國家同步輻射研究中心
National Synchrotron Radiation Research Center

The Design and Progress of Taiwan Photon Source

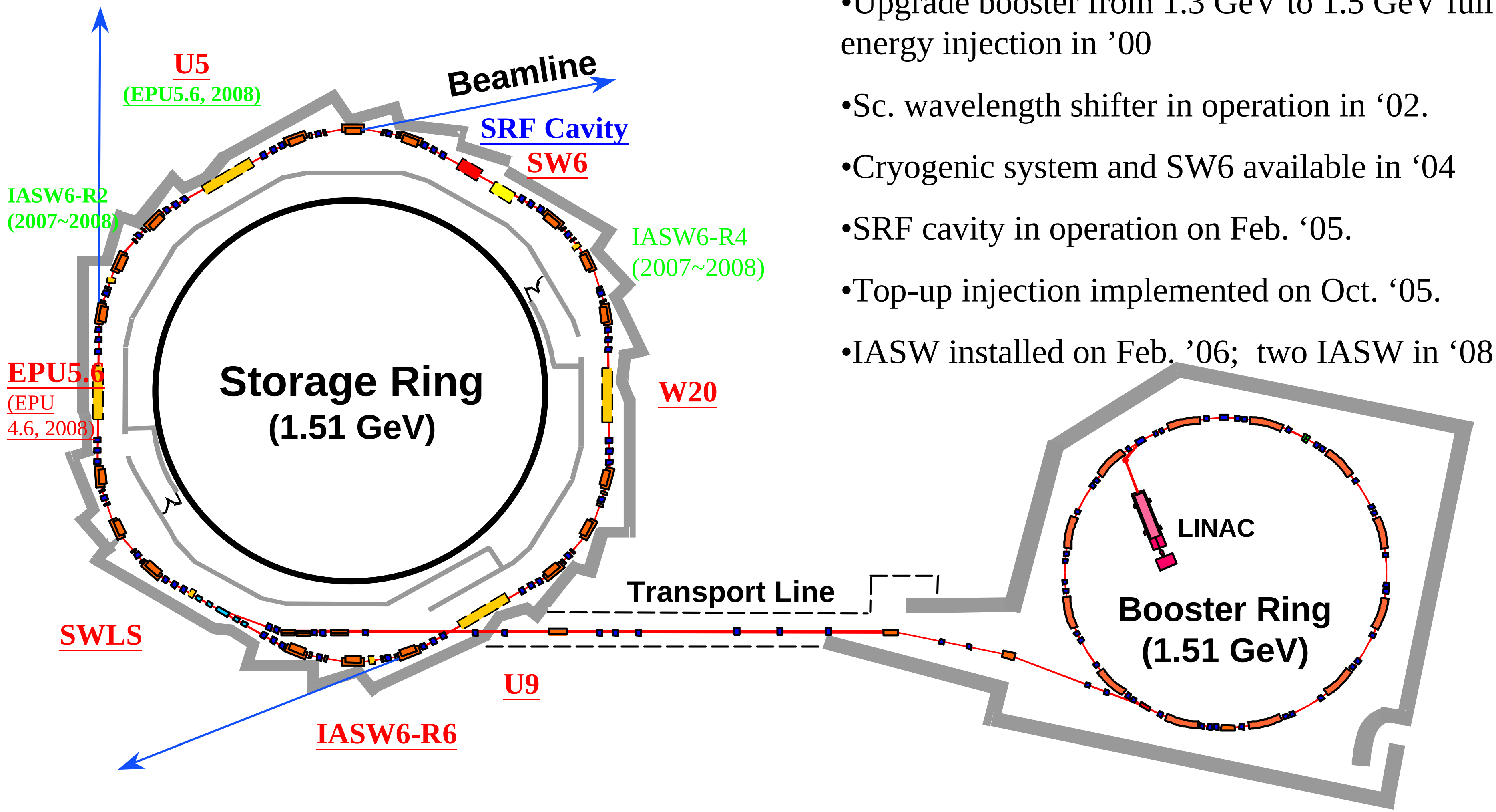
Gwo-Huei Luo
on behalf of TPS Design Team

Department of Physics
NCTU, Hsinchu, Taiwan, March 5, 2008

Outline

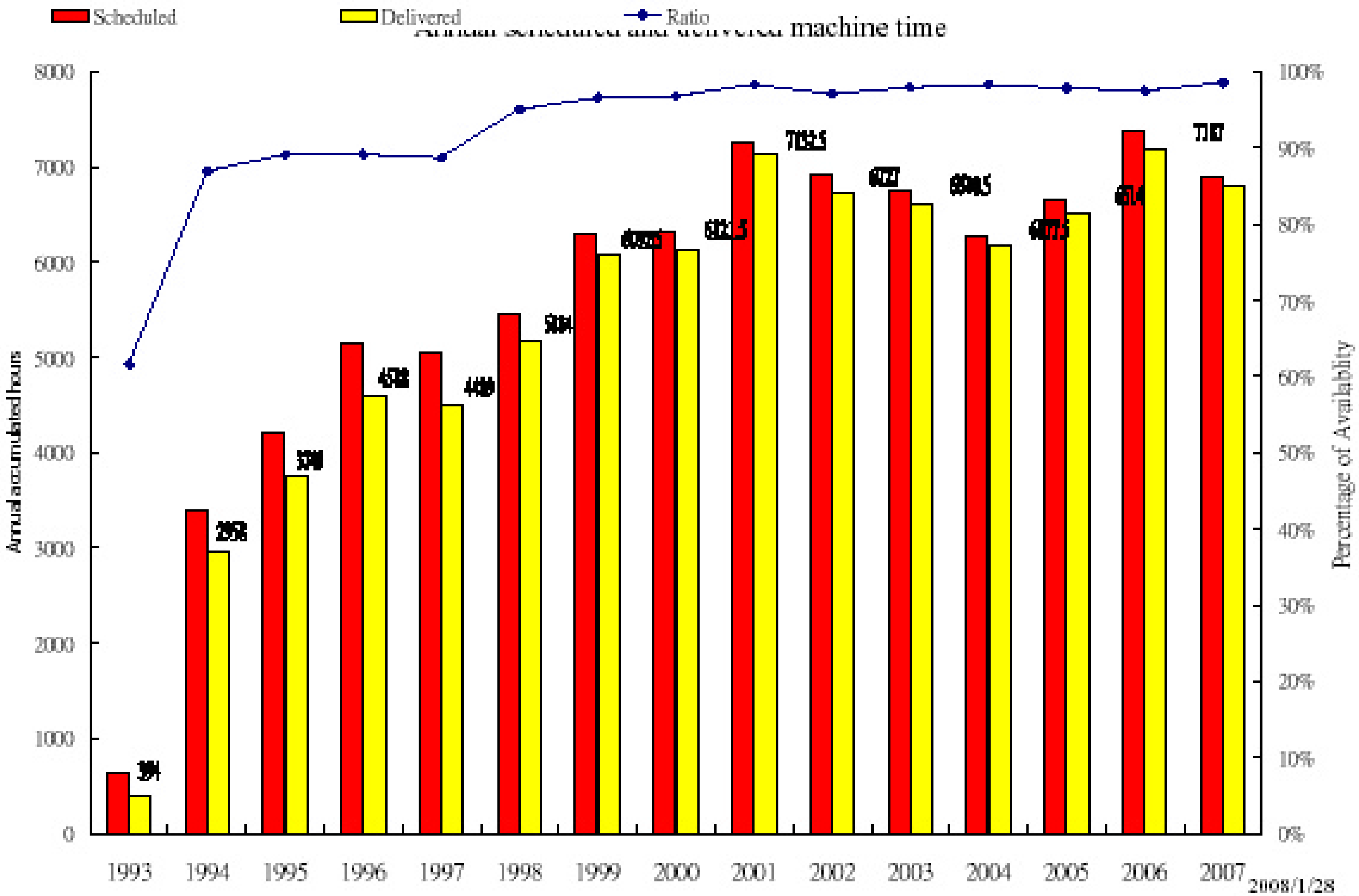
- Status of Taiwan Light Source
- Design of TPS lattice
  - Basic parameters
  - Linear and non-linear effects
  - SC wigglers to lattice configurations
- Accelerator Engineering System
  - Magnets, Insertion devices, and Spectrum
  - Vacuum, front-end and utilities layout
- Layout of civil construction
  - Instrumentation, tunnel and exp. Hall
- Radiation safety issues
- Summary

Schematic and major milestones of TLS



- Commission on Apr. open to users on Oct. '93
- 1.3 to 1.5 GeV ramping in operation in '96
- 240 mA operation beam current in '96
- Upgrade booster from 1.3 GeV to 1.5 GeV full energy injection in '00
- Sc. wavelength shifter in operation in '02.
- Cryogenic system and SW6 available in '04
- SRF cavity in operation on Feb. '05.
- Top-up injection implemented on Oct. '05.
- IASW installed on Feb. '06; two IASW in '08

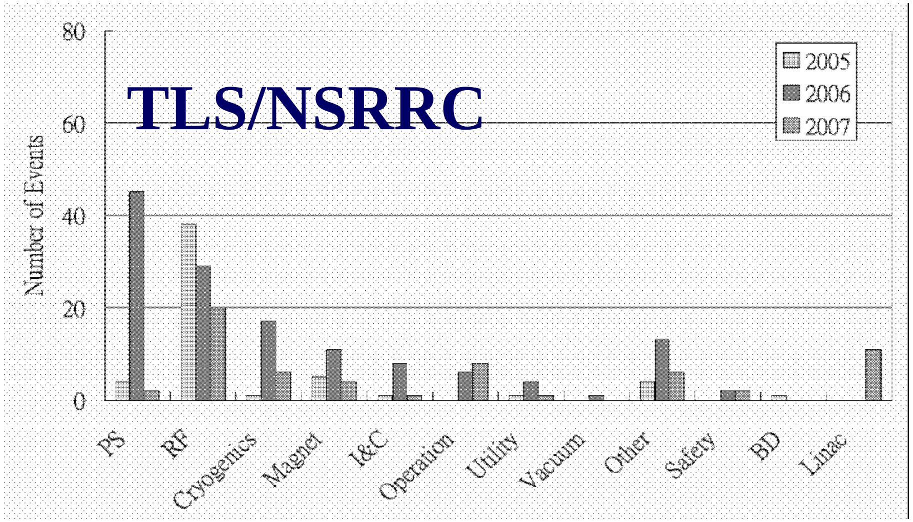
Operation statistics

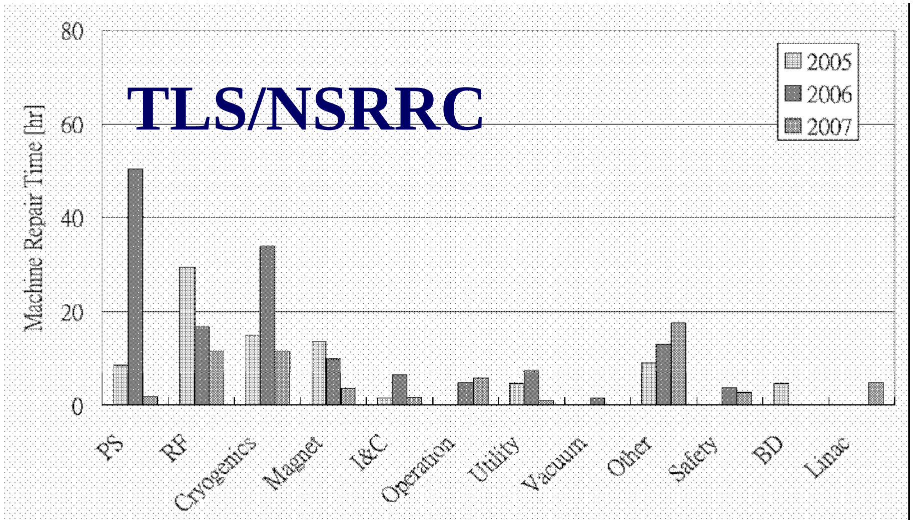


Scheduled, Delivered and the Availability ratio in 15 years of TLS Operation.

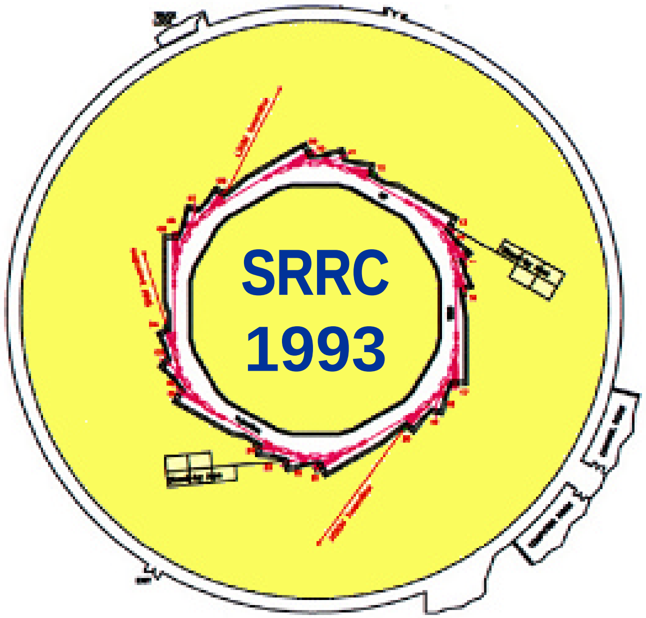
Comparison of operation performance among major SR facilities

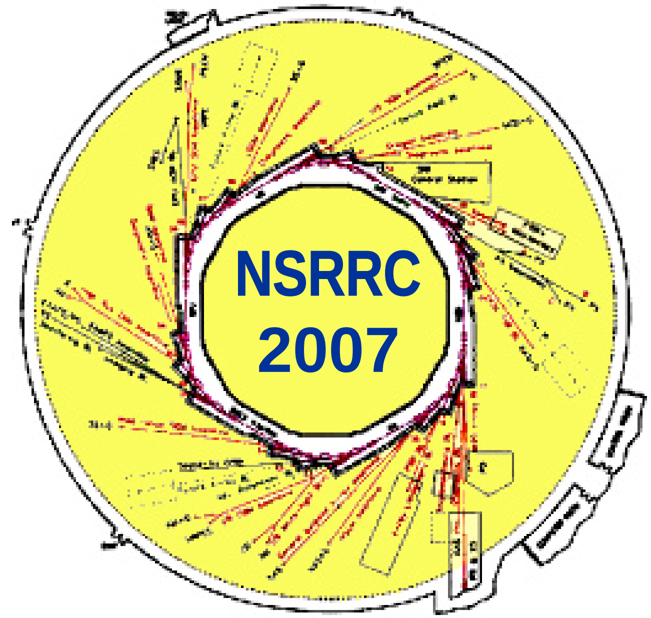
	Year	Annual Machine Time (hr)	User Time			Opertion Mode	I0 Stability (%) ($\Delta I_0/I_0<0.2\%$)
			Annual User Time (hr)	Up-time (%)	MTBF (hr)		
TLS	2002	6927	4785 (69.1%)	95.8%	154.4	Decay Mode	47%
	2003	6749	5017 (74.3%)	97.2%	313.6	Decay Mode	86%
	2004	6283	4235 (67.4%)	97.5%	69.4	Decay Mode	85%
	2005	6659	4576 (68.7%)	96.8%	83.2	Top-up Mode(3/12)/SRF	76%
	2006	7370	5552 (75.3%)	96.7%	40.8	Top-up Mode/SRF	99.0%
	2007	6902	5219 (75.6%)	98.1%	85.6	Top-up Mode/SRF	98.6%
SLS	2002	N.A.	4470	94.0	30.0	Top-up Mode	N.A.
	2003	N.A.	5290	94.2	45.9	Top-up Mode	N.A.
	2004	N.A.	5120	96.3	59.5	Top-up Mode	N.A.
	2005	N.A.	4950	98.4	73.0	Top-up Mode	N.A.
	2006	N.A.	5160	95.4	60.0	Top-up Mode	N.A.
	2007*	N.A.	5050*	97.1*	53.0*	Top-up Mode	N.A.
Spring8	2004	5759.2	4590.9 (79.7%)	98.1	N.A.	Top-up Mode	N.A.
	2005	5317.1	3698.2 (69.6%)	98.3	N.A.	Top-up Mode	N.A.
	2006	5026.2	3790.1 (75.4%)	98.7	N.A.	Top-up Mode	N.A.
ALS	2005	N.A.	5521	96.4	40.0	Decay Mode	N.A.
	2006	N.A.	6201	97.5	50.0	Decay Mode	N.A.





Facility Development





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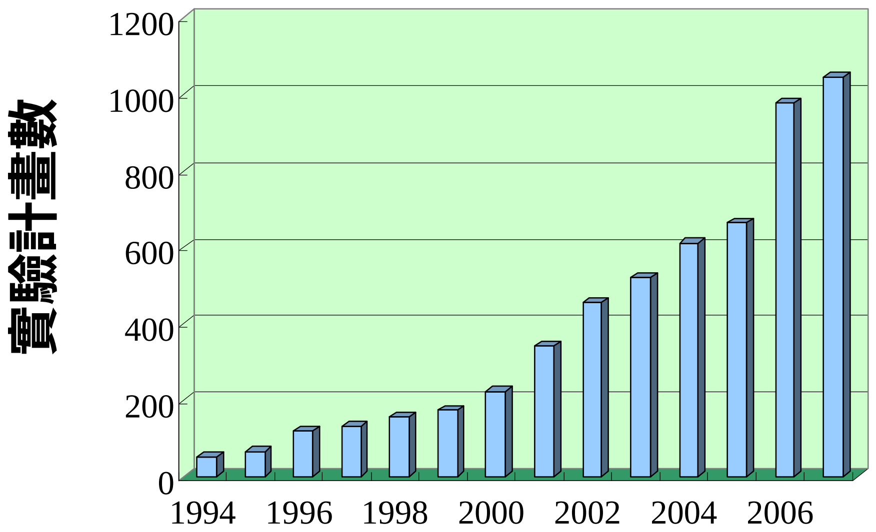
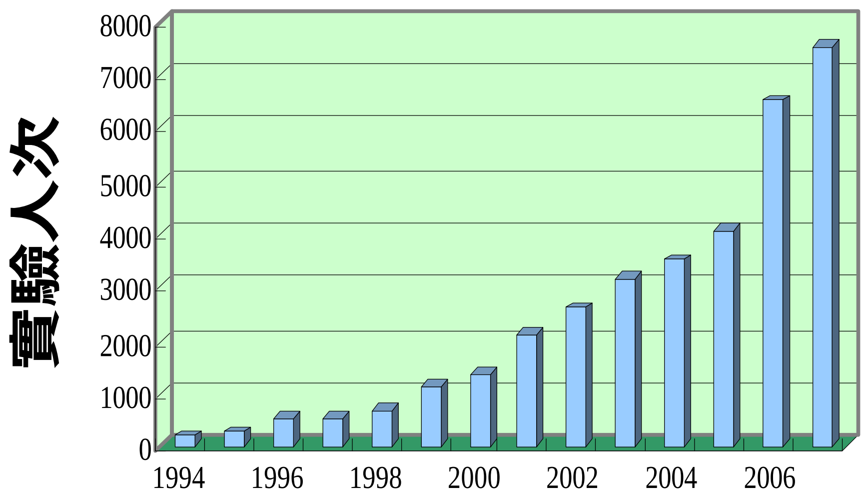
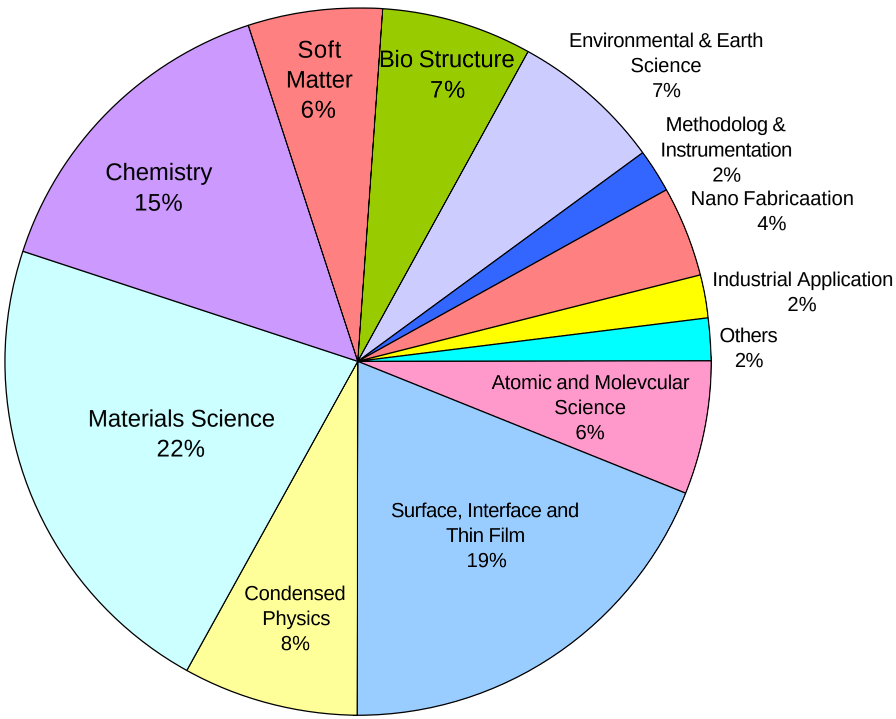
- Light Source: 1.3 → 1.5 GeV
- Insertion Device: 0 → 7+2 (Inst.)
- Beamline: 3 → 27+5 (C.C.)
- End Station: 3 → 54

Taiwan Contract Beamlines at SPring-8

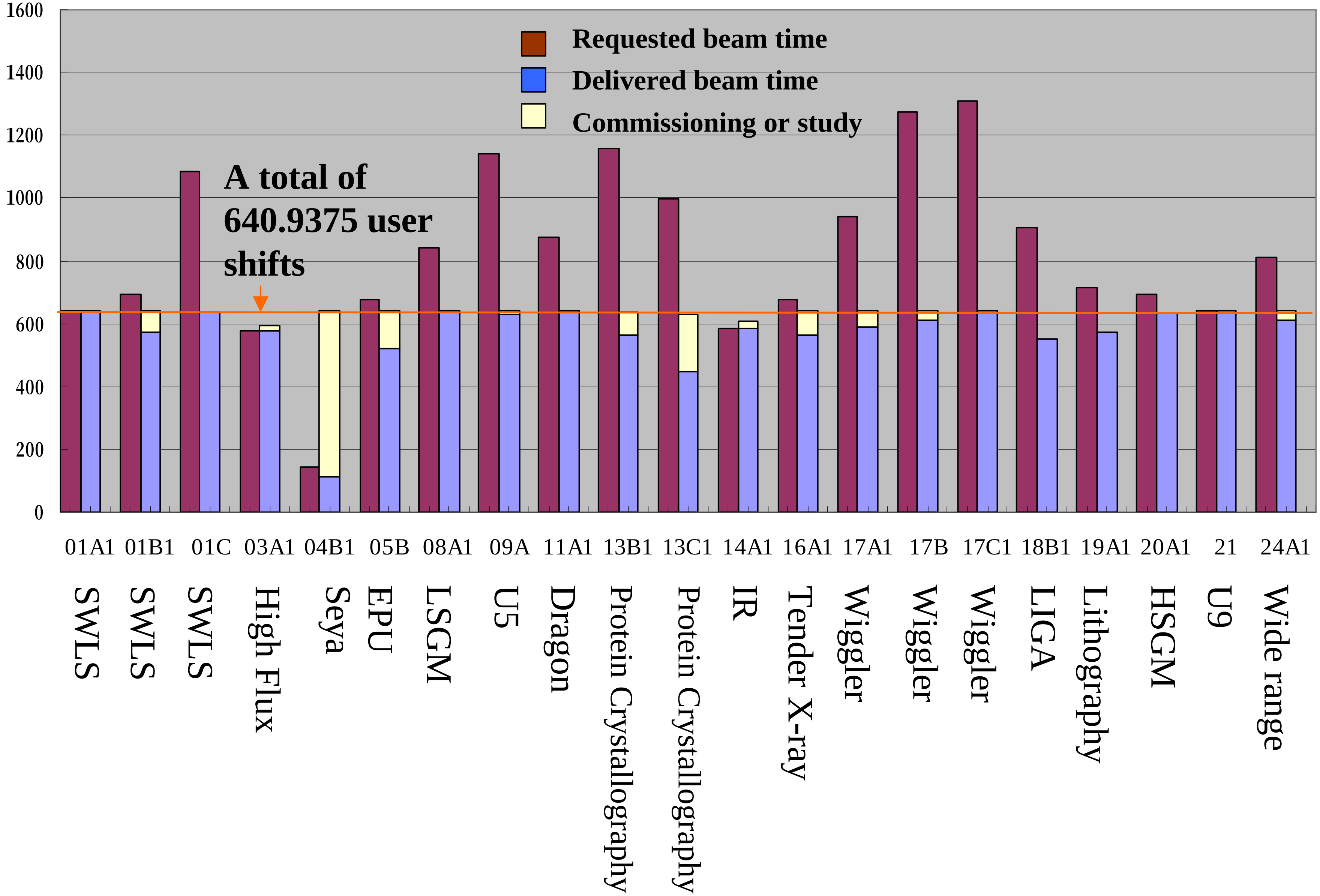
Statistics of Users' Experiments







Beam time requested vs. allocated for different beamlines in 2007



Progress of Taiwan Photon Source

台灣光子源重要里程及規劃之時程

2006年03月	「台灣光子源興建計畫書諮議委員會」第一次會議(核心成員)
2006年04月	「台灣光子源興建計畫書諮議委員會」第二次會議(核心成員)
2006年06月 2006年09月 2006年10月 2006年11月	「台灣光子源興建計畫書諮議委員會」第三次會議(海內外所有成員) 第二屆第一次董事會通過加速器基本設計、建造地點及經費需求 「台灣光子源興建計畫書」提報國科會 國科會通過「台灣光子源同步加速器興建計畫書」，並核准大型研究設施專題研究計畫95年預算1億元。「台灣光子源同步加速器興建計畫書」 與「台灣光子源土木建築計畫書」提報國科會轉呈行政院核定
2007年02月 2007年03月 2007年03月	「台灣光子源興建計畫書諮議委員會」第四次會議(核心成員) 經建會原則同意通過「台灣光子源土木建築計畫書」 (共17.5億) 行政院原則同意通過「台灣光子源興建計畫書」與「台灣光子源土木建築計畫書」
2007年6月	立法院通過96年TPS新興計畫科技預算2.5億
2007年6月 2007年7月 2007年7月 2007年10月	第一次國際性Machine Advisory Committee (MAC) 委員會議，審查TPS規劃進度 第五次諮議委員會議 (Steering Committee) (核心成員) 公開徵求土木建築師團隊規劃TPS建物 完成土木建築師甄選與簽約
2008年1月	第二次國際性Machine Advisory Committee (MAC) 委員會議，儲存環基本磁格參數定案。 第一次用戶與光束線規劃策略會議。
2008年6月 2008年7月	完成英文版加速器細部設計初步報告 第三次國際性Machine Advisory Committee (MAC) 委員會議
2008年9月	土木建築完成細部設計、申請建照
2008年12月 2009年1月	第一次國際性Science Advisory Committee (SAC)委員會議 施工廠商招標完成、基地破土興建

Basic Features of TPS

- Low emittance lattice – increasing the brightness
- Robust and flexible operation lattice – suitable for various operation condition
- Top-Up operation – Constant thermal loading
- Sharing tunnel booster – Low emittance, easy for injection, and reduce the complexity of civil construction
- Single bunch injection – few bunches, hybrid filling pattern
- SRF cavities – Reduction of HOMs, increasing photon flux and less cavities.
- Crab cavities or laser slicing – hundreds femto-seconds short-bunch operation
- Potentially operate with Free Electron Laser or Energy Recovery Linac

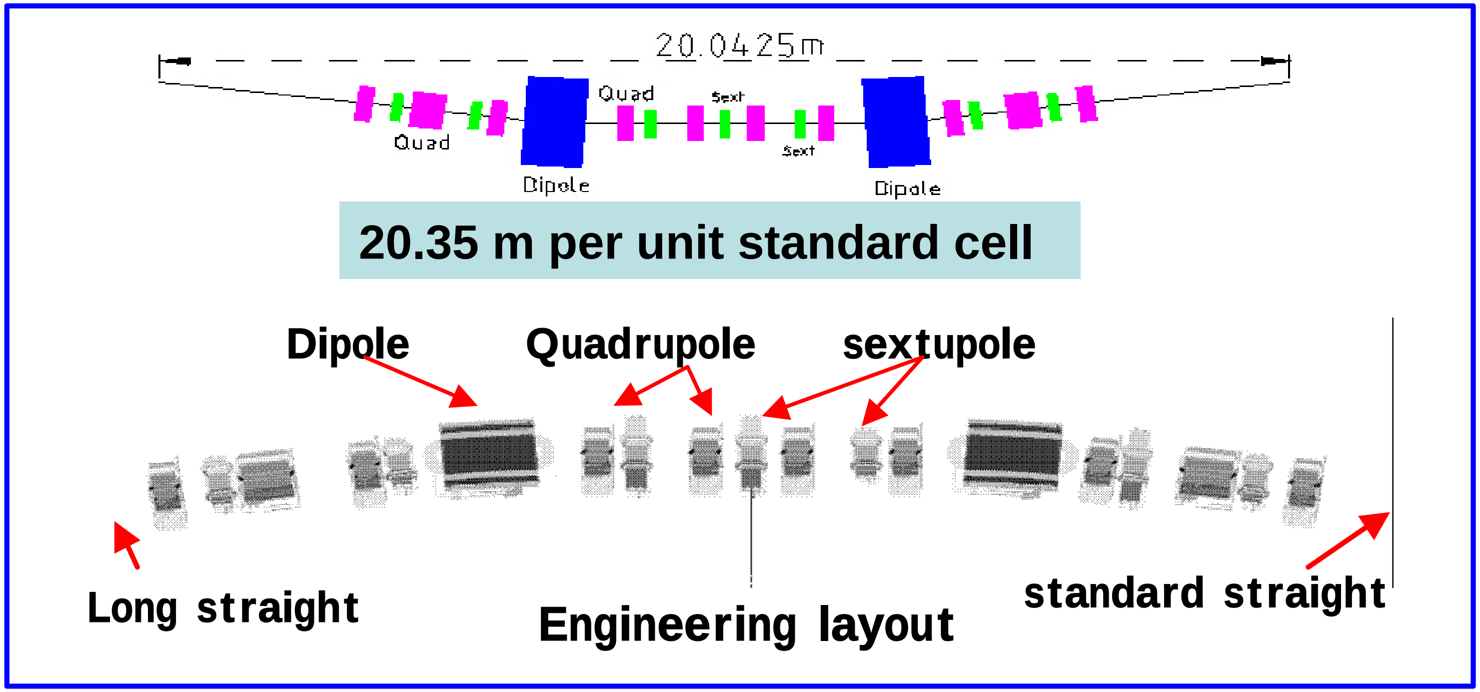
TPS DBA Parameters (I)

	DBA79H1 Low emittance mode	DBA79IA1 Low-dispersion mode	DBA79JA1 Zero-dispersion mode
Energy (GeV)	3.0	3.0	3.0
Beam current (mA)	400	400	400
Circumference (m)	518.4	518.4	518.4
Nat. emittance ε_x (nm-rad)	1.6	2.5	4.9
Cell / symmetry / structure	24 / 6 / DBA	24 / 6 / DBA	12 / 6 / DBA
Straights	12m*6+7m*18	12m*6+7m*18	12m*6+7m*18
β_x / β_y / η_x (m) LS middle	10.28 / 6.05 / 0.117	10.07 / 6.17 / 0.067	10.21 / 6.15 / 0.0
β_x / β_y / η_x (m) SS middle	5.39 / 1.62 / 0.087	5.39 / 1.71 / 0.05	5.17 / 1.71 / 0.0
Beam size (σ_x / σ_y) (μm) LS centre (1% coupling)	165.10 / 9.85	170.32 / 12.50	224.22 / 17.41
Beam Div. ($\sigma_{x'}$ / $\sigma_{y'}$) (μrad) LS centre (1% coupling)	12.49 / 1.63	15.85 / 2.02	21.96 / 2.83
Beam size (σ_x / σ_y) (μm) SS centre (1% coupling)	120.81 / 5.11	124.98 / 6.58	159.62 / 9.19
Beam Div. ($\sigma_{x'}$ / $\sigma_{y'}$) (μrad) SS centre (1% coupling)	17.26 / 3.14	21.65 / 3.85	30.85 / 5.36

TPS DBA Parameters (II)

	DBA79H1 Low emittance mode	DBA79IA1 Low-dispersion mode	DBA79JA1 Zero-dispersion mode
Betatron tune n_x / n_y	26.2 / 13.25	26.218 / 13.35	26.31 / 13.36
Mom. comp. (a_1, a_2)	2.4×10^{-4}, 2.1×10^{-3}	2.5×10^{-4}, 1.7×10^{-3}	2.9×10^{-4}, 8.7×10^{-4}
Nat. energy spread s_E	8.86×10^{-4}	8.86×10^{-4}	8.86×10^{-4}
Damping time (ms) (t_x / t_y / t_s)	12.20 /12.17 / 6.08	12.20 /12.17 / 6.08	12.20 /12.17 / 6.08
Nat. chromaticity x_x / x_y	-75 / -27	-75 / -26	-75 / -26
RF frequency (MHz)	499.654	499.654	499.654
RF voltage (MV)	3.5	3.5	3.5
Harmonic number	864	864	864
SR loss/turn, dipole (MeV)	0.8526	0.8526	0.8526
Synchrotron tune n_s	6.09×10^{-3}	6.27×10^{-3}	6.72×10^{-3}
Bunch length (mm)	2.86	2.94	3.15
Dipole length (m)	1.1	1.1	1.1
Dipole field (Tesla)	1.1908	1.1908	1.1908
Critical energy dipole (keV)	7.12	7.12	7.12
Number of D/Q/S magnets	48/240/168	48/240/168	48/240/168

TPS DBA Standard Cell

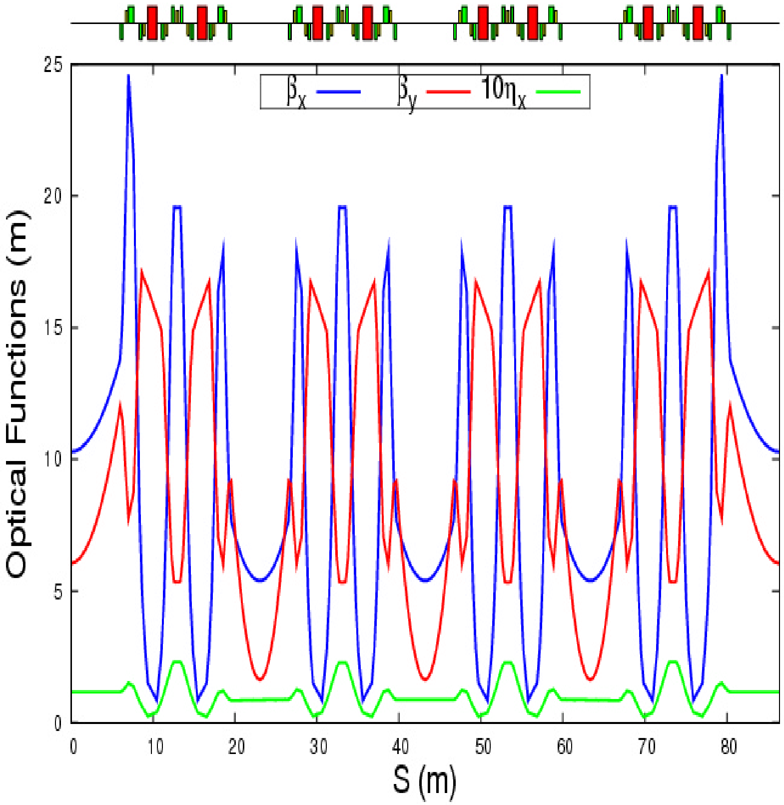


Dipole length 1.1 m (1.19 T)

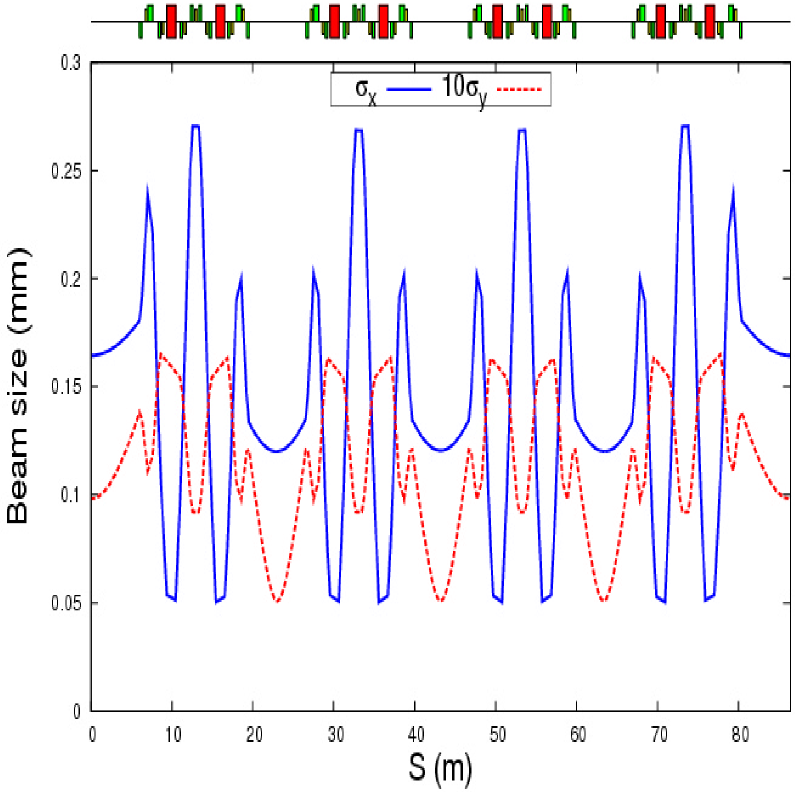
Quadrupole length = 60, 30 cm
Quad strength < 17 T/m at 3 GeV
10 quadrupoles/cell
8-family quadrupoles /DBA

Sextupole length = 25 cm
Sextupole strength < 5.5 m^{-2} at 3 GeV
7 sextupoles/cell
8-family sextupoles/DBA

Optical Functions



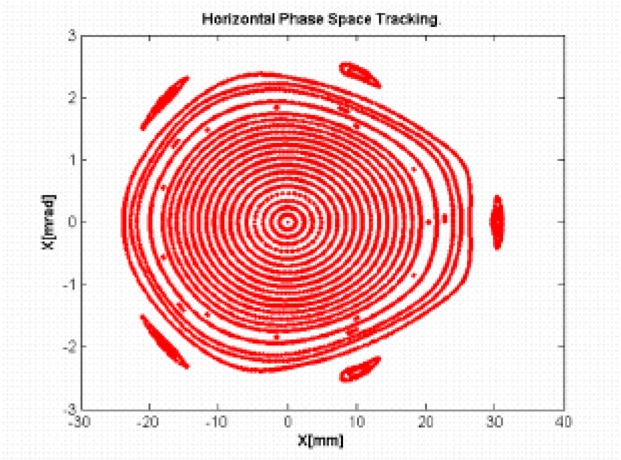
Emittnace=1.6 nm-rad

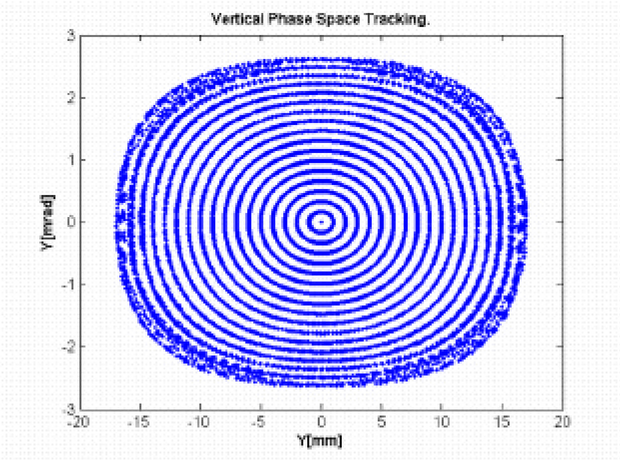


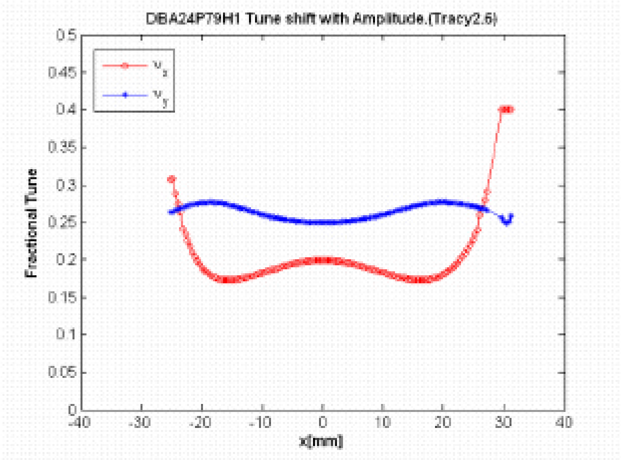
Beam size @ 1% coupling

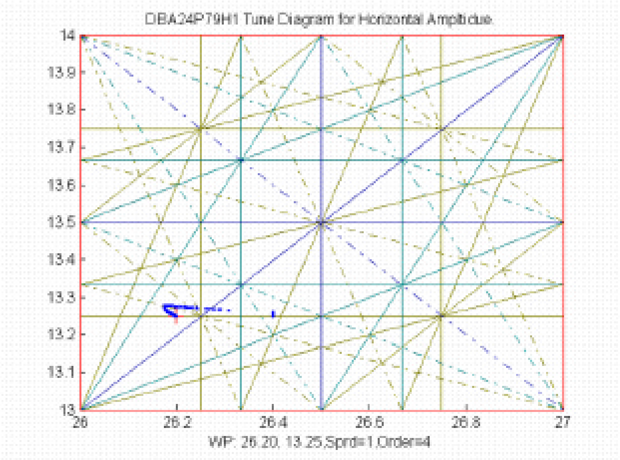
Phase Space Tracking and Tune Shift with Amplitude

-- TPS low emittance mode

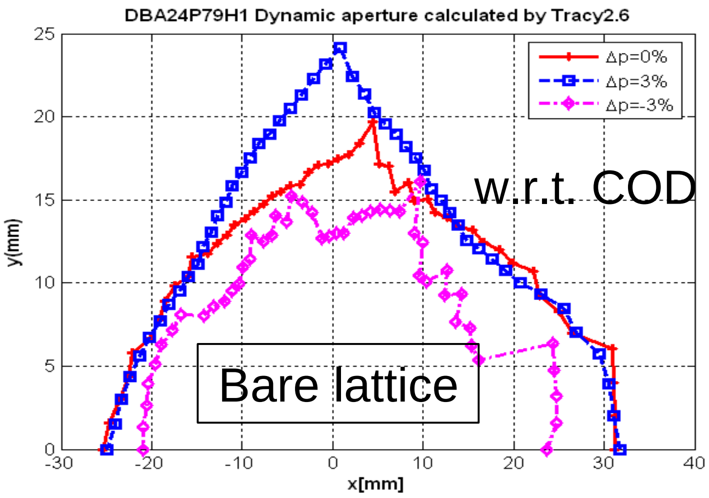


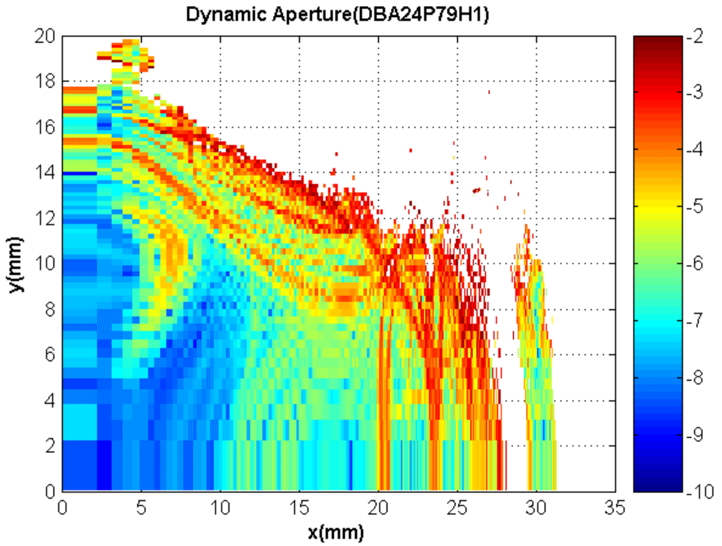


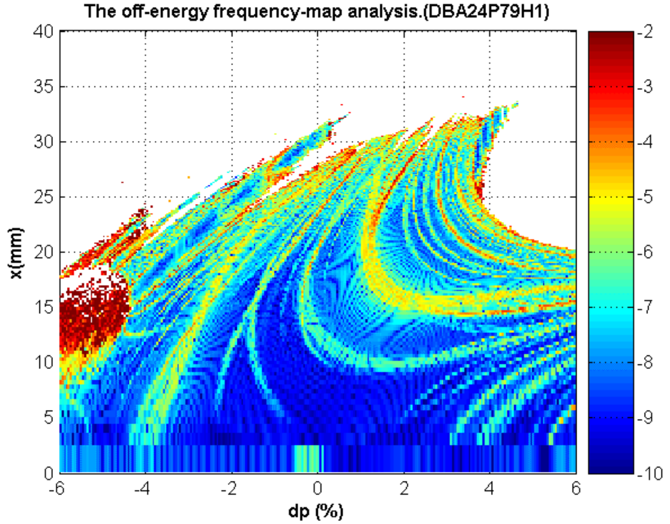


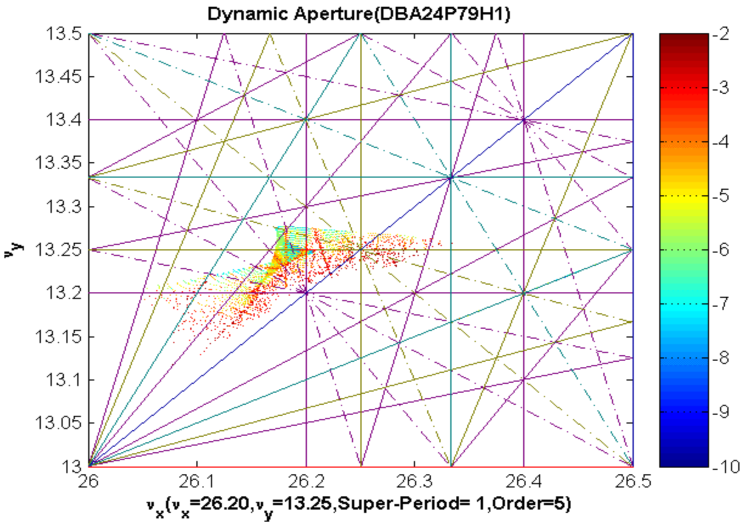


TPS DBA
Dynamic Aperture and FMA

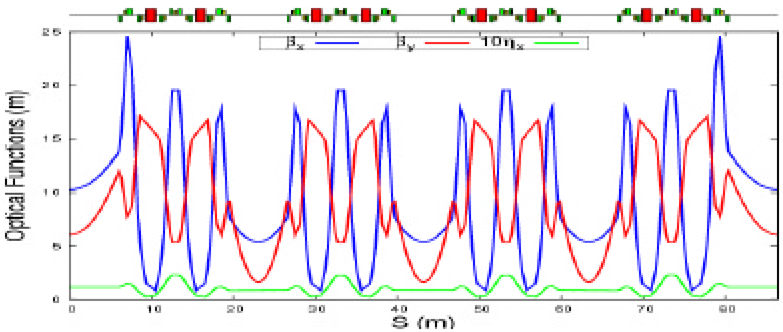




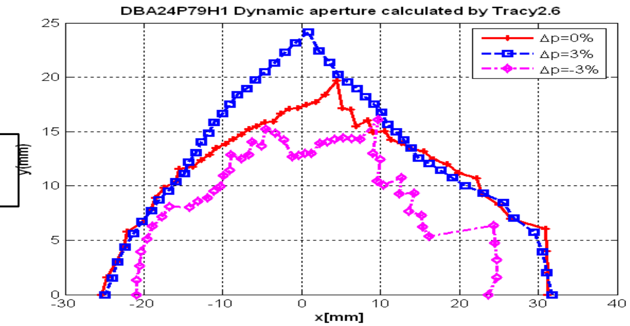


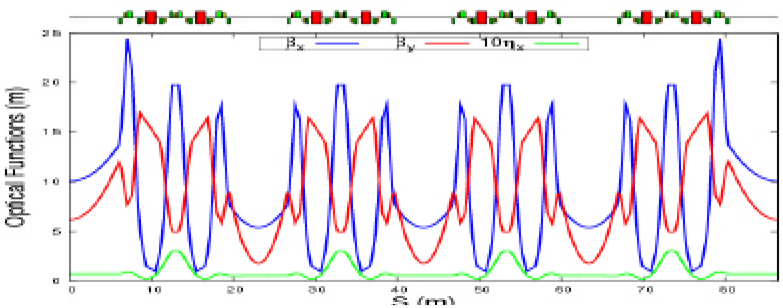


Lattice Functions and Dynamic Aperture

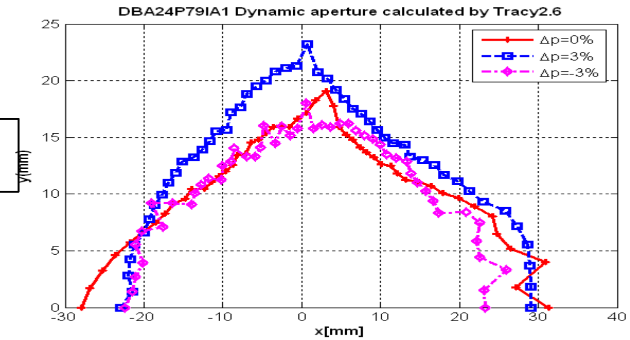


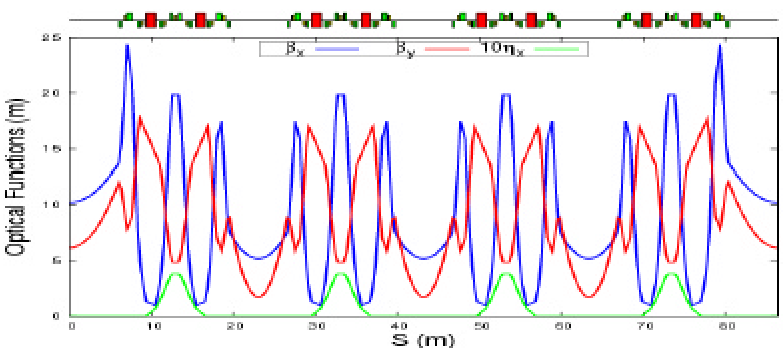
1.6 nm-rad



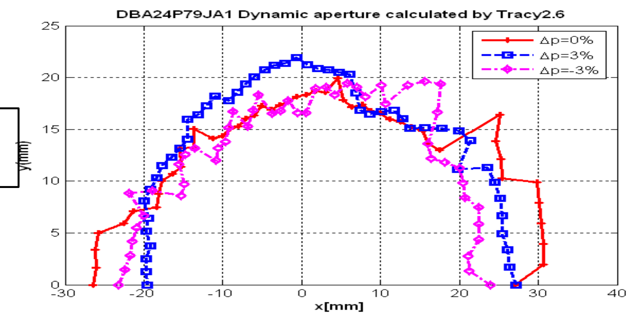


2.5 nm-rad





4.9 nm-rad



8-family quadrupoles

8-family sextupoles

COD Correction

- Quad misalignment displacement without girder in x/y
  → Amp. factor= 54.5/40.3 in x/y rms
- With girder in x/y
  → Amp. factor = 30.6/8.0 in x/y rms

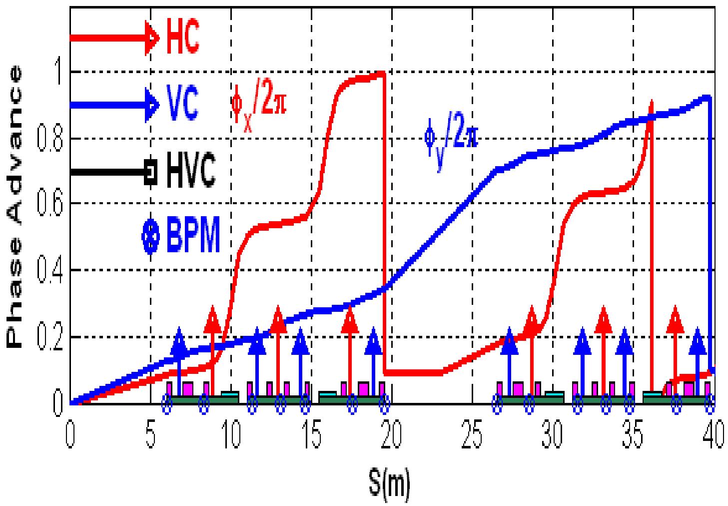
- Errors: (rms)

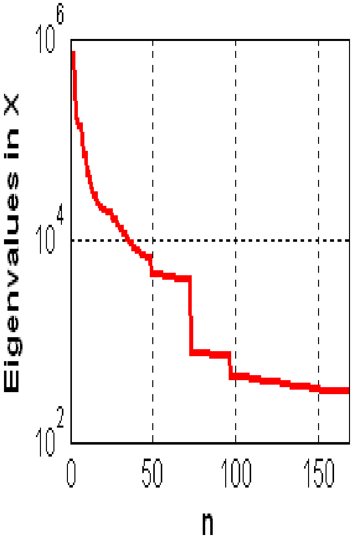
  Quad displacement w.r.t. girder: 0.03 mm
  Sextupole displacement w.r.t. girder: 0.03 mm
  Girder displacement: 0.1 mm
  Bend displacement w.r.t. girder: 0.5 mm
  Bend roll: 0.2 mrad
  Girder roll: 0.1 mrad
  Bend relative field error : 0.001
  BPM error: 0.1 mm

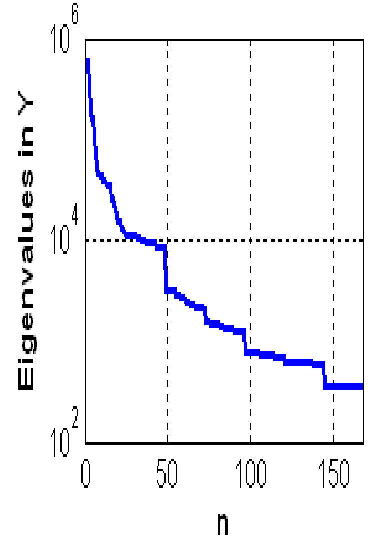
- COD before correction:
  rms COD X/Y= 3.9 / 2.1 mm

- COD after correction:
  rms COD X/Y= 0.102/0.081mm

7 BPM each cell
3 HC(+1) and 4 VC(+1) each cell for SVD but all sextupoles are with HC and VC.

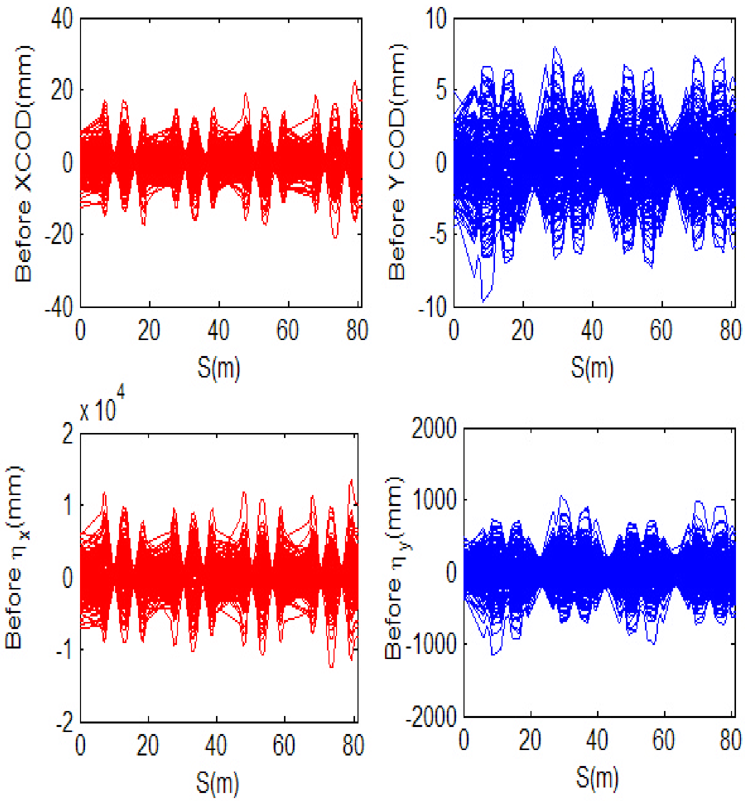




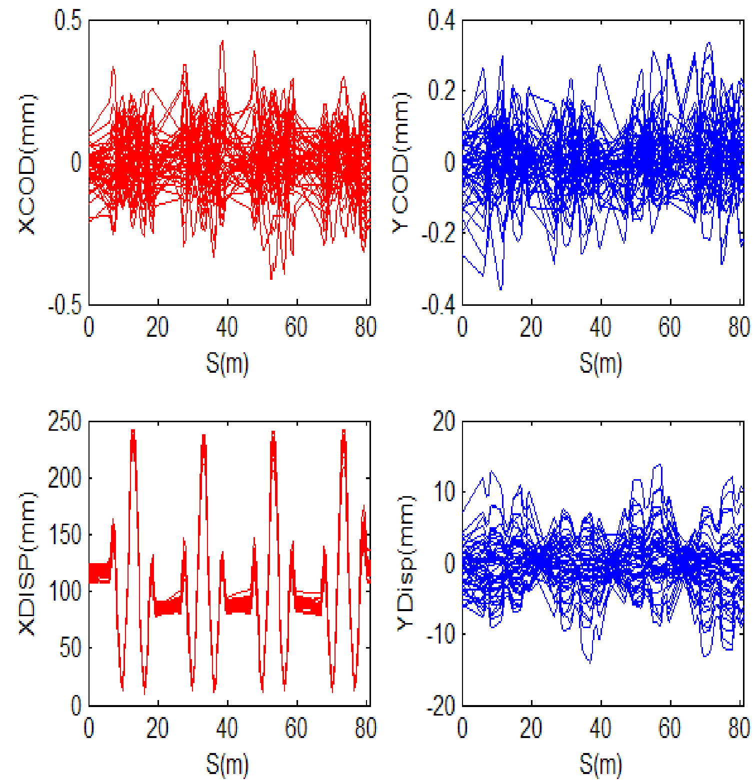


COD and Dispersion Function Before and After COD correction

(no optics correction)



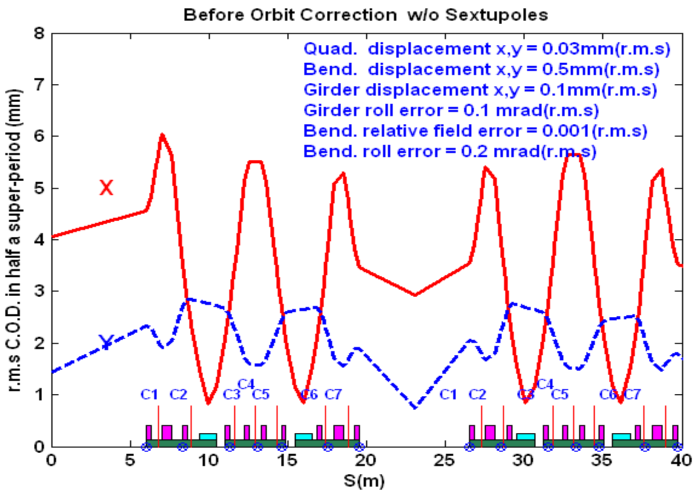
Before COD Correction

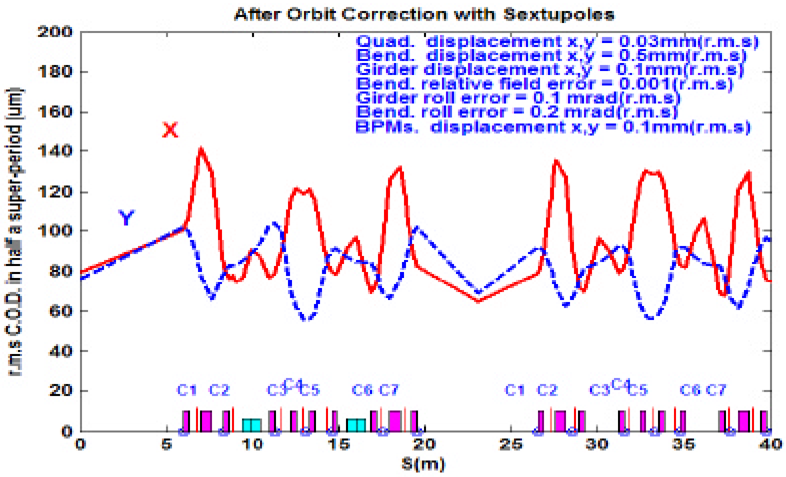


After COD correction

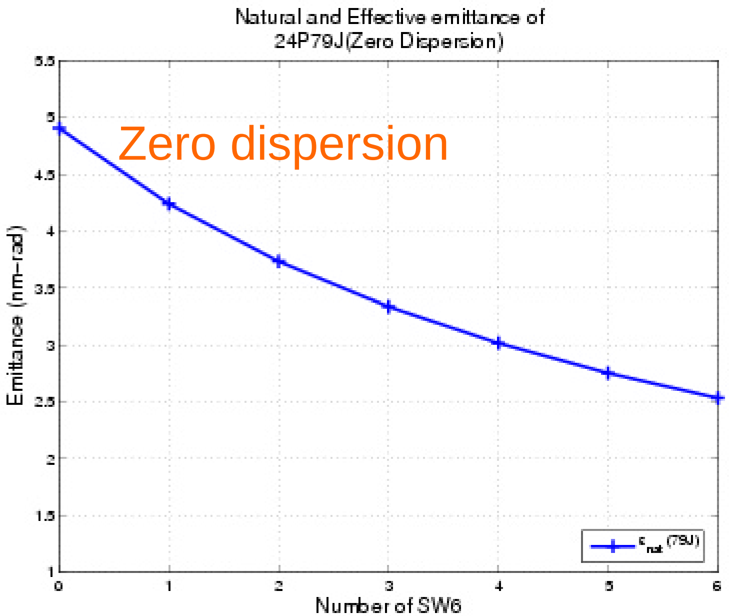
Closed Orbit Correction Statistics (24P79H1 sextupole on)

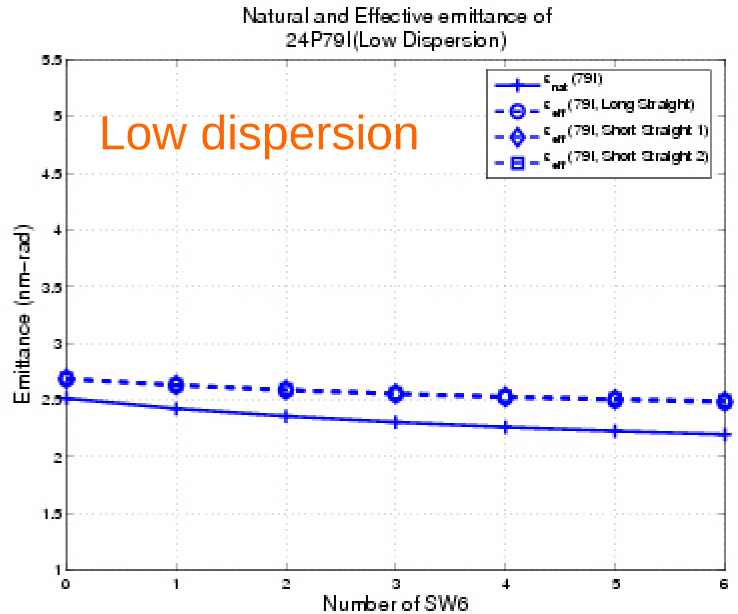
	Before Correction		After Correction	
	X	Y	X	Y
COD mm (r.m.s.)	3.90	2.11	0.102	0.081
Max. COD mm	23.64	9.20	0.801	0.479
Max. Cor Strength mrad	0.530 (x),		0.316 (y)	
Mean Cor Strength mrad	0.079 (x),		0.030 (y)	

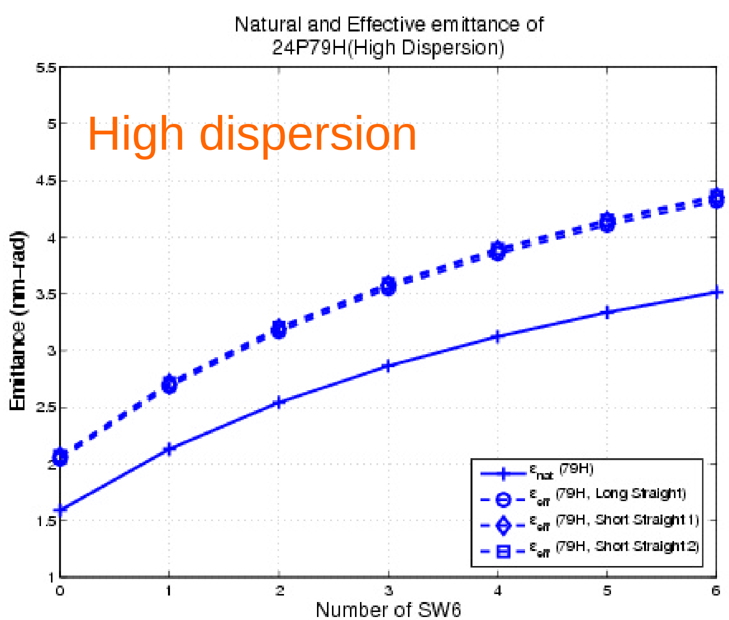




Natural and Effective Emittance with High Field IDs







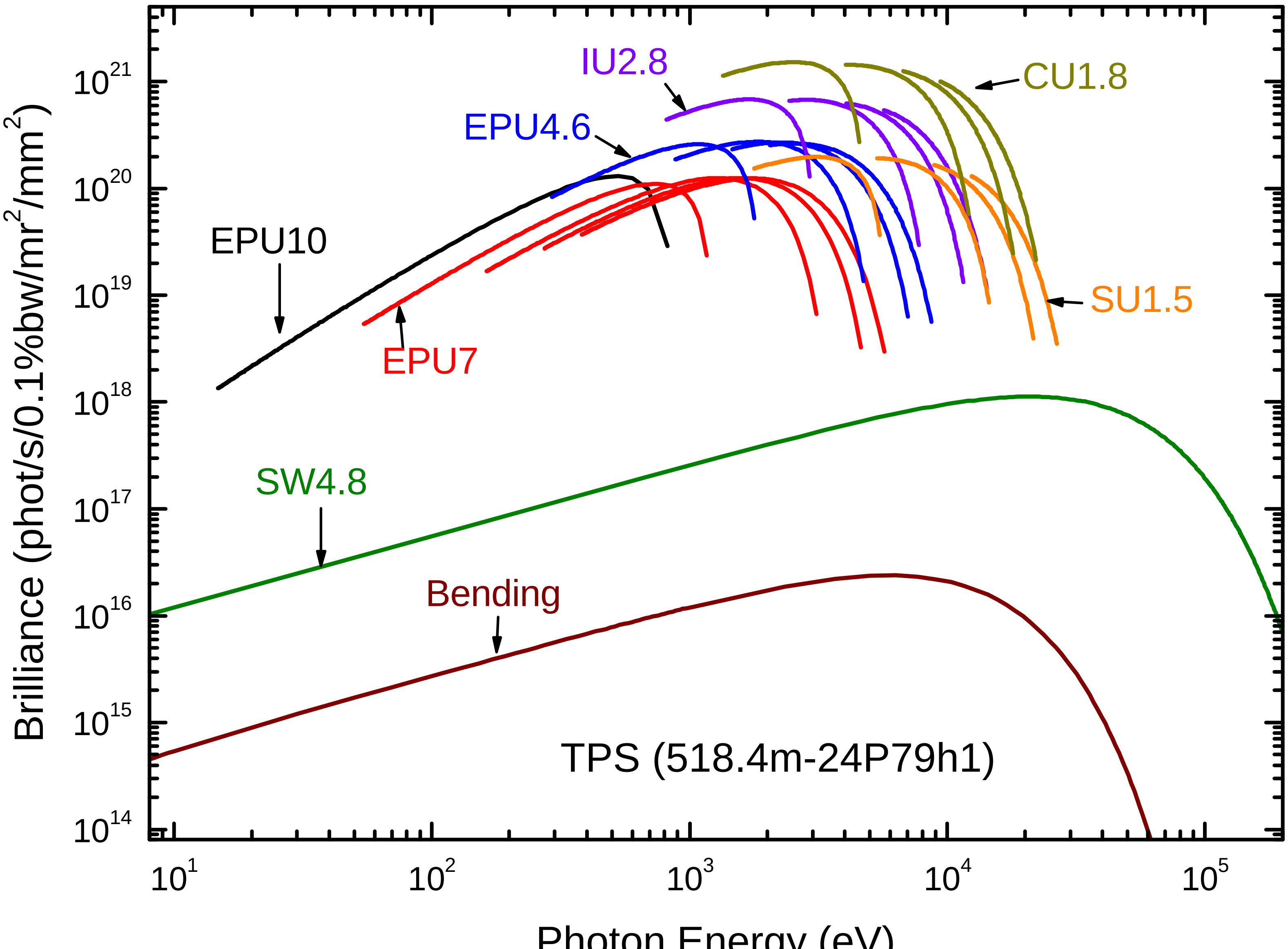
Effective emittance $e_{x,eff} = \sqrt{e_x^2 \left(1 + \frac{s_E^2 h_x^2}{b_x}\right)}$

	SW6
Current (mA)	400
?(mm)	60
N_{period}	33
By (T)	3.5
L (m)	2
Peak Power density (kW/mr^2)	52.5
Total power (kW)	62.4

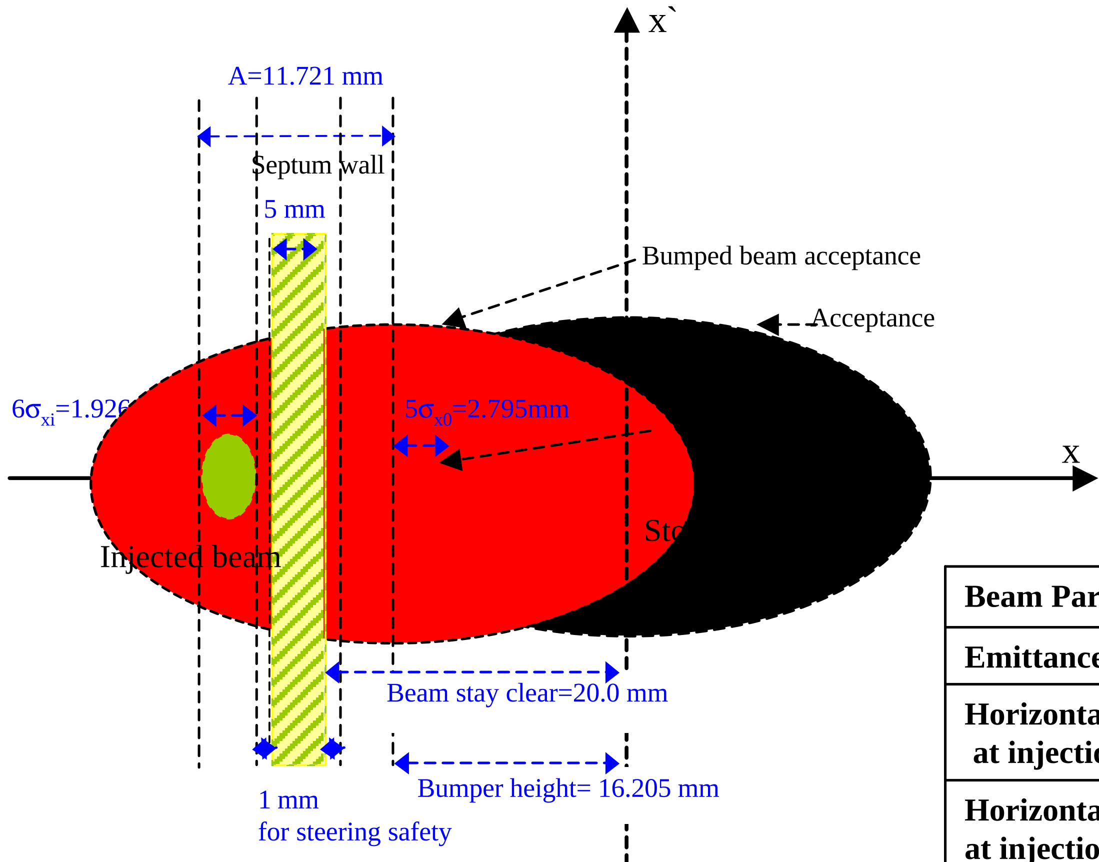
TPS insertion devices - proposed

Ee (GeV) 3		EPU10	EPU7	SW4.8	EPU4.6	IU2.8	SU1.5	CU1.8
Photon energy (keV)	HP	0.014-4	0.055-5.7	20-100	0.3-8.7	0.81-14.25	1.8-26.6	1.35-22.2
	VP	0.02-4	0.09-5.7		0.58-8.7			
Current (A)		0.4	0.4	0.4	0.4	0.4	0.4	0.4
λ (cm)		10	7	4.8	4.6	2.8	1.5	1.8
N_{period}		88	64	30	97	160	67	250
By (T)		1.14	1	4.2	0.76	0.9	1.4	1.34
Bx (T)		0.99	0.77		0.49			
Ky_{max}		10.65	6.54	18.83	3.27	2.35	1.96	2.25
Kx_{max}		9.25	5.03		2.11			
L (m)		8.8	4.48	1.44	4.462	4.48	1.005	4.5
Gap (mm)		15	15	14	15	7	5.6	5
Peak Power density (kW/mr^2)		35.23	22.48	44.25	25.89	50.58	32.95	117.66
Total power (kW)		26.06	10.21	57.89	5.87	8.27	4.49	18.41

Brilliance of 518.4 m DBA lattice

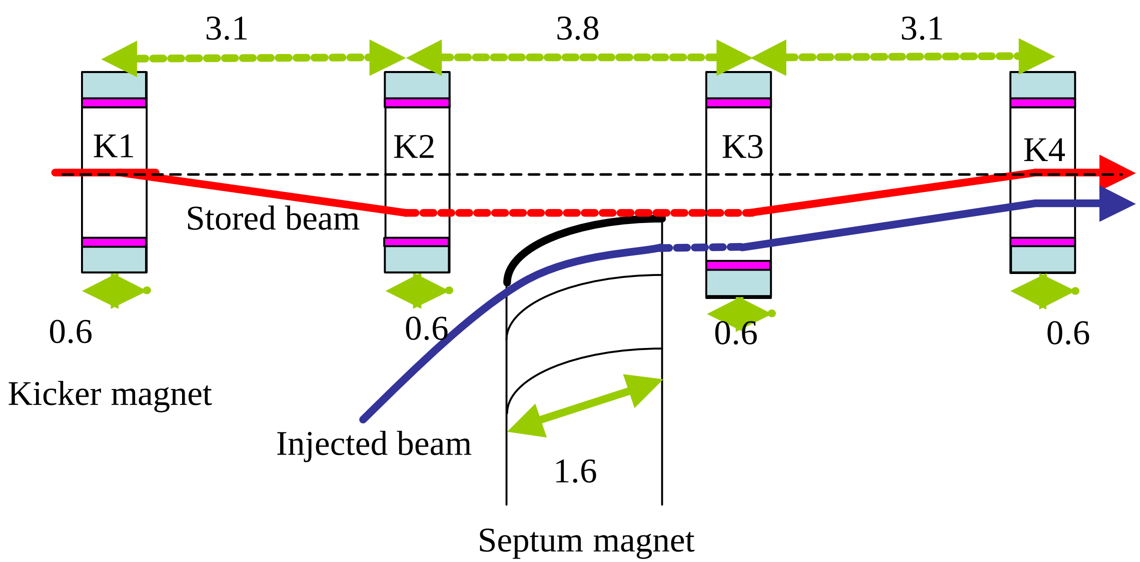


Storage Ring injection scheme



Beam Parameter	Storage Ring	Transfer Line
Emittance(3 GeV) (nm-rad)	1.912*4*4=30.6	50
Horizontal beta value at injection point (m)	10.211	2.0613
Horizontal dispersion at injection point (m)	0.0	0.0
Energy spread	8.8585e-4	
Horizontal beam size(mm)	0.559	0.321

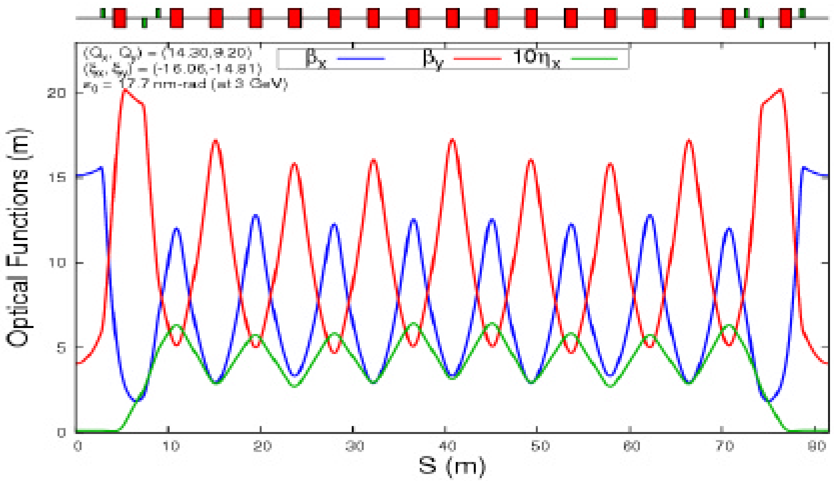
Kicker and Septum Magnet Parameters for SR injection (7.5 degree case)



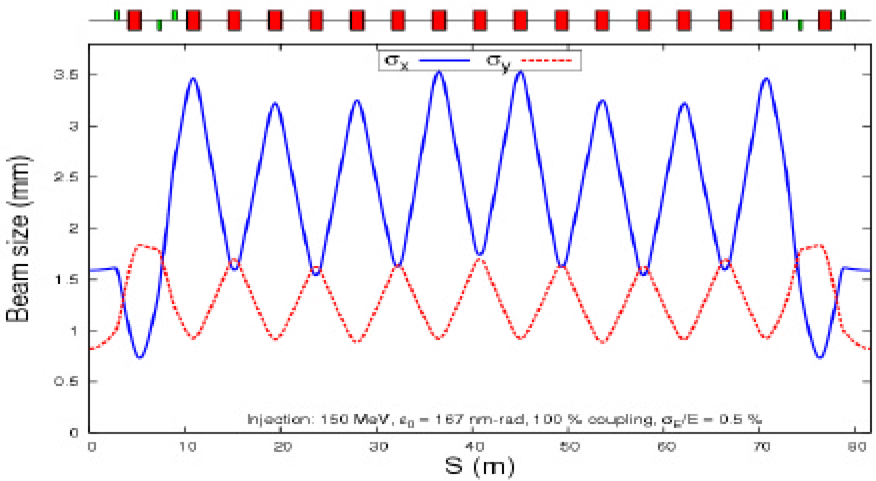
	Septum	**Kicker**
Magnetic Length (m)	**1.6**	**0.60**
Maximum Field (T)	**0.818**	**0.087**
Deflection (mrad)	**130.9**	**5.227**
Bumper height (mm)		**16.205**
Magnet Current Waveform(half-sine)		**5.184 us**

TPS Booster – missing diople FODO lattice

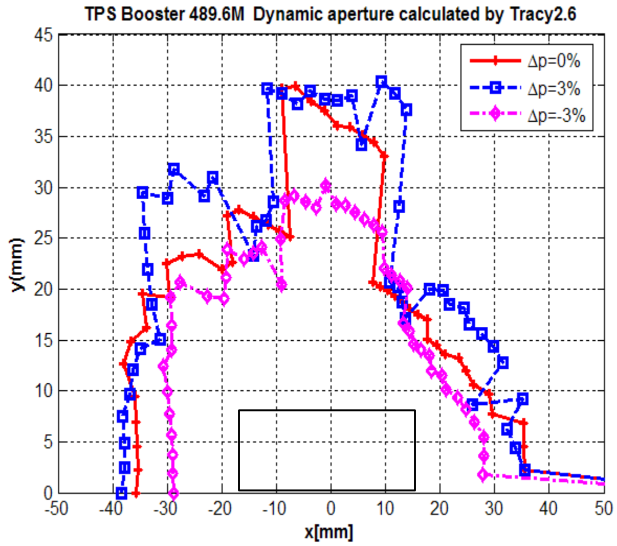
Optical Functions



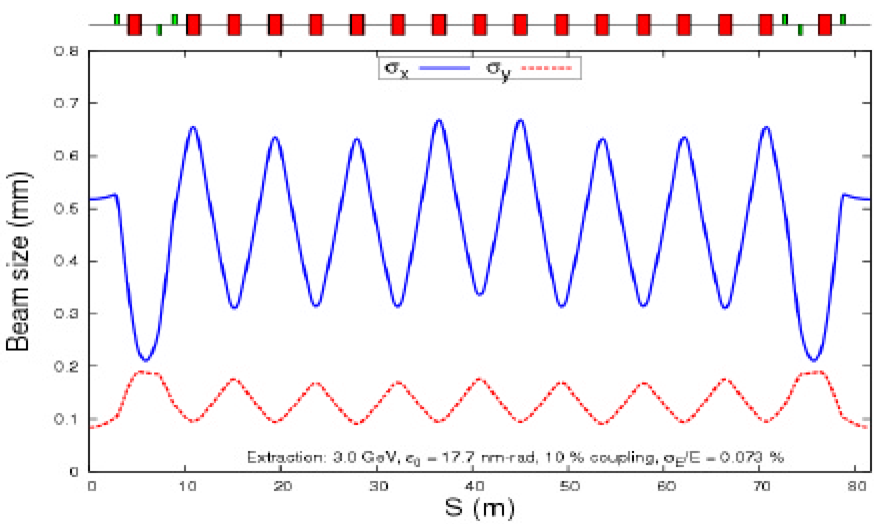
Beam size at injection



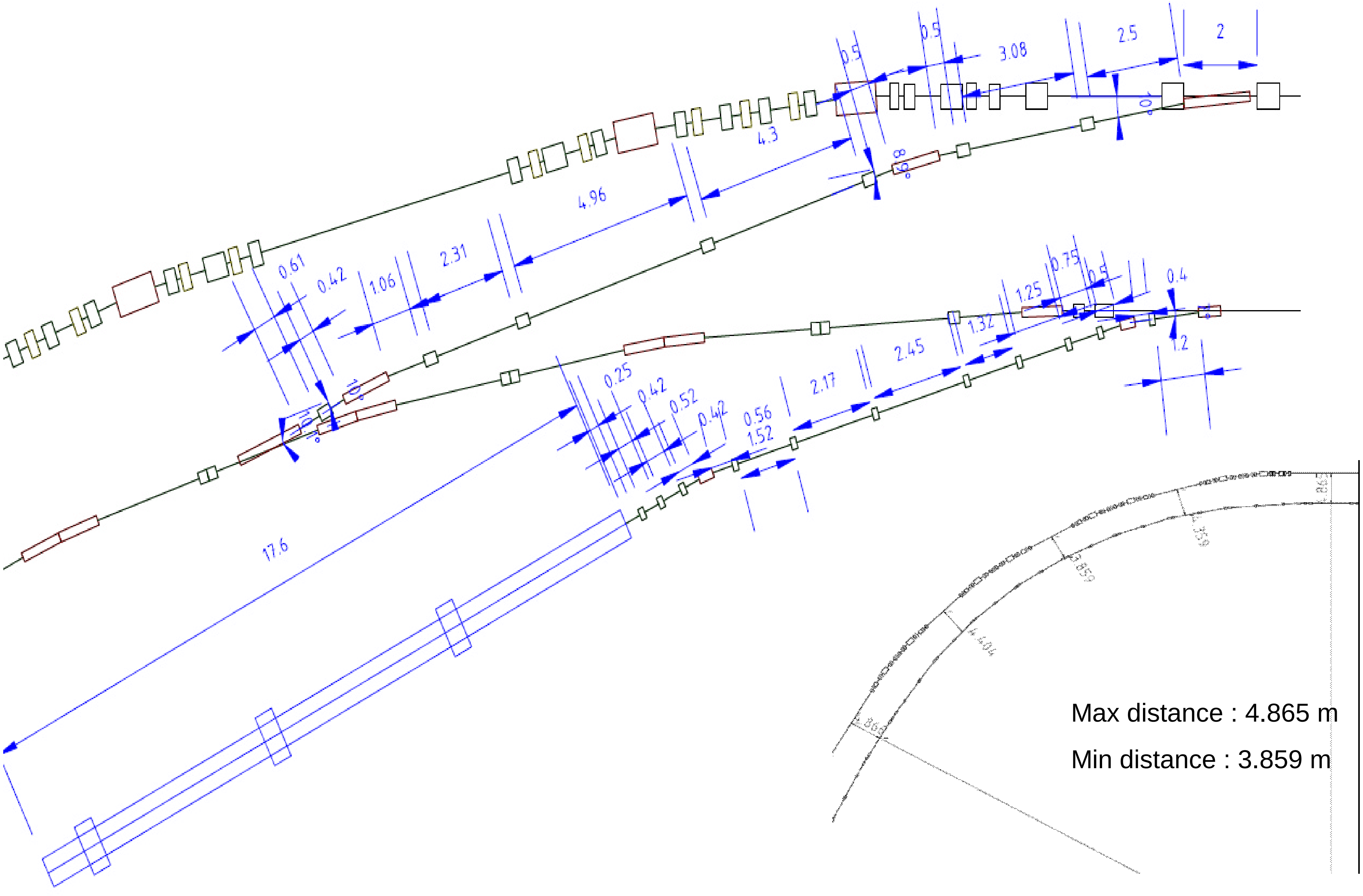
Dynamic Aperture (ξx=+3, ξy=+3)



Beam size at extraction



Injection into SR -- layout for 10º BM in BTS

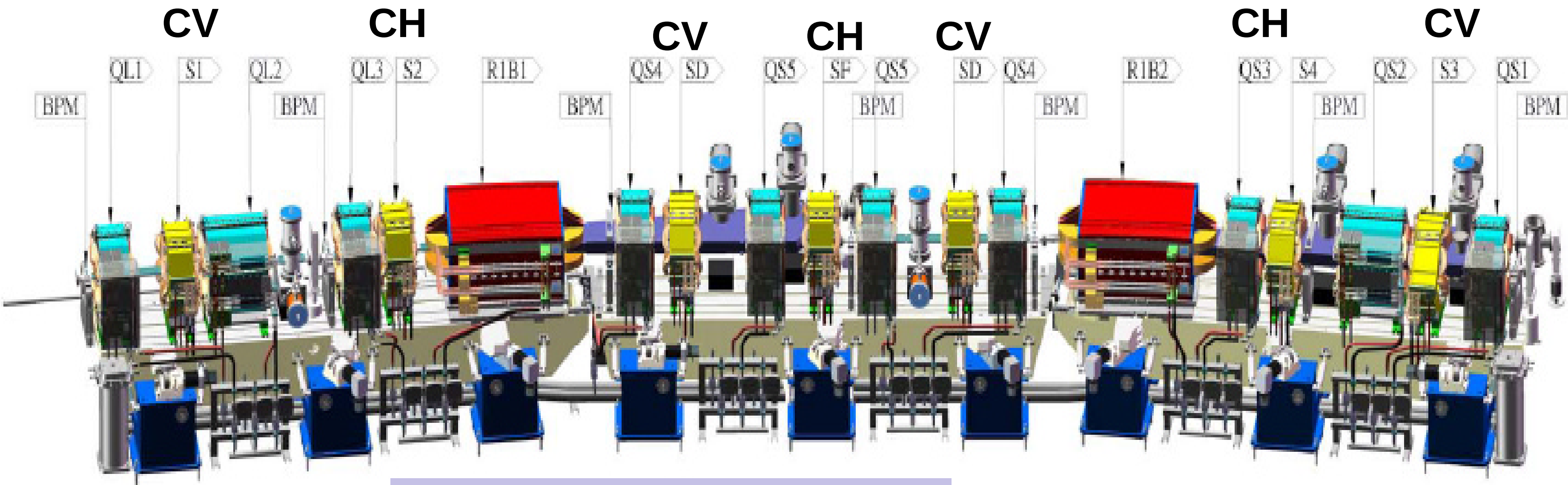


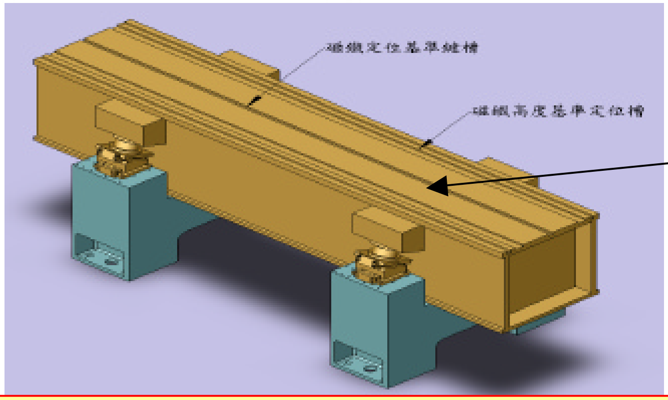
Max distance : 4.865 m

Min distance : 3.859 m

Accelerator Engineering System

Girder support and COD correction scheme



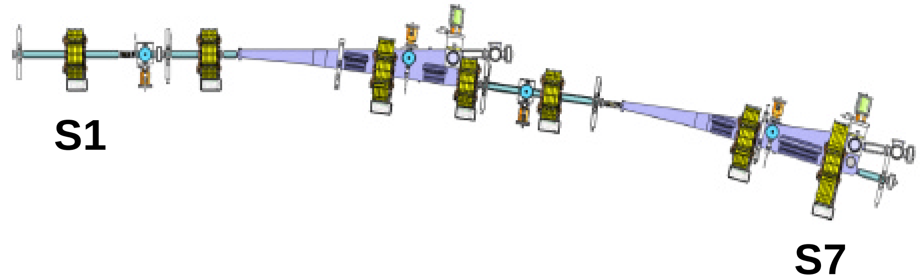


Precision ~ 15 mm

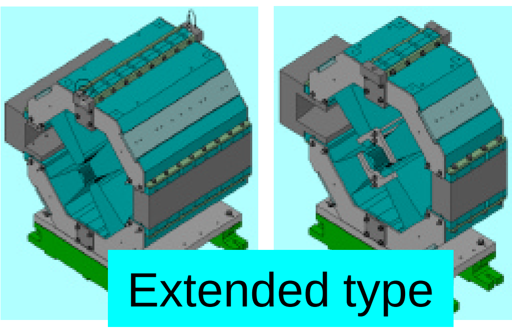
7 BPM each cell
3 HC(+1), 4 VC(+1) each cell for SVD but all sextupoles are with HC and VC.

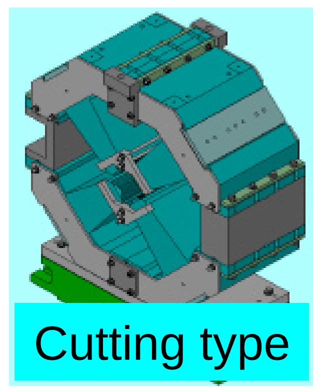
Design of Dipole, Quadrupole and Sextupole

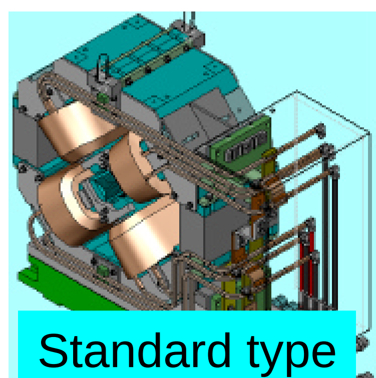
Four types of QP lamination shape



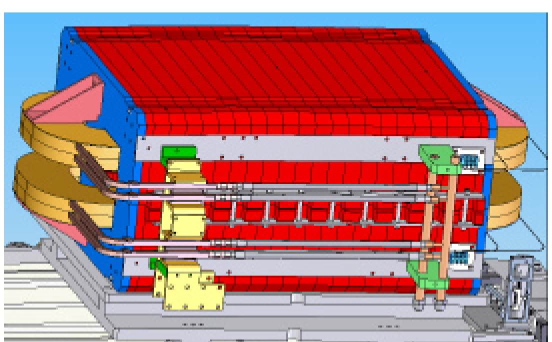
Three types of SP lamination shape

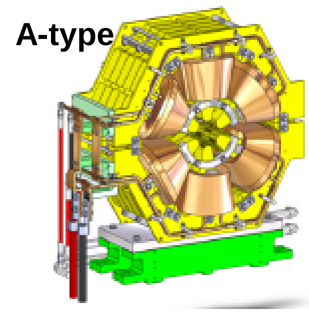


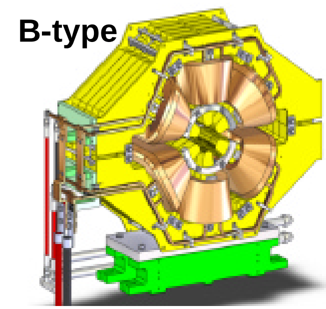


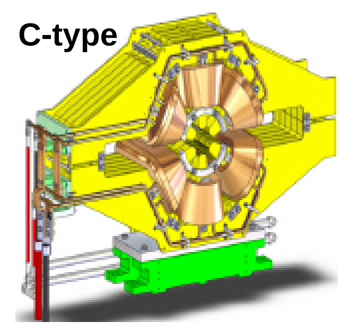


H-type DP lamination shape









Available length for insertion devices

- Length and numbers of straight section: 7m ×18+ 12m ×6
- Component's length at straight sections including vacuum chamber, bellows, flanges, pumping, BPM (total 1.4 m), and taper length (0.46 m) is 1.86 m.
- The length of chicane mechanism is 0.5 m.
- Useful ID length in 7 m straight section with and without chicane is 4.64 m and 5.14 m.
- Useful ID length in 12 m straight section with and without chicane is 9.64 m and 10.14 m.
- Maximum length of superconducting wiggler and undulator is 2m and 1 m, respectively.
- Length of EPU, IU and CU can be up to 4.5 m long. Two IDs can be installed in the same section

SU1.5 Design & Coil winding

(i) 0.77x0.51 mm rectangular wire winding

- **Superconducting wires specification**

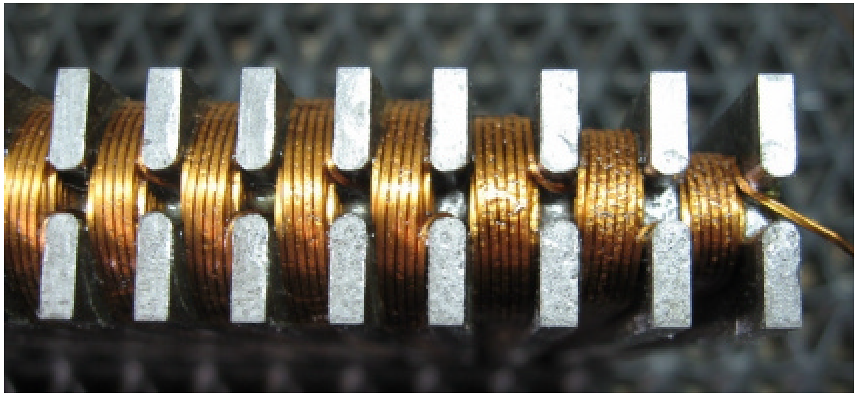
1. <u>Magnetic field:</u>

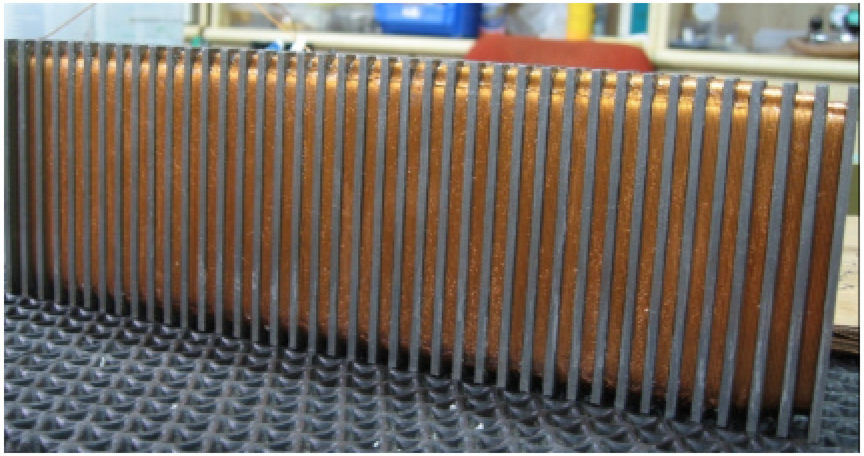
<u>B0=-1.41T@510A</u>, Bs=3.02T

2. <u>SC wire spec:</u>

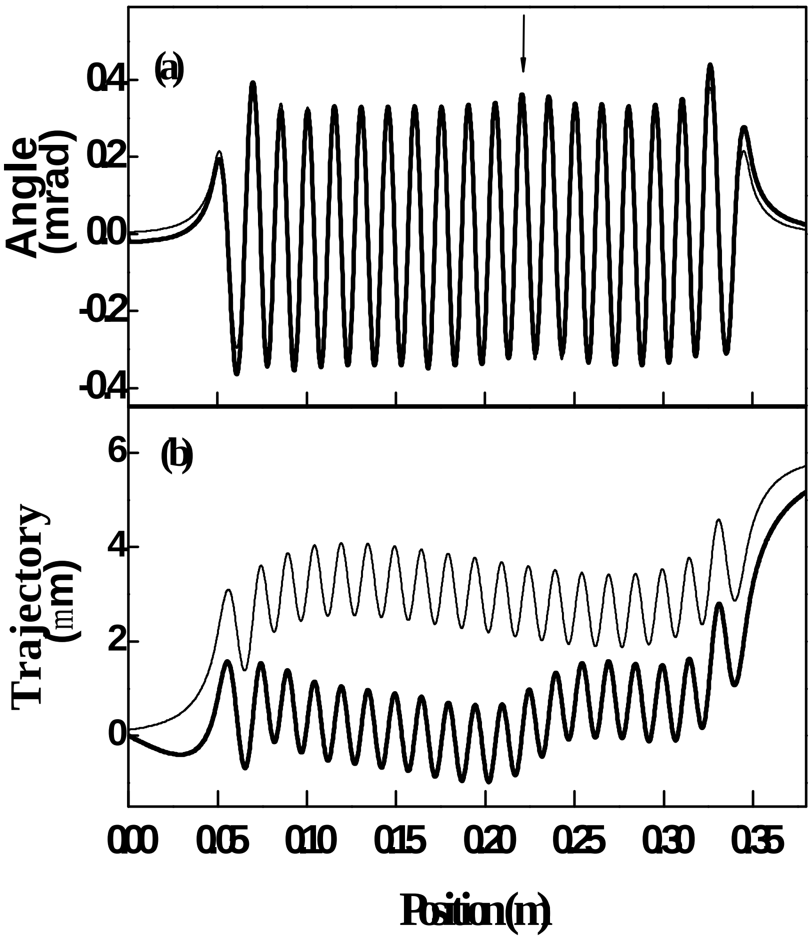
<u>Ic=3.2T @511A</u>

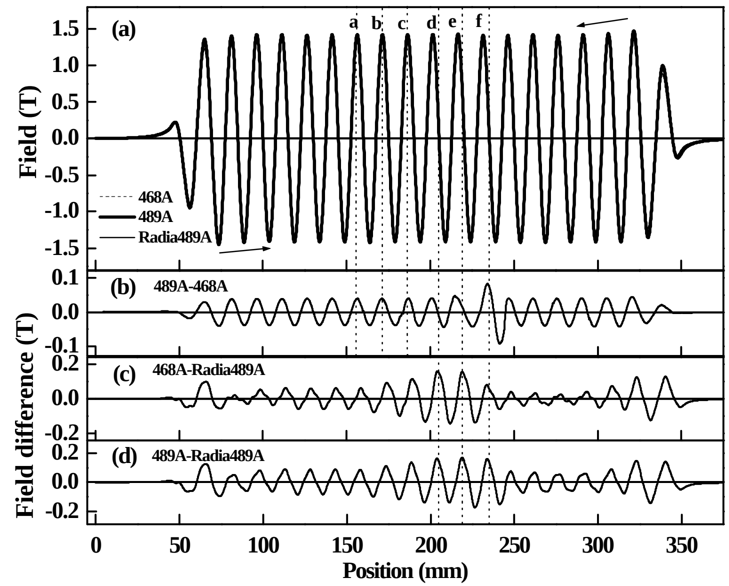
Cu/SC ratio	: 1.35
Twist pitch (mm)	: 26±2
Filament size (µm)	: 54
Number of filaments	: 54
R.R.R.	: 70

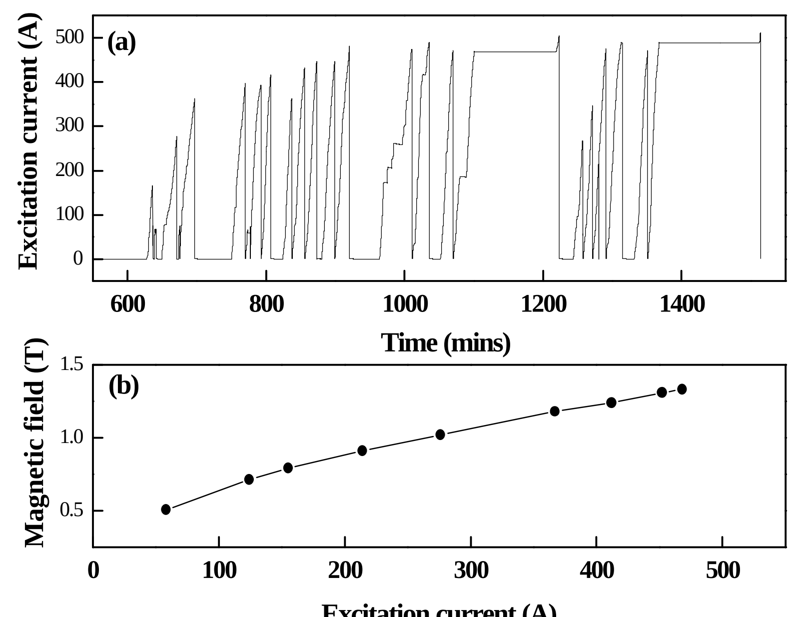




Field measurement & analysis of SU 1.5

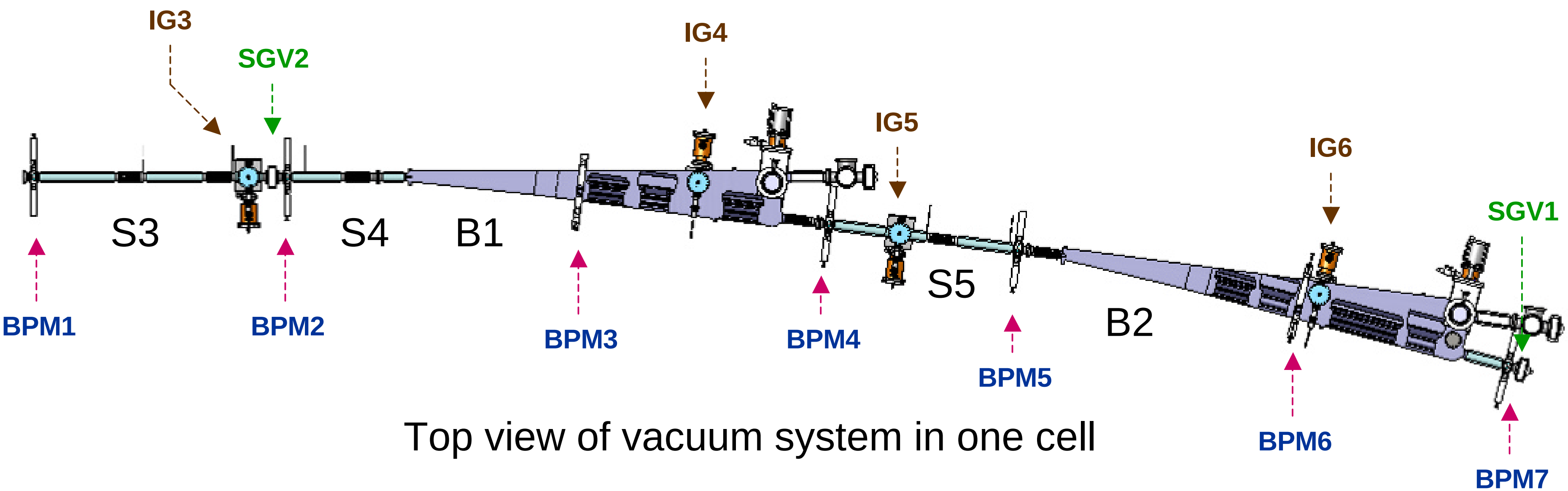




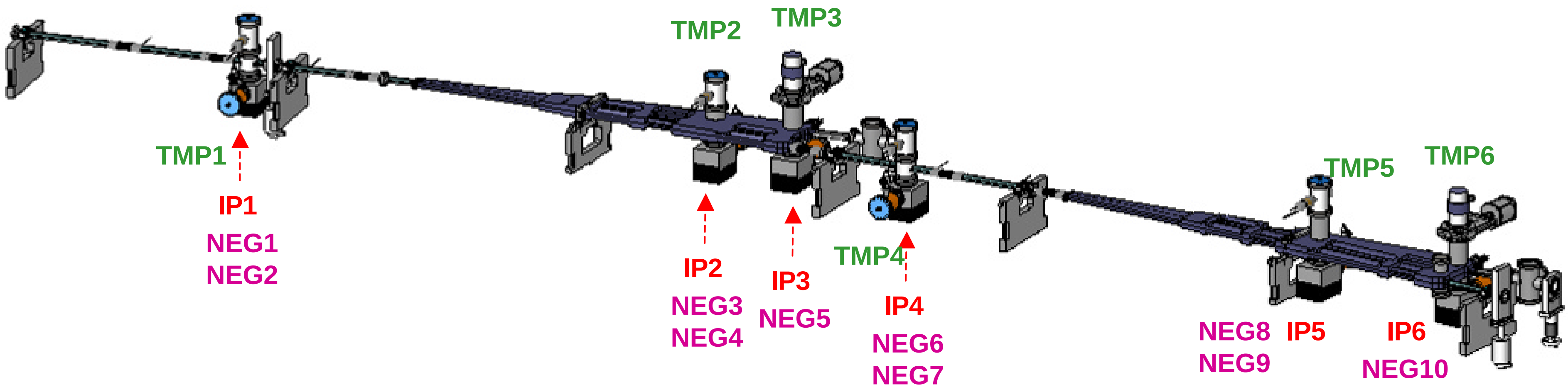


B0=1.45T@510A

Layout of Vacuum system

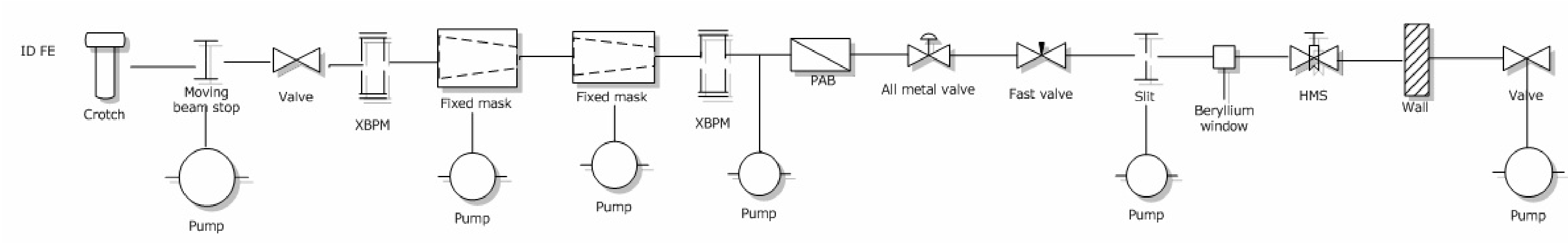


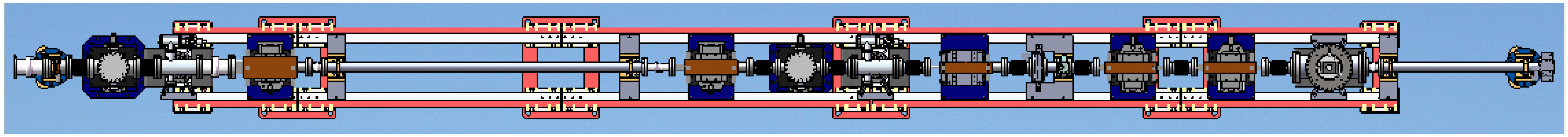
Top view of vacuum system in one cell

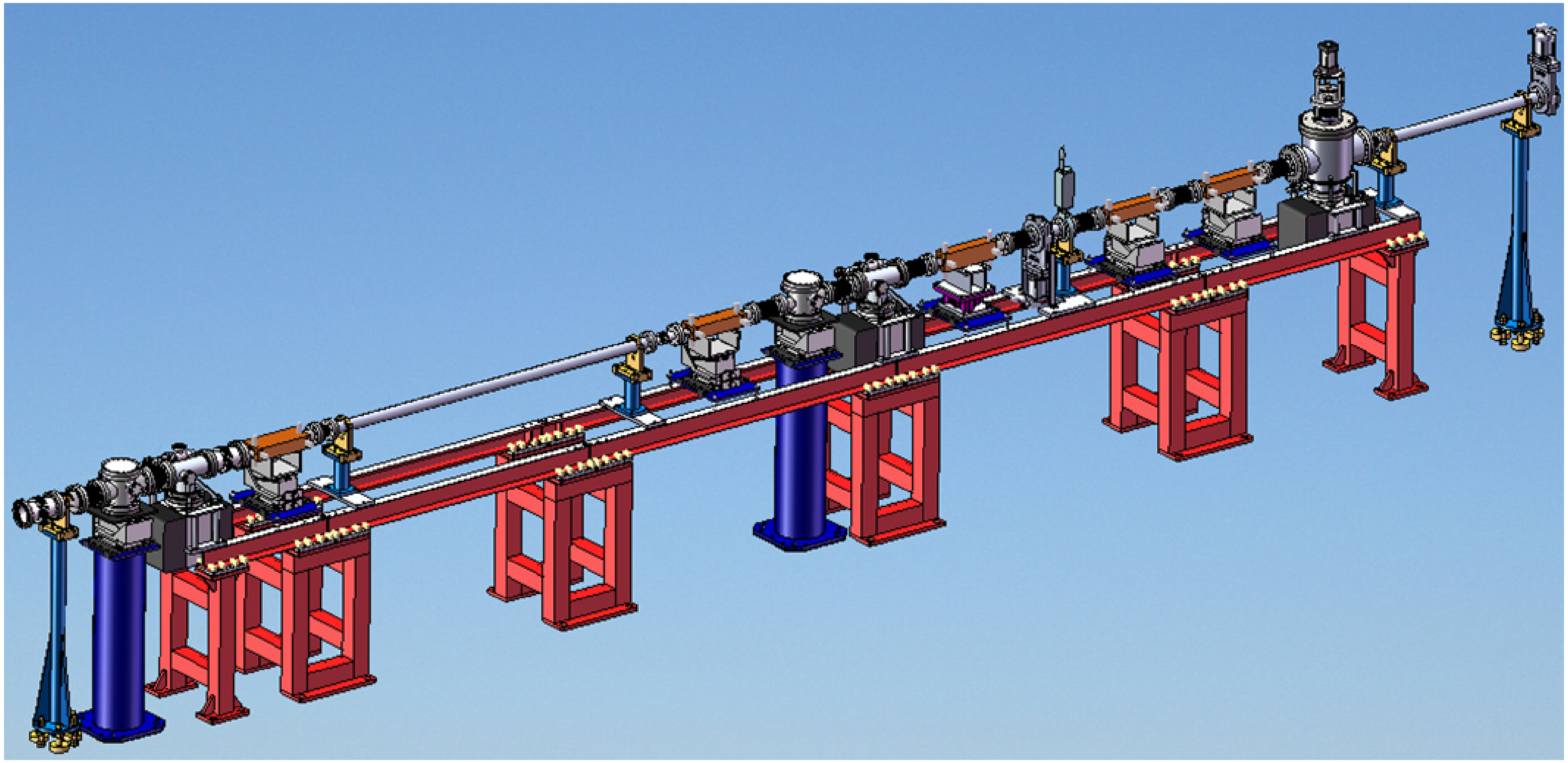


side view of vacuum system in one cell

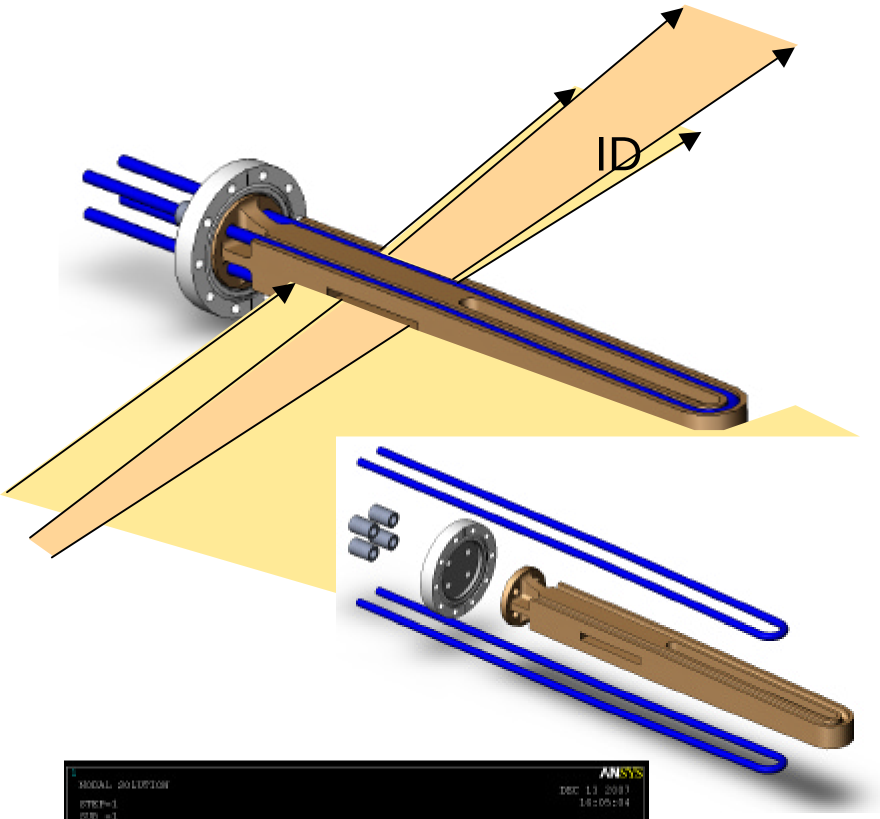
Front-end Layout of insertion devices

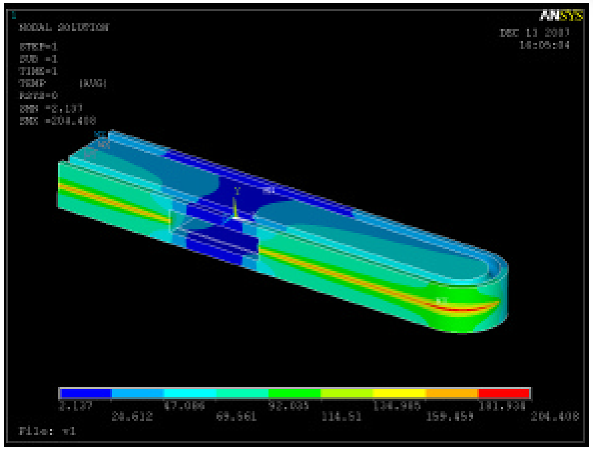




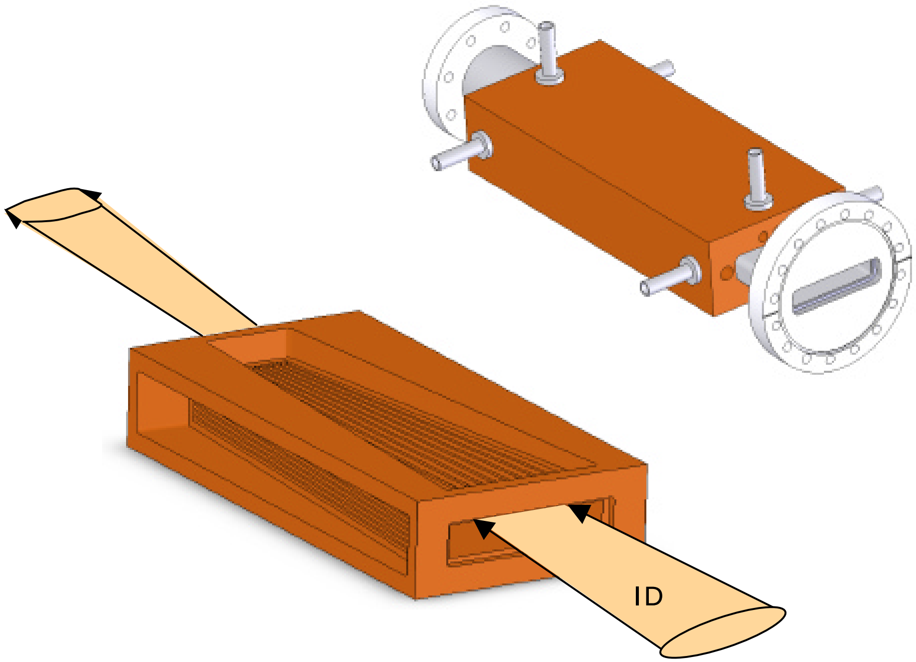


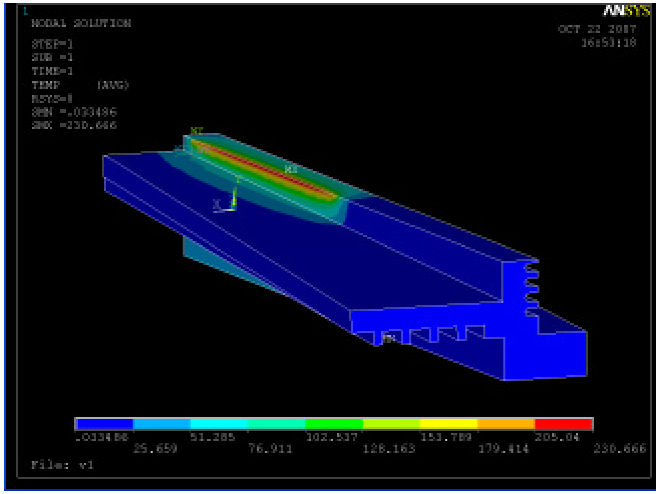
Crotch absorber





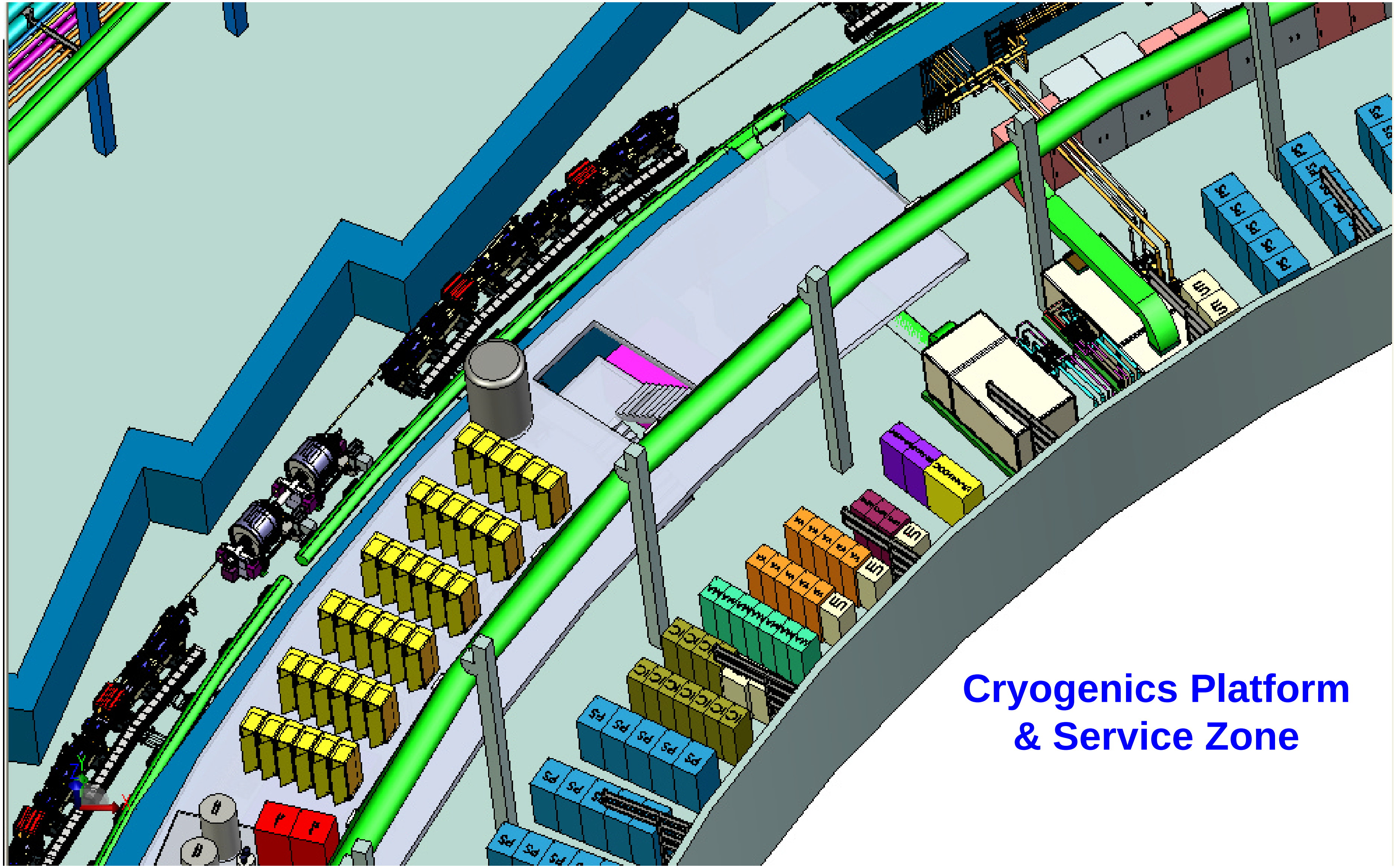
ID fixed mask





SW4.8 fixed mask 27w/mm2 (5 deg. incident angle)

Layout of Cryogenics Platform and Service Zone

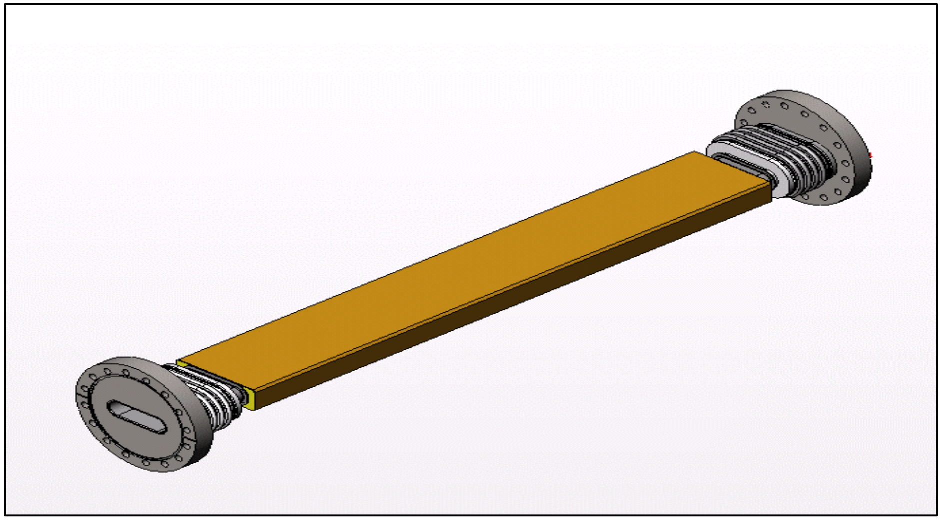


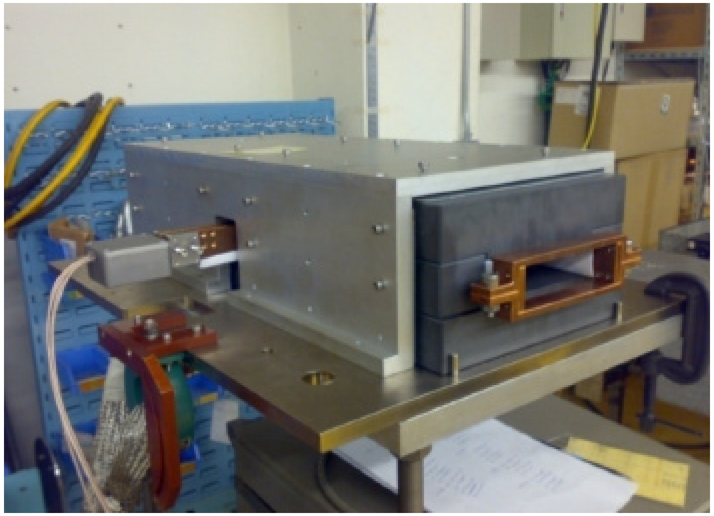
Pulse Magnets

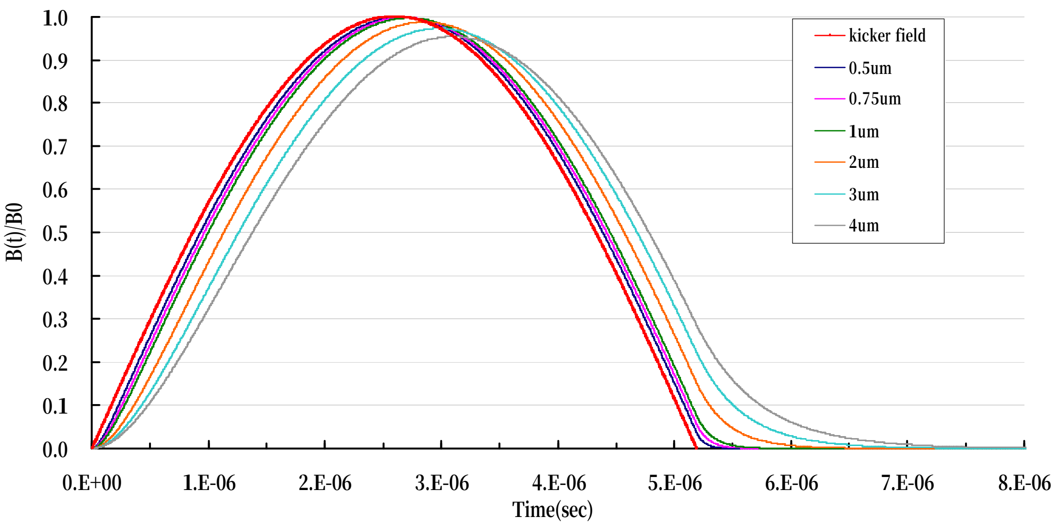
- Kicker Magnet Prototype
- Kicker Magnet EMI reduction

- Design of Septum Magnet

Kicker Magnet Prototype



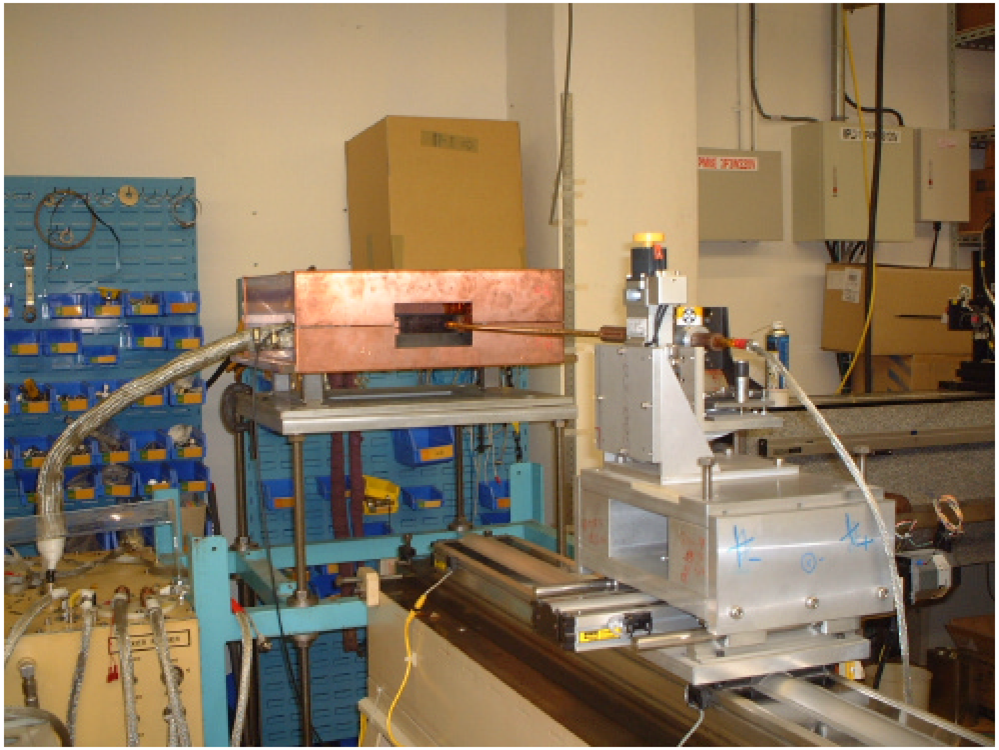




TPS Kicker Magnet Specification	
Magnet Aperture	110 x 35 mm
Effective Length	600 mm
Ferrite Core	CMD5005
Turns per Coil	1
Max. Field	662 Gauss
Peak Current	2200 A
Current Waveform	5.184 μs
Pulse Repetition Rate	2 Hz
Coil Inductance	2.6 μH
Deflection Angle	5.64 mrad
Amplitude Stabilities	0.1 %

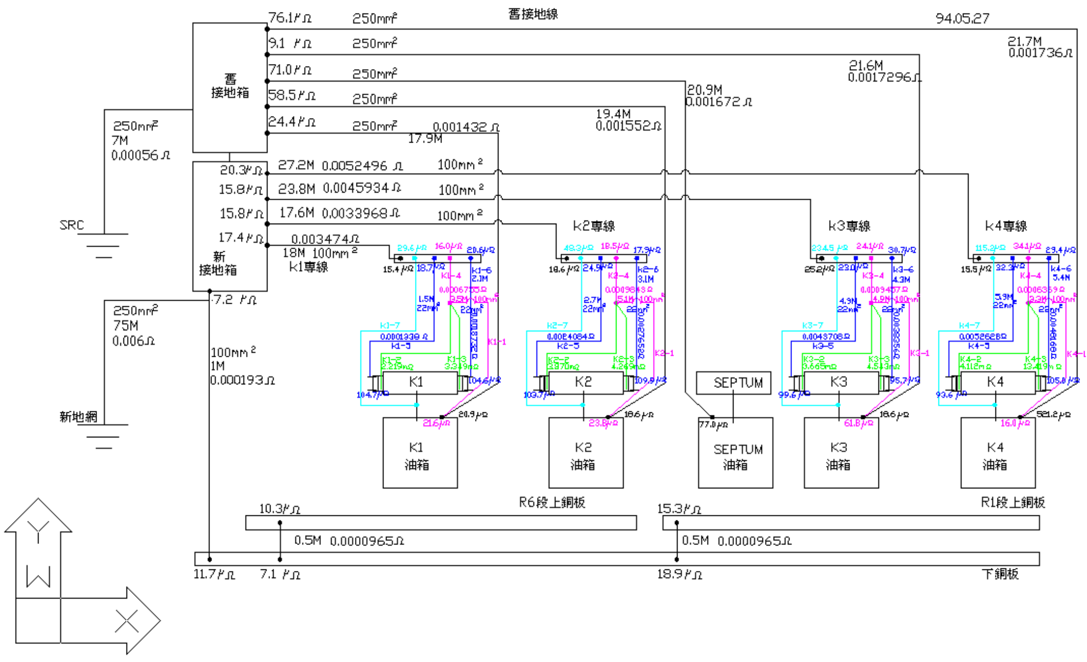
Kicker Magnet EMI Reduction (1)

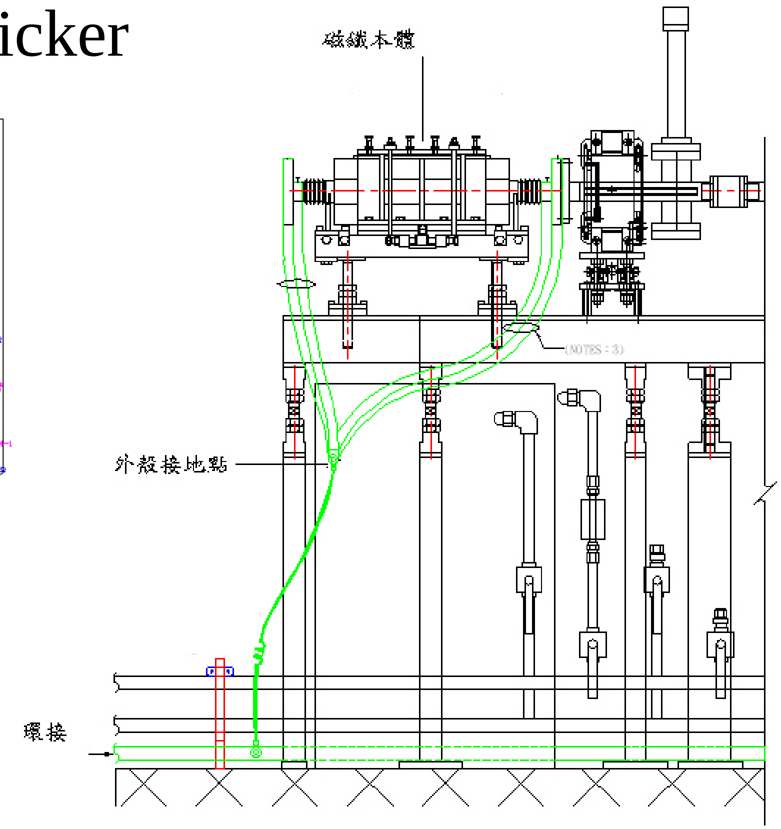
- Kicker Magnet Shielding: Copper/ μ-metal
- Cable Shielding (Pulsed current)



Kicker Magnet EMI Reduction (2)

- Add the spray ground routs
- Specialized Ground bus for each kicker

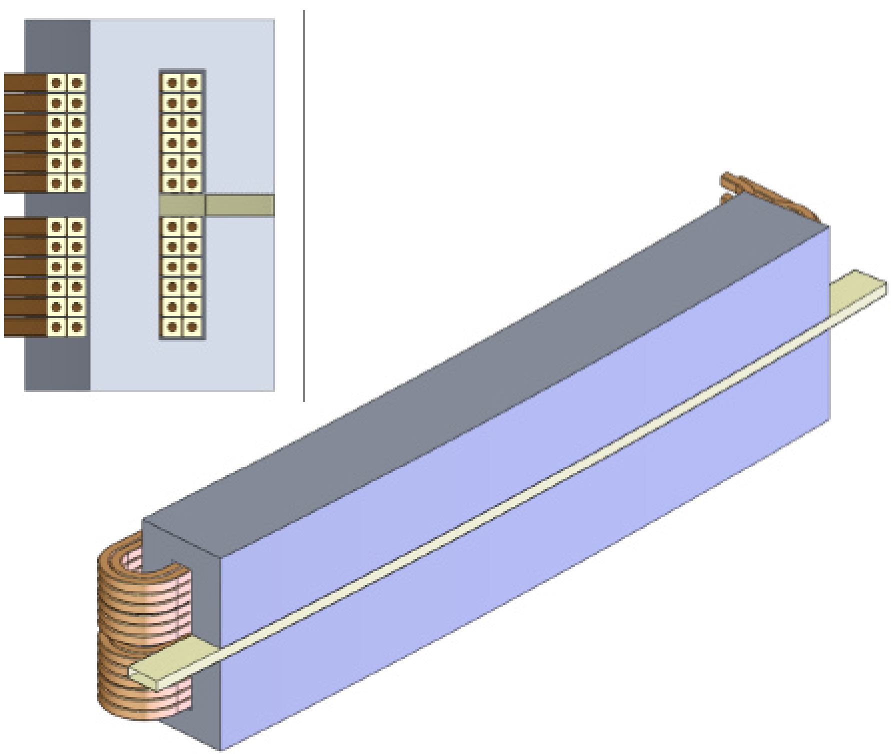


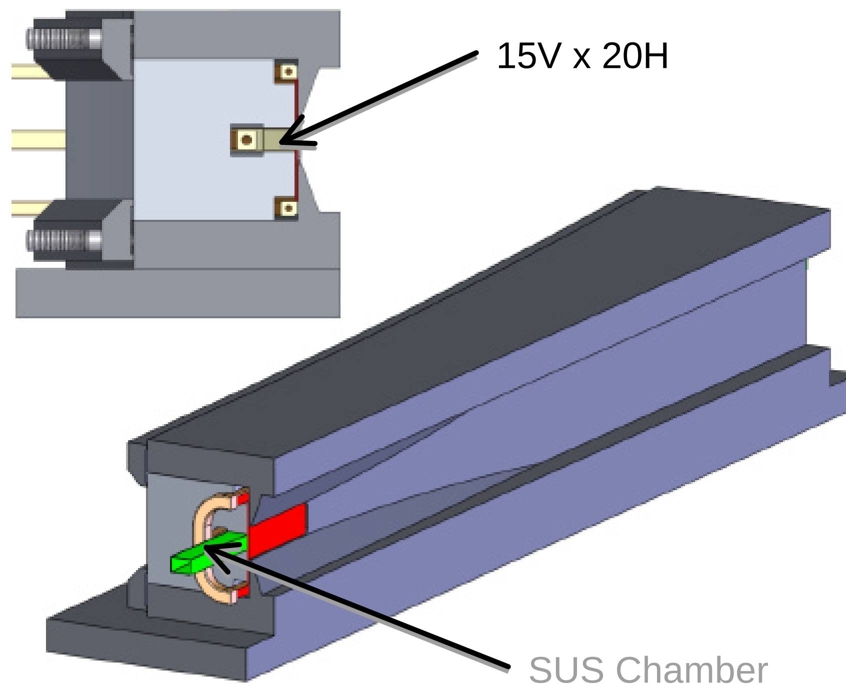


Design of Septum Magnet

Deflection angle(degree)	**5**
Field Strength (T) @3GeV	0.97
Magnetic length (m)	0.9
Magnet Aperture (mm2)	15V X 45H
Pulse length (μs)	DC
Coil Turns	24
Current (A)	450

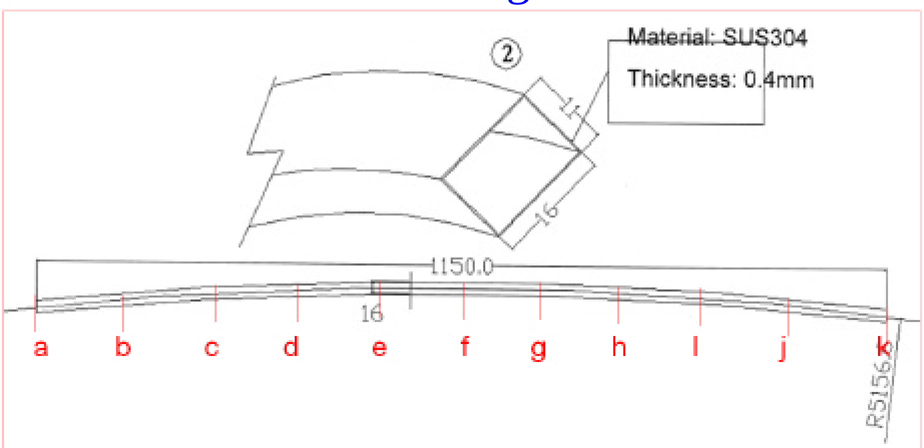
Deflection angle(degree)	**5**
Field Strength (T) @3GeV	0.97
Magnetic length (m)	0.9
Magnet Aperture (mm2)	15V x 20H
Pulse length (μs)	300
Coil turns	1
Current (A)	11000



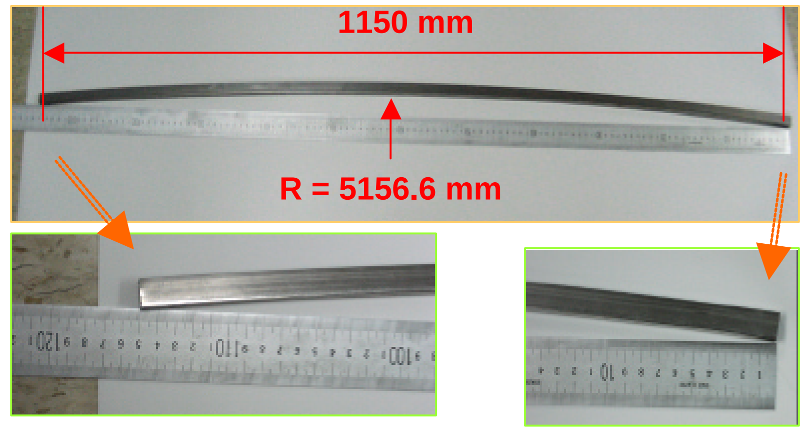


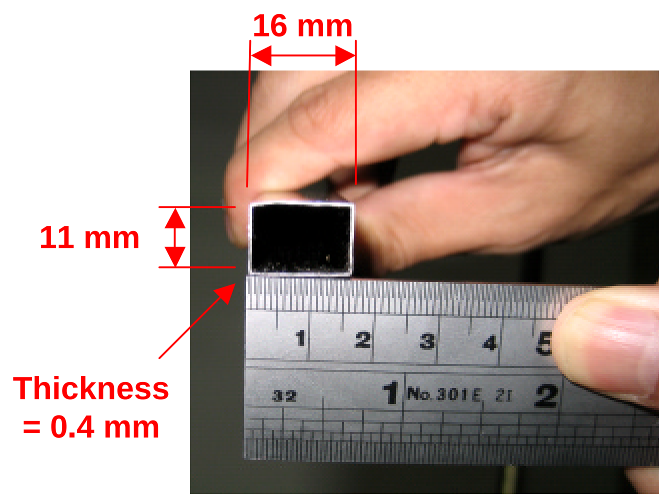
Prototype of a 0.4 mm thick stainless steel chamber for the injection Septum magnet

Manufacture of a 0.4 mm thick stainless steel prototype chamber for the injection septum, 16 mm in width, 11 mm in height. After folding and μ-TIG welding to the straight chamber, then bend to a curvature radius of 5.156 m and length of ~ 1.15 m.



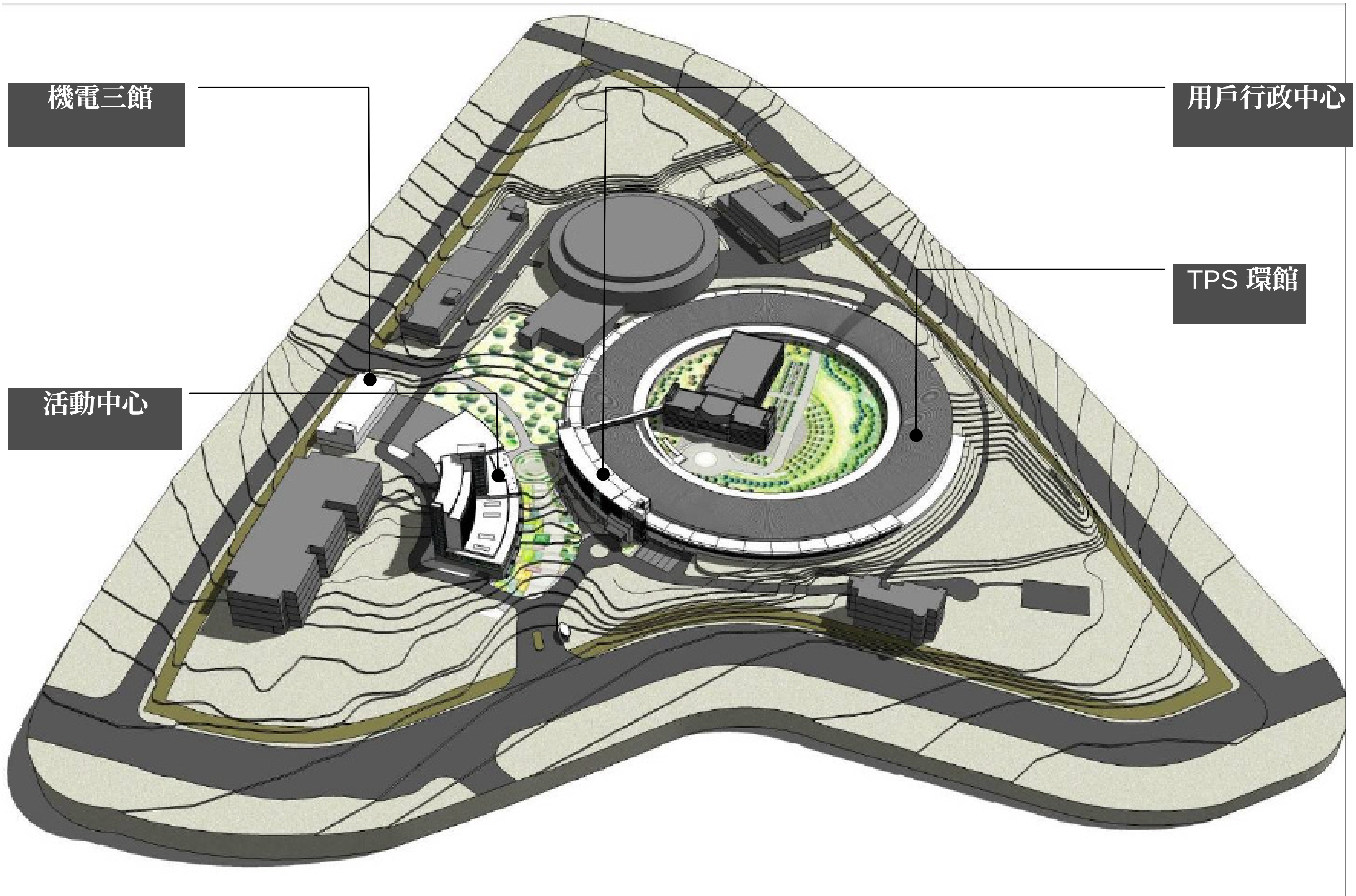
Unit (mm)	a	b	c	d	e	f	g	h	i	j	k
Height	11.08	11.00	11.00	10.98	11.00	11.00	11.00	11.00	10.98	10.98	10.92
Width	16.02	16.02	15.96	15.98	15.96	15.94	15.98	15.97	15.98	15.96	16.02





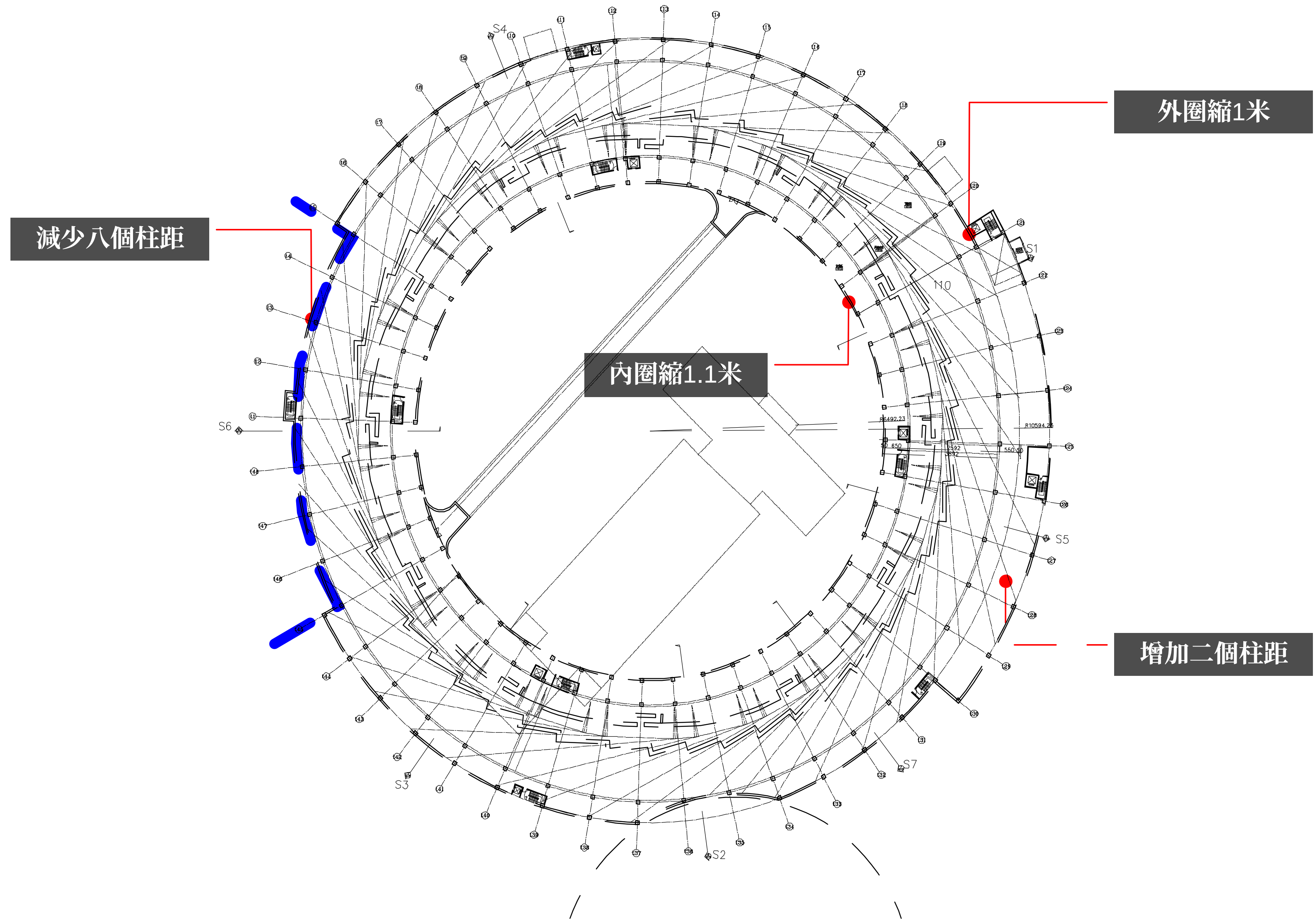
Layout of Civil Construction

全區透視圖及景觀規劃

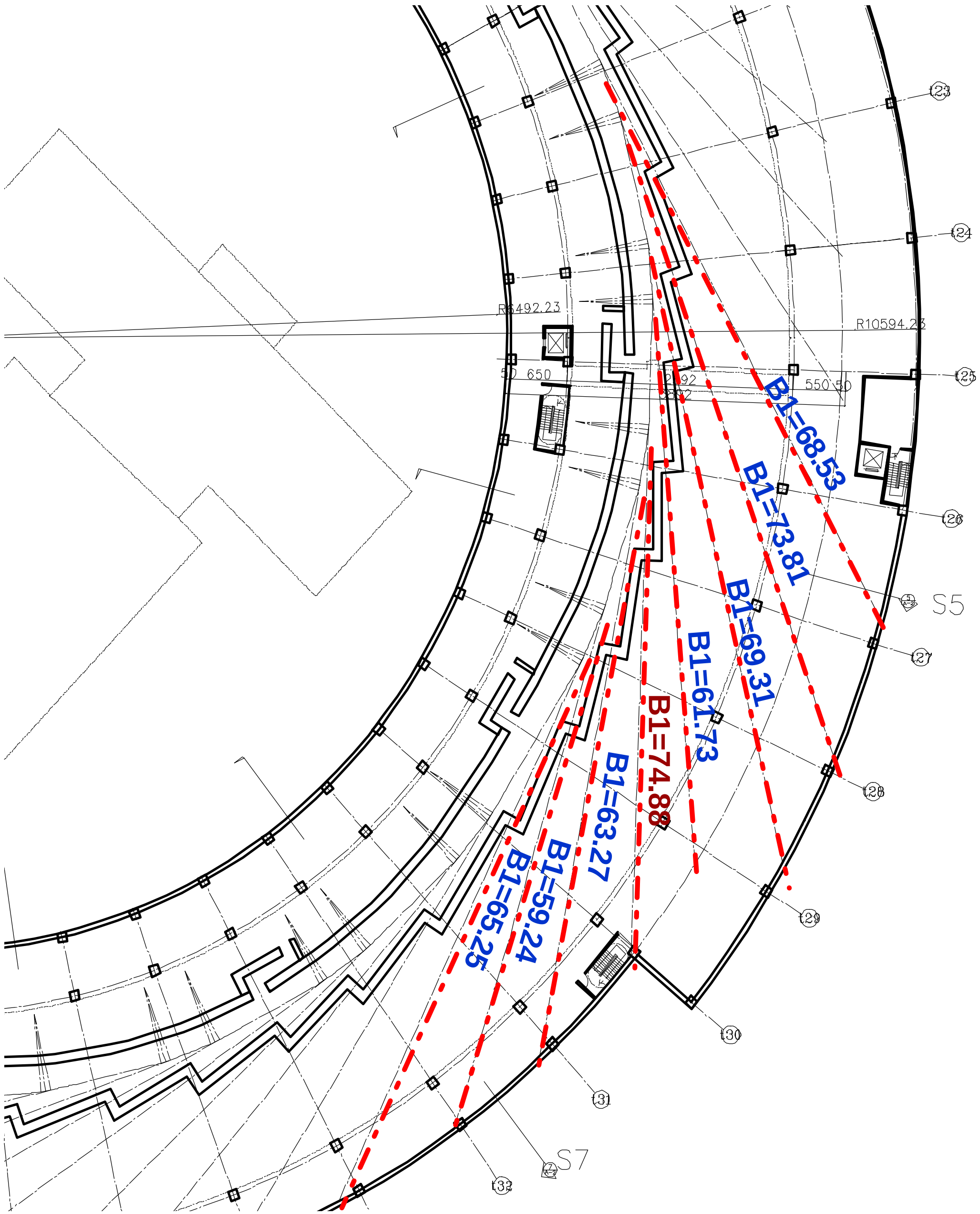


全區透視圖及景觀規劃 ------透視圖(入口意像)

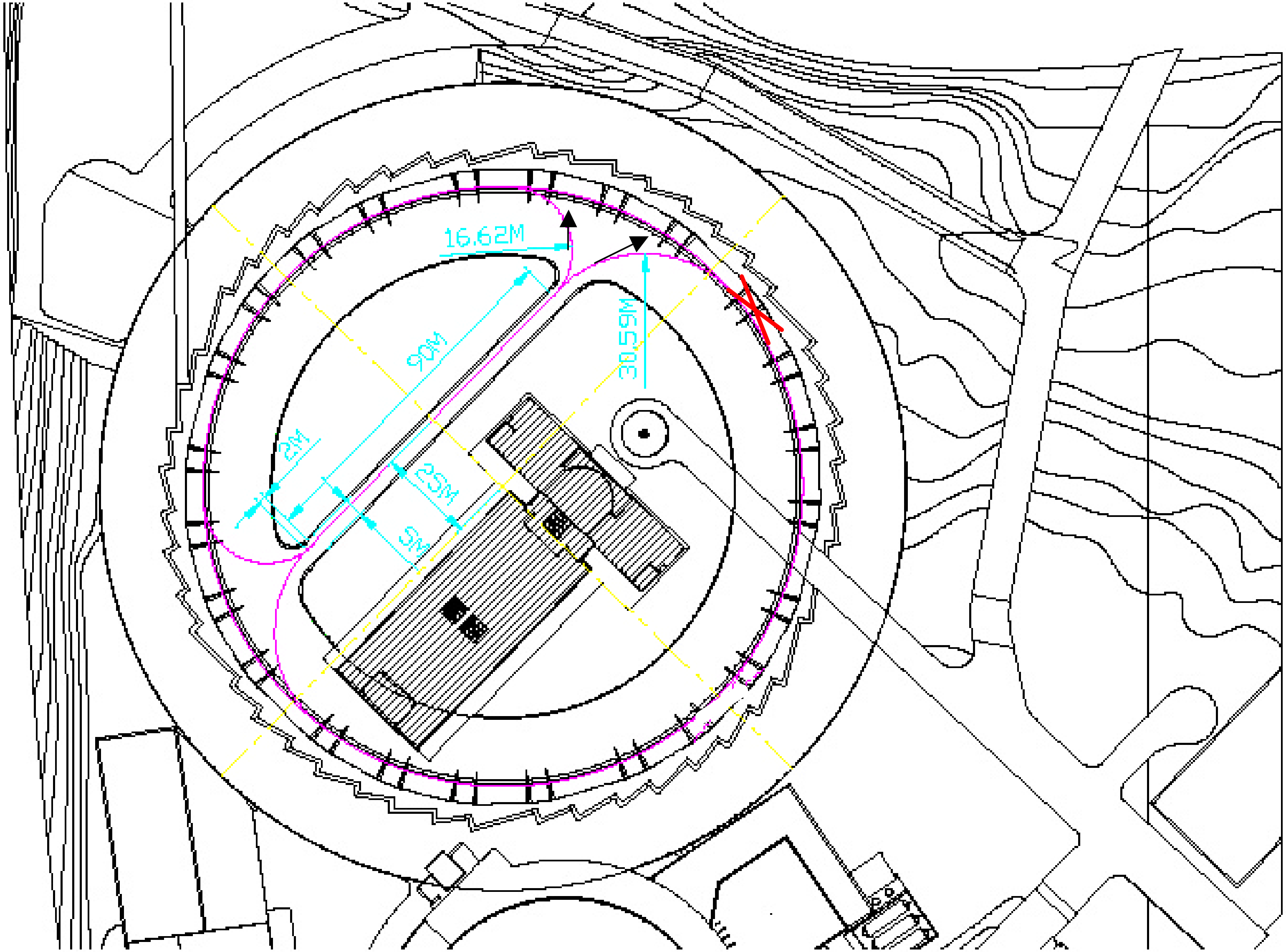
儲存環館與用戶行政中心之規劃 ------1F平面圖



儲存環館與用戶行政中心之規劃



Schematic of Energy Recovery Linac

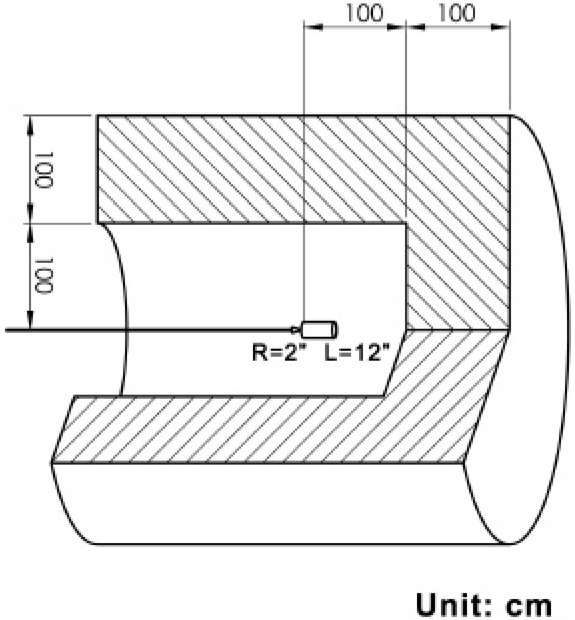


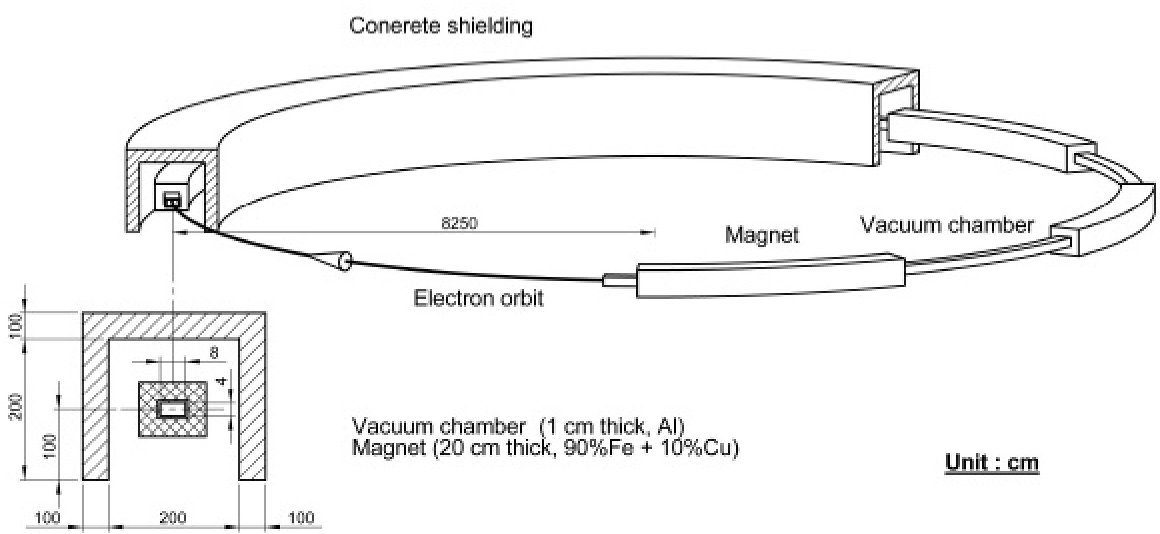
Radiation Safety

Dose assessment of storage ring

- Assumptions:
  - Simple geometries
  - Simple beam loss scenarios

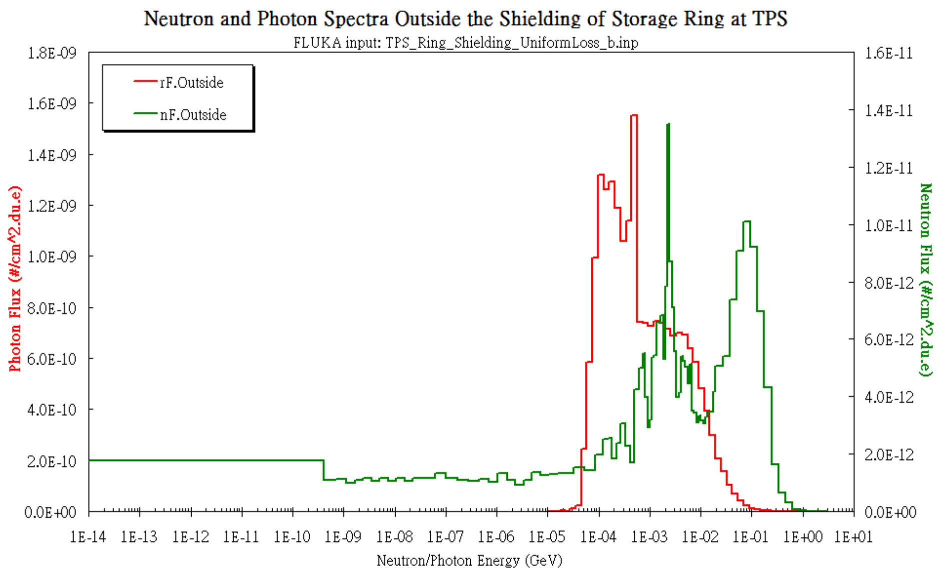
- Case 1: point loss (localized beam loss)
- Case 2: uniform loss (uniformly distributed beam loss)

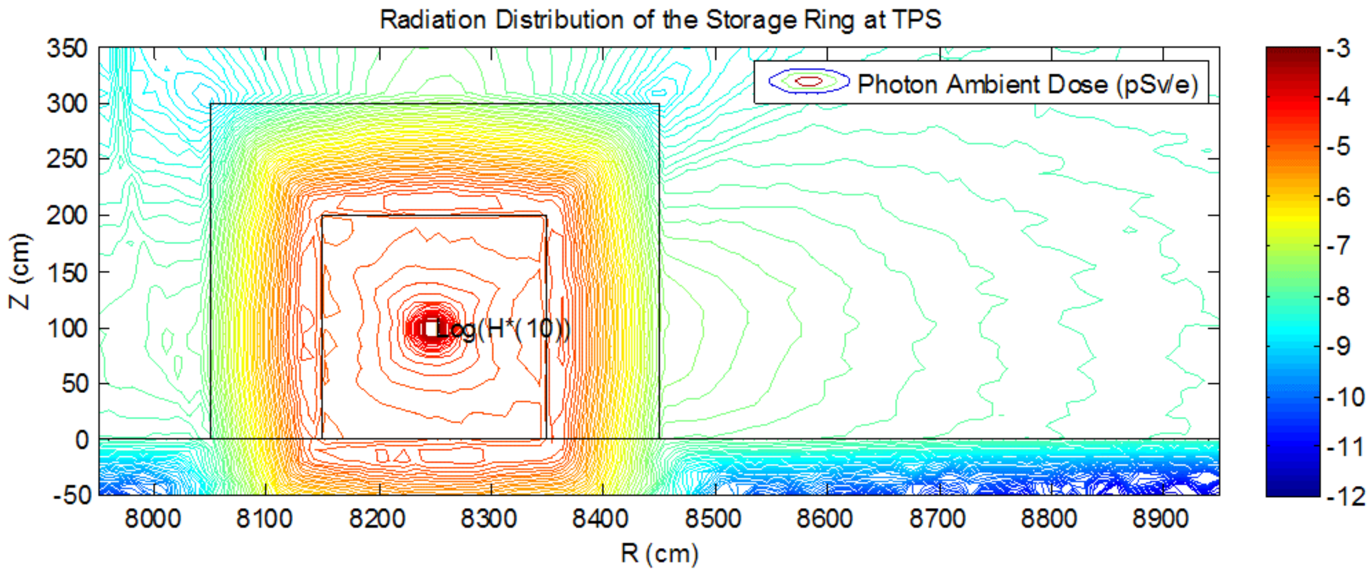




Dose assessment of storage ring

- Prompt radiation fields (gamma-ray, neutron and muon)
  - Energy spectrum
  - Spatial distribution





Dose assessment of storage ring

- Radiation doses outside the 1-m lateral shielding wall
  - Total dose contribution:
    - photon ~ neutron (~50%),
    - high-energy neutron dominates neutron contribution,
    - muon negligible (~1%)
  - Full beam loss event: (400 mA)

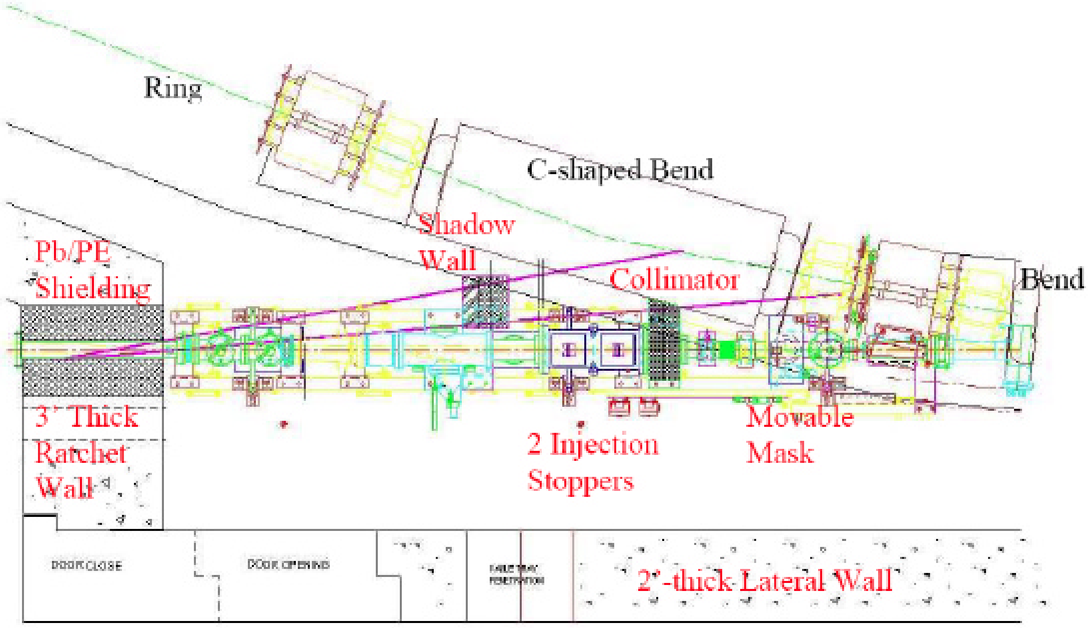
    ~ 12 and 0.2 μSv per event, respectively for point & uniform losses.
  - Normal beam injection: (5 W inj. power, 80% inj. eff.)

    ~ 21 and 0.3 μSv/h, respectively for point & uniform losses.
  - Normal beam storage: (400 mA, 15-h lifetime)

    ~ 0.8 and 0.01 μSv/h, respectively for point & uniform losses.
  - Abnormal cases:
    - Not defined yet!
- Injection section: lateral wall 100cm → 120cm
  - To better approximate the validity of uniform-loss assumption
- 1 mSv/y design limit ~ reasonably achievable

Dose assessment of BL frontend

- Generic shielding approach, based on
  - Site-specific generated source terms and attenuation lengths for various angles and for different materials
  - Ray-tracing from possible beam loss points
  - Source term, attenuation and inverse square law



Summary

- A designed DBA lattices was presented to the Machine Advisory Committee.
- The design and optimization of accelerator components are on going.
- A general layout of new campus is proposed by J.J. Pan Architect Co.
- The shielding design and interlock system of radiation issues are in progress.
- The detail design report of TPS is expected to be completed before the end of June, 2008.

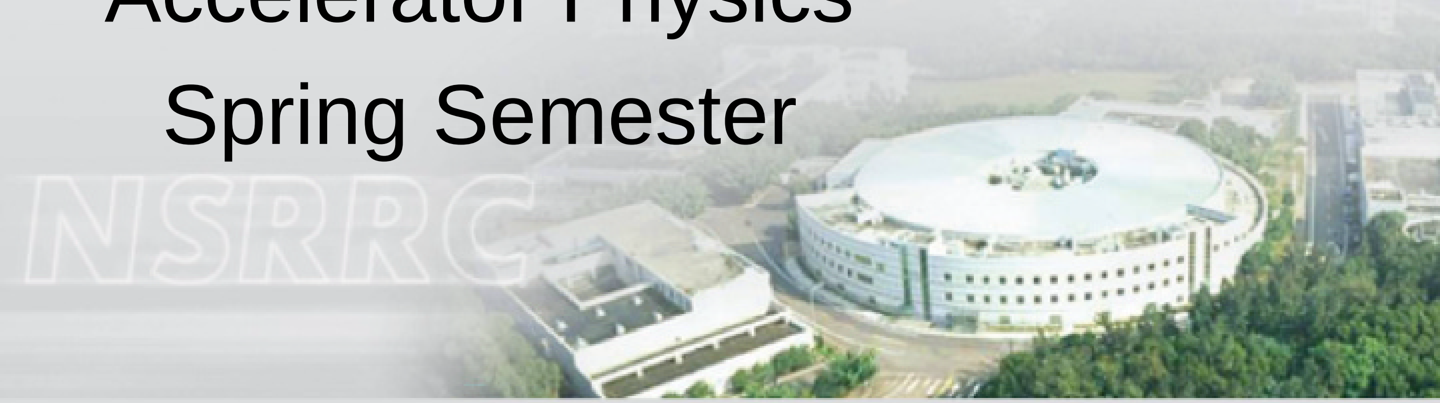
國家同步輻射研究中心
National Synchrotron Radiation Research Center

Detail of the Theory and Computation

PHYS553000

Accelerator Physics

Spring Semester



國家同步輻射研究中心
National Synchrotron Radiation Research Center

Thank you for your attention!