BAPS Accelerator Design and its R&D

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Outline

- Introduction of BEPCII/BSRF
- Consideration on BAPS Accelerator
- R&D for BAPS accelerator
- Summary

Beijing Electron Positron Collider & BEPCII

One machine for dual purpose: BEPC, upgraded to BEPCII in 2004-2008

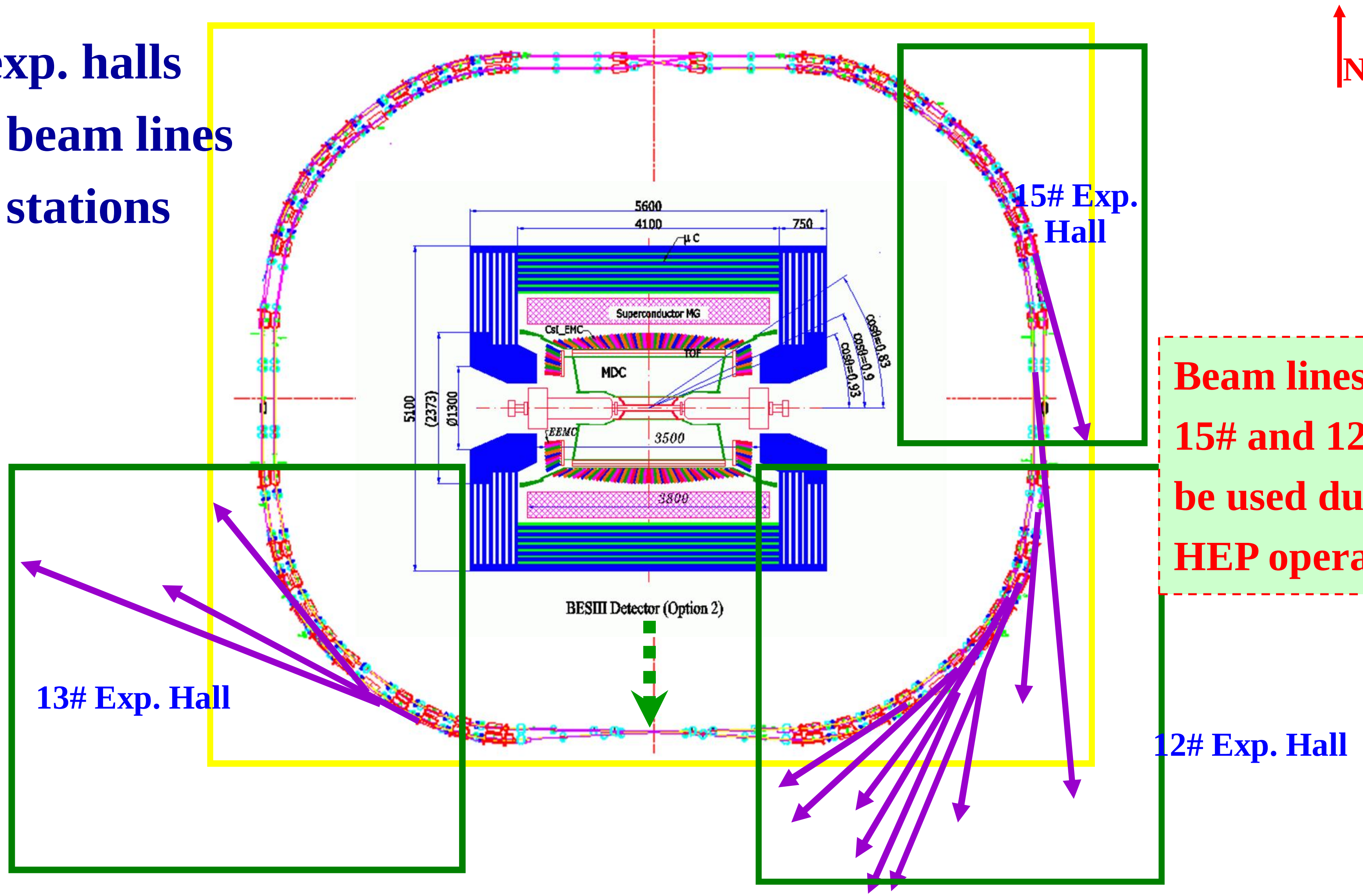
- — A two-ring e-/e+ collider for HEP
- — Dedicated and parasitic mode to SR (BSRF)

Beamline distribution around the storage ring

3 exp. halls

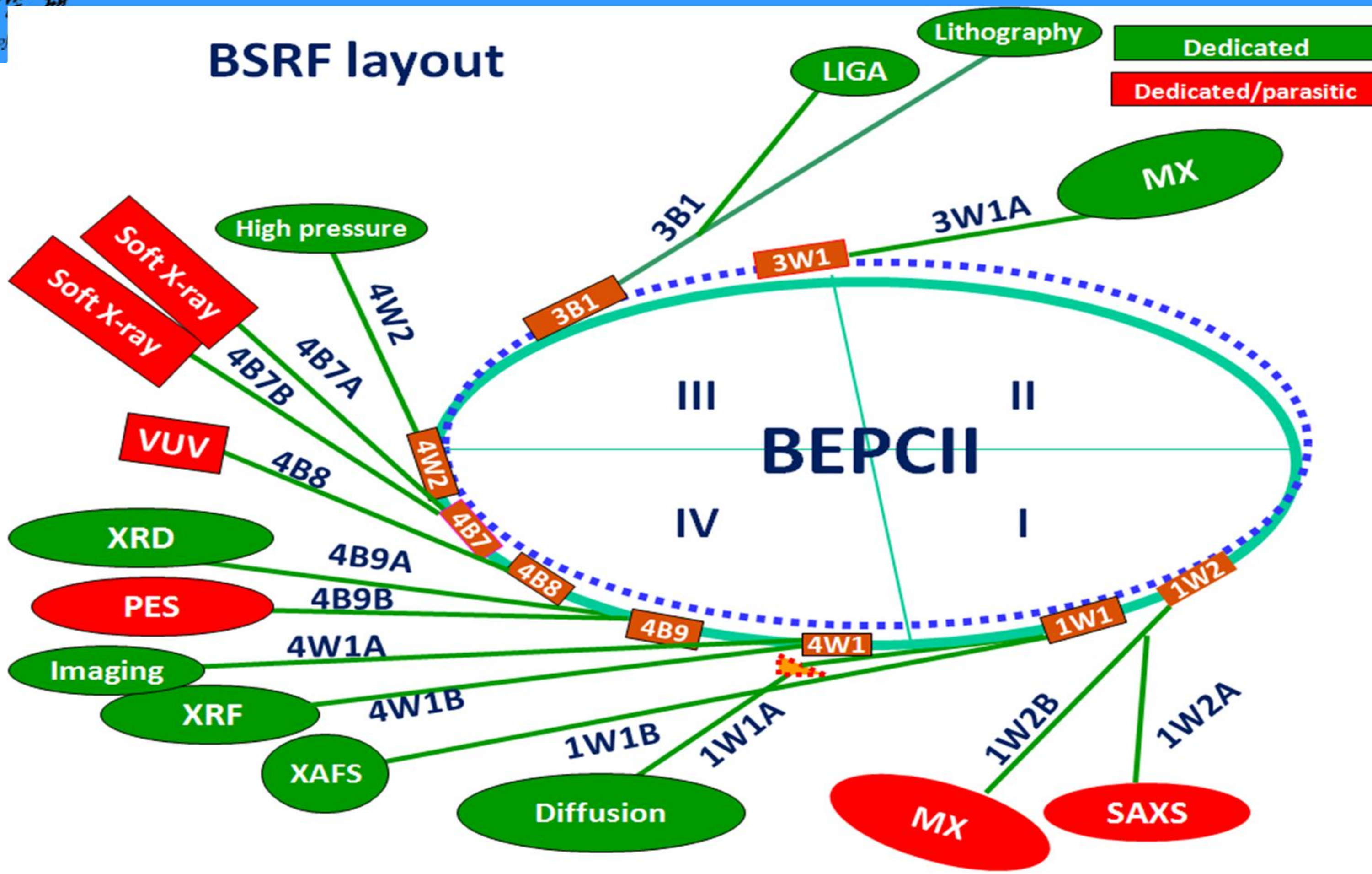
14 beam lines

15 stations



Beam lines in 15# and 12# can be used during HEP operation

BSRF

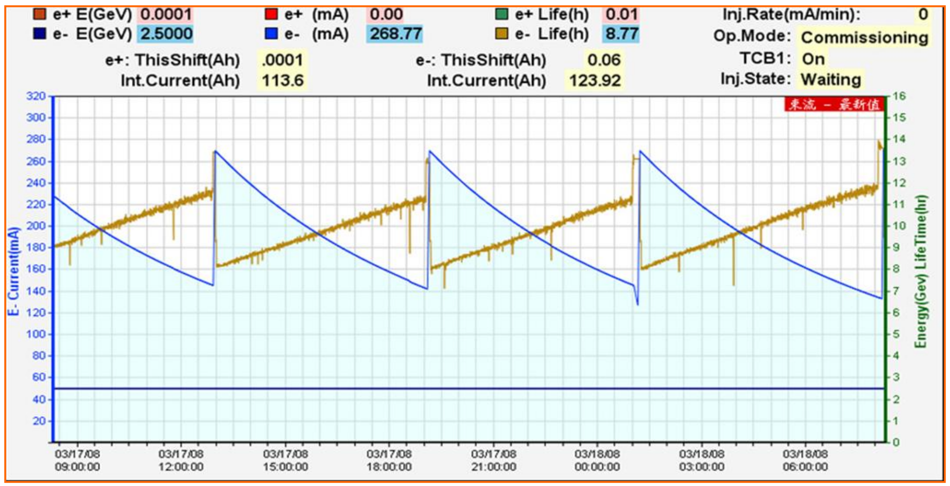


5 Wigglers, 4 bending magnets
14 beamlines
15 end-stations
Dedicated mode: 2.5GeV/250mA
Parasitic mode: depending on HEP

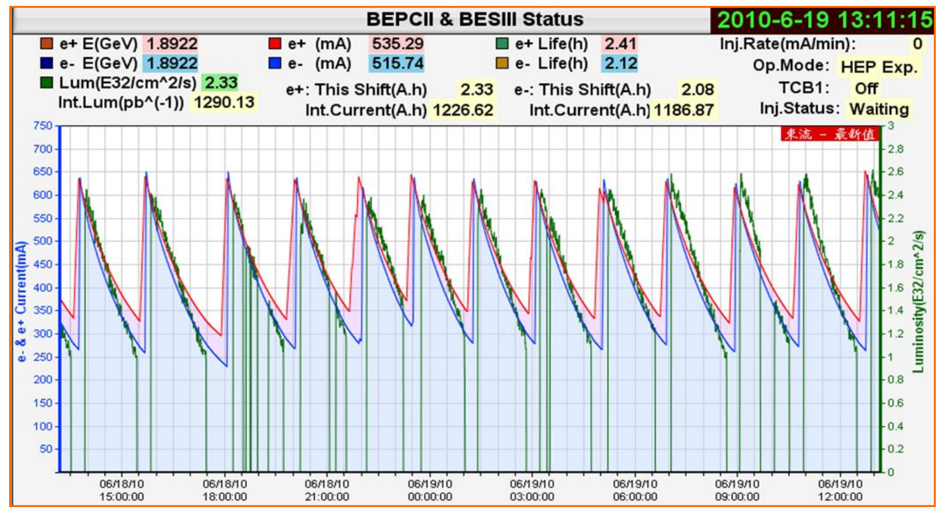
Beamtime: ~2000 hrs/year
Proposals: ~550/year
Users: ~1800/year
Papers: ~170/year

- **Dedicated synchrotron radiation operation**

- **Beam energy: 2.5Gev,**
- **Current: 250-200mA;**
- **Emittance: 100 nm□rad;**
- **Life time: >10 hours;**



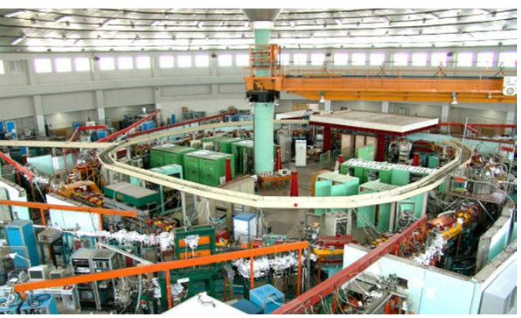
- **Operation of parasitic SR mode/collision mode**
  - **With one wiggler（1W2, No luminosity degradation.**
  - **Deliver beam to HEP and SR users simultaneously!**
  - **Beam energy: depend on HEP**
  - **Current: 700-500mA**

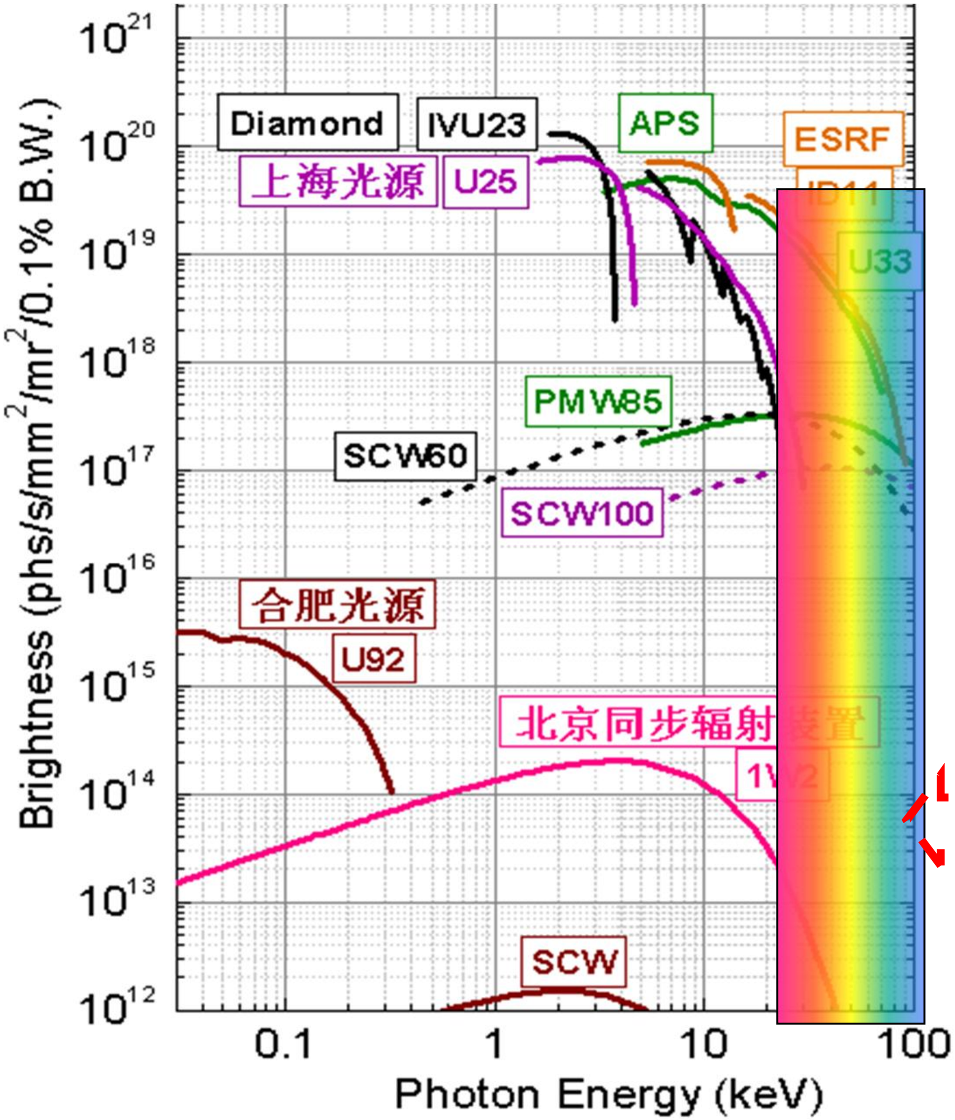


The SR facilities in mainland of China

BSRF (2.5GeV, 1GLS)

HLS (0.8GeV, 2GLS)





SSRF (3.5GeV, 3GLS)

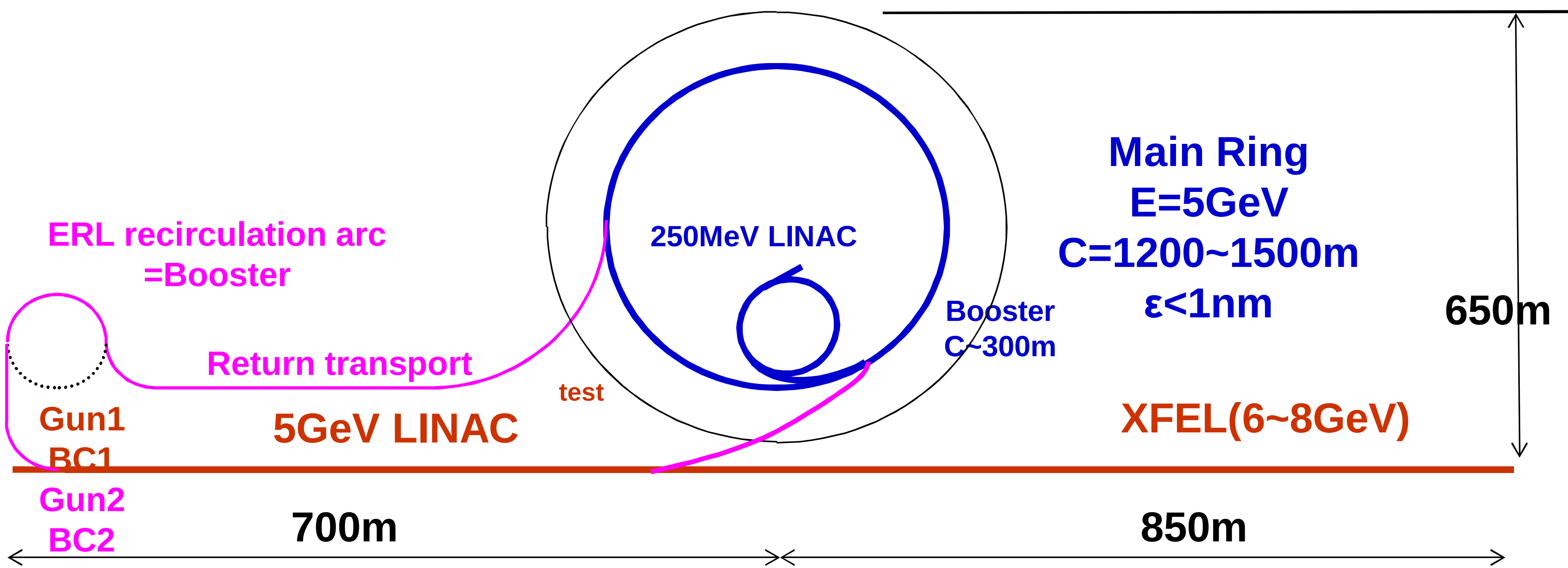
BAPS (5GeV)

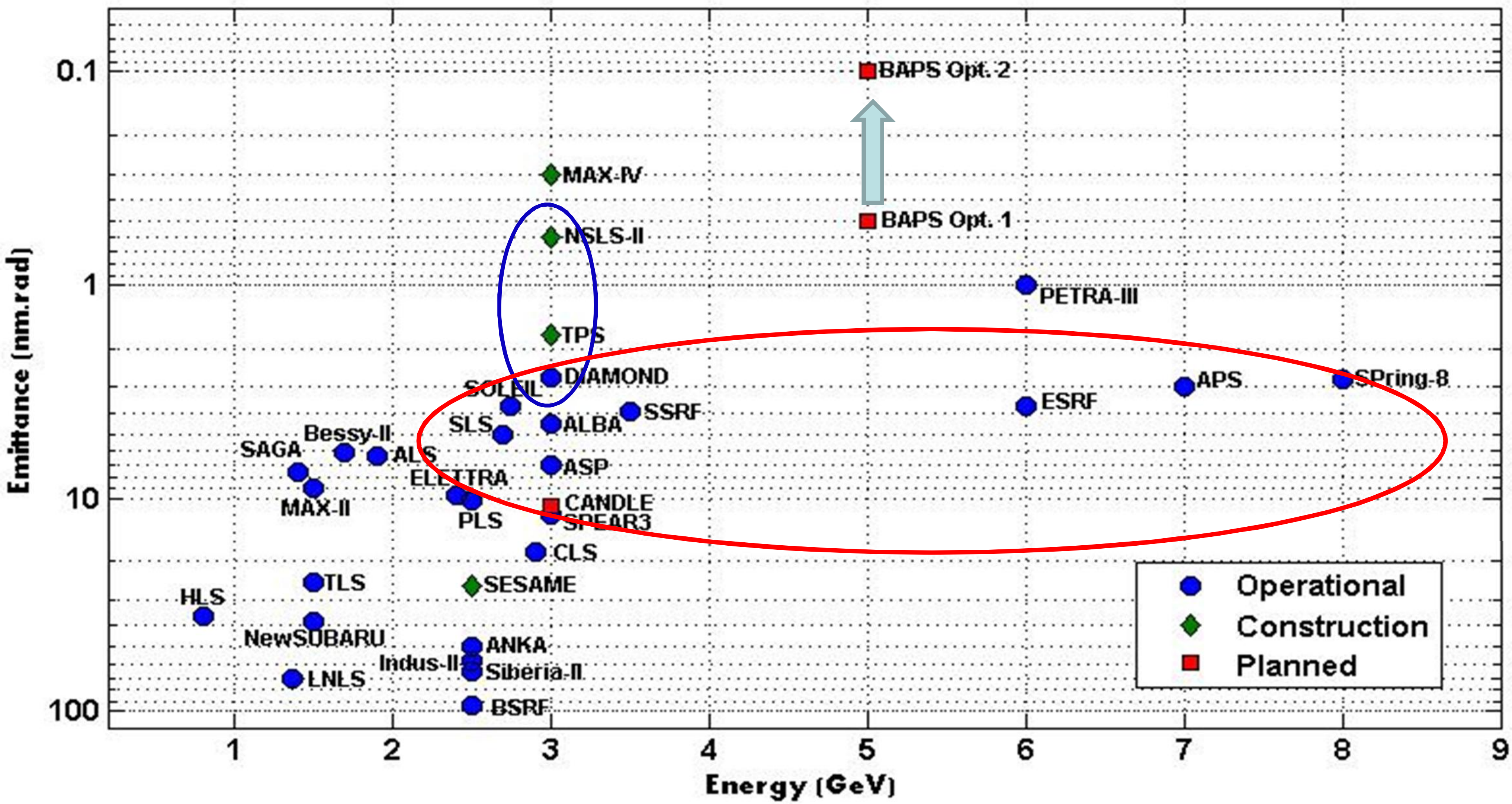
More hard X-rays are required, BAPS in Beijing is proposed.

Project of BAPS

- R&D project in the 12th five-year plan (2011-2015)
- BAPS construction in the 13th five year plan(2016-2020)
- Location in Huairou, Beijing Adanced Science Innovation Center

A 5-GeV light source, with very small emittance and the possibility to have ERL and X-FEL in the future




0.1
1
10
100
Emittance (nm.rad)
1
2
3
4
5
6
7
8
9
Energy (GeV)
BAPS Opt. 2
BAPS Opt. 1
MAX-IV
NSLS-II
TPS
PETRA-III
DIAMOND
SOLEIL
SSRF
ALBA
SLS
Bessy-II
SAGA
ALS
ELETTRA
ASP
MAX-II
PLS
CANDLE
SPEAR3
CLS
APS
SPring-8
ESRF
TLS
SESAME
HLS
NewSUBARU
ANKA
Indus-II
Siberia-II
LNLS
BSRF
Operational
Construction
Planned

Design goal of BAPS in phase I

Beam energy	GeV	5
Circumference	m	~ 1300
Beam current	mA	200 – 300
Natural horizontal emittance	nm·rad	<0.5
Critical photon energy	keV	~10
Brightness	Photons/s/mm^2 /mrad^2/0.1%BW	~10^{21}

Parameter choice for low emittance

$$\varepsilon_{MBA\min} = \frac{C_q \gamma^2}{4\sqrt{15}(2 - 2 * 3^{1/3} + M * 3^{1/3})^3} (\frac{2\pi}{n})^3 = \frac{C_q \gamma^2}{4\sqrt{15}(\frac{2-2*3^{1/3}}{M} + 3^{1/3})^3} (\frac{2\pi}{Mn})^3$$

Where M is number of bending magnets in one period of achromat, n is the number of the periods

To achieve low emittance, compromise between the number of bending magnets and the number of straight sections for IDs,

As the primary request is to serve more users and the technology is relative mature, a TBA scheme with 36 IDs available is chosen as the baseline design at the moment.

Possible lattices of storage ring

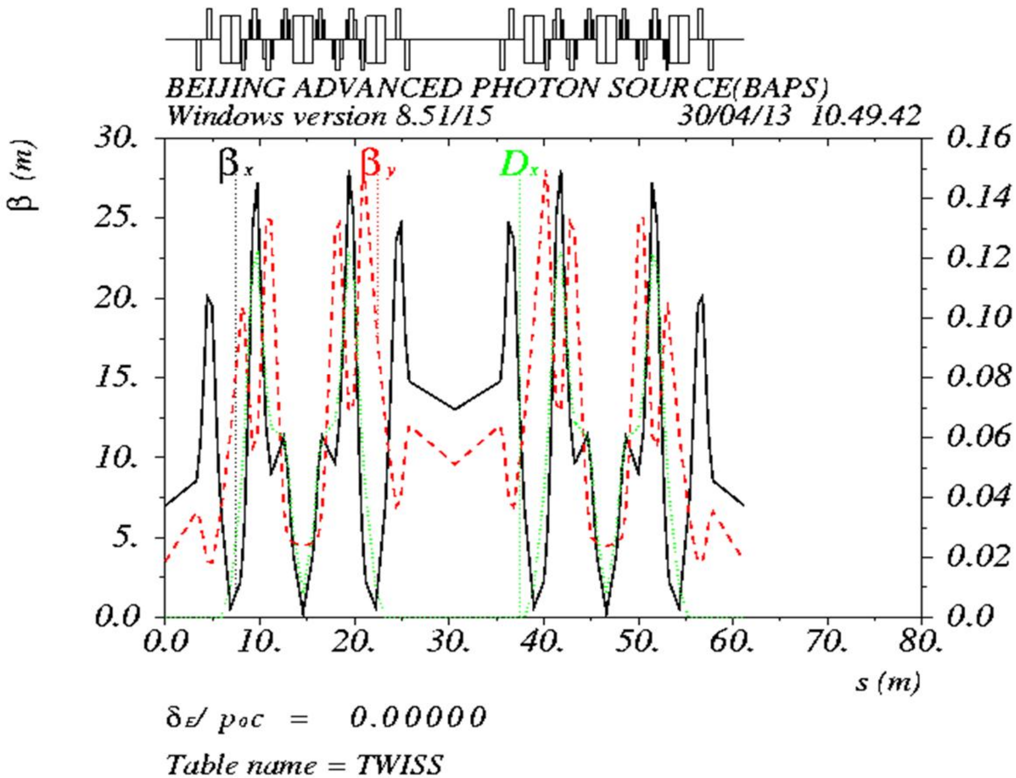
	48–DBA	36–7BA	32–7BA	40-TBA
Circumference (m)	1208	1522	1263	1284
Bare lattice emit. (pm)	1440	50	75	460
Emit. w/ D.W. or Sol. (pm) (H/V)	500/5	7.5/7.5	10/10	150/5
Beam current (mA)	200 – 300	100	200	200-300
Straight section (N * L)	44*6.4 + 4*14.6	18*12 + 18*8	16*12 + 16*8	20*6.6 + 20*9.6
Critical energy (keV)	13.4	5.37	7.56	10.66/5.33
Energy loss per turn (MeV) (dipole)	2.67	1.07	1.51	1.6

Balance among cost (cir.), No. of beamlines, technology mature

- **A primary lattice of the storage ring**

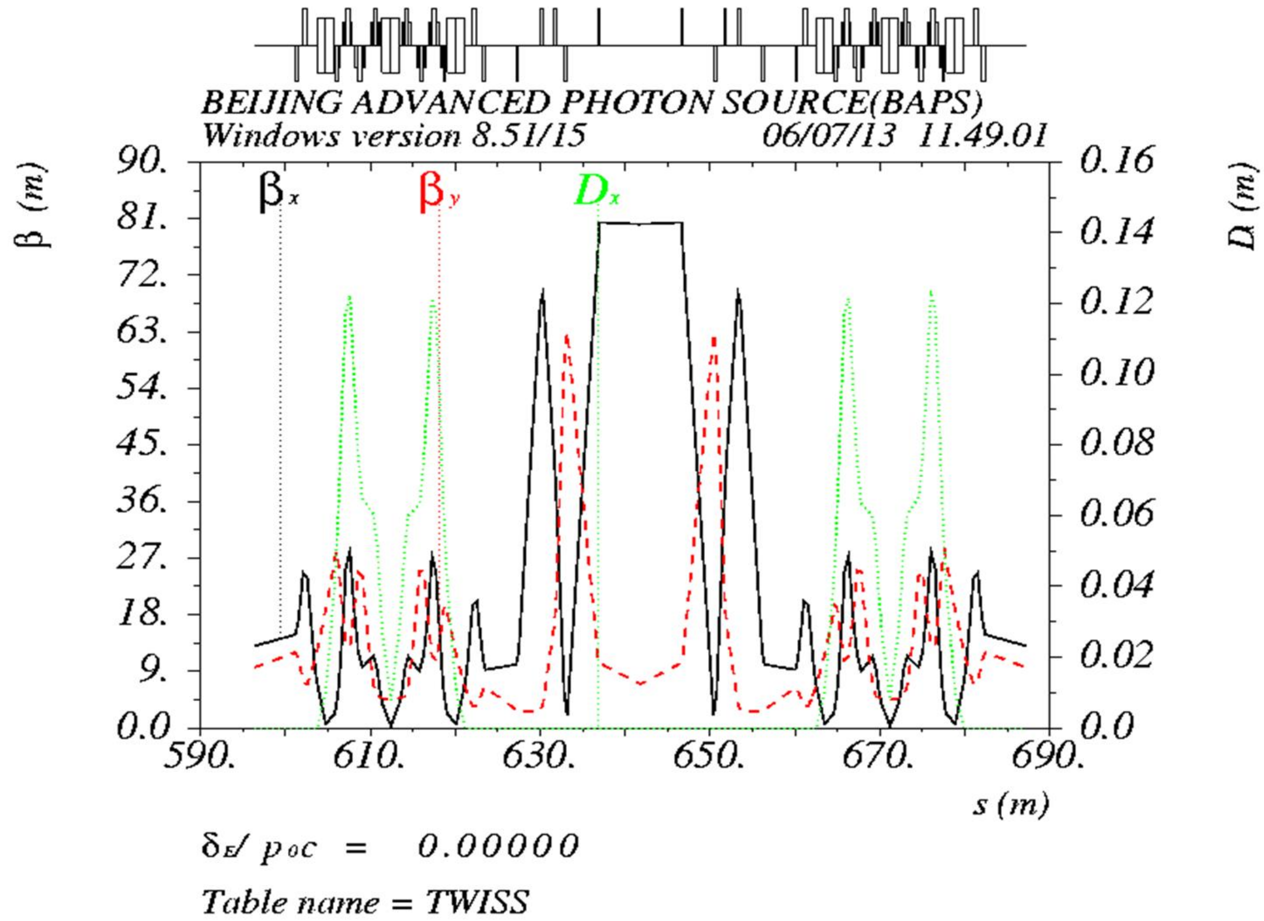
TBA with TME mid bend

20*9.6m+20*6.6m mixed TBA



- **In order to get lower emittance, we directly set the mid bend to the TME case, so the achromat condition just depend on the side bends.**
- **At the meantime, taking a larger bending radius of the side bends can decrease its contribution to I5.**
- **For fabricating simply the bending magnets have the same length, the radius of side bends is double the mid one**

High beta insertion for pulse sextupole Injection



To increase the dynamic aperture, a high beta insertion replaces the short straight insertion, the phase advance for this injection insertion are standard value+1 for both H/V

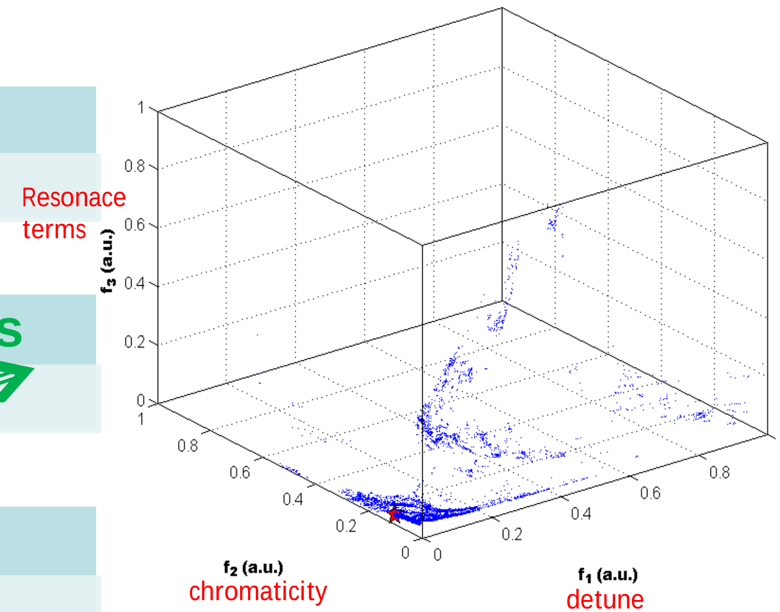
BAPS ultralow emittance design and optimization

Linear optics
Analyzer based on Lie Algebra and Hamiltonian analysis

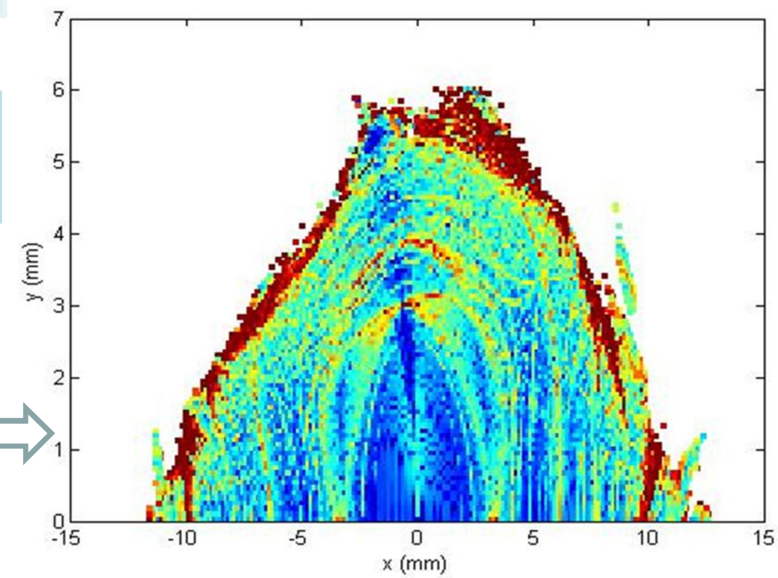
Analytical expressions of non. driving terms
MOGA

Pareto-optimal solutions
Numerical tracking | Frequency map analysis

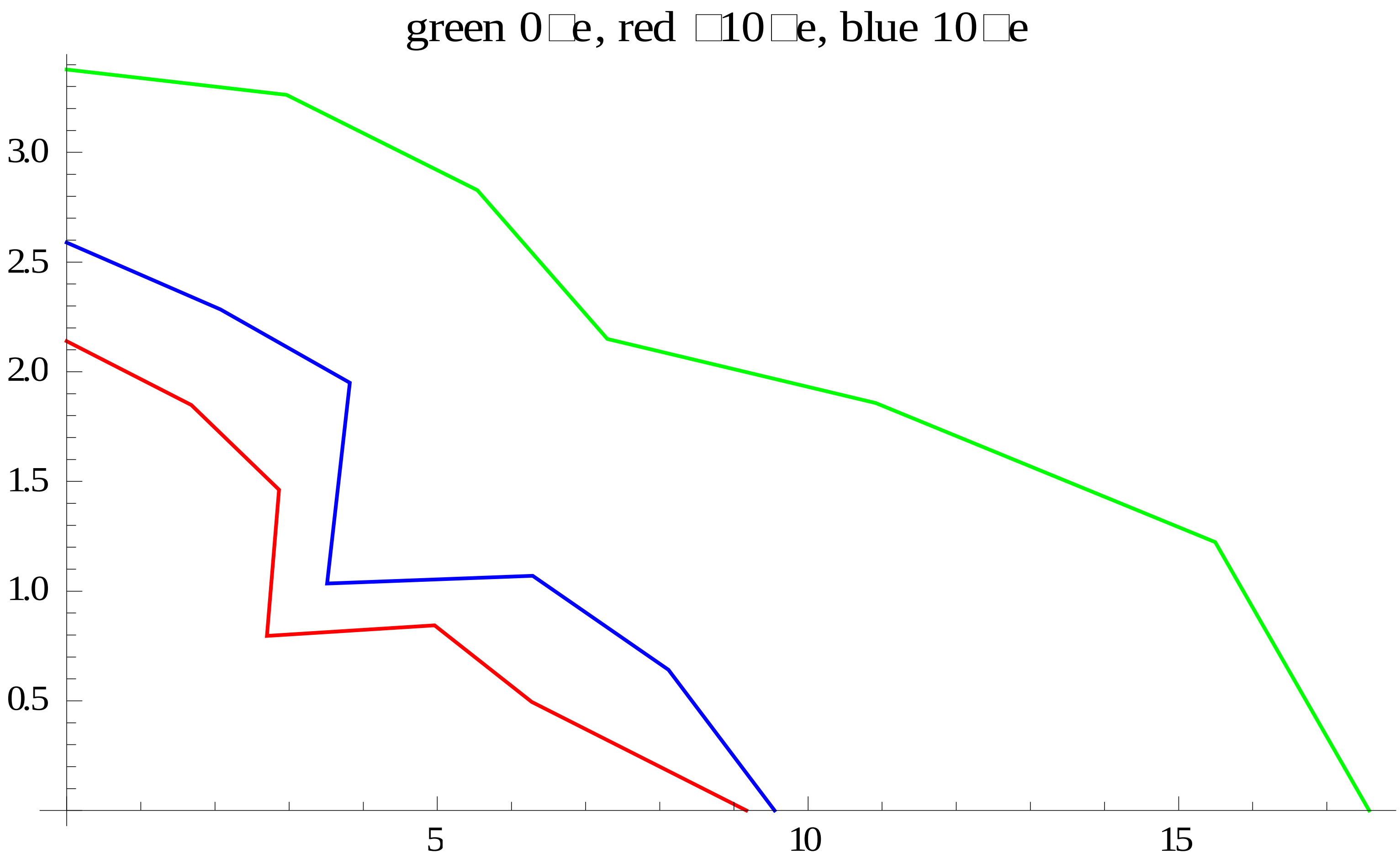
Final optimal solution



On-momentum DA at the center of the inj. Straight.



G. XU, Y. JIAO, Chinese Physics C, 37(5), 057003, 2013.

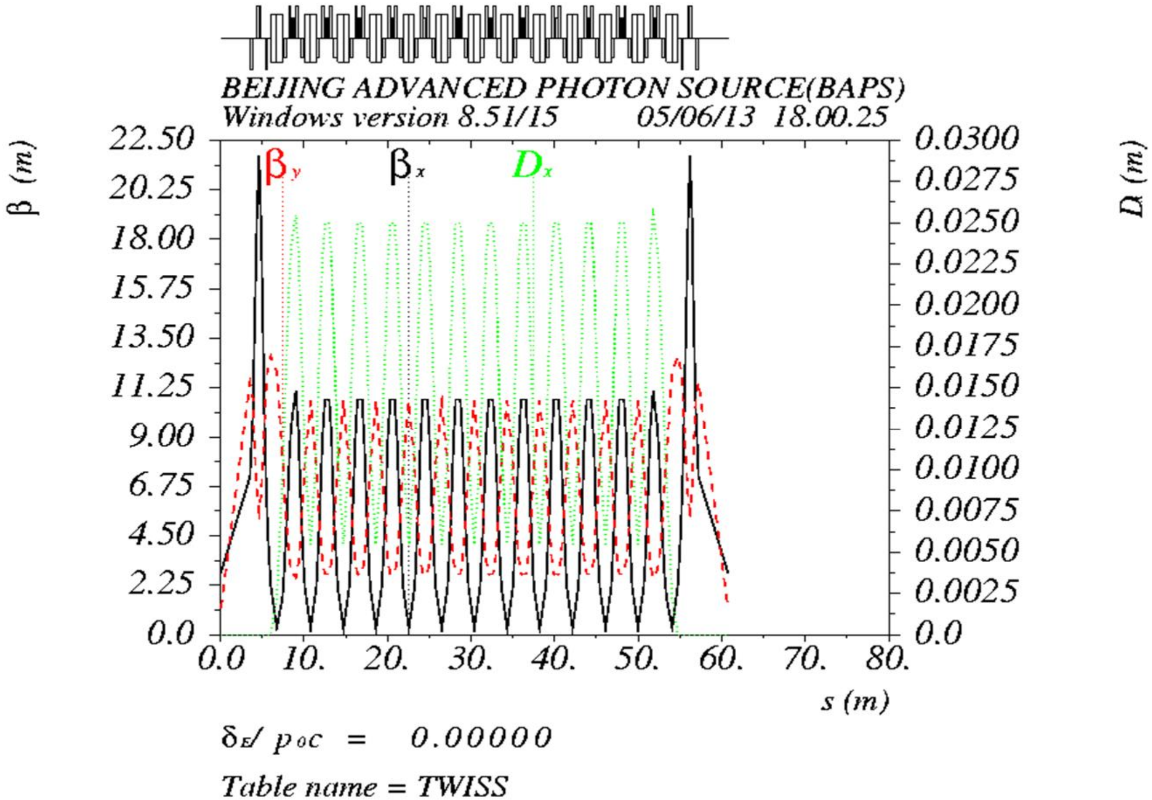


Dynamic aperture(mm)

Considering on the second phase: The ERL or USR in the same tunnel

- **The emittance for TBA design is 0.46nm or 0.15nm with ID and damping wiggler.**
- **In order to keep the possibility to 10pm, a wide tunnel is reserved to insert the other ring ERL or USR**
- **For ERL, TBA structure can be used**
- **For USR, a preliminary design of 20*13BA with high beta insertion for pulse sextupole injection**

USR design



Circumference 1272m Emittance 36pm(bare)

Use damping wiggler and full coupling the emittance get down to 10pm/10pm

Phase 2: Inner ring of USR Design

	20–13BA
Beam Energy (GeV)	5
Circumference (m)	1272.23
Bare lattice emit. (H/V nm)	0.036/0.005=〉 0.01/0.01*
Beam current (mA)	100
Straight section (N * L)	20
Critical energy (keV)	5.3
Energy loss per turn (MeV)	1.02
Tune (H/V/Z)	118.3/41.3/0.0037
Natural chromaticity (H/V)	□246.4/□101.9
Momentum compaction factor 10^{-3}	0.034
Bunch length (ps/mm)	1.26
Brightness ($Phs/s/mm^2/mrad^2/0.1\%BW$)	～10^{22}

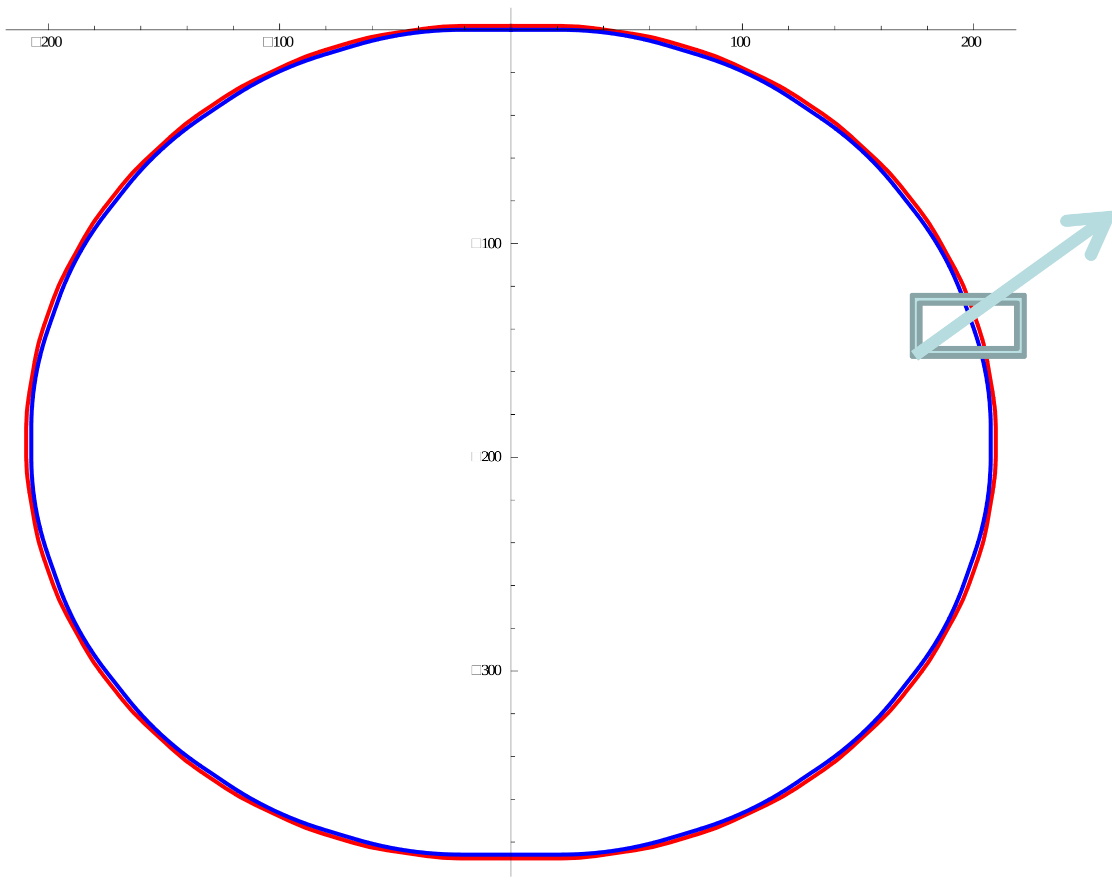
To achieve diffraction limit emittance

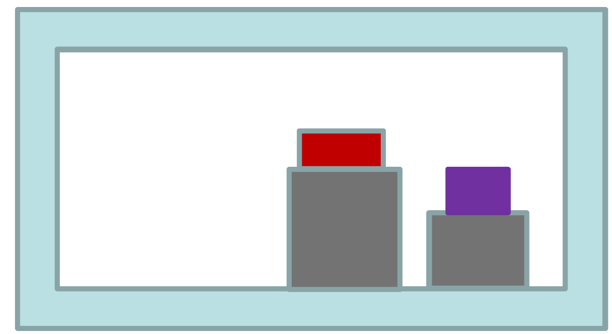
- Target emittance of ~10pm for spacial coherent x-rays @10keV.
- *with damping wiggler to reduce emittance and round beam to reach 10/10 pm with scheme of coupling control (locally using solenoid & anti-solenoid or globally using resonance)
- DA is still under optimization with the goal >10mm
- Injection with pulsed magnet will be adopted

Beijing Advanced Photon Source(BAPS) complex

Outer-ring : ‘typical’ 3rd gen. lightsource@5GeV

Inner-ring options: USR or ERL





Main ring tunnel

- two rings in same tunnel
  - Distance:1.78m
  - Outer ring is TBA
  - Inner ring is 13BA
- vertically different to extract inner-ring’s light

- **Workshop on Accelerator R&D for USR (Ultimate Storage Rings) held in Beijing, Oct. 30 – Nov. 1, 2012**

R&D of BAPS (2012 – 2015)

Accelerator:

- Accelerator physics issues (lattice, collective effects, etc) for low emittance, optimization of machine parameters,
- Extremely high (<1μm) precision measurement, control and feedback of beam orbit
- High precision magnets and power supply (Pulsed sextupole for injection)
- Design and manufacture of key devices of BI (BPM etc.)
- High performance insertion devices
- Test hall for simulation of high precision alignment, installation and long term stability

= > Completion of CDR of BAPS

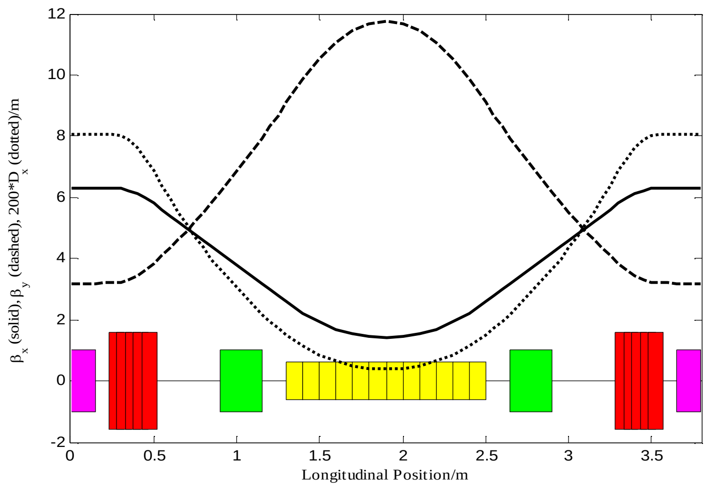
R&D on beamlines and stations

- Insertion Devices
- High energy X-ray monochromator
- Cryogenically Cooled DCM
- detectors
- High Precision Bending and Metrology
- Nano focusing optics
- Nano positioning and scanning device
- Dynamics extreme conditions (P-T)
- Time-resolved technique
- Diffraction contrast imaging

Accelerator Physics Study of BAPS

Ultralow-emittance storage ring design and optimization

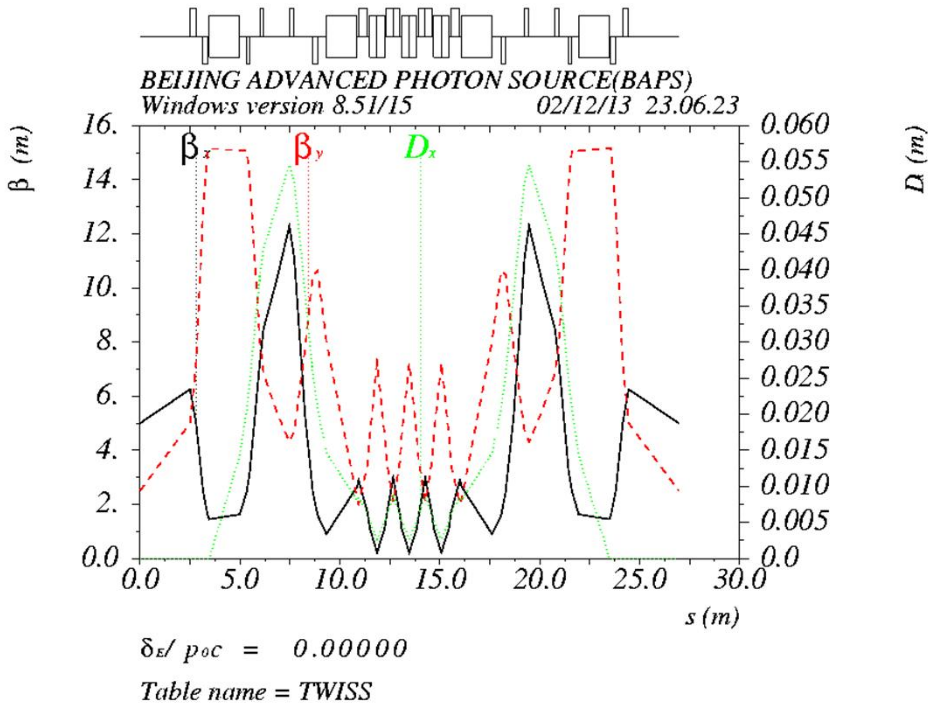
- **Theoretical minimum emittance (TME) structure**



Modified-TME unit cell study
Compact magnet design
Ingenious control of the emittance, natural chromaticity, and circumference
Emittance reduction with damping wigglers, robinson wigglers

Lower emittance lattice

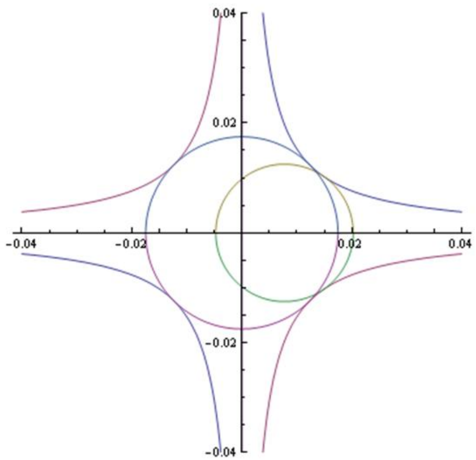
A cell adopting ESRF design



Same circumference: 1296m
7BA*48
Emittance=34pm@6GeV
Difficult on DA:
On axis injection may be required
Challenge on magnets:
1) Combined function dipole with strong quadrupole
2) Strong quadrupole>100T/m

Primary consideration on magnet scheme

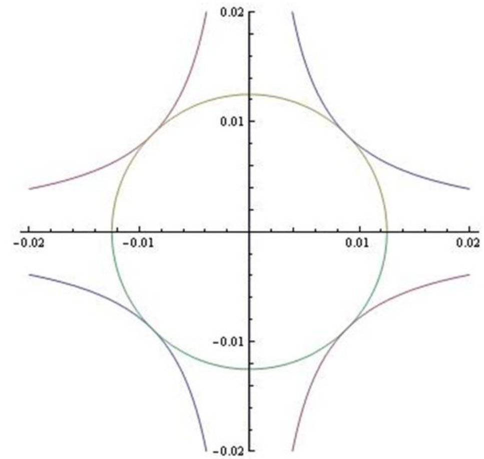
二四极组合磁铁



孔径	35mm
真空盒外径	25mm
离磁铁中心	7.76mm
弯转半径	41m
极面场强	1.1T
二极场强	0.4881T
四极梯度	62.9T/m
磁铁长度	0.7667m

Dipole with gradient

超强梯度四级铁



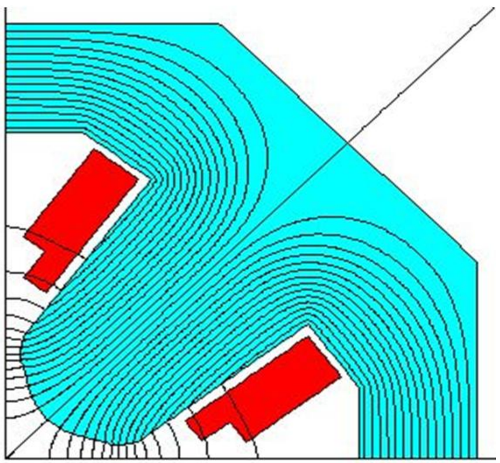
孔径	25mm
真空盒外径	25mm
极面场强	1.25T
四极梯度	100T/m
长度	0.69m

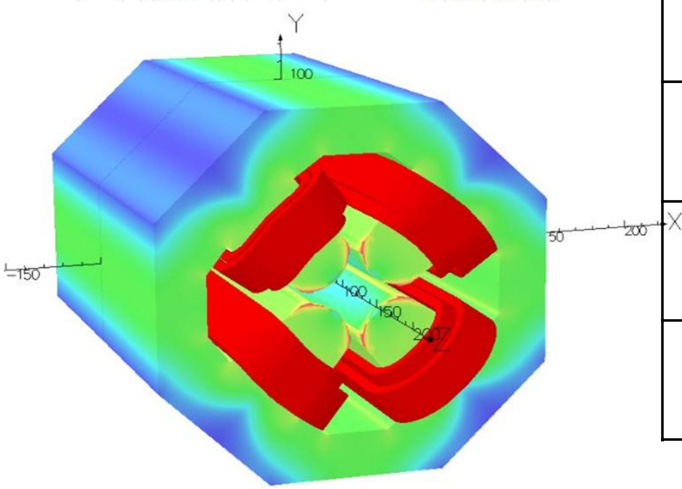
Quadrupole

R&D on magnets of BAPS

- High focus strength
  - Field gradient is very high (46.9T/m, 7500T/m^2)
  - Small aperture (25mm) to achieve the focus strength
- High precision
  - Field or gradient homogeneity better than 1×10^{-4}
- Combined function
  - Dipole/Quadrupole or Quadrupole/Sextupole
  - Carefully optimized pole profile to get good field quality

Quadrupole design by Y.S. Zhu





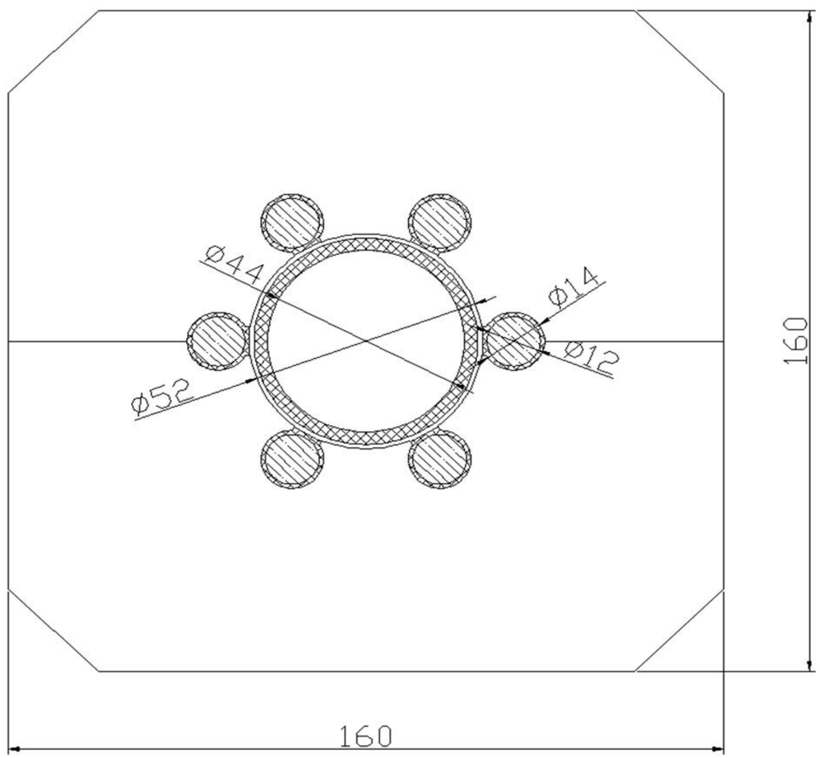
Systematic high order multipoles (Unit: 10^{-4})

B_n/B_2 / n	2D simulation	3D simulation	
		Before chamfering	After chamfering
2	10000	10000	10000
6	1.38	-8.15	-0.31
10	0.19	0.68	-0.01
14	0.003	-0.003	0.09

Easy to design, hard to fabricate

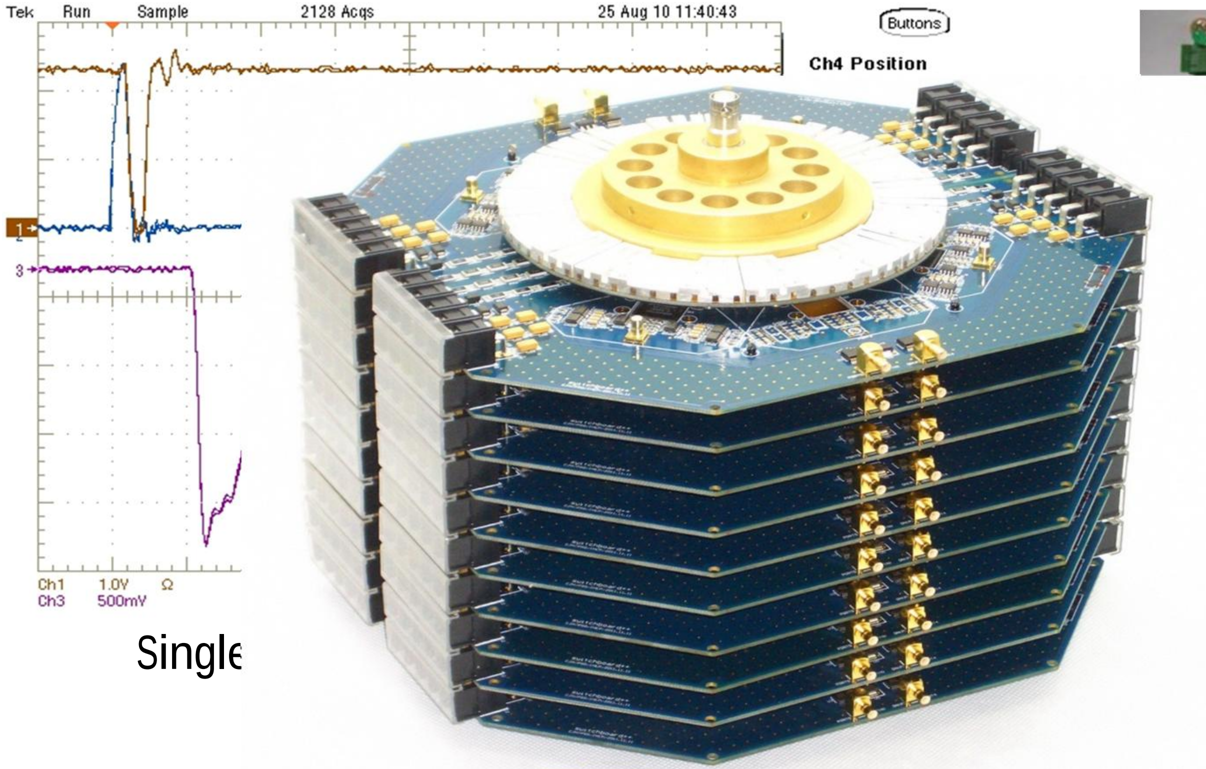
- **High precision magnet needs**
  - **high precision machining**
    - Ten microns of random machining error brings about 1×10^{-4} of multipoles
    - To meet the requirement, the pole surface machining tolerance should be better than 5 microns, and the mounting surface machining tolerance should be better than 10 microns.
    - High precision machining and measuring equipment
      - Wire electrical discharge machining (1 micron)
      - Coordinate measuring machine (1 micron)
  - **And high precision assembling**
    - Good procedure with skilled workers
    - Quality management

For Injection: Pulsed sextupole magnet

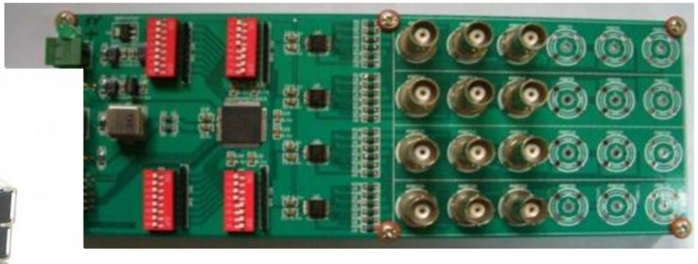


Waveform	Half sine
Pulse width	4μs
Strength of sextupole field	>1000 T/m^2
By(x=5mm, y=0)	>125Gs
By(x=15mm, y=0)	>1125Gs
Aperture	52 mm
Magnetic length	500 mm
Core length	490 mm
Turns per pole	0.5
Max. current	3888A
Inductance	3.5μH

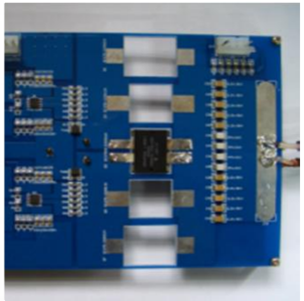
For injection in small DA with "swap-out" : IHEP Pulse Source for ILC Damping Ring Kicker

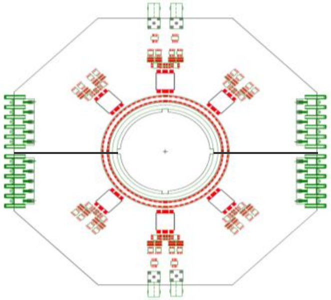


Single

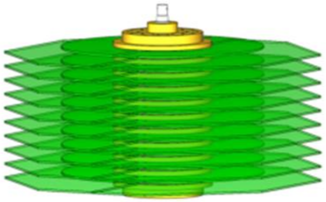


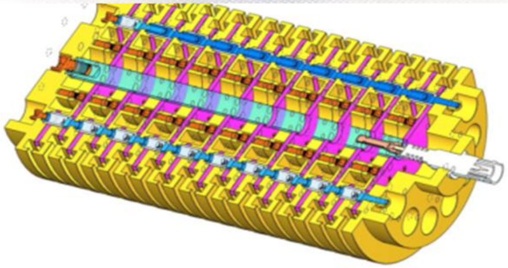
Multi-channel Clock





MOSFET Driver



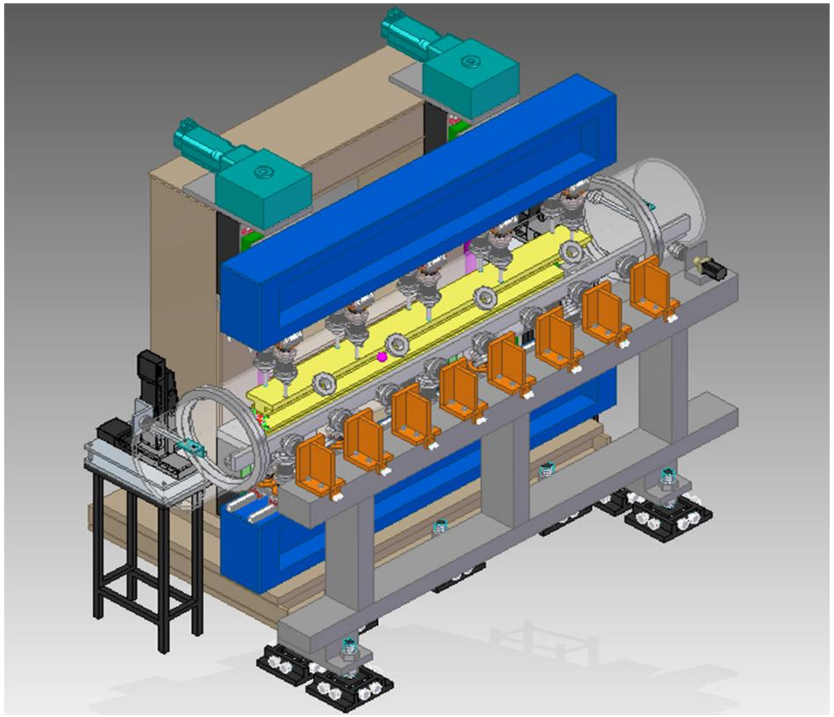


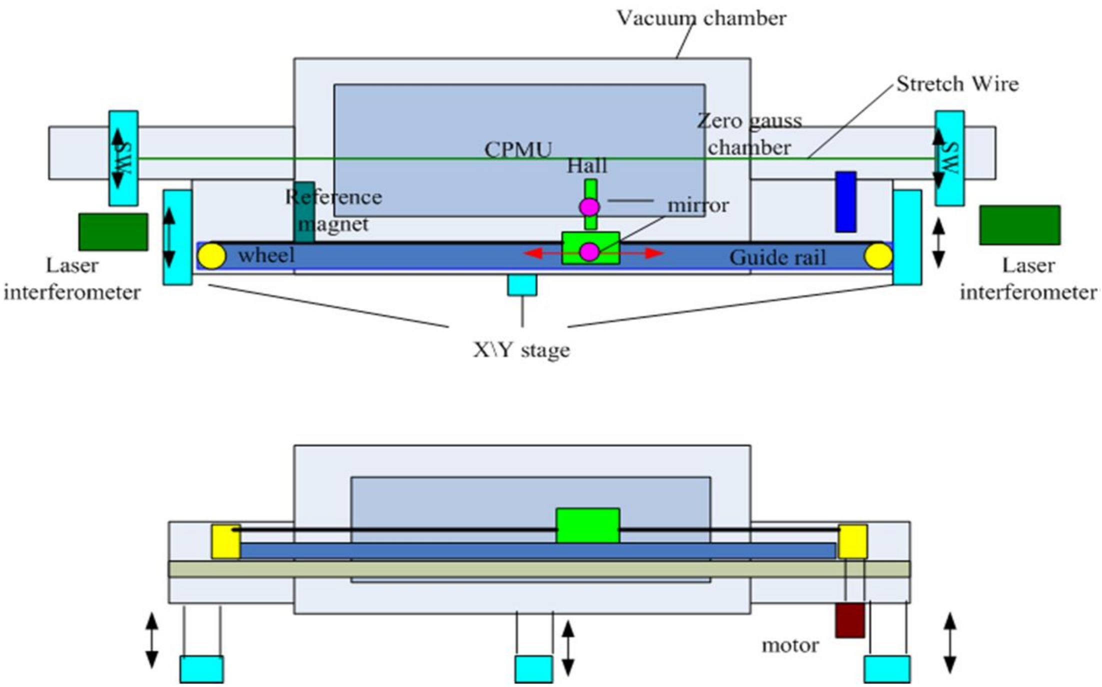
Inductive Adder

The whole system will be integrated and tested in the end of 2011 with the goal of the pulse length <10 ns,1 MHz, ± 5 kV

R&D for HEPS Insertion Device System

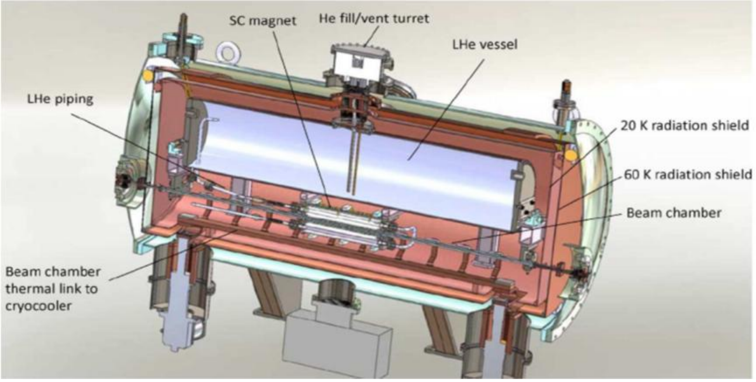
- Development of CPMU Prototype and Measurement Bench





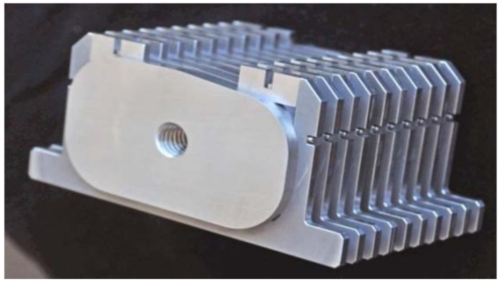
Research on Key Technologies of Small Period Superconducting Damping Wiggler

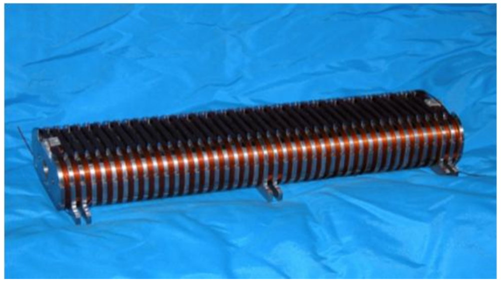
- Engineering Design of Cryomodule



APS, IPAC10, P3198

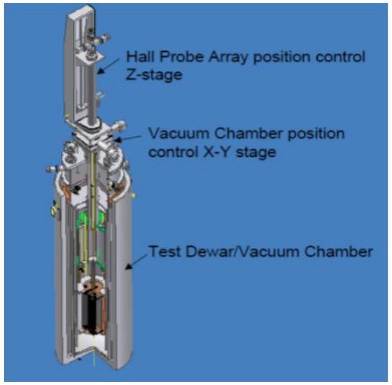
- Development of Magnetic Structure





APS, ANL, Vadim Sajaev report

- Vertical Cryostat for Test



BNL, Workshop on SCU & Wigglers, ESRF, 2003

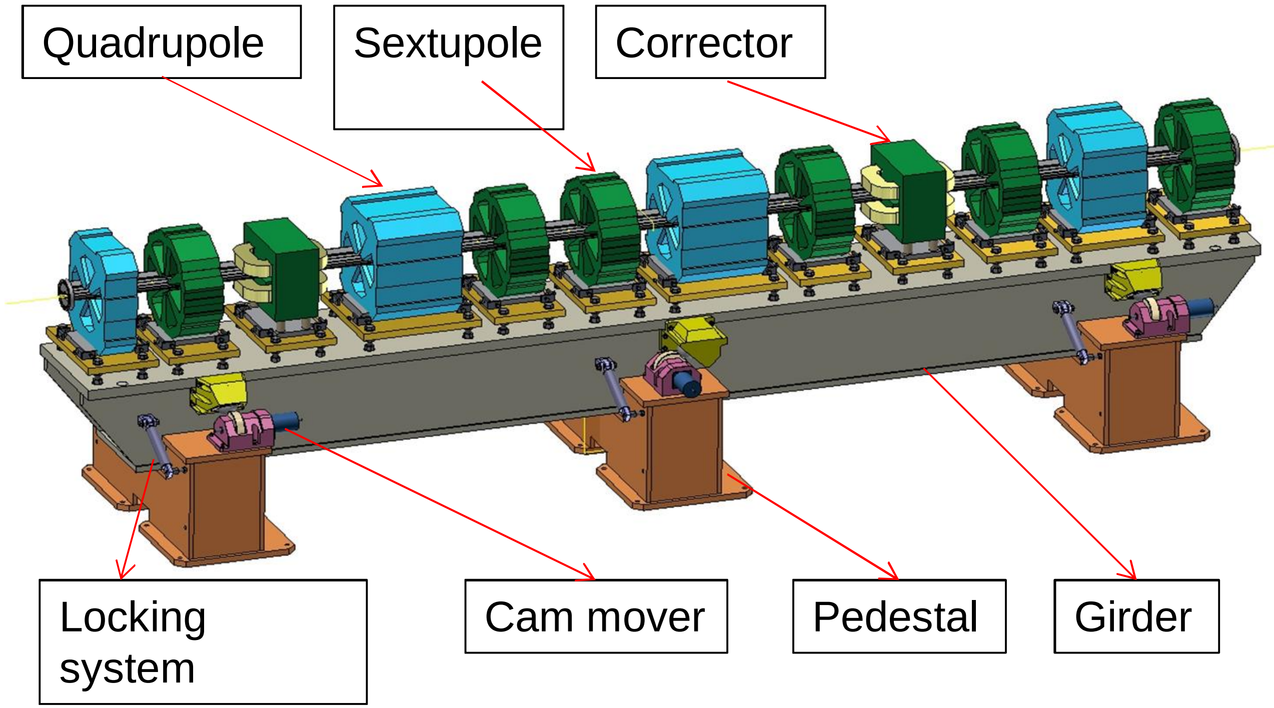
Mechanical & Alignment System

Beam-based girder

- **Design concepts and requirements**
  - **Position and tighten magnets within ±.030 mm of target.**
  - **High natural frequency above 30 Hz.**
  - **Beam-based girder alignment to position girders in storage ring within ±.050 mm**
- **Design Consideration**
  - **Cam mover to adjust girder position automatically.**
  - **6 point support system with automatic locking system to increase natural frequency.**
  - **Vibration damping system to reduce magnet vibrations.**
  - **Magnets can be pre-Aligned by vibration wire method.**

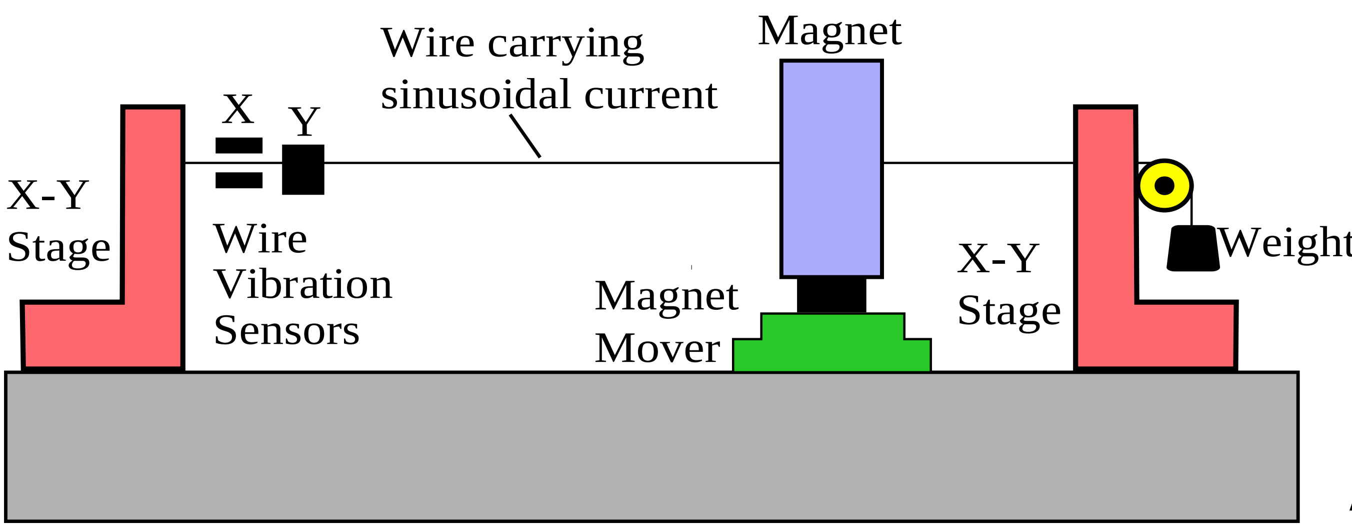
Beam-based girder

- **Design Content:**
  - **Girder body**
  - **Cam mover**
  - **Locking system**
  - **Pedestal**
  - **Sensor system**
  - **others**
- **Testing work:**
  - **Resolution**
  - **Vibration**
  - **Adjustability**
  - **Thermal stability testing**
  - **Control system**



Vibrating Wire Measurement System

- **Based on the accuracy required for locating the magnetic centers, the vibrating wire technique developed at Cornell University will be used.**
- **NSLSII has applied this technique successfully in the alignment of mutipole magnets.**



Vibrating wire technich

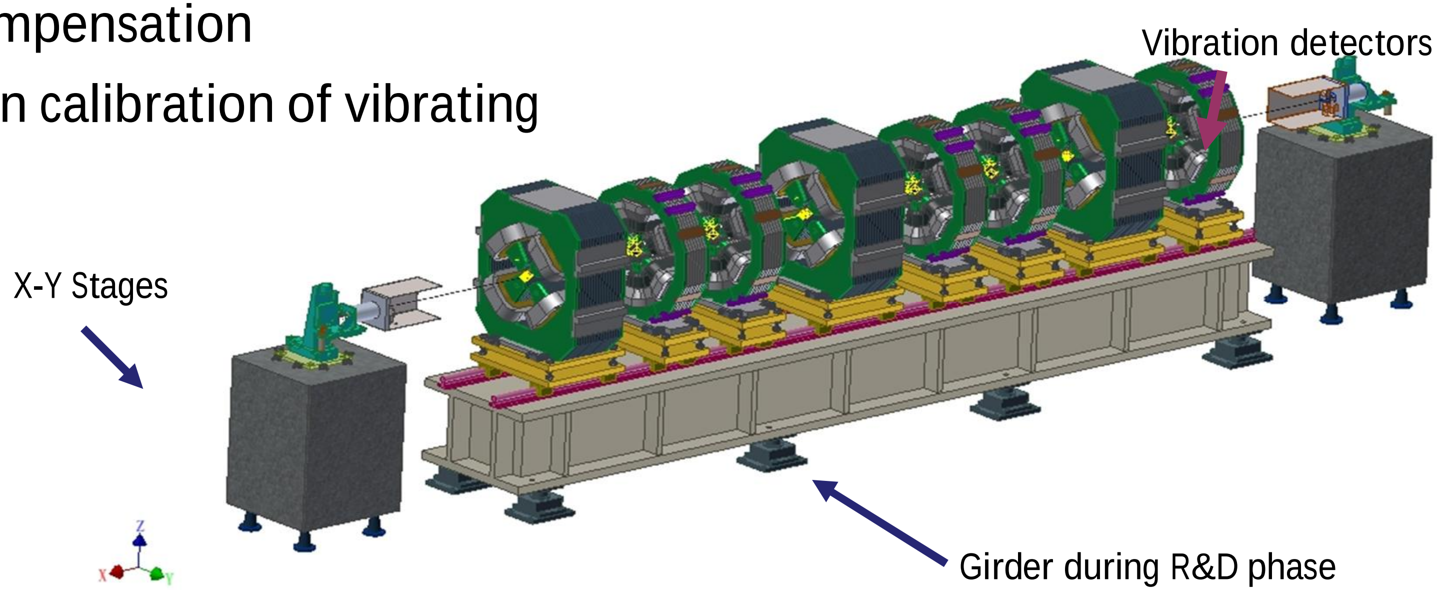
A. Jain
LER2010

Vibrating Wire Measurement System

Temperature controlled environment: **±0.1℃**

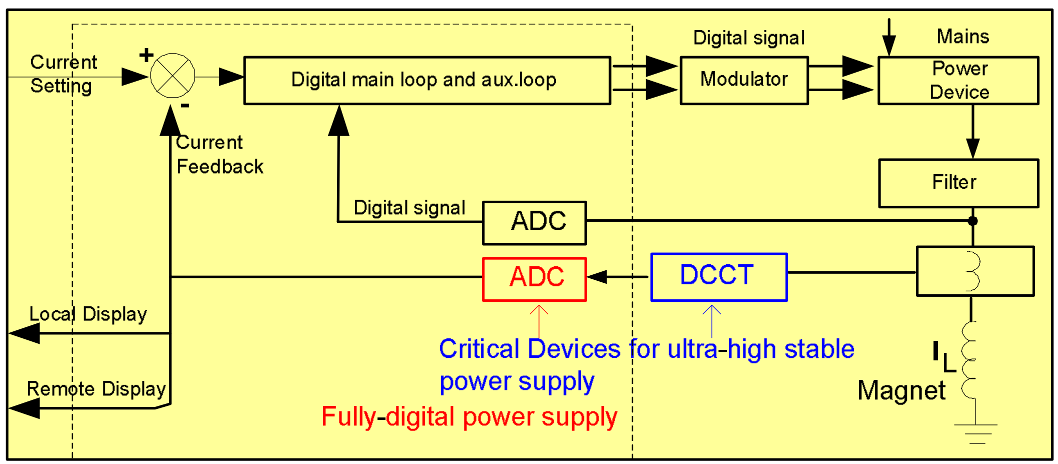
- Vibration wire technique studies:
  - Relationship between vibration amplitudes and magnet position
  - Resonant mode chosen
  - Sag compensation
  - Position calibration of vibrating wire

- High precision achievement
  - Measurement error Control
  - Eliminate disturbed data



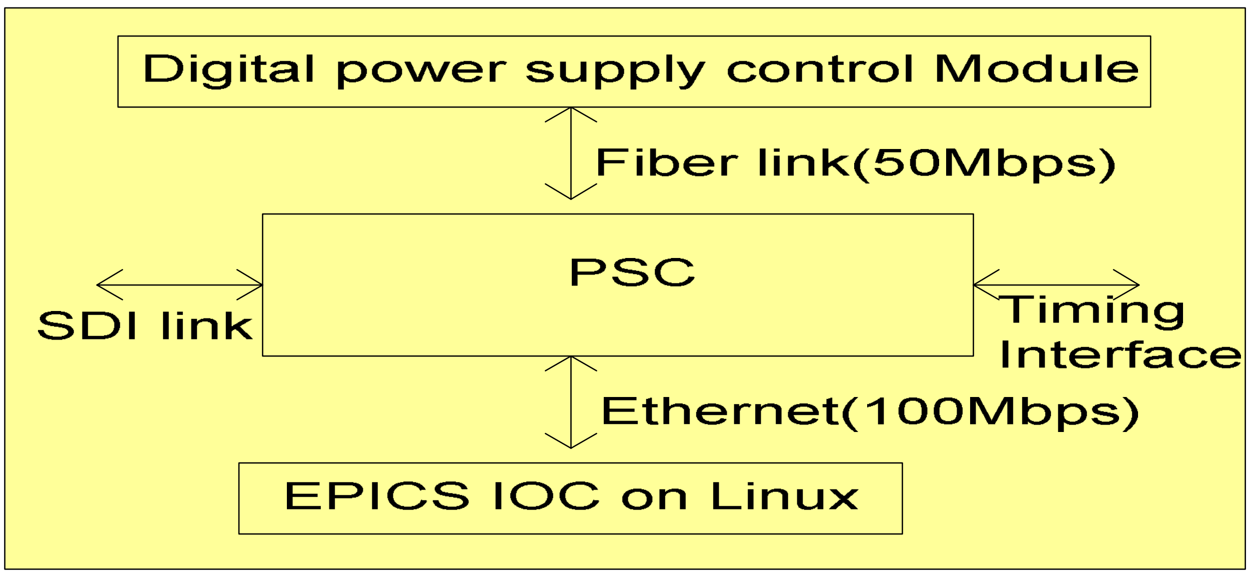
R&D of ultra-high stable power supply

- 10PPM ultra-high stable power supply
  - Stability requirements: an order of magnitude higher than BEPCII power supplies.
  - For fully-digital power supply, application of highly precious and stable ADC is most important.
  - Research on the water-cooling, air-cooling and power room temperature control to ensure 10ppm stability.
  - Following shows the block diagram of BAPS digital power supply.



R&D of fast correction magnet power supply

- Fast correction magnet power supply
  - Remote interface has become a part of digital power supply control module.
  - The current setting should be updated greater than 100KHz.
  - Fast link interface (fiber link, 50Mbps) will be developed for BAPS digital power supply.



Digital BPM electronics

- The beam orbit measurement and control system is very important for accelerator, especially for BAPS. Now many accelerators use digital electronics like as libera brilliance BPM. But it's very expensive, we hope we can make it by ourselves.
- As the first step, we have bought some hardware and done some researches about FPGA algorithm, data processing and data, we hope to realize the function of beam position measurement on the base of commercial hardware.
- Then the second step, to produce digital BPM by ourselves.

Beam size measurement

- The beam size of BAPS is about 3um, the measurement resolution should be less than 0.3um, we plan to take KB mirror to measure the beam size, but we have no experience on this method.

Summary

- BAPS, a 5-GeV advanced light source is being planned in China to meet the increasing demands from SR users
- The BAPS aims to high brilliance with the state of art performance, while keeps the potential of future upgrade.
- The R&D project for BAPS has been approved by the central government, and will start soon. The design of BAPS will be optimized according to the R&D progress.
- There are big challenges in both of accelerator and beamline. Particularly, some key technologies towards USR.
- To meet the challenges, corporations with international community are expected.

Acknowledgement

- Xu Gang kindly provided the slides presented at the LER2013 workshop and the latest result on the lattice design.
- The team of BAPS R&D project provided the corresponding material.

Thank you for you attention!

Prototype magnets for BAPS

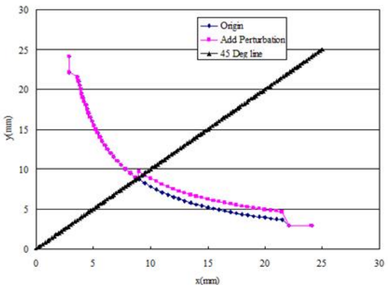
	Unit	Quadrupole/Sextupole combined function magnet	Small aperture quadrupole	Small aperture sextupole
Magnetic length	mm	300	250	200
Bore aperture	mm	48	25	25
Field gradient	T/m	23.4	46.9	-
Sextupole field	T/m^2	292	-	7500
Pole tip field	T	0.646	0.586	0.586
Good field region	mm	± 15	± 10	± 10
GFR/Aperture ratio	%	62.5	80	80
High order multipoles	10^{-4}	1	1	1

The machining error effect

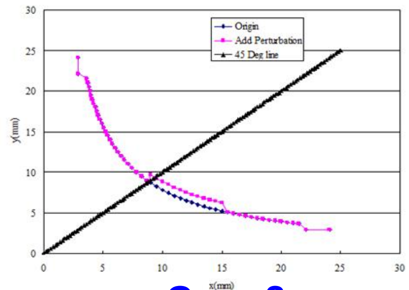
- **The machining error effect for the quadrupole is simulated with following assumptions:**
  - Machining errors occur in the first and the fourth quadrants
  - The poles in the second and the third quadrants keep ideal
  - The model is on the x-axis symmetric
- **The machining error effect for the sextupole is estimated in another way**
  - The model is six-fold symmetric including the profile errors, so only systematic harmonics errors are induced.
  - 10 microns of the deviation nearby the pole tips induces B9 about 2×10^{-4}, and the same deviation on the pole side induces B9 about 1×10^{-4}.

The machining error effect

- **Multipoles caused by machining errors**

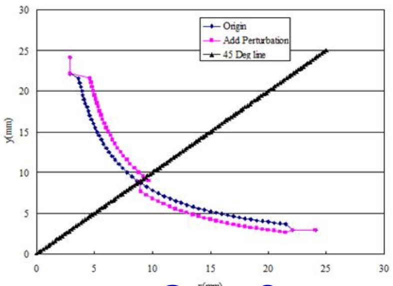


Case 1

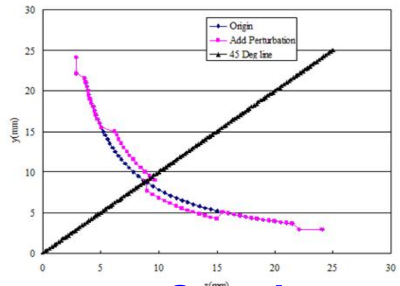


Case 2

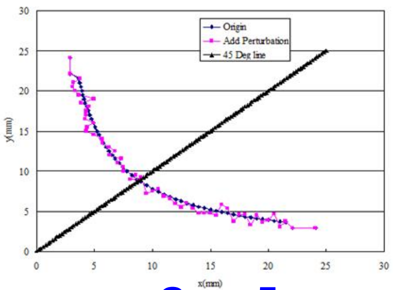
Case	B3/B2	B4/B2	B5/B2	B6/B2
0	0	0	0	1.38
1	4.29	-3.81	2.33	0.80
2	4.03	-3.49	1.99	1.12
3	-6.90	7.63	-3.35	1.37
4	-5.36	7.00	-3.86	1.38
5	-1.10	1.20	-1.01	1.71
6	0.2	-0.01	-0.14	1.38
7	-2.94	0.001	-0.15	1.37



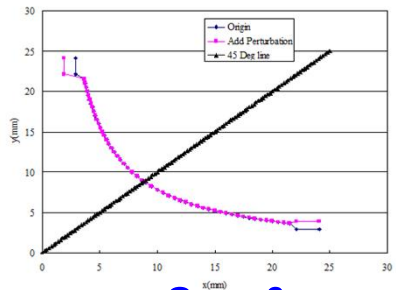
Case 3



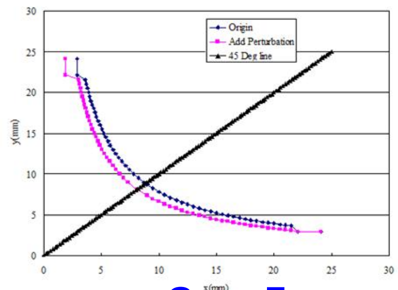
Case 4



Case 5



Case 6



Case 7

The main multipoles @r=10mm caused by 10 microns of pole profile errors for the quadrupole magnet (Unit: 10^{-4})

Quadrupole/Sextupole combined function magnet design

- **2D design with POISSON**
  - **The equipotential equation with quadrupole and sextupole component is used to compute the pole profile.**