Technologies and Tests for e+e- Circular Colliders: SuperKEKB and Tau-Charm

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Snowmass: Accelerator Technologies Capabilities

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U.S. DEPARTMENT OF ENERGY

Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Topics and Contributors

SuperKEKB Tsukuba

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Super CT Novosibirsk

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Super Tau-Charm Tor Vergata-Frascati

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Discussion: US Roles, Test Beams, Technologies

Performance Achievements by PEP-II, KEKB, DAFNE, and BEPC-II

Two ring colliders with one IR work well.

Energy asymmetry ok.

Greater than 1000 bunches per beam can be used.

Bunch-by-bunch feedbacks effective with 4 nsec bunch spacings.

Multi-megawatt continuous RF systems manageable.

IP collisions with either head-on and crossing angles work.

Low detector backgrounds achievable with ampere beams.

Crab cavities, crab waist, and low emittance tuning can be done.

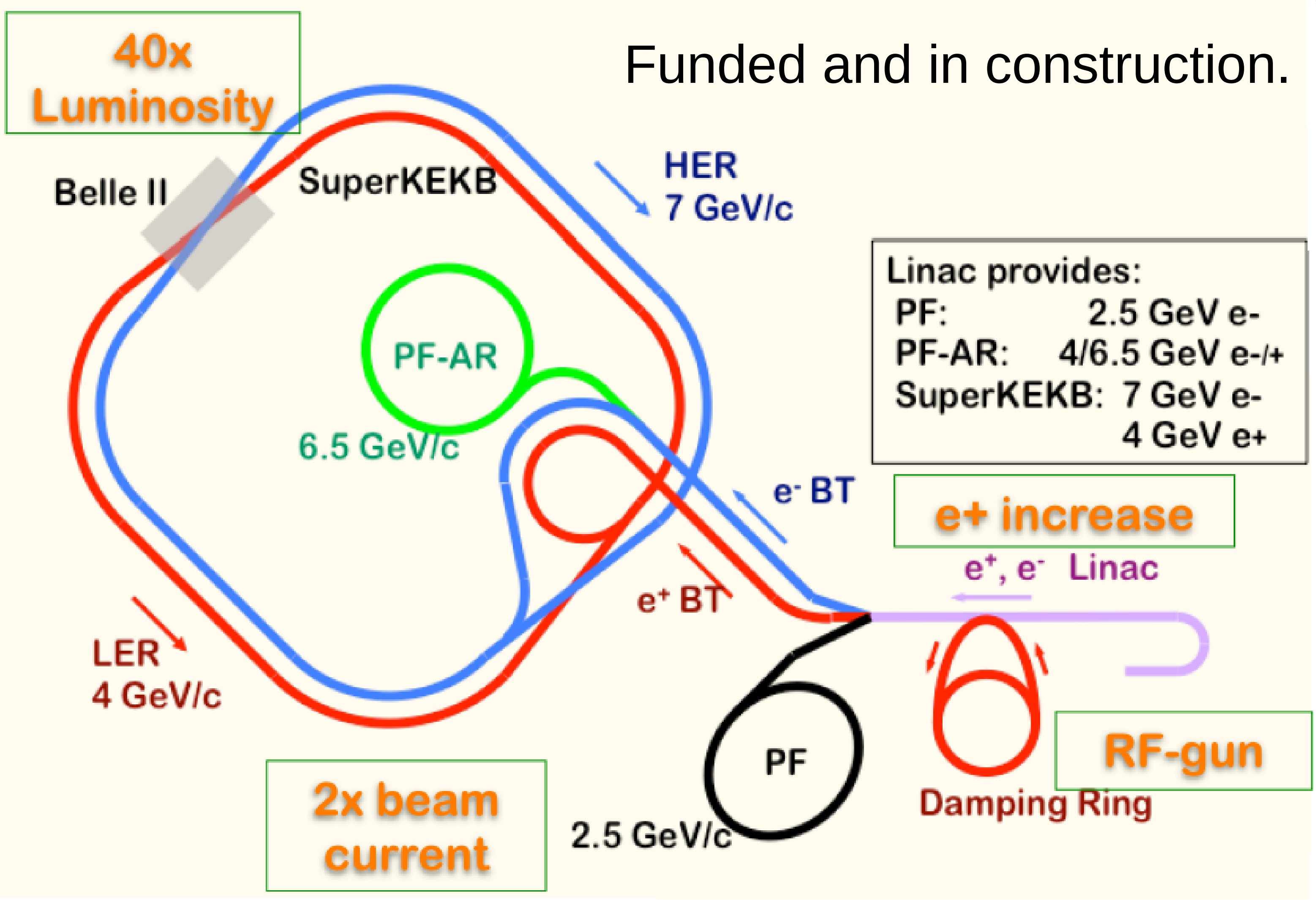
Beam instabilities (ECI, FII, IBS, resistive wall, …) mostly tamed.

High power (10kW/m) vacuum systems can be constructed.

Full energy injection

Top-up injection

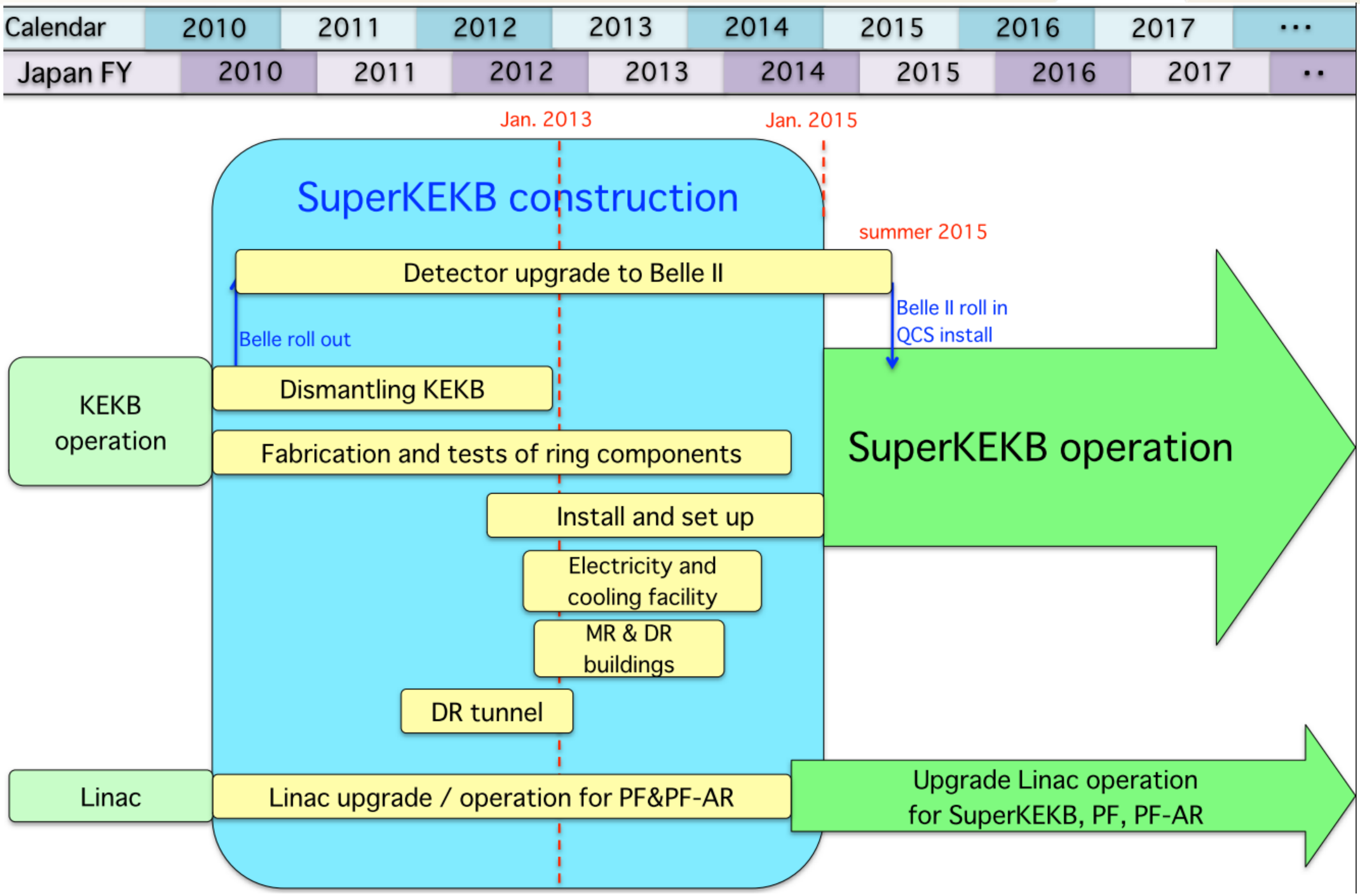
SuperKEKB Tsukuba: Accelerator Layout



SuperKEKB Tsukuba: Parameters

2011/July/20	LER	HER	unit
E	4.000	7.007	GeV
I	3.6	2.6	A
Number of bunches	2,500		
Bunch Current	1.44	1.04	mA
Circumference	3,016.315		m
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/11.5(1.5)	nm/pm
Coupling	0.27	0.28	
β_x^*/β_y^*	32/0.27	25/0.30	mm
Crossing angle	83		mrad
α_p	3.25×10^{-4}	4.55×10^{-4}	
σ_δ	$8.08(7.73)\times10^{-4}$	$6.37(6.31)\times10^{-4}$	
V_c	9.4	15.0	MV
σ_z	6.0(5.0)	5(4.9)	mm
ν_s	-0.0247	-0.0280	
ν_x/ν_y	44.53/44.57	45.53/43.57	
U_0	1.87	2.43	MeV
$\tau_{x,y}/\tau_s$	43.1/21.6	58.0/29.0	msec
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807	
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$

SuperKEKB Schedule



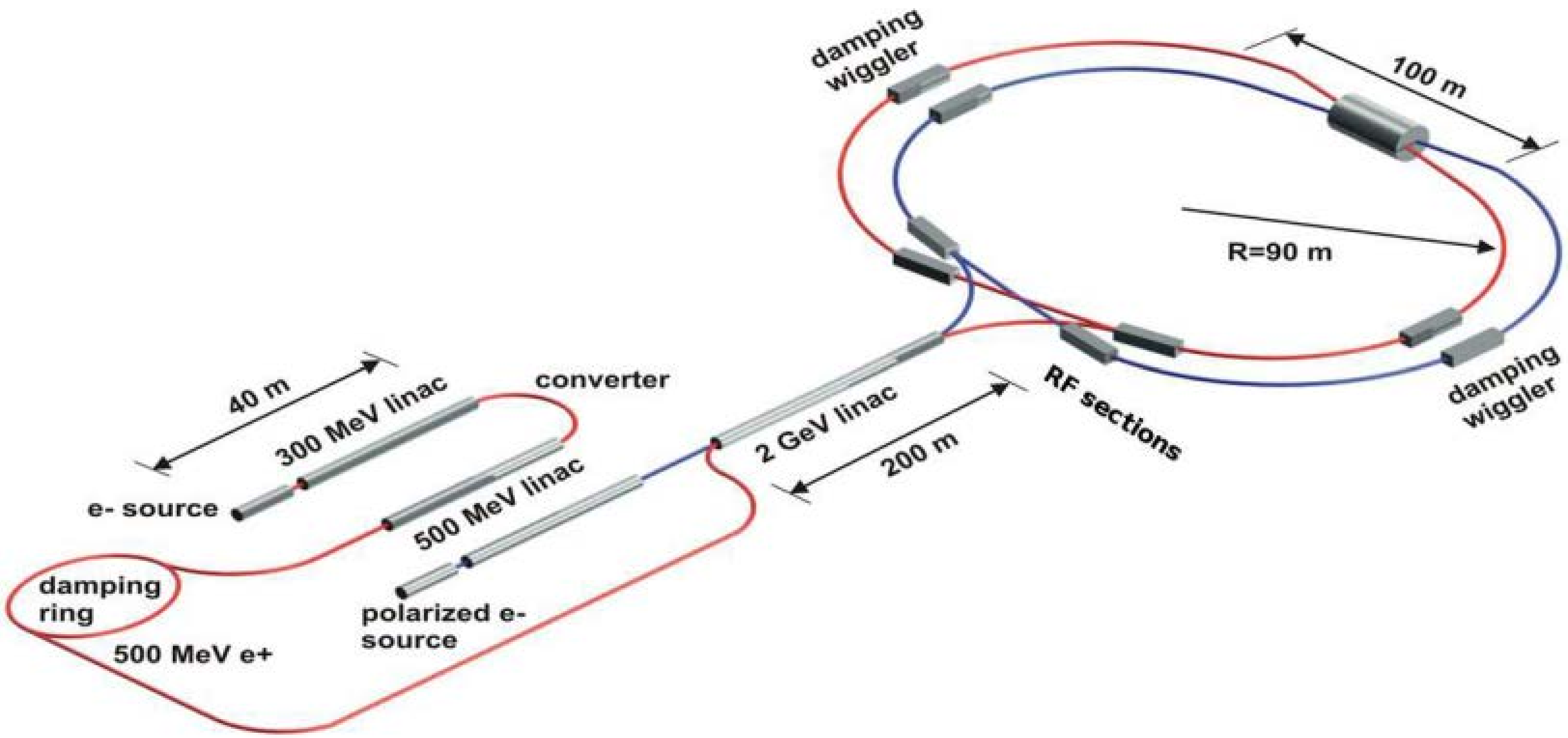
SuperKEKB Rings Components

Potential US-Japan and SLAC-SuperKEKB Collaboration Items

- Collaboration has been already going on
  - Bunch-by-bunch feedback
  - X-band deflector for beam diagnostics at Linac
  - X-band structure development
  - Beam dynamics for CSR, beam-beam, etc.

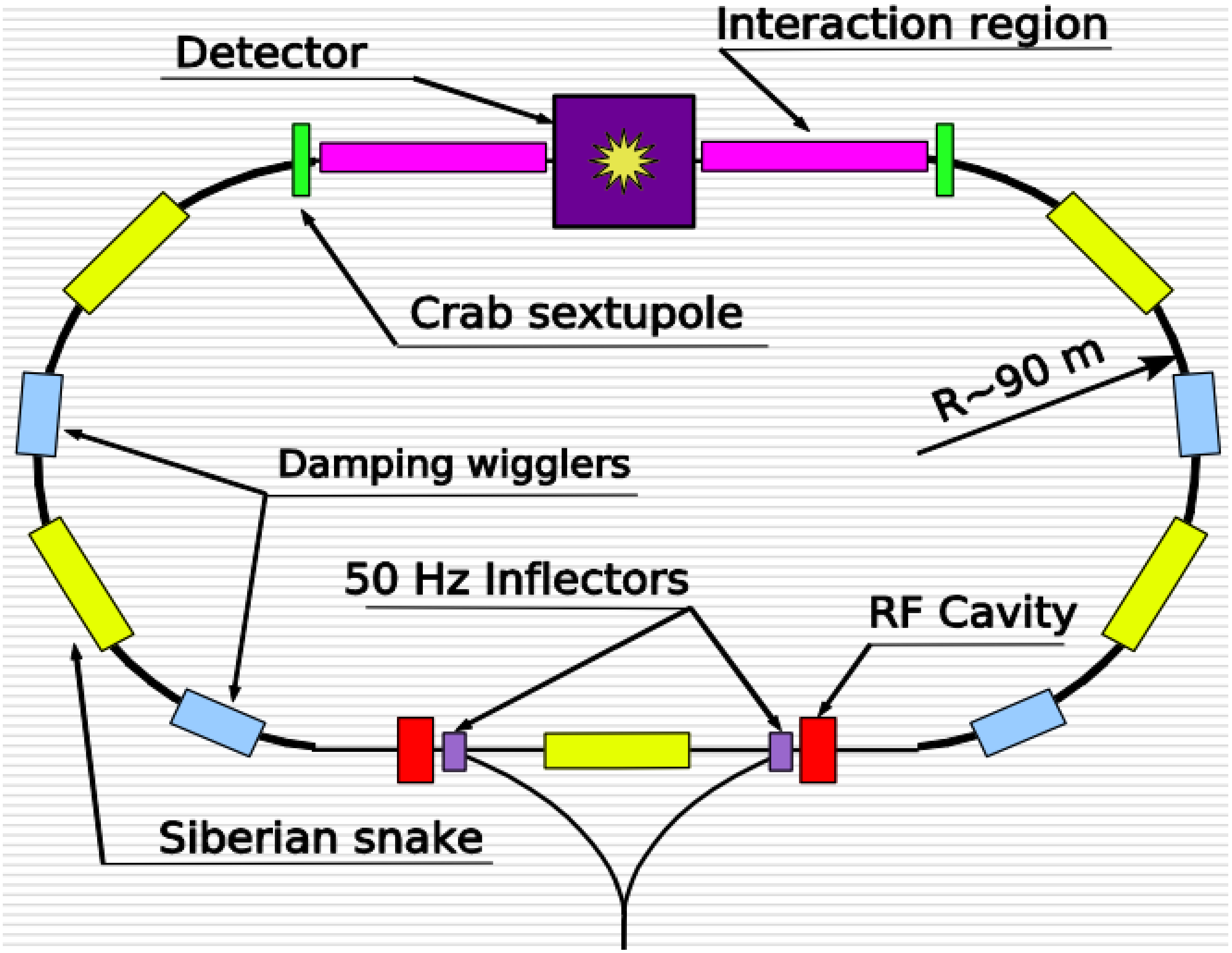
- Possible items for collaboration with SLAC for SuperKEKB:
  - Machine-detector interface, beam background at collision with top-up injection. Collimation schemes and hardware.
  - Low-emittance & high luminosity tuning with high-current collision. Beam-beam collision feedback, dithering, etc.
  - Low emittance & high current e+e- injector, from gun through Linac.
  - Commissioning of the e+ damping ring.
  - e+ source, flux concentrator, as well as beam commissioning of linac to DR.
  - Synchronization of 5 rings and the linac.
  - Alignments for Linac and/or rings.

Super CT Novosibirsk: Overall Layout



CDR is completed. Seeking funding.

Super CT Novosibirsk: Ring Layout



Super CT Novosibirsk: Parameters

Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	766.6 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	30/30/15 ms			
Bunch length	16 mm	11 mm	10 mm	10 mm
Energy spread	$10.1 \cdot 10^{-4}$	$9.96 \cdot 10^{-4}$	$8.44 \cdot 10^{-4}$	$7.38 \cdot 10^{-4}$
Momentum compaction	$1.00 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$
Synchrotron tune	0.007	0.010	0.009	0.008
RF frequency	508 MHz			
Harmonic number	1300			
Particles in bunch	$7 \cdot 10^{10}$			
Number of bunches	390 (10% gap)			
Bunch current	4.4 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.15	0.15	0.12	0.095
Luminosity	$0.63 \cdot 10^{35}$	$0.95 \cdot 10^{35}$	$1.00 \cdot 10^{35}$	$1.00 \cdot 10^{35}$

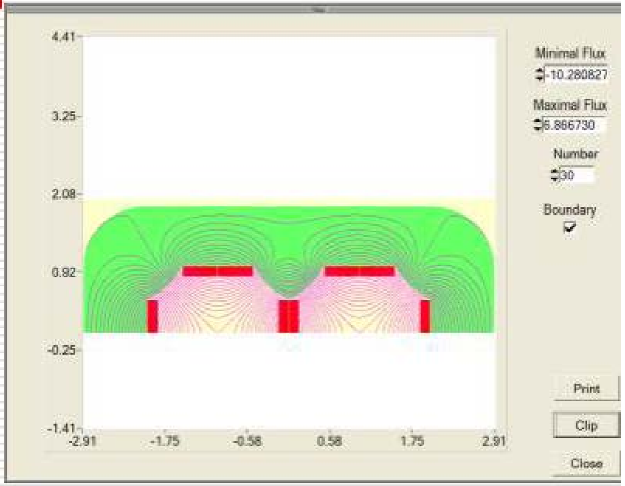
Super CT Novosibirsk: Main Collider Features

- Two Rings
- Crab waist collisions
- Small Beta Function at IP (β_y ~ 800 um)
- Superconducting wigglers to keep the same damping and emittance in the whole energy range
- High Beam Current
- 5 Siberian Snakes
- Electron Polarization Source
- 2.5 GeV Linac
- 50 Hz Injection Rate

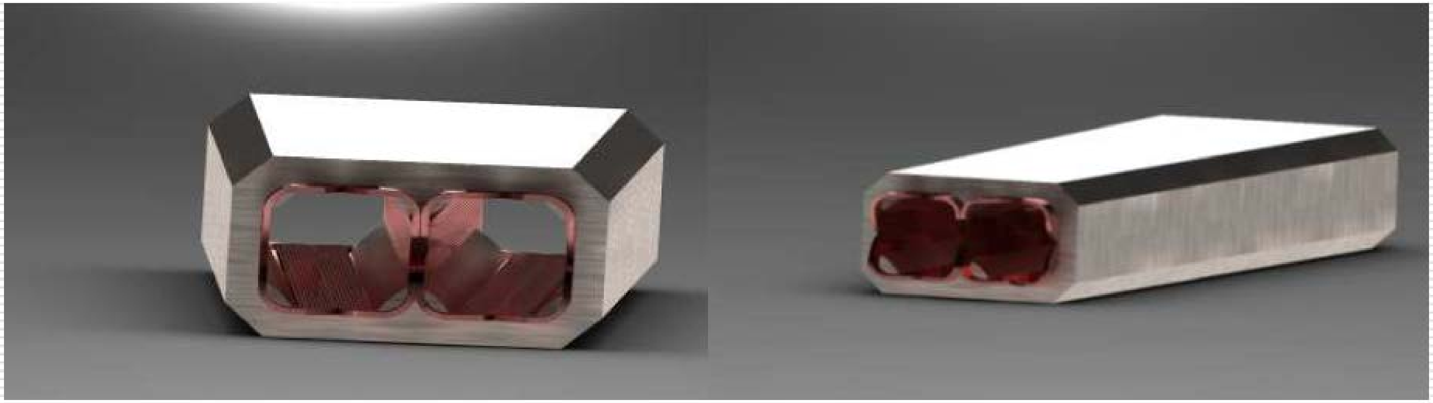
Super CT Novosibirsk: IR quadrupoles

QD0 Lens

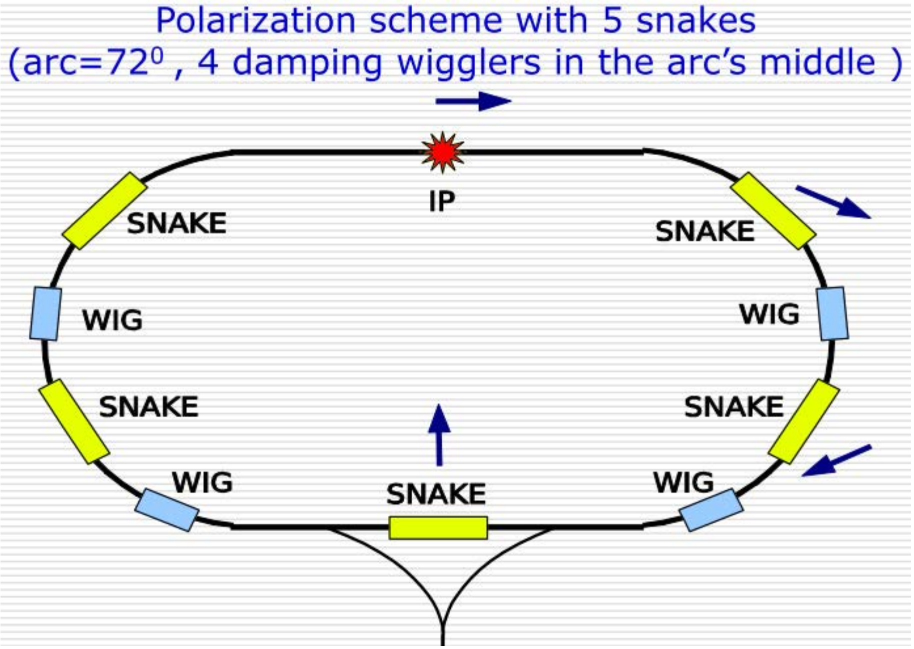
SC iron yoke twin aperture magnet
Excitation current 1.15 kA
Aperture diam 2 cm
Gradient 10.7 kGs/cm
Length 20 cm

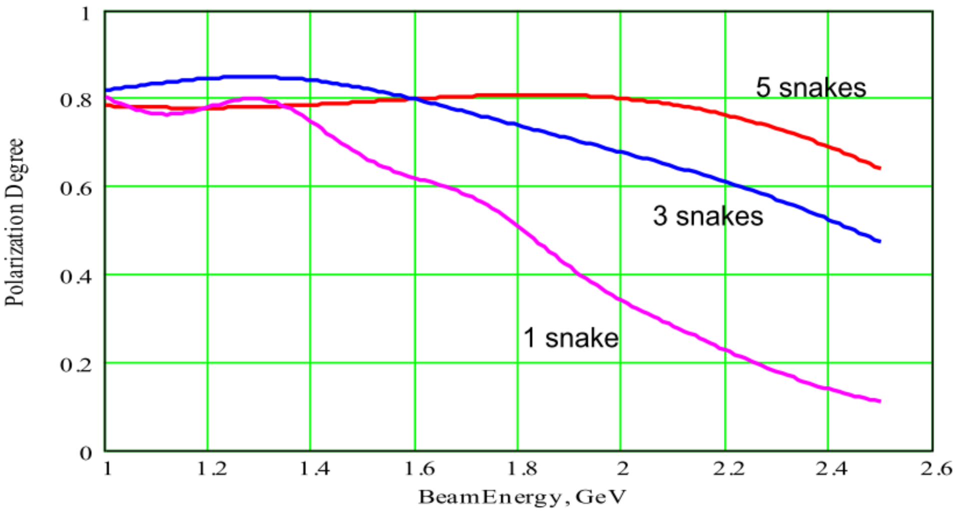


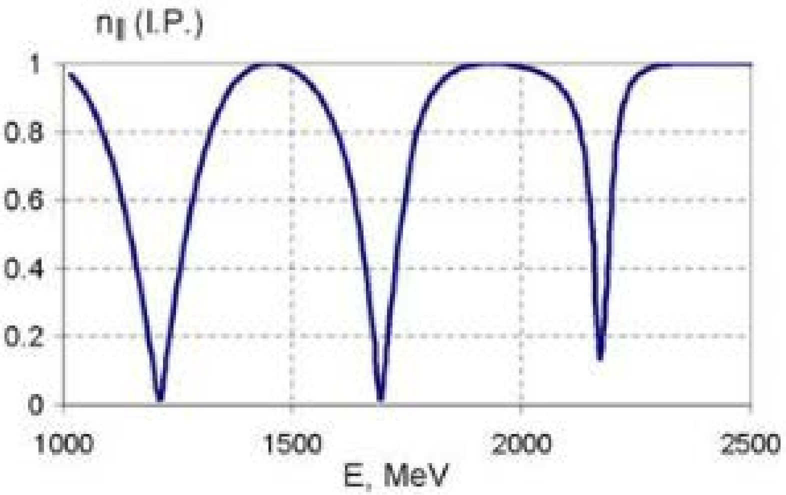
Prototype of QD0 now is constructed at BINP



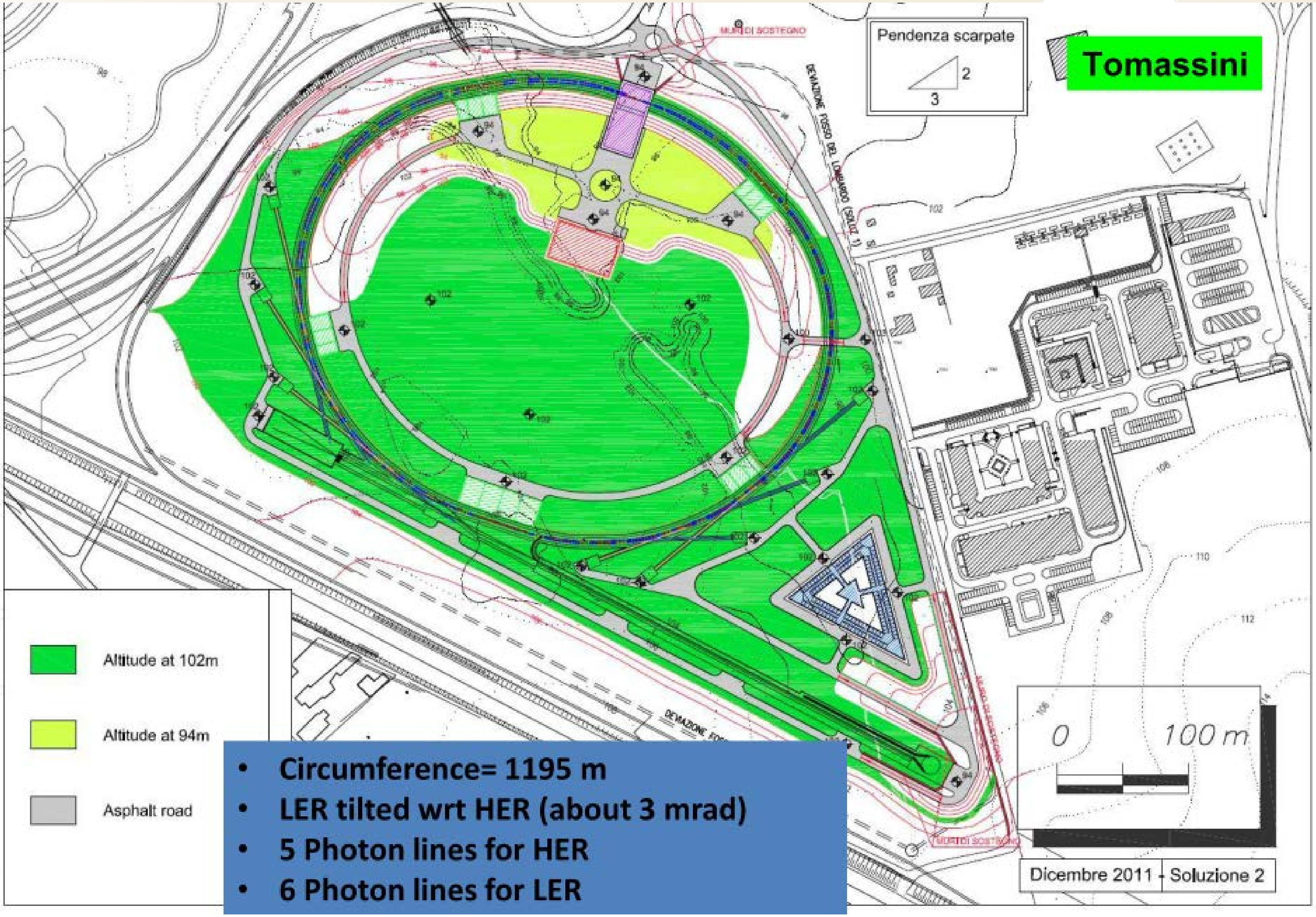
Super CT Novosibirsk: Polarization







Tau-Charm Factory at Tor Vergata-Frascati, Italy



- Circumference= 1195 m
- LER tilted wrt HER (about 3 mrad)
- 5 Photon lines for HER
- 6 Photon lines for LER

Tor Vergata-Frascati Tau-Charm Factory Parameters

SLAC

		Base Line		Low Emittance		High Current		τ/charm	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY (10^{36})	$cm^{-2}\ s^{-1}$	1		1		1		1	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrad	60		60		60		60	
Piwinski angle	rad	20.80	16.91	29.42	23.91	13.12	10.67	8.00	6.50
β_x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
ε_x (without IBS)	nm	1.97	1.82	1.00	0.91	1.97	1.82	1.97	1.82
ε_x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
ε_y	pm	5	6.15	2.5	3.075	10	12.3	13	16
σ_x @ IP	μm	7.211	8.872	5.099	6.274	10.060	12.370	18.749	23.076
σ_y @ IP	μm	0.036	0.036	0.021	0.021	0.054	0.054	0.092	0.092
Σ_x	μm	11.433		8.085		15.944		29.732	
Σ_y	μm	0.050		0.030		0.076		0.131	
σ_L (0 current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
σ_L (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Buckets distance	ns	4.20		4.20		2.10		2.10	
Ion gap	%	2		2		2		2	
RF frequency	MHz	476		476		476		476	
Harmonic number		1998		1998		1998		1998	
Number of bunches		465		465		931		931	
N. Particle/bunch (10^{10})		5.08	6.56	3.92	5.06	4.15	5.36	1.83	2.37
Tune shift x		0.0026	0.0040	0.0020	0.0031	0.0053	0.0081	0.0063	0.0096
Tune shift y		0.1067	0.1069	0.0980	0.0981	0.0752	0.0755	0.1000	0.1001
Long. damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
σ_E (full current)	δE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.94E-04	7.34E-04
CM σ_E	δE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Total lifetime	min	4.23	4.48	3.05	3.00	7.08	7.73	11.41	6.79
Total RF Power	MW	16.38		12.37		28.83		2.81	

Tau-Charm Factory at Tor Vergata-Frascati, Italy

Assuming that the cm energy should range from J/Ψ(3100) to Ψ(4415) GeV, with asymmetric beam energies, there are several options (no boost at J/Ψ)

Difficult to keep large currents and have reasonable lifetimes at low energy
→ lower limit 1.3 GeV

Polarization resonances force electron E to be 1.536 or 2.417 GeV

		Pol beam	in red		
E_{cm}	Resonance	E_LER	E_HER	Boost	Notes
10,58	Υ(4S)	4,18	6,700	0,24	SuperB
3,686	Tau	1,3	2,613	0,36	Larger boost but no polarization
		1,405	2,417	0,27	
		1,536	2,211	0,18	
3,770	Charm	1,3	2,733	0,38	Larger boost but no polarization
		1,470	2,417	0,25	
		1,536	2,313	0,21	
4,400	Max E	1,3	3,723	0,55	Larger boost but no polarization
		1,536	2,211	0,18	
		2,002	2,417	0,09	

Tau-Charm Factory at Tor Vergata-Frascati, Italy

Priorities must be defined for optimizing the machine design.

Luminosity

Polarization

Asymmetric option

Status: Design is under revision to be presented to the Italian Government later in the year.

Key Common Facility Features for these e+e- Colliders

Two rings with a single interaction point
Crossing angle at the IP with very flat beams (emittance ratio = ~300)
Need low detector backgrounds
Crab waist collisions
Wigglers to reduce damping times and emittances
Picometer-vertical and nanometer-horizontal emittances
Longitudinal polarized e- beams at the IP with spin rotators
Low emittance beam with beam-beam effects
Polarized beam with strong beam-beam effects
High currents:
- Coherent Synchrotron Radiation (CSR)
- Electron Cloud Instability ECI
- Fast Ion Instability FII
- Low impedance vacuum chambers
- High power vacuum chambers

Interaction Point Design

Key issues: 300 micron scale βy^*, large betas in IR quadrupoles, quadrupoles inside the detector, collision feedback, vacuum chamber design, magnet tolerances, alignment and jitter tolerances, crab cavities, crab waist,

US relevance: LHC, Muon collider, ILC, Higgs factory

Test accelerators/facilities: SuperKEKB, CESR-TA, PETRA-3, vibration stabilization facility

Technologies:

- 100+ Hz IP dither feedback on luminosity
- Superconducting magnets
- Permanent magnets
- Power supply stability
- Vibration control
- Non-linear optics

Machine Detector Interface

Key issue: Synchrotron radiation backgrounds, lost particle backgrounds, SR heating of vacuum chambers, radiation damage/lifetime of detectors, sensor occupancy, luminosity measurement.

US relevance: LHC, Muon collider, ILC, Higgs factory

Test accelerators/facilities: SuperKEKB, LHC, lab tests of high power vacuum chambers, lab tests of detector lifetime

Technologies:

- IP vacuum pumping
- Advanced masking
- Rapid luminosity feedback
- Detector design

Low Emittances

Key issue: Component tolerances, vibration control, emittance measuring hardware, active feedbacks, field nonlinearities.

US relevance: ILC, Ultimate Storage Ring

Test accelerators/facilities: SuperKEKB, PETRA-3, CESR-TA, NSLS-II, lab tests of x-ray size monitors

Technologies:

- 300 to1 emittance tuning techniques
- Coherent Synchrotron Radiation CSR simulations and measurements
- Fast Ion Instability FII simulations and measurements
- Intra-Beam Scattering IBS simulations and measurements
- Electron Cloud Instability ECI simulations and measurements
- Effects of spin rotators.
- Effects of beam-beam interaction

High Current Effects

Key issues: Beam stability, high power RF, high power vacuum components, AC wall efficiency, injector capabilities, I> 1 A.

US relevance: LHC, muon collider, muon storage ring, Project X, Ultimate Storage Ring

Test accelerators/facilities: SuperKEKB, CESR-TA

Technologies:

- Better bunch feedbacks
- ECI control
- IBS mitigations
- FII mitigations
- More efficient klystrons
- High power cavities
- Longitudinal beam feedback

Longitudinally Polarized e- Beam at the Interaction Point

Key issue: Injected polarization, beam lifetime, polarization lifetime, spin rotators, polarization measurements, effect on IP optics, beam-beam effect on polarization.

US relevance: ILC

Test accelerators/facilities: SuperKEKB?, VLEPP-2000?

Technologies:

- Siberian snakes
- Solenoidal rotators
- Beam-beam depolarization diagnostics
- Spin manipulation in the Damping Ring and Linac.
- e- polarized source

Example: Project Considerations (US-Japan or SLAC-SuperKEKB)

IP feedback on luminosity:
- Fast dither x, y and y’ (100 Hz) position and angle
- Lock in amplifiers for amplitude and phase
- All planes at once
- Single step or Newton algorithm

Linac beam position monitors (BPM):
- Single passage for linac use
- Multi-passage for ring use
- Present hardware not reliable nor precise enough

Beam collimation:
- Moveable jaws like PEP-II design
- Low impedance
- Multiple stages for effective spray elimination

Accelerator physics:
- IP MDI, IP masking
- CSR
- Beam-beam effect
- Commissioning

Bunch-by-bunch feedback:
- Circuit design
- Power amplifier analysis
- Synchronization studies