NSLS-II Insertion Device Development

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NSLS - II

Second Mini-Workshop on Magnet Simulations
for Particle Accelerators in PAC07
2007/06/26-27

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Outline

1) NSLS-II Project
2) Lattice Magnets (W. Meng & R. Gupta)
3) Permanent Magnet Damping Wiggler
4) Elliptically Polarized Undulator (EPU)
5) 3 Pole Wiggler
6) Cryo-Permanent Magnet Undulator (CPMU)
   - New Magnet / Pole Materials
7) Superconducting Insertion Devices
   - SCU, SCW and SEPU
   - High Temperature Superconductor (HTS)

High Level Description of NSLS-II

A highly optimized x-ray synchrotron delivering:

- extremely high brightness and flux;
- exceptional beam stability; and
- a suite of advanced instruments, optics, and detectors that capitalize on these special capabilities.

Together, these enable:

- ~ 1 nm spatial resolution,
- ~ 0.1 meV energy resolution, and
- single atom sensitivity.

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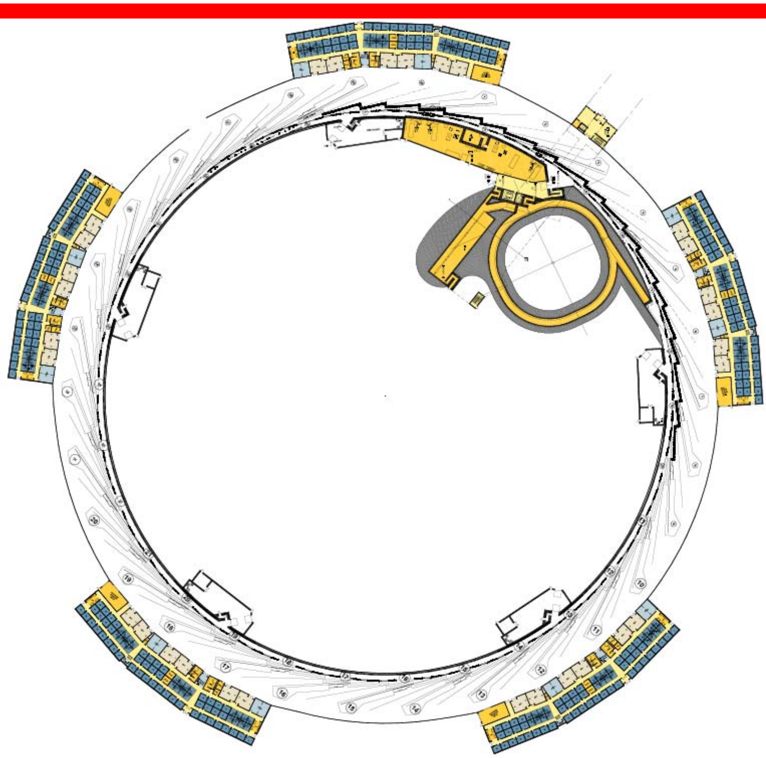
NSLS-II Accelerators



NSLS-II Machine Concept

- New 3 GeV Electron Storage Ring
- Large Circumference (791.5 m), H = 1320
- "Compact" (~158m, H=264) booster
- Large Current (500 mA)
- Superconducting RF
- Top-Off Operation
- DBA30 Lattice
- 15 short and 15 long straights
- Ultra-Low Emittance (<1 nm)
- Damping Wigglers (21 – 56 m)
- Large Dipole Bend Radius (25 m)
- Provision for IR Source
- Three-pole wiggler x-ray sources

Selected Technical Challenges

- Lattice Design: dynamic aperture, energy acceptance
- Source Stability: vibrations, thermal issues, PS and RF noise, feedback
- Impedance Budget: Small gap (5 mm) ID tapers, etc
- Insertion Device: CPMUs, EPUs, SCUs(?)

Storage Ring Functionalities

- 3 GeV, 500 mA ± 1%
  - Upgradeable to 3.6 GeV or 700 mA
- Estimated beam life-time: 2 – 3 hours
- Top-off injection to achieve better than 1% beam current variation for the heat load stability

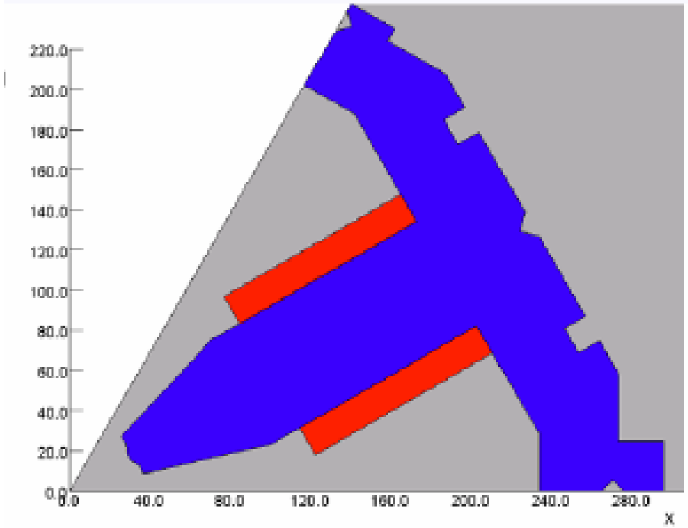
- Ultra-small emittance (ε_x, ε_y) :
  - Bare Lattice: ~2 nmrad Horizontal & ~0.01 nmrad vertical
  - Baseline: ~1 nmrad horizontal & ~0.008 nmrad vertical
  - Fully built-out: ~1/2 nmrad horizontal, ~0.008 nmrad vertical
- High level of reliability and stability of operation

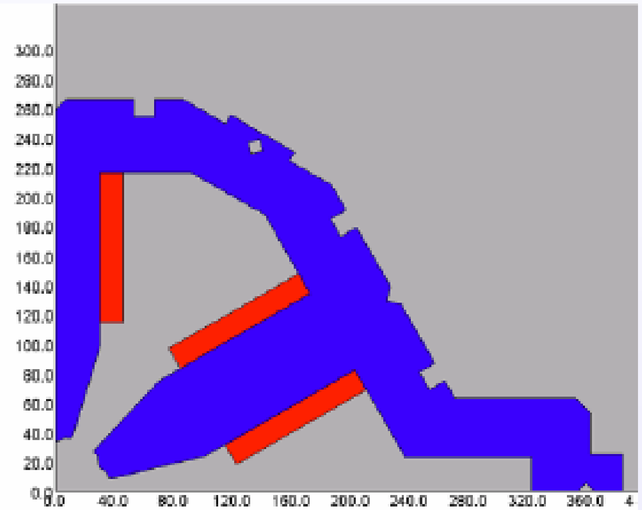
- Magnet Inventory:
  - 60 dipoles: 2.5 m long, 54 with 35 mm gap, 6 with 93 mm gap
  - 330 quadrupole magnets:
  - 390 sextupoles magnets.
  - 210 corrector magnets

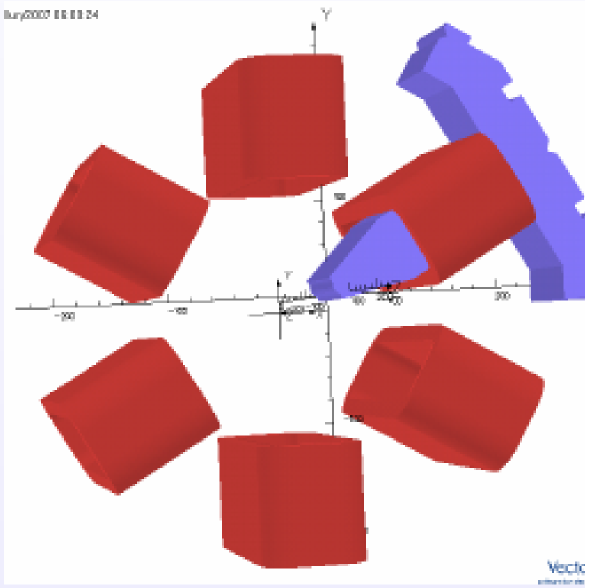
3D Simulation Codes

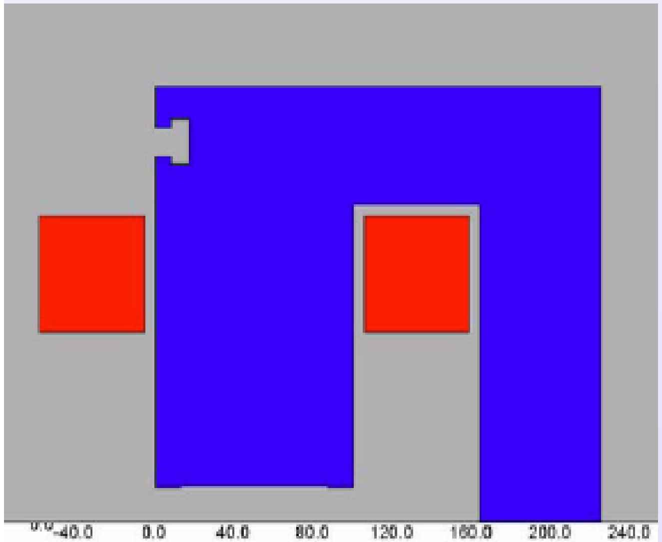
- **Radia** (v.4.1 can be obtained from www.esrf.eu, v.4.117 from soleil ?)
  - Mathematica's mathlink program using boundary integral method
  - No need to mesh free space & infinity → no truncation error for field integral
  - Field inside magnetization volume is not accurate due to discontinuity
  - Importing BH curve file of a material is not trivial → It can be done
  - RHS x-horizontal, z-vertical, y-longitudial
- **Opera 3D / Tosca**
  - Preprocessor → complicated shaped object difficult
  - Modeller → meshing errors hard to analyze
  - Making parametrized model difficult
- **ANSYS / Emag**
  - Quick Optimizer
  - Can be combined with stress analysis

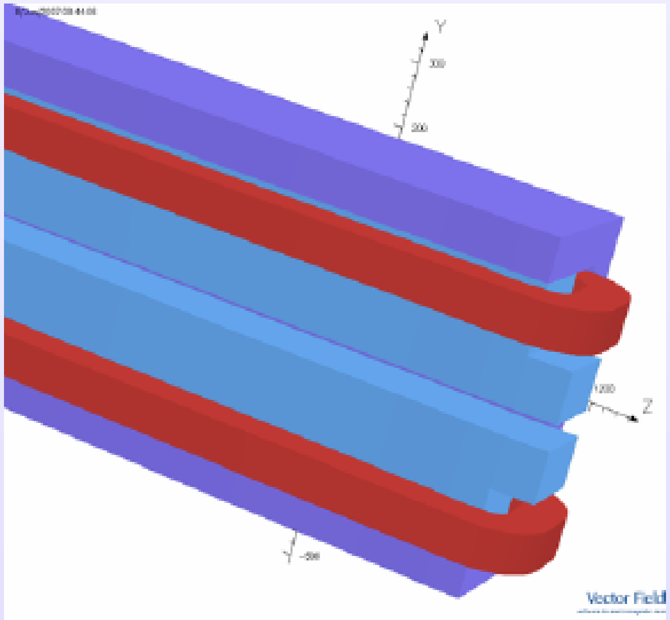
Recent Magnetic Models

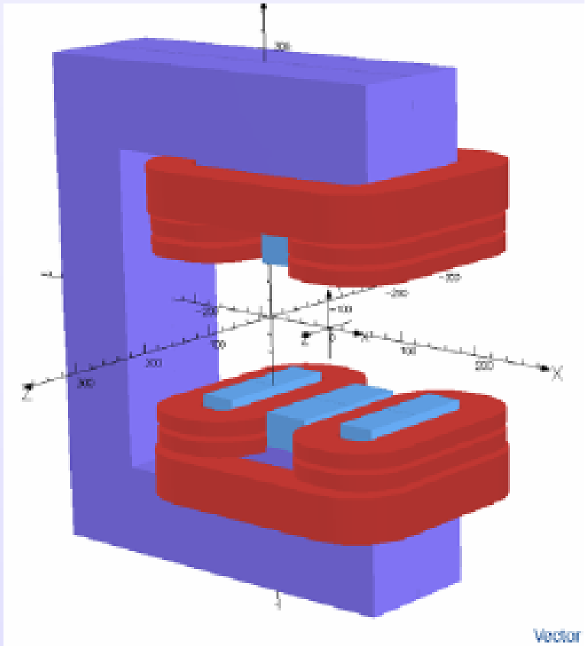






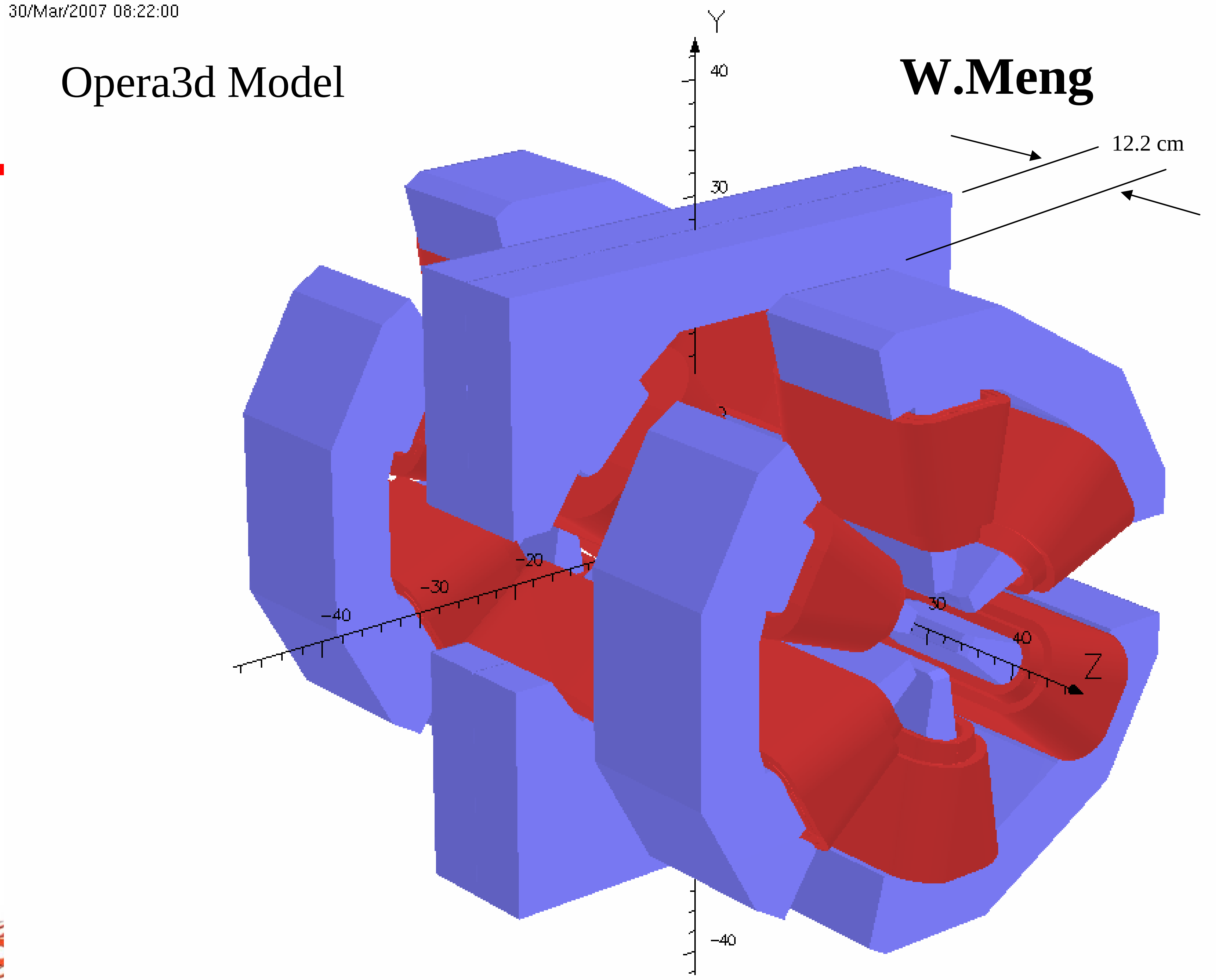




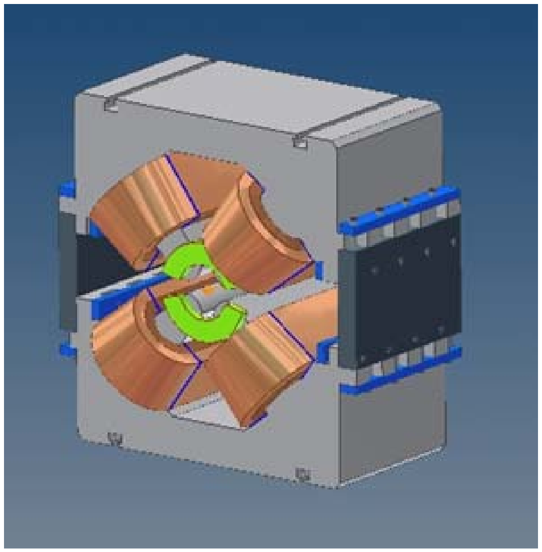


Opera3d Model

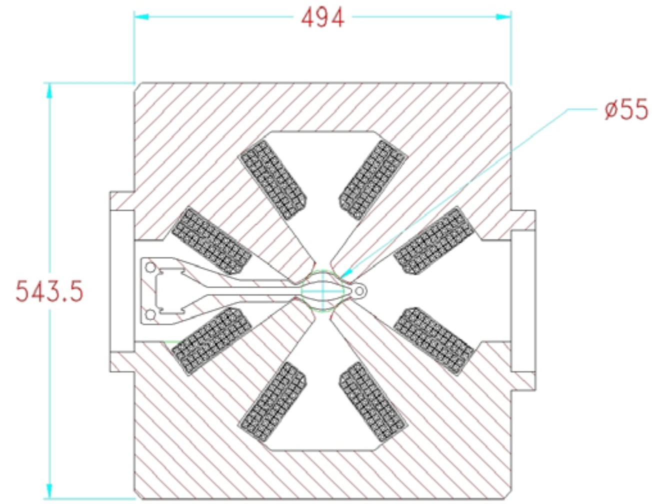
W.Meng



Quadrupole Magnet (Meng)



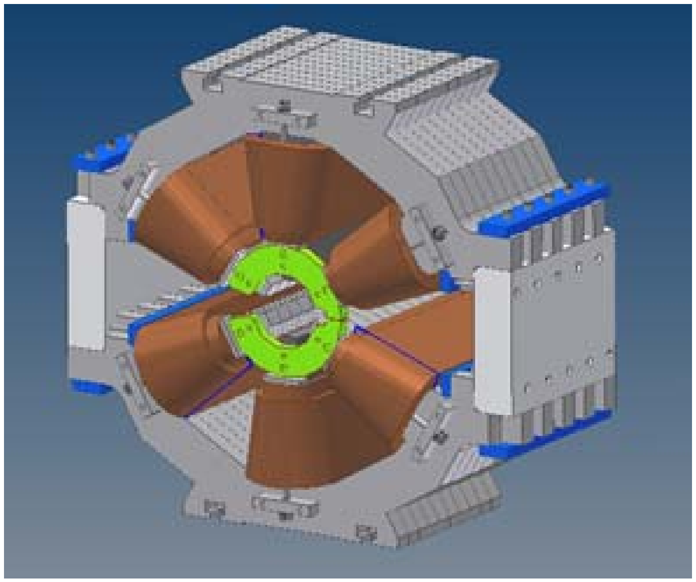
Quadrupole Magnet



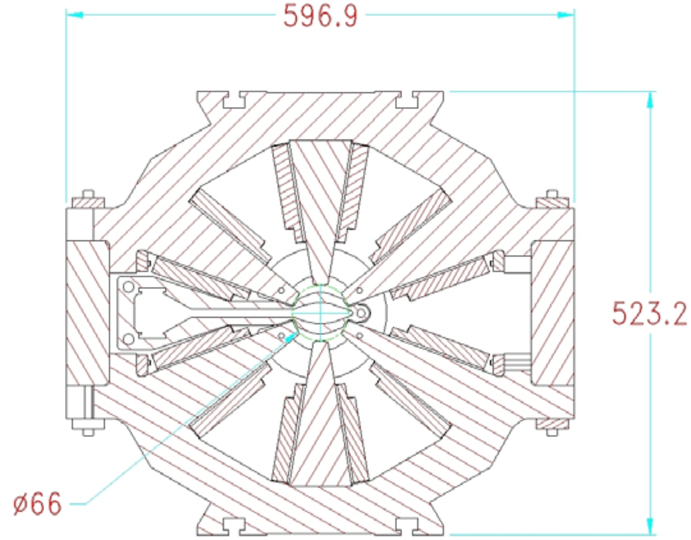
QUADRUPOLE MAGNET (55mm)

- Magnet designs must be robust. Field quality (harmonic contents) should remain within specified tolerances after repeated disassembly and reassembly.
- Several different designs (SPEAR, SLS, APS) are being evaluated.
- A 2-segment quadrupole design is being developed.

Sextupole Magnet (Meng)



Sextupole Magnet



SEXTUPOLE MAGNET (66mm)

A 2-segment sextupole design is being developed.

List of NSLS-II IDs

Name	U14	**U19**	**U45**	U100	**DW-1.8T**	**3PW**	SCW
Type	SCU	CPMU	EPU	QEPU	PMW	PMW	SCW
Photon energy range	Hard x-ray (1.8-30keV)	Hard x-ray (1.5-20keV)	Soft x-ray (180eV-7keV)	VUV (8eV-4keV)	Broad band (<10eV-100keV)	Broad band (<10eV-40keV)	Very hard x-ray (<10eV-200keV)
Type of straight section	5m	5m	8m	8m	8m		5m
Period length (mm)	14	19	45	100	100		60
Total undulator length (m)	2.0	3.0	4.0	4.0	7.0	0.3	1.0
Number of periods	143	158	89	40	70		17
Magnetic gap (mm)	5	5	10	10	15	32	15
Peak magnetic field strength B (T)	1.68	1.21	0.68(Heli) 1.03 (Lin)	1.50	1.80	1.1	3.50
K	2.20	2.03 (eff)	2.87 (eff) 4.67 (eff)	14.01	15.92 (eff)		19.61
hν fundamental, eV	1788.8	1469.7	183.1	8.6			
hν critical, keV				11.8	21.0	6.8	2.4
Total power (kW)	16.08	11.18	12.09	25.64	64.60	0.32	34.89
G(K)	0.9842	0.9818	0.9959	0.9996	0.9997		0.9998
On-axis power density ($kW/mrad^2$)	103.70	77.86	40.03	26.33	55.30		25.60

Quantities to Characterize an Undulator

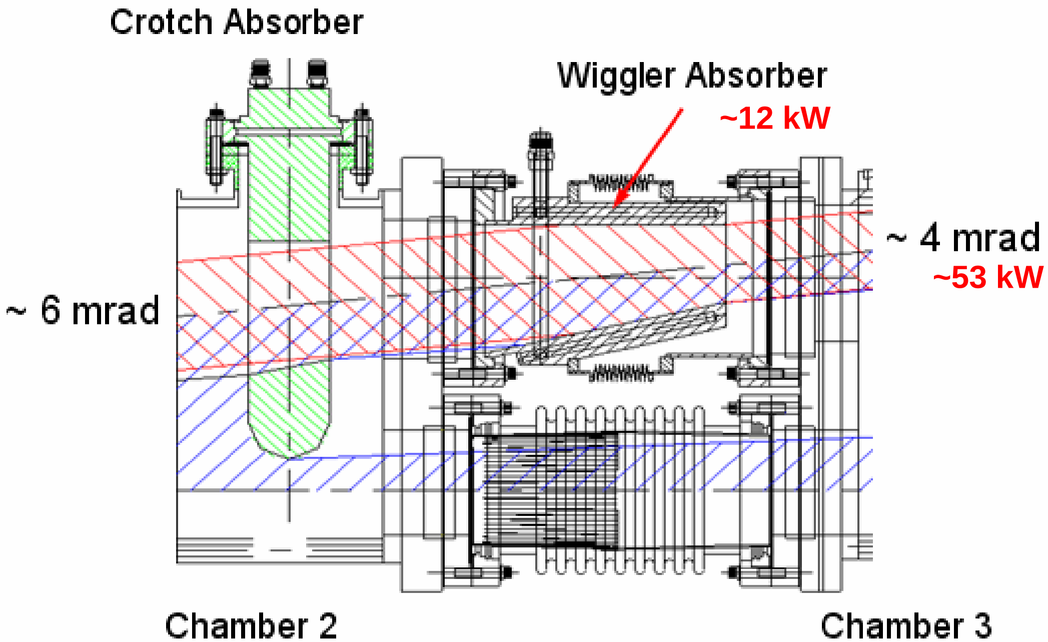
- Good Field Region (less then 0.5% reduction in peak field)
  - Determined by the pole&magnet width. Closely related to multipoles
- Trajectory (Gap dependence)
  - Straightness
  - 1st integrals (normal/skew dipole) → kick angle
  - 2nd integrals → trajectory shift
- Phase Error
  - Spectral brightness in higher harmonics
- Integrated Higher Order Multipoles
  - Normal / Skew Quadrupoles, Sextupoles, etc.

Wiggler Design Issues

- Angular Power Density / Total Power
  - Limited by absorber / optics designs
- Fan Angle
  - ~ +/- K/γ
  - Flux User → Big fan can be shared
  - Brightness User → Off-Axis radiation not preferable
- Longitudinal Harmonics Content
  - Related to fan angle and DA
- Dynamic Integral
  - For long period device, wiggling amplitude is not negligible

Canting of Damping Wigglers

- A 7 m long damping wiggler can be divided into two ~3 m long wigglers with canting magnets in between.
- The DW absorber system can handle the radiation with the total fan angle of 6 mrad.



Possibilities are:

- Straight DW (7m long) with ±3 mrad fan as with 100 mm period DW

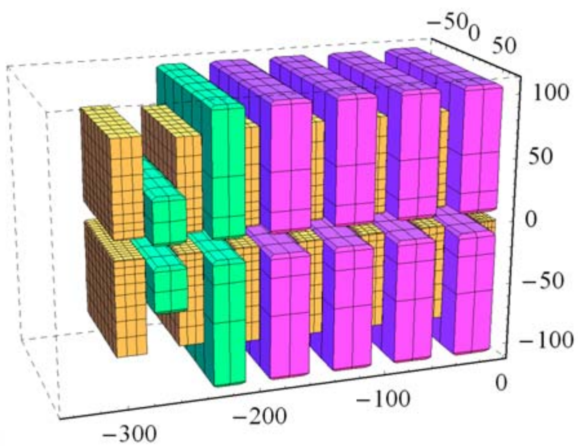
  or

- 2 mrad canting of two DW (~3 m long) with ±2.3 mrad fan as with 80 mm period DW

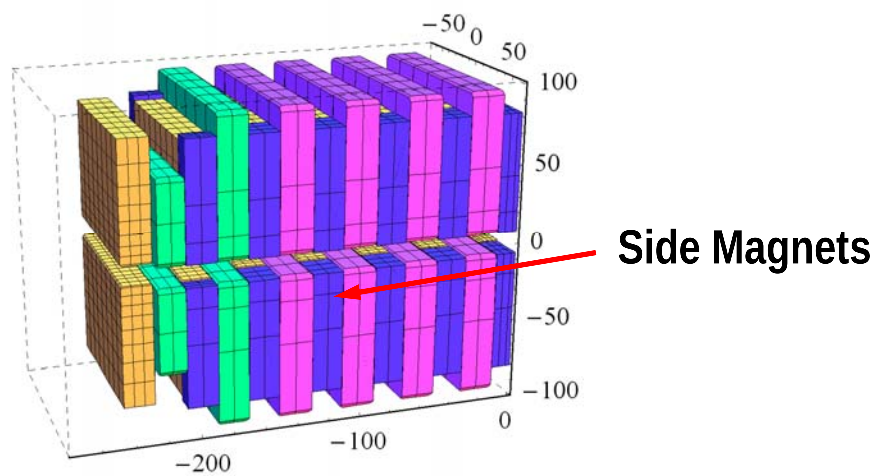
- ± 0.25 mrad beam deviation from its nominal orbit and an additional ± 1 mm machining and alignment tolerance can be allowed. The electron beam is dumped by interrupting RF if it deviates more than ± 0.25 mrad.

PM-Damping Wiggler

- CDR DW (λ_w=100mm, Gap=15mm)
  - Br=***1.35T***
  - Integral of B^2=0.1459 T^2.m (90.0% of ideal 1.8T sinusoidal field=0.162 T^2.m)
  - K_{eff}/γ = 2.71 mrad
- New Design with side magnets (λ_w=80mm, Gap=12mm)
  - Br=***1.30T***
  - Integral of B^2=0.1334 T^2.m (103% of ideal 1.8T sinusoidal field=0.1296 T^2.m)
  - K_{eff} / γ = 2.32 mrad



- **W100**



- **W80**

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Importing BH file to Radia

- Non-linear material properties are described with:
  - μ_0*H(A/m) vs μ_0*M(A/m)
  - **M** = (**H**/|**H**|)*[ms1*tanh(ks1*|**H**|*/ms1) + ms2*tanh(ks2*|**H**|/ms2)* + *ms3*tanh(ks3*|**H**|/ms3)].*

- Changing "H(Oe) vs B(G)" to μ_0*H(A/m) vs μ_0*M(A/m)=B(T)-myu0*H(A/m)
  - Use {h,m} array in "radMatSatIso[{{h1,m1},{h2,m2},...}] "

- Extrapolation appears to be used in higher field
  - Last two sets should represent saturation

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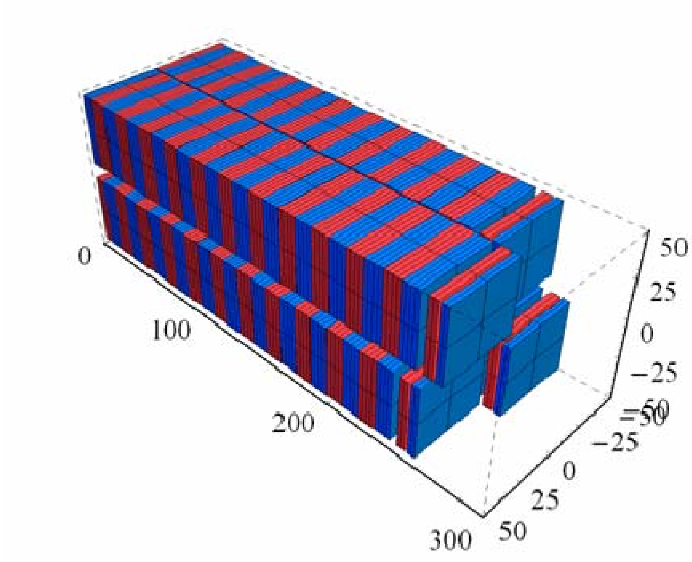
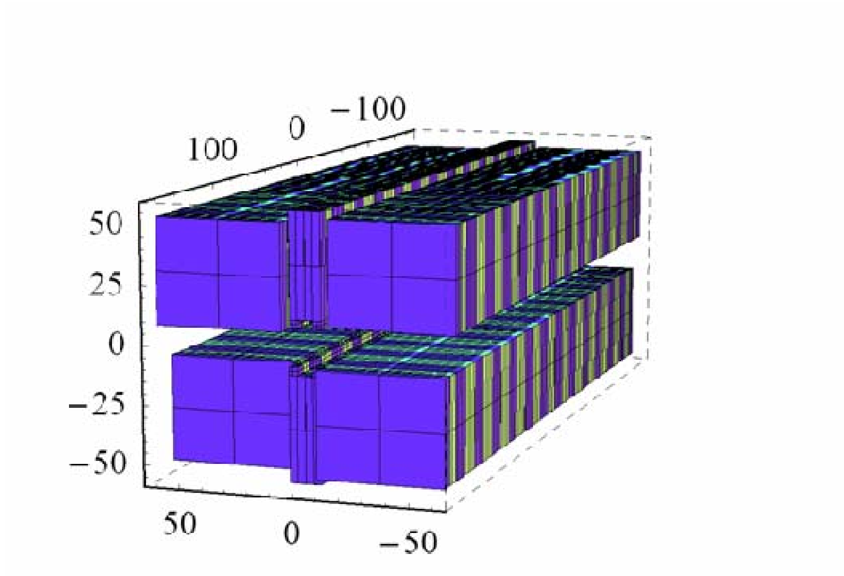
EPU

- Apple-II v.s. HiSOR EPU





- Gap / Phase dependent first integral must be minimized.
  - End effects due to non-unity anisotropic permeability of PM
- Multipoles must be minimized.
  - Skew terms problematic

3 Pole Wiggler

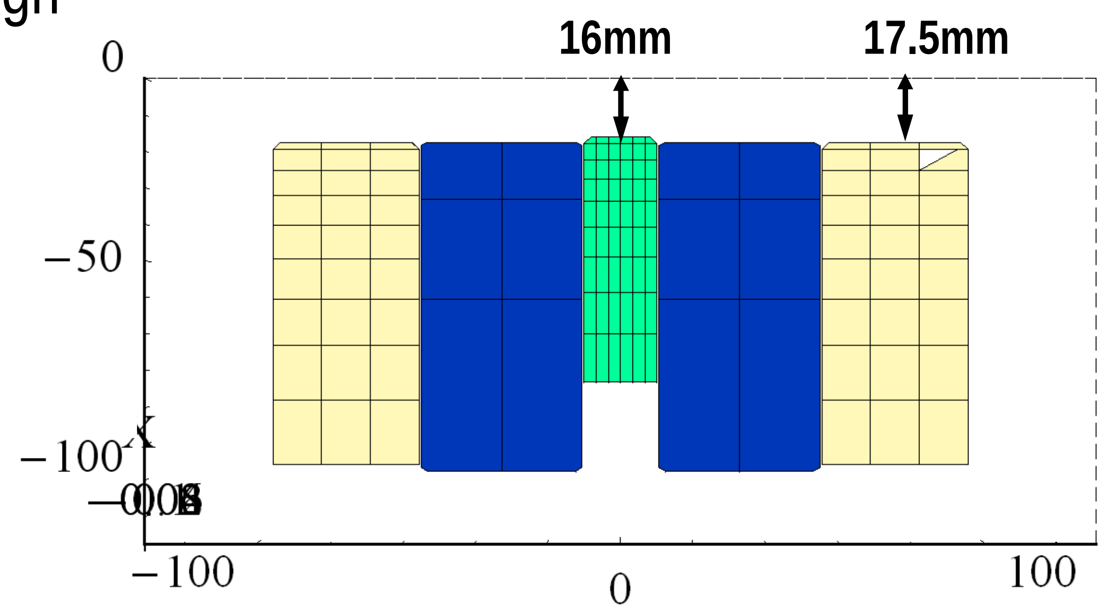
- Requirements:
  - More than 2 mrad of radiation fan above 1T field
  - Use narrow gap dipole (35 mm Gap) chamber
  - Fixed gap and removable from one side of the chamber
  - Simple and economical

- Preliminary Magnetic Design
  - **Br=1.35T**
  - **Permendur Center Pole**
  - **Soft Iron (1006) Side Poles**
  - **Rectangular Magnets**

Main Magnets: 120 x 44. x 90 mm

Center Pole: 120 x 20 x 65 mm

End Poles: 95 x 40 x 86 mm



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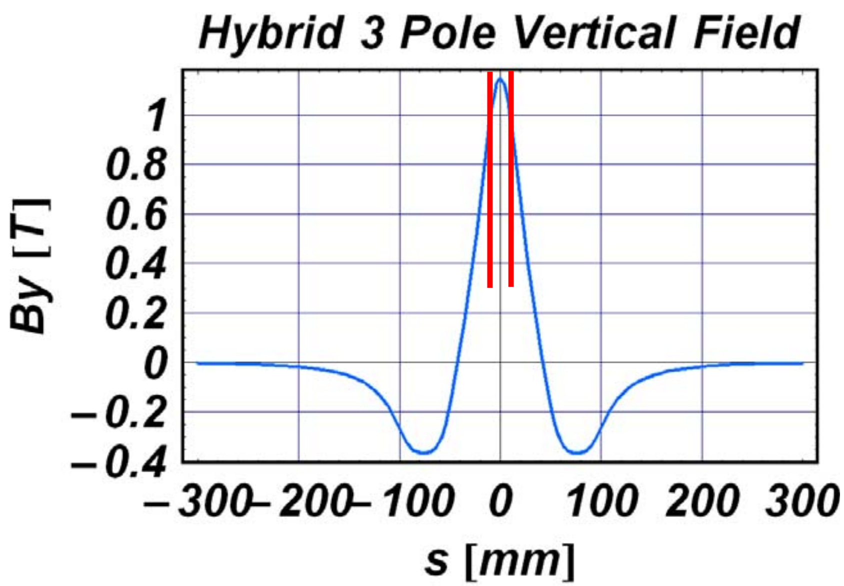
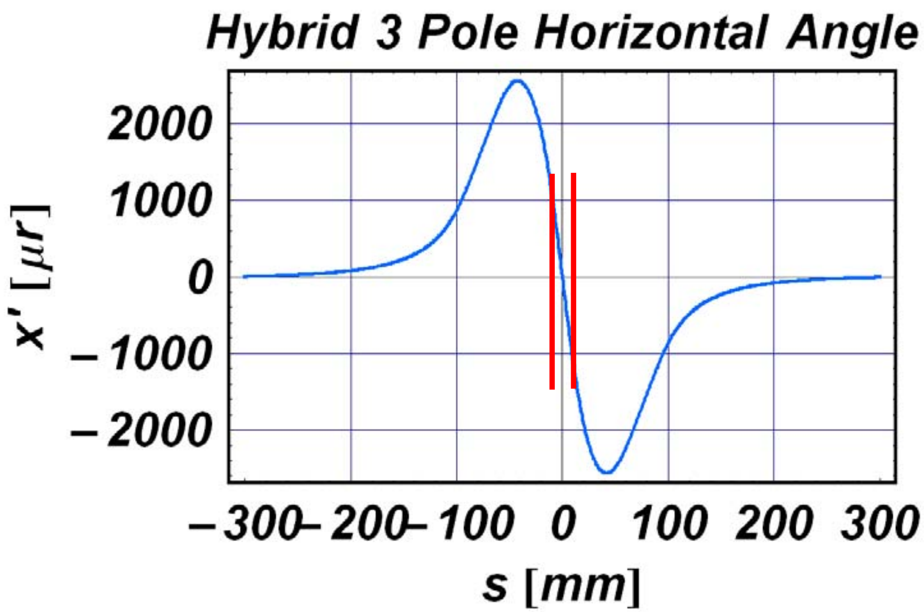
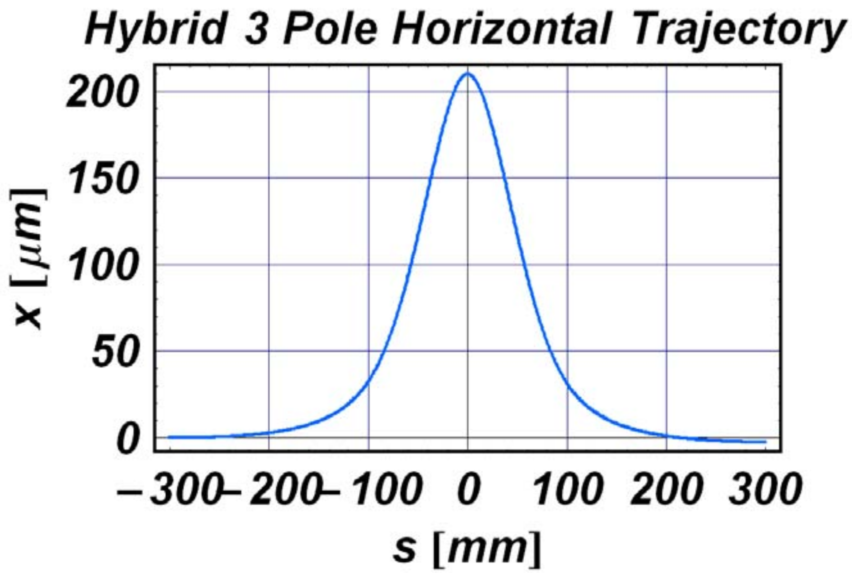
By, Angle, Trajectory

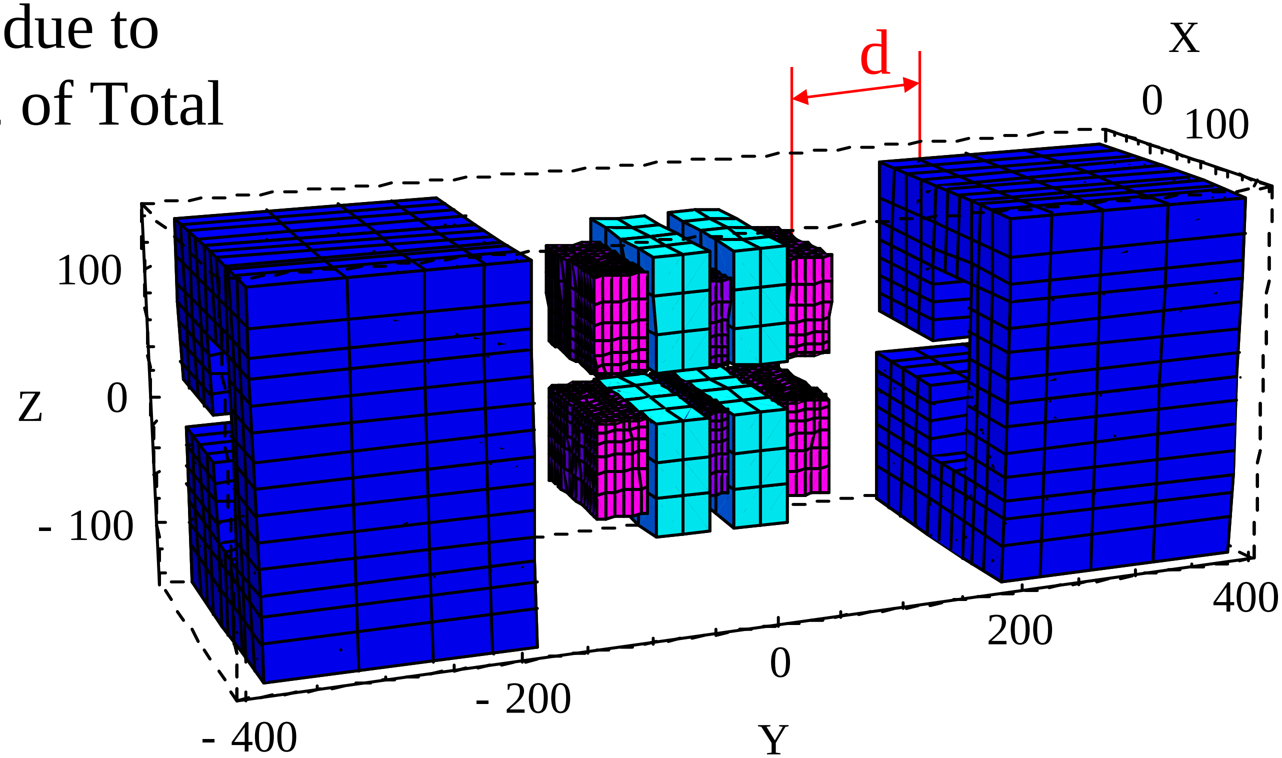




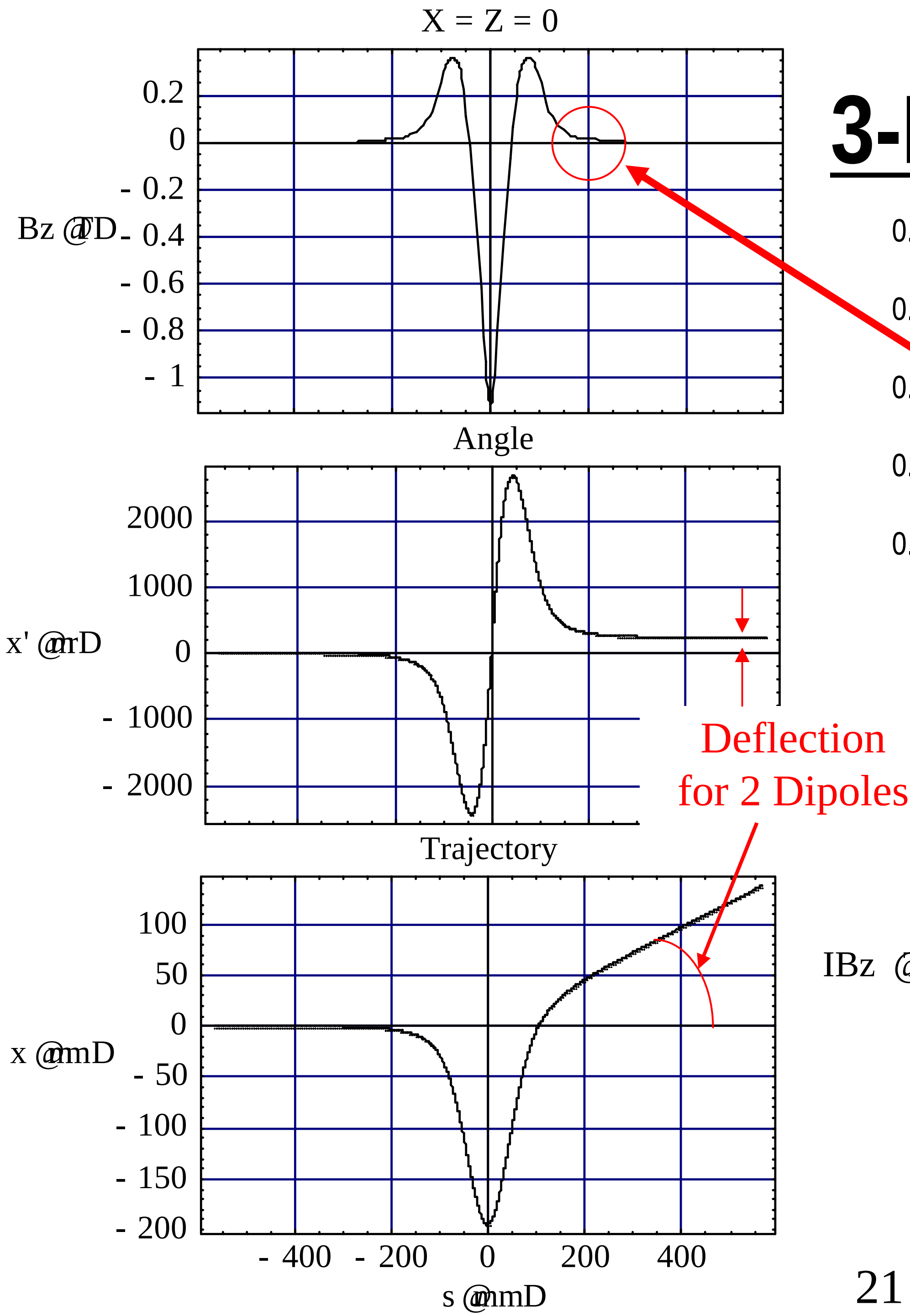


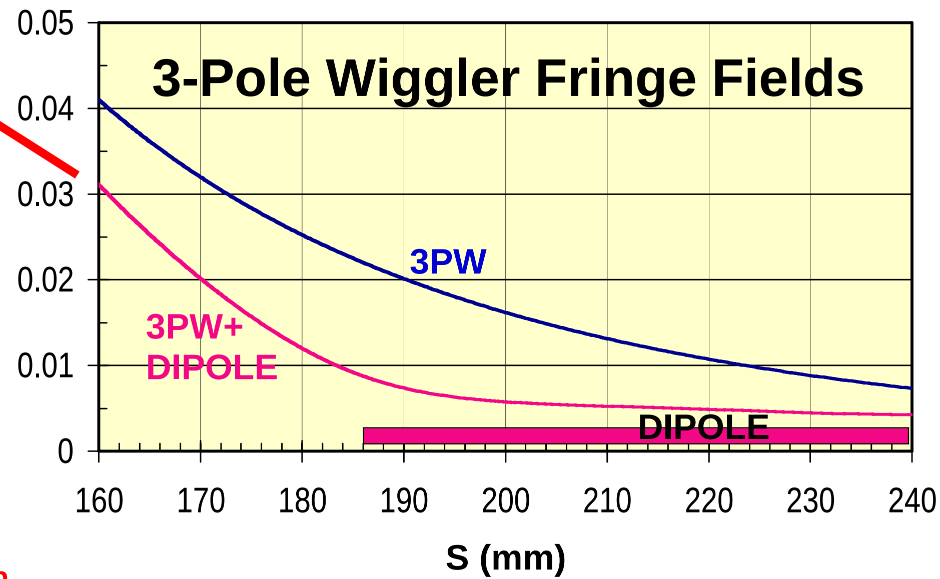
3-Pole Wiggler with Nearby Dipole

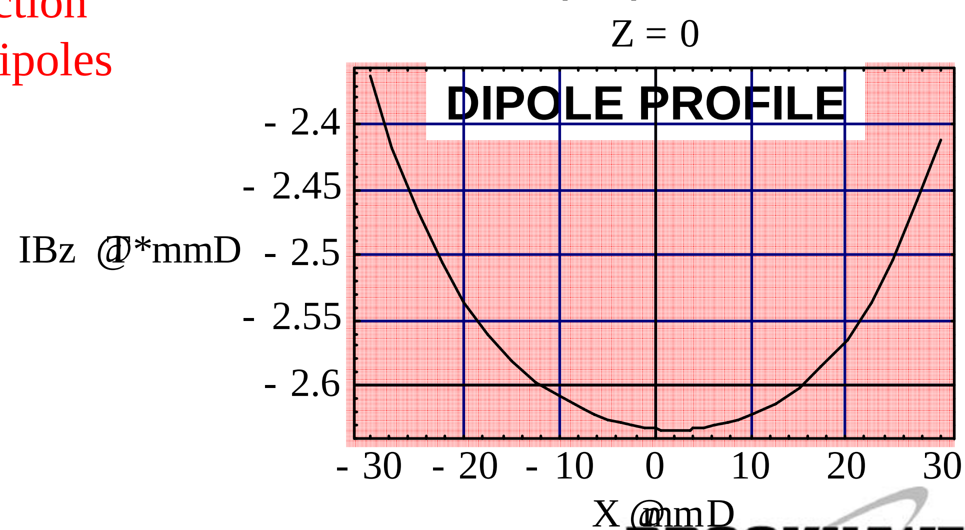
- Model 2 dipoles for symmetry
- Multipole change due to ONE dipole = 1/2 of Total



3-Pole Wiggler + Dipole







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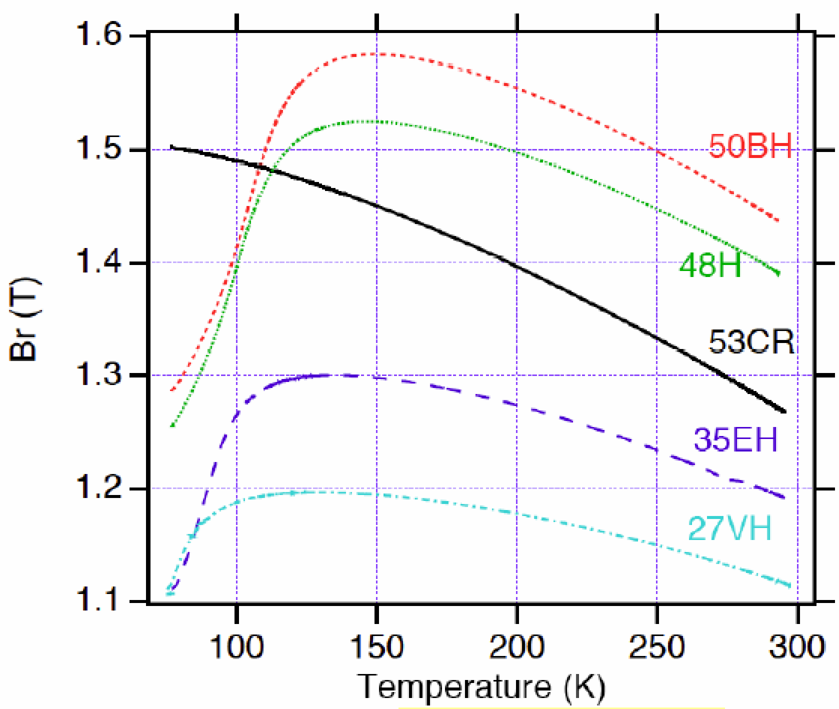
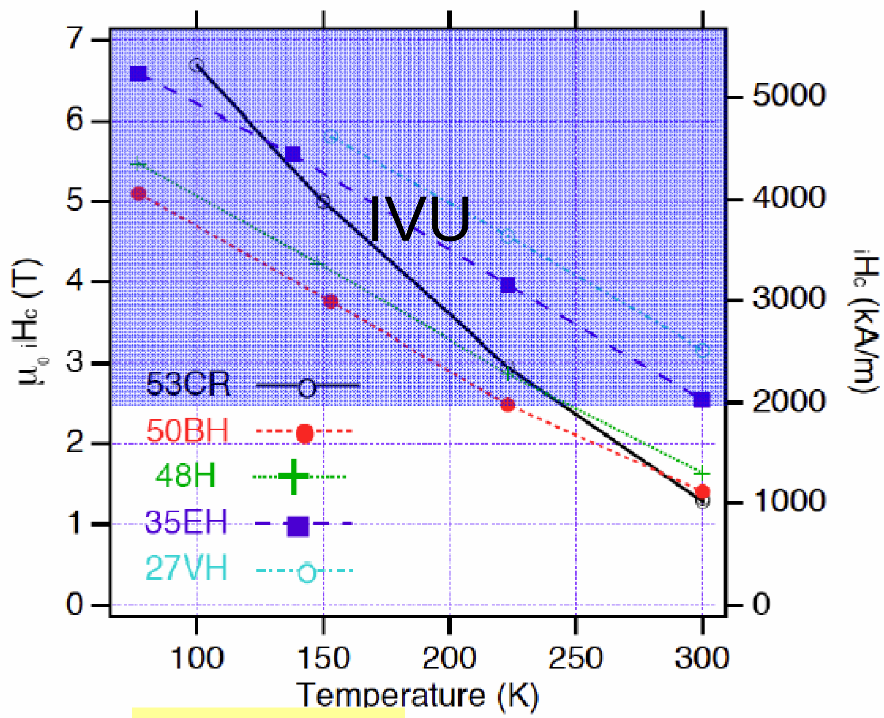
CPMU

- **Cryo-Permanent Magnet Undulator** (Hara, *et. al*, 2004)
  - *Simple Concept*: NdFeB has a negative thermal coefficient of remanent field (Br) [-0.1 % / K@20ºC], and of intrinsic coercivity (Hcj) [-0.5% / K@20ºC]
  - *PrFeB* (53CR by Hitachi-Metal) shows no “spin reorientation” at the lower temperature. However, it does not have high enough coercivity at the high temperature needed for baking.



Remanence



Coercivity

Simulation Challenge for CPMU

- Mechanical sizes (period, width, etc.) are temperature dependent
  - Thermal expansion coefficients are material dependent

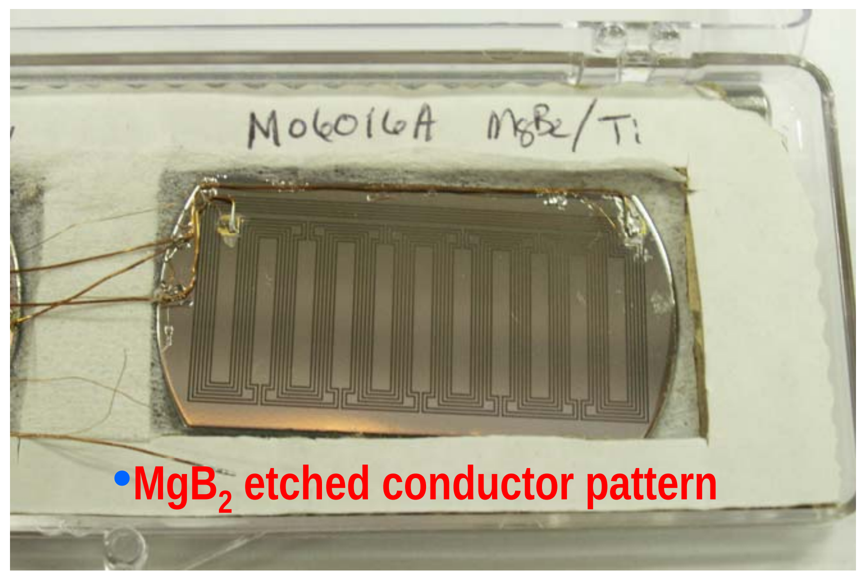
- Low temperature BH curve for material should be used
  - Permanent magnet
  - Pole material

- Thermal calculations
  - Sources are difficult to quantify

5) Superconducting Insertion Devices

- **Low Temperature Superconducting Undulator/ Wiggler**
  - Test APC-NbTi wire
- **Low Temperature Superconducting EPU**
  - Design study, especially winding technique
- **High Temperature SC Devices**
  - Rapid conductor development in the industry
  - New type such as coated conductor and thin film available → *More design flexibility*
  - Once the conductor exceeds the necessary performance level, it will be very promising candidates for future IDs

YBCO HTS tape undulator



• MgB_2 etched conductor pattern

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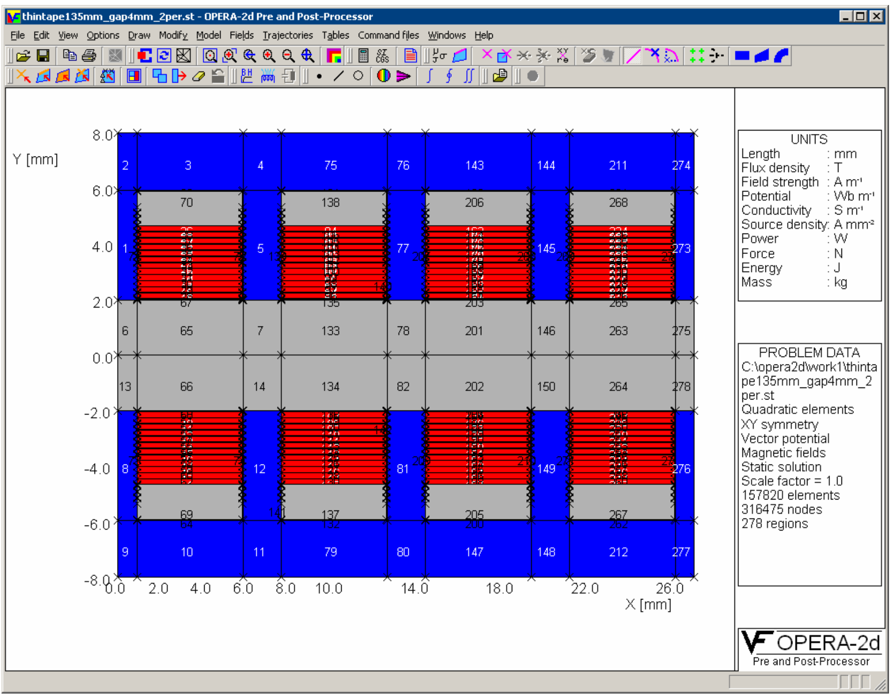
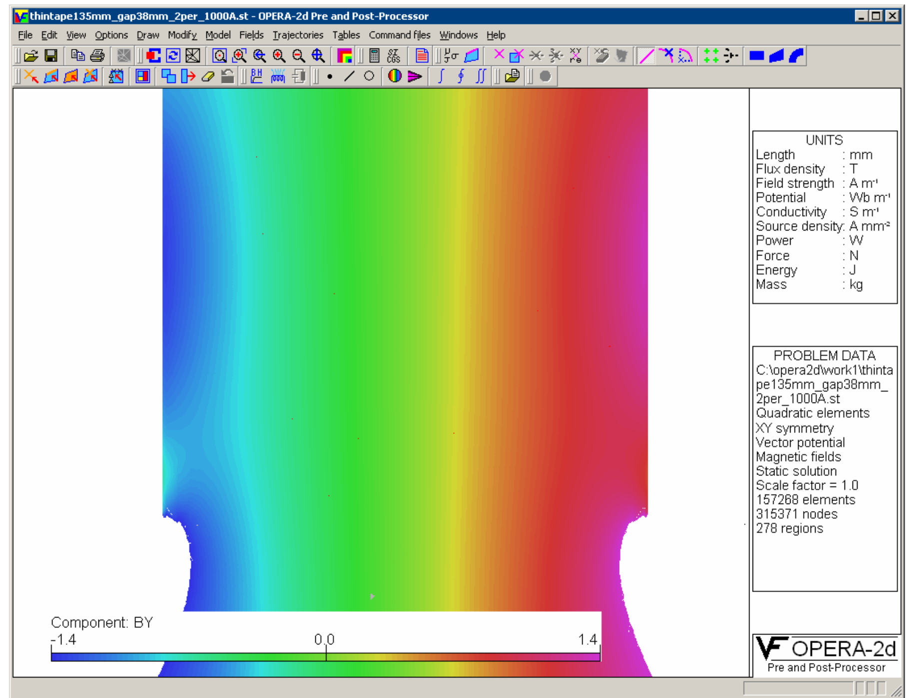
Minimizing Perpendicular Field

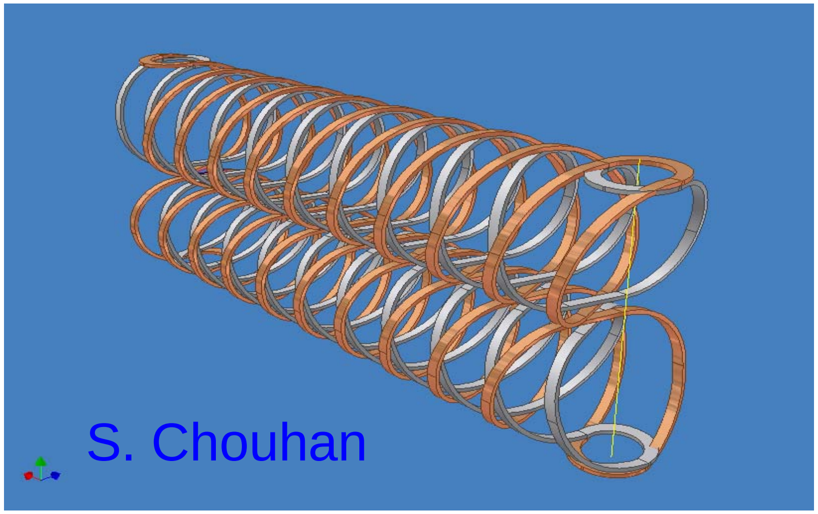
- Je=1000A/mm^2, λ_u = 13.5mm, Gap=3.8mm, B_{peak} = 1.4T,



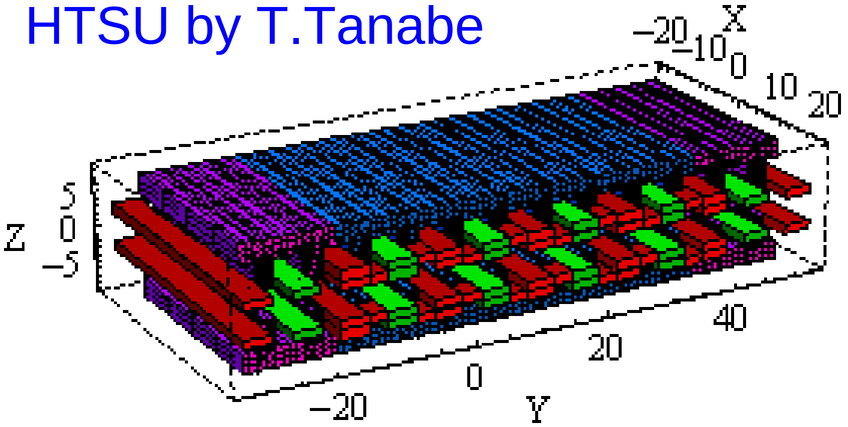


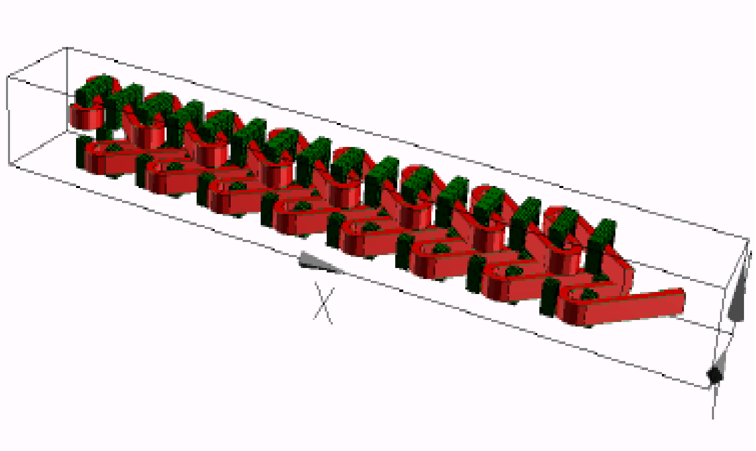
- **Radia cannot take diamagnetic properties of SC coil material**
- **End Calcuations have to be done with TOSCA 3D model**

SC-EPUs and a HTS Undulator



HTSU by T.Tanabe



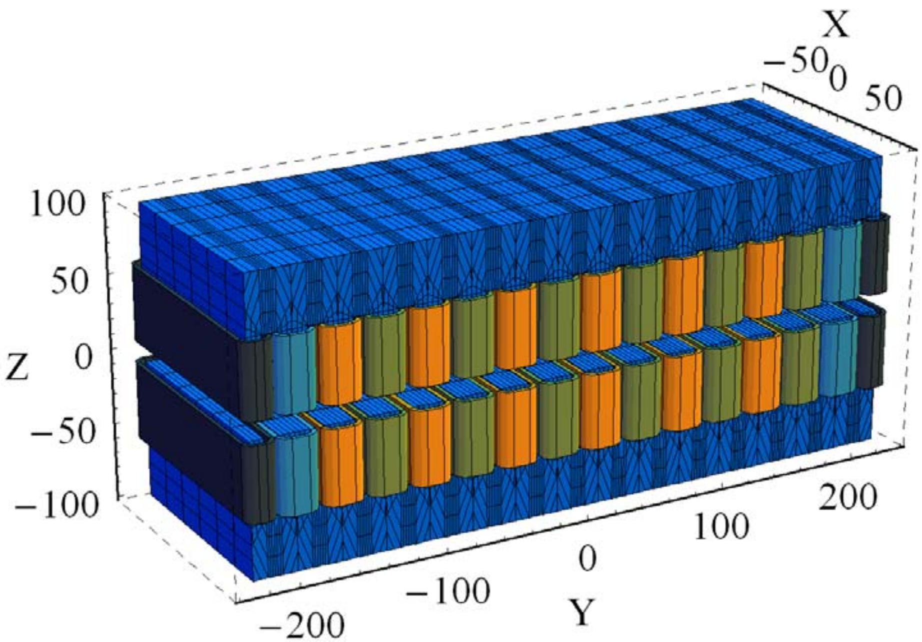


Sasaki Snake

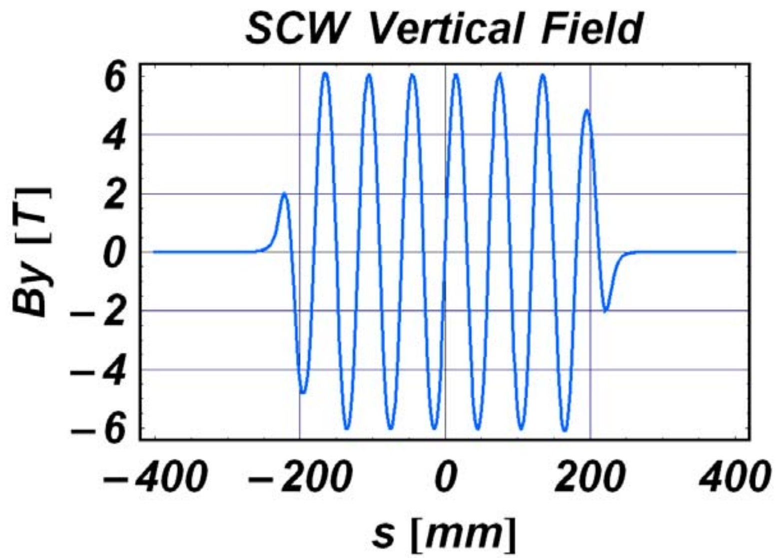
Rossmanith

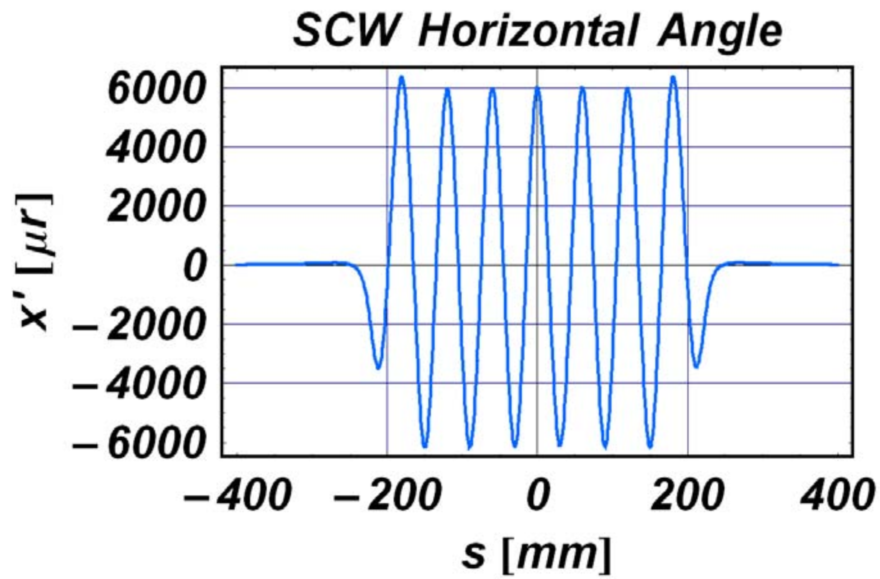
Superconducting Wiggler

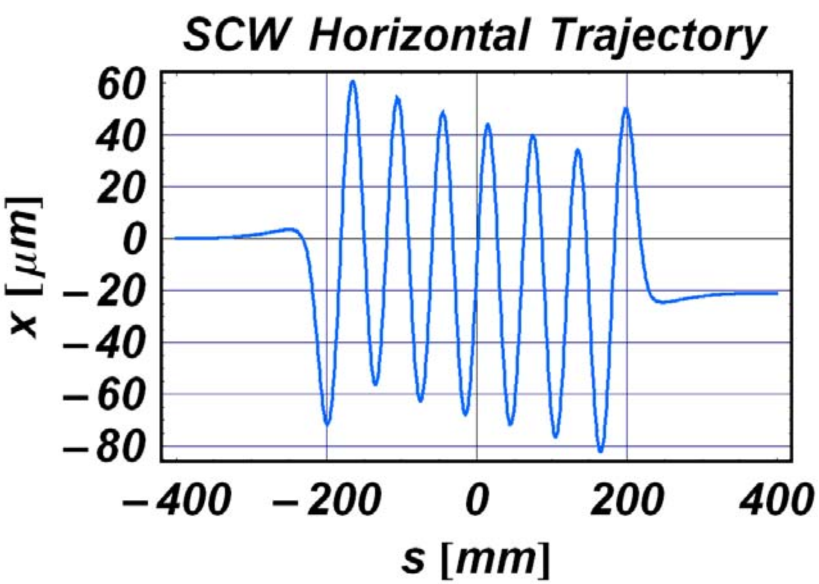
- CDR-SCW
  - 17 pole @ 6.0T (λ_u=6.0cm, g_{pole}=15.0mm)
  - K_{peak} = 33.6
  - Critical Photon Energy = 35.9 keV
  - Total Power = 102.6 kW
  - Peak on-axis angular power density = 36.7 kW / mrad



B_y, X_{angle}, $X_{trajectory}$







With 1006 Steel,

Required Current Density = 1300 A / mm²

Too much for conventional NbTi wire

Summary

- **Lattice Magnet**
  - Dipole - Opera 3D / Tosca (preprocessor) & ANSYS
  - Quadrupole / Sextupole /Corrector - Opera 3D / Tosca (preprocessor)
- **PM Insertion Device**
  - Radia with external BH file is most useful with parametic model
  - CPMU simulation requires low temperature BH curve as well as other thermal parameters to be accurate.
- **Super Conducting ID**
  - Complicated conductor shape in combination with yoke
  - Material data between at 4K and 77K not readily available