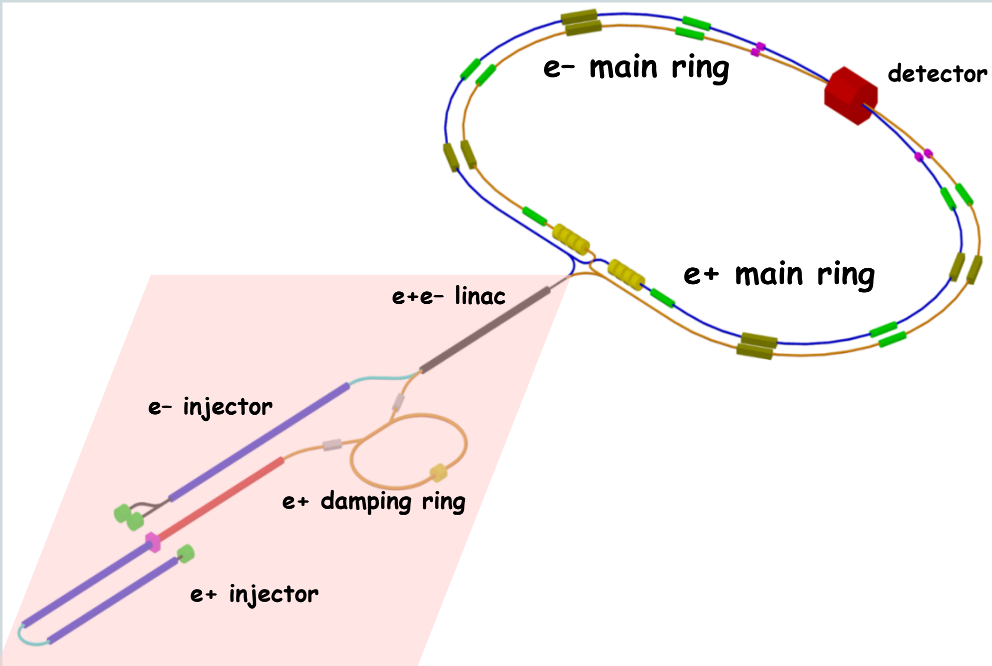
FCCee / CEPC		Z	W^+W^-	ZH	ttbar	
Beam energy	GeV	45.6 / 45.5	80 / 80	120 / 120	175	182.5
Luminosity / IP	10^{34} cm^{-2} s^{-1}	230 / 32.1	28 / 10.1	8.5 / 2.93	1.8	1.55
IP	2/2					
Beam current	mA	1390 / 461	147 / 87.9	29 / 17.4	6.4	5.4
Bunches per beam	#	16640 / 12000	2000 / 1524	328 / 242	59	48
Average bunch spacing	ns	19.6 / 25	163 / 210	994 / 680	2763	3396
Bunch population	10^{11}	1.7 / 0.8	1.5 /1.2	1.8 / 1.5	2.2	2.3
Horizontal emittance e_x Vertical emittance e_y	nm pm	0.27 / 0.18 1.0 / 1.6	0.84 / 0.54 1.7 / 1.6	0.63 / 1.21 1.3 / 3.1	1.34 2.7	1.46 2.9
β_x^* - β_y^*	m - mm	0.15 - 0.8 / 0.2 - 1	0.2 - 1.0 / 0.36 - 1.5	0.3 - 1.0 / 0.36 - 1.5	1.0 - 1.6	
beam size at IP: σ_x^* - σ_y^*	μm - nm	6.4 - 28 / 6 - 40	13 - 41 / 13.9 - 49	13.7 - 36 / 20.9 -68	36.7-66	38.2 -68
Beam-beam parameter x_x / x_y		0.004 - 0.133 / 0.041 - 0.056	0.01 - 0.141 / 0.013 -0.106	0.016 - 0.118 / 0.031 - 0.109	0.088 - 0.148	0.099 - 0.126

SCTF

- National scale. Tau Charm collider.

Layout and parameters

Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	813.1 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	30/30/15 ms			
Bunch length	18 mm	12 mm	10 mm	10 mm
Energy spread	$11 \cdot 10^{-4}$	$11 \cdot 10^{-4}$	$9.3 \cdot 10^{-4}$	$7.2 \cdot 10^{-4}$
Momentum compaction	$8.5 \cdot 10^{-4}$	$8.8 \cdot 10^{-4}$	$8.8 \cdot 10^{-4}$	$8.8 \cdot 10^{-4}$
Synchrotron tune	0.007	0.010	0.009	0.008
RF frequency	499.95 MHz			
Harmonic number	1356			
Particles in bunch	$7 \cdot 10^{10}$			
Number of bunches	406(10% gap)			
Bunch current	4.2 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.135	0.135	0.121	0.097
Luminosity	$0.6 \cdot 10^{35}$	$0.9 \cdot 10^{35}$	$1.0 \cdot 10^{35}$	$1.0 \cdot 10^{35}$



Main requirements & solutions

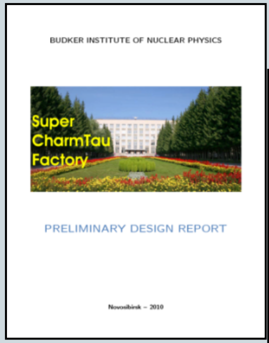
- Beam energy from 1.0 to 2.5 GeV
- Luminosity 10^{35} $cm^{-2}s^{-1}$ at 2 GeV
- Longitudinal polarization of electron beam at IP
- Beam energy calibration by Compton backscattering

- Double ring collider
- Crab waist collisions
- Beta-function less than 1 mm
- Constant beam emittance and damping time (damping wigglers)
- High beam current (feedbacks)
- 5 Siberian Snakes
- High intensity source of positron
- High intensity source of polarized electron
- 2.5 GeV linac
- 50 Hz top-up injection

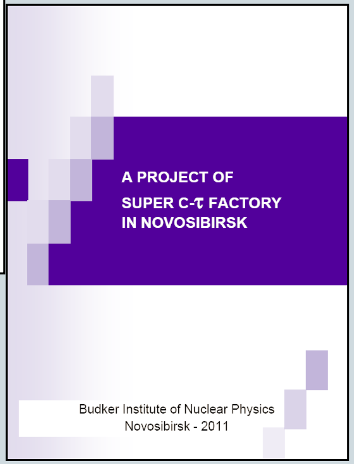
- STRONG SYNERGY WITH SuperKEKB and SuperB - TauCharm studies

Status

2010 – Preliminary Design Report



(178 pages)

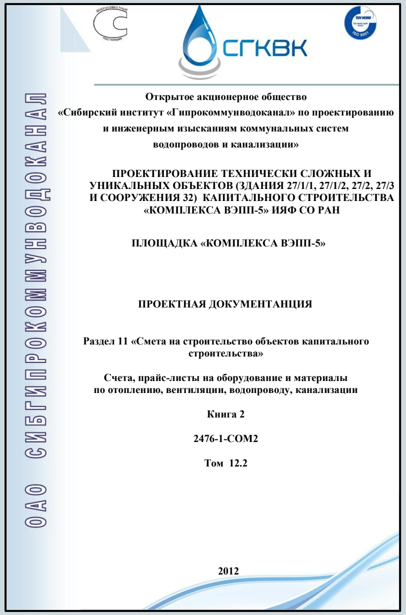


(202 pages)

2011 – Conceptual Design Report

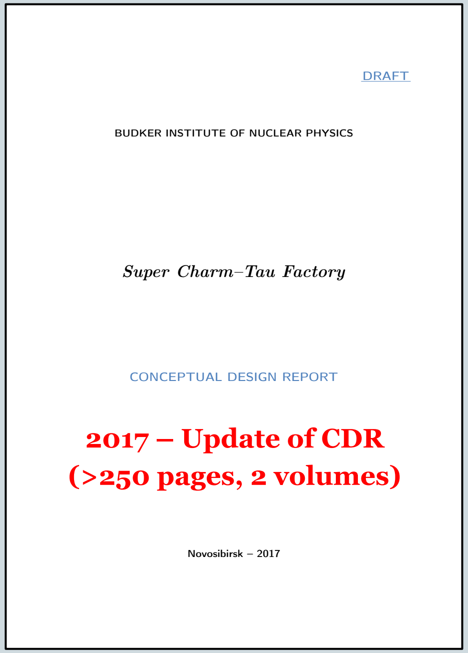
(112 pages)

2011 – Roadmap



(12 volumes)

2012 – Building project




Новосибирская область

- INFN: There is a general interest to participate to this project (sinergy with SuperKEKB and SuperB)

SUMMARY

Summary for strategy

- Accelerators e^+-e^- community well followed the previous recommendations for EU strategy
  - -ILC mature, still waiting for decision
  - -CLIC developed the x band technology, close to be mature, TDR missing.
  - -Circular colliders are in design phase
  - -Both profits from ATF nanobeam studies. XFEL & ILC
  - -Tau Charm is a project at the national scale, they are looking for collaboration.

- Linear colliders -> MEDIUM TERM PROJECTS (more ILC)
- Needs a trigger (budget and political)
- ILC is a quite mature project (but positron target…TDR), CLIC still need minor R&D efforts and industrialization program.
- INFN important past contribution visible on different aspects.
- - SRF cavities, X band, Recombination ring and loops, RF deflectors…..
- On going: X band and Linac techniques at LNF. Possible developments.
- R&D direction -> REDUCTION OF COSTS (construction and operation) is still the key issue (ILC working in this direction)!
- INFN Ready for (strong) participation, need of technical and PM personnel for big projects.
- SRF, RF and Linacs, Low emittance beams, Linac techniques, DR design

- Recommendations -> decision that Linear is the best (if it is..) / START

- Circular colliders -> LONG TERM
- Projects in phase of CDR.
- INFN contribution is visible but not well supported (2 main activities) with small groups. Dafne history supports the possibility to provide 'heavy contributions'.
- Need to be strengthen for visible participation and not to lose lepton collider expertise.
- CRAB WAIST in all projects
- Impedances and coatings, IP studies, Low emittance rings studies.
- CEPC is already at the CDR phase, no main showstoppers identified, R&D programs defined. The final design has naturally converged to FCCee.
- FCCee waiting for Summary CDR
- Decision is mainly political

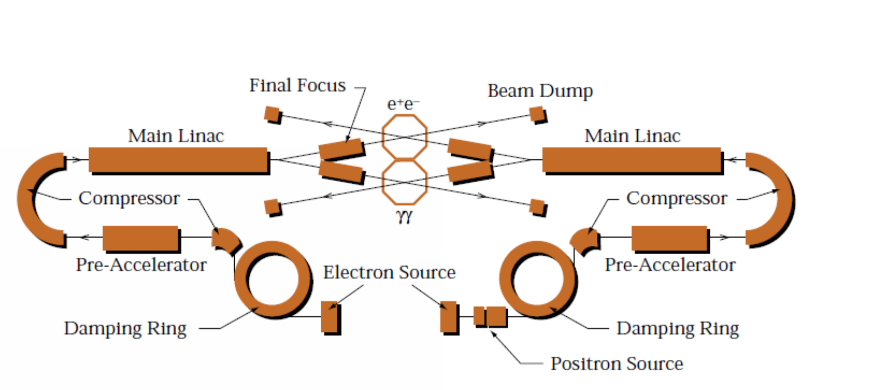
- Recommendations - > recommendable that both studies goes on in synergy up to the redaction of a complete TDR of both machines…)

- High precision SCTF to be evaluated. -> SHORT TERM. LNF developed a lot of the related topics in the SuperB framework.
- Good bridge towards the long term….!!
- Synergies with KEK (but it is a pity that CERN does not pay efforts in the HEP national scale projects)
- Ready for participation avoiding, in my opinion, 'minimal contribution scenarios' that has visible impact on the labs activities
- Similar project in Hefei (USTC)

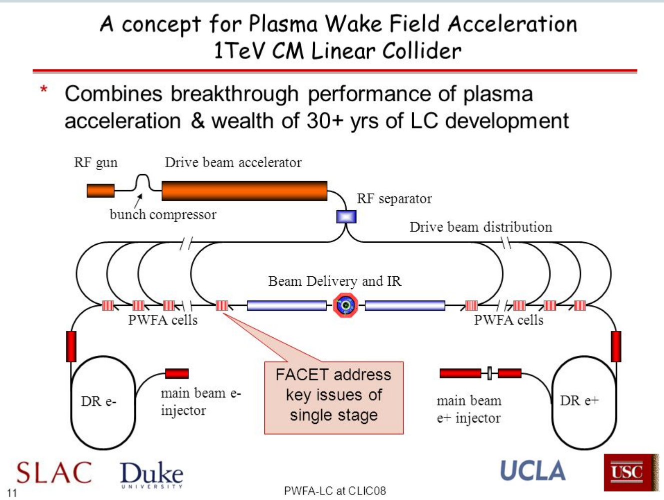
- Recommendations -> Explore true participation of these projects in the community. Very important if high energy machine is a 'long term machine'…

No limits for new ideas
Lepton colliders are also the pillars of others futuristic projects so a minimal effort should always be in place

γ–γ colliders based on linear colliders



Plasma colliders based on linear colliders



Needs work on frep!!!

Muon colliders based on FCC ee

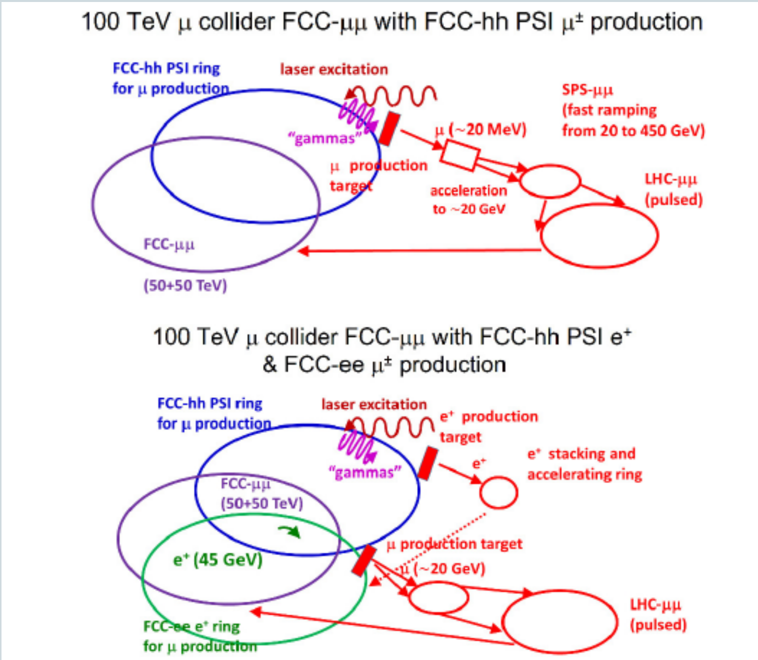


Figure 2: Example variants of a 100 TeV muon collider based on the FCC complex [3].

Linear vs Circular

- Luminosity : Circular ok, at low energy. For the tt is comparable. Higgs is still to be discussed…First plot indicates that for a machine up to Higgs factory circular is better, if an energy upgrade is mandatory linear is better.
- Cost : Huge for both (close to 10^{10}). Estimated cost mature only for linear, but we can suppose that cost for circular will be bigger if starting from green field. Need a deep investigation for circular (both).
- Feasibility : at present no project shows important showstoppers…Tech R&D to be pursued.
- Operation cost we are always talking of n.100 MW class machines ($1.2<n<5.9$). Equilibrium has to be found between construction and operation but it depends on the scientific political strategy (what's the energy of LC?).
- But linear infrastructures cost increases if we increase the energy (but this is the goal to build a linear one….).
- CLIC preferred to ILC for the TeV range (but SRF technology R&D progresses…). Cost for the Higgs factory comparable if CLIC with the klystron solution is adopted…

	CLIC				ILC				FCC ee					CEPC		
Energy (GeV)	380	1500	3000		250	500	1500		90 (Z)	160 (W)	240 (H)	365 (t)		90 (Z)	160(W)	240(H)
Power (MW)	252	364	589		120	205	300		275	288	308	364		148	223	270
Cost (Meuro)	6650				5260	7800			Less than 12					less than 4 ?		
Luminosity (cm^{-2} s^{-1})	1,5	3,7	6		1,35	1,79			>200	>25	>7	>1.4		32	10	3
ATTENTION : XFEL budget total cost 1.22 Meuro -> operating cost close to 10%																

Conclusions

- No projects shows, at present, insuperable showstoppers.
- Linear colliders more mature (especially ILC). Needs a decision (that has been already bypassed, taking into account that only one project will be possible). Better for extension at high energy. INFN strong visibility - ready
- Circular colliders need to go through the design and R&D program (CDR& TDR). Both should be developed in synergy up to the design maturity. Better for Higgs and lower. INFN can participate but need effort to increase the visibility
- Tau charm factory is a useful mid term project, CDR ready, should proceed to the TDR. INFN was the 'source' of this project but at present low interest. Should preserve the community.
- At this level the main recommendations for what is the reasonable path comes from the physics and the coupled variable politics-budget (see last slide).

Challenges (not extensive) :

1. Nanobeam
2. Alignment and stability (local and global)
3. Sources: positrons and polarization
4. Polarization and polarization dynamics
5. Industrialization

6. Large energy range up to tt
7. Beamstrahlung dynamics at high energy
8. Large SR energy loss
9. Short beam lifetime (top up)
10. Impedances and new instabilities from beam-beam interaction
11. Asymmetric IR optics to control SR in the IR (at all energies)
12. Strong sawtooth effect, tapering of magnet strength
13. IP momentum acceptance
14. Bootstrapping injection
15. Polarization (FCC ee)
16. Positrons sources
17. Alignments
18. SRF
19. Small IP beta functions
20. CRAB WAIST integration

- Thanks for your attention and to all the colleagues providing the material for the slides.

DISCUSSION

Let me ask some question….

Is there any scenario in which linear and circular lepton colliders are compatible? If yes in what scenario?

Next lepton collider will only cover Higgs?

What is a reasonable budget?