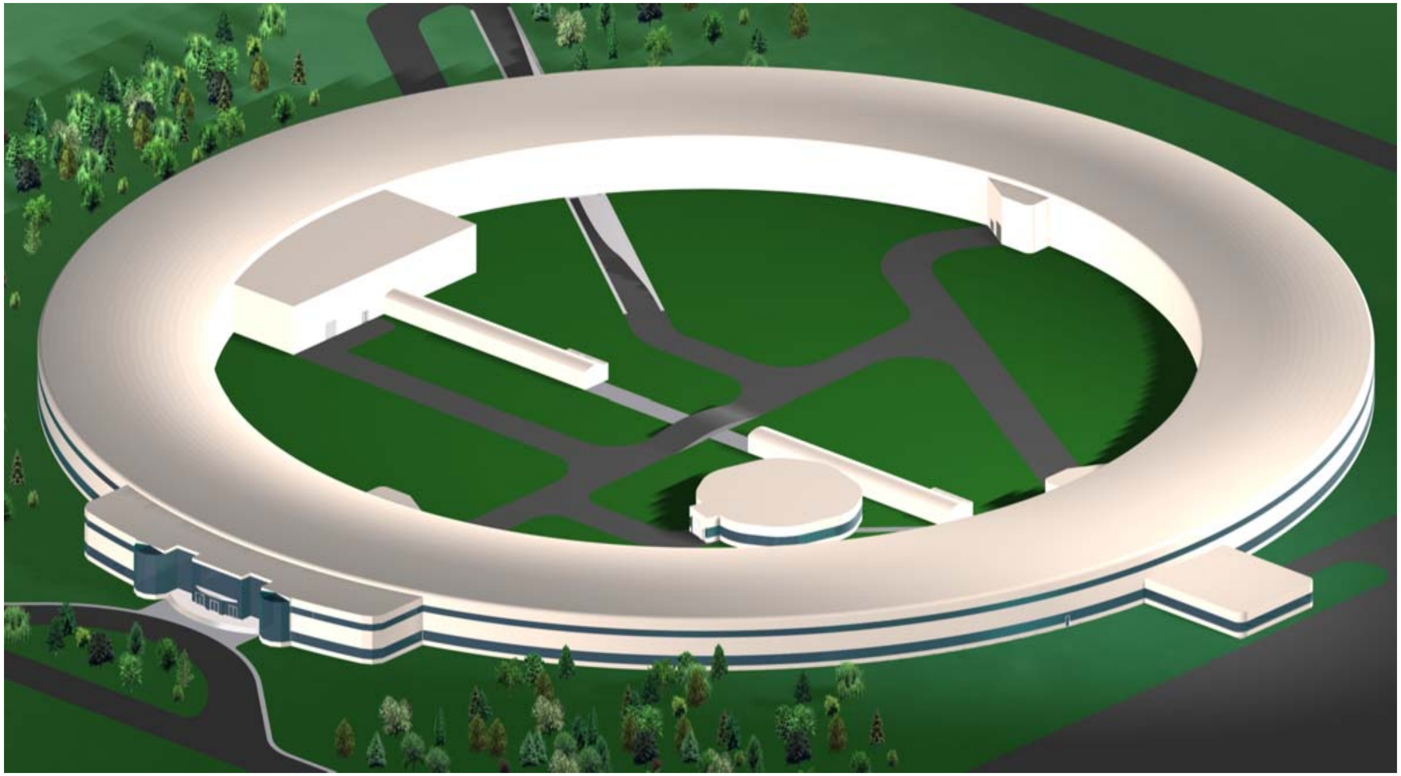
Acceleration of Electrons in the NSLS-II



T. Shaftan for the NSLS-II team

My colleagues: R. Heese, I. Pinayev, D. Raparia, J. Rose

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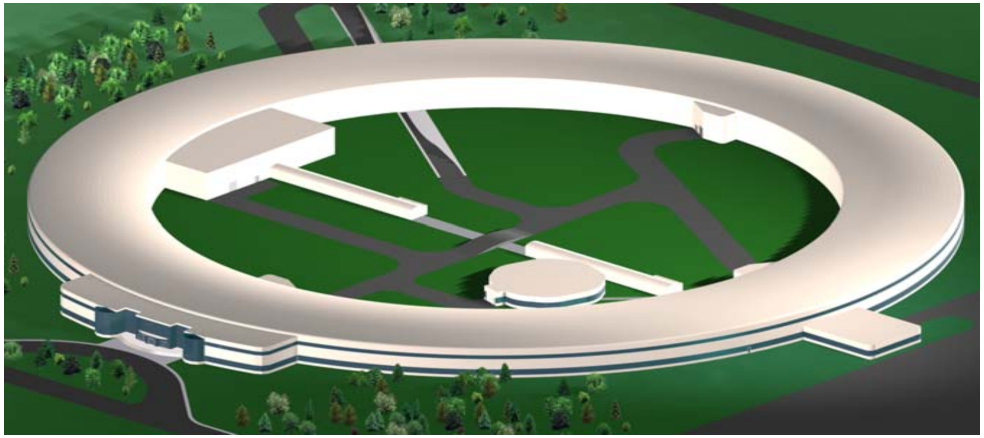
NSLS-II: High-brightness electron and photon beams



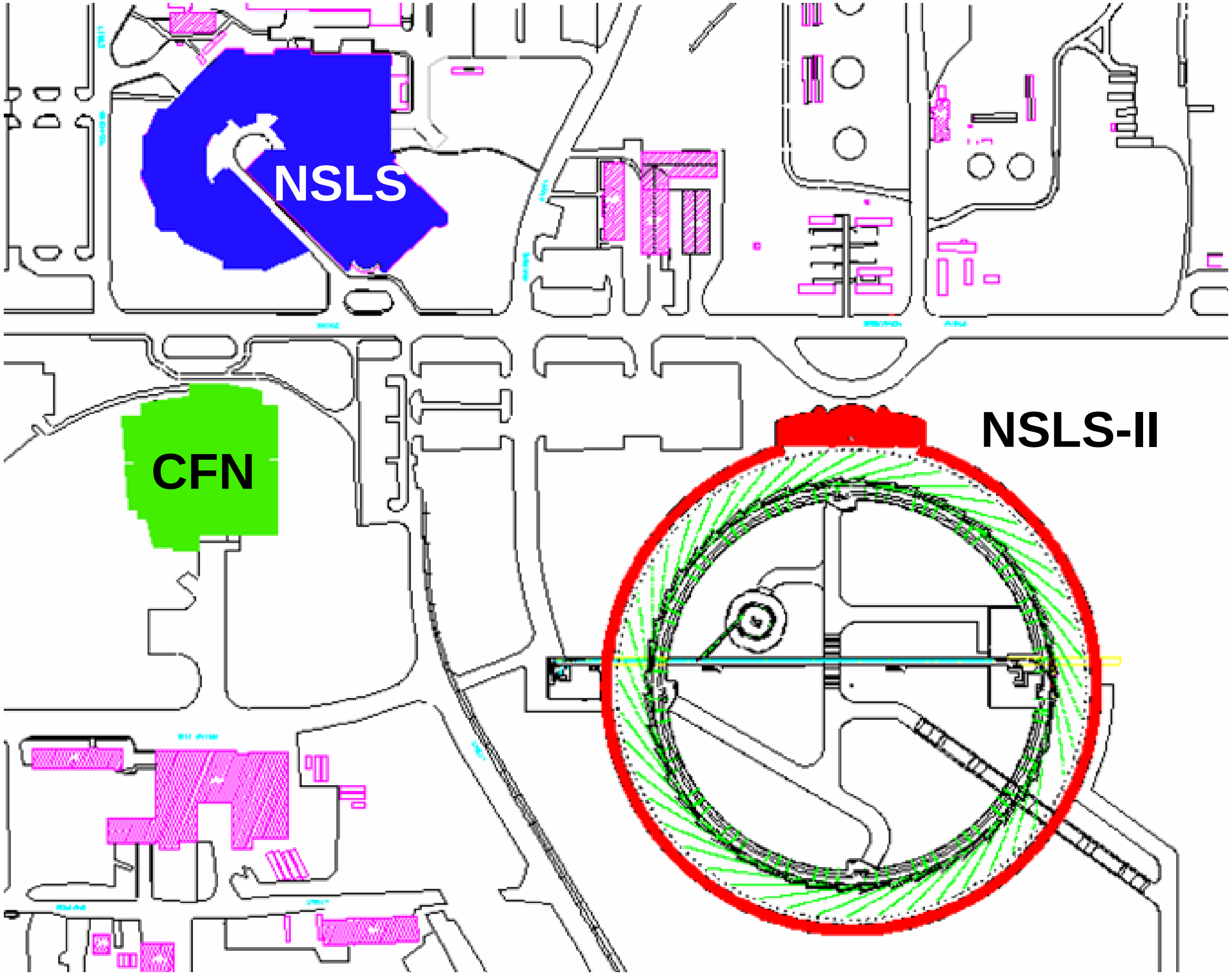
NSLS II Machine Concept

- New Electron Storage Ring
- Ultra Low Emittance (<1.0 nm)
- Damping wigglers
- Medium Energy (~3 GeV)
- Large Current (500 mA)
- Top-Off Operation
- Short-period Undulators
- Circumference (~800 m)

Challenge is to transform the machine concept into a design!

- Lattice & Tracking: Dynamic aperture, optimal machine layout
- SCU: Design & measurement, heat load, …
- Impedance Budget: Small gap ID tapers, etc
- Top Off Ops: multi-bunch injection, booster design, etc.
- Project is evolving: this talk shows only current situation!

NSLS–II Site



Facility Features

- ~ 800m Circumf.
- ~ 18,000m^2

Site Features

- Glacial sand
- Largely undeveloped

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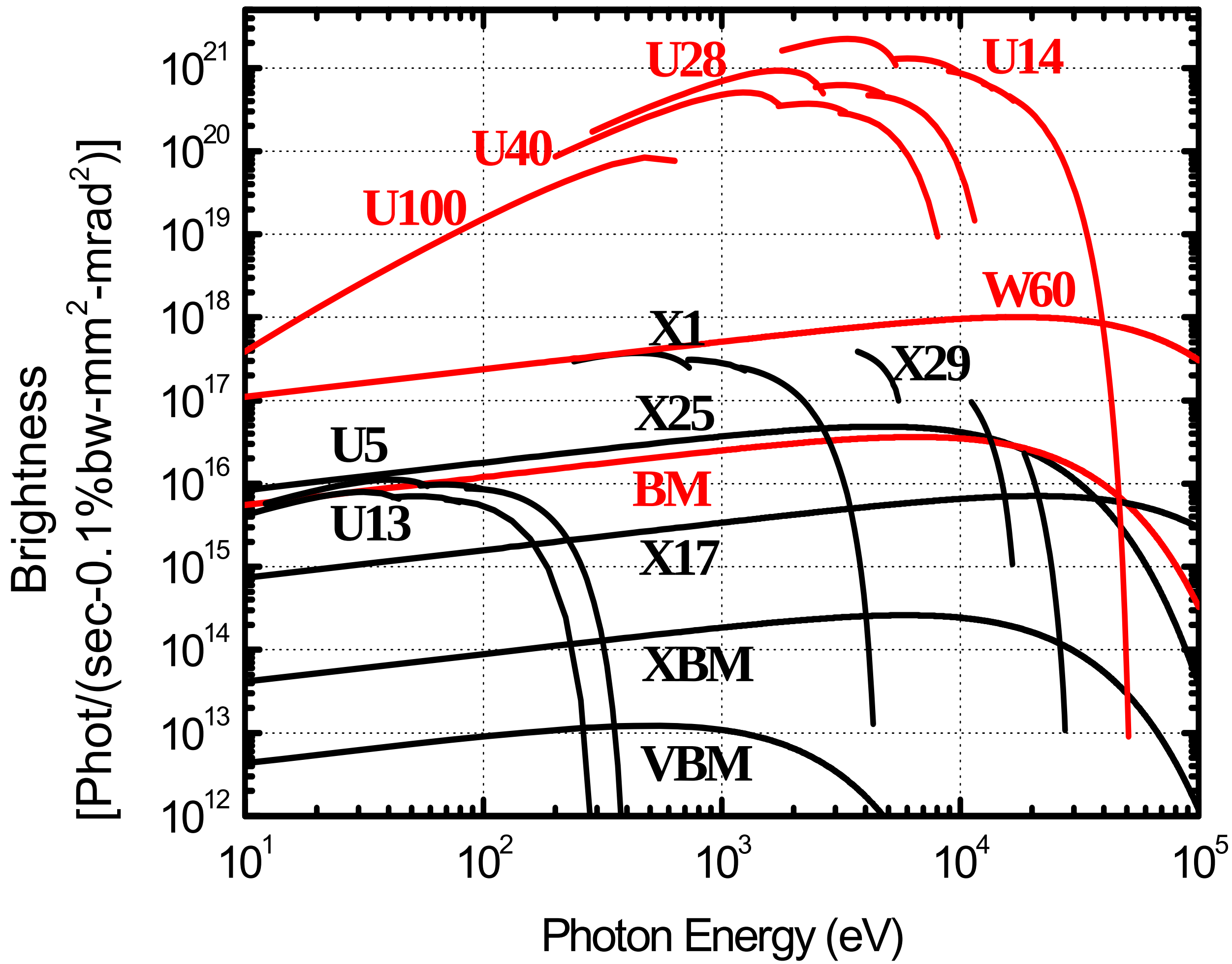
NSLS II: Ultra Low Emittance Ring

1 MAX4

X-Ray Brightness



NSLS	NSLS-II	Gain
X25	U14	3×10^4
BM	U14	5×10^6
BM	BM	10^2
X1	U40	10^3
U5	U100	10^2-10^3

	NSLS	NSLS-II
# Und	5	~20+
# BM	30	32

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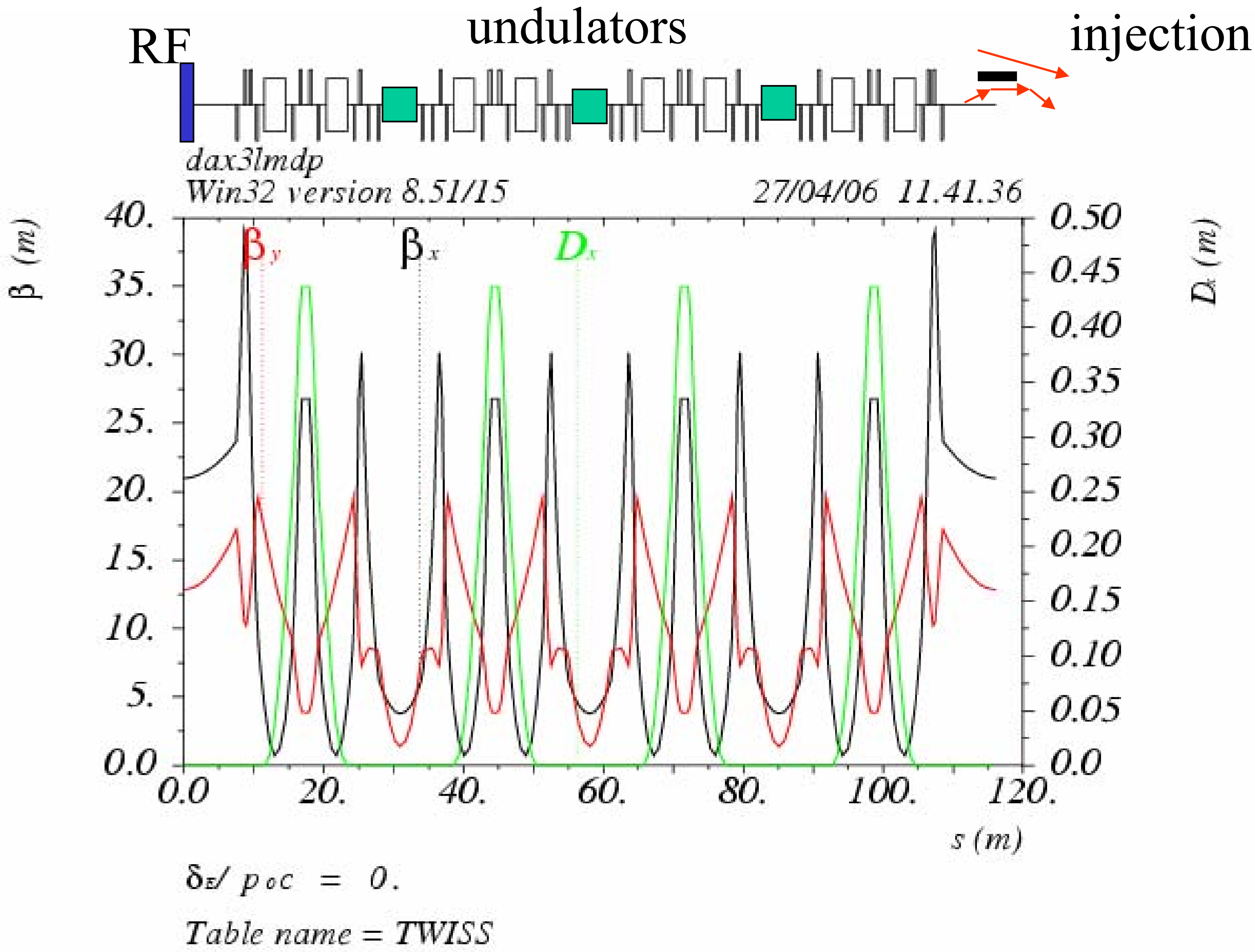
Version of the NSLS-II lattice

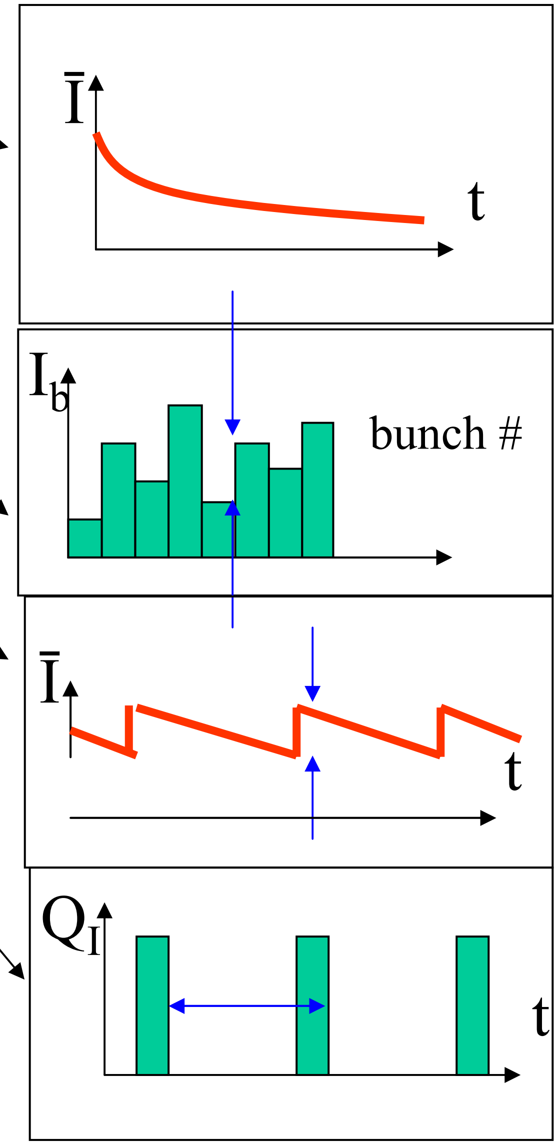


NSLS-II parameters (current DBA-32)

Energy	3.0 GeV	**Betatron Tunes H/V**	35.71/21.37
Circumference	929 m	**Energy Spread**	~0.1%
Number of Periods	32DBA	**RF Frequency**	500 MHz
Maximum ID Length	5 m	**RF Bucket Height**	~3%
Emittance	1.5-0.5nm	**RMS Bunch Length**	~15 ps
Betatron Coupling	0.5%	**RF Voltage**	~4 MV
Momentum Compaction	.00033	**Maximum Current**	500 mA
Dipole Bend Radius	15-30 m	**Current per Bunch**	0.4 mA
Beam Size (σ_x, σ_z)	61, 2.6 μm	**Charge per Bunch**	1.25 nC
Beam Divergence(σ_x', σ_z')	16, 2 μrad		

NSLS-II Injection Specs

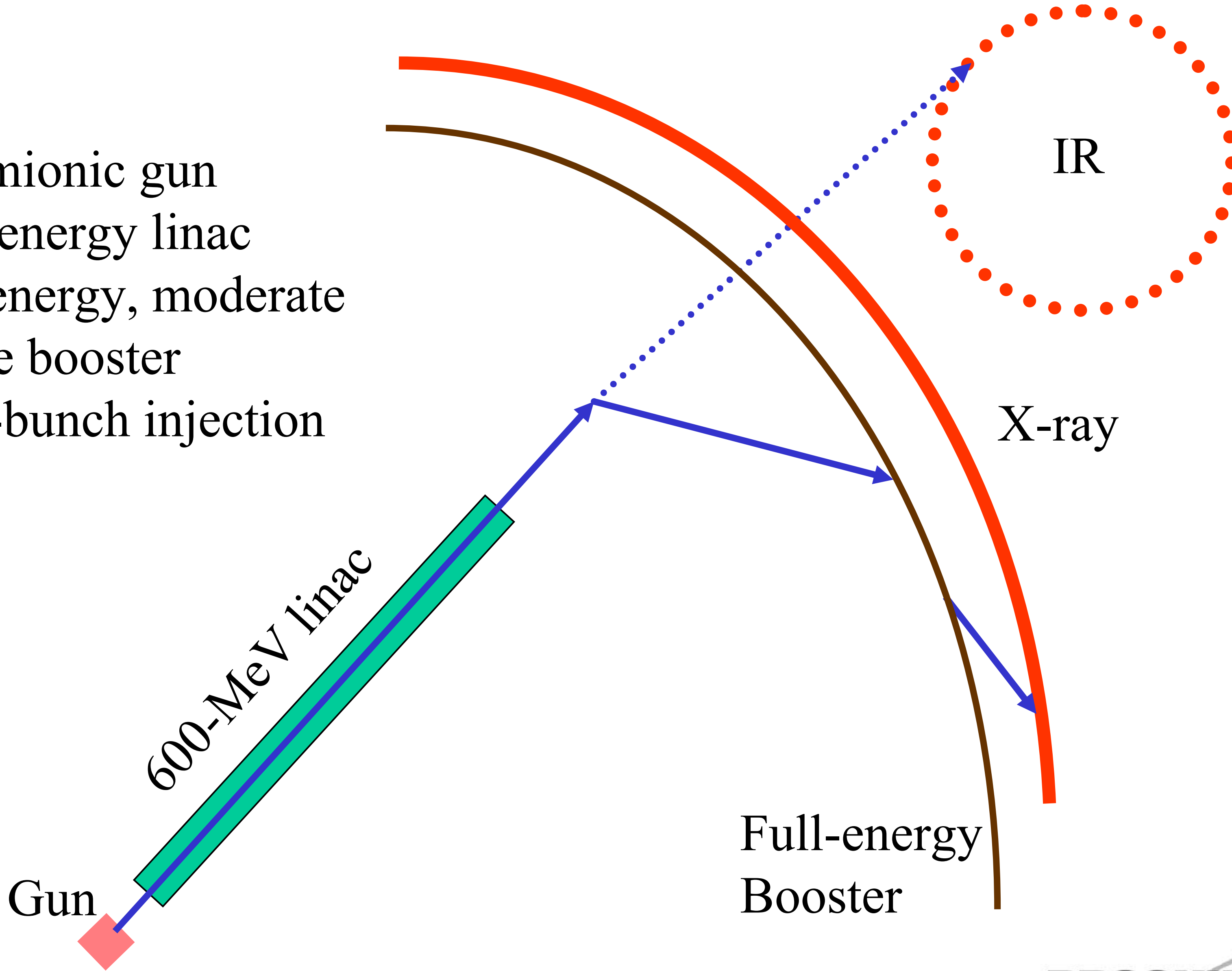
- **Lifetime = ~3 hours**
- **Filling pattern uniformity = ~20 % bunch-bunch**
- **Average current stability = ~0.5 %**
- **Time between top-off cycles = 60 s**
- **3 GeV, 500 mA, 1600 buckets → 1.2 nC/bucket**



\\Nslsnt1\AccPhy\NSLS2_Injection\

NSLS-II injection scenario

- Thermionic gun
- Low-energy linac
- Full-energy, moderate rep-rate booster
- Multi-bunch injection



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NSLS-II injection parameters

Parameter	X-ray ring
Energy, GeV	3
Circulating current, A	0.5
Circumference, m	936
Revolution period, μs	3.12
RF frequency, MHz (wavelength, m)	500 (0.6)
Circulating charge, μC	1.56
Total number of buckets	1560
Number of filled buckets	$1560 \cdot {}^{4}/_{5} \approx 1280$
Charge per bucket, nC	1.22
Current per bucket, mA	0.39
Lifetime, min	~180
Interval between top-off cycles, min	1
Current variation between top-off cycles, %	0.55%
Current variation between top-off cycles, mA	2.7
Charge variation between top-off cycles, nC	8.6
Damping time, ms	75

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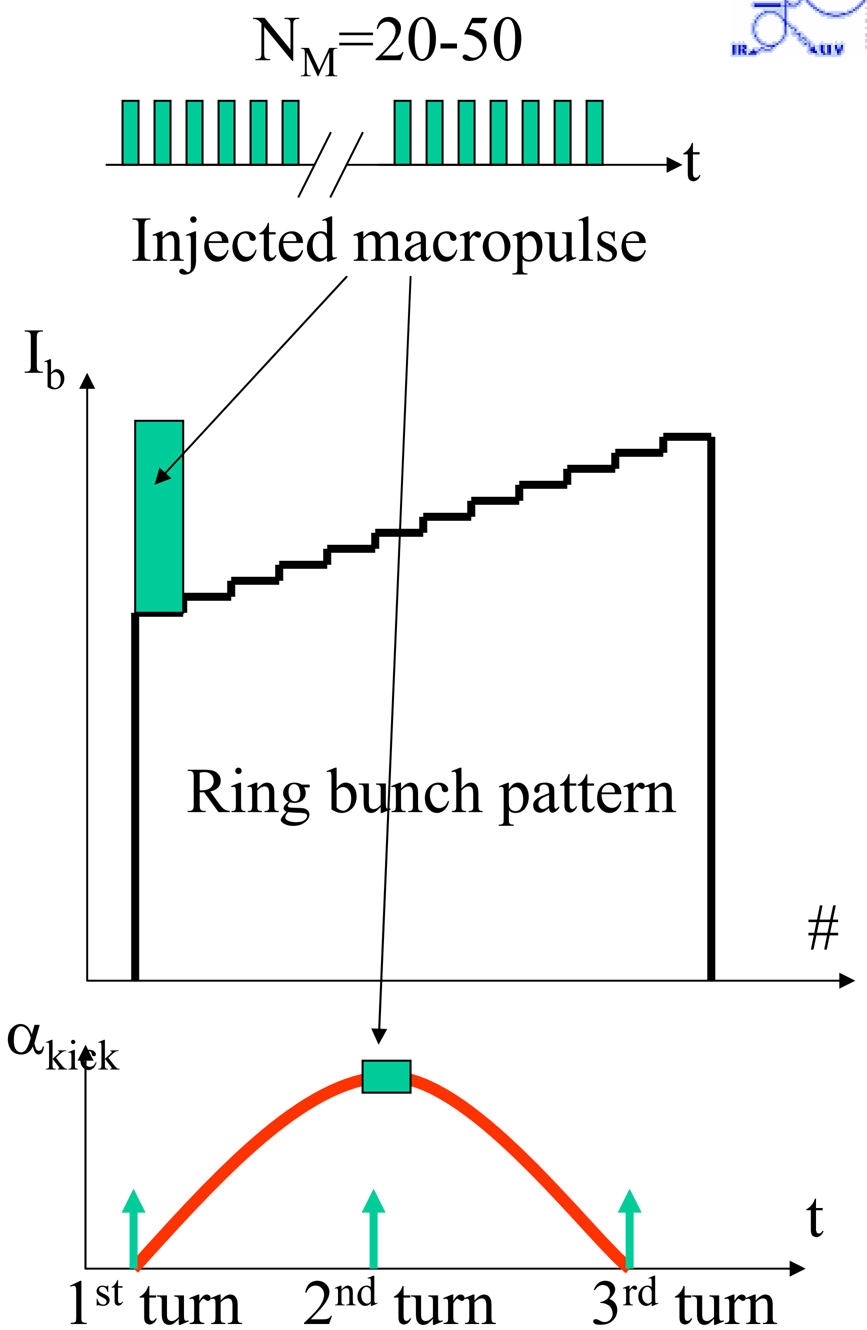
Top-off scenario

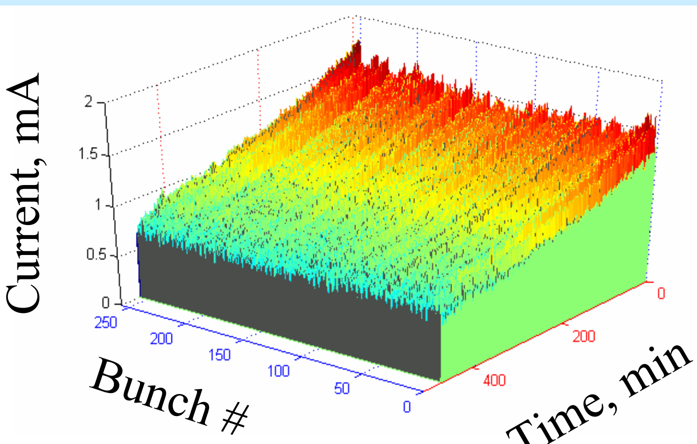
- Many (~1000) bunches
- Multi-bunch mode
- Filling N_M consecutive buckets in the ring
- 1 minute between top-off cycles
- 1 Hz repetition rate suffices with pulse train injection
- Kickers duration can be 2 turns long (5 usec) or longer
- Considered in ALS top-off (10 bunches)



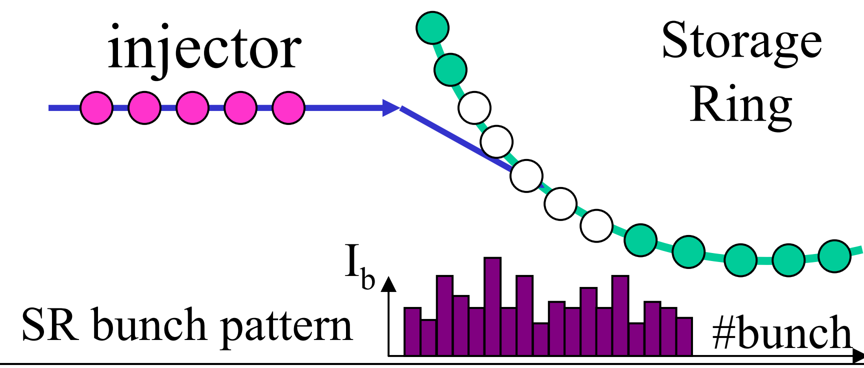
Multi-bunch injection

- Short lifetime → multi-bunch mode
- SLS experience: feedback for enhancement of the bunch pattern purity
- “Hunt&Peck” mode: is it necessary for NSLS-II ?
- Studies at ALS on pattern evolution
- “Flat-top ramp” mode in the booster → short pulse kickers

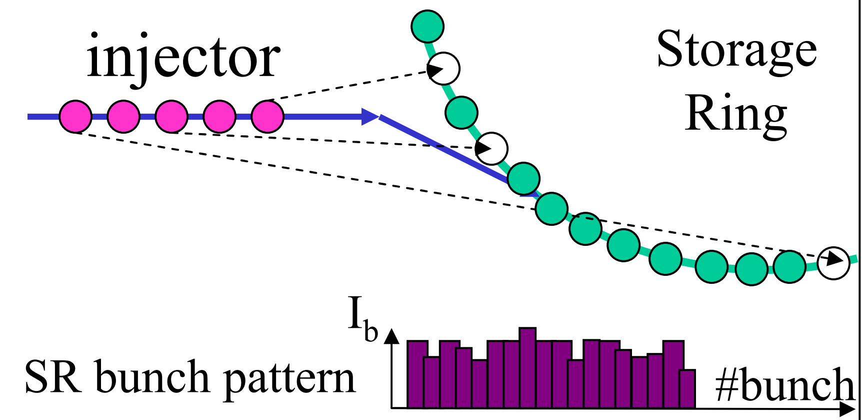
Studies at NSLS and ALS (in progress)



Bunch train mode



“Hunt&Peck” mode



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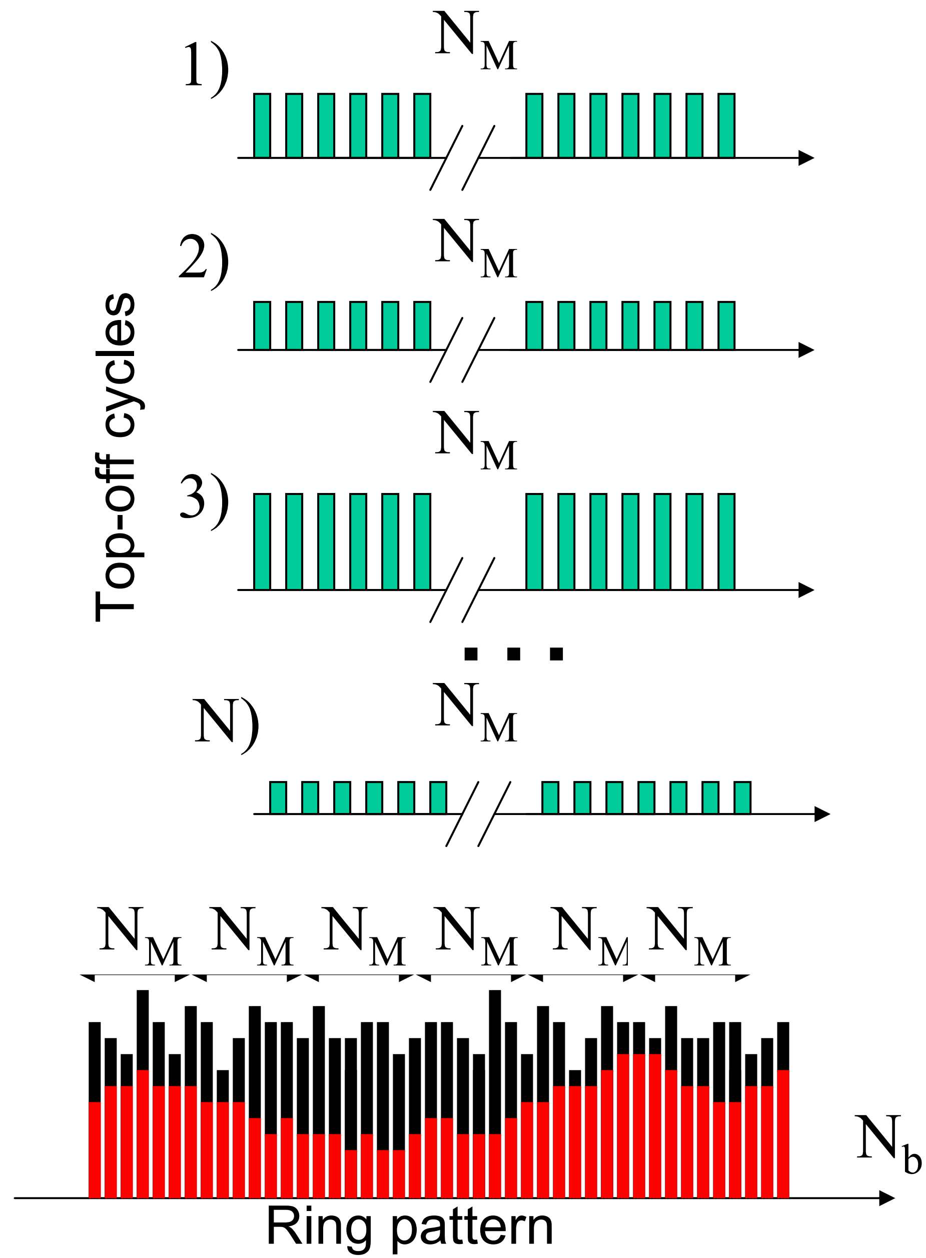
“Hunt&Peck”: Adjusting average value

- Measure charge in the ring buckets
- Every top-off cycle adjust gun grid voltage → adjust charge per bunch
- Inject macropulse (N bunches) with average charge equal to missing charge in N-bunches in the ring
- Eliminates all bunch-bunch variations on $N_b > N_{MICRO}$ scale
- Can be done is “sequential” or “hunt & peck” modes



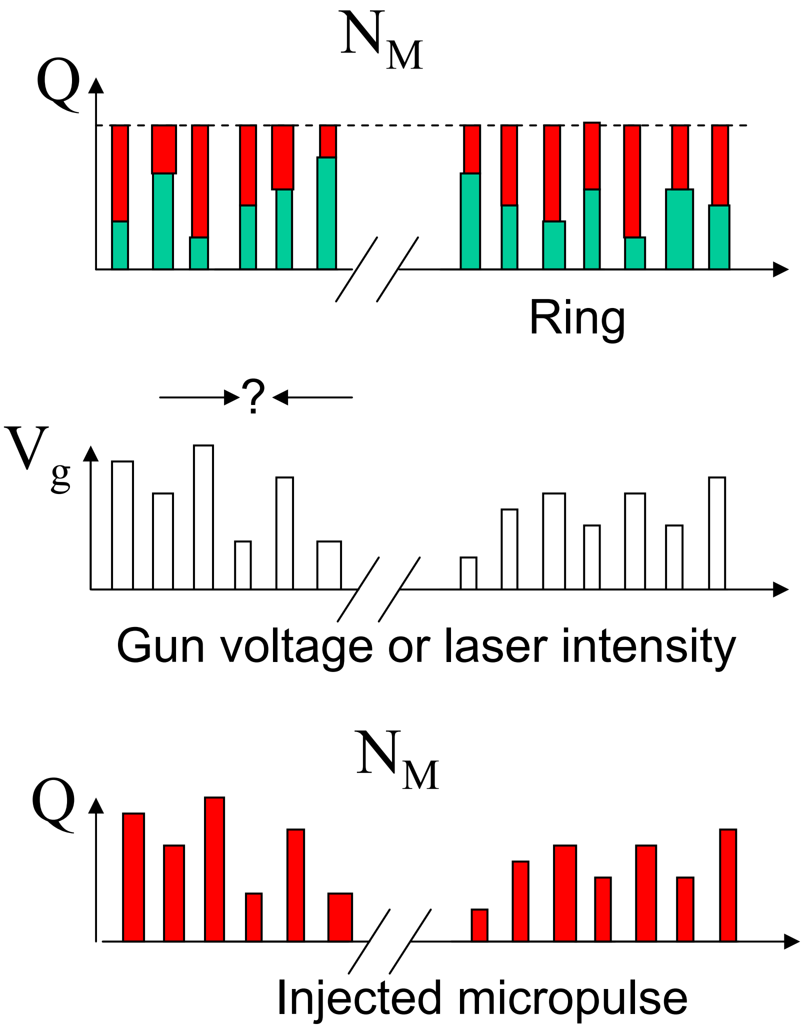
"Hunt&Peck": Fast modulation of macropulse

- Measure charge in the ring buckets
- Modulate gun voltage (laser intensity) with inverse of the charge/bunch in the pattern

or

- Stack bunches in the booster via multiple injections

- Inject "premodulated" macropulse into the ring

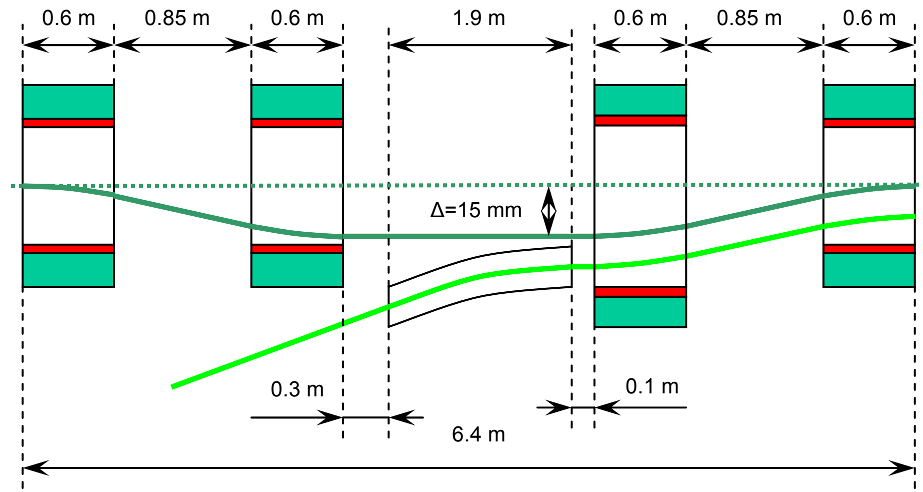


Injection straight-section

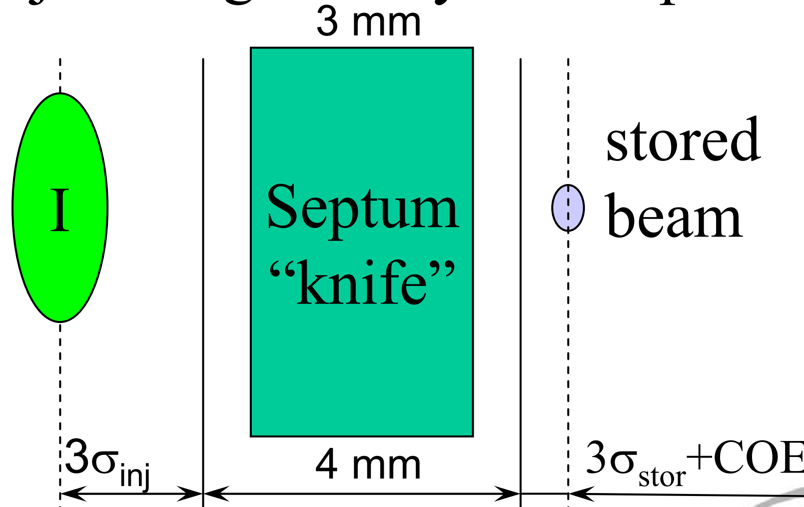
- Closed non-interleaved bump design
- Fits into a single straight section of the ring
- 2-turns long pulsed kickers
- Sufficient injection tolerances providing high injection efficiency
- Minimization of injection transients effect on stored beam
- Damping time is ~75ms

(no damping wigglers)

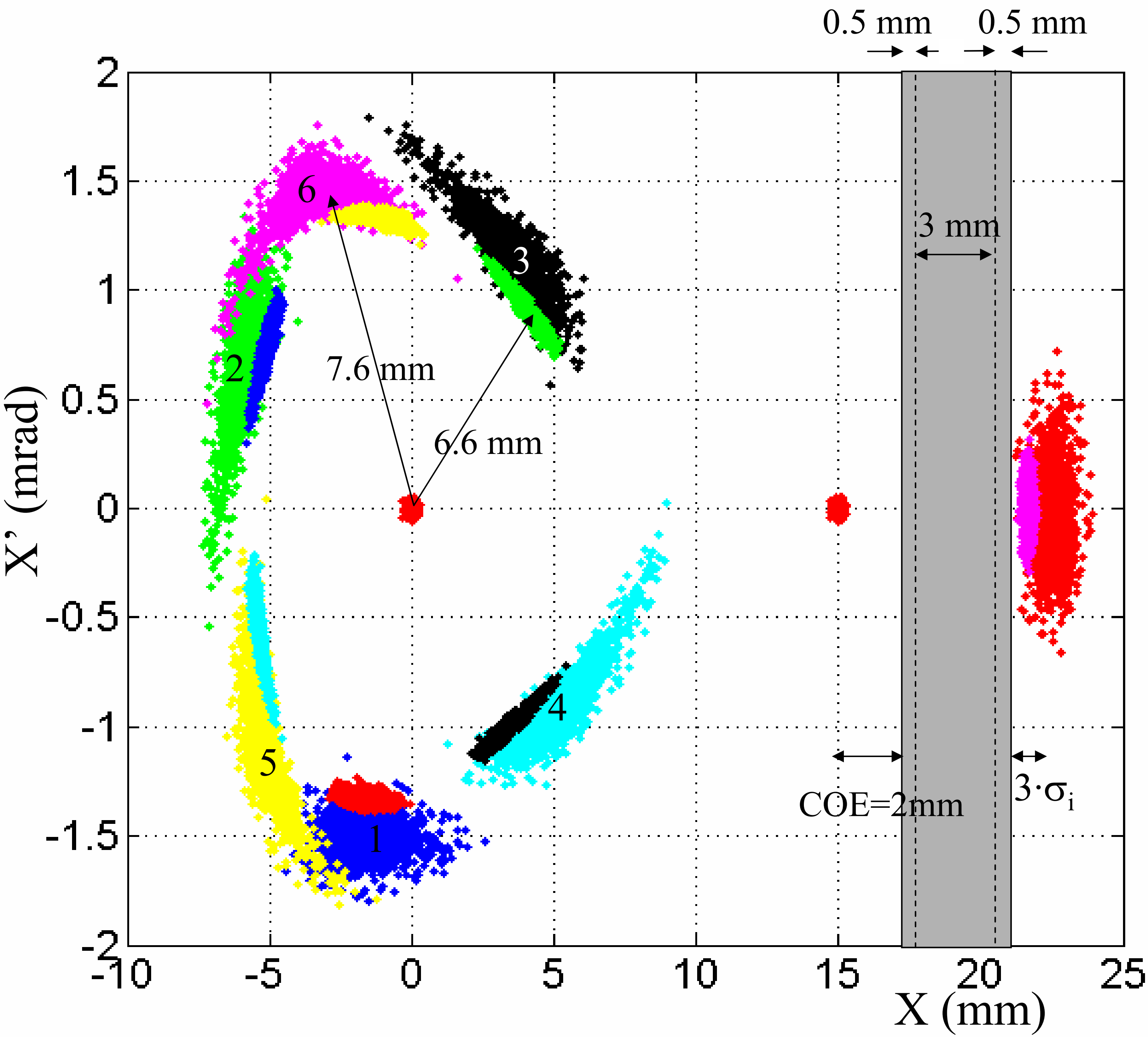
Closed bump design



Injection geometry near septum

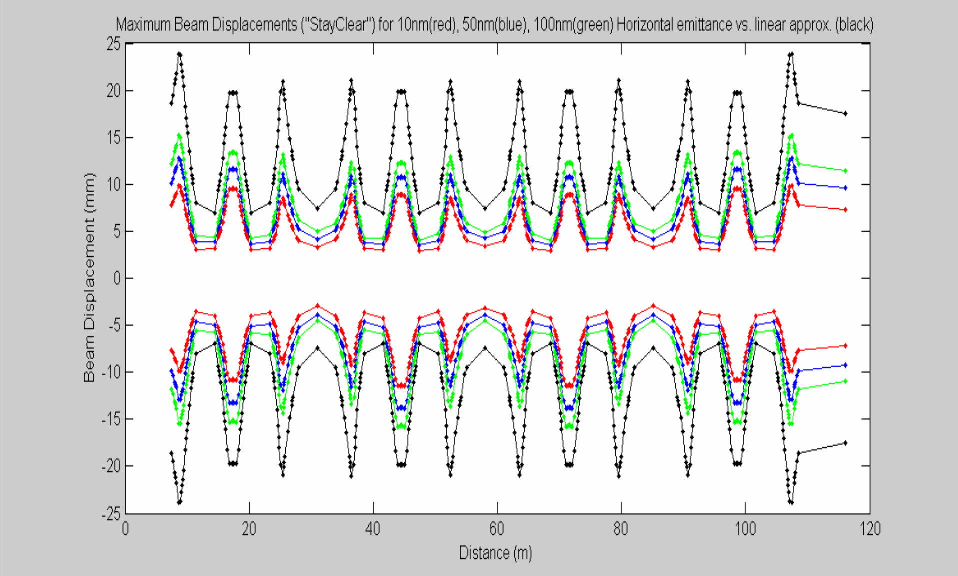


Phase space for 6 turns



Storage ring stay-clear

- TRACY was modified to include injection tracking
- Tracking with 3 injected beam emittances (10, 30 and 100nm)
- Beam envelope is recorded at each element of lattice
- Linear estimate (black curve) is determined by septum and ID gap
- Stay-clear aperture required for injection
- Next step: including field errors, RF cavity, etc.
- Injection tolerances: limits on misalignments/mismatch of injected beam



Horizontal. Beam is injected at an initial displacement of about 17.5mm (septum location).

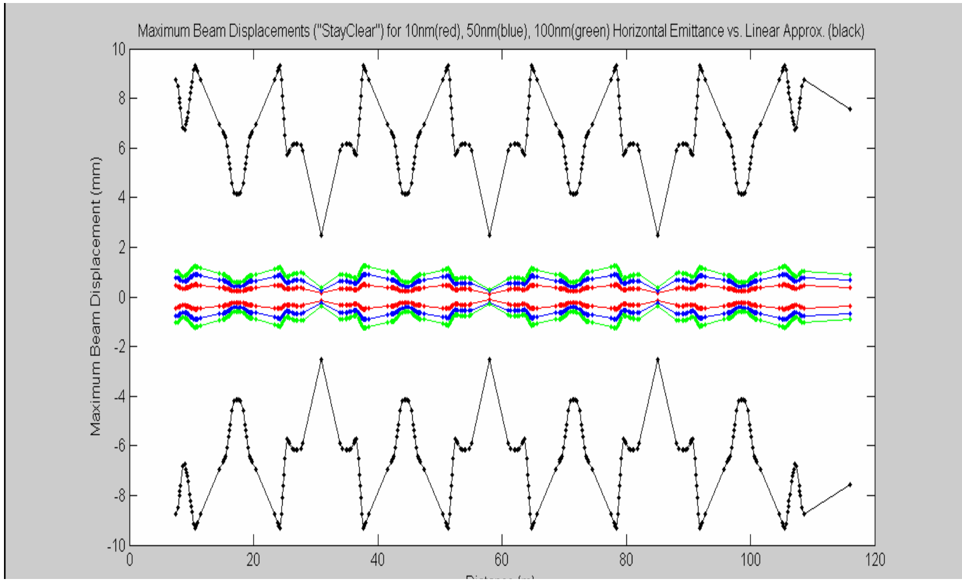
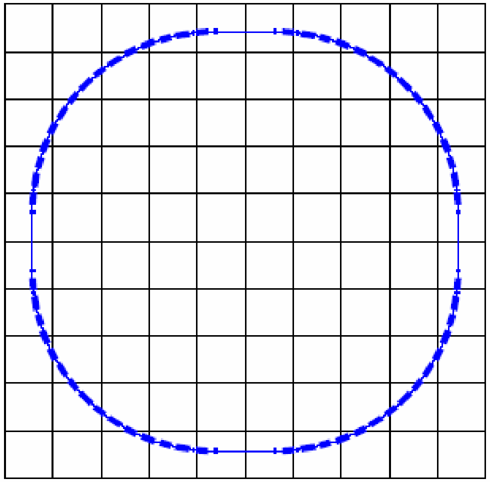


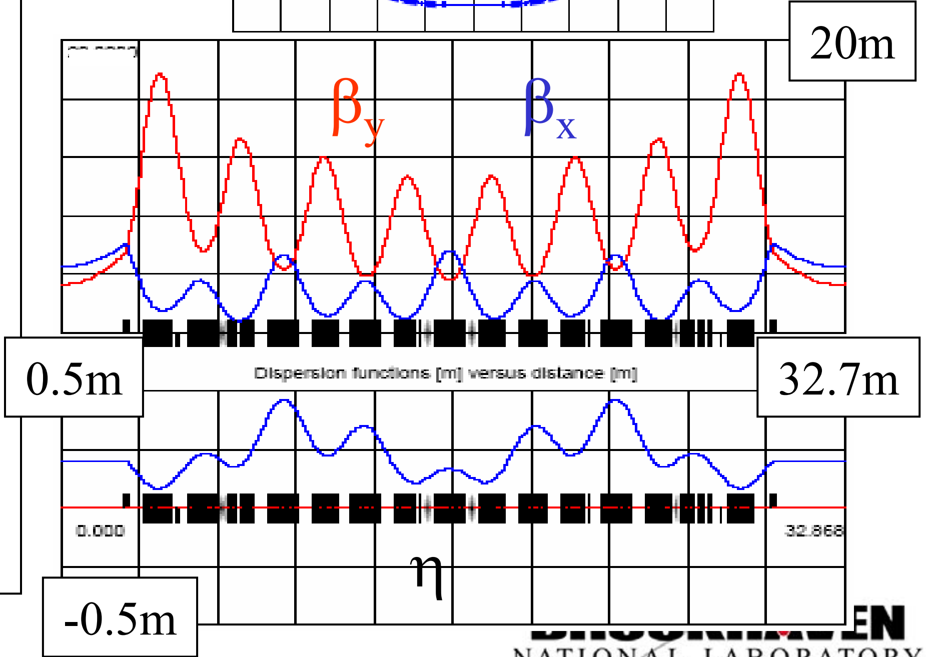
Figure 2) Injected beam envelope (Vertical). Physical aperture at ID ½ gap of 2.5mm

Courtesy of J. Rose, I. Pinayev, J. Bengtsson and T. Shaftan

ASP booster (Danfysik)

- Energy: 0.1→3 GeV
- Rep. Rate: 1 Hz
- Circumference: 130 m
- RF frequency: 500 MHz
- Emittance: 30 nm rad
- Radiation loss: 743 keV/turn
- Beam current: >5 mA
- Magnet power: 240 kW





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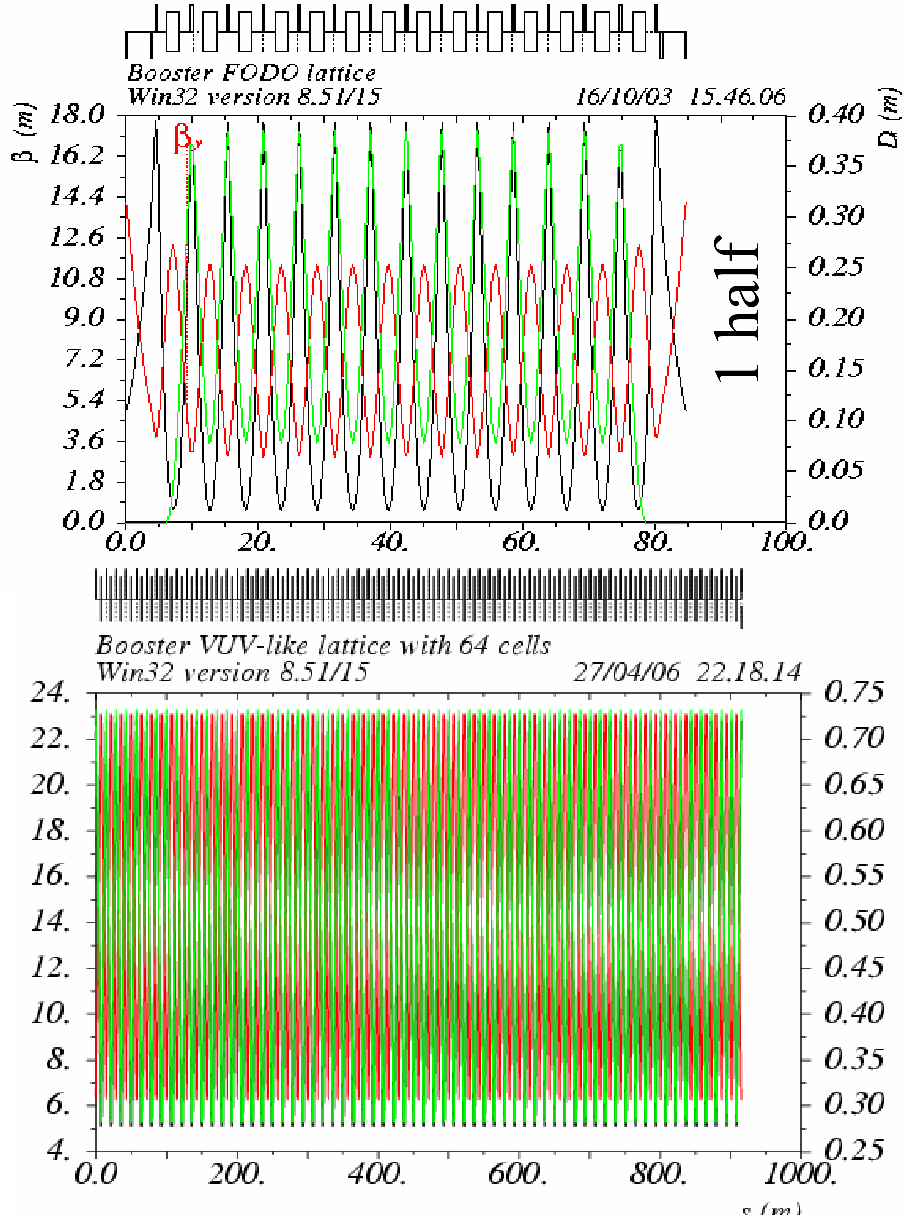
Full-energy booster

- <u>Compact booster</u>
  - 24-cell TME lattice with 4 dispersion suppressors
  - Two 10-m straights for RF and injection and for extraction
  - Single dipole power supply
  - Requires building of NSLS X-ray ring size
- <u>"Same-tunnel" booster</u>
  - Same circumference as the main ring
  - 64-cell TME, 10 m between dipoles
  - Require additional families of quadrupoles and sextupoles
  - 8 "small" dipole power supplies
  - Requires rearrangement of the lattice for optimization

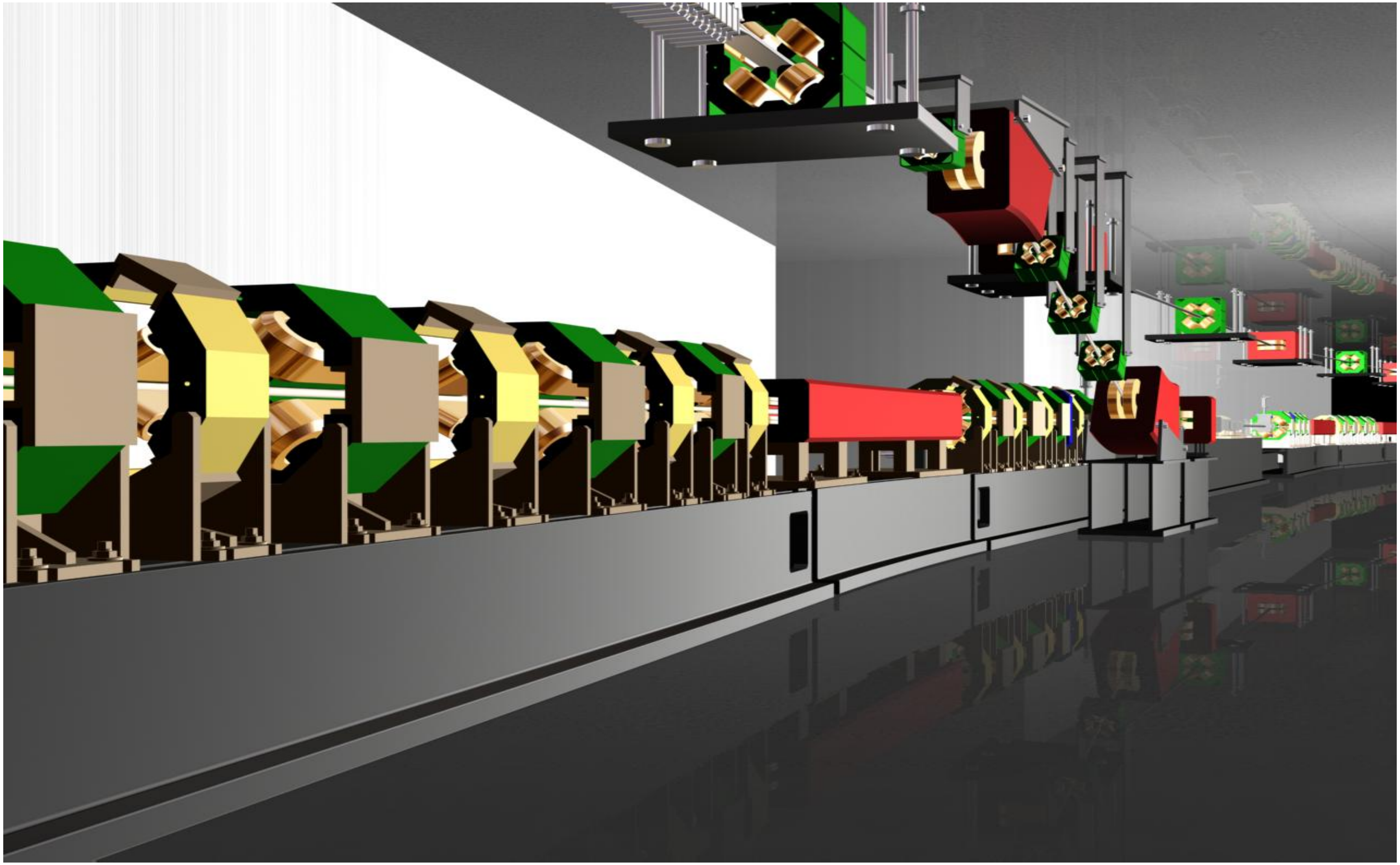


Booster comparison

Parameter @ 3.6 GeV & 1Hz	**"Compact" booster**	**"Same tunnel" booster**
Dipole	13.8°, 1.0 T, 2.9m, 15cm, 2.5cm, 10 turns, $2.5e^3$ mm^2, 4.8 mΩ, 10 mH	5.625°, 0.8 T, 1.5m, 15cm, 2.5cm, 12 turns, 165mm^2, 4.6 mΩ, 7.5 mH
Total peak power	Active 120 kW Reactive 525 kW	Active 8 x 16 kW Reactive 8 x 52 kW
Voltage x Current from PS	650V x 1.0 kA	8 x 100V x 680A
Booster current in top-off	13 mA	2.8 mA
SR losses	1.25 MeV/turn, 16 kW	1 MeV/turn, 2.8 kW
Cavity Voltage, RF acceptance	2MV, 0.9%	2MV, 0.9%

NSLS II Tunnel

NSLS II Tunnel



Conclusions

- NSLS-II project is in progress
- This talk is about current situation of the project!
- Effort of the NSLS-II Team