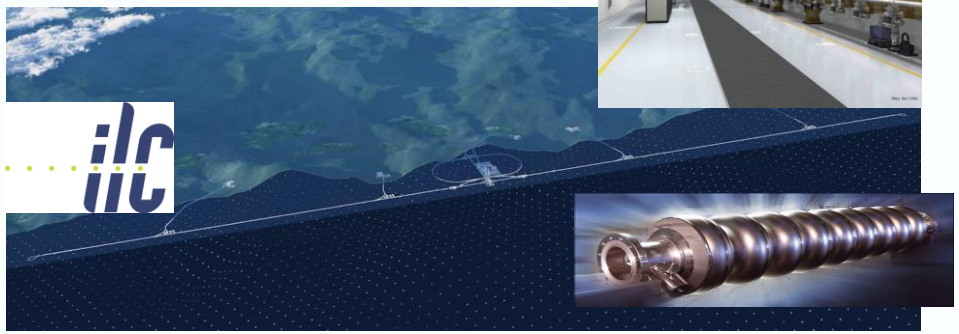
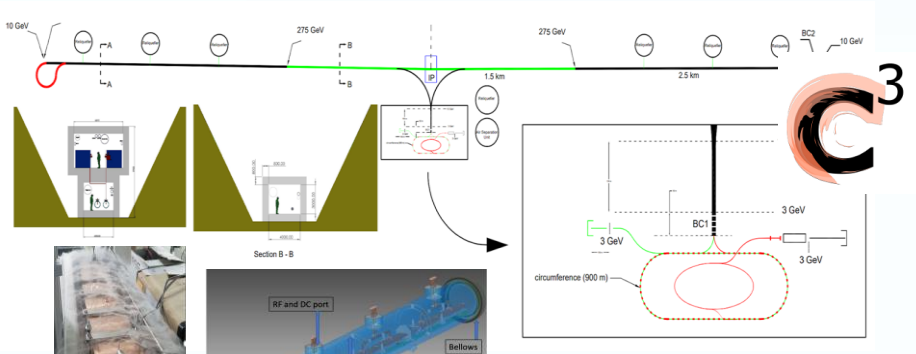
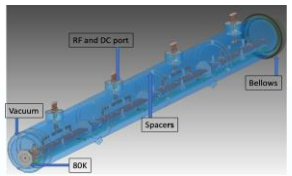
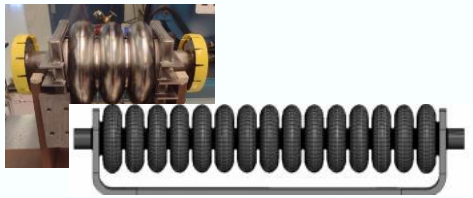
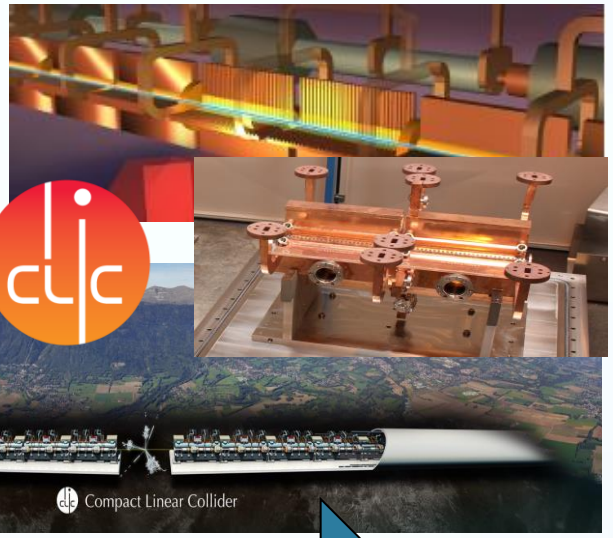
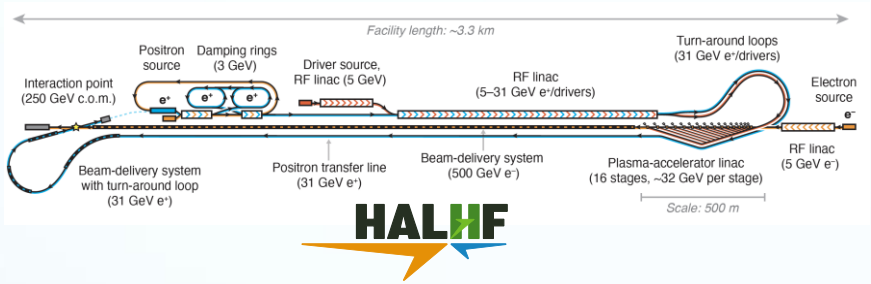






BDS Considerations for LCF@CERN

V. Cilento & A. Faus-Golfe

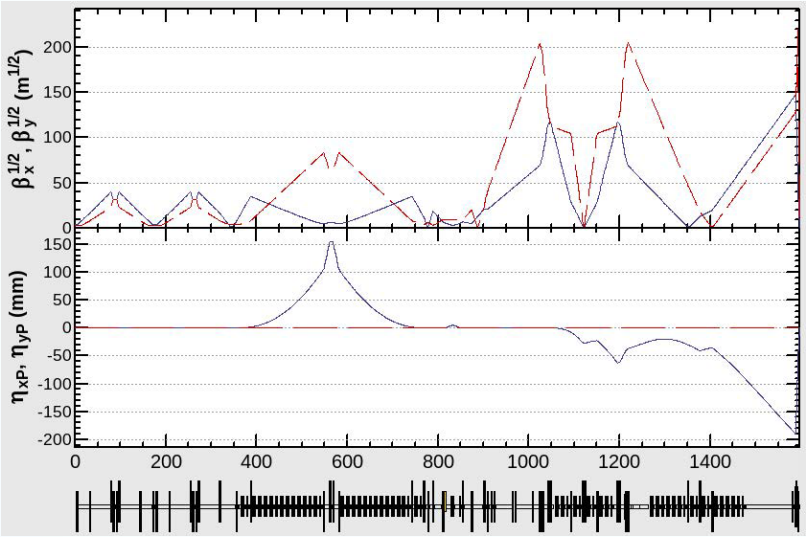
The LC@CERN baseline

The Roadmap

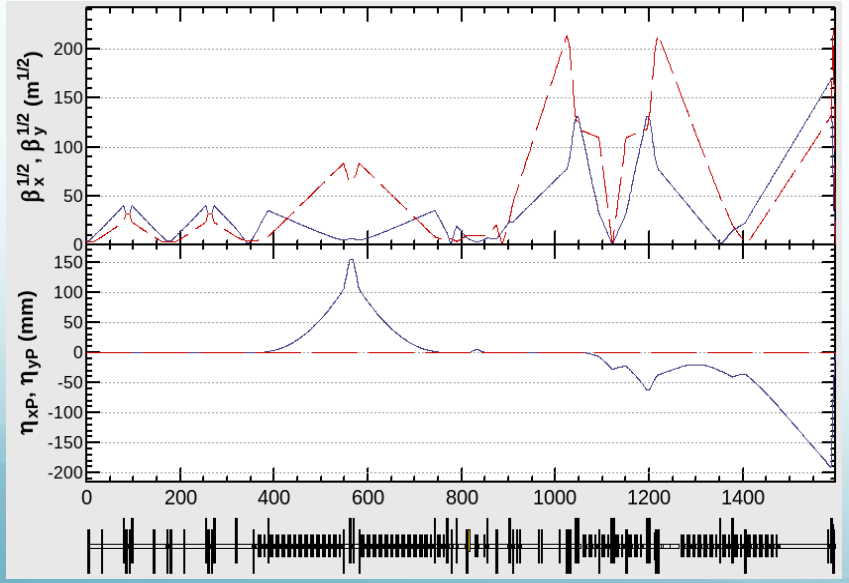
Basic assumption is to provide a scenario that can start “now” and that can be progressively upgraded to cover the physics needs and/or to be able to react on “surprises”. The guiding line should be to avoid as much as possible major civil construction for the upgrades. Upgrades should benefit from technology updates with the aim that the LC project benefits but also drives the innovation.

- The first step is construction of **250 GeV ILC** at CERN. This requires a 21 Km tunnel in the CERN area, a first implementation already studied by CLIC project, with **2 IRs** sharing Luminosity.
- After 10 years construction and 10 years data taking at at 250 GeV, the accelerator will be upgraded in stages with more advanced technologies to achieve higher-energies (500 GeV – 1 TeV) or higher-luminosities as:
  - Higher-gradient SRF, NCRF CLIC or Cool Copper C^3
  - ERL
  - Plasma wakefield
  - $\gamma\gamma$ collider (optical or XFEL lasers)
  - ...
- Upgrades have to be understanded like: we have a tunnel with an ILC machine available and we need R&D to see how the new technologies can fit in such a facility, where DRs exists, tunnel diameter is fixed and a cryo-system is available.
- In later stages the 2IRS can be used by sharing luminosity by running parallel programs at higher and lower energy as a testbed for technology development.

The ILC BDS baseline and the energy upgrades



BDS for 250 GeV with half-lenght FD ($\beta_{x,y}$ = 13 / 0.41 mm)*



BDS for 500 GeV ($\beta_{x,y}$ = 11 / 0.48 mm)*

The **current baseline ILC BDS at 250 GeV** (BDS-250) has been designed to be scaled until 1 TeV (BDS-1000), keeping the **same geometry**. The total length is around 2400 m with a crossing angle of 14 mrad.

The optics has been designed taking as starting point the BDS-250 magnet configuration. The **BDS-500** optics has been matched with the same magnet configuration. The field strength of the Final Doublet (FD) quadrupoles (QD0, QF1) for the BDS-250 is half of the BDS-500.

The **BDS-1000 needs some additional magnets**, in dedicated locations that are free magnet areas for the lower energy operation modes.

The performance and tolerances optimization, including different bending magnets strengths compatible for all the energies, collimation depths and different possible beamline geometries between others, are ongoing.

The crossing angle choice

The **long ILC inter-bunch spacing** of 554 ns (366 ns for upgrade luminosity), gives the possibility of having a **large range of crossing angle configurations** from large (20 mrad) to quasi head-on (2 mrad).

- **Larger crossing angle** separate the incoming beam from spent beam, with no shared FF magnets. This separation facilitate the beam optics for the spent beam extraction line at the expense of some detector hermeticity in the forward region and the more complex tracking calibration procedures. In addition, larger crossing angles are more reliant on a Crab Cavity (CC) system, which rotates the bunches, in order to maximize their overlap and hence the luminosity.

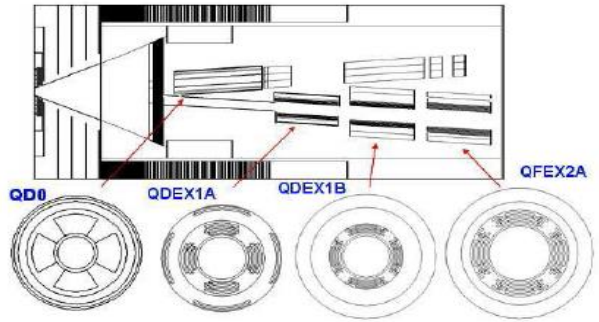


Figure 5: 14 mrad crossing angle IR [14]. The incoming beam is separated from the outgoing one.

- **Small crossing angles** are generally favoured from the point of view of detector hermeticity and are less reliant on the CC system. However, the fact that the incoming and outgoing beams must to share the inner most magnets reduces significantly the design flexibility that has to deal with the reduction of the backgrounds and the minimisation of energy losses in the critical elements.

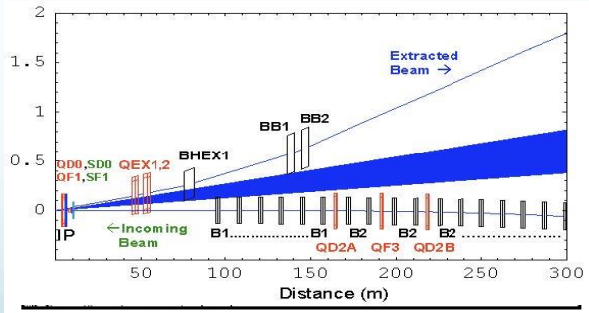
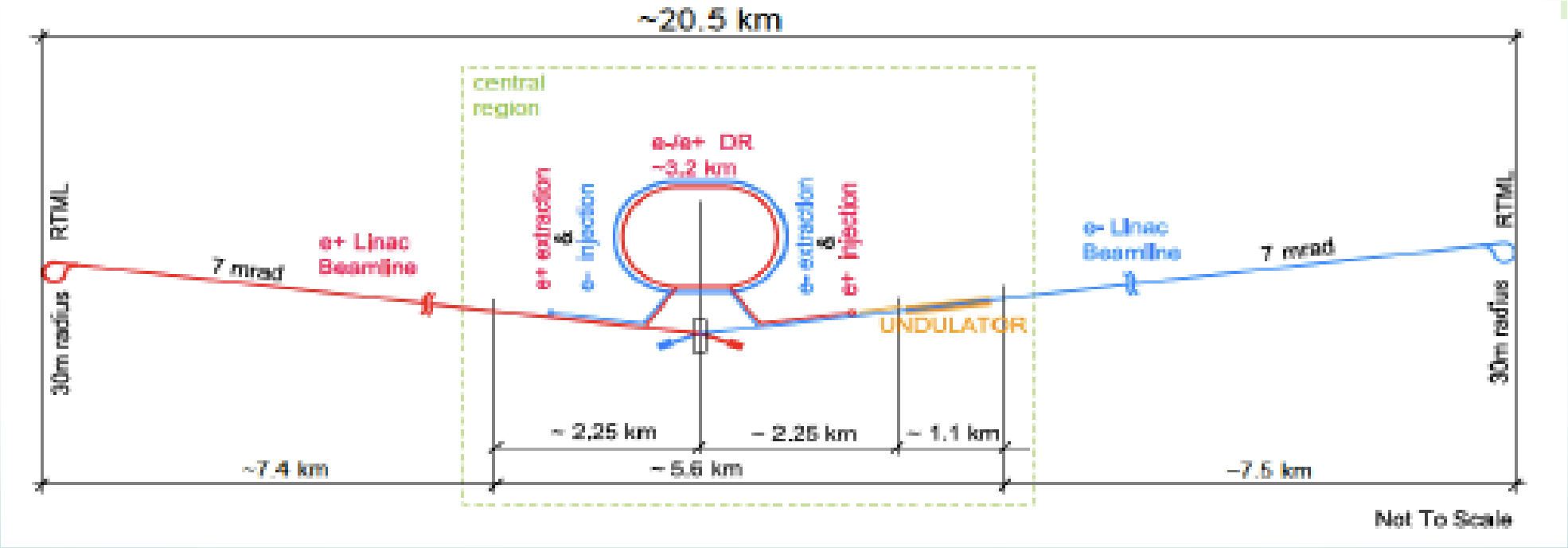


Figure 6: 2mrad solution, where incoming and outgoing beams must share the magnets closest to the IP.

The crossing angle choice

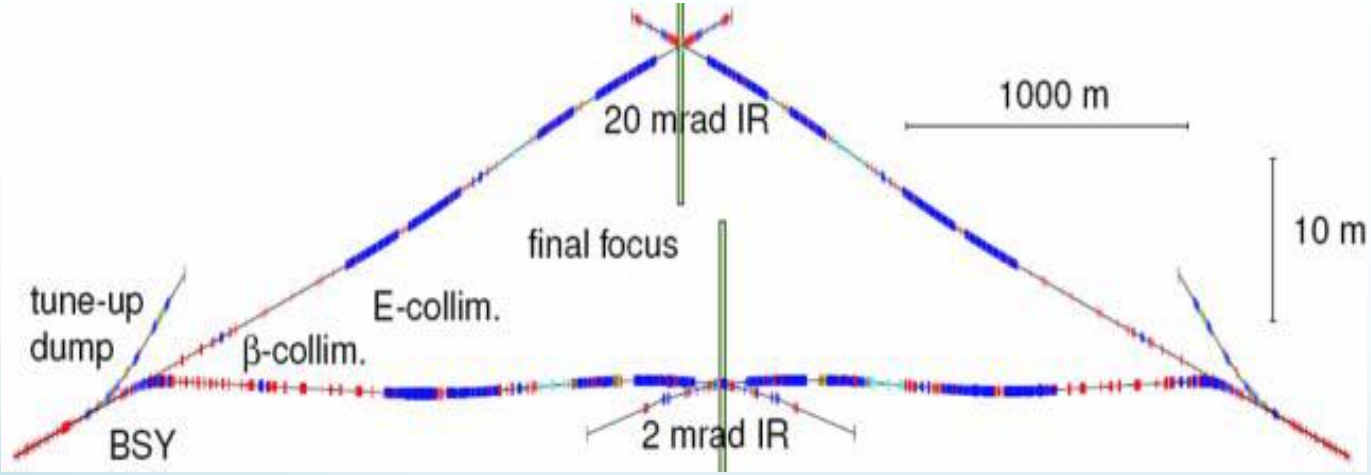
The present **ILC baseline configuration** has a 14 mrad IP crossing angle, minimum angle allowing in one hand independent magnetic channels for ingoing and outgoing beams by means of compact SC magnets and in the other hand makes easier the straightforward spent beam extraction while facilitating post-IP diagnostics.



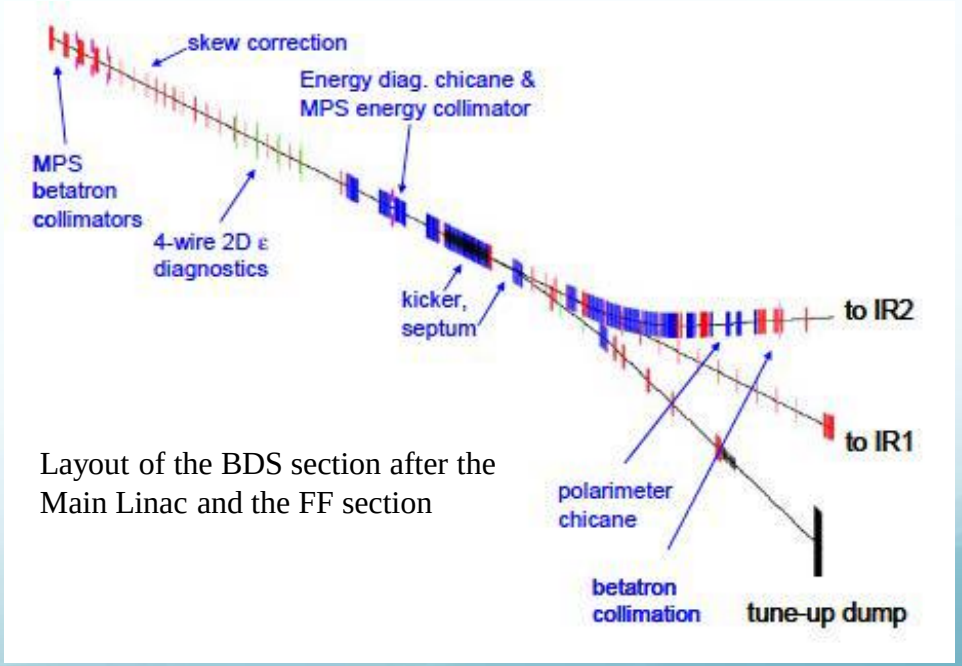
IP crossing angle 14 mrad

ILC@CERN with 2 IPs

In the ILC Baseline Conceptual Design, the ILC was designed with 2 BDS sections and two independent IRs with 20 and 2 mrad. At that time others schemes were under study, including one of 14 mrad and a head-on scheme.



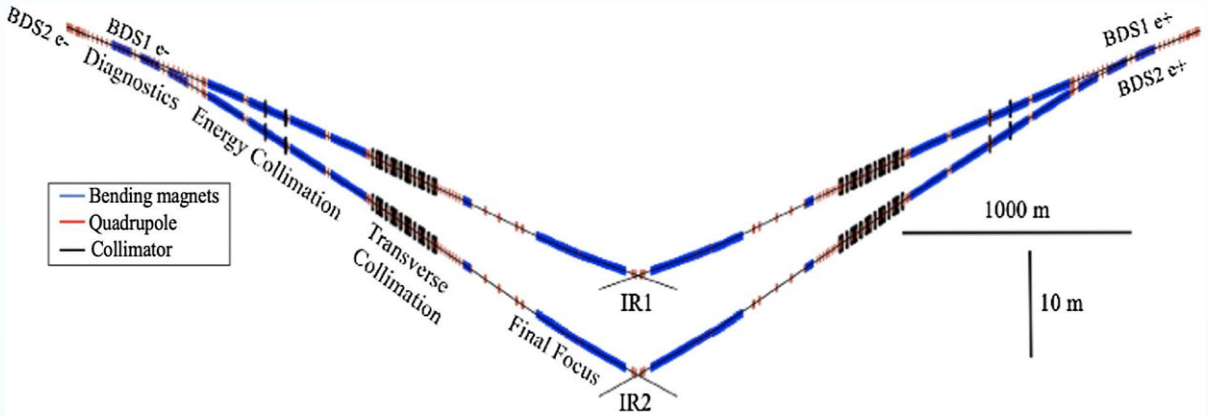
Layout of the two IRs with 20 and 2 mrad crossing angle



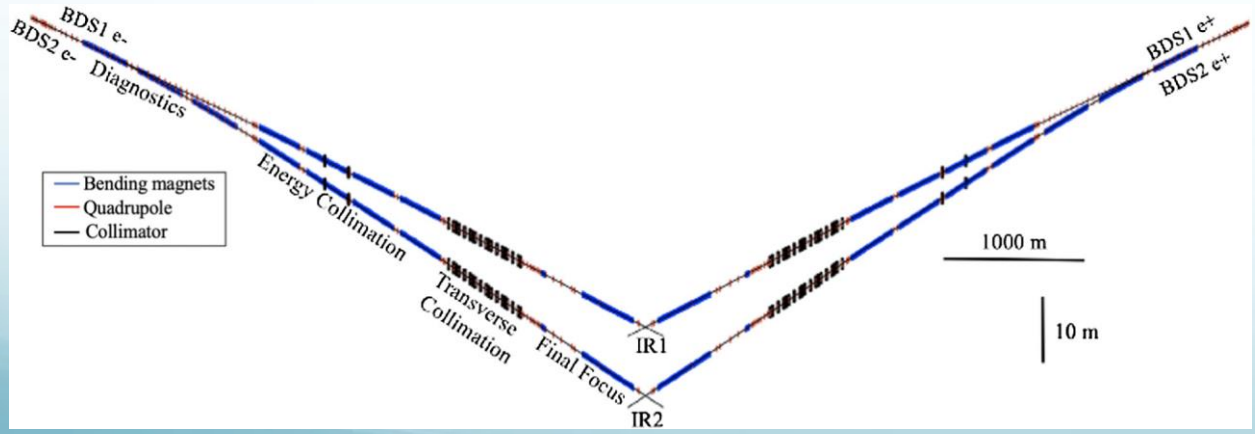
Layout of the BDS section after the Main Linac and the FF section

ILC@CERN with 2 IPs

A detailed study of dual BDS serving 2 IPs has been realized in the framework of the CLIC project, this work could be taken as reference for future studies



Layout of the two IRs at 380 GeV with 16.5 and 20 mrad crossing angle



Layout of the two IRs at 3 TeV with 20 and 25.5 mrad crossing angle

The design of the dual BDS system is optimized to minimize the luminosity loss due to emittance increase and related widening of the beam sizes caused by the emission of SR generated in the bending magnet section in the first added part of the BDS, to separate the 2 IRs. This effect is much more significant for the CLIC at high-energies as the 3 TeV case, since the contribution to the IP beam size scales with the fifth power of energy. To mitigate luminosity loss from this contribution the bending angle, needs to be as large as possible, which determines the length of the BDS.

ILC@CERN with 2 IPs (I)

The angle choice has not been determined, but in principle the 2 angles will be different to have physics complementarity between he two detectors. Preliminary design studies and CFS cost with 20 mrad between the MLs, and with **2 IPs** with **14 / 26 mrad** crossing angle with the two detectors in the same longitudinal position, are being performed but not detailed design of the optics is being planned. Discussions are ongoing to found an optimal solution; some issues have been identified:

- In the case of **2 IPs** only **baseline operation** will be used (baseline 554 ns bunch separation / high-lumi 366 ns).
- Concerning the crossing angle, options including a **“quasi-head on”** (2 mrad) are **very difficult** to implement from the outgoing beams.
- Options for **different longitudinal positions** for the **2 IPs**, indeed they the advantage of allowing less separation between the 2 detectors will have **timing issues** due to the different lengths for the BDSs, implementation will be complex (for instance, the length has to be half-integer of the DR length).
- In the **same longitudinal position** for the 2 IPs, an optimization of the 2 IPs cavern have to be performed to provide a minimum distance of 30 m between two detectors.
- The **beam dumps** have to be reconfigured and special attention has to be paid to the photon dump location. In particular, the photon dump location at the center (between two tilted beams) becomes a critical issue in the case of the undulator positron source.

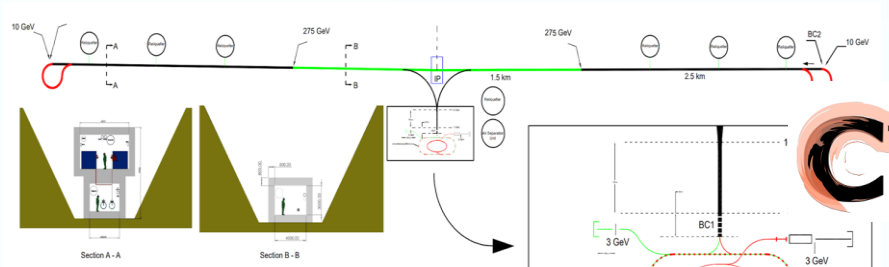
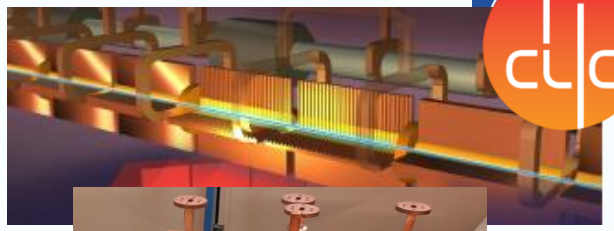
ILC@CERN with 2 IPs (II)

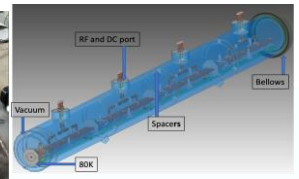
- Options for **different longitudinal positions** for the 2 IPs, indeed they have the advantage of allowing less separation between the two detectors will have timing issues due to the different lengths for the 2 BDSs. The implementation of these type of options will be complex, and will suppose a global optimization design for all the accelerator systems as the Damping Rings (DR) (for instance, the length of the BDSs has to be half-integer of the DR length) or the injection system.
- The **angle between the MLs** has to be optimized to minimize the SR generated by the bending magnets of the BDS separation region, taking into account the 2 IPs crossing angle choice.
- The idea of having parallel MLs is also being considered and this option could be better for the future implementation of an upgrade by means of ERLs, nevertheless the impact of the increase of total length and the SR losses in the splitting section should be considered.
- The **split location of the BDSs** has to studied in detail, as well as the split magnet technology for the high-energy upgrades.
- Compatibility with a possible future $\gamma\gamma$ **collision** mode have to be evaluated, with both optical lasers or FEL options. Options with XFEL lasers are optimal when the crossing angle is "quasi-head on" contrary to the optical ones.
- ....

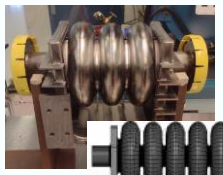
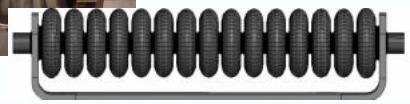
C^3 2 IPs & Energy upgrades

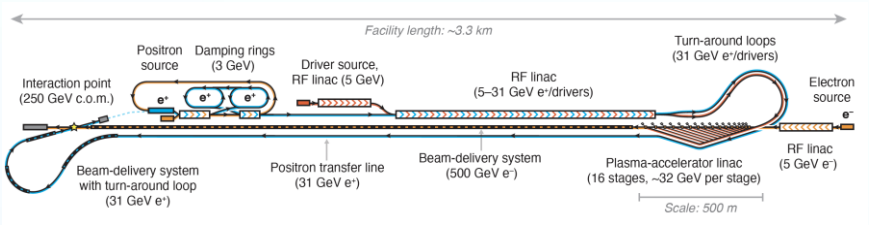
C^3 comments about the **2 IPs** and **energy upgrades**

- The **14/26** IPs are **fully compatible** with C3 plans.
- The planned **BDS upgradable** to 1 TeV BDS is also a good baseline for us in the LC Vision 20 km baseline. It leaves plenty of tunnel space for 1 TeV C^3 upgrade and allows for a smooth transition to a 550 GeV - 1 TeV.
- The BDS would need to be **updated** for **2 TeV** CoM C3 in the 20 km linac.

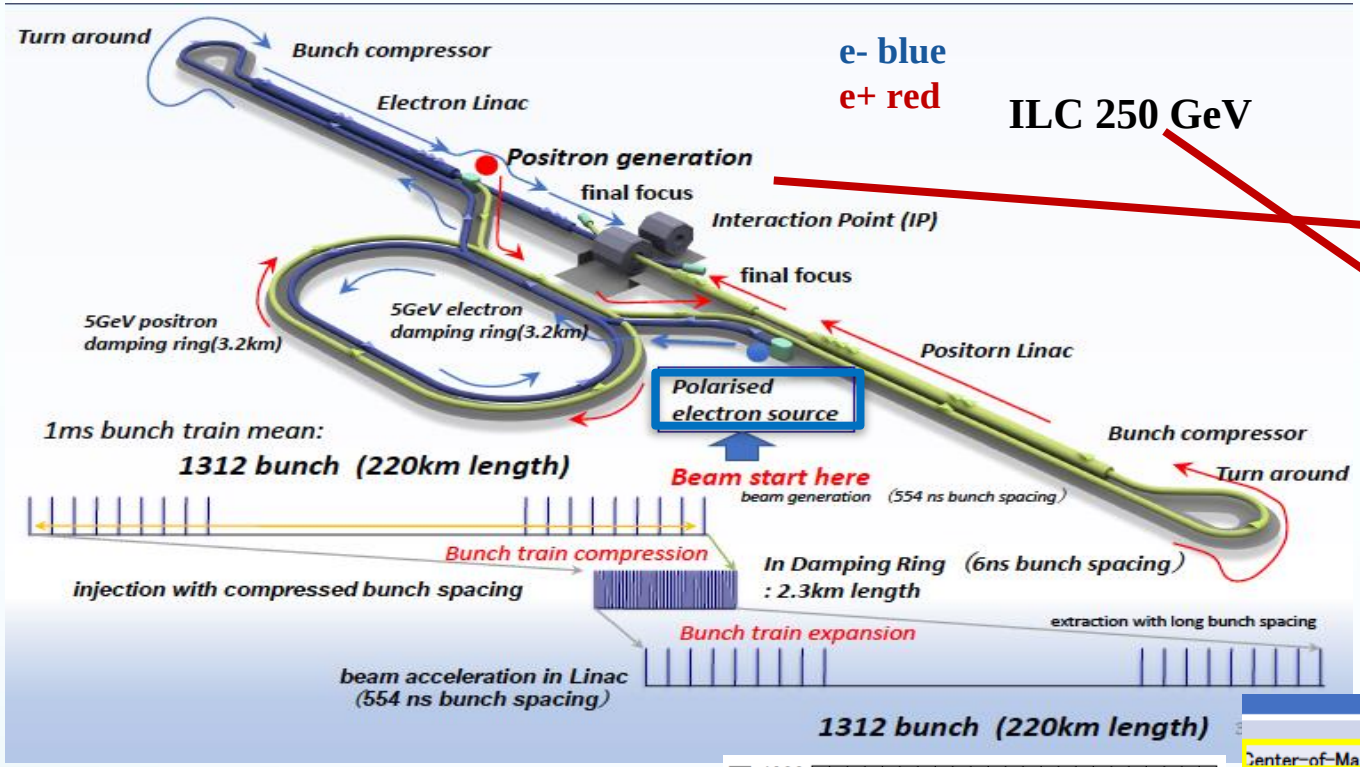



Thanks for your attention

Thanks for the inputs and discussions:
T.Okugi, N. Terunuma, K. Yokoya, A. Yamamoto, T. Barklow, G. Moortgat-Pick,
S. Stapnes, R.Tomas Garcia, R.Poeschl, J. List, E. Nanni

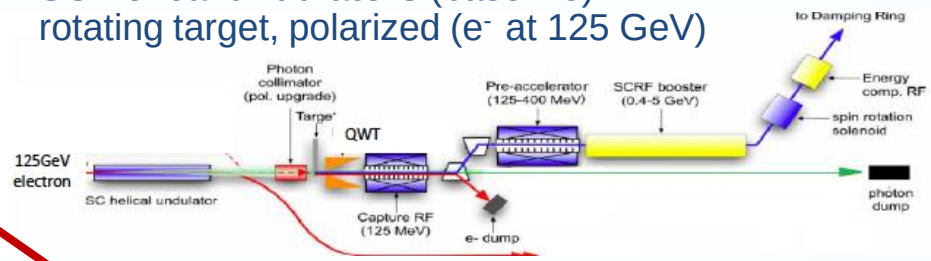
ILC parameters and beam accelerator sequence



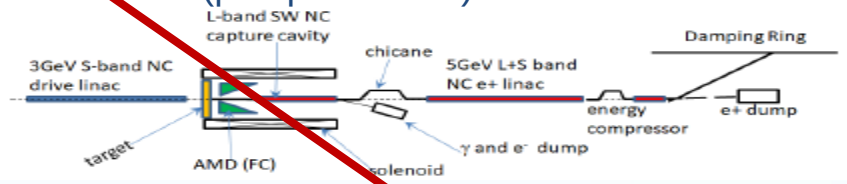
e- blue
e+ red

ILC 250 GeV

- **SC helical undulators** (baseline): rotating target, polarized (e^- at 125 GeV)

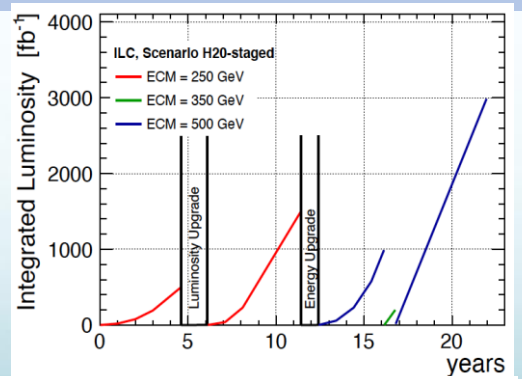


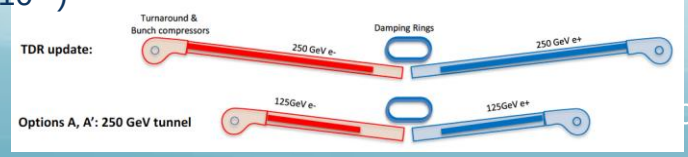
- **Electron driven source**: dedicated 3 GeV NC S-band TW e^- (pair production).



- **Energy upgrades**: 500 GeV (31.5 MV/m Q_0=1 x 10^{10}) , 1TeV (45 MV/m Q_0=2 x 10^{10}, 300 MW) more SCRF, tunnel extension
  - Kitakami site: 50km long, sufficient for 1TeV

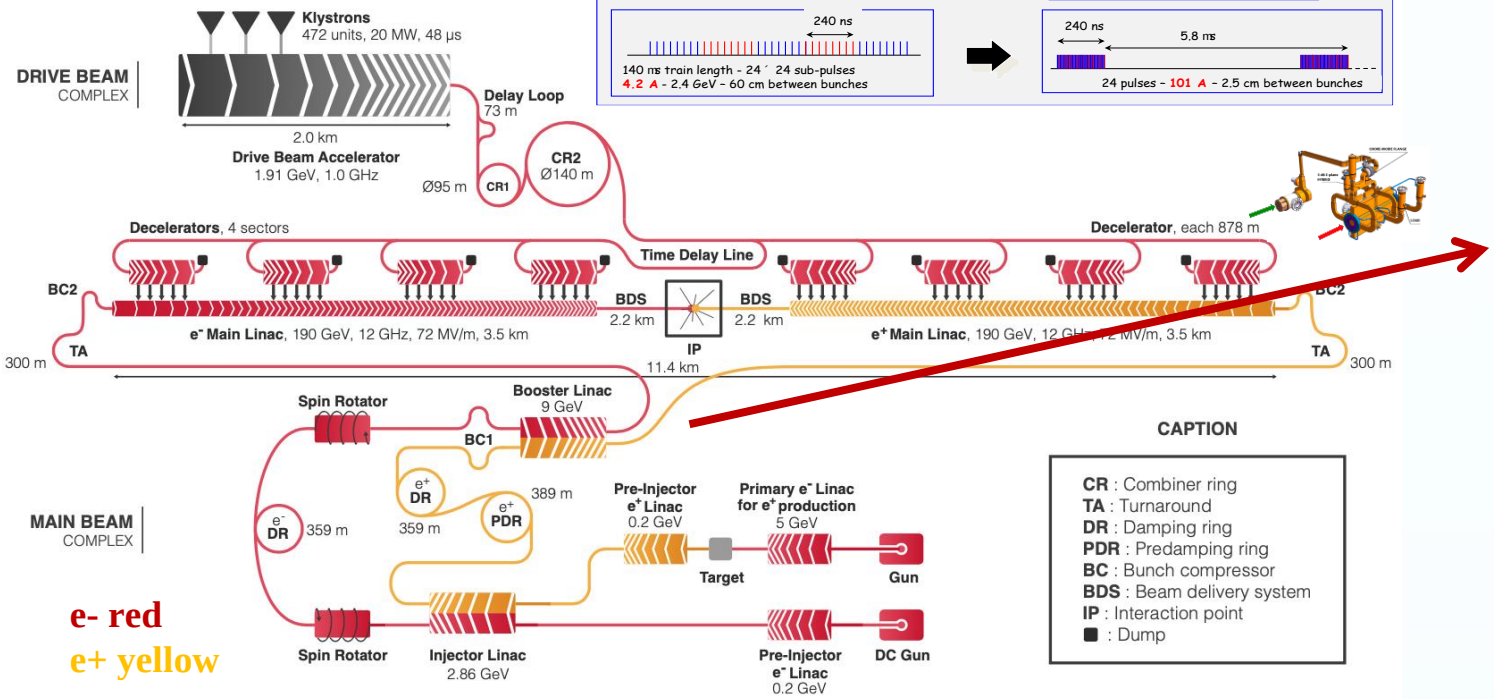
- **Luminosity upgrades**:
  - 2 x bunches, 2 x RF (1.35 -> 2.7x10^{34})
  - Run = 500GeV machine at 250GeV, 10Hz: factor 2 (2.7x10^{34} -> 5.4x10^{34})
  - Improve power efficiency





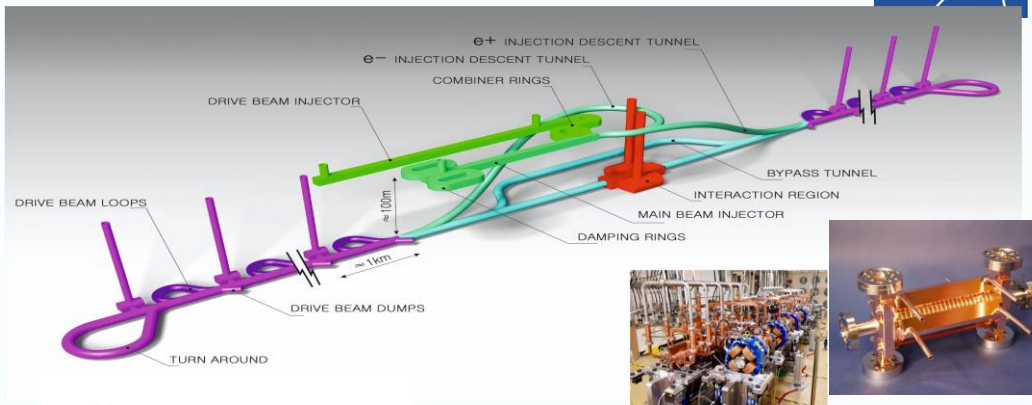
			Z-Pole [4]		Higgs [2,5]			500GeV [1*]		TeV [1*]
			Baseline	Lum. Up	Baseline	Lum. Up	L Up 10Hz	Baseline	Lum. Up	case B
Center-of-Mass Energy	E_{cm}	GeV	91.2	91.2	250	250	250	500	500	1000
Beam Energy	E_{beam}	GeV	45.6	45.6	125	125	125	250	250	500
Collision rate	f_{col}	Hz	3.7	3.7	5	5	10	5	5	4
Pluse interval in electron main linac		ms	135	135	200	200	100	200	200	200
Number of bunches	n_b		1312	2625	1312	2625	2625	1312	2625	2450
Bunch population	N	10^{10}	2	2	2	2	2	2	2	1.737
Bunch separation	Δt_b	ns	554	554	554	366	366	554	366	366
Beam current		mA	5.79	5.79	5.79	8.75	8.75	5.79	8.75	7.60
Average beam power at IP (2 beams)	P_B	MW	1.42	2.84	5.26	10.5	21.0	10.5	21.0	27.3
RMS bunch length at ML & IP	σ_z	mm	0.41	0.41	0.30	0.30	0.30	0.30	0.30	0.225
Emittance at IP (x)	$\gamma\varepsilon^*_x$	µm	6.2	6.2	5.0	5.0	5.0	10.0	10.0	10.0
Emittance at IP (y)	$\gamma\varepsilon^*_y$	nm	48.5	48.5	35.0	35.0	35.0	35.0	35.0	30.0
Beam size at IP (x)	σ^*_x	µm	1.118	1.118	0.515	0.515	0.515	0.474	0.474	0.335
Beam size at IP (y)	σ^*_y	nm	14.56	14.56	7.66	7.66	7.66	5.86	5.86	2.66
Luminosity	L	$10^{34}/cm^2/s$	0.205	0.410	1.35	2.70	5.40	1.79	3.60	5.11
Luminosity enhancement factor	H_D		2.16	2.16	2.55	2.55	2.55	2.38	2.39	1.93
Luminosity at top 1%	$L_{0.01}/L$	%	99.0	99.0	74	74	74	58	58	45
Number of beamstrahlung photons	n_γ		0.841	0.841	1.91	1.91	1.91	1.82	1.82	2.05
Beamstrahlung energy loss	δ_{BS}	%	0.157	0.157	2.62	2.62	2.62	4.5	4.5	10.5
AC power [6]	Psite	MW			111	138	198	173	215	300
Site length	Lsite	km	20.5	20.5	20.5	20.5	20.5	31	31	40

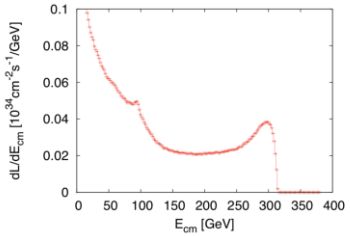
CLIC parameters and beam accelerator sequence



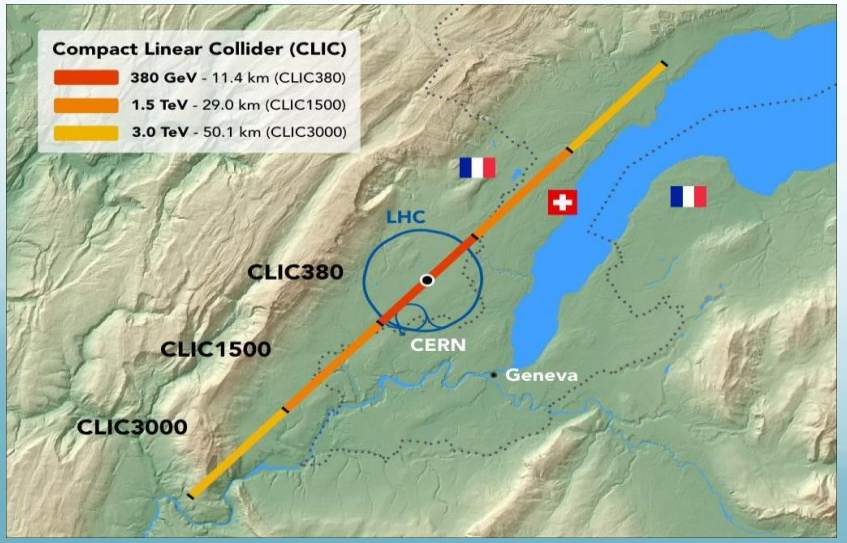
CAPTION

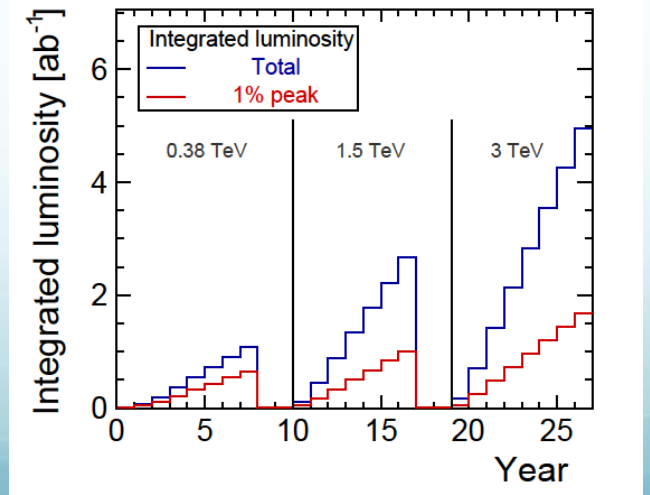
CR : Combiner ring
TA : Turnaround
DR : Damping ring
PDR : Predamping ring
BC : Bunch compressor
BDS : Beam delivery system
IP : Interaction point
■ : Dump





Luminosity performance studies
(Z-pole and gamma-gamma)





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

The LCs Table

Mode / Parameters	Baseline ILC	Baseline CLIC	Baseline C3	ILC 2IPs CERN	Up CLIC 2IPs	Up C3 2IPs
Beam energy E_0 [GeV]	250	380	250	250		
Total length [km]	20.5	11.4	8.0	20.5	20.5	20.5
Luminosity [10^{-34} cm^{-2}s^{-1}]	1.35	1.3	1.3			
Horizontal emittance ε_x [nm]	500	900	900			
Vertical emittance ε_y [nm]	35	20	20			
RF Gradient [Mv/m]	31.5	72	70			
Linac length [km]						
Bunch length σ_z [mm]	300	70	100			
Bunches / train n_b	1312	352	266			
Bunch separation Δt_b [ns]	554	0.5				
Bunch population N_b [10^{10}]	2	0.52				
Repetition rate f_{rep} [Hz]	5	50	60			
Bunch charge [nC]	3.2	0.83	1			
# of IPs n_{IP}	1	1	1	2	2	2
Crossing angle θ_c [mrad]	14	16.5	14			
L^* [m]	4.1	6.0	4.3			
BDS length [km]						
β_x^* [mm]	8.0	8.0	12.0			