HZB BESSY II Light Source

PM BASED ACCELERATOR MAGNETS FOR NEXT GENERATION SYNCHROTRON LIGHT SOURCES

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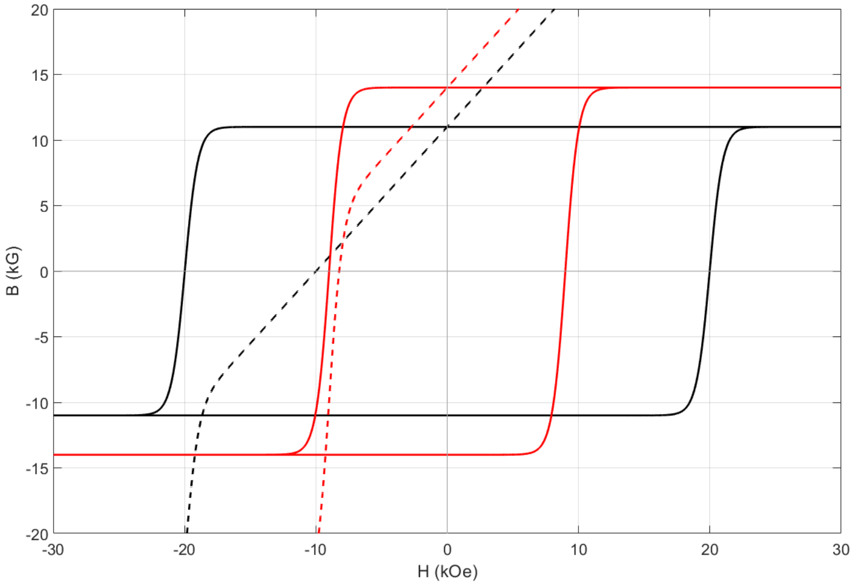
6th February 2023 - DESY

HZB BESSY II Light Source

-> Examples for existing and planed accelerator projects

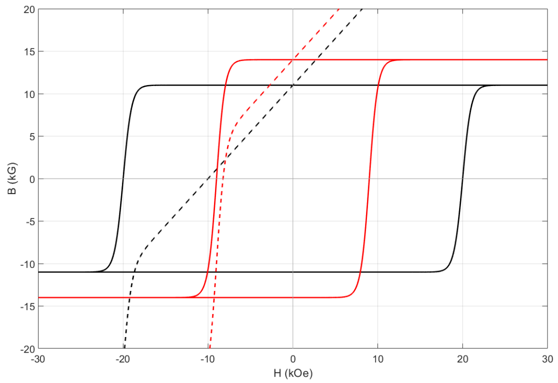
-> BESSY II+ and BESSY III

Permanent Magnets

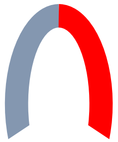


- different types of materials and properties (examples)
  - -> Neodymium-Iron-Boron (NdFeB)
  - -> Samarium Cobalt (SmCo)
  - -> Iron with Aluminum-Nickel-Cobalt (AlNiCo)

Material	B_r (T)	H_c (kA/m)	energy product (kJ/m^3)	T_C (°C)	α_{Br} (%/°C)	α_{Hc} (%/°C)
NdFeB	1.00 … 1.49	800…1040	230 … 430	100 … 300	-0.12	-0.75
SmCo	1.17 … 1.19	860…880	255…265	820	-0.035	-0.25
AlNiCo	0.50 … 1.30	38…83	10…150	700-800	<-0.2	-

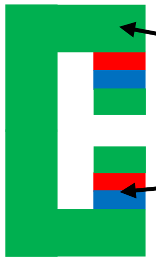


PM



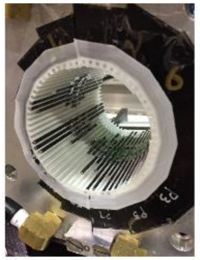
pure PM designs (Hallbach)

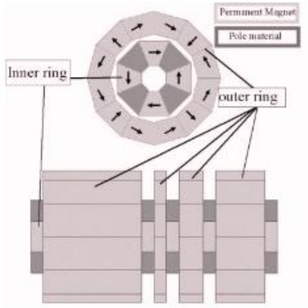
Hybrid Magnets

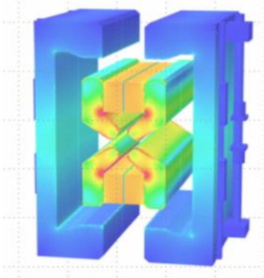


Ferromagnetic Material (yoke)

PMs







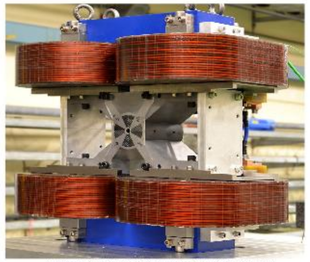
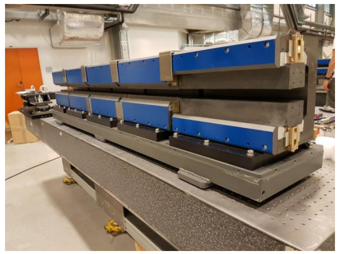
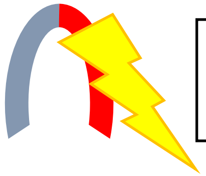


Figure 5: The fully assembled prototype

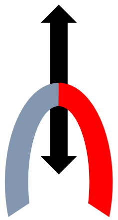




electrically adjustable designs

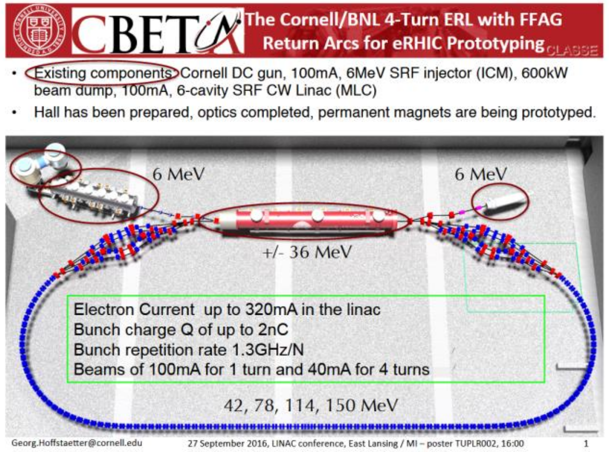
and/or

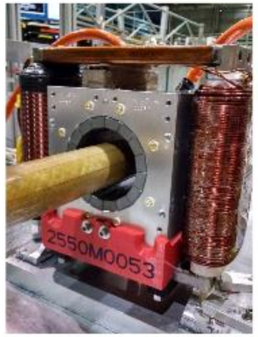
mechanically adjustable* designs



CBETA (USA)

- Multiturn ERL with a Fixed Field Alternating Gradiet Lattice
- 7 beams with four different energys in a single beamline





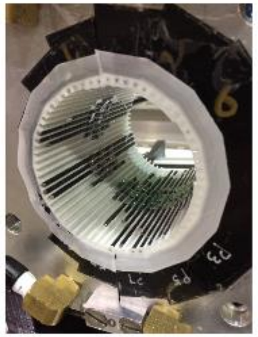
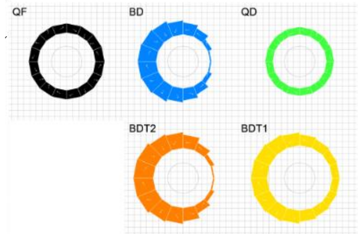


Table 1: Magnet Specifications

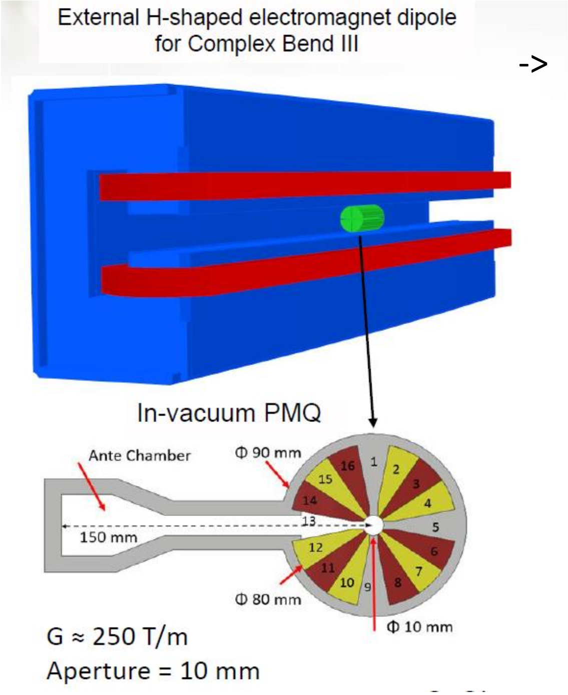
Magnet type	Count	Dipole (T)	Gradient (T/m)	Length (mm)	Aperture radius (mm)	Good field radius (mm)
QF	107	0	-11.5624	133	43.1	25
BD	32	-0.3081	11.1475	122	40.1	25
BDT2	20	-0.2543	11.1475	122	44.938	25
BDT1	28	-0.1002	11.1475	122	49.085	25
QD	27	0	11.1434	122	40.1	25
QFH	1	0	-11.5624	66.5	43.1	25
BDH	1	-0.3081	11.1475	61	40.1	25



Sum: 216 magnets -> **ca. 0.17m³ NdFeB**

NSLSII (USA)

- 3 GeV SLS (30 arcs - DBA)
- 790m circumference
- Upgrade NSLS-CB
- Halbach QP structures installed in the gap of an electro dipole (complex bend)
- QP gradients up to 250T/m + 0.49T (dipole)

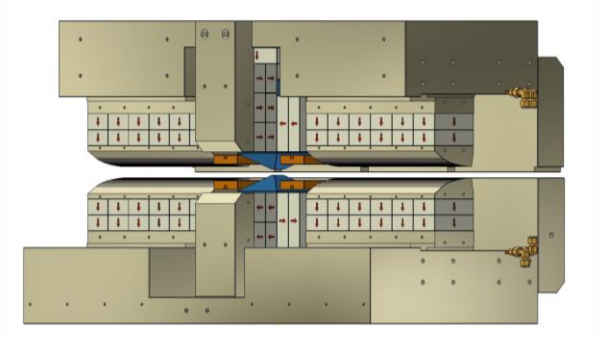


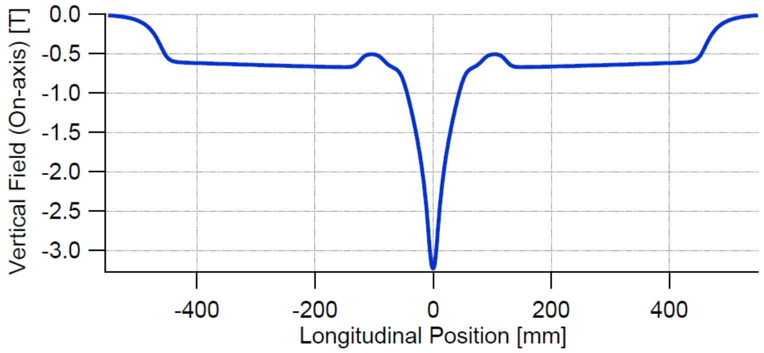
-> 60 bends à 3.1m length + 90mm diamater Hallbach PM structure

In total: **ca. 0.7m³ NdFeB**

Sirius (LNLS - Brazil)

- 3 GeV (20 x 5BA)
- 518m circumference
- 20 PM Super-Bends with 3.2 T peak field

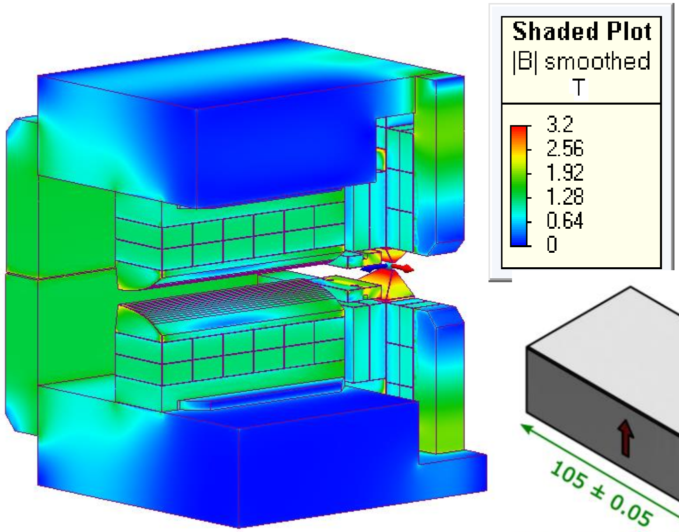


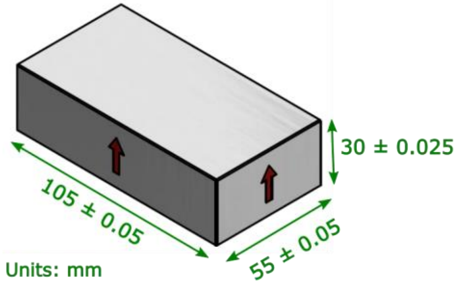


Permanent Magnets	
Material	NdFeB
Remanent Field	1.36 T
Hcj	> 1590 kA/m
Block weight	1.3 kg
Number of magnets per dipole	96

In total: **ca. 0.33m³ NdFeB**

Dipole Design Parameters	
Maximum Field	3.2 T
Critical Photon Energy	19 keV
Angular Deflection	4.3°
Length	0.913 m
Integrated Field	-0.75 T.m
Integrated Gradient	6.25 T
High Field Gap	10.2 mm
Low Field Gap	30.7 mm





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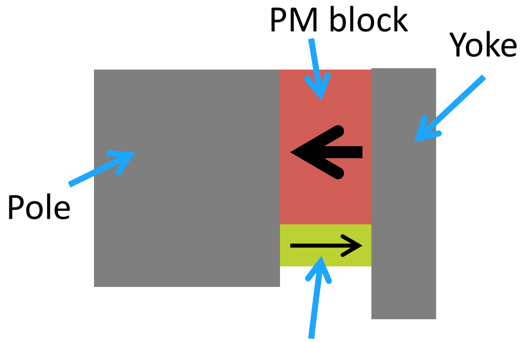
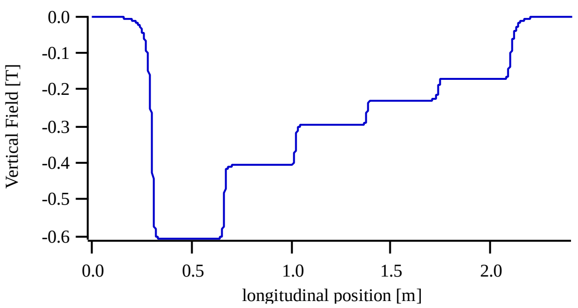
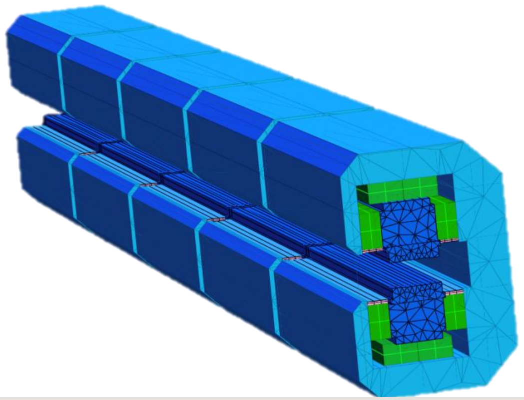
ESRF (France)

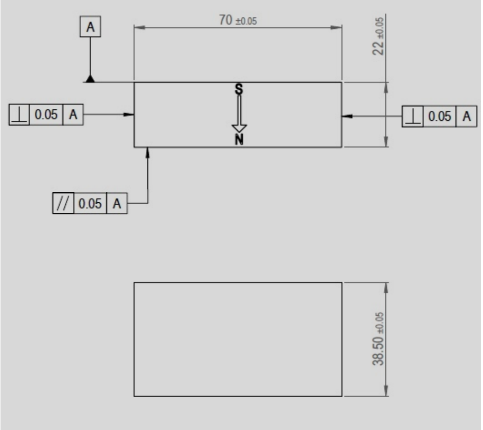
- 6 GeV (32 x 4BA)
- 844m circumference
- Upgrade 2018-2020 PM dipols
- Each dipole consists of five blocks with up to 30 PMs



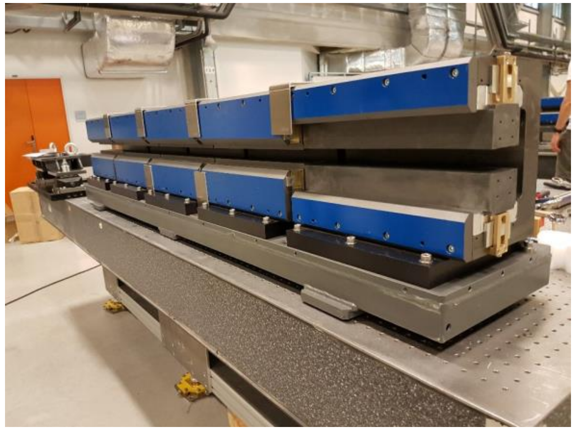
Special Fe-Ni shunt (low Curie temperature)
THERMOFLUX (VACUUMSCHMELZE)

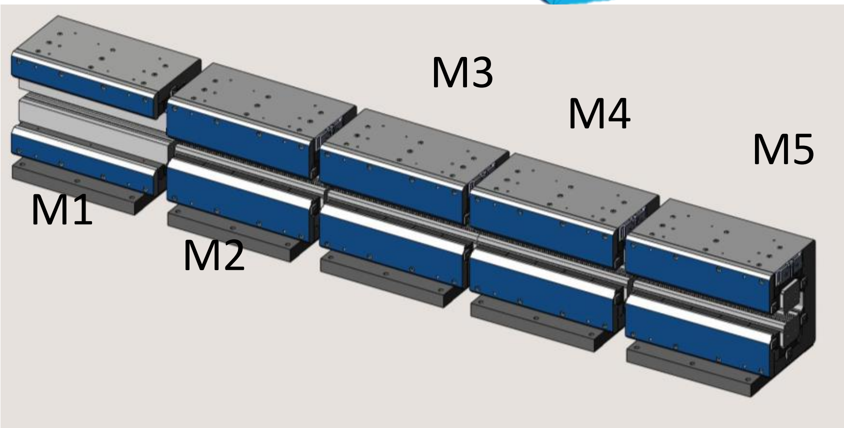






Dipole		
Gap	mm	25.5 – 30.5
Iron length	mm	1788
Permanent magnet		Sm_2Co_{17}
Iron		Pure iron
Number of dipoles		128





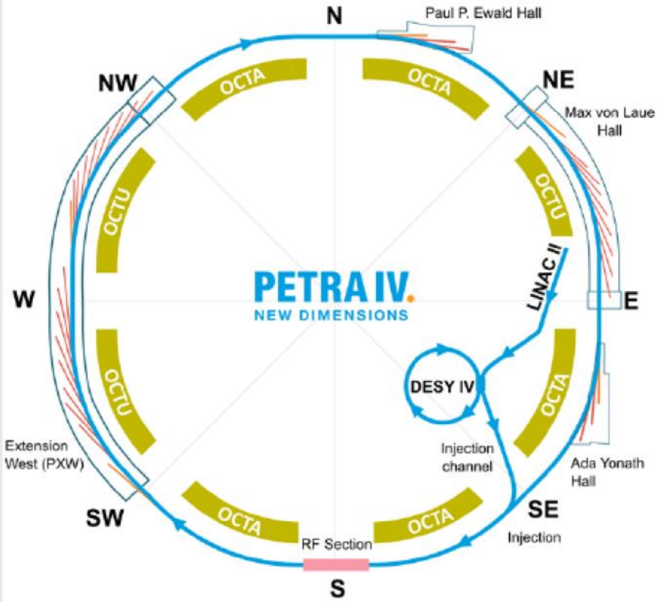
Permanent magnet procurement

- Around 6000 kg of permanent magnet (15130 blocks)
- Procuded by Magsound (China)
- Sorting of magnets before delivery
- Magnet delivered in two batches

In total: **ca. 0.9m³ SmCo**

PETRA IV (Germany)

- 6 GeV (72 x 6BA)
- 2304m circumference
- Reconstruction prgram of PETRA III (start 2027)
- Combined function bend consisting of PM (similar to ESRF)
- Options for extrem strong QP magnets based on PMs
- In total: **ca 0.9 – 1 m³ SmCo**



Based on H6BA cell – 8 octants with 9 cells each

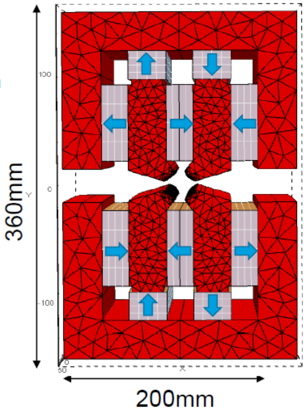
Strongly favored as the present PIII-beamlines can be conserved

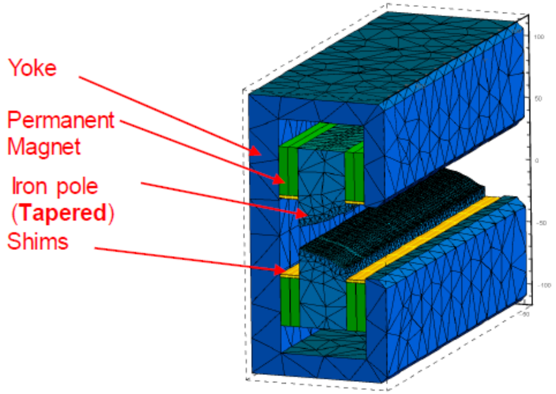
	PETRA IV
Lattice	H6BA
Energy (GeV)	6
Horizontal emittance (pm rad)	<20
Circumference (m)	2304

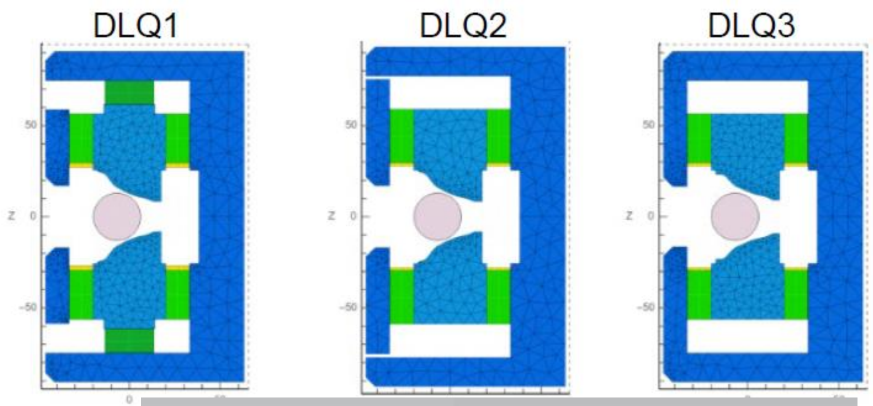
Specification for Petra IV PMQ

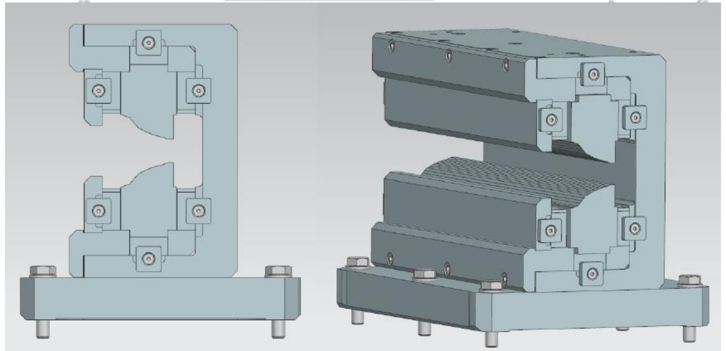
- Gradient: 120 T/m
- Gradient tuning: ~5 T/m
- Bore Radius: 11 mm
- GFR: +-6.5 mm
- DG/G0: 5.10^-4
- Length: 0.169 m
- Vertical gap: 8.8mm

Radia model









HZB BESSY II Light Source

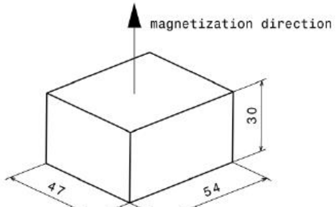
SLS 2.0 (Switzerland)

- 2.7 GeV (12 x 7BA)
- 288m circumference
- Reconstruction program of SLS (magnet delivery end of 2023)
- Combined function bends, QP and super bend based on NdFeB
- In total: **> 2m³ NbFeB**

Permanent Magnets

BN	56	Dipole
VB	96	Quad
VBX	24	Quad
AN	120	Quad
ANM	24	Quad
BE	24	Dipole
VE	24	Quad
2T BS	4	Dipole

Total : 372



- 1 block size for all magnet types: 30 mm x 47 mm x 54 mm
- Rare earth : $\mathbf{Nd_2Fe_{14}B}$ (Remanent field B_r: ~1.35 T @ 20°C)
- Weight : 0.57 kg
- Coercive field : 1015 kA/m
- Temperature dependence : -0.12 %/°C (thermal stabilization needed)

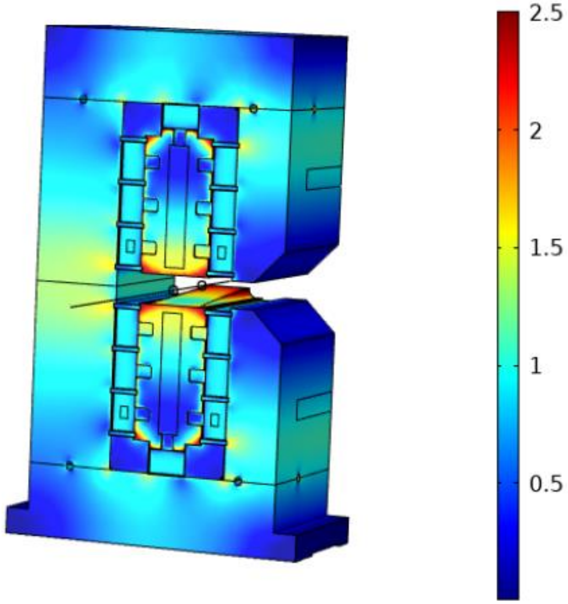
We need about 34 000 blocks
16.6 Tons

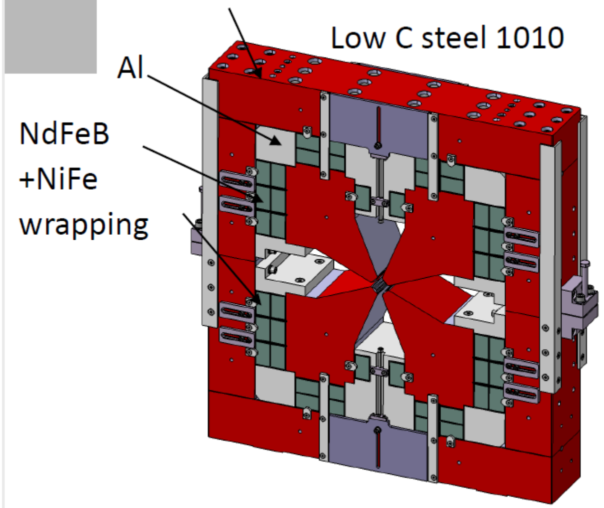
SLS2.0 Triplet = VB-BN-VB

Total number of triplets: 60

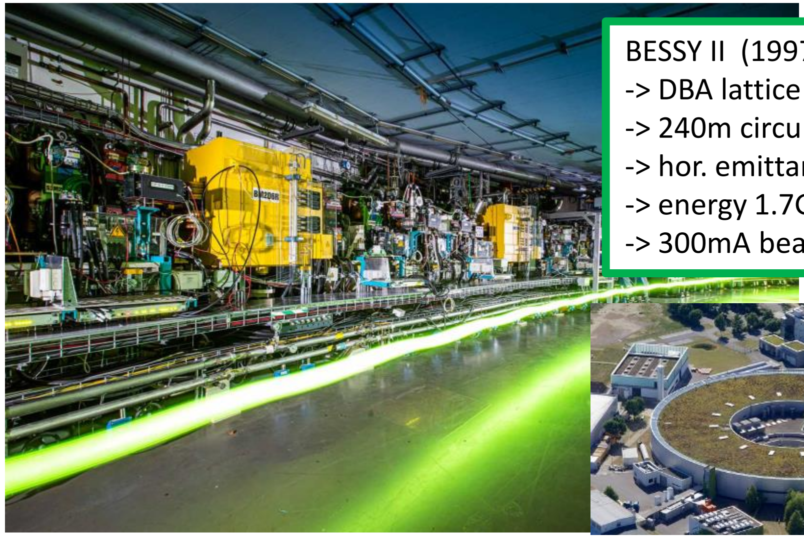
BN: By=1.35 T; VB: GdL=-40.64 T/m

Total Weight=900 kg

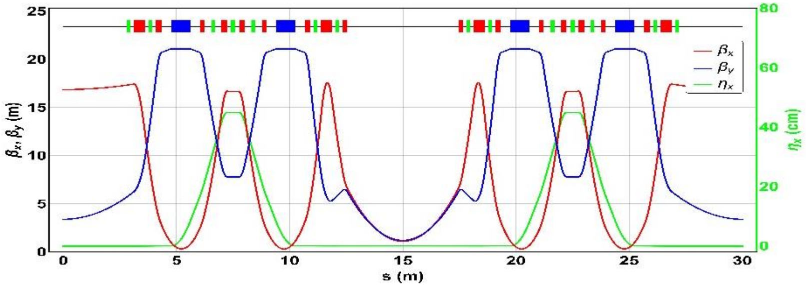


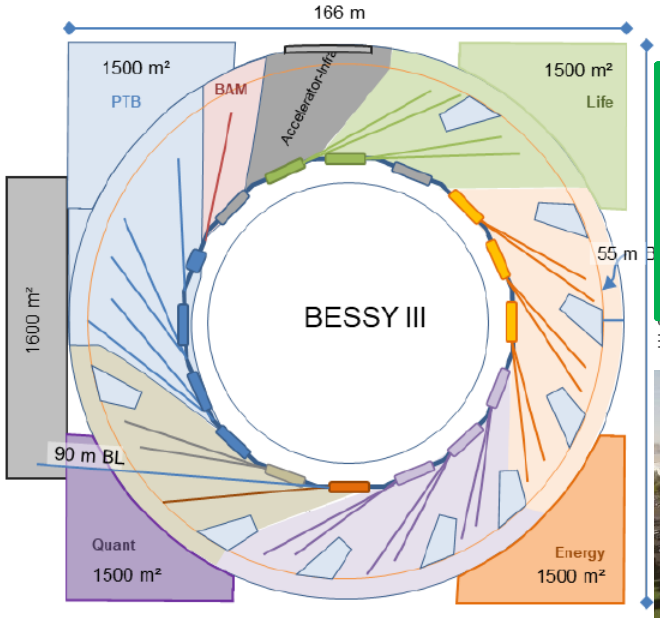


BESSYII+ and BESSYIII

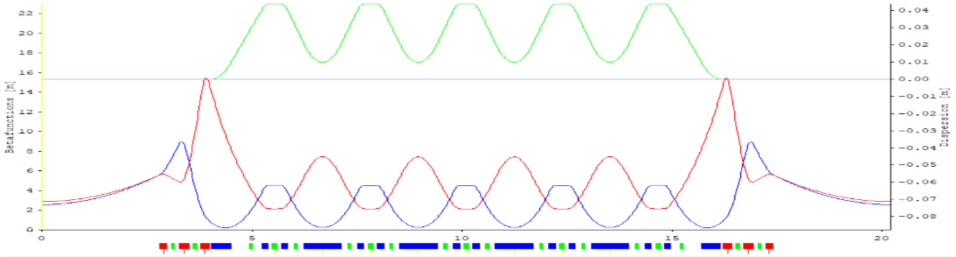


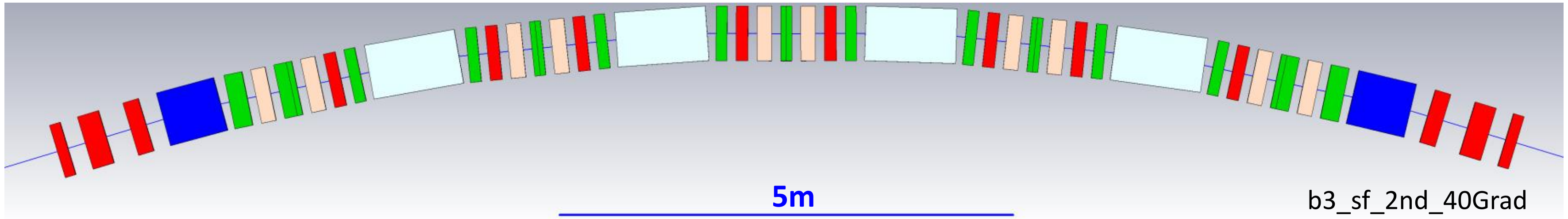
BESSY II (1997)
-> DBA lattice (16 arcs)
-> 240m circumferance
-> hor. emittance ~1nmrad
-> energy 1.7GeV
-> 300mA beam current



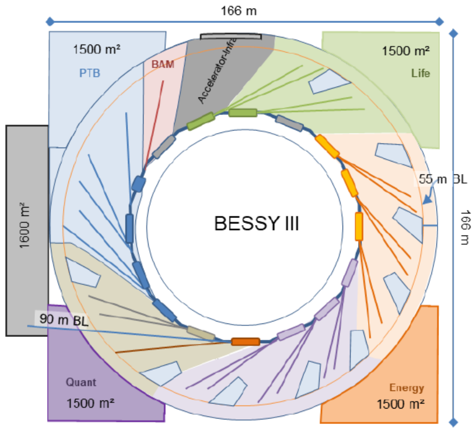


BESSY III (2035)
-> MBA (6BA) lattice (16 arcs)
-> ~340m circumferance
-> hor. emittance <100pmrad
-> energy 2.5GeV
-> up to 500mA beam current

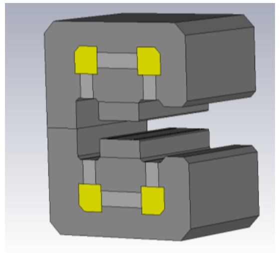
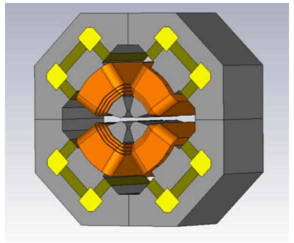
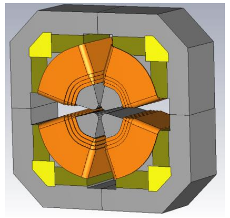
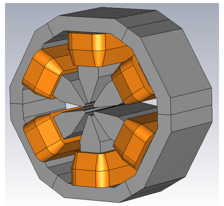




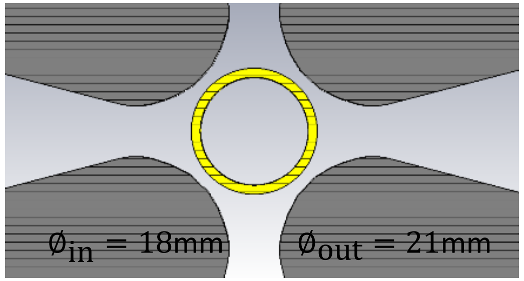
Quadrupoles | Transverse gradient bends | Homogenous bends | Reverse bends | Sextupoles

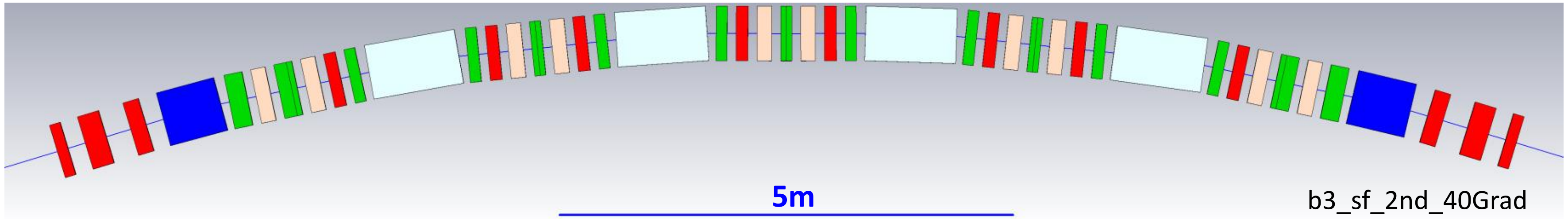


	Dipole	Quadrupole	Reverse Bends	Sextupole
Field/gradient (def. Limits)	0.6-0.8 T (1.3 T)	50-80 T/m (80 T/m)	80 T/m and (0.18-0.22) T (30 T/m and 0.8 T)	<4000 T/m² (4000 T/m²)
Quality	$0.1 \cdot 10^{-4}$	$\sim 1 \cdot 10^{-4}$	$\sim 1 \cdot 10^{-4}$	tbd
Stability	$<1 \cdot 10^{-4}$			
Variation	-	10%	5%	100%
Power consumption (PM / elctro)	**0 kW / 290 kW**	**<67 kW / 317 kW**		**124 kW**

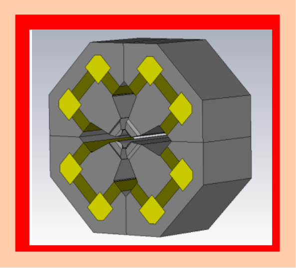





min. aperture radius for all magnets: 12.5mm

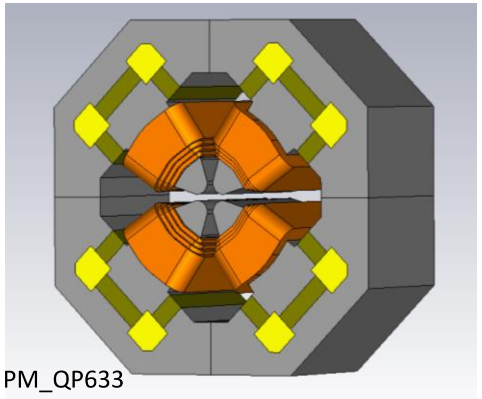


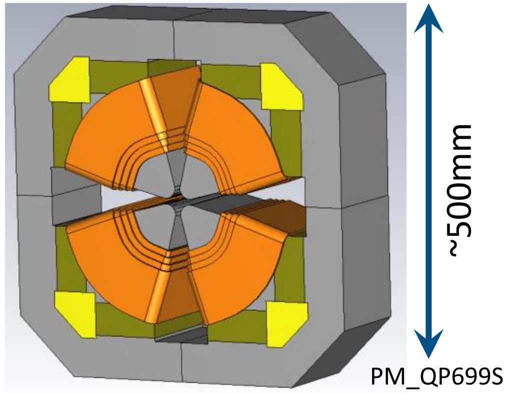


Quadrupoles | Transverse gradient bends | Homogenous bends | Reverse bends | Sextupoles



Variable Permanent Hybrid Magnets





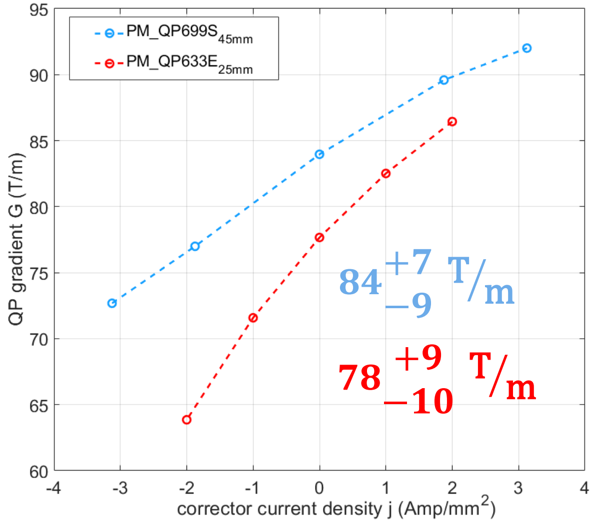
Parameter	PM_QP633	PM_QP699S
Yoke Length	160mm	
Yoke dimension	500x500mm^2	520x520mm^2
Bor Diameter	25mm	
PM thickness	25mm	35mm
PMs per layer	16	
Nominal gradient	78 T/m	84 T/m
Coil thickness	20mm	12mm
Max. power per magnet	**200W**	**240W**

-> PM based Quadrupole or Dipole magnets

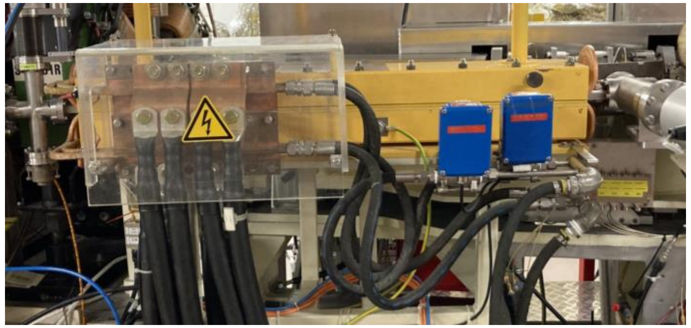
-> **10 mm – 20 mm thick corrector coils**
(air convection cooled)

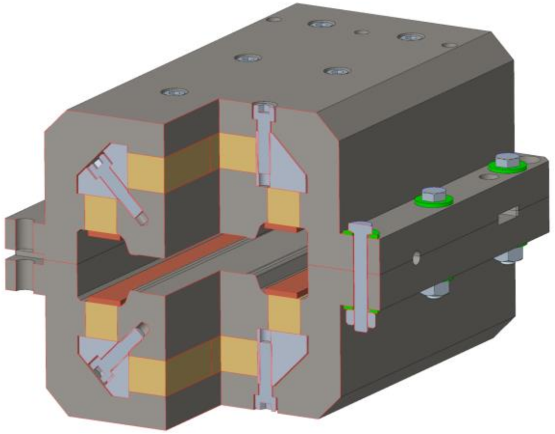
-> current densities **< 2.5A/mm²**

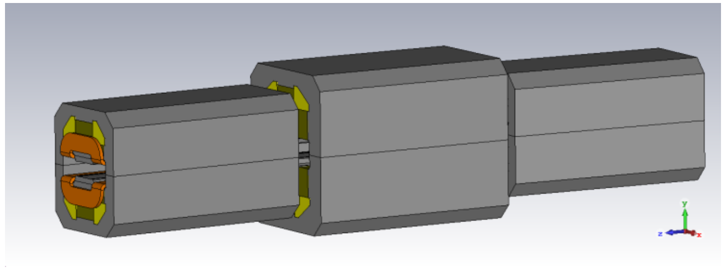
-> gradient variation up to **10% of design value**

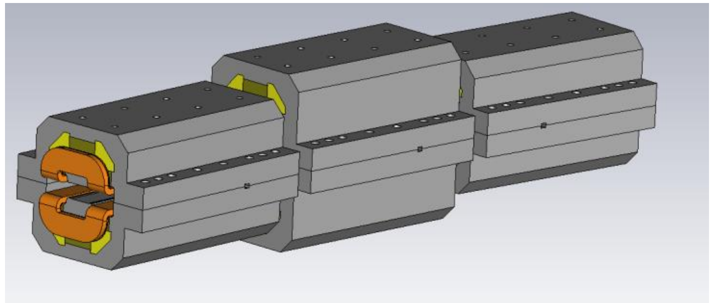


VPHM will be used for B2PT@BESSYII
(last dipole magnet in transfer line):
$P_{el} \cong 60$ kW $\sim$ **0.42 GWh / year**

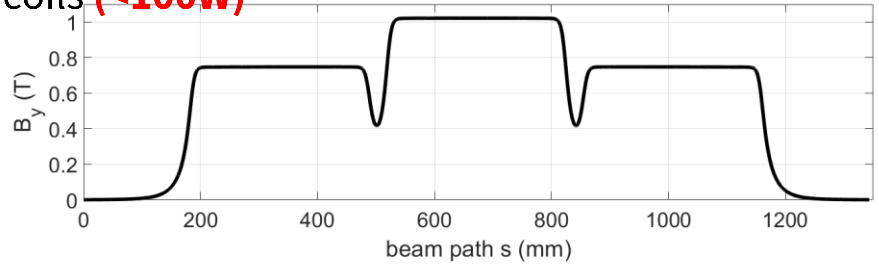


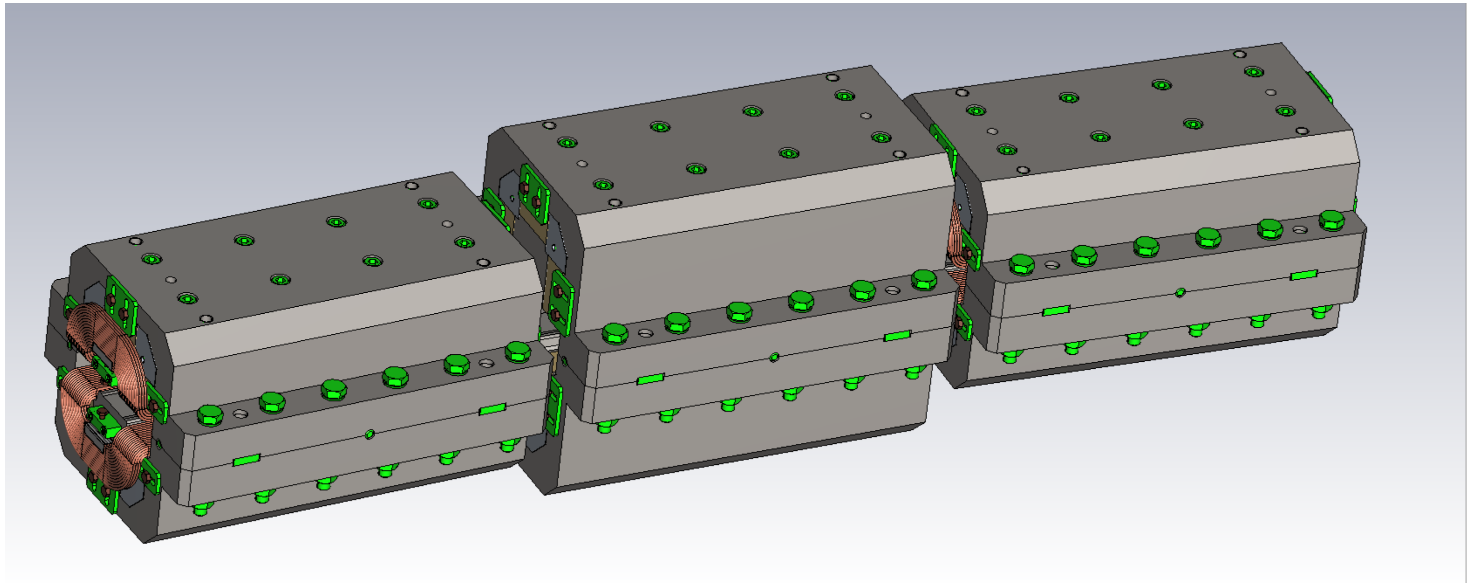






New Magnet design (BESSYII+)
3 homogen. Bends + 2 corrector coils **(<100W)**

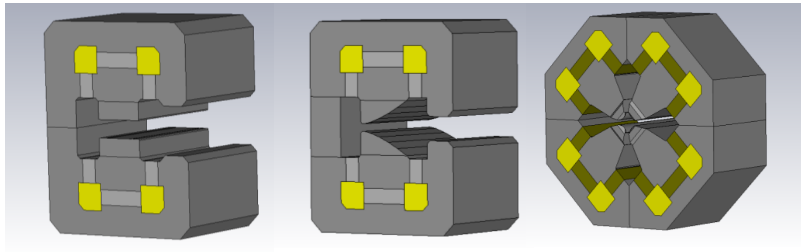




-> General PM bridge design based of NdFeB magnet blocks

-> Electric power consumption of the magnets in BESSYIII storage ring can be reduced down to 20%

	Conservative (electro) Magnets	**Permanent Magnets (VPHM)**
Bends (96)	290 kW	0 kW
Quadrupoles (224) + Reverse Bends (160)	317 kW	< 67 kW
Sextupoles (240)	124 kW	124 kW
Total* (720)	**731 kW**	**< 191 kW**
7000 operation hours /year	**5.12 GWh / year**	**< 1.34 GWh/ year**

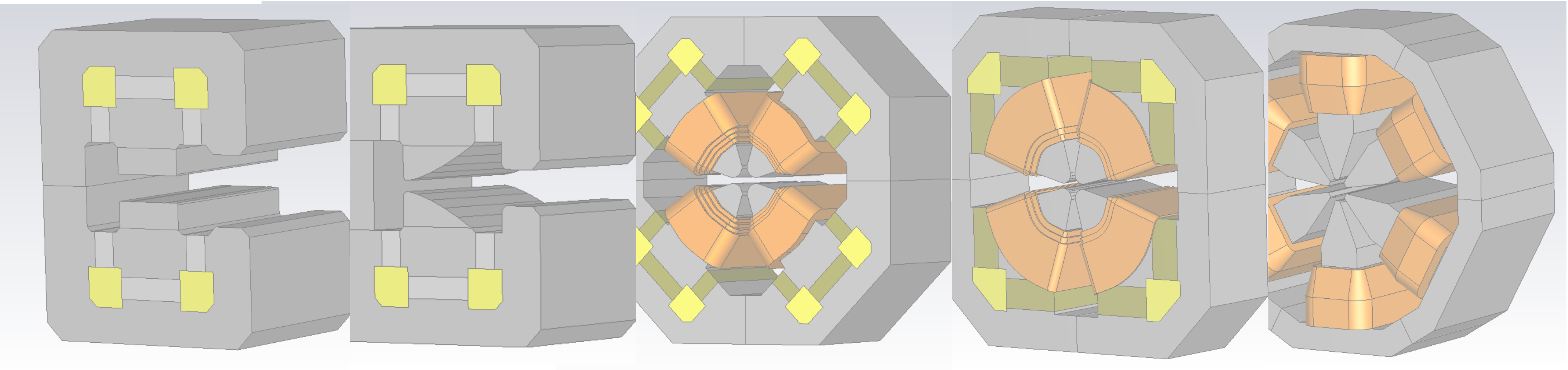


Goal: operating BESSYIII with the same or **less energy requirements** as BESSYII

-> **More stable beam operation: less/no** current ripple and less vibration (no cooling water)
-> longterm Temp. drift must reduced (**passive thermal compensation**)

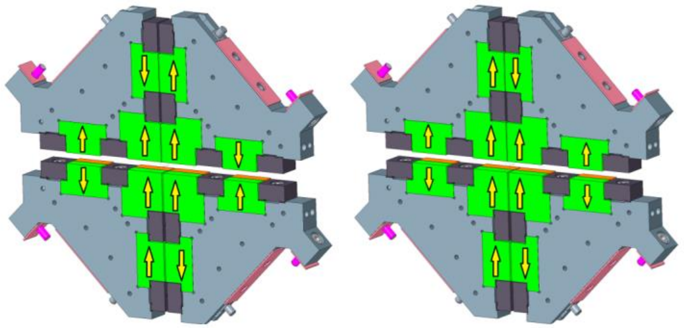
-> PM based magnets will be tested in BESSYII+
-> injector magnets (2024) and (super-)bends in storage ring
(running up to 2035 – start of BESSYIII)

In total:
ca. 2.0 m^3 NdFeB
+ca. 0.5m^3 for undulators

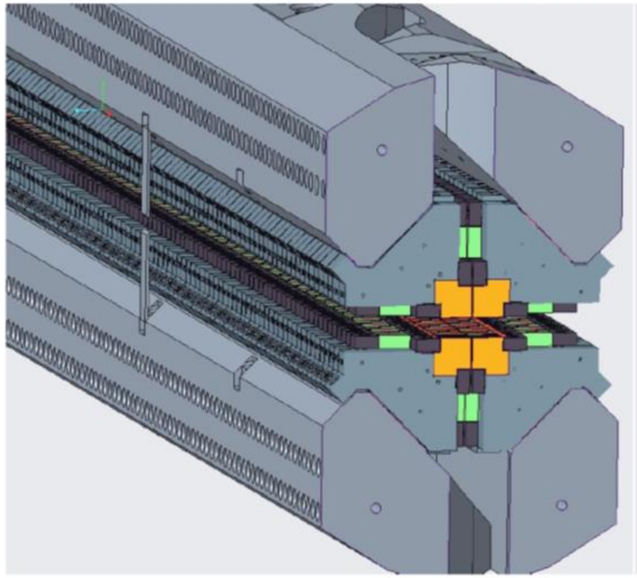


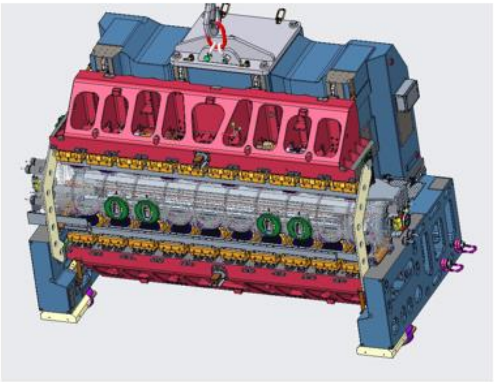
Thank you.

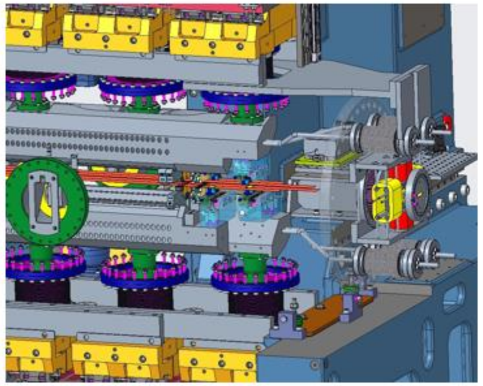
Partners: ALBA DESY. PAUL SCHERRER INSTITUT PSI PerMaLIC



Force compensation
J. Bahrdt, S. Grimmer, SRI 2018, Taipeh, Taiwan



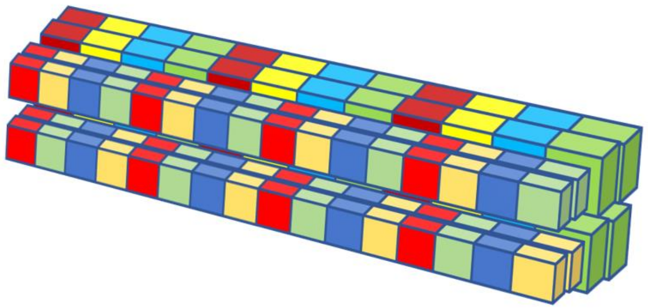


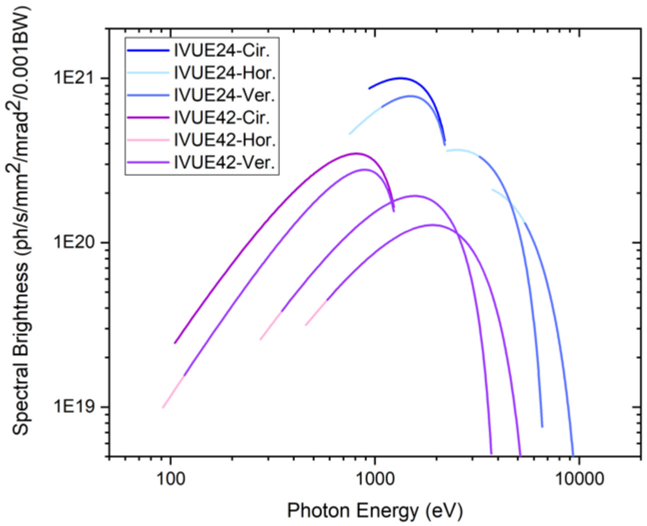


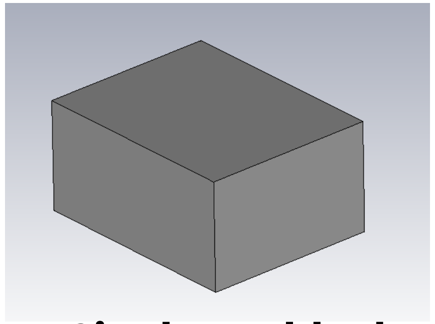
- Development of an **In-Vacuum APPLE II Undulator (IVUE32).**

Proposal

Double Period Undulator (DoPU).



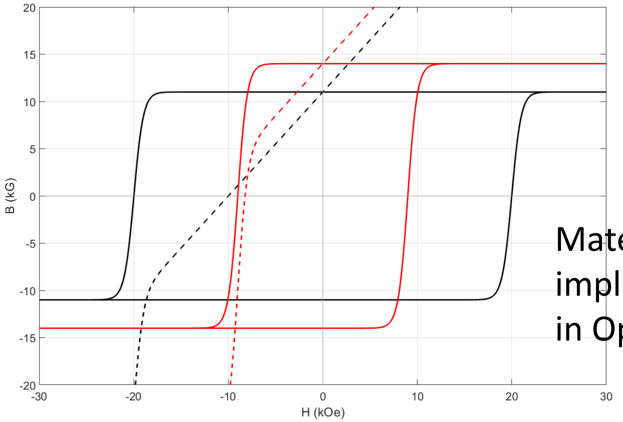




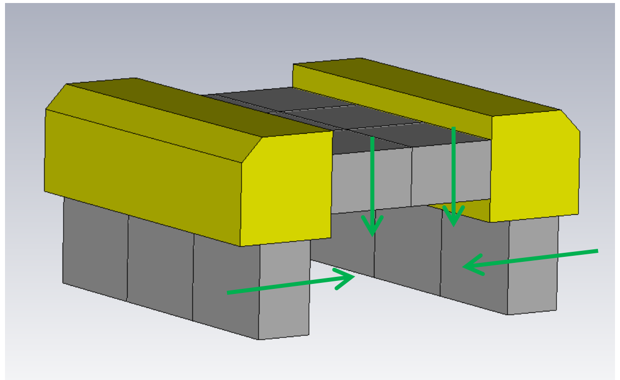
Single PM block

(e.g. 50 x 40 x 25 mm^3)

Magnet	NdFeB
B_r (T)	**1.2-1.4**
H_c (kA/m)	**800-1000**
T_C (°C)	80-150
ΔF/T (%/K)	~-0.1

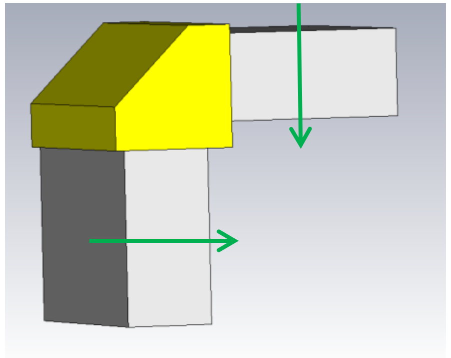


Material data implemented in Opera+CST

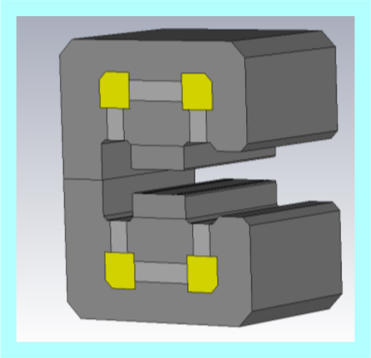


General PM bridge design

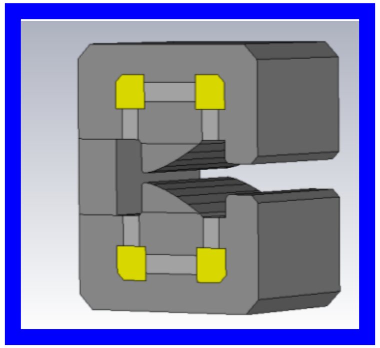
PM blocks and aluminum spacer between Yoke and Pole finger

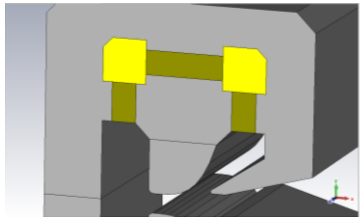


Magnetic fields are 3D calculated via Opera and CST (Ansys was also tested)

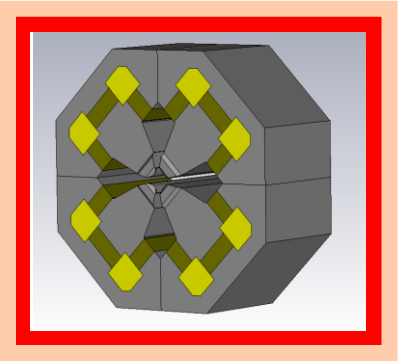


homogen. bend / TGB (2 poles)

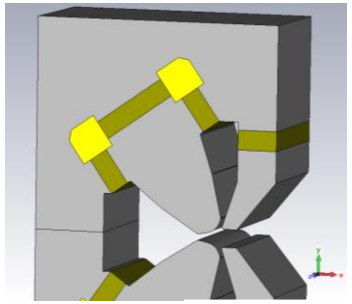




Combined function bend (4 poles)

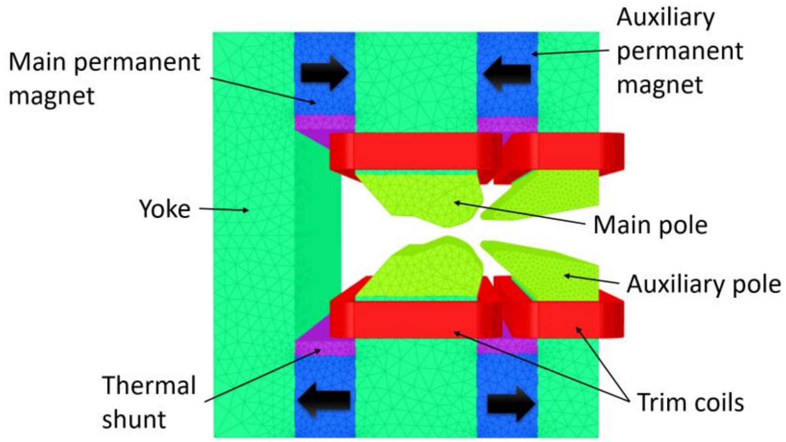


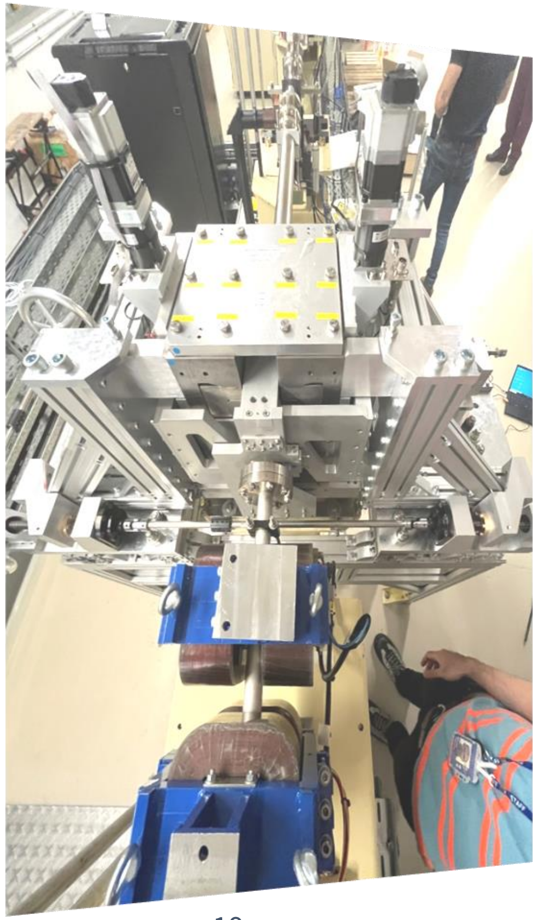
QP (+ off-axis)

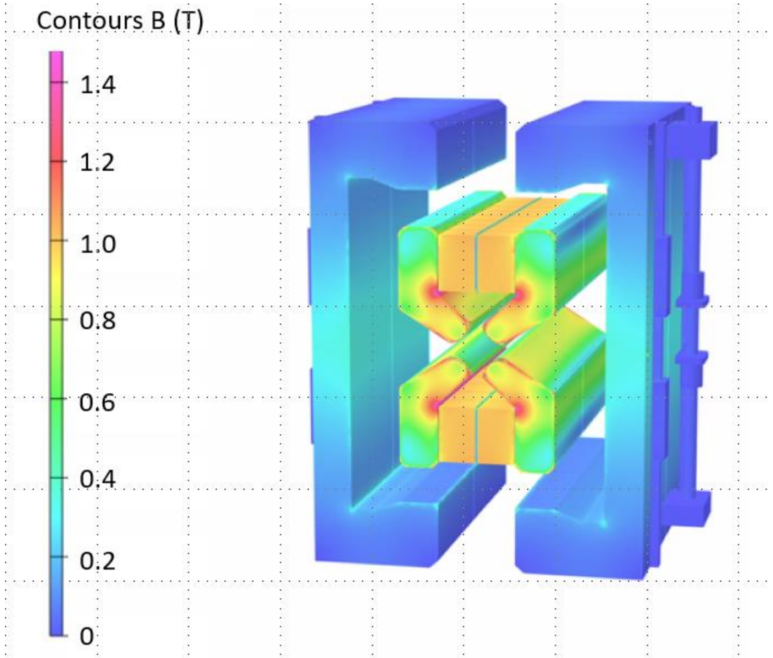


asym. QP

ZEPTO @ Diamond Light Source







References:

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"CBETA Permanent Magnet Production Run", S. Brooks, (DOI:10.18429/JACoW-IPAC2019-THPTS088)

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"Permanent Magnet Dipoles (DLs) for EBS-ESRF", C. BENABDERRAHMANE, (1st PerMaLIC workshop – 22nd September 2021)

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"Sirius "Superbend": design, construction, installation and tests", James Citadini, PerMaLIC Talk June 09, 2022

"Permanent Magnet Dipoles (DLs) for EBS-ESRF", C. Benabderrahmane, (1st PerMaLIC workshop – 22nd September 2021)

"Status of the PM-based Combined-Function Dipoles for PETRA-IV" , M. Tischer(2nd PerMaLIC workshop – 3rd November 2022)

"Development of High Gradient Hybrid PMQ for Petra-IV" , MP. N'gotta (2nd PerMaLIC workshop – 3rd November 2022)

"Permanent Magnets program for PETRA IV " , O. Lahyaoui (1st PerMaLIC workshop – 22nd September 2021)

"Permanent Magnets for SLS2.0" , C. Calclaio (1st PerMaLIC workshop – 22nd September 2021)

"SLS2.0 Magnets" , S. Sanfilippo (2st PerMaLIC workshop –03rd November 2022)

"Permanent Magnets at STFC" , B. Shepherd (2nd PerMaLIC workshop – 3rd November 2022)