Parameters of a 100km Very Large Hadron Collider

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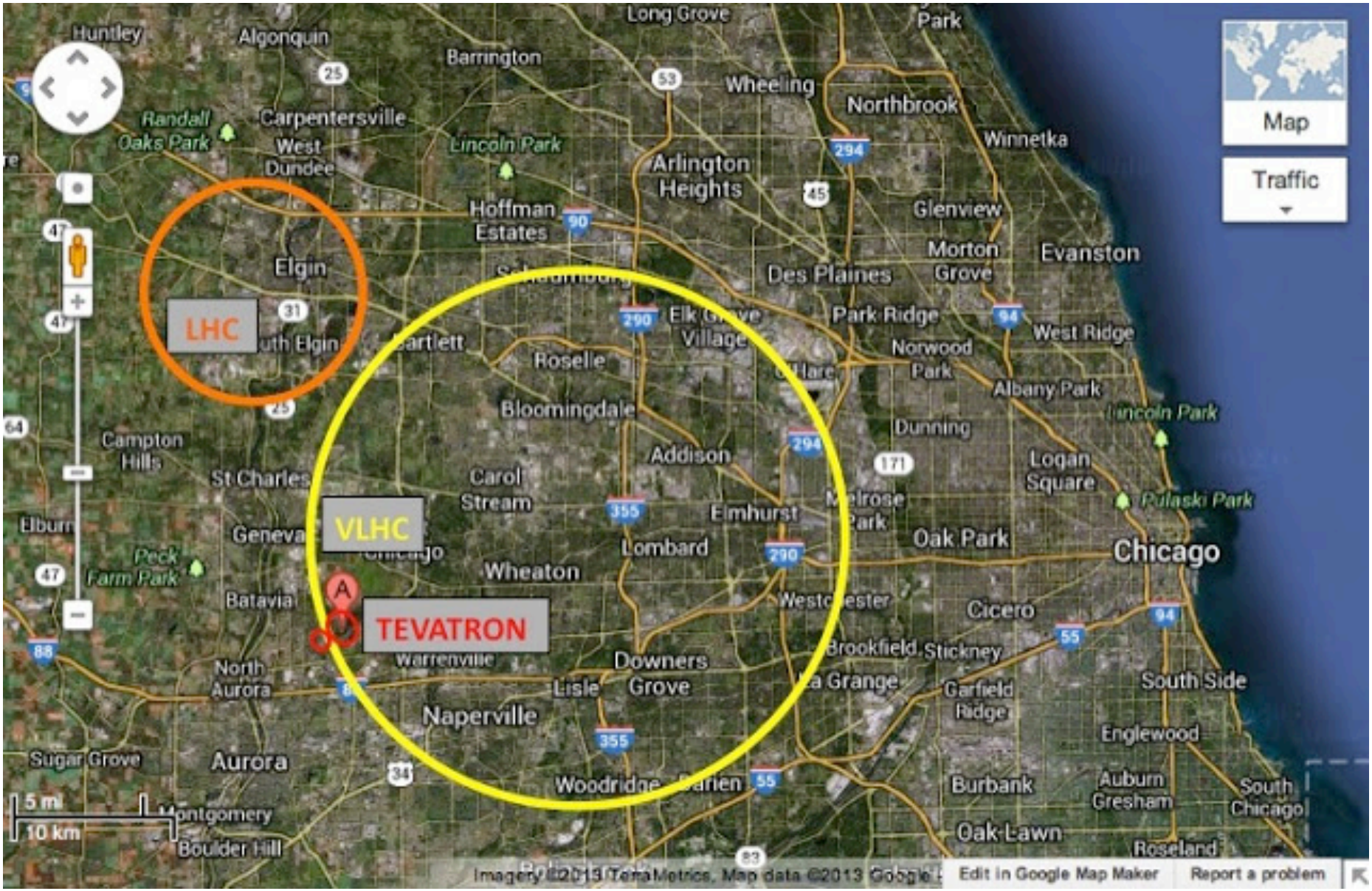
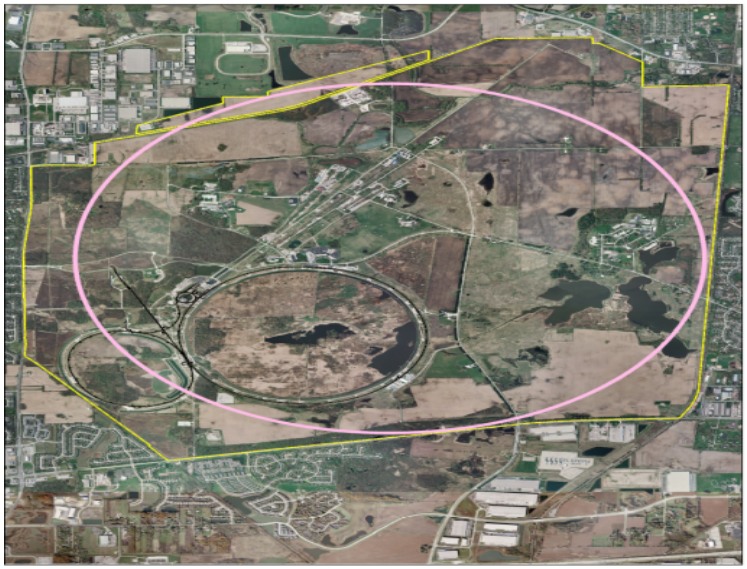
Outline

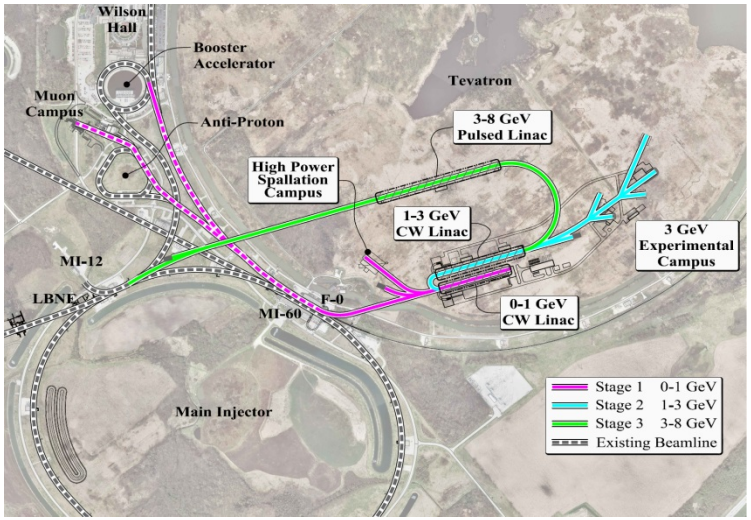
- VLHC: The Plan
  - Progress in colliders
- Important Parameters
  - Calculations
  - Methods
- Time Evolutions
  - Results and comparisons



Physics central blog

Injectors for the collider





- Ion source, Linac, Booster, Main Injector, Tevatron
- Project X for high intensity low emittance 8 GeV beam
  - Replace Linac and Booster
- Main injector to deliver 150 GeV beam
- New injector to accelerate from 150 to ~ 3 TeV

  - Reuse Tevatron tunnel with 16 T magnets

Hadron Colliders - Wikipedia

Hadron colliders	
Intersecting Storage Rings	CERN, 1971–1984
Super Proton Synchrotron	CERN, 1981–1984
ISABELLE	BNL, cancelled in 1983
Tevatron	Fermilab, 1987–2011
Relativistic Heavy Ion Collider	BNL, 2000–present
Superconducting Super Collider	Cancelled in 1993
Large Hadron Collider	CERN, 2009–present
High Luminosity Large Hadron Collider	Proposed, CERN, 2020–
Very Large Hadron Collider	Theoretical

Hadron Colliders

	ISR	SPS	Tevatron	RHIC (pp)	LHC (2012)
Circumference [km]	0.94	6.9	6.3	3.8	26.7
Energy [GeV]	31	315	980	255	4000
Number of bunches	dc	6	36	107	1380
Bunch spacing [ns]	-	1150	396	108	50
Bunch intensity [$\times 10^{11}$]	-	2.75	(3.1/1)	2.0	1.7
Particles/beam [$\times 10^{14}$]	9.8	7.8/4.2	112/36	143	3089
Trans. rms Emitt [µm]		1.5/0.15	(3/1.5)	3.3	2.5
Beam-beam tune shift	0.0035x8	0.005x3	0.013x2	0.007x2	0.01x2
Luminosity [$\times 10^{32}$ $cm^{-2}s^{-1}$]	1.3	0.06	4.0	2.3	77
# of events/crossing			12		37
Stored beam energy [MJ]	0.005	0.04	1.75/0.57	0.57	140

VLHC Principles of Design

- Early plans
  - 233 km circumference
  - Stage 1 ring: (1 to 20) TeV
  - Stage 2 ring : (20 to 87.5) TeV
  - Super-ferric magnets for the 2 T low field, stage 1, Injection from Tevatron
  - Nb_3Sn magnets for 10T high field, stage 2. Injection from Stage 1
- 50 TeV in a 100 km ring with 16T dipoles.
- Synchrotron radiation dominated hadron collider. Damping time ~ 1 hr; integrated luminosity is nearly independent of the initial emittance
- All modules in units of half cell length
- Cell length = integer multiple of bunch spacing. Ensures bunches collide in all detectors.
- Bunch spacing = integer multiple of Tevatron 53 Mhz bucket length.

Design parameters

	VLHC (2013)	LHC (design)
Circumference [km]	100	26.7
Top Energy [TeV]	50	7
Peak Luminosity [$x10^{34}$ cm^{-2} s^{-1}]	4.6	1
Bunch Intensity [$x10^{11}$]	0.15	1.15
Number of Bunches	17255	2808
β^*_x/β^*_y (m)	0.5 / 0.05	0.55 / 0.55
Norm. rms. ($\varepsilon_x,\varepsilon_y$) [μm]	1.5 , 1.5 (initial)	3.75 , 3.75
Beam size at IP (x,y) [μm]	(3.8, 1.2)	16.7, 16.7
Bunch length, rms (cm)	2.7	7.5
Crossing angle [μrad]	90	255
Beam Current (A)	0.12	0.58
Beam lifetime from pp [h]	11.3	18.4
Stored energy (MJ)	2073	362
# of interactions/crossing	132	19 (37 in 2012)

Luminosity

- Quality measurement: how many interactions from the beams.
- Luminosity expression

$$L = N_p^2 * M_b * f_{rev} / 4\pi * \sigma_x * \sigma_y * * R(\phi_c)$$

$$R(\phi_c) = 1/\sqrt{1 + (\phi_c * \sigma_{s,rms} / 2 * \sigma_{x,av})^2}$$

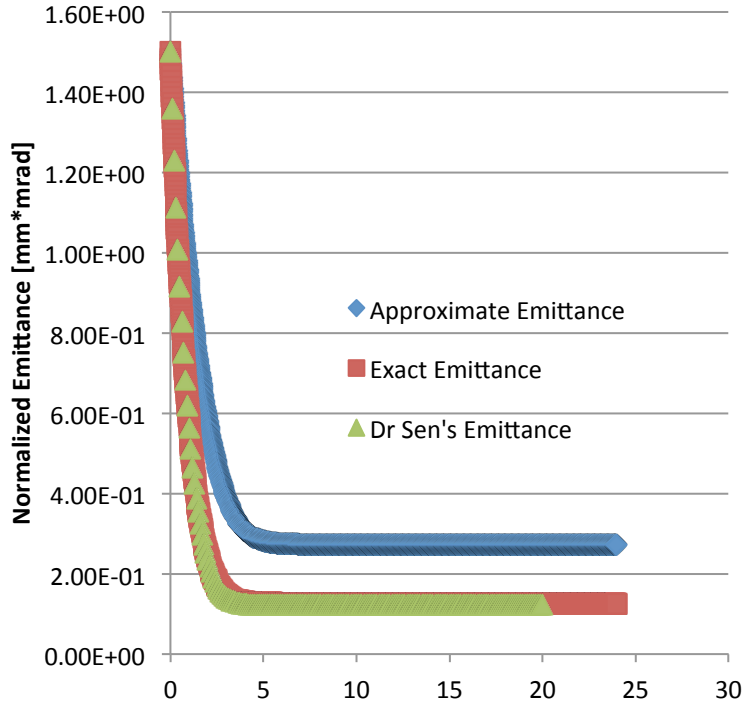
- The crossing angle can be made dynamic for "luminosity leveling."

Java Program

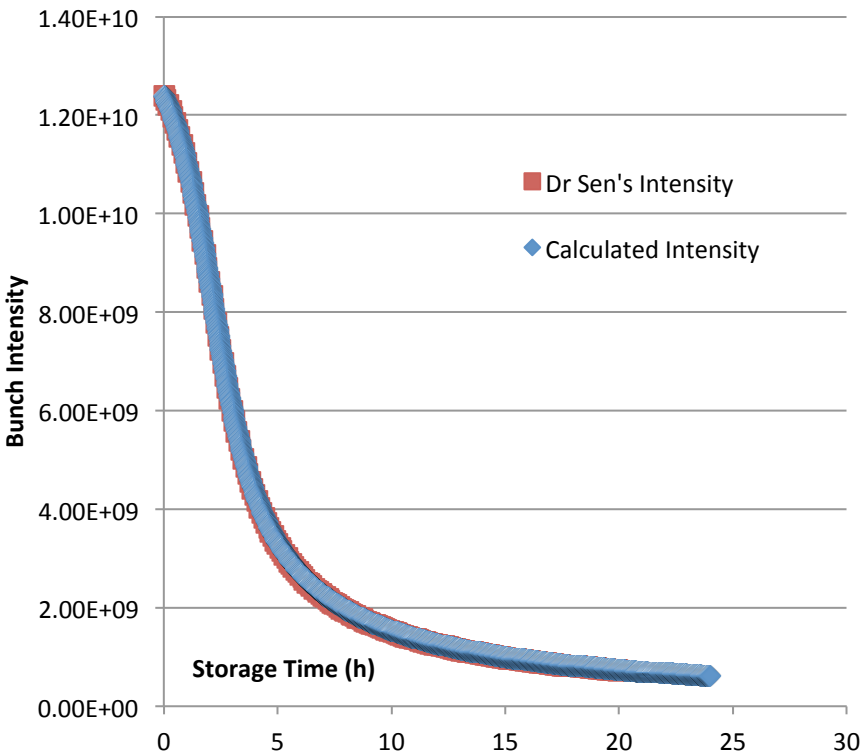
- Considers
  - Synchrotron radiation damping
  - Intra-beam scattering
  - Crossing angle manipulation
  - Longitudinal emittance is kept constant by noise injection
- Evaluates evolutions
  - Transverse emittance
  - Bunch Intensity
  - Luminosity
    - Average
    - Integrated
    - Leveling
  - Beam-beam tune shifts

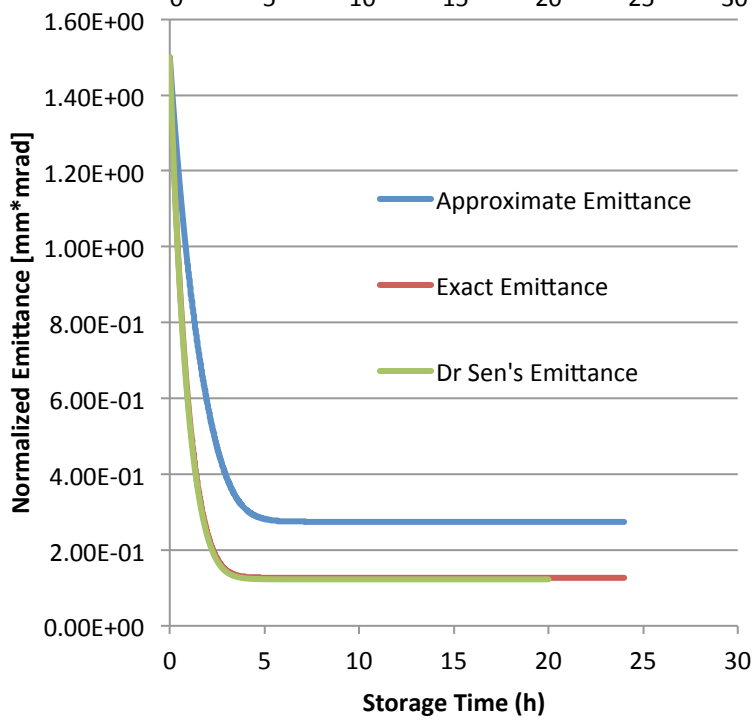
Time Evolution

Transverse emittance

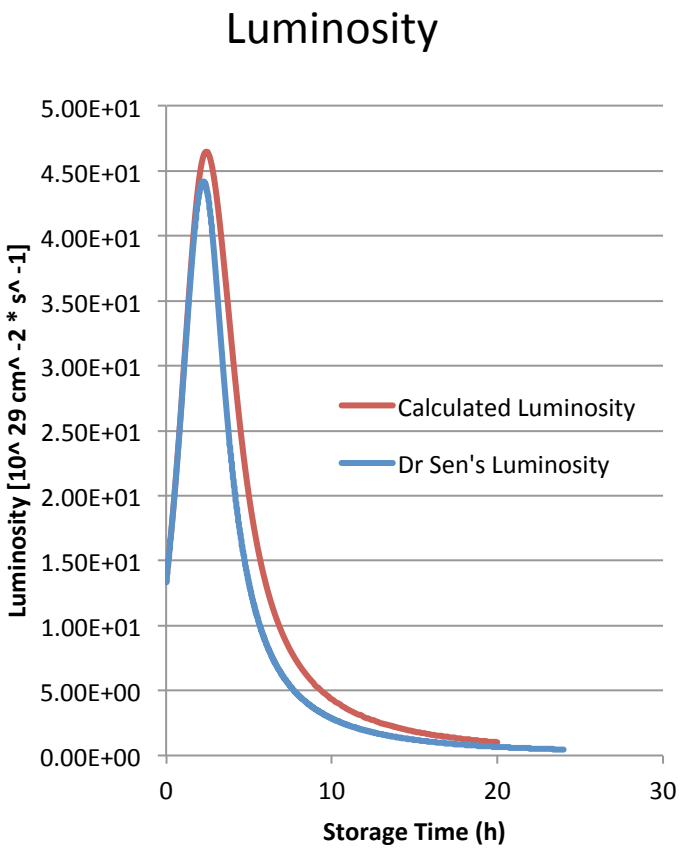


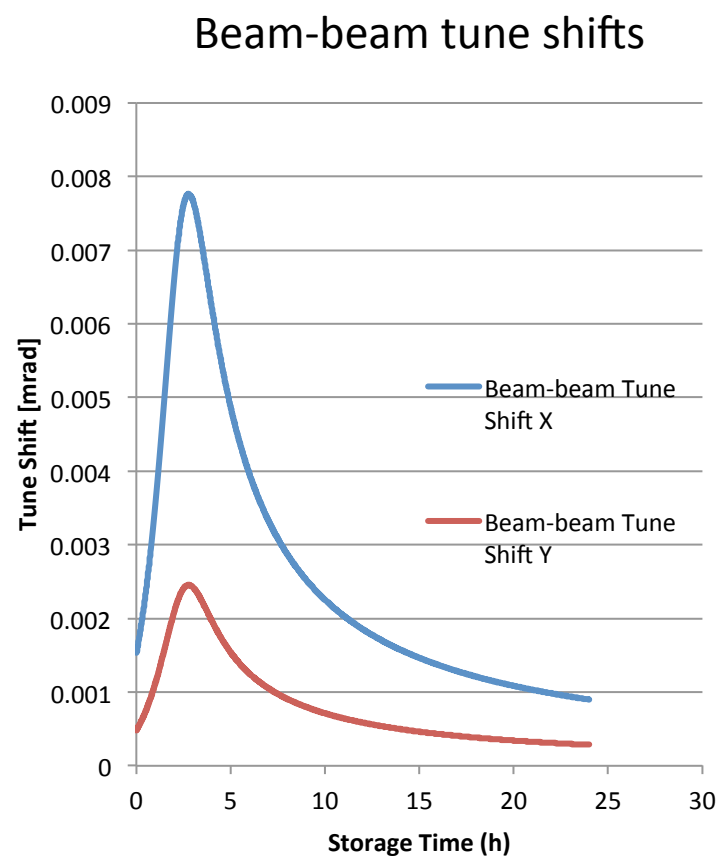
Bunch Intensity





Time evolution (cont)





Peak Luminosity ~ 4.5×10^{30} cm^{-2} s^{-1}
Optimal store time ~ 6 hours

Final Notes

50-50 TeV pp collider

- Testing of theory at level beyond current technology

Future developments for the project and the advancement of physics (as well as the economy)

- R&D on nonlinear optics, beam-beam compensation, novel diagnostics, radiation damage, new tunneling techniques, … to reduce cost.

Acknowledgements

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- Tanaji Sen
- Pushpa Bhat
- SIST Program
- Fermilab, DOE

pp design Parameters - 3

Lattice

	VLHC (2013)	LHC (design)
Cell Length [m]	225.8	106.9
Main bend field [T]	15.1	8.3
Phase advance /cell [deg]	90	90
(β^{max}x, β^{min}) in arc [m]	(385, 66)	180, 30
(D_x^{max}, D_x^{min}) in arc [m]	(2.5, 1.2)	2.0, 0.95
γ_t	95.5	55.7

Rf system

	VLHC (2013)	LHC (design)
Revolution frequency [kHz]	2.96	11.25
Harmonic number	215214	35640
Rf voltage	80	16
Synchrotron frequency [Hz]	7.25	21.4
Bucket area [eV-sec]	20.8	8.0
Bucket half height /rms energy spread	5.3	3.3

Beam-beam limits

Head-on : ξ achieved :

0.013 (Tevatron), ~ 0.01 (LHC)

Build a site filler tunnel (~ 16 km)
with lower field magnets (slide 4)

Equations

- Emittance diff eq

$$d\varepsilon/dt = (1/\tau_{ibs} - 1/\tau_{rad})*\varepsilon, \ \tau_{ibs}/\tau_{ibs,0} = (\varepsilon/\varepsilon_0)^{2.2}$$

- Intensity diff eq

$$dN/dt = -\sigma_{xsect,tot} * L/M_b$$

$$L = N_p^2 * M_b * f_{rev}/4\pi * \sigma_x * \sigma_y * R(\phi_c)$$