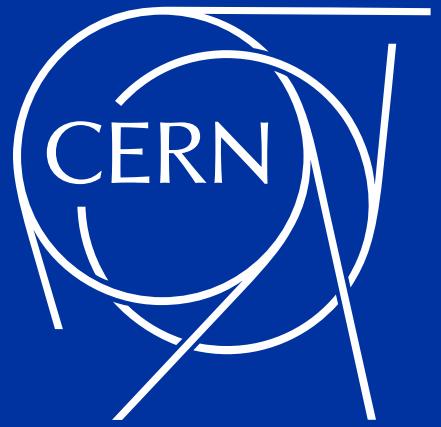


EIC / FCC beam instrumentation

Anke-Susanne Müller (KIT), David Gassner (BNL), Todd Satogata (JLAB) and **Thibaut Lefevre** (CERN)

12th November 2020, FCC Workshop

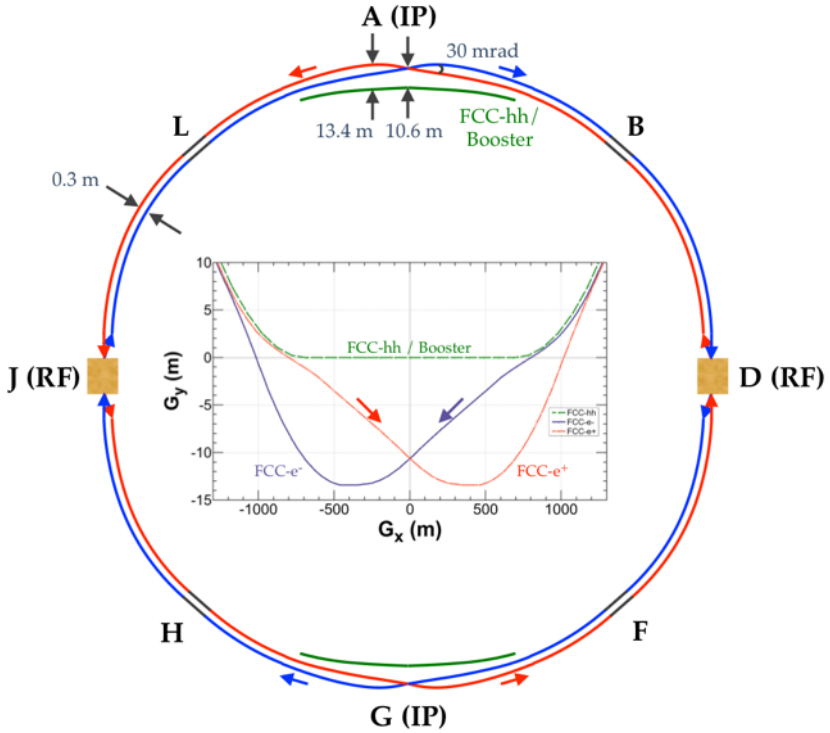
The Future Circular Collider Innovation Study (FCCIS) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 951754

Outline

- EIC and FCC electron beam parameters and Challenges for BI
- Proposed Beam Instrumentation work packages (a 1st Draft)
- Extra synergies with CERN BI activities
- Conclusions

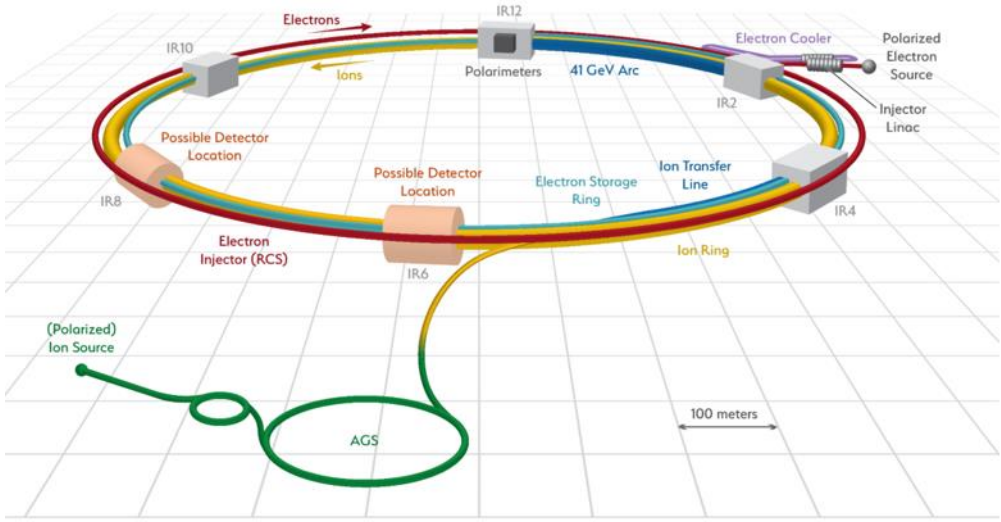
Machine Layout

FCC-ee



97.75 km double ring, full-energy $e^{\pm}$ injection,
injection every ~2 min into same bucket

EIC



3.83 km double ring,
full-energy e^{-} injection,
injection rate 1 Hz,
every 2 min into same bucket

Beam Parameters

	EIC	FCC-ee-Z
Beam energy [GeV]	10	45.6
Bunch population [10^{11}]	1.7	1.7
Bunch spacing [ns]	10	15, 17.5 or 20
Bunch length, rms [mm]	10	3.5 -12
Beam current [A]	2.5	1.39
RF frequency [MHz]	591 or 394	400
Horiz. geometric emittance [nm]	22	0.27
Vert. geom. emittance [pm]	1000	1.0
SR power / beam /meter [W/m]	4000	600
Critical photon energy [keV]	9	19

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Highly relevant for Beam intensity, position, loss and bunch length measurments

High bunch / beam intensities and similar bunch length
→ Similar issues in terms of impedance & beam induced heating

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Low / Ultra-Low emittances →

Similar challenges in measuring small beam sizes (worse for FCC !)

Beam Parameters

	EIC	FCC-ee-Z
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Similar bunch population, bunch length, bunch spacing

→ Similar design choices in terms of mitigating impedance and beam heating issues

→ Similar design choices electronic and acquisition system

Beam Parameters

	EIC	FCC-ee-Z
Beam energy [GeV]	10	45.6
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Similar SR Characteristics (at least for FCC ee-Z) →
Similar design choices for absorber, shielding and cooling scheme

Beam instrumentation workpackages

- **Identify and follow-up design challenges**
- **Concentrate on performance (1st) and cost (2nd) related issues**
- **Define responsibilities with collaborating partners**

Beam instrumentation work packages

Task 1 - Beam Position Monitoring

1.1 Design and construction of a low impedance electrostatic Pick-up

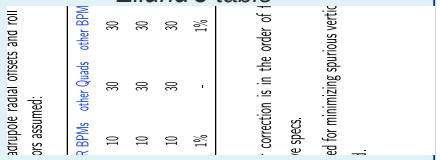
- Electro-magnetic design
- Mechanical design compatible with alignment tolerances
- Prototyping and validation tests

Tessa's table

	$\sigma_x(\mu m)$	$\sigma_y(\mu m)$	$\sigma_\theta(\mu rad)$
arc quads	100	100	100
IP quads	100	100	100
sextupoles	100	100	100
dipoles	100	100	100
BPMs	20	20	150

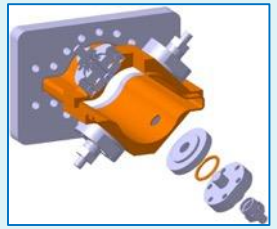
*BPM error relative to quadrupole position

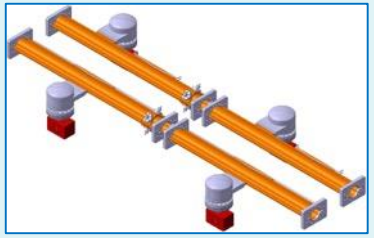
Eliana's table



1.2 Impedance and beam heating simulations for FCCee and EIC

- EM and heat load simulations
- Estimate the need for water cooling





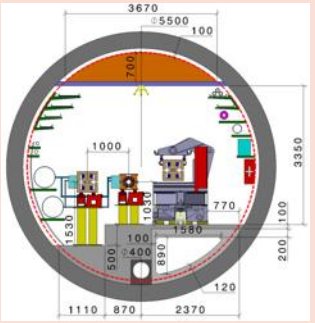
1.3 Specifications (and design) of a cost-effiicient bunch-by-bunch, turn-by-turn BPM acquisition system with sub-micron resolution

- Resolution, Accuracy, Dynamic Range, Radiation-Hardness,..
- System architecture and implementation (in view of large production: e.g. 6000 BPMs)

Beam instrumentation work packages

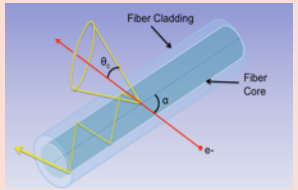
Task 2 - Beam Intensity and Beam Loss Monitoring

2.1 R&D on DC Beam Current Transformer (?)
- Define specifications : Resolution, Accuracy and Dynamic range
- System design and integration



2.2 R&D on fast Beam intensity measurement for bunch-by-bunch, turn-by-turn acquisitions (?)
- Define specifications : Resolution, Accuracy and Dynamic range
- System design and integration

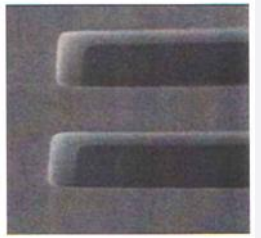
2.3 R&D on a beam loss monitoring systems
- Define specifications – Resolution, Dynamic range and Time response **(?)**
  - Design study for identifying losses from different beams (electron/ion, main ring/booster)
- Design study for BLM system insensitive to X-rays
  - Design, Prototyping and Validation tests **(CERN?)**



Beam instrumentation work packages

Task 3 - Transverse Beam Size/Profile Monitoring

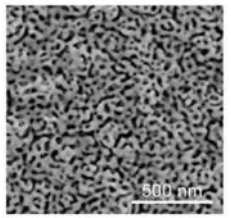
double slit



3.1 Updated Specifications

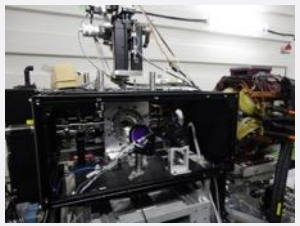
3.2 R&D on Beam Size monitoring system based on Synchrotron Radiation interferometry

- X-ray interferometric system using micro-slits **(KEK)**
- X-ray interferometric system using nanoparticles **(CERN)**



Nanoporous material

LWS at KEK



3.3 R&D on Beam Profile monitoring system based Laser wire scanner (?)

- System design and integration (incl. fiber laser technology and laser cavity interaction)
- Bunch-by-bunch acquisition

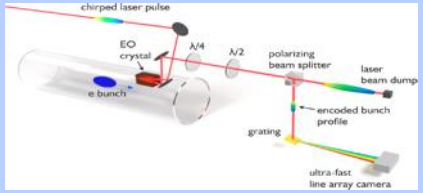
3.3 Design of an energy spread monitoring system based on imaging techniques (KIT)

Beam instrumentation work packages

Task 4 - Bunch Length Monitoring

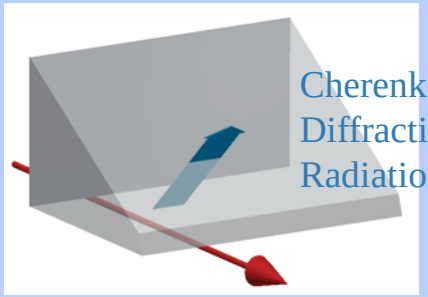
4.1 R&D on Bunch Length monitoring system based on Electro-Optical (EO) Spectral Decoding (KIT)

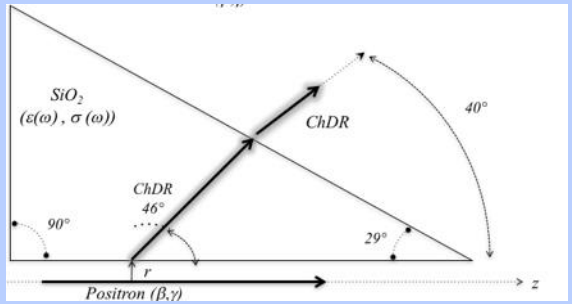
- Design of an in-vacuum, low impedance EO pick-up (KIT, CERN)
- Design of a bunch-by-bunch, turn-by-turn acquisition system with sub-picosecond time resolution

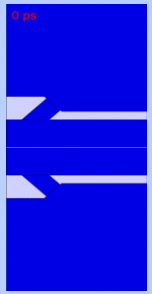


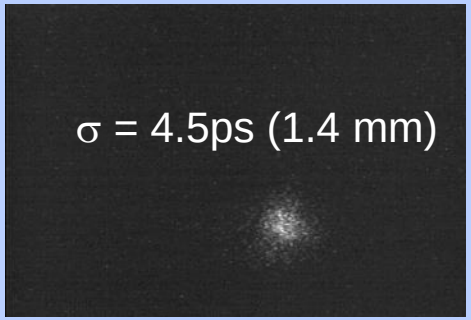
4.2 R&D on Bunch Length monitoring system based on Streak camera measurements - CERN

- Design of radiation source : Synchrotron radiation or Cherenkov Diffraction radiation









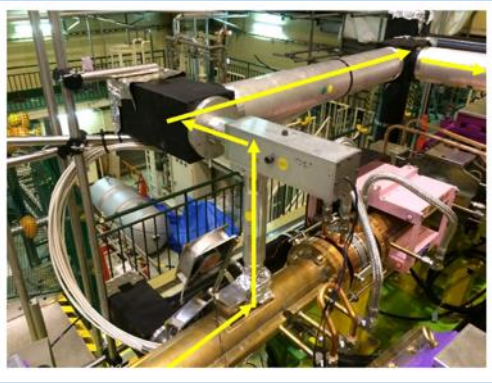
Beam instrumentation work packages

Task 5 Polarisation and Luminosity monitoring

5.1 Design of Polarimeter based on Compton scattering (EIC) (BINP)

5.2 Design of Beamstrahlung measurement systems (EIC)

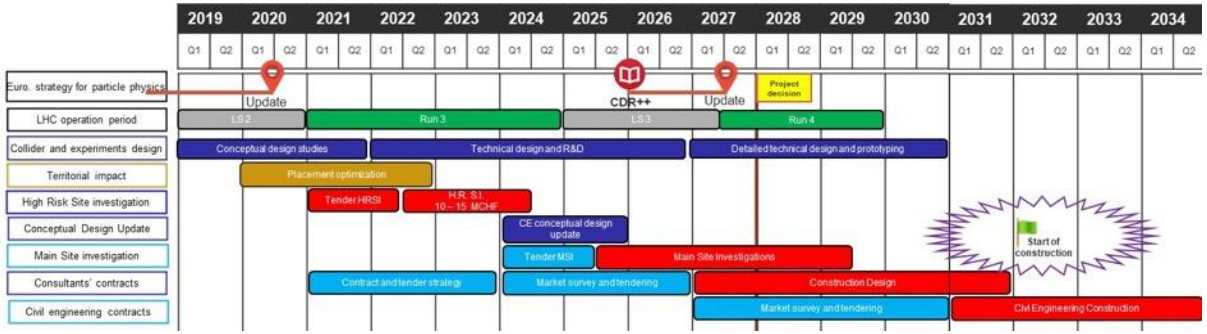
implementation at SuperKEKB



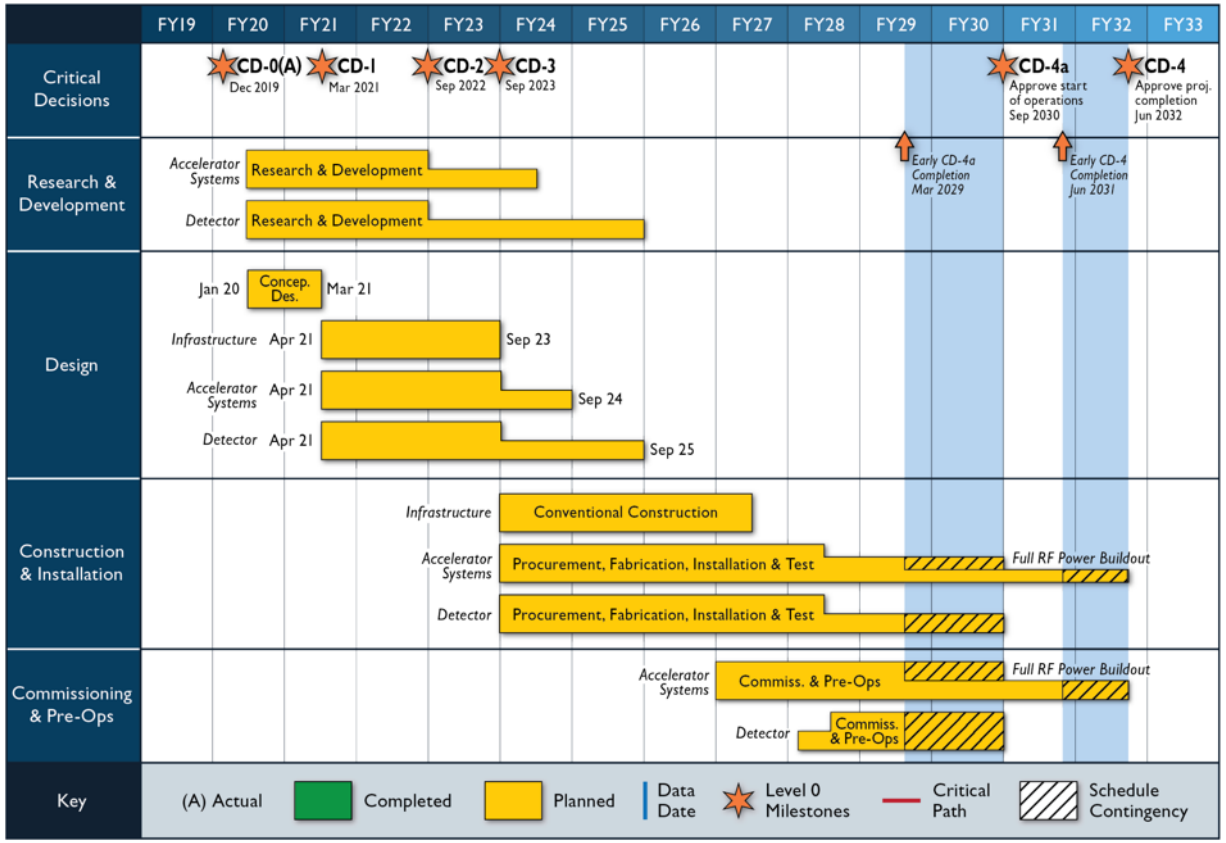
5.3 Design of luminosity monitor based on zero degree calorimeter (?)

Roadmap

FCC-ee



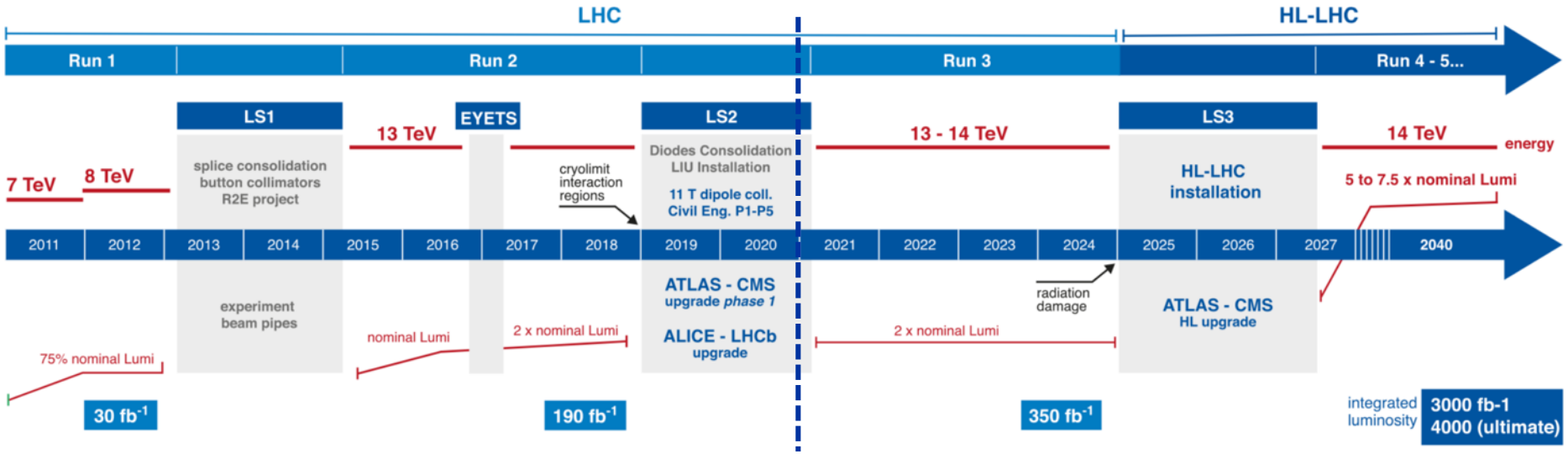
EIC



- *EIC beams ~10 years before FCC-ee commissioning*
- *Still an opportunity to have common design and prototype validation steps*

Roadmap

High-Luminosity LHC at CERN

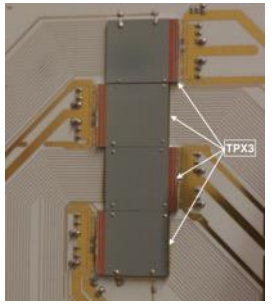


- Work on new beam instruments to be operational for Run 4 (2027)
- Consolidation of existing LHC beam instrumentation during LS3 (2025) and LS4 (2030)

Could also be considered for possible collaboration topics between CERN & EIC

Possible CERN-EIC ‘Ions’ synergies

- New beam instruments for Hilumi
  - Beam size monitoring using residual gas ionization and modern pixel detectors
  - Radiation-hard luminosity monitors based on Cherenkov radiators
  - Rad-hard ASIC for Beam loss monitoring
  - Schottky monitors
  - …



- Consolidation of existing beam instrumentation
  - New Bunch-by-bunch, turn-by-turn BPM acquisition system with micron resolution
  - New acquisition system for Beam loss monitors
  - Rad-hard optical links, rad-tolerant FE electronics
  - Large production

Conclusions

- Strong synergies between FCC-ee and EIC studies open paths to fruitful collaborations in the future
- A first draft of Beam Instrumentation work packages have been discussed
- Some on-going activities carried out by already identified partners (KIT, KEK, Alba, Uni. Milano, BINP,..) should be strengthened to meet the specific needs of the projects
- Welcoming (new) partners to take responsibilities in the proposed work packages / activities
- Recent collaboration agreement with CERN Beam instrumentation group providing
  - Ionization chambers for the FRIB facility in US
  - Wire scanners and Ionization chambers for ESS in Sweden

Many thanks to all people involved

&

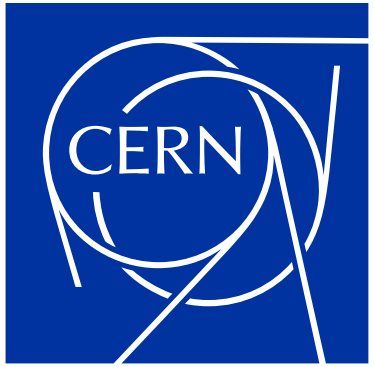
Many thanks for your attention !

The Future Circular Collider Innovation Study (FCCIS) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 951754

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	2	7	2	7	2	7.5	2
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	

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18



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