Accelerator highlights from ICHEP 2022

https://www.ichep2022.it/

J. Gao

July 22, CEPC Day

Accelerators: Physics, Performance and R&D for future facilities

This session addresses technologies and performances of both existing and next generation accelerators (including HL-LHC) and their potential and impact on the present and future particle physics research.

Conveners:

Benedetto Giacobbe (INFN BO, LOC liaison)
Frank Zimmermann (CERN)
Angeles Faus-Golfe (IJCLab)
Vladimir Shiltsev (FNAL)
Jie Gao (IHEP, Chinese Academy of Sciences)
Gaku Mitsuka (KEK)

https://agenda.infn.it/event/

Accelerators: Physics, Performance, and R&D for future facilities - Room 12 (Celeste) (09:00 - 10:45)

-**Conveners: Angeles Faus-Golfe**

time	title	presenter
09:00	Crystal-based positron source for the lepton colliders	CHAIKOVSKA, Iryna
09:15	Considerations for Fermilab Multi-MW Proton Facility in the DUNE/LBNF era	NAGAITSEV, Sergei
09:30	Beam Dynamics Effects in the Muon g-2 Experiment	DRIUTTI, Anna
09:45	Tracking the magnetic field in the Fermilab Muon g-2 experiment	REIMANN, René
10:00	The Advanced Beam-Cooling Program at Fermilab: First Experimental Demonstration of Optical Stochastic Cooling	NAGAITSEV, Sergei
10:15	Pion-Production Target for Mu2e-II: Simulation Design and Prototype	PRONSKIKH, Vitaly
10:30	Crystal-based extraction of the electron beam circulating in the DESY II Booster Synchrotron	MAZZOLARI, Andrea

Accelerators: Physics, Performance, and R&D for future facilities - Room 12 (Celeste) (11:15 - 13:00)

-**Conveners: Jie Gao**

time	title	presenter
11:15	The CLIC and ILC accelerator status and plans	FAUS-GOLFE, Angeles
11:35	Report of electron beam acceleration with STF-2 cryomodules for the ILC	KURATA, Masakazu
11:50	Study status of the CEPC Machine-Detector Interface and Interaction Region	SHI, Haoyu
12:05	FCC-ee Energy Calibration and Polarization	KEINTZEL, Jacqueline
12:20	FCC-ee Booster Design	DALENA, Barbara
12:35	FCC-ee Collective Effects and their mitigation	CARIDEO, Emanuela

Accelerators: Physics, Performance, and R&D for future facilities - Room 12 (Celeste) (14:30 - 16:30)

-Conveners: Gaku Mitsuka

time	title	presenter
14:30	The FCC-ee Preinjector and the PSI Positron Production at SwissFEL	CRAIEVICH, Paolo
14:45	Overview of the LHeC and FCC-he accelerator concepts	HOLZER, Bernhard
15:05	PERLE: The development of a multi-turn, high current ERL	KAABI, Walid
15:20	The Electron-Ion Collider: an overview	VERDÚ-ANDRÉS, Silvia
15:40	Status and challenges of the Future Circular Hadron Collider FCC-hh	GIOVANNOZZI, Massimo
16:00	Progress towards the CERN Gamma Factory	MARTENS, Aurelien

Accelerators: Physics, Performance, and R&D for future facilities - Room 12 (Celeste) (17:00 - 19:00)

-Conveners: Vladimir Shiltsev

time	title	presenter
17:00	Plans for future energy frontier accelerators to drive particle physics discovery	PASTRONE, Nadia
17:20	Machine-detector interface studies for a multi-TeV muon collider	CALZOLARI, Daniele
17:35	High Field Magnet Development for HEP in Europe – A Roadmap by the LDG HFM Expert Panel	AUCHMANN, Bernhard
17:50	High-resolution, low-latency, bunch-by-bunch feedback systems for nano-beam production and stabilization	BURROWS, Philip
18:05	A new method with minimized systematic error sources to detect axion dark matter in storage rings using an rf Wien filter	KIM, On
18:20	Storage ring proton EDM comprehensive systematic errors study for 10^{-29} e-cm level.	SEMERTZIDIS, Yannis
18:35	Channeling at accelerators high-energy frontier and future developments from GALORE	ROMAGNONI, Marco

Accelerators: Physics, Performance, and R&D for future facilities - Room 5 (Avorio) (09:00 - 10:45)

-**Conveners: FRANK ZIMMERMANN**

time	title	presenter
09:00	"Snowmass'21 Accelerator Frontier: Summary of Discussions on Future HEP Facilities in the US	SHILTSEV, Vladimir
09:20	HL-LHC status and operational scenarios	DE MARIA, Riccardo
09:40	FCC-ee Collider Design Overview	HOFER, Michael
10:00	Current Status of the ILC and CLIC projects	BURROWS, Philip
10:20	The muon collider progress	SCHULTE, Daniel

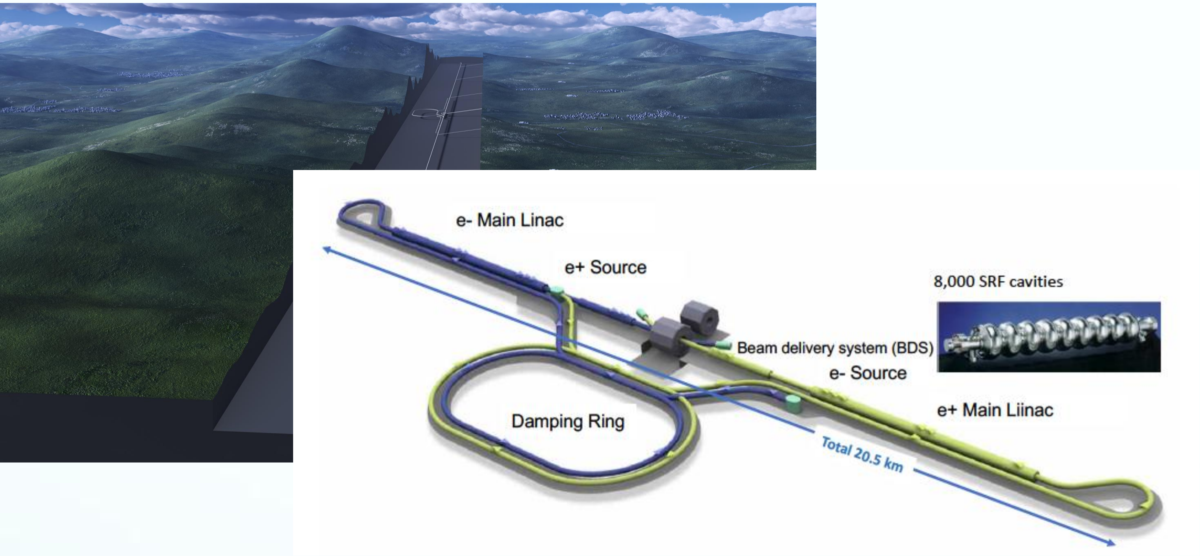
Highlights mainly on the following subjects:

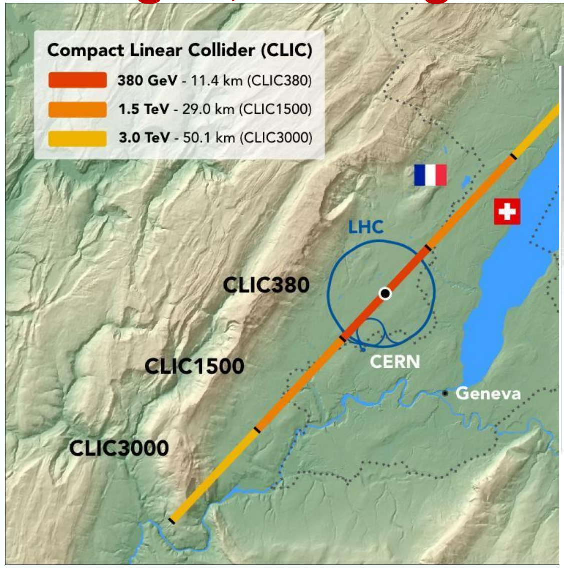
ILC, CLIC, FCCee,hh, EIC, PIPI,II, Muon collider, ERL and key technologies...

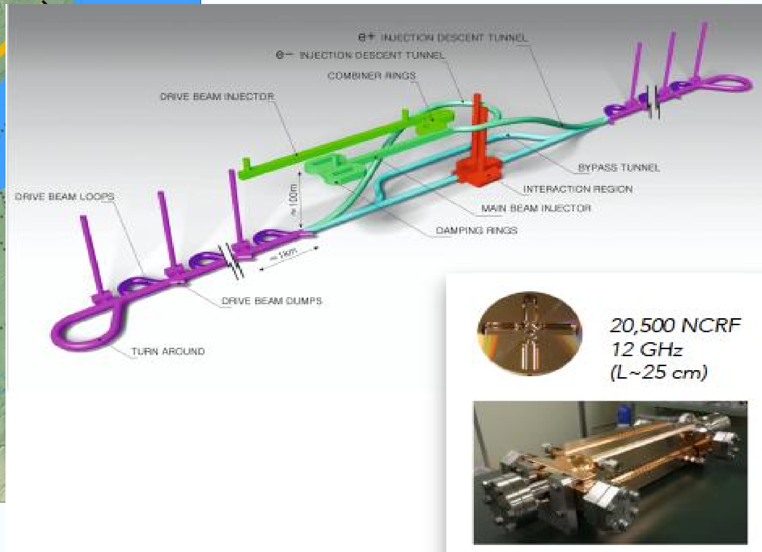
ILC and CLIC in a nutshell

A. Faus's talk

Two e+e- linear collider designs, starting as a Higgs factory







International Linear Collider ILC

- Superconducting Cavities, 1.3GHz, 31.5 (35) MV/m
- Klystrons
- 250GeV CME, upgradeable to 500, 1000GeV
- L = 1.35×10^{34} cm^{-2}s^{-1} (at initial 250GeV)
- 20km length, in Tohoku / Japan
- Polarisation 80%(e-), 30%(e+)

Compact Linear Collider CLIC

- NC Copper Cavities, 12.0GHz, 72 – 100 MV/m
- Two-beam acceleration (Klystrons)
- 380GeV CME, upgradeable to 1500, 3000GeV
- L = 1.50×10^{34} cm^{-2}s^{-1} (at initial 380GeV)
- 11.4km long, at CERN / France & Switzerland
- Polarisation 80% (e-)

ILC Technology level

Since the publication of the conceptual design report (RDR) in 2007 and the Technical Design Report (TDR) in 2013, the technical development has been progressing steadily toward the start of construction.

Status	(RDR) (TDR)	2021	(EDR)*	
SRF cavity, CM	～2017 Technology development ->Model work-> Prototype	2018～2021 High performance and cost reduction of cavities	International mass production, and transfer demonstration	ILC construction
SRF Linac	Model work: small-scale models, partial/component models.	European XFEL user operation		
e- source	～2017 Tech. Design->Tech. Development->Tech. Demonstration		Tech. confirmation	
e+ source Undulator scheme	～2017 Tech. Design->Tech. Development	2018～2021 Tech. Demonstration	Target and magnetic focusing	
e+ source e-driven scheme	～2017 Tech. Design->Tech. Developmen	2018～2021 Tech. Demonstration	Target and capture cavity	
DR	～2017 Design->Tech. Development-> Tech. demonstration achieved at KEK ATF		Kicker	
Final focus	～2017 Design->Tech. Development->Tech. demonstration achieved at KEK ATF		Stable op.	
Dump	～2017 Tech. Design->Tech. Development	2018～2021 Facility design	Remote handling	

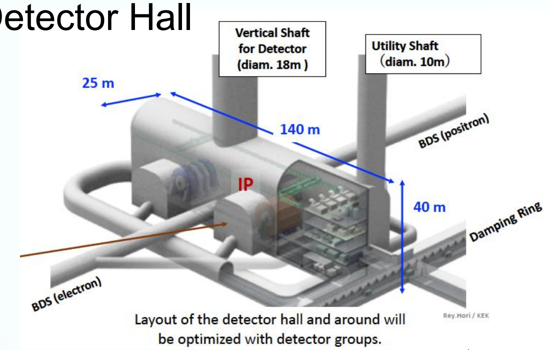
: ～2017
: 2018～2021
: Pre-lab

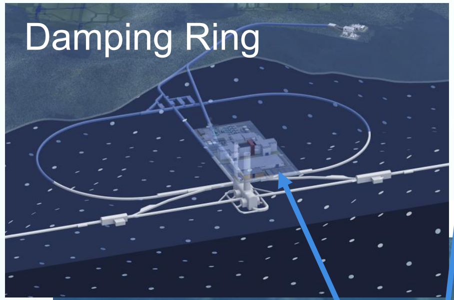
A. Faus's talk

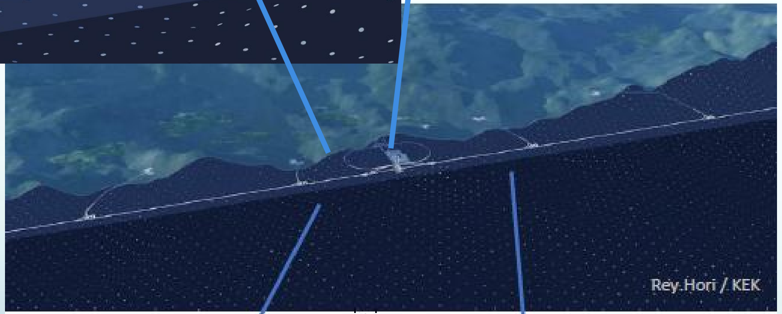
*EDR:Detailed Engineering Design Report required to start construction.

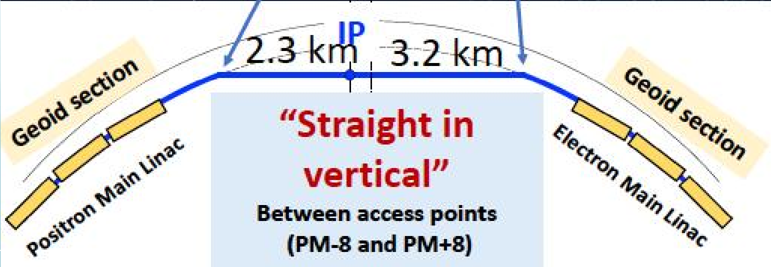
ILC Site Selection and Civil Engineering

Detector Hall





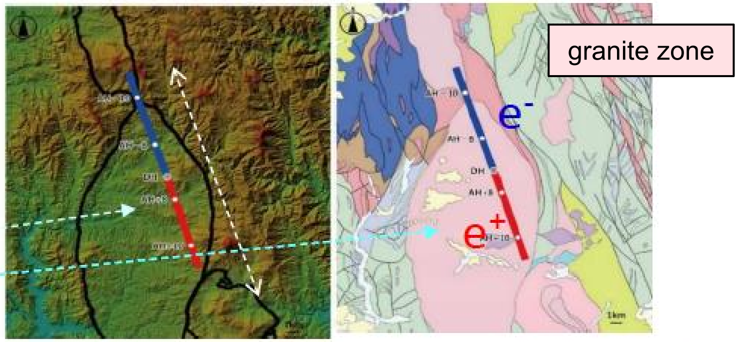




Kitakami mountains

① ILC Location

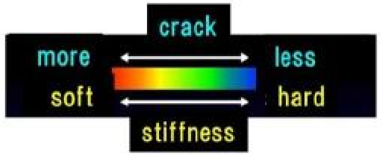
ILC accelerator area : inside the granite rock bodies
→ inside black curves (left)
→ in the pink color (right)
→ possible up to 50 km

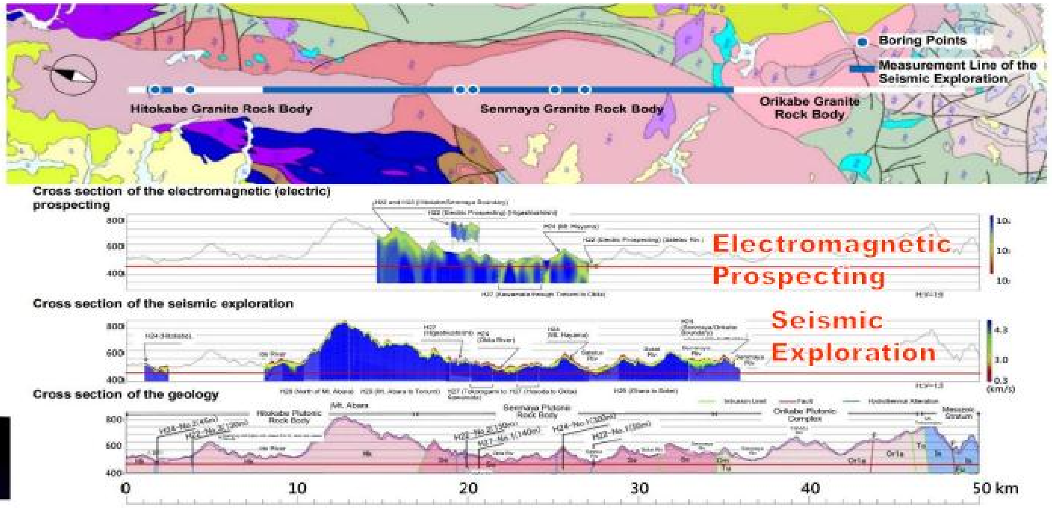


→ On-going jobs : Optimal accelerator placement, considering surface environment, land-use and land-acquisition

② Geological Surveys

- Electric Prospecting (crack)
- Seismic Exploration (stiffness)
- Boring Survey
- Borehole Camera
- Measurement of Initial Stress of the Ground





→ no issues from previous surveys

→ requiring : additional surveys around access tunnel head and access tunnel inside for detailed designing

A. Faus's talk

"Green ILC" and Carbon neutrality

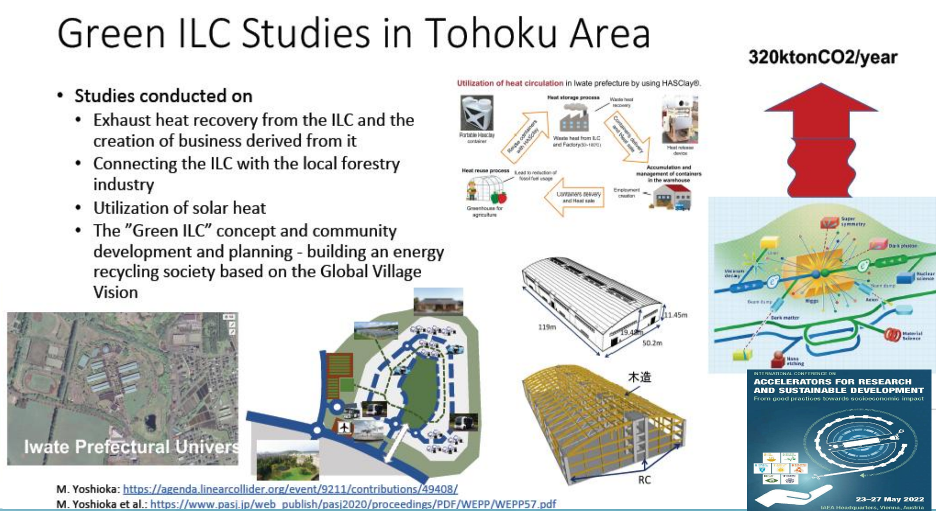
Although SRF has been adopted, the AC power consumption for ML part is <50%, what is a total of 110 MW

- **"Green ILC"**: Past efforts include increasing the efficiency of accelerators (SC, klystron) https://green-ilc.in2p3.fr/documents/
- **Carbon neutrality**: Common challenge for all future HEP accelerators. The use of SC will contribute to carbon neutrality in the future.

Work is ongoing to study these issues in collaboration the "ILC Environmental Assessment Advisory Board"

Summary of the Discussion

https://www2.kek.jp/ilc/ja/contents/docs/Strategic_Environmental_Assessment_of_the_ILC_Project_Summary_of_the_Discussion_r.pdf



ILC Timeline

- **International Development Team** (IDT) prepares **Pre-Lab**
- 4 year Pre-Lab (hosted by KEK, Japan) phase for **R&D**, **Engineering Design Report**, Construction preparation
- **ILC Laboratory** (international): 10 year construction phase

2022

2026

	IDT	ILC Pre-Lab				ILC Lab.										
	PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.
Preparation CE/Utility, Survey, Design Acc. Industrialization prep.																
Construction																
Civil Eng.																
Building, Utilities																
Acc. Systems																
Installation																
Commissioning																
Physics Exp.																

Following a four-year ILC Pre-Lab phase, ILC construction will continue for about 9 years + 1 commisioning

A. Faus's talk

ILC upgrade options

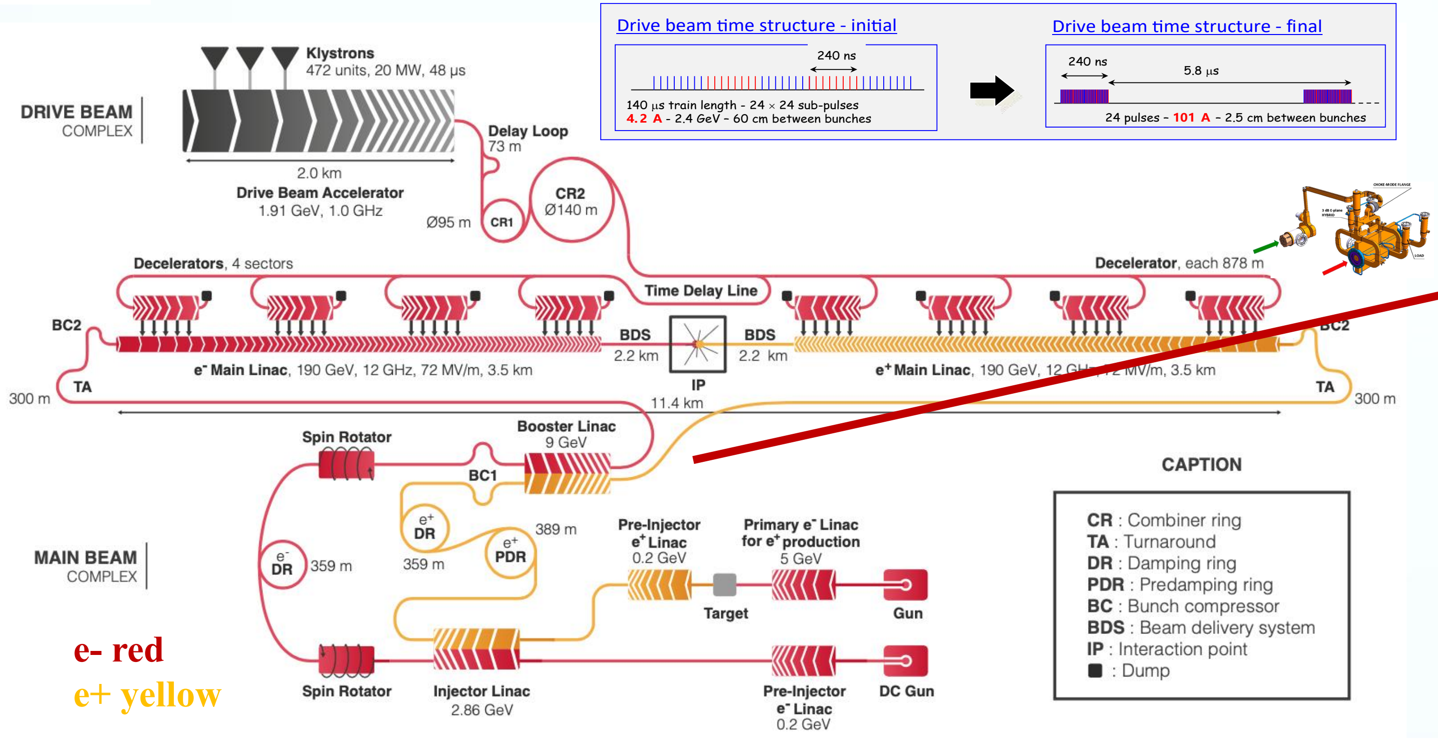
Energy

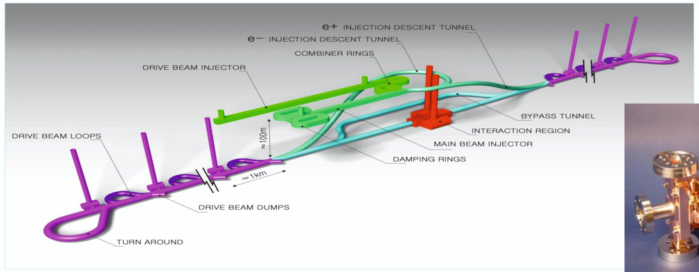
Philip Burrows's talk

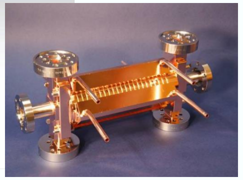
Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	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	$\gamma\epsilon_{\text{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\text{y}}$	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

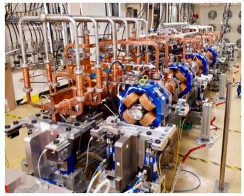
Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$ [26]. *): For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

CLIC parameters and beam accelerator sequence

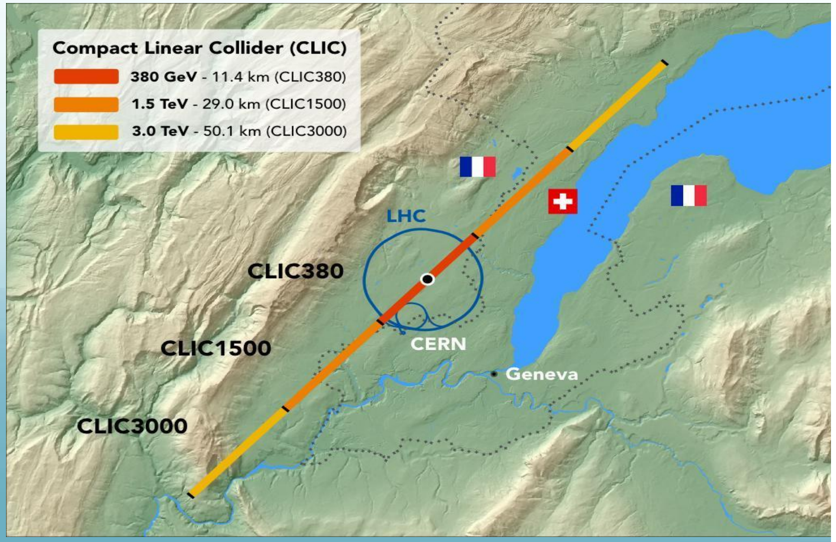


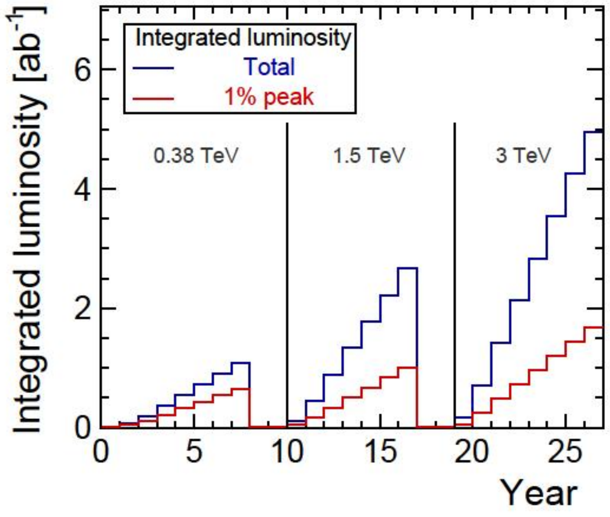






1. **Drive beam** accelerated to ~2 GeV using conventional klystrons
2. **Intensity increased** using a series of delay loops and combiner rings
3. Drive beam **decelerated** and produces high-RF
4. Feed high-RF to the less intense main beam using waveguides

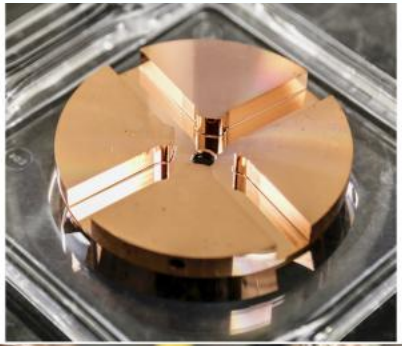




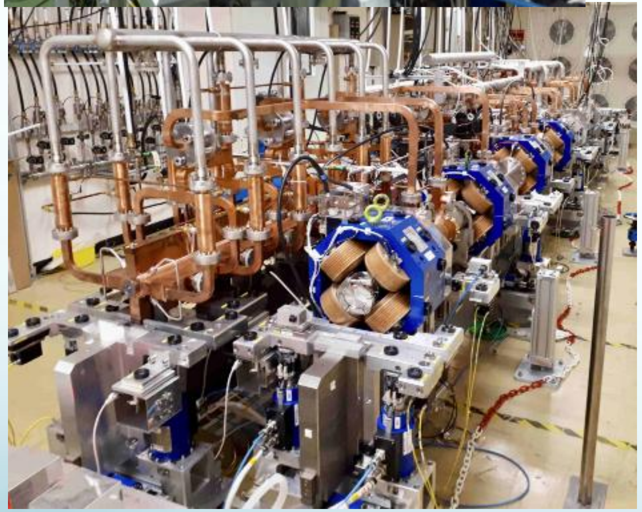
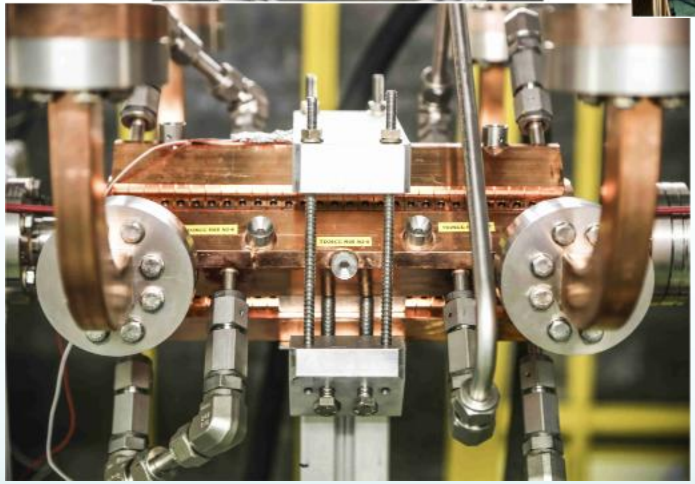
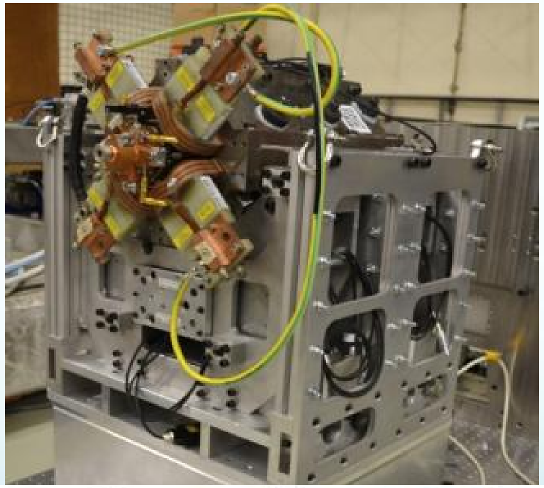
Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,cm^{-2}s^{-1}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,cm^{-2}s^{-1}$	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

Examples of technical developments

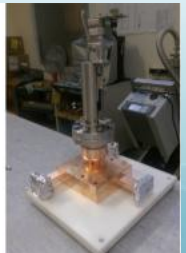
CLIC Technical developments of key elements

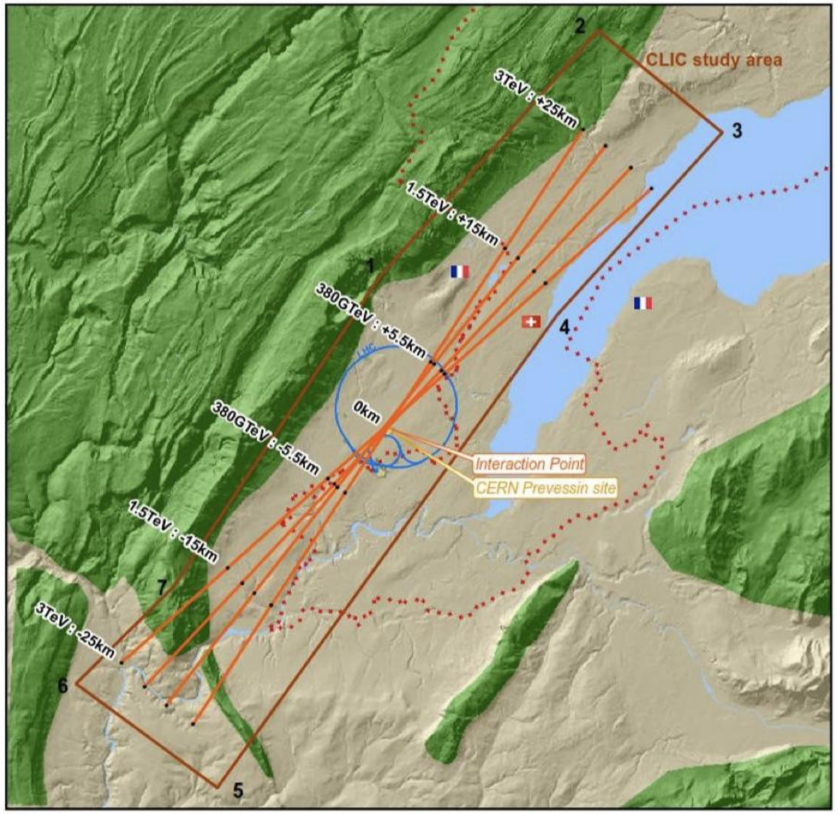


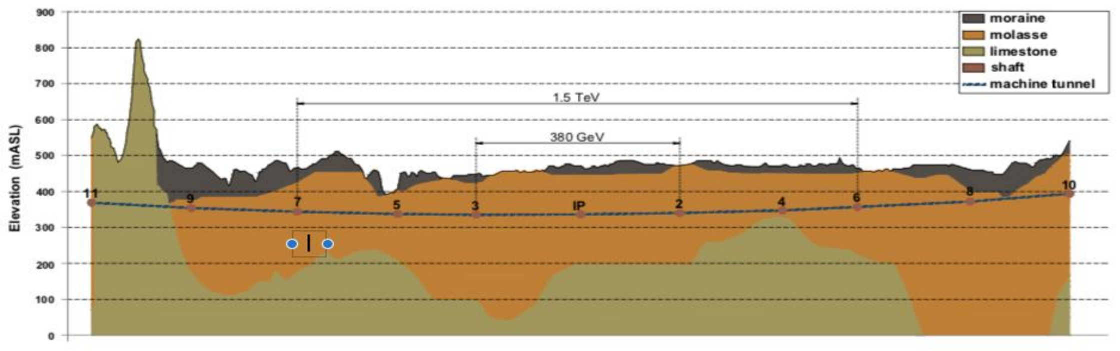







CLIC Site Selection and Civil Engineering

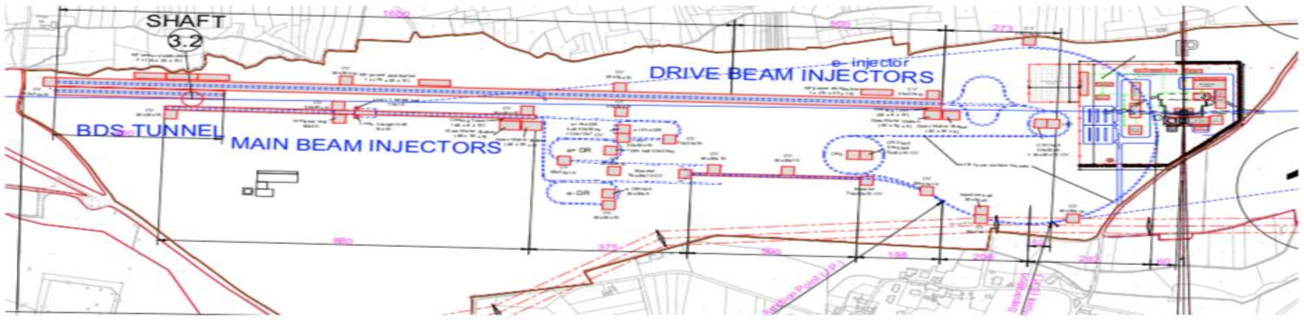


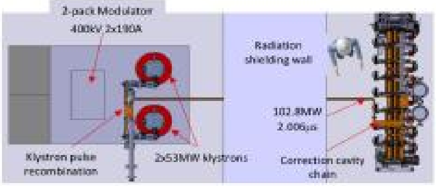


Important effort within:

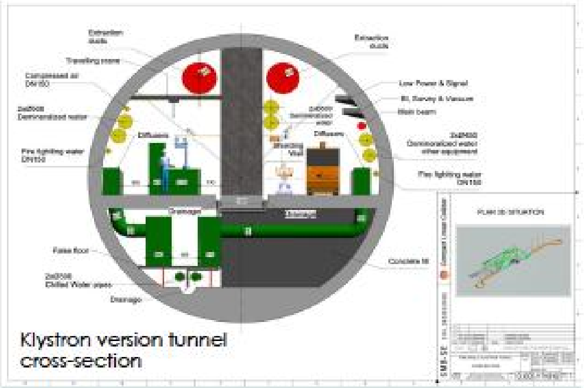
- Civil engineering
- Electrical systems
- Cooling and ventilation
- Transport, logistics and installation
- Safety, access and radiation protection systems

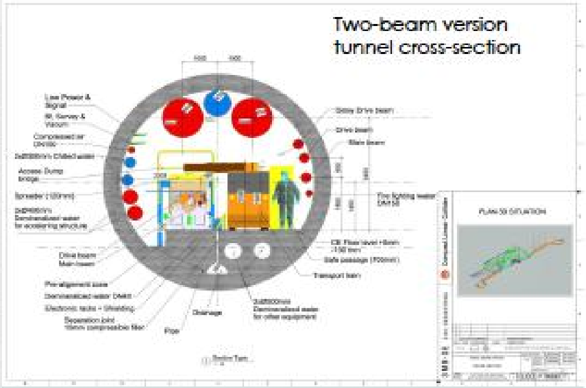
Crucial for cost/power/schedule





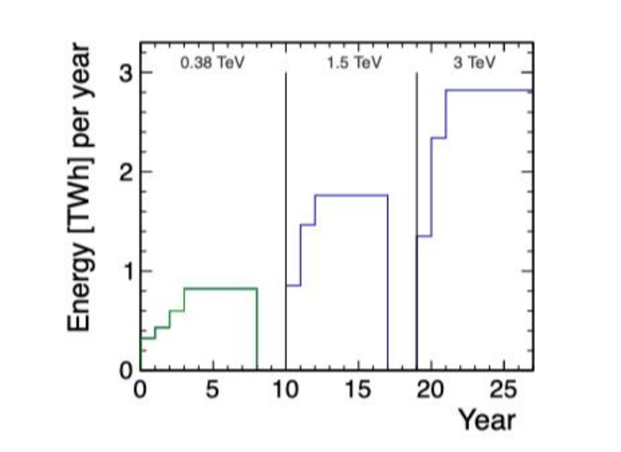
- Klystron-powered version studied and costed for 1st stage (380 GeV c.m.)
- Upgrade to 1 TeV and beyond based in any case on Two-beam scheme (klystron-based sectors re-usable with modifications)





“Green CLIC” and Carbon neutrality

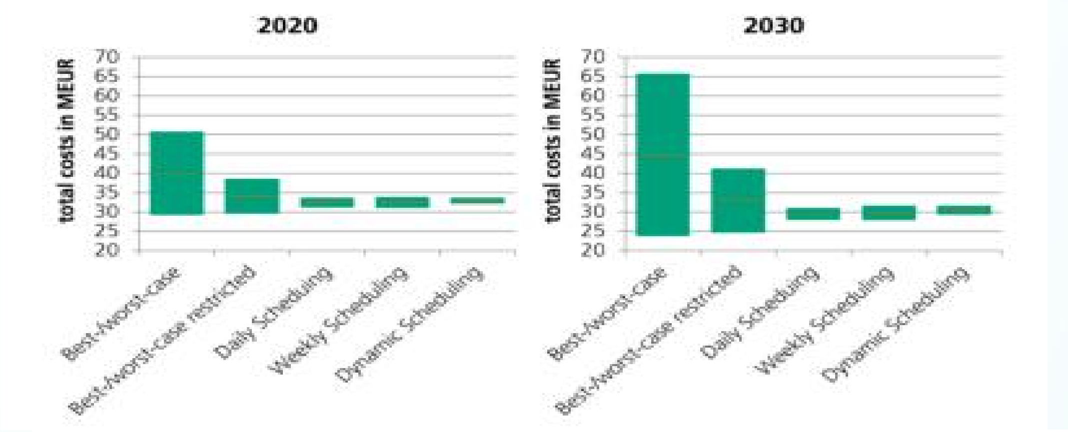
Collision energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	110	25	9
1500	364	38	13
3000	589	46	17



- Very **large reductions** since **CDR**, better estimates of nominal settings, much more optimised drive-beam complex and more efficient klystrons, injectors more optimisation, etc
- Further savings possible, main target damping ring RF and improved L-band klystrons for drive-beam

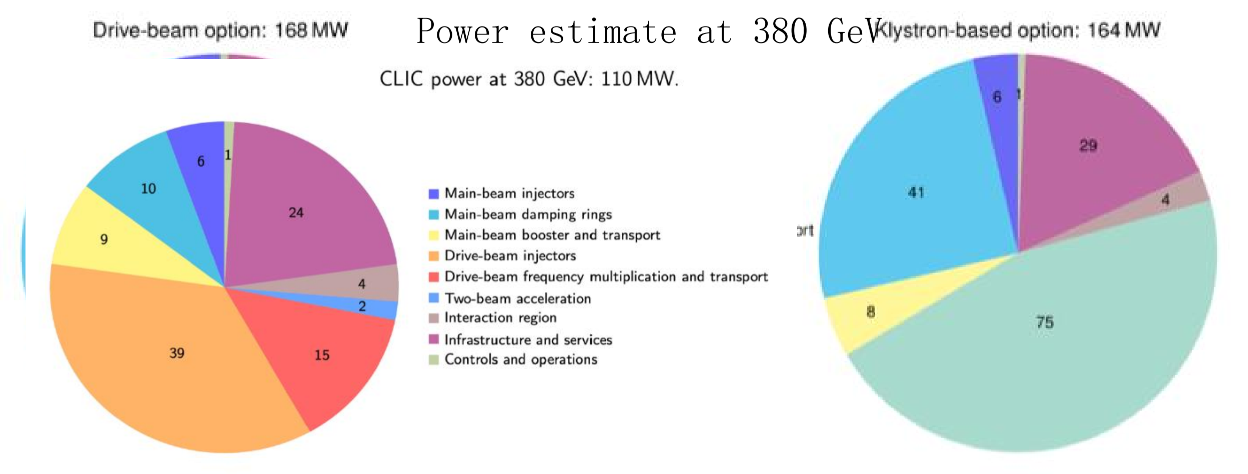
➢ **Energy studies:**

- Running when energy is cheap



Relative energy cost by no scheduling, avoiding the winter months (restricted), daily, weekly and dynamic scheduling. Central values of the ranges shown should be considered best estimates. The absolute cost scale will depend on price, contracts and detailed assumption about running times, but the relative cost differences indicate that significant cost-reductions could be achieved by optimizing the running schedule of CLIC to avoid high-energy cost peri... fer)

- Recovering energy



CLIC Timeline

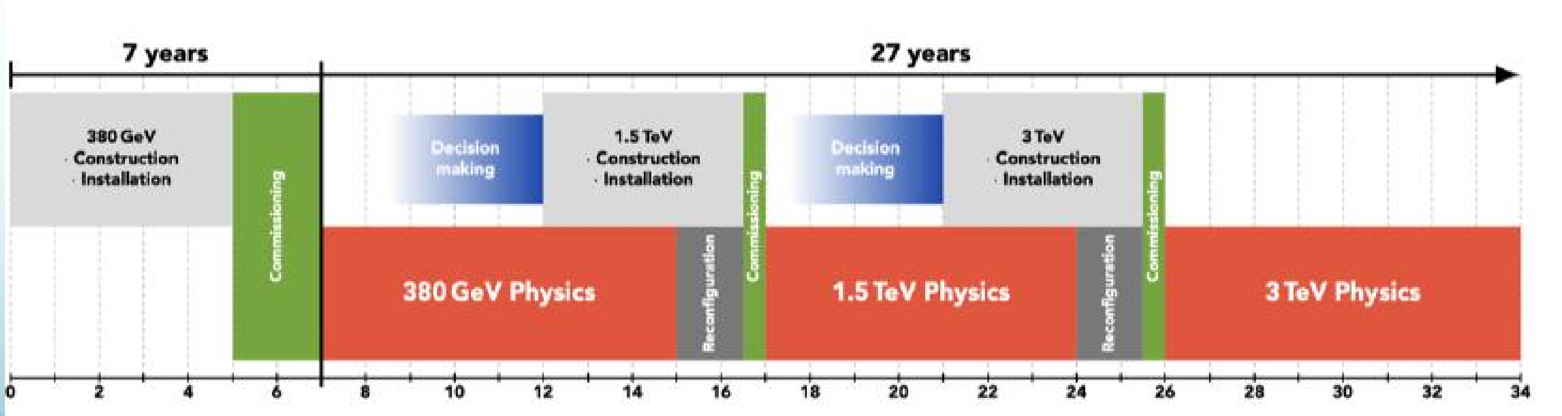
Project Readiness Report as a step toward a TDR – for next ESPP

Assuming ESPP in 2026, Project Approval ~ 2028, Project (tunnel)construction can start in ~ 2030.

- Focusing on:
  - **The X-band technology** readiness for the 380 GeV CLIC initial phase
  - **Optimizing the luminosity** at 380 GeV
  - **Improving the power efficiency** for both the initial phase and at high energies

- More details:
  - X-band studies: Structure manufacturability and optimized conditioning, interfaces to all connecting systems for large scale production, designs for and support of use in applications from the 1 GeV linac at LNF to medical linacs
  - Luminosity: beam dynamics studies and related hardware optimisation for nanobeams from damping rings to final focus (mechanical and thermal stability, alignment, instrumentation, vacuum systems, stray field control, magnet stability, etc)
  - Improving damping ring and drive beam RF efficiency, study parameter changes to reduce power at multi-TeV energies maintaining high luminosities

- **Technology Driven Schedule** with a preparation phase of ~5 years is needed before (estimated resource need for this phase is ~4% of overall project costs)

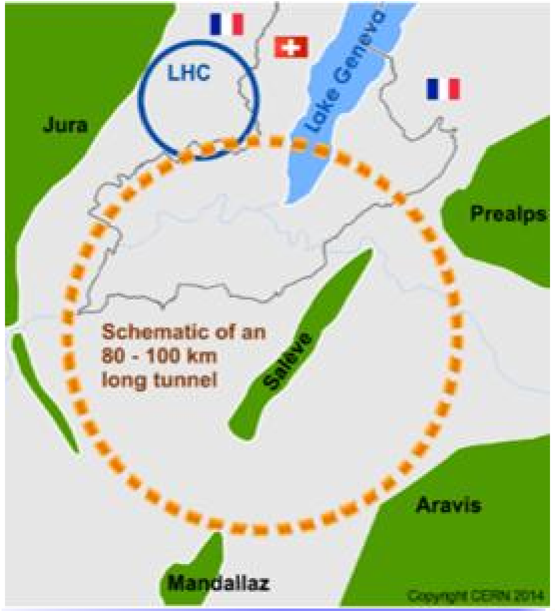


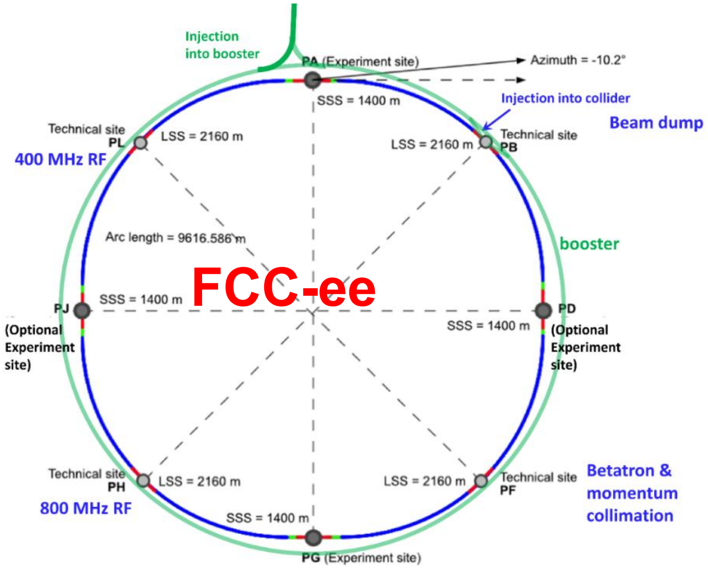
The FCC integrated program

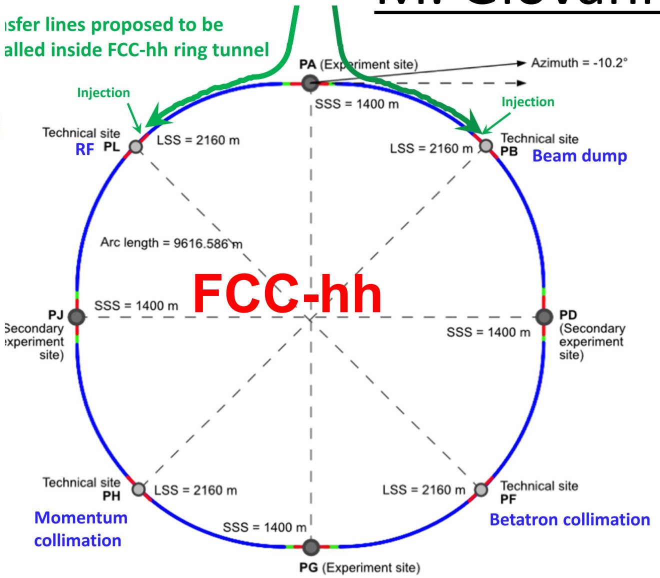
Comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures, reusing CERN's existing infrastructure
- FCC integrated program allows continuation of HEP after completion of the HL-LHC program

M. Giovannozzi's talk







2020 - 2040 | 2045 - 2060 | 2070 - 2090++

FCC CDR and Study Documentation

- **FCC-Conceptual Design Reports (completed in 2018):**
  - **Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC**
  - CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4)**

  EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 , EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

- **Summary documents provided to EPPSU SG**
  - **FCC-integral, FCC-ee, FCC-hh, HE-LHC**
  - Accessible on http://fcc-cdr.web.cern.ch/

M. Giovannozzi's talk

Feasibility study goals and roadmap

M. Giovannozzi's talk

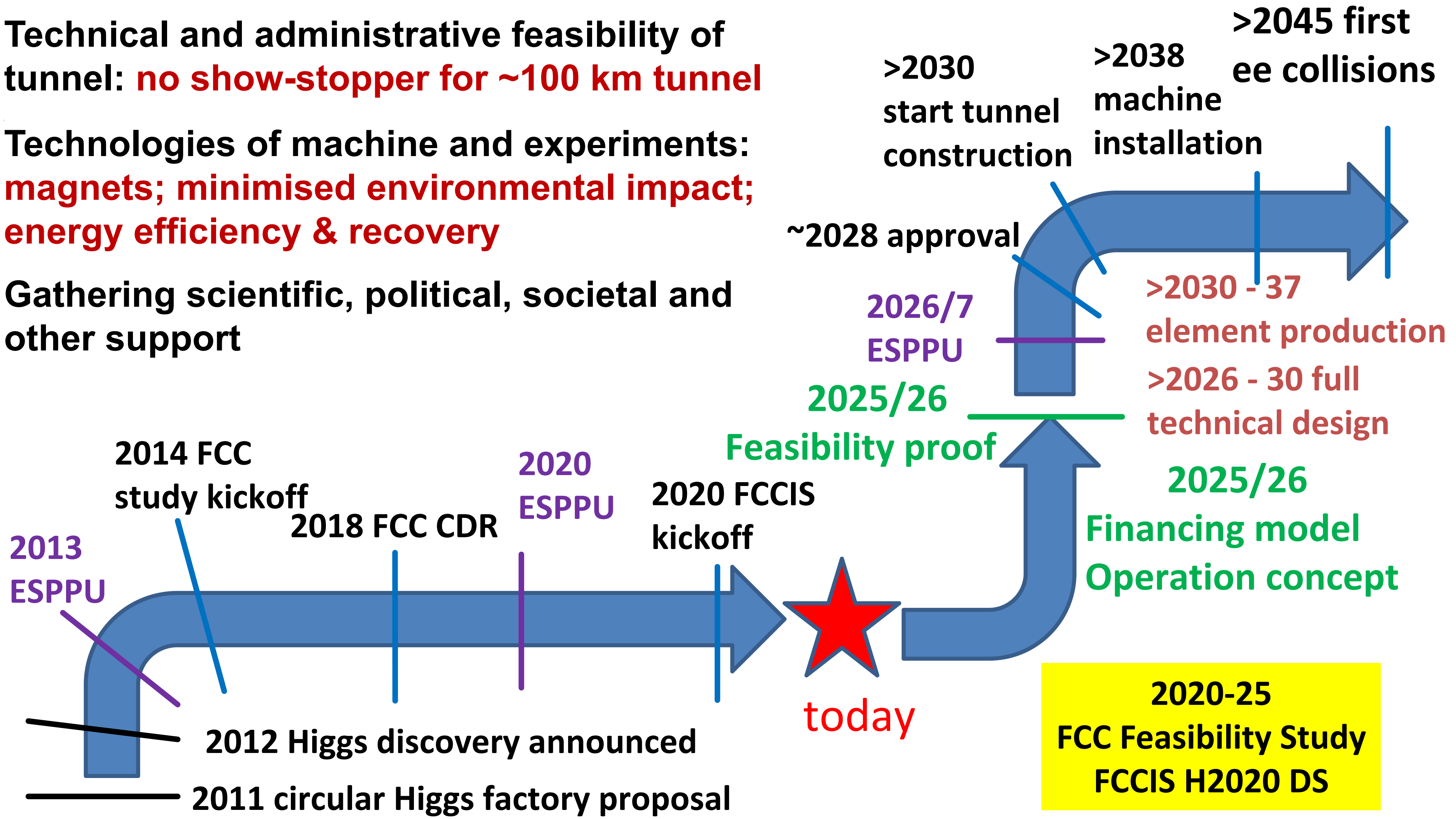
Highest priority goals:

Financial feasibility

Technical and administrative feasibility of tunnel: no show-stopper for ~100 km tunnel

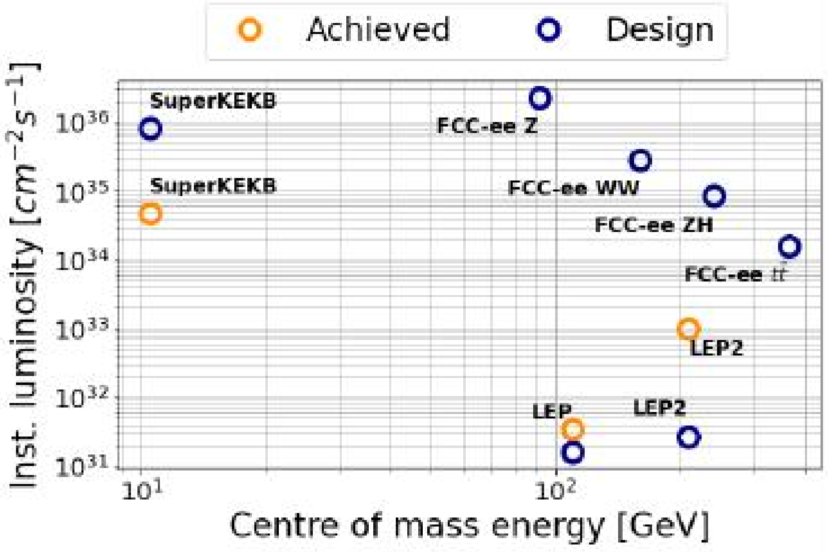
Technologies of machine and experiments: magnets; minimised environmental impact; energy efficiency & recovery

Gathering scientific, political, societal and other support



FCC-ee Luminosity Goal

- Design of a highest-luminosity, energy frontier e^+e^- collider, optimized to study Z, W, Higgs, and top particles



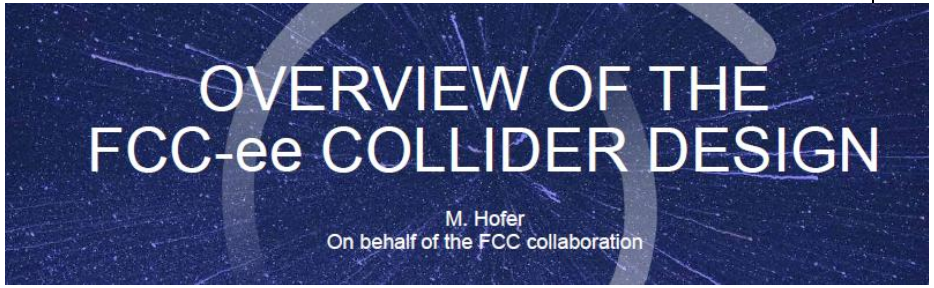
Sources: 1,2,3,4

- Aim for:
  - 75 ab^{-1}/IP at Z-pole (91 GeV)
  - 5 ab^{-1}/IP at WW-threshold (161 GeV)
  - 2.5 ab^{-1}/IP at ZH (240 GeV)
  - 0.8 ab^{-1}/IP at $t\bar{t}$-threshold (365 GeV)
  - Other operation mode (direct H production) under study

- Need to be compatible with design of the hadron collider (FCC-hh)

see presentation by M. Giovannozzi, Thu 3:40 pm

M. Haufer's talk

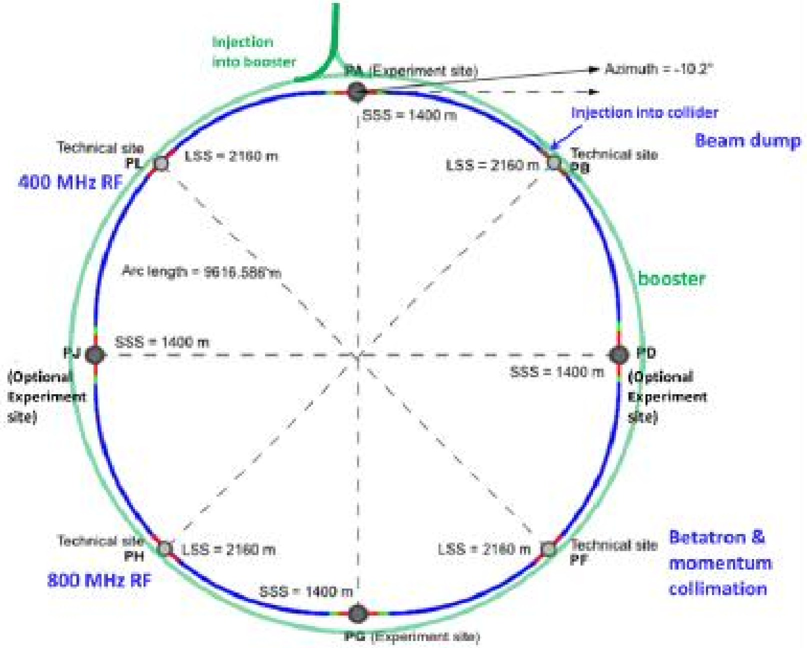


FCC-ee main parameters

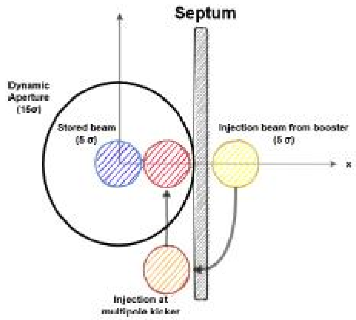
Layout	PA31-1.0			
	Z	WW	ZH	$t\bar{t}$
Circumference (km)	91.174117 km			
Beam energy (GeV)	45.6	80	120	182.5
Bunch population (10^{11})	2.53	2.91	2.04	2.64
Bunches per beam	9600	880	248	36
RF frequency (MHz)	400			400/800
RF Voltage (GV)	0.12	1.0	2.08	4.0/7.25
Energy loss per turn (GeV)	0.0391	.37	1.869	10.0
Longitudinal damping time (turns)	1167	217	64.5	18.5
Momentum compaction factor 10^{-6}	28.5		7.33	
Horizontal tune/IP	55.563		100.565	
Vertical tune/IP	55.600		98.595	
Synchrotron tune	0.0370	0.0801	0.0328	0.0826
Horizontal emittance (nm)	0.71	2.17	0.64	1.49
Verical emittance (pm)	1.42	4.34	1.29	2.98
IP number	4			
Nominal bunch length (mm) (SR/BS)*	4.37/14.5	3.55/8.01	3.34/6.0	2.02/2.95
Nominal energy spread (%) (SR/BS)*	0.039/0.130	0.069/0.154	0.103/0.185	0.157/0.229
Piwinski angle (SR/BS)*	6.35/21.1	2.56/5.78	3.62/6.50	0.79/1.15
ξ_x/ξ_y	0.004/0.152	0.011/0.125	0.014/0.131	0.096/0.151
Horizontal β^* (m)	0.15	0.2	0.3	1.0
Vertical β^* (mm)	0.8	1.0	1.0	1.6
Luminosity/IP (10^{34}/cm^{2}s)	181	17.4	7.8	1.25

*SR: syncrotron radiation, BS: beamstrahlung

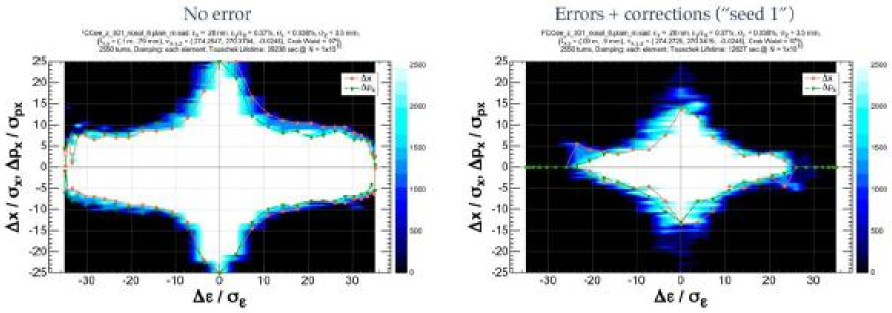
Emanuela Carideo's talk



Dynamic Aperture



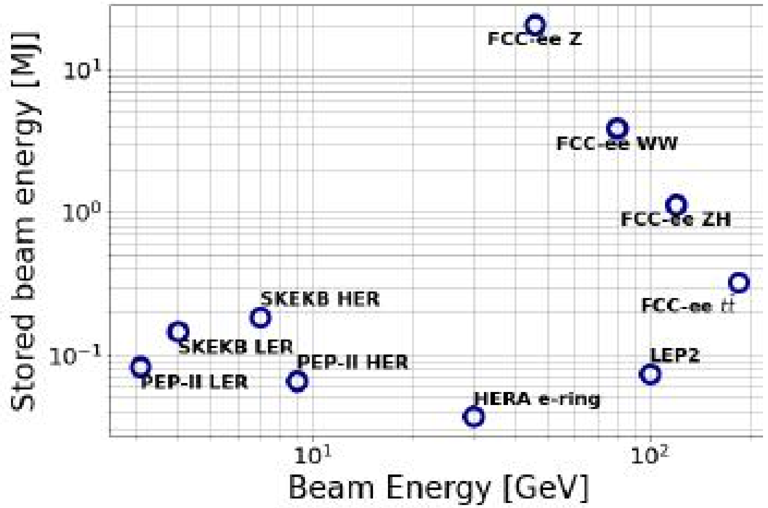
- Dynamic aperture requirement given by top-up injection
  - Target for on-momentum injection is more than 15σ
- Target for momentum acceptance based on beam lifetime in the presence of large energy spread due to beamstrahlung
  - For $t\bar{t}$, requirement is $\delta_{acceptance} > 2.8\%$, while for Z, target $\delta_{acceptance} > 1.3\%$
- DA optimization done using 75(Z) / 146 ($t\bar{t}$) non-interleaved sextupole pairs in the arcs
  - Constraints from chromaticity and chromatic optics in the IP
- Without errors, targets are met
  - Errors can significantly reduce DA, optimization in the presence of errors in progress

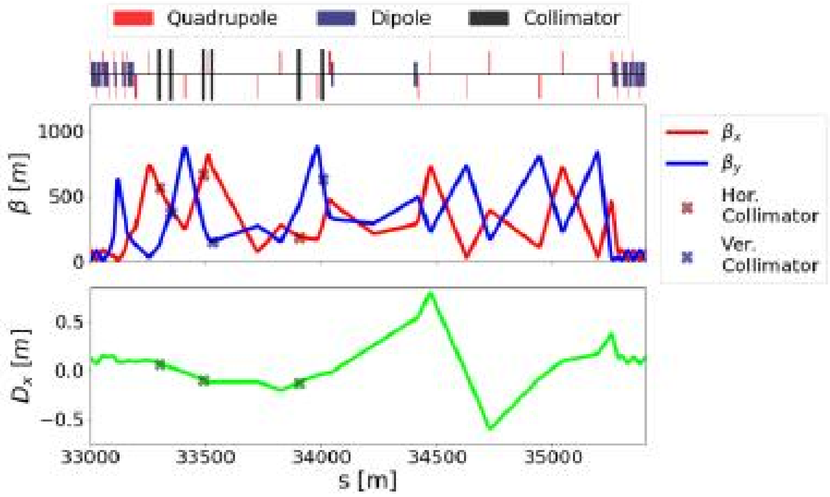


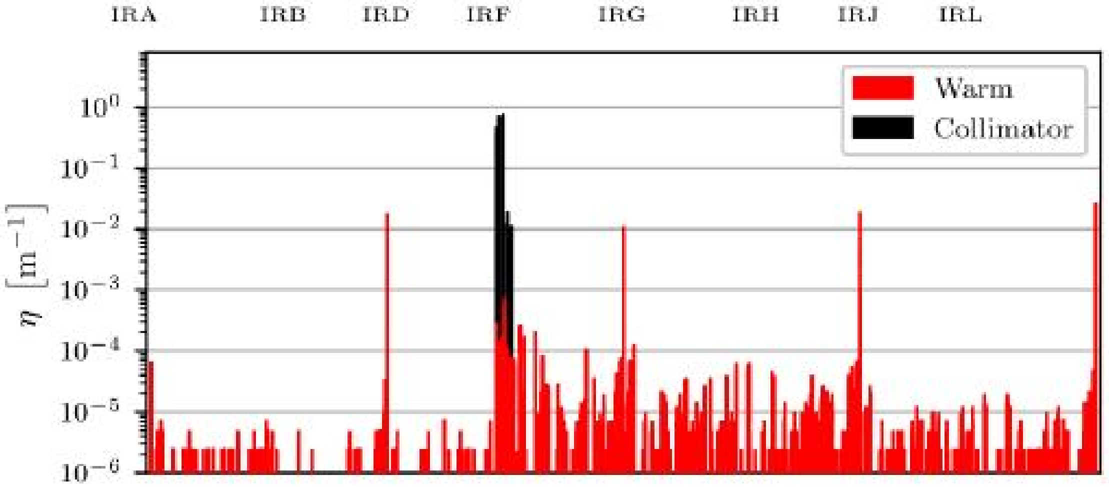
M. Haufer's talk

Collimation

- Stored beam energy in FCC-ee reaches 20.7 MJ, similar to heavy ion operation in LHC
  - A halo collimation system is being developed to protect equipment (e.g. SC final focus quadrupoles) from unavoidable loss
  - One straight section to host both betatron and momentum collimation







M. Haufer's talk

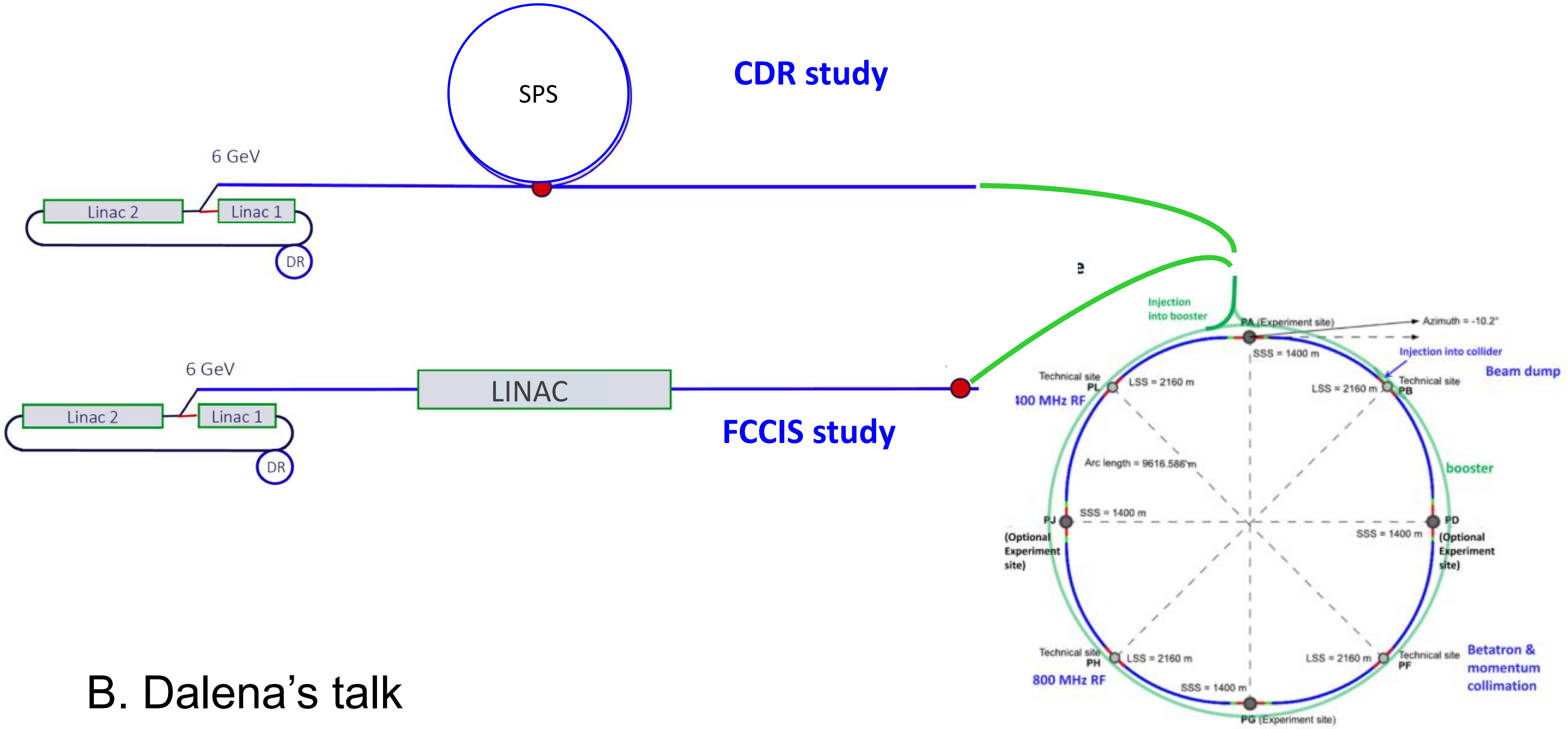
A. Abramov et al.

Injectors complex

Injection energy into the booster **20 GeV** (or lower ?)

Ramping: **80-100 GeV / s (< 1 s)**

Alternatives: SPS as Pre Booster Ring (**PRB**) and a **Linac**



B. Dalena's talk

90°/90° Optics for H and ttbar modes

Magnet	Parameter	Unit	Value
Dipole	Field at injection (20 GeV)	G	71
	Field at ttbar energy (182.5 GeV)	G	650
	Length	m	11.1
Quadrupole	Gradient at injection (20 GeV)	T/m	2.5
	Gradient at ttbar energy (182.5 GeV)	T/m	22.5
	Length	m	1.5
Sextupole	Gradient at injection (20 GeV)	T/m²	174
	Gradient at ttbar energy (182.5 GeV)	T/m²	1582
	Length	m	0.5

- FODO cells of ~52 m
- Made of 4 dipole, 2 quadrupoles and 2 sextupoles

Distance between dipoles: 0.4 m
Distance between quadrupole and sextupole: 0.165 m
Distance between dipole and sextupole: 0. 504 m
Distance between quadrupole and dipole: 0.869 m
(it includes space for BPM and dipole correctors)

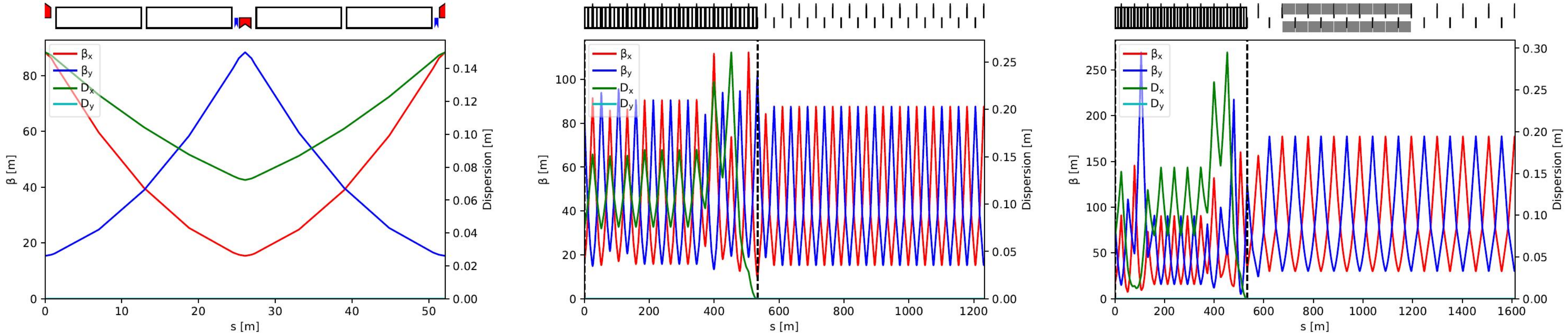
dipoles = 2×2944

quadrupoles = 2944

sextupoles = 2632/4

B. Dalena's talk

⇒ Very challenging **low** dipole field at injection (preliminary magnet design by **J. Bauche** @ FCC week 2022 https://indico.cern.ch/event/1064327/contributions/4888487/)



60°/60° Optics for Z and W modes

Magnet	Parameter	Unit	Value
Dipole	Field at injection (20 GeV)	G	71
	Field at W energy (80 GeV)	G	284
	Length	m	11.1
Quadrupole	Gradient at injection (20 GeV)	T/m	1.74
	Gradient at W energy (80 GeV)	T/m	6.9
	Length	m	1.5
Sextupole	Gradient at injection (20 GeV)	T/m²	75
	Gradient at W energy (80 GeV)	T/m²	300
	Length	m	0.5

$\Rightarrow$ Very challenging **low** dipole field at injection

- FODO cells of ~52 m
- Made of 4 dipole, 2 quadrupoles and 2 sextupoles

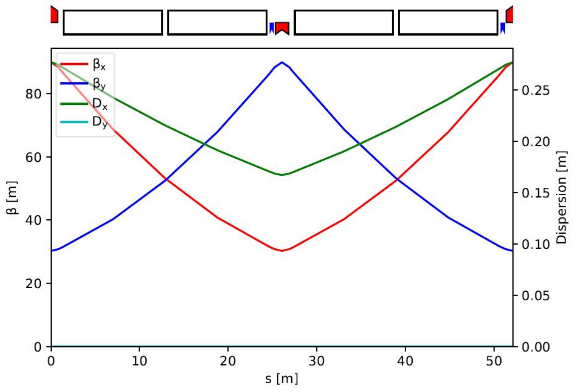
Distance between dipoles: 0.4 m
Distance between quadrupole and sextupole: 0.165 m
Distance between dipole and sextupole: 0. 504 m
Distance between quadrupole and dipole: 0.869 m
(it includes space for BPM and dipole correctors)

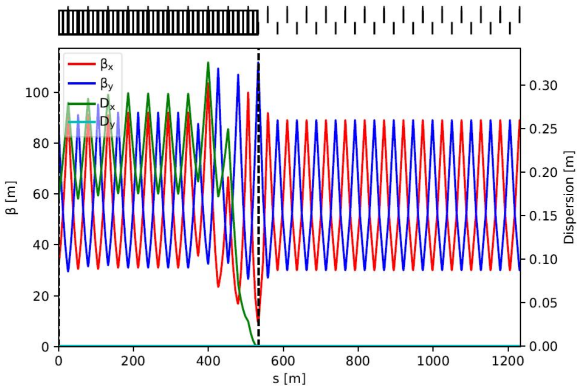
dipoles = 2×2944

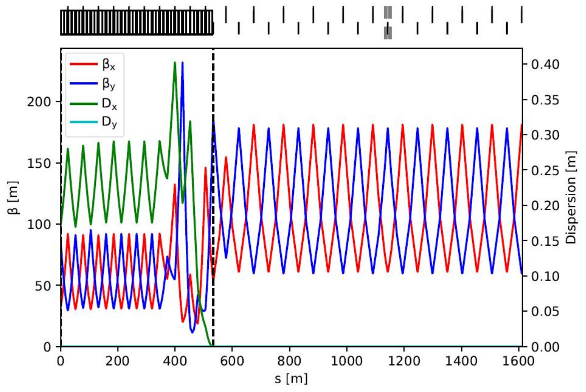
quadrupoles = 2944

sextupoles = 2632/6

B. Dalena’s talk







DA at injection (20 GeV) with multipole errors

Static dipole field errors of the CT dipole design at 56Gs considered + 10% random part

Dynamic field effect not taken into account in this simulations: dipole and multipole reproducibility expected to be $\leq$ **5×10^{-4}**

MadX Thin-Lens Tracking (60 seeds)

DA: Stable initial amplitude @ 4500 turns (~15% *tx* 20 GeV)

Courtesy of F. Zimmermann and Jie Gao

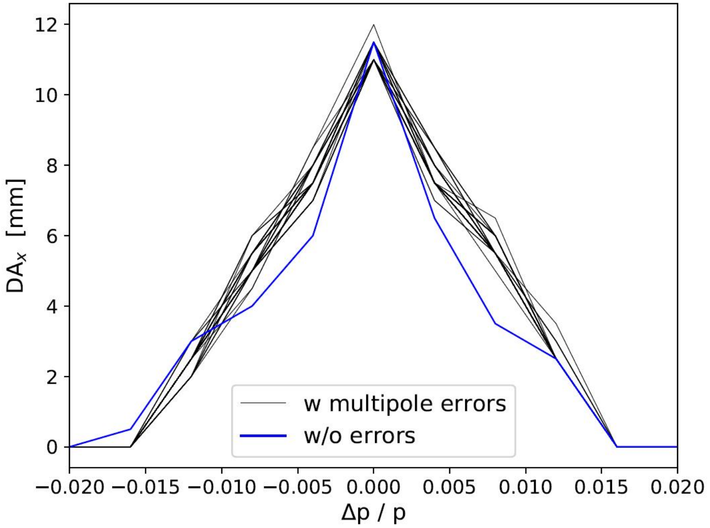
	CT dipole		Iron-core dipole	
GFR=R26	28Gs	56Gs	28Gs	56Gs
B1/B0	-5.20E-04	-1.04E-04	-1.56E-03	-2.60E-04
B2/B0	4.73E-04	5.41E-04	-2.03E-03	-2.03E-04
B3/B0	-7.03E-06	1.05E-04	3.52E-04	1.76E-04
B4/B0	-9.14E-04	-3.66E-04	4.57E-04	-1.83E-04
B5/B0	3.56E-05	-2.38E-05	-2.38E-05	-3.56E-05
B6/B0	6.18E-04	2.16E-04	-3.09E-04	9.27E-05

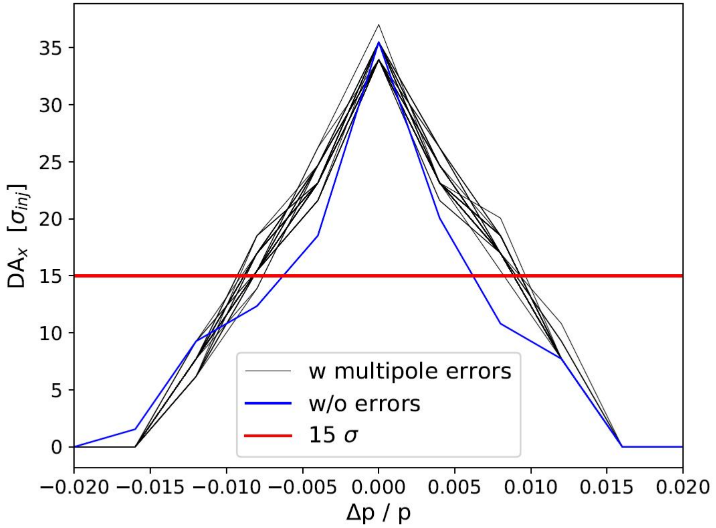
relative values @ R = 26 mm

91km 60°/60° optics

$\beta_x = 83.2$ m $\beta_y = 32.2$ m $D_x = 0$ m

Geometric emittance injected 1.27 nm





B. Dalena's talk

preliminary

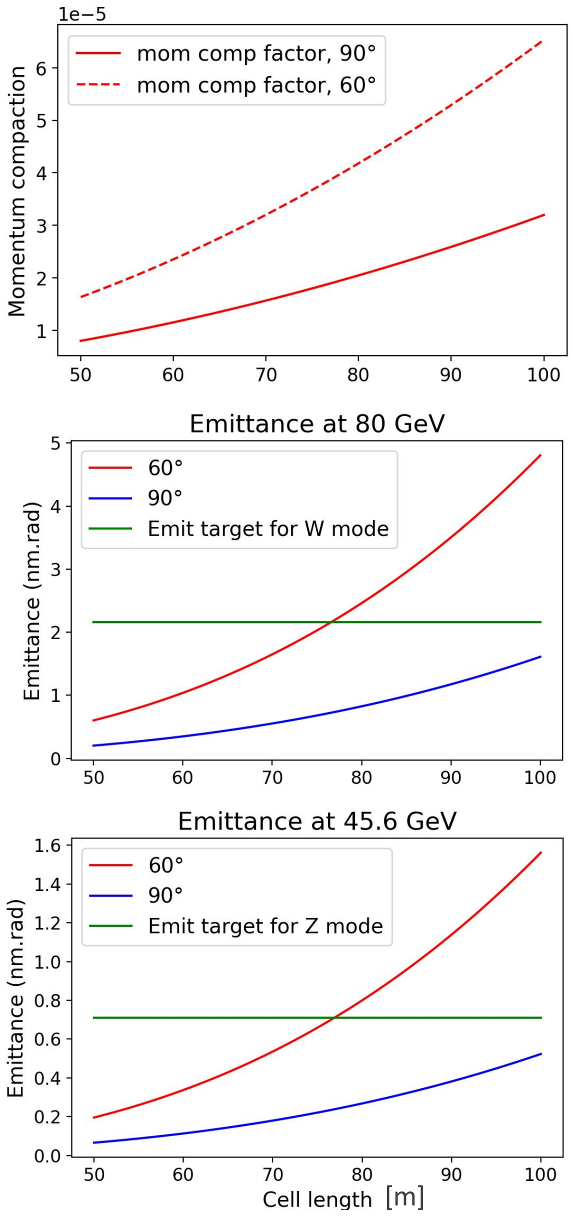
DA of 91km **90°/90° optics** is **~ 5mm** (due to longitudinal motion)

Equilibrium emittances

- Booster rms emittance at extraction ≤ collider

Beam Energy [GeV]	Eq. Emittance [nm rad] 60°/60°	Eq. Emittance [nm rad] 90°/90°	Eq. Emittance Collider [nm rad]	new Eq. emittance Collider new [nm rad]
45.6 (Z)	0.235	0.078	0.24	**0.71**
80 (W)	0.729	0.242	0.84	**2.16**
120 (H)	4.229	0.545	0.63	**0.64**
175 (tt)	3.540	1.172	1.48	**1.49**

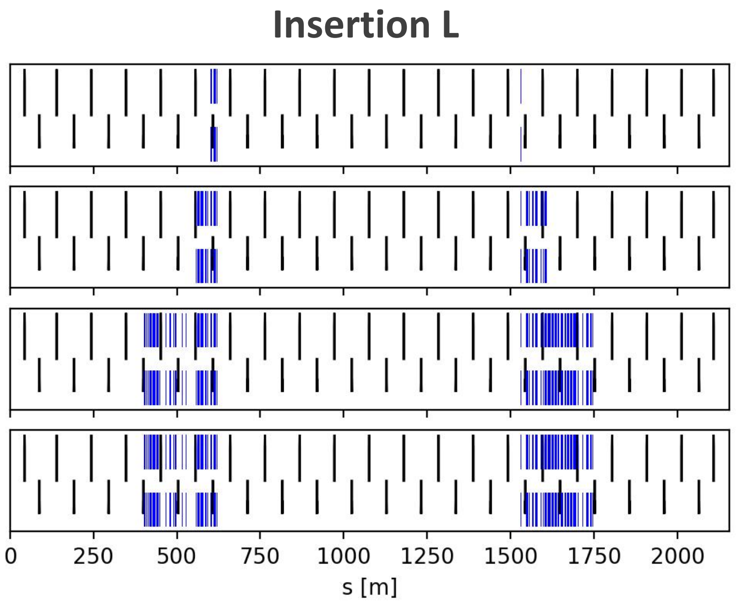
⇒ 90°/90° required for H and ttbar final emittances
⇒ 60°/60° retained for Z and W operation (mitigation of MI and IBS)
⇒ **90°/90° 100 m cell** could gain a bit in momentum compaction at Z & W



B. Dalena's talk

RF insertions

- Currently, the cavities are inserted in the insertions H and L.
- The cell FODO length in the RF insertion is 104 m.
- **400 MHz** cryomodule length: 11.4 m
- **800 MHz** cryomodule length: 7.5 m

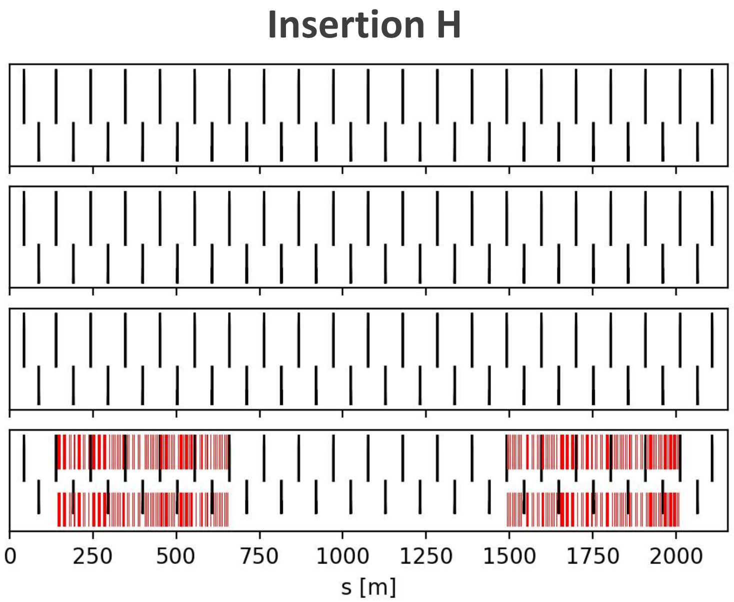


Z mode

W mode

H mode

tt mode



- Z mode: 2 CM left, 1 CM right of IPL
- W mode: 7 CM left, 6 CM right of IPL
- H mode: 17 CM left, 17 CM right of IPL
- tt mode: 17 CM left, 17 CM right of IPL

- tt mode: 60 CM left, 60 CM right

➢ **Proposal** of the **RF group** to use **800 MHz only** for all mode of the Booster: https://indico.cern.ch/event/1064327/contributions/4888581/ (**F. Peauger**)

B. Dalena's talk

FCC-hh (pp) collider parameters

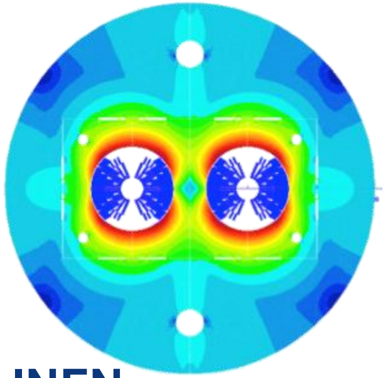
parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	16		8.33	8.33
circumference [km]	97.75		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2400		7.3	3.6
SR power / length [W/m/ap.]	28.4		0.33	0.17
long. emit. damping time [h]	0.54		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	8.4		0.7	0.36

M. Giovannozzi’s talk

16 T dipole design activities and options

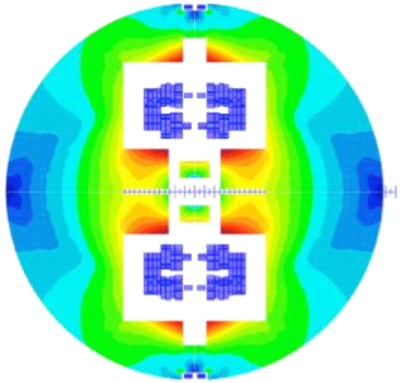
Swiss contribution

Cos-theta



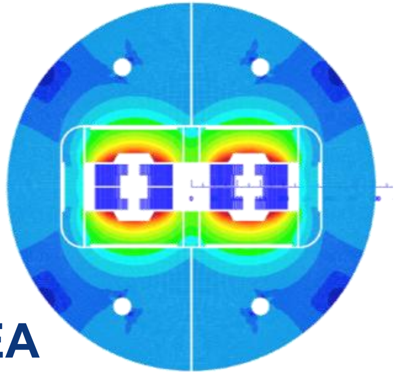
INFN

Common coils



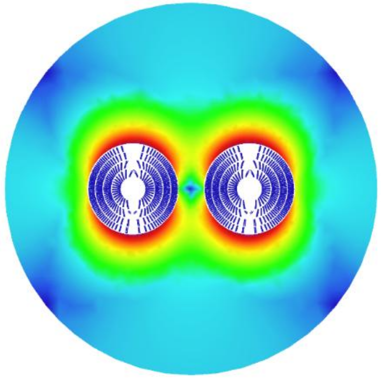
CIEMAT

Blocks



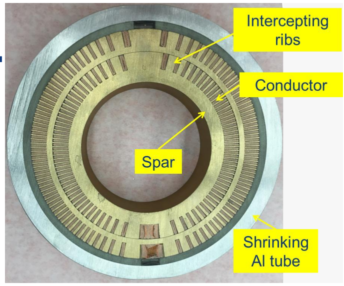
CEA

Canted Cos-theta

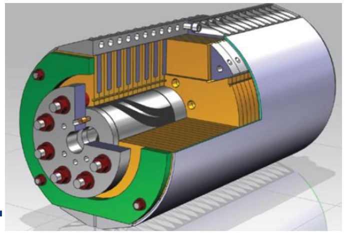


PSI

LBNL



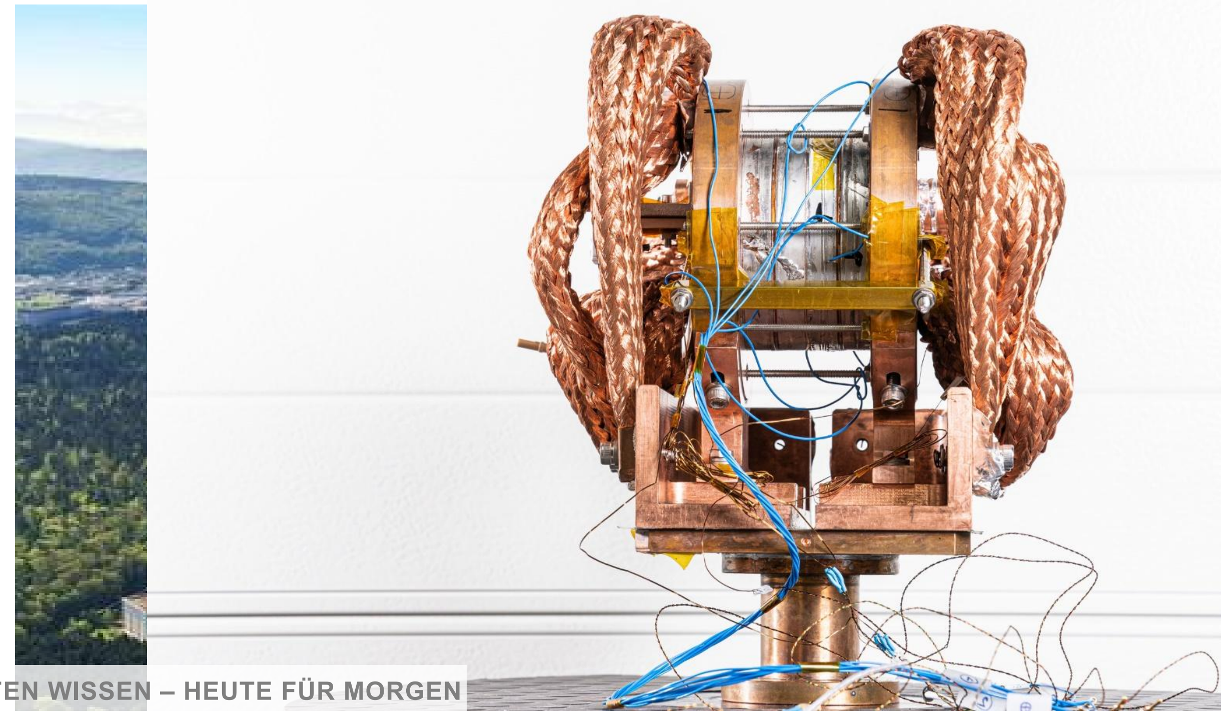
FNAL



Short model magnets (1.5 m lengths) will be built until ~2025

M. Giovannozzi's talk

PAUL SCHERRER INSTITUT



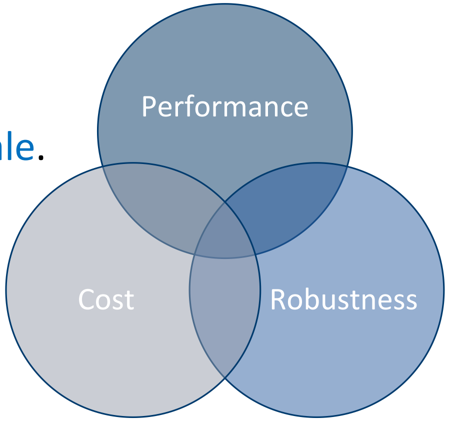
07.07.22 – ICHEP Conference, Bologna, Italy

High-Field Magnet Development for HEP in Europe – A Roadmap by the LDG HFM Expert Panel

LDG Expert Panel: B. Auchmann (PSI/CERN), A. Ballarino (CERN), B. Baudouy (CEA Saclay), L. Bottura (CERN, *Technical Secretary*), P. Fazilleau (CEA Saclay), L. Garcia-Tabarés (CIEMAT, *Co-Chair*), M. Noe (KIT), S. Prestemon (LBNL), E. Rochepault (CEA Saclay), L. Rossi (INFN Milano), B. Shepherd (STFC), C. Senatore (Uni Geneva), P. Védrine (CEA Saclay, *Chair*)
HFM Project at CERN: A. Siemko (CERN)
PSI MagDev Team: D. M. Araujo, A. Brem, M. Daly, M. Duda, C. Hug, J. Kosse, T. Michlmayr, H. G. Rodrigues, S. Sanfilippo

Work at PSI supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

HFM R&D Goals



1. Demonstrate **Nb_3Sn magnet technology** for large scale deployment, pushing it to its limits in terms of maximum field and production scale.
   a. The effort to quantify and demonstrate Nb_3Sn ultimate field comprises the development of conductor and magnet technology towards the ultimate Nb_3Sn performance.
   b. Develop Nb_3Sn magnet technology for collider-scale production, through robust design, industrial manufacturing and cost reduction.
2. Demonstrate the **suitability of HTS for accelerator magnets,** providing a proof-of-principle of HTS magnet technology beyond the reach of Nb_3Sn.

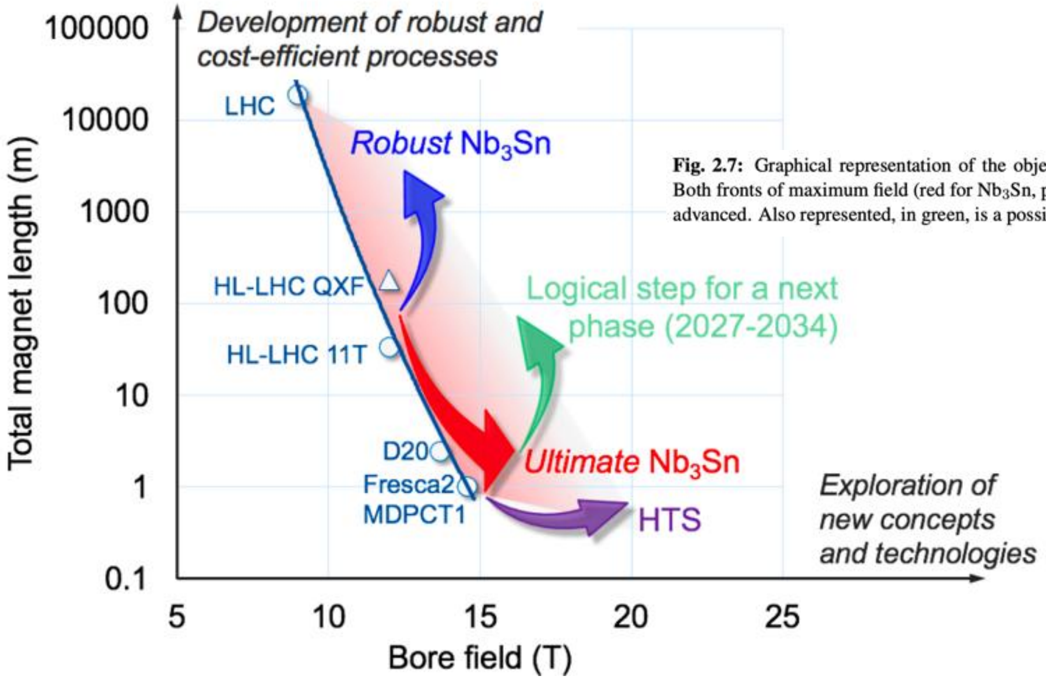


Fig. 2.7: Graphical representation of the objectives of the HFM R&D programme from 2021–2027. Both fronts of maximum field (red for Nb_3Sn, purple for HTS) and large-scale production (blue) will be advanced. Also represented, in green, is a possible evolution for the longer term, 2027–2034.

R&D Focus Areas and Cross-Cutting Activities

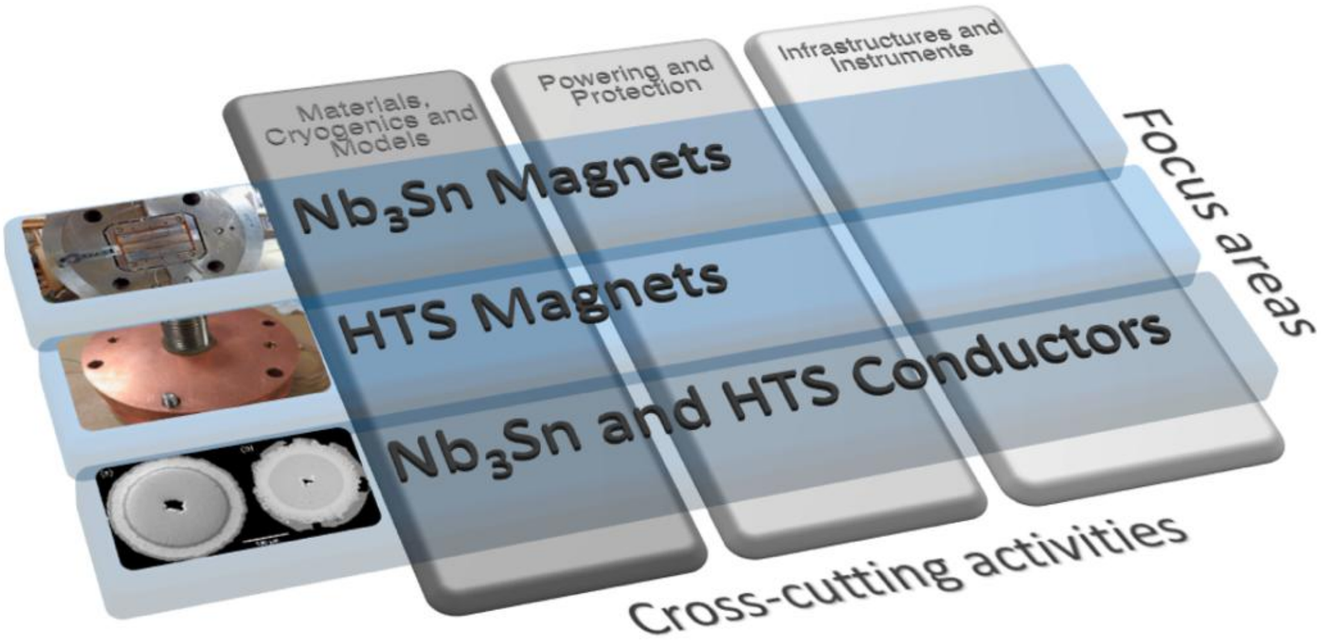


Fig. 2.9: Schematic representation of the structure of the proposed programme, consisting of three focus areas pursued with the support of cross-cutting activities.

- "The R&D programme must be holistic in nature: a compatible selection of electromagnetic, mechanical and thermal design approaches, conductors, materials, and manufacturing processes and methods needs to be integrated seamlessly with instrumentation and protection into a specific magnet solution responding to the required specification."
- Conversely, work across R&D areas must be closely coordinated.

HFM R&D Timeline –
HTS Conductor and Magnet R&D

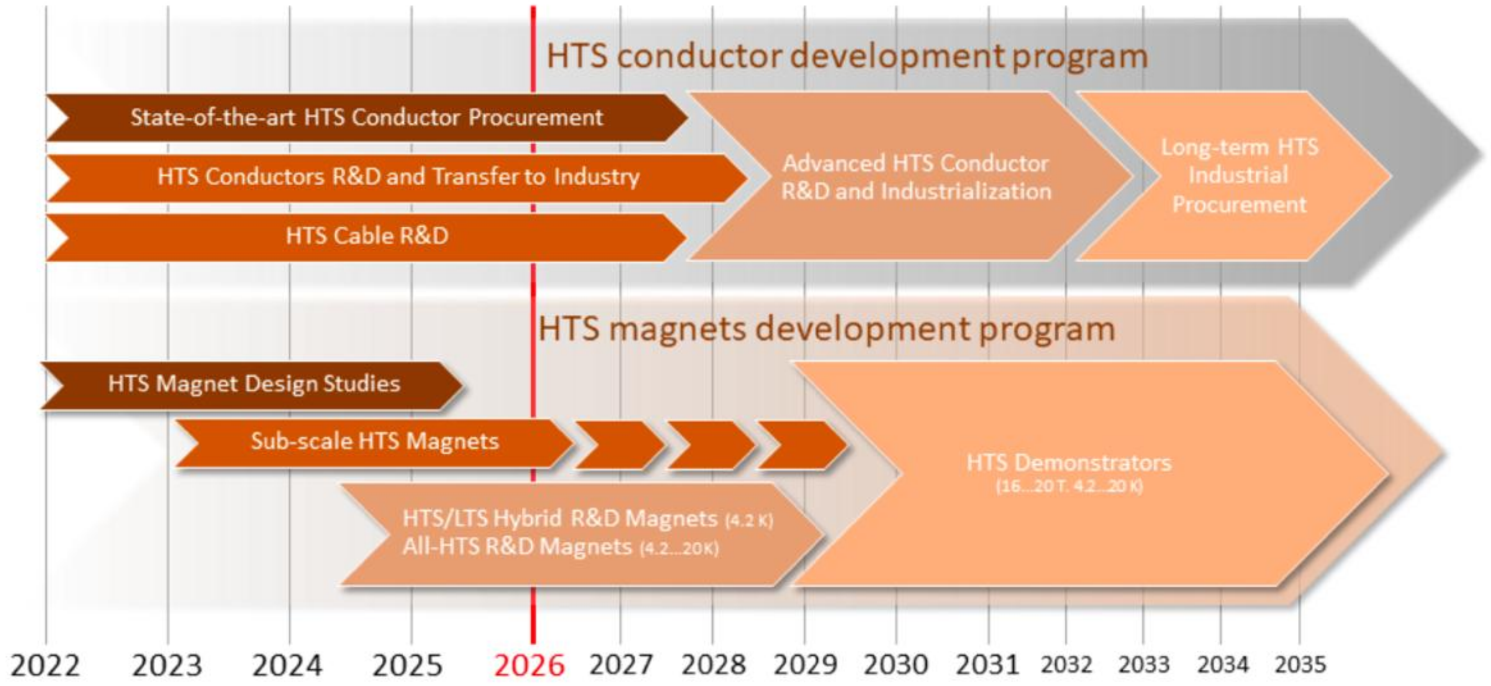
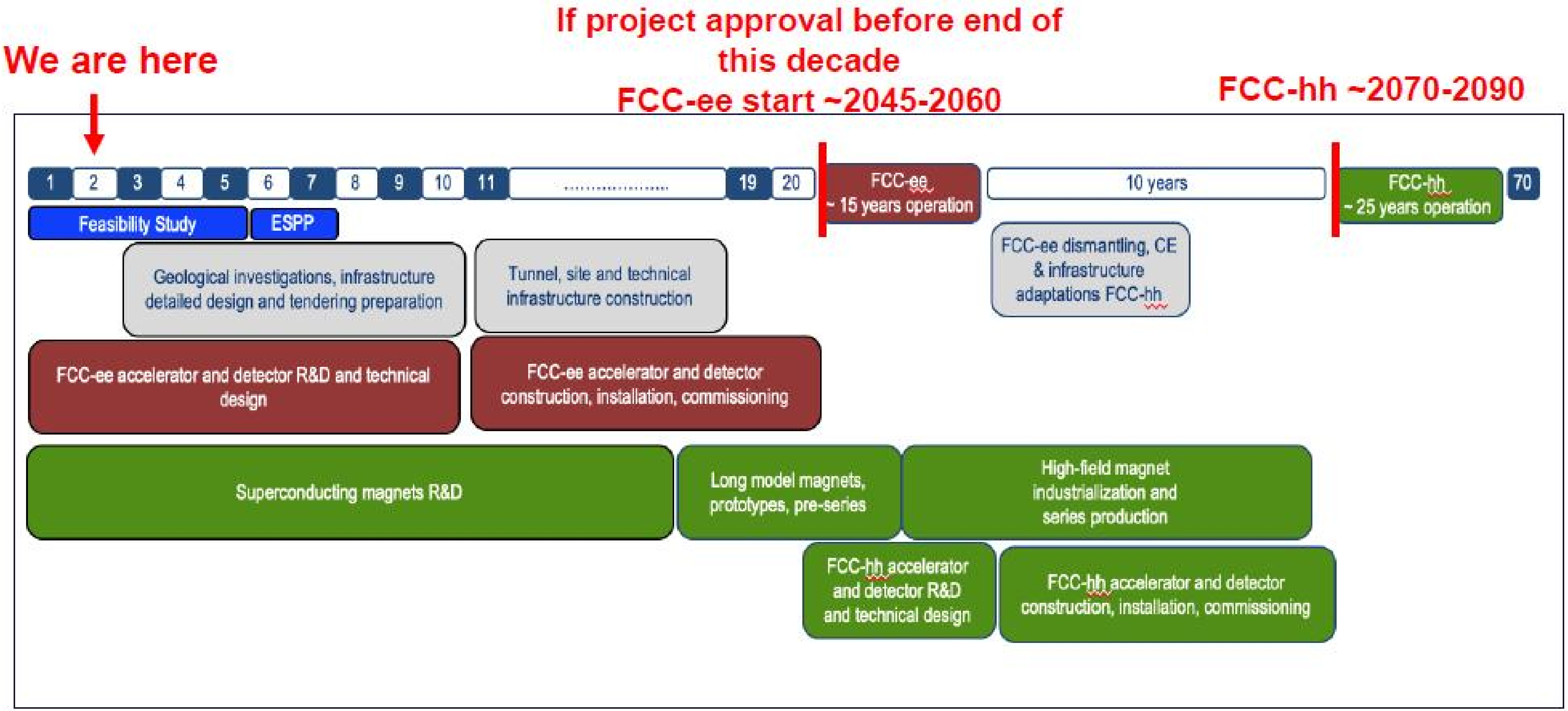


Fig. 2.13: Overview of proposed roadmap for high-field magnet development and associated technologies.

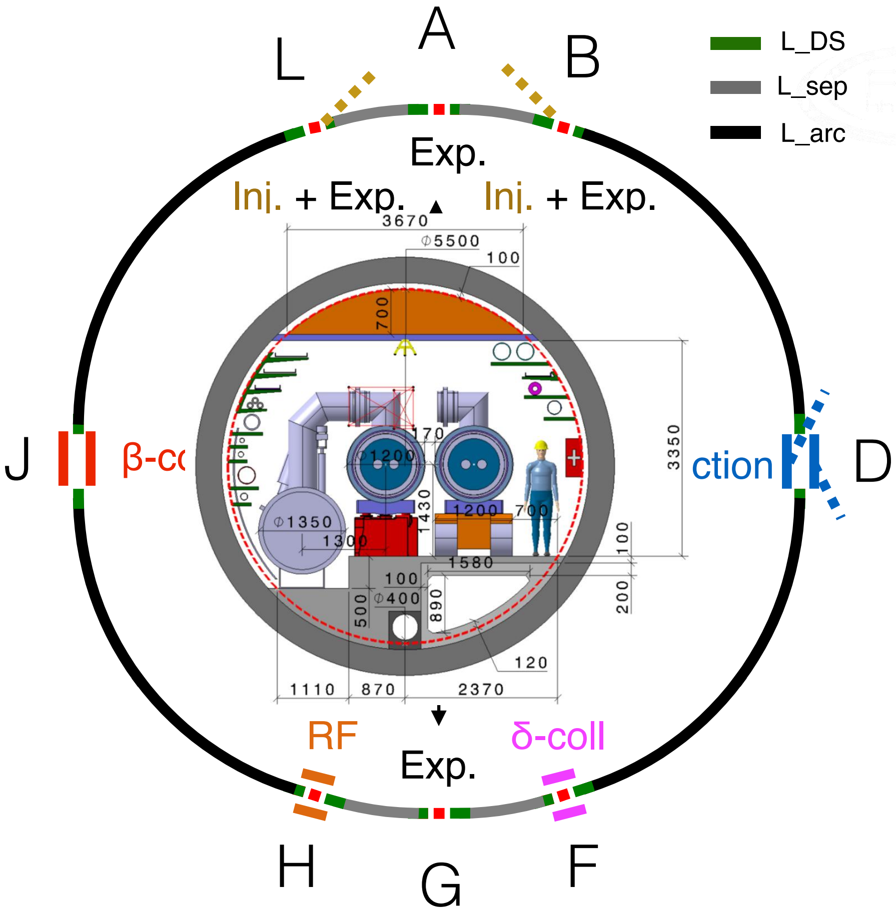
Tentative Technical Timeline



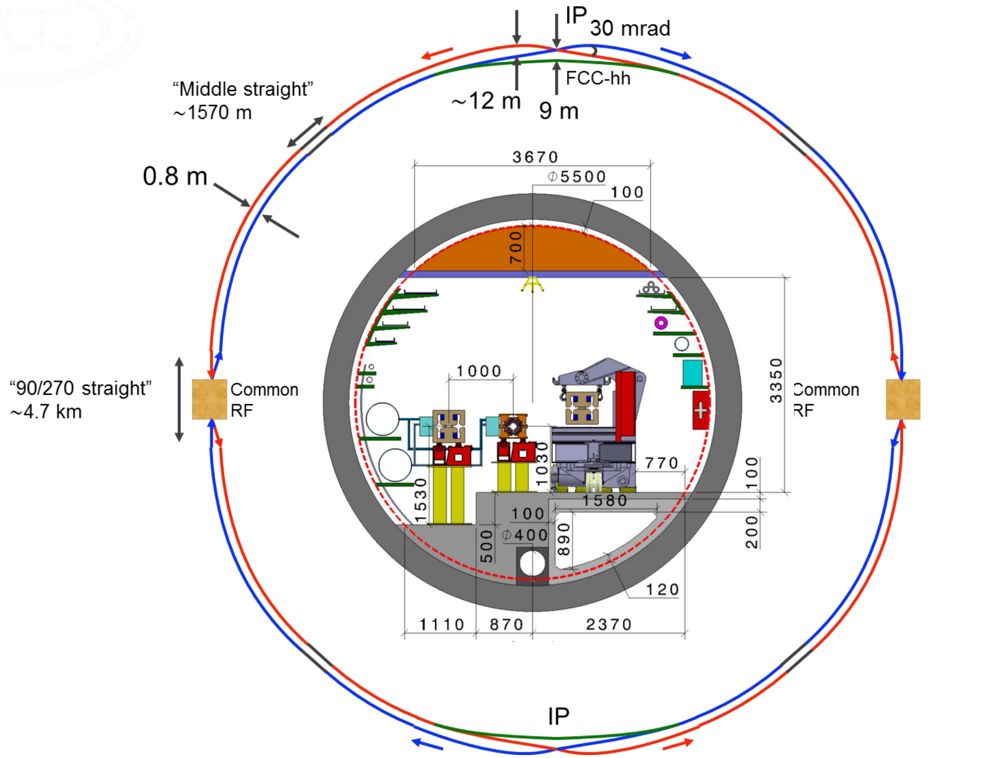
M. Benedikt, FCC Feasibility Study overview

FCC consistent machine layouts

FCC-hh



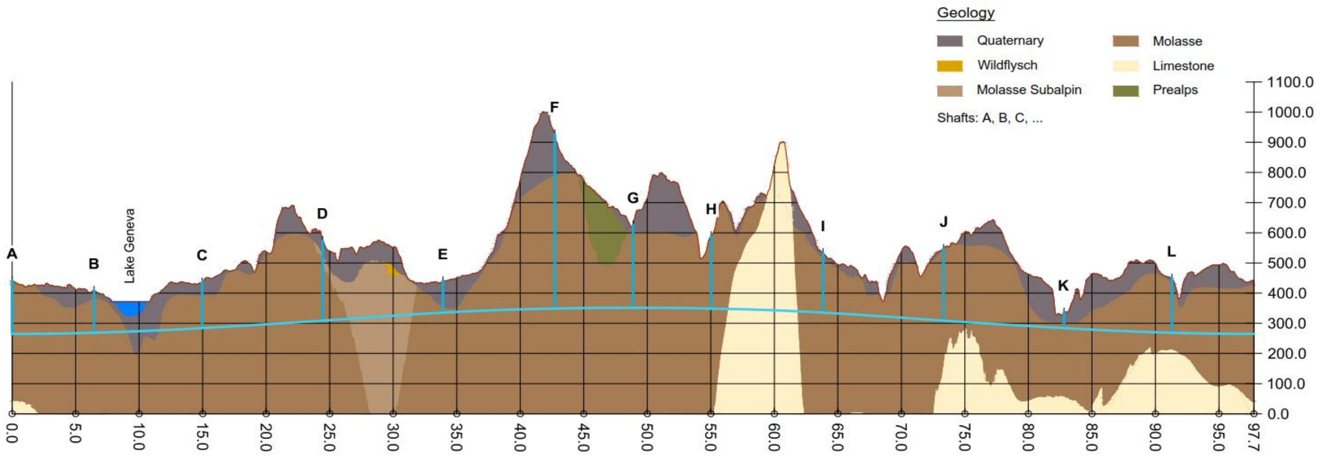
FCC-ee 1, FCC-ee 2, FCC-ee booster (FCC-hh footprint)

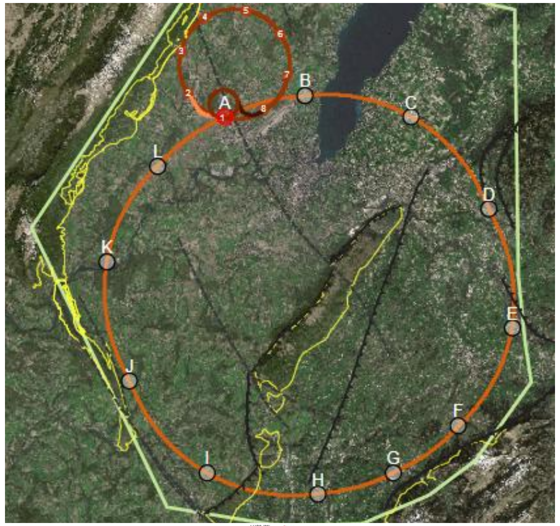


Optics solutions for full ring for both machines available

M. Giovannozzi's talk

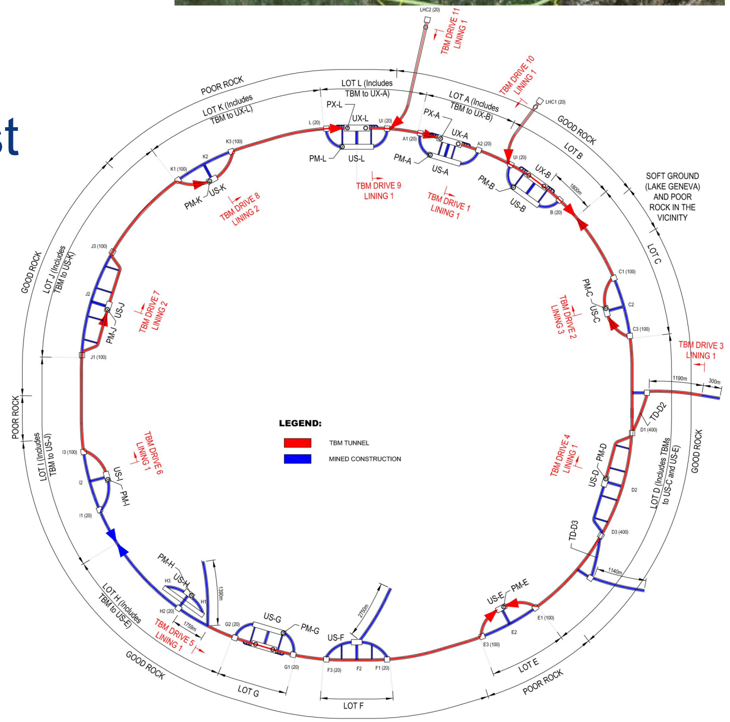
FCC implementation - footprint baseline



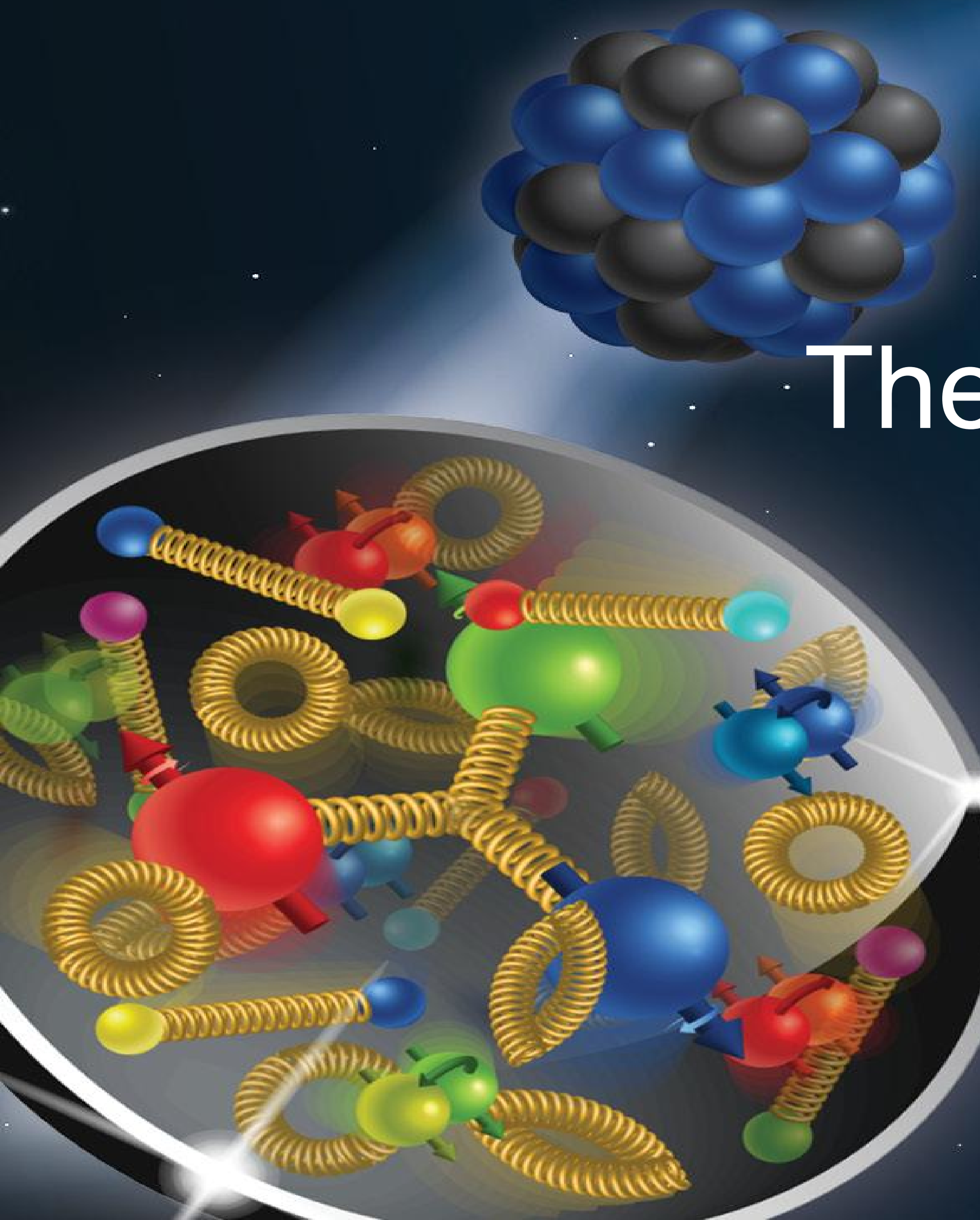


Current baseline position based on:

- lowest risk for construction, fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)
- **90 – 100 km circumference**
- **12 surface sites with few ha area each**



M. Giovannozzi's talk



The Electron-Ion Collider: an overview

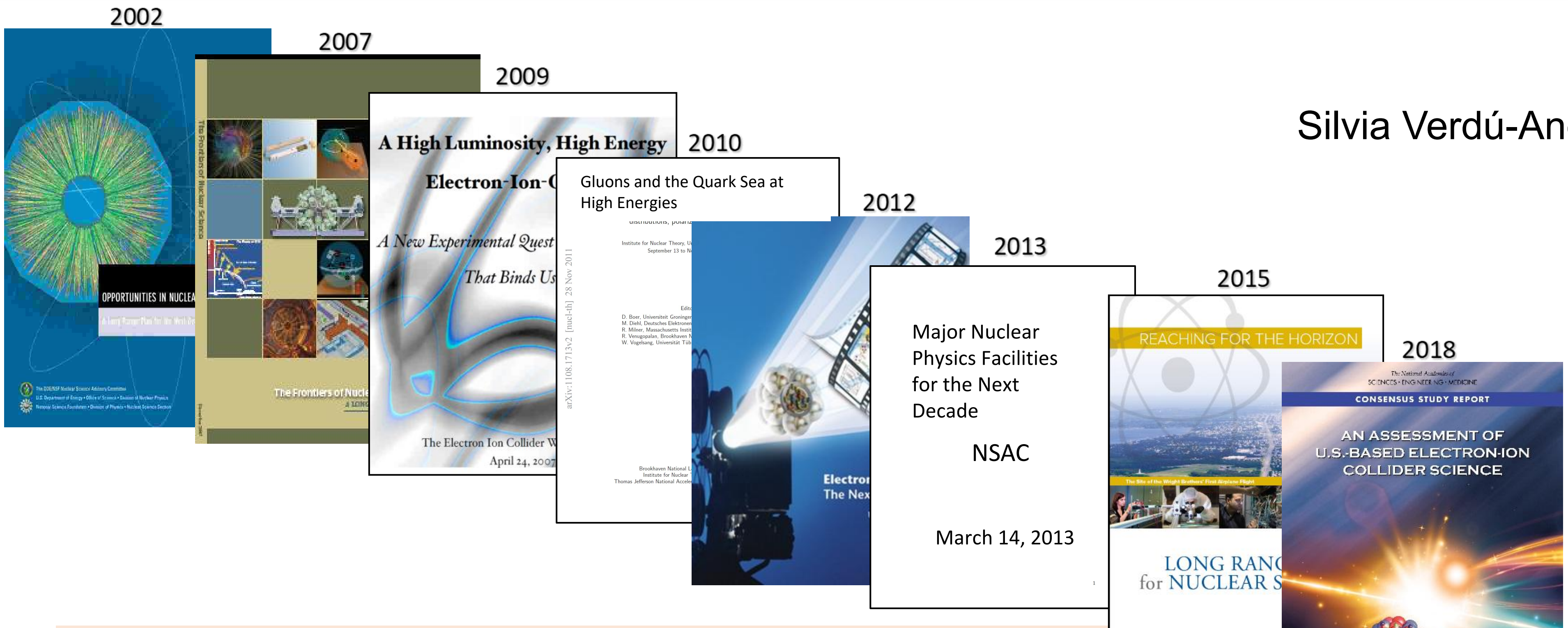
Silvia Verdú-Andrés
Brookhaven National Laboratory

Acknowledgements to the EIC team, and specially to
Elke Aschenauer, Maria Chamizo-Llatas, Ferdinand Willeke,
Binping Xiao

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY   Jefferson Lab   U.S. DEPARTMENT OF ENERGY | Office of Science

Building Up the EIC's Case



Silvia Verdú-Andrés' talk

The unanimous conclusion of
the U.S. National Academy of Science
Committee Report (2018) is that an EIC would be...

> *"... a unique facility in the world that would answer science questions that are compelling, fundamental, and timely, and help maintain U.S. scientific leadership in nuclear physics."*

The EIC's Design Goals

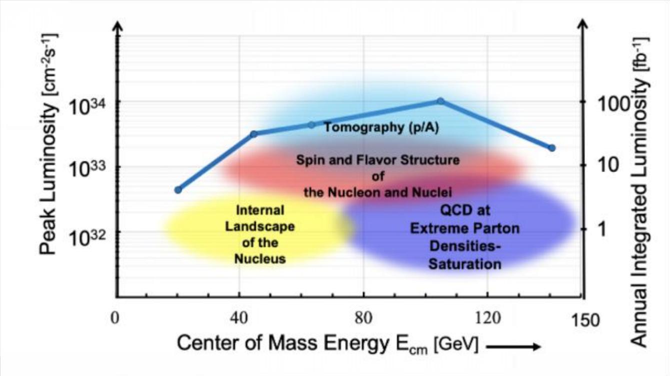
- **High luminosity**: $L = (0.1 - 1.0) \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}; 10 - 100\ \mathrm{fb}^{-1}/\mathrm{year}$
- Collisions of **highly polarized** ($\sim 70\%$) e and p / light ion **beams** with flexible bunch by bunch spin patterns
- Large **range of ion species**: Protons to Uranium
- Large **range of Center-of-Mass energies**: $E_{CM} = 20 - 140\ \mathrm{GeV}$
- Large **detector acceptance**
- Accommodate a **second Interaction Region** (IR)
- Good **background conditions** (hadron particle loss and synchrotron radiation in the IR)

x100 to 1000 higher than HERA

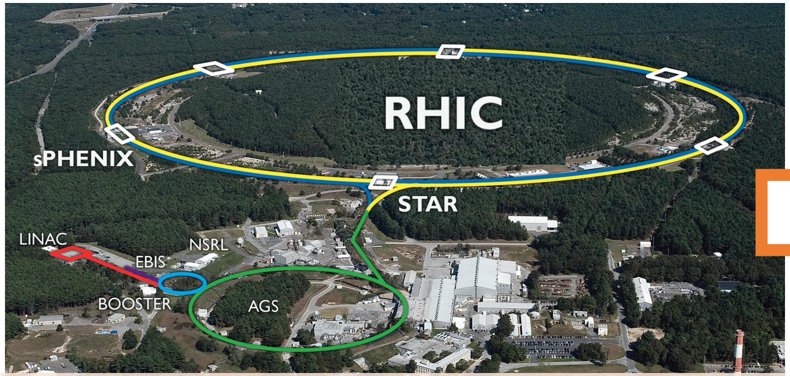
World's first

Silvia Verdú-Andrés' talk

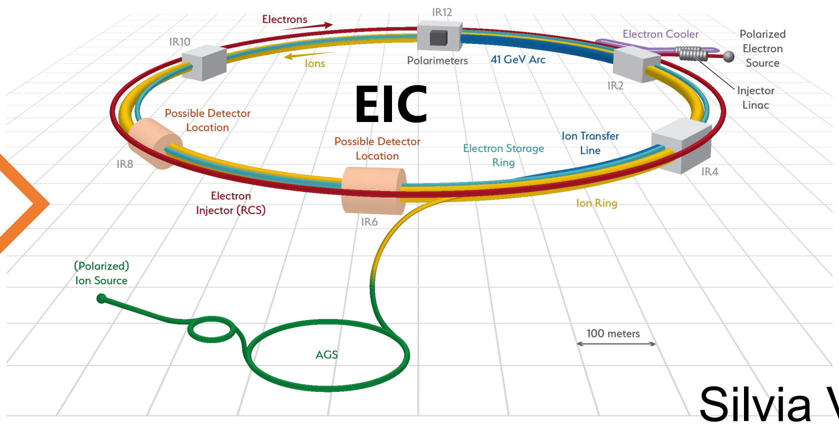
▻ *Goals meet or exceed NSAC Long Range Plan (2015) and EIC White Paper requirements endorsed by NAS (2018)*



RHIC will transform into the EIC



> Well maintained and operating at its peak <



Silvia Verdú-Andrés' talk

	Proton		Au ion	
	RHIC demonstrated	**EIC design**	**RHIC demonstrated**	**EIC design**
Energy [GeV/nucleon]	255	275	100	110
Particle per bunch [10^{10}]	22.5	20	0.22	0.1
RMS norm. emit., h/v [μm]	3.1/3.1	5.9/2.5	2.0/2.0	2.0/2.0
BB parameter, h/v [10^{-3}]	-18/-18	+15/+10	-4/-4	+11/+4
RMS long. emit. [10^{-3} eV· s]	55	110	0.27	0.2
RMS bunch length [cm]	55	6	7.7	10
RMS $\Delta p/p$ [10^{-4}]	1.7	6.8	7.7	10
Polarization [%]	55	70	–	–

Source: EIC CDR

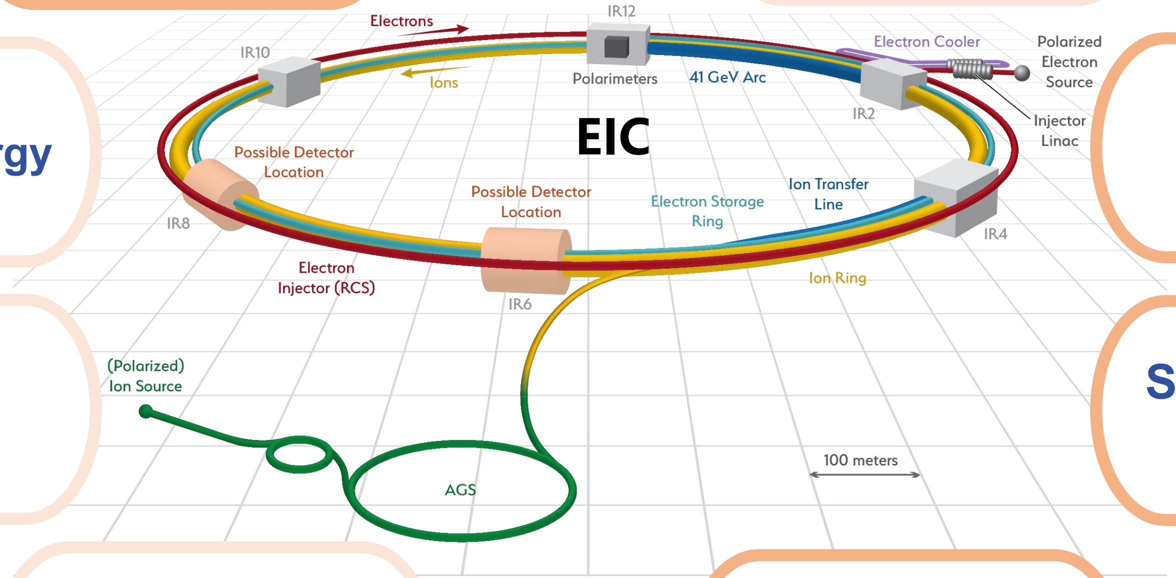
Key Updates of RHIC towards the EIC

Injection System Upgrade

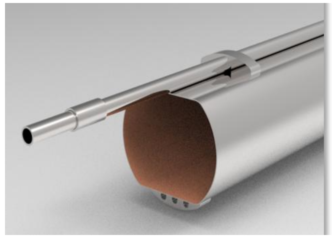
Beam Instrumentation Upgrade

Silvia Verdú-Andrés' talk

Path Length Variation, Energy Upgrade



Vacuum Chamber Update



Interaction Regions

Strong Hadron Cooling

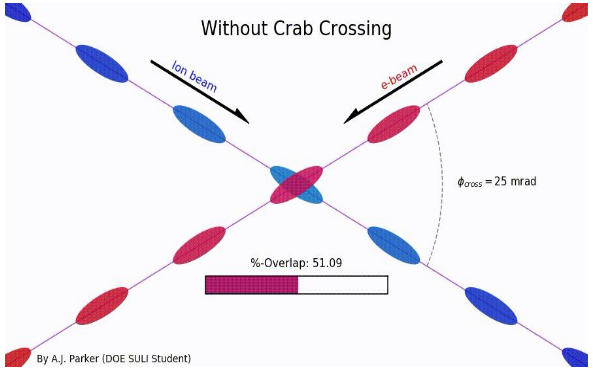
Additional Snakes

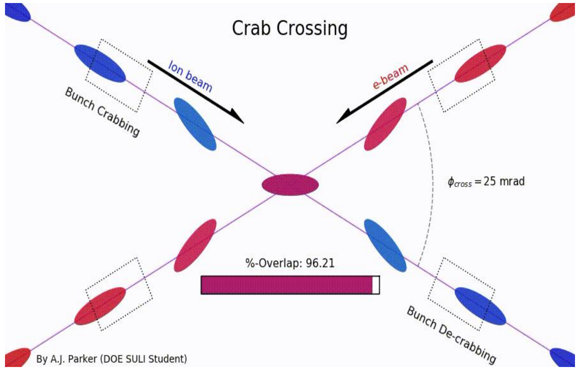
Hadron Ring RF Systems

Many of these areas are part of Accelerator R&D. Other Accelerator R&D areas not related to the HSR are: **polarized electron gun source, IR design and magnet prototyping, hadron polarimetry, vacuum systems, ESR injection kicker.**

Crab Crossing

- **Short bunch spacing (10 ns)** for high lumi requires **large crossing angle (25μrad) to reduce parasitic interactions and detector background**. The **ineffective overlap** with crossing angle **reduces lumi** to less than 20% of luminosity with head-on collisions:

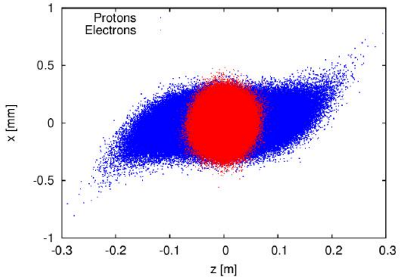




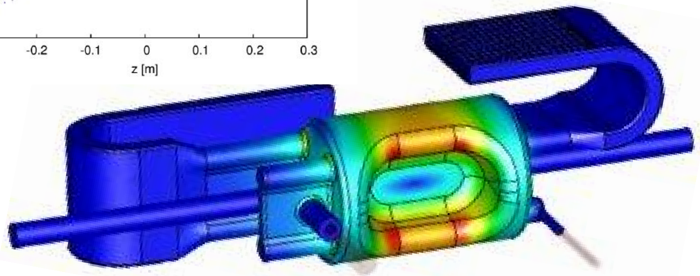
Silvia Verdú-Andrés' talk

⇒ Crab Cavities (CC) will reestablish head-on collisions to maximize lumi

- Electron crabs will operate at 394 MHz;
  two sets of hadron crabs to **linearize kick**:
  fundamental at 197 MHz; harmonic at 394 MHz.
- **High-gradient, compact** crab cavity needed:
  baseline uses Radio-Frequency (RF) Dipole.
- Very tight (~1 μrad) **tolerance to RF noise** and need to suppress fundamental mode driven **transverse instability require feedback**.



"Snake"-shaped proton bunch (blue) from 197 MHz CC kick



High Luminosity EIC Parameters

Table 3.3: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.1	6.2	6.9	17.2	6.9	17.2	4.8	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.69	0.227	1	2.5	1	2.5	0.69	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	5.2/0.47	845/71	3.3/0.3	391/26	3.2/0.29	391/26	2.7/0.25	196/18	1.9/0.45	196/34
RMS emittance, h/v [nm]	18/1.6	24/2.0	11.3/1.0	20/1.3	30/2.7	20/1.3	26/2.3	20/1.8	44/10	20/3.5
β^*, h/v [cm]]	80/7.1	59/5.7	80/7.2	45/5.6	63/5.7	96/12	61/5.5	78/7.1	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/11		95/8.5		138/12		125/11		198/27	
K_x	11.1		11.1		11.1		11.1		7.3	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
BB parameter, h/v [10^{-3}]	3/3	93/100	12/12	72/100	12/12	72/100	14/14	100/100	15/9	53/42
RMS long. emittance [10^{-3}, eV·s]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	0.7	7	0.7	7	0.7	7.5	0.7
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.007	neglig.	0.004	neglig.	0.026	neglig.	0.021	neglig.	0.05	neglig.
Piwinski angle [rad]	6.3	2.1	7.9	2.4	6.3	1.8	7.0	2.0	4.2	1.1
Long. IBS time [h]	2.0		2.9		2.5		3.1		3.8	
Transv. IBS time [h]	2.0		2		2.0/4.0		2.0/4.0		3.4/2.1	
Hourglass factor H	0.91		0.94		0.90		0.88		0.93	
Luminosity [$10^{33}cm^{-2}s^{-1}$]	1.54		10.00		4.48		3.68		0.44	

Source: EIC CDR

Silvia Verdú-Andrés' talk

The EIC's Project

PERFORMANCE AND SCOPE

- Full-energy, full-luminosity accelerator
- One interaction region with allowance for a second
- One detector

COST

- DOE Critical Decision 0 approved with a range of \$1.6B - \$2.6B

SCHEDULE

Silvia Verdú-Andrés' talk

- Completion in ~10-15 years

COLLABORATIVE STRATEGY

The EIC Project will be conducted "***as a full intellectual partnership between the BNL and the JLab teams (and other collaborators) with major participation by all*** ". (T. Hallman, NSAC 3/2/20)

EIC Project Timeline

2019	DOE Critical Decision 0: *Mission Need Approval* *EIC Site Selection:* Brookhaven National Lab
2020	BNL-TJNAF Partnering Agreement Approval
2021	DOE Critical Decision 1: *Preliminary Baseline Approval*
Mar. 2022	Decision on Project Detector: ECCE as reference
Jun 2023	Clarify In-kind Deliverables and Agreements
2024	DOE Critical Decision 2: *Performance Baseline*
2025	DOE Critical Decision 3: *Construction Start*
2032	DOE Critical Decision 4: *Early Completion*

Silvia Verdú-Andrés' talk

Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

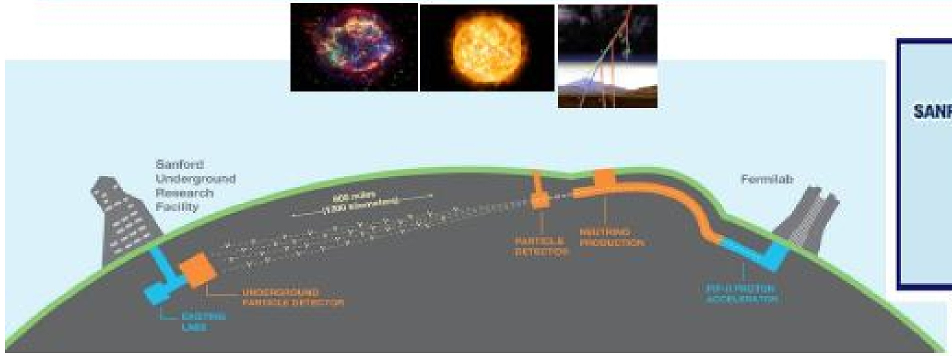
Considerations for Fermilab Multi-MW Proton Facility in the DUNE/LBNF era

S. Nagaitsev, J. Eldred, V. Shiltsev, A. Valishev, R. Zwaska

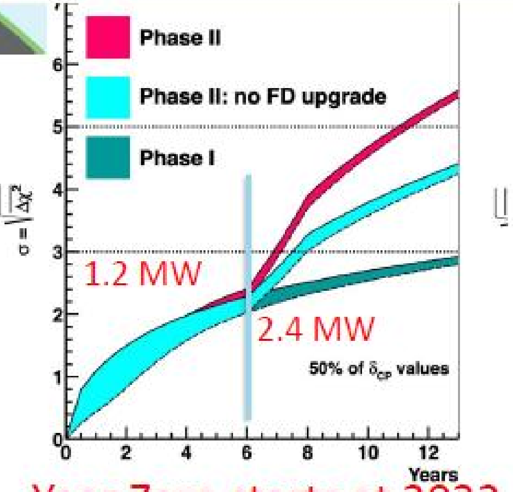
ICHEP 2022
July 7, 2022

S. Nagaitsev's talk

DUNE physics program



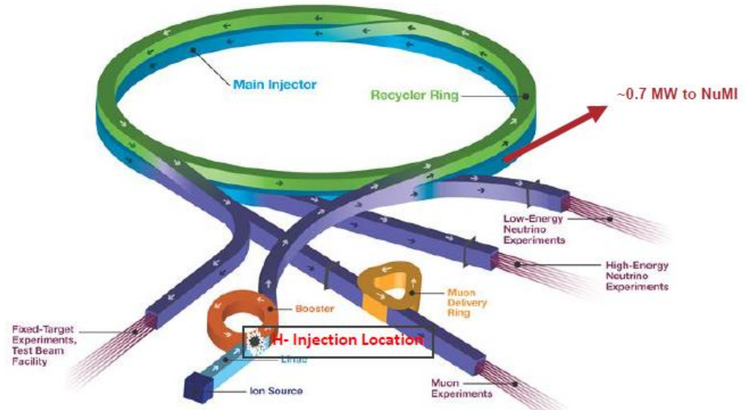
- Unambiguous, high precision measurements of Δm^2_{32}, δ_{CP}, $\sin^2\theta_{23}$, $\sin^2 2\theta_{13}$ in a single experiment
- Discovery sensitivity to CP violation, mass ordering, θ_{23} octant over a wide range of parameter values
- Sensitivity to MeV-scale neutrinos, such as from a galactic supernova burst
- Low backgrounds for sensitivity to BSM physics including baryon number violation



Year Zero starts at 2032 with 1.2 MW on target

Fermilab at present

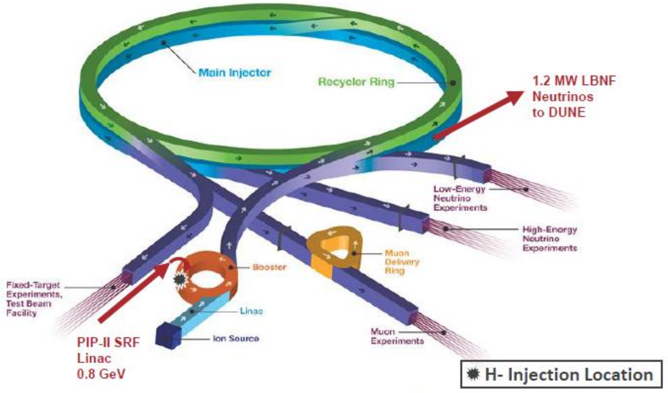
Fermilab Accelerator Complex



Record Main Injector power 893kW (120 GeV, 1.33 sec cycle)
Record Booster power 89 kW (8 GeV, 15 Hz)

Fermilab Upcoming Upgrades: PIP-II 1.2MW

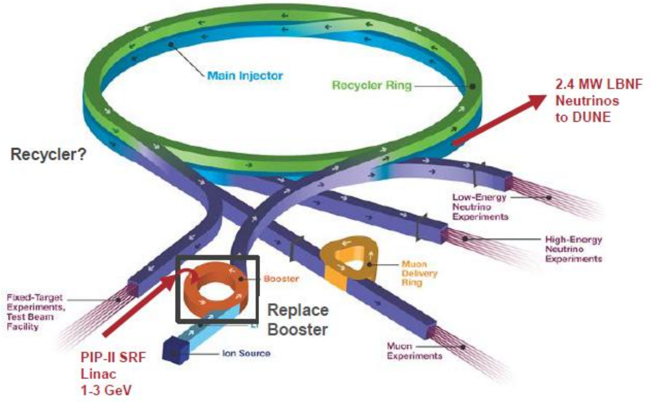
Fermilab Accelerator Complex



New SRF linac raises Booster injection energy, new LBNF beamline.

Fermilab Upcoming Upgrades Future 2.4MW

Fermilab Accelerator Complex



Booster prevents x2 PIP-II power, injection energy and transition-crossing limits

S. Nagaitsev’s talk

PIP-II Linac & Upgrades (1.2 MW power on target)

800 MeV H− linac
- Warm Front End
- SRF section

Linac-to-Booster transfer line
- 3-way beam split

Upgraded Booster
- 20 Hz, 800 MeV injection
- New injection area

Upgraded Recycler & Main Injector
- RF in both rings

Conventional facilities
- Site preparation
- Cryoplant Building
- Linac Complex
- Booster Connection

E. Pozdeyev, SpaceCharge19

Project started in 2016 (CD0)
First beam in Booster: 2028 (plan)
MI 1.2 MW beam on target: 2032 (projection)

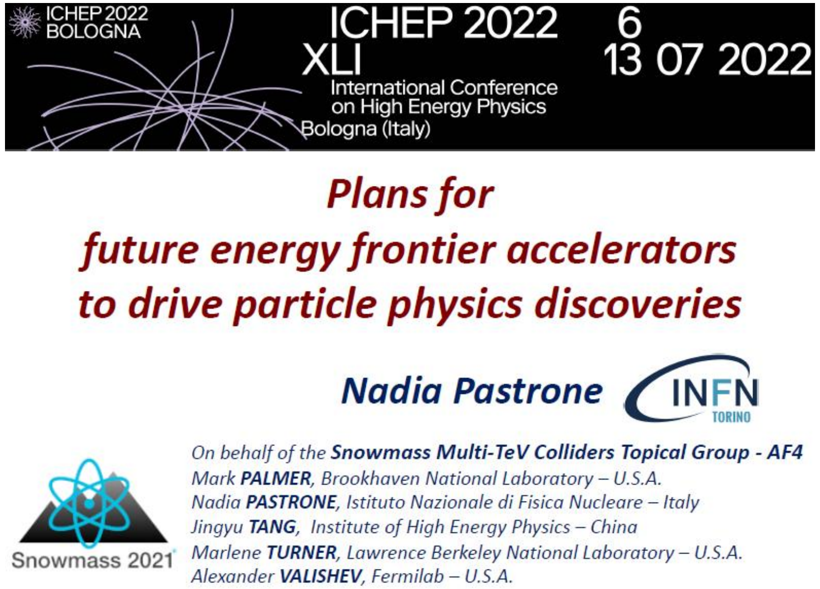
PIP-II Booster Power

	PIP	PIP-II
MI Beamline	NuMI	LBNF
RR/MI Intensity	$54 \cdot 10^{12}$ protons	$65 \cdot 10^{12}$ protons
RR/MI Rep. Time	1.333 s	1.2 s
MI Power	0.7 MW	1.2 MW
Booster Intensity	$4.5 \cdot 10^{12}$ protons	$6.5 \cdot 10^{12}$ protons
Booster Rep. Rate	15 Hz	20 Hz
Booster Ext. Power	85 kW	165 kW
Injection Energy	0.4 GeV	0.8 GeV
Efficiency	95%	98%

The primary purpose of the PIP-II is to inject into the Booster, and in turn power the high-energy proton complex including DUNE/LBNF program.

S. Nagaitsev's talk

Most important questions for Particle Physics



Nadia Patrone's talk

- Standard Model (SM) of particle physics is confirmed with high precision
- Fundamental questions are still open and unexplained

- A physics program must be envisaged to push the exploration of particle physics to the TeV energy scale and beyond to pursue:

➔ in-depth precise studies of the SM

➔ exploration of physics beyond the SM (BSM) to discover new particles and interactions

Colliders at the energy frontier are a unique tool for investigation

50 years at the forefront of scientific HEP discoveries!

Multi-TeV concepts parameters

Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$. e^-/e^+	$\mathcal{L}_{\text{int}}$ ab^{-1}
HE-LHC	pp	27 TeV		15
FCC-hh SPPC 125 TeV	pp	100 TeV		30
LHeC	ep	1.3 TeV		1
FCC-eh		3.5 TeV		2
CLIC	ee	1.5 TeV	±80/0	2.5
		3.0 TeV	±80/0	5
High energy muon-collider	$\mu\mu$	3 TeV		1
		10 TeV		10

Nadia Patrone's talk

U.S. possible options

- A US-sited linear e+e− (ILC/CCC) Collider
- Hosting a 10 TeV range muon collider
- Exploring other e+e− collider options to fully utilize the Fermilab site

Muon Collider @ FNAL option

10 TeV collider requires ~16 T dipoles in RCS scenarios With rapid-cycling 2-4 T magnets

Fermilab has formed a Future Colliders Group, which is actively exploring a site filler option

Site filler Accelerator

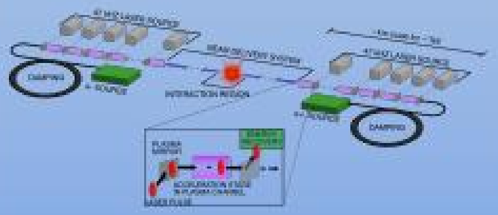
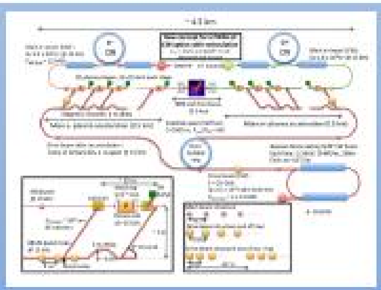
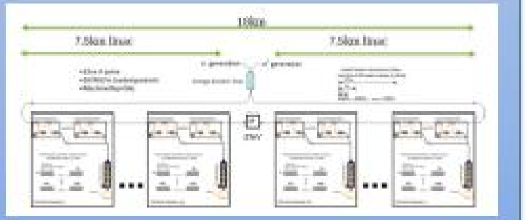
- ➤Proton Source
  - PIP-III→target
- ➤μ Cooling
- ➤Linac + RLA → 65 GeV
- ➤RCS 1 and 2 → 1000 GeV
  - Tevatron-size
- ➤RCS 3 → 5 TeV
  - Site filler accelerator

10 TeV collider
Collider Ring ~10 km

Fermilab

Multi-TeV e+e- Collider Based on Advanced Plasma and Structure Accelerators

- Acceleration goal: ~GV/m average gradients in wakefields ➔ **compact TeV colliders**
- **Three different collider design** based on the energy source: laser pulses (LPA) or electron beams (PWFA, SWFA) and the medium sustaining the wakefields: plasmas (LPA,PWFA) or dielectric based structures (SWFA)
- **All concepts will require extensive R&D efforts**

Laser Plasma Accelerator (LPA)	Beam-Driven Plasma Wakefield Accelerator (PWFA)	Beam-Driven Structure Wakefield Accelerator (SWFA)
		

ANA technology	PWFA	PWFA	PWFA	SWFA	SWFA	SWFA	LPA	LPA	LPA
Center-of-mass energy [TeV]	1	3	15	1	3	15	1	3	15
Beam energy [TeV]	0.5	1.5	7.5	0.5	1.5	7.5	0.5	1.5	7.5
Geo. Luminosity [10^{34} cm^{-2} s^{-1}]	1	10	50	1	10	50	1	10	50
Particles/bunch [10^{9}]	5.0	5.0	5.0	3.1	3.1	3.1	1.2	1.2	7.5
Single beam power [MW]	1.7	16.8	15.5	2.8	27.0	24.8	4.5	13.5	10.3
RMS bunch length [μm]	5	5	5	40	40	40	8.5	8.5	2.2
Repetition rate [kHz]	4.2	14	2.6	11	36	6.6	47	47	1.1
Facility site power (to main) [MW]	22.4	224	206	16.9	166	152	113	338	344

Nadia Patrone's talk

FCChh/SppC vs Muon Collider

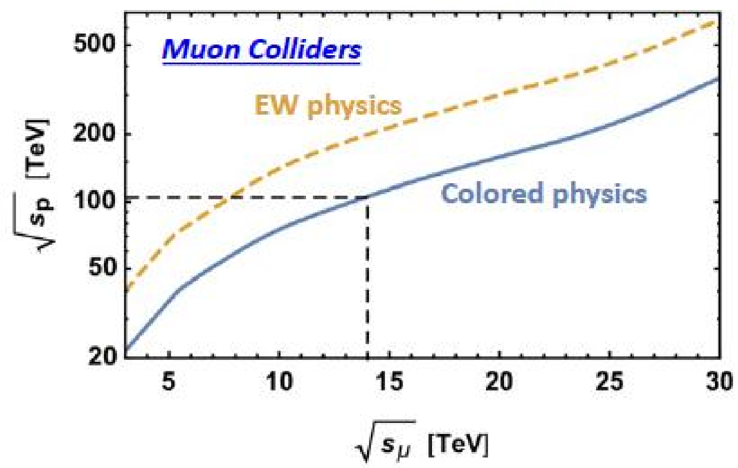
A 100 TeV proton-proton collider (e.g. FCC-hh, SppC) provides an effective energy reach similar to that of a 10-TeV scale muon collider with sufficient integrated luminosity

The 100 TeV hadron collider will have an advantage when it comes to searching for colored states, while the muon collider naturally is stronger for EW states

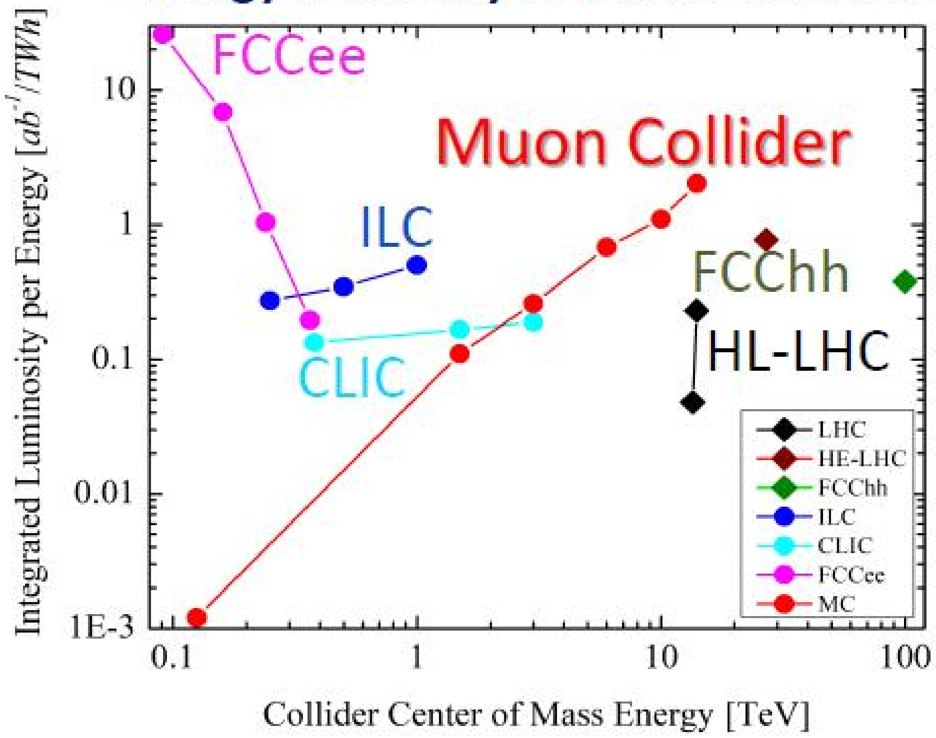
One of the key measurements from the multi-TeV colliders is the measurement of the Higgs self-coupling measurement to a precision of a few percent, and the possibility of scanning (establishing?) the Higgs potential

Strong synergy on High Field Magnets R&D and much more!

Energy at which $\sigma_{pp} = \sigma_{\mu\mu}$



Energy Efficiency of Future Colliders



Nadia Patrone's talk

Introduction

Previous studies in US (now very strong interest again), experimental programme in UK and alternatives studies by INFN

International MUON Collider Collaboration

New strong interest:

- Focus on high energy
    - 10+ TeV
    - potential initial energy stage
- Technology and design advanced

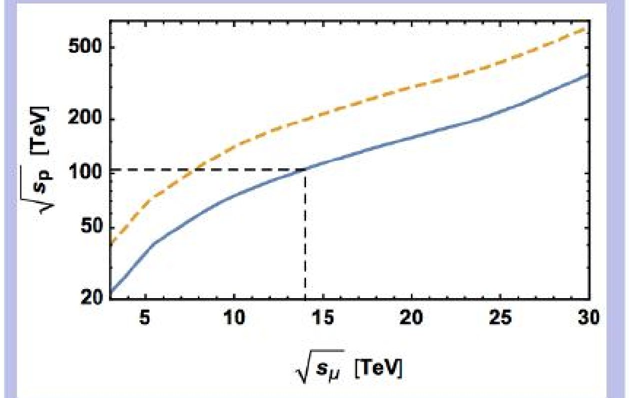
New collaboration started

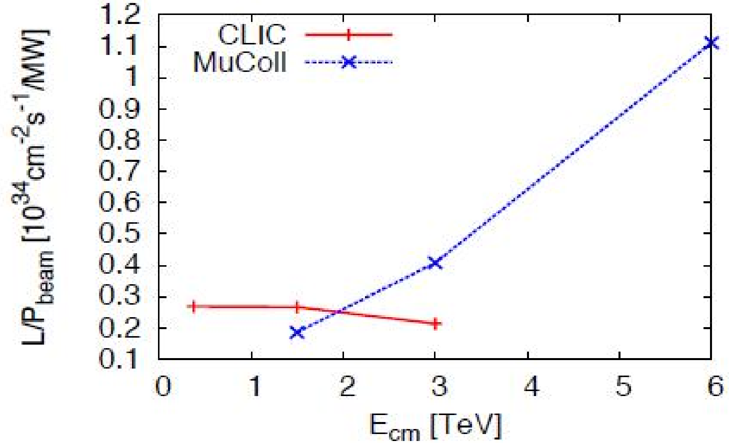
Initial integrated luminosity targets

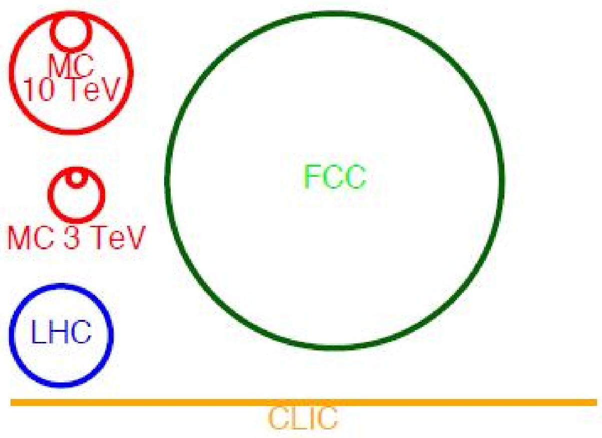
- could be reached in 5 years
- to be refined with physics studies

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Discovery reach
14 TeV lepton collisions are comparable to 100-200 TeV proton collisions for production of heavy particle pairs







D. Schulte's talk

Initial Target Parameters

International MUON Collider

Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Note: currently focus on 10 TeV, also explore 3 TeV

- Tentative parameters based on MAP study, might add margins
- Achieve goal in 5 years
- FCC-hh to operate for 25 years
- Aim to have two detectors

Parameter	Unit	3 TeV	10 TeV	14 TeV	CLIC at 3 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	40	2 (6)
N	10^{12}	2.2	1.8	1.8	
f_r	Hz	5	5	5	
P_{beam}	MW	5.3	14.4	20	28 MW
C	km	4.5	10	14	
<B>	T	7	10.5	10.5	
ε_L	MeV m	7.5	7.5	7.5	
σ_E / E	%	0.1	0.1	0.1	
σ_z	mm	5	1.5	1.07	
β	mm	5	1.5	1.07	
ε	µm	25	25	25	
$\sigma_{x,y}$	µm	3.0	0.9	0.63	

D. Schulte   Muon Collider, ICHEP, July 2022

R&D from 2021-2026 needs manpower and financial fund

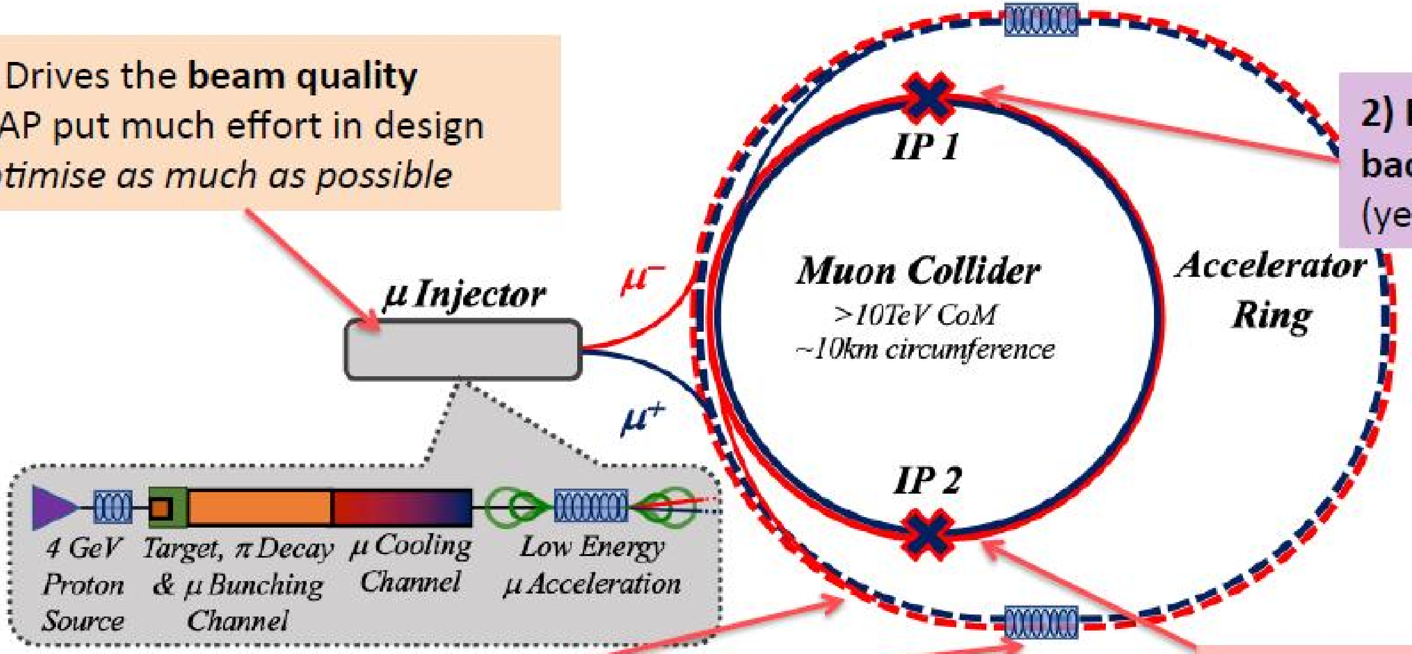
Scenario	FTEy	M MCHF
Full scenario	445.9	11.9
Reduced scenario	193	2.45

D. Schulte's talk

Key Challenges

4) Drives the **beam quality**
MAP put much effort in design
optimise as much as possible

2) **Beam-induced background**
(yesterday)



1) **Dense neutrino flux**
mitigated by mover system and site selection

3) **Cost** and **power** consumption limit energy reach
e.g. 35 km accelerator for 10 TeV, 10 km collider ring
Also impacts **beam quality**

D. Schulte's talk

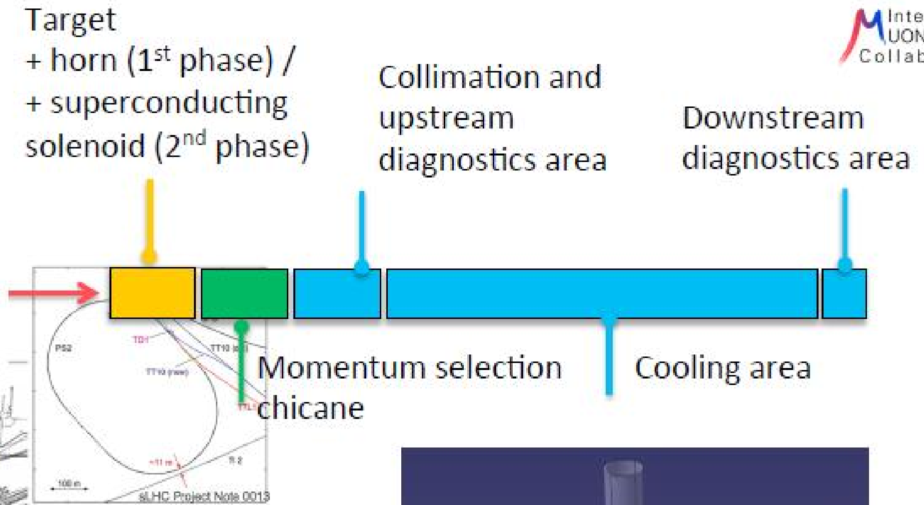
Demonstrator Facility Consideration

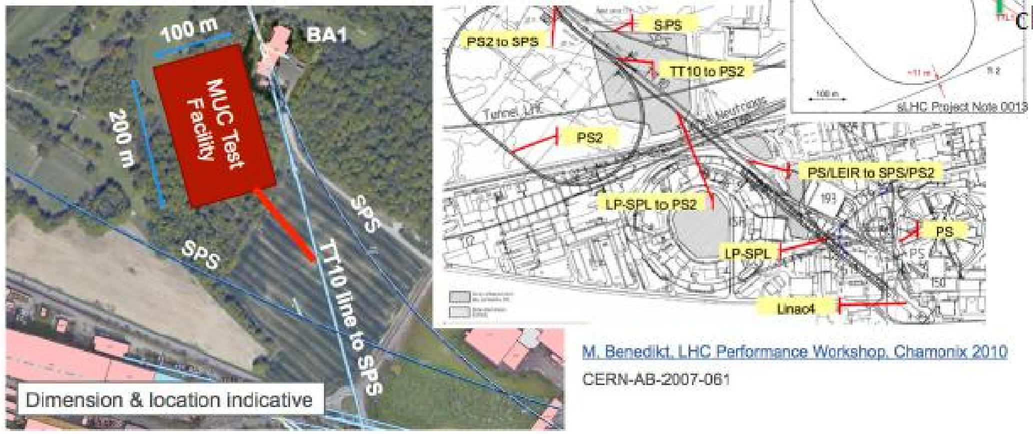
Planning **demonstrator** facility with muon production target and cooling stations

Suitable **site exists** on CERN land and can use **PS proton beam**

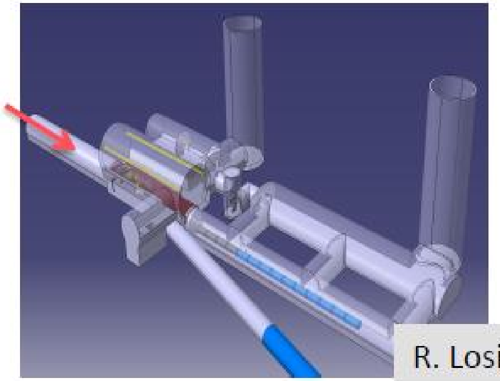
- could combine with **NuStorm** or other option

Other sites should be explored (FNAL?)

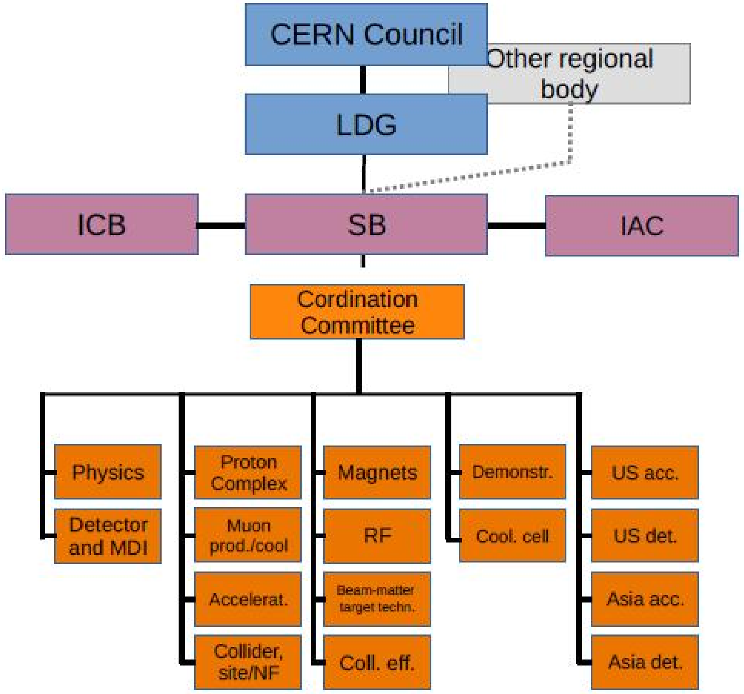




M. Benedikt, LHC Performance Workshop, Chamonix 2010
CERN-AB-2007-061



R. Losito et al.

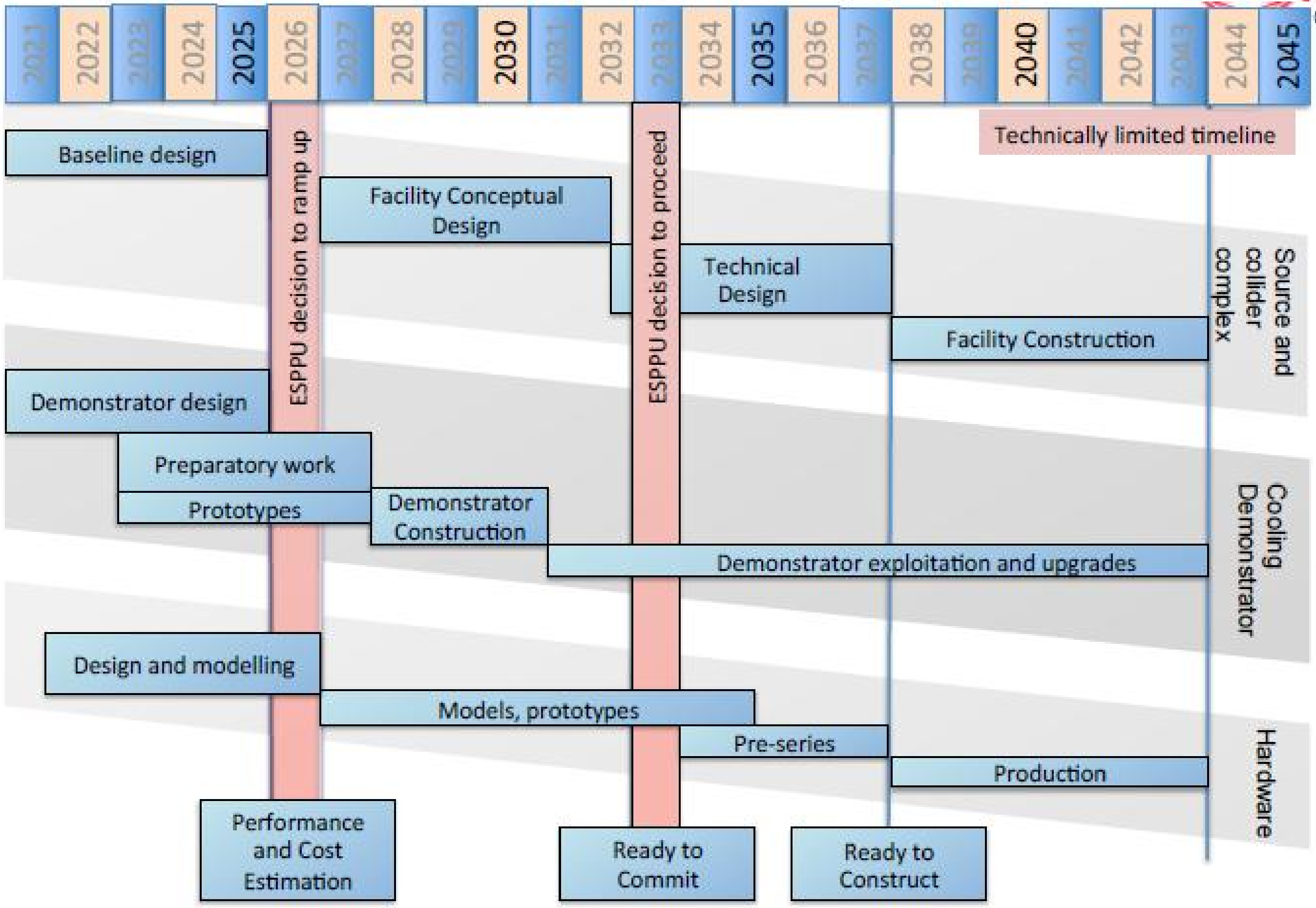


D. Schulte's talk

Timeline

Goals for next strategy
- Assessment report
- R&D plan ready for implementation

Prudently explore if MuC can be option as next project (i.e. operation mid 2040s)
- e.g. in Europe if higgs factory built elsewhere
- very strong ramp-up required after 2026
- some compromises on initial performance



D. Schulte's talk

International Conference on High Energy Physics

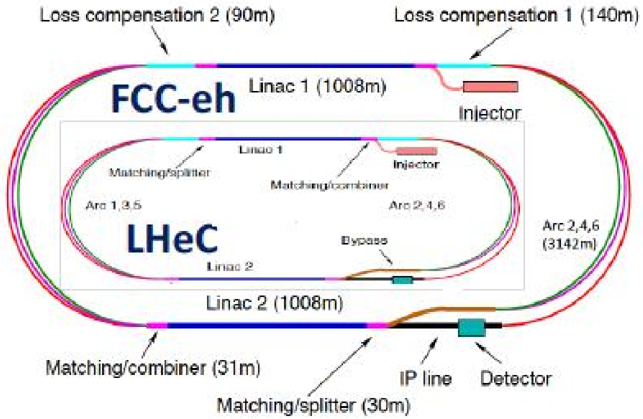
PERLE: The development of a multi-turn, high current ERL

Bologna, July 7th 2022

By Walid KAABI on behalf of PERLE Collaboration

- **ep collisions at LHC**. It appeared that the ideal machine combines the **proton of LHC** (from 7 TeV up to 13 TeV) with an **electron beam of 50-70 GeV** and a target luminosity of 10^{34} $cm^{-2}s^{-1}$.

→ the electron machine is an **ERL**, with in summary current = 20mA, 3+3 passes (to reach 60 GeV)

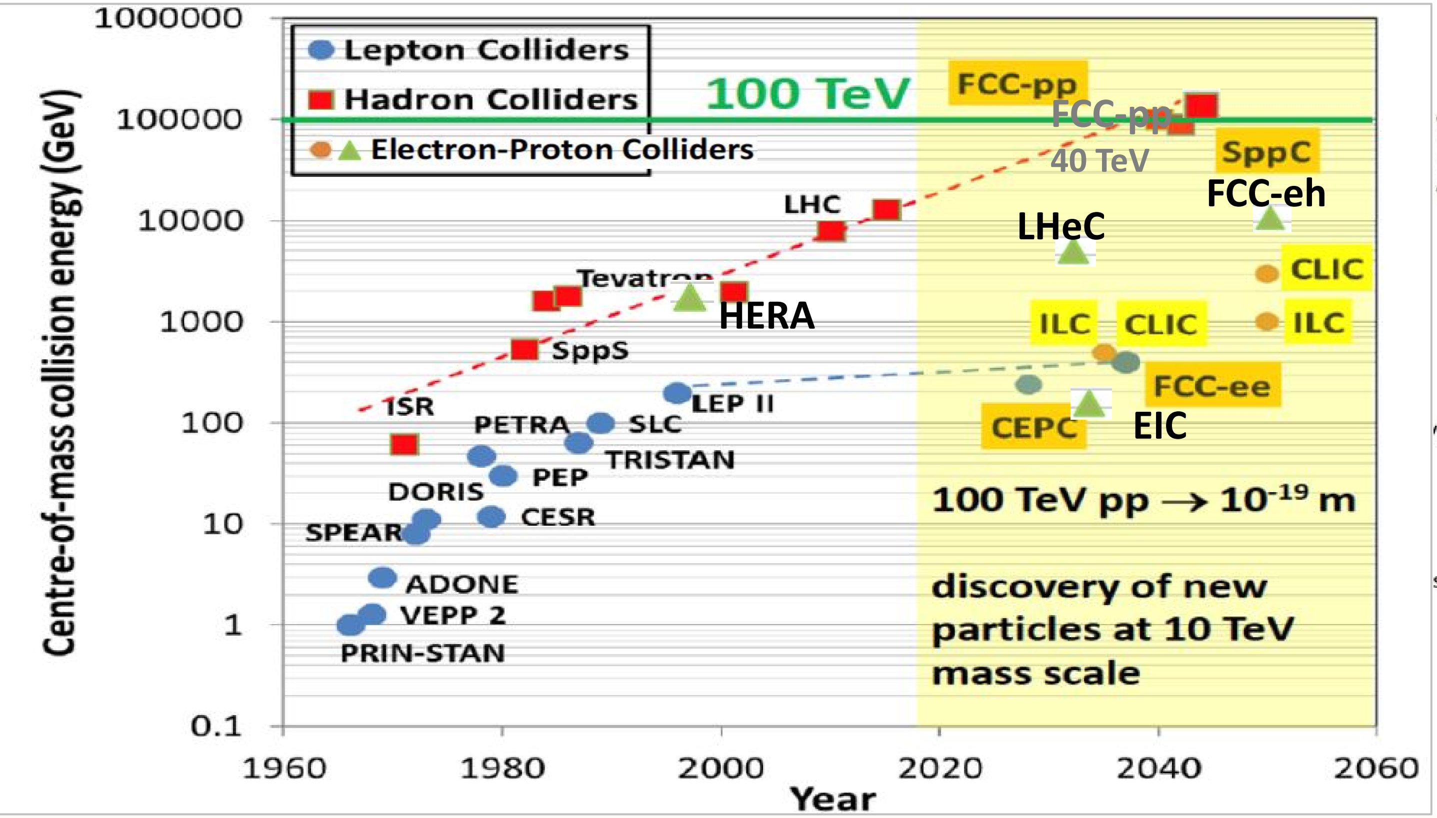


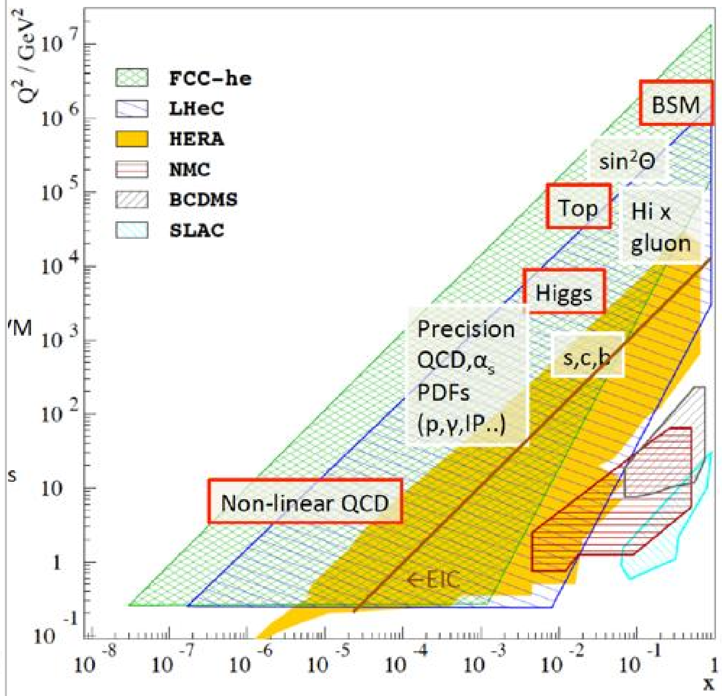
sqrt(s_{ep}) = 1-4 TeV

L(HERA) x 1000
(ERL and LHC)

1206.2913, JPhysG
2007.14491, JPhysG

f=802Mz,
3+3 passes: 20mA x 6
20 MV/m, $Q_0 > 10^{10}$





Raison(s) d'etre of ep/eA at the energy frontier

Cleanest High Resolution Microscope: QCD Discovery

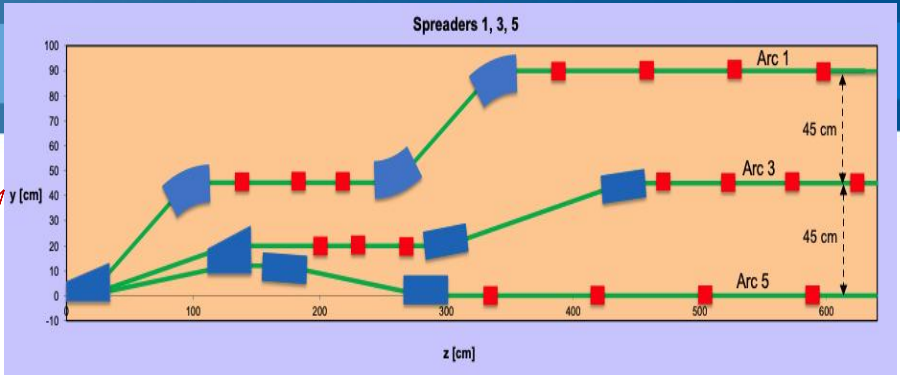
Empowering the LHC/FCC Search Programme

Transformation of LHC/FCChh into high precision Higgs facility

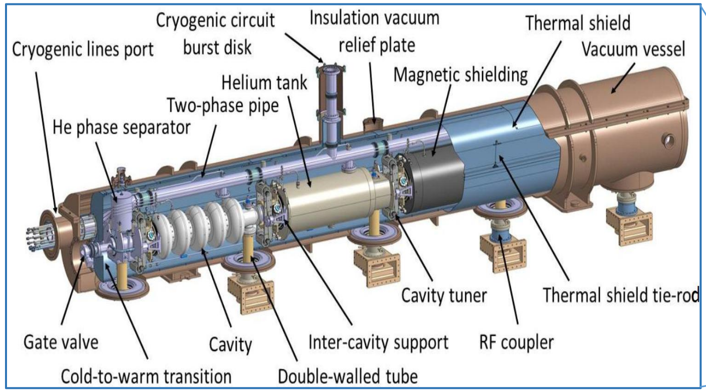
Discovery (top, H, heavy ν's..) Beyond the Standard Model

A Unique Nuclear Physics Facility

PERLE Configuration



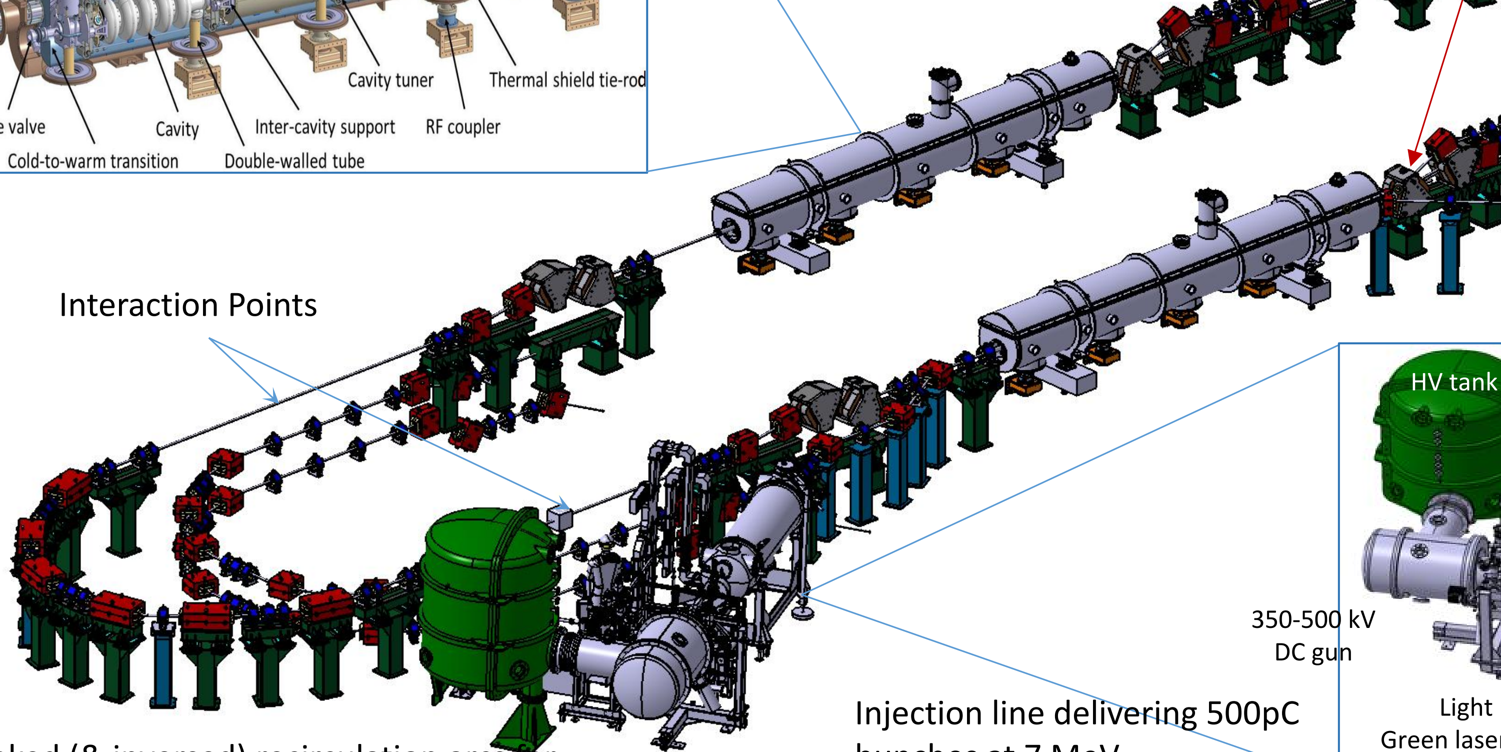
PERLE: first multi-turn ERL, based in SRF technology, designed to operate at 10MW (20 mA, 500 MeV) power regime



- Cryomodule with 4 five-Cell cavities
- Total gradient 82 MeV
- 3 acc & 3 decc beams at different energies travelling in the CM.

Switchyard: vertical separation/recombination of beams at different energies

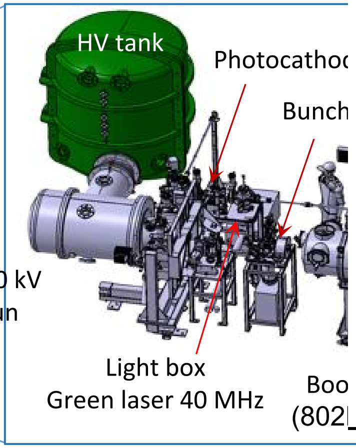
3 staked recirculation arcs for beams at different energies (Arcs 1, 3, 5).



Beam Dump

Interaction Points

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

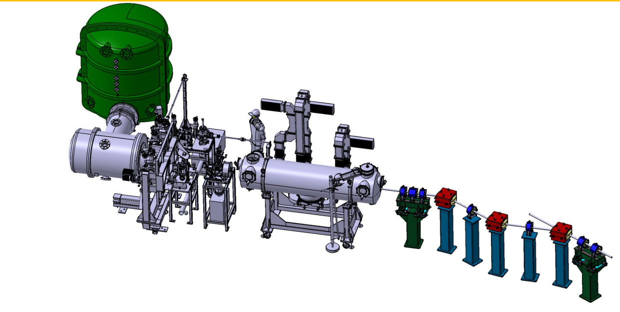


350-500 kV DC gun

Injection line delivering 500pC bunches at 7 MeV.

3 staked (& inversed) recirculation arcs for beams at different energies (Arcs 2, 4, 6)

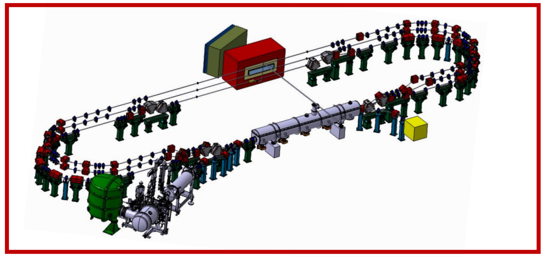
PERLE Timeline for TDR phase and beyond



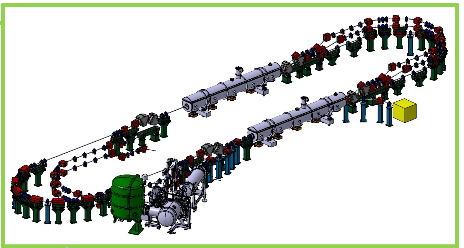
2023
PERLE TDR

2025
End Phase 0: Injection line

2028
End Phase 1: PERLE @ 250MeV



2030
End Phase 2: PERLE @ 500MeV



Walid KAABI's talk