

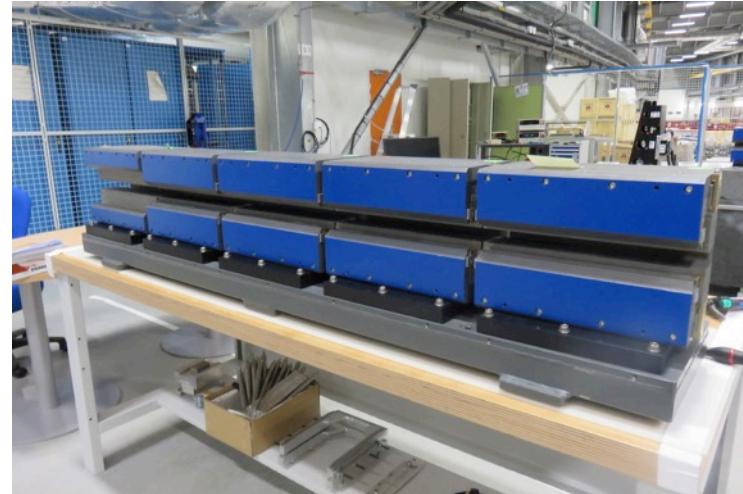
Permanent Magnet Dipoles for the ESRF Upgrade

MT25, 30 August 2016

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OUTLINE

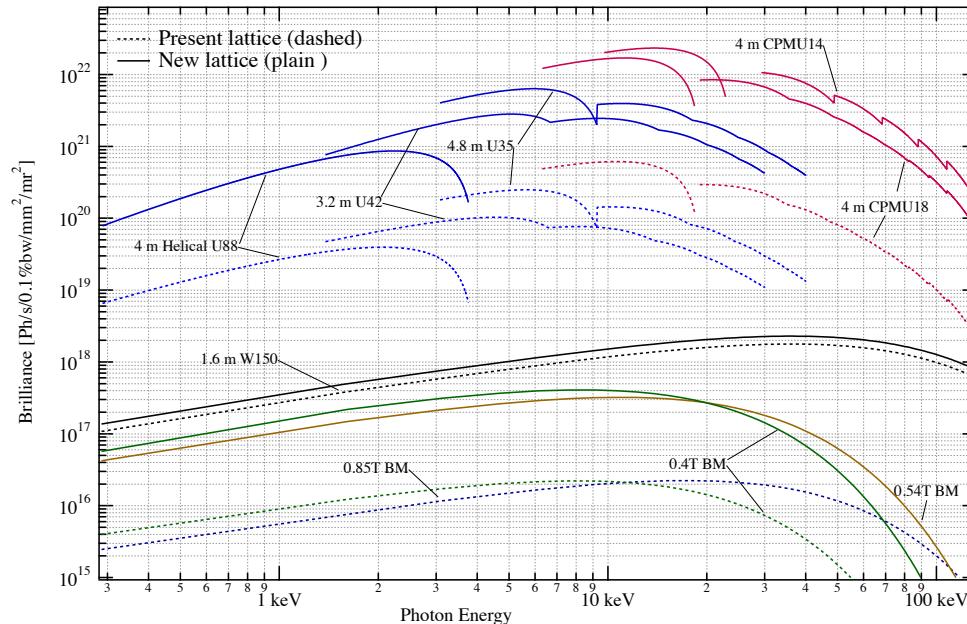
- Context & motivation
- Design
- construction
- Magnetic stability
- Status & summary



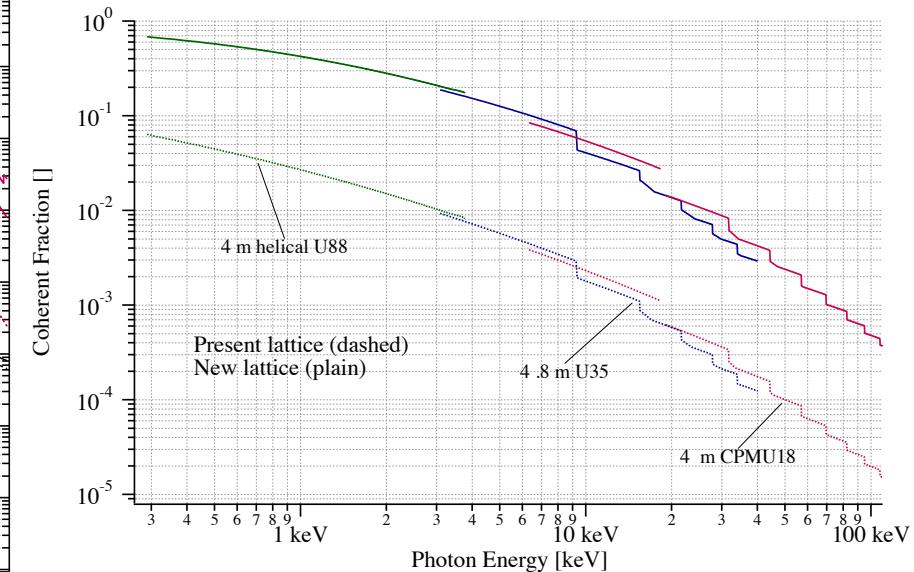
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EBS:BRILLIANCE & TRANSVERSE COHERENCE

Brilliance



Coherent flux fraction



Hor. Emittance [nm]	4	0.134*
Vert. Emittance [pm]	5	5
Energy spread [%]	0.1	0.095
Beta _x /Beta _z [m]	37/3	6.8/2.9
Beam current [mA]	200	200

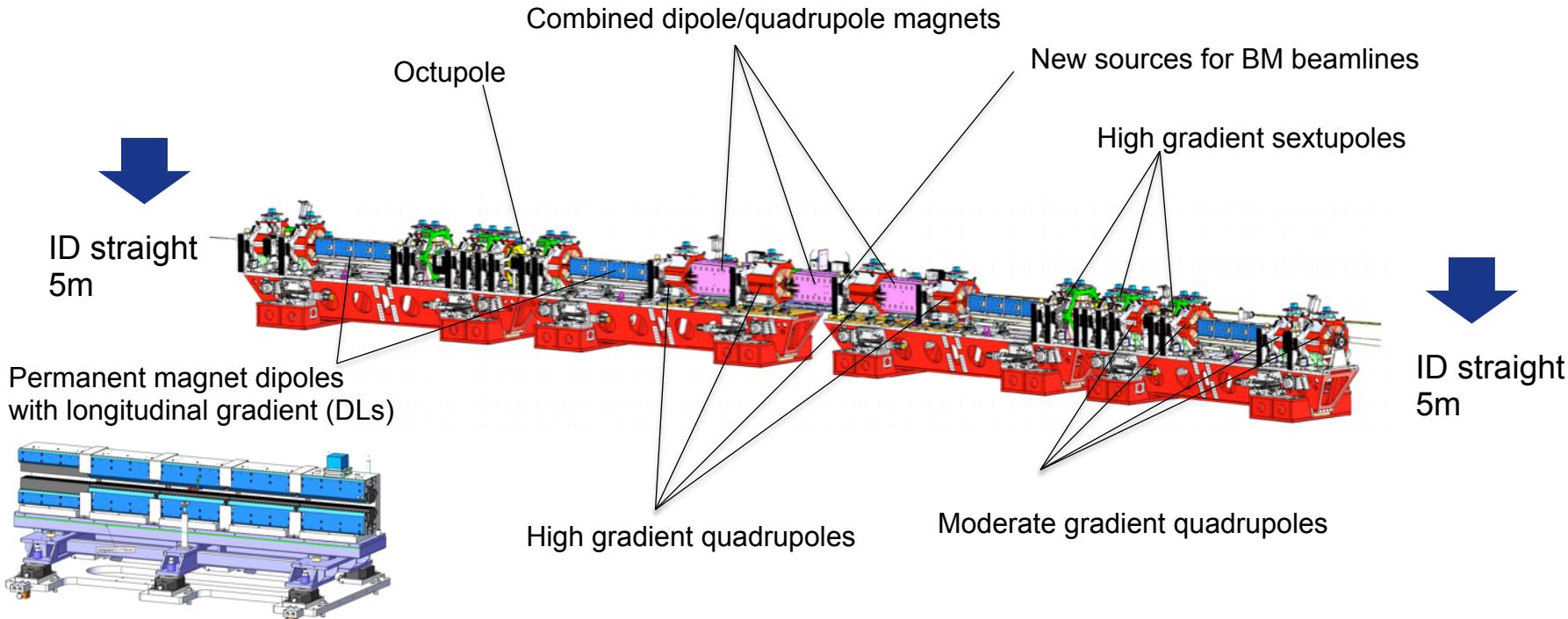
ESRF present

ESRF-EBS
(Extremely Brilliant Source)

* w/o IDs

ESRF-EBS STORAGE RING MAGNETS

- Important design effort, new types of magnets
- Compact magnet lattice
- 4 supporting girders/cell

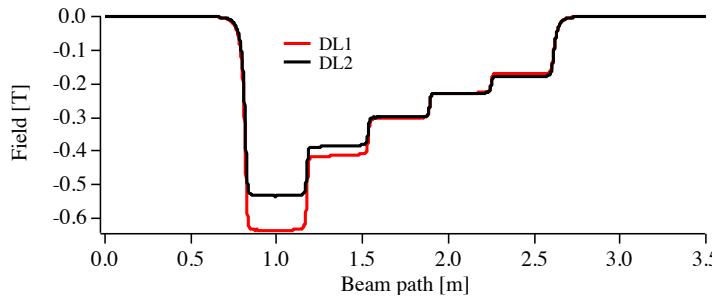


PERMANENT MAGNET Dipoles

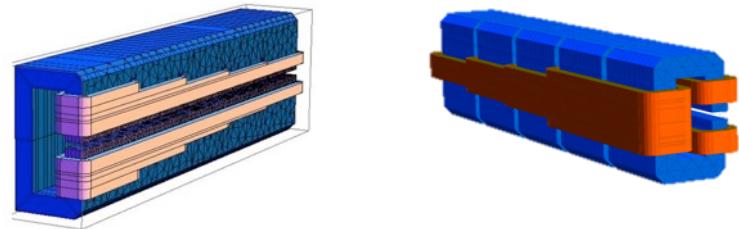
Dipoles with longitudinal gradient (DL)

Non constant field along beam path

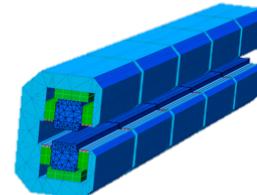
- Field matched to varying horizontal dispersion (emittance reduction)
 - Higher field at lower dispersion
 - Lower field at higher dispersion
- Practically done with field steps (5 in our case)



Early resistive designs



Permanent magnet design

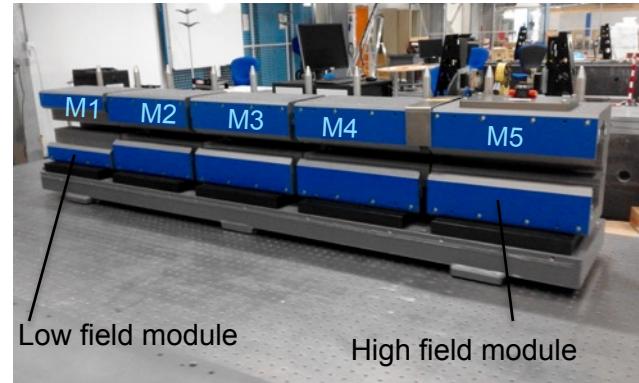


Permanent Magnet (PM) structure

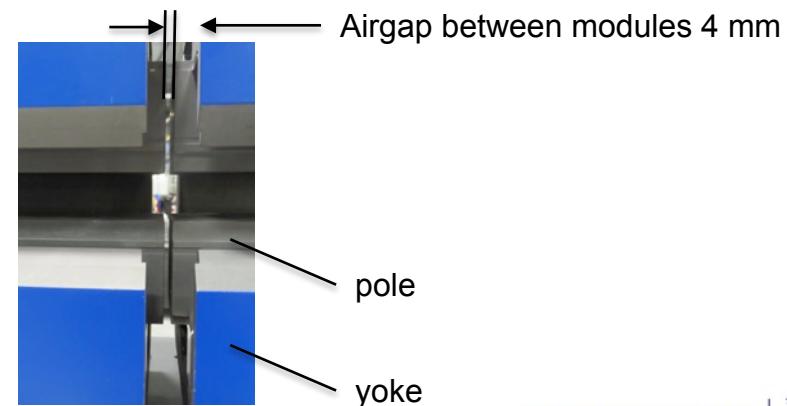
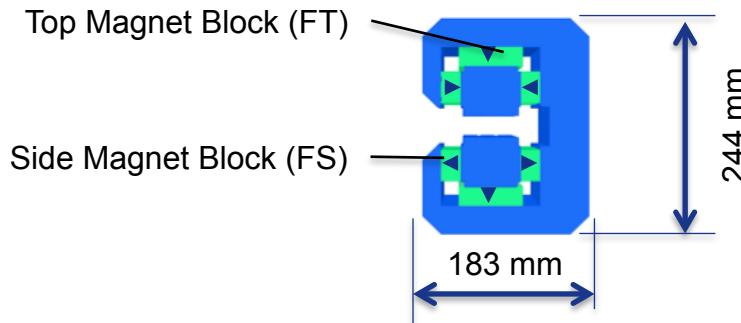
- Demonstrate feasibility of low cost PM Dipoles
 - Low procurement cost
 - Low running cost ~ 0
- Benefits from in-house experience on PM devices (Insertion-Devices)
- Well adapted to the segmentation approach
- compactness

DL MAGNETIC STRUCTURE

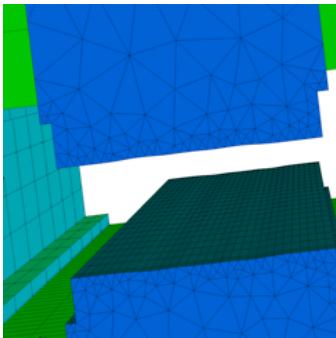
Parameter	Value	Unit
Field	0.64 to 0.17 (DL1) 0.53 to 0.17 (DL2)	T
Mech. length	1784	mm
Gap	25	mm
Deflection angle	31.7 (DL1), 29.4 (DL2)	mrad
Power	0	kW
Mass	500 (100/module)	kg
# of units	128+4	
GFR (HxV)	26x18	mm
$\Delta B/B$ in GFR	<10 ⁻³	



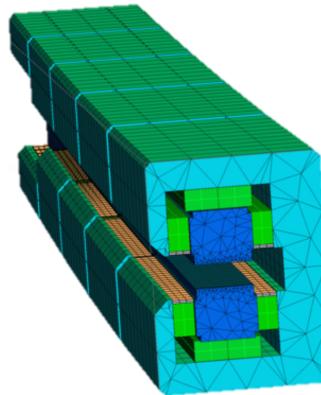
- Module M2 to M5 geometrically identical but populated differently with magnet blocks
- Module M1 (low field) modified for integration of a photon beam absorber



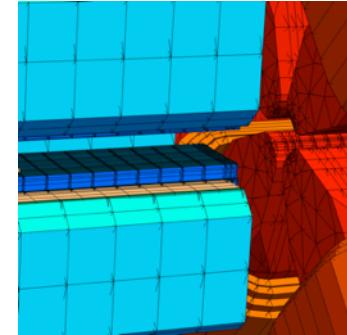
DL MAGNETIC DESIGN



Pole shape optimization



3D magnetic model (RADIA)



Magnetic cross-talk with neighboring magnets

Beam dynamic model

- Field representation
- Magnetic length
- Multipoles
- ..etc

Magnetic optimization

- Magnetic interaction between modules (gap between modules)
- Modules place on curved beam path
- Magnetic crosstalk with neighboring magnet
- Field tuning scheme (flux shunts)
- passive thermal compensation (Fe-Ni shunts)

... etc

Simulation of magnetic measurements (Stretched moving wire)

- individual modules
- full magnet assembly
- Field integrals

PERMANENT MAGNET MATERIAL

PM material: $\text{Sm}_2\text{Co}_{17}$ XGS30H (Magsound, China, <http://www.magsound.com>)

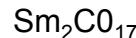


Recent progress in $\text{Sm}_2\text{Co}_{17}$ materials @ Magsound

Material	Grade	Energy Product(BH)max		Residual Induction Br		Coercive Force HcB		Intrinsic Coercive Force Hcj		Density D	Rev.Temp Coeff α(Br)	Curie Temp TC	Max Working Temp Tw
		KJ/m³	MGsOe	T	KGs	KA/m	KOe	KA/m	KOe				
New grades	XGS30M	223-247	28-31	1.08-1.12	10.8-11.2	318-804	4.0-10.1	398-1194	5.0-15.0	8.4	-0.03	≥850	350
	XGS30	223-247	28-31	1.08-1.12	10.8-11.2	700-828	8.8-10.4	1194-1990	15.0-25.0				
	XGS30H	223-247	28-31	1.08-1.12	10.8-11.2	700-828	8.8-10.4	≥1990	≥25.0				
	XGS32M	231-255	29-32	1.10-1.15	11.0-11.5	318-804	4.0-10.1	398-1194	5.0-15.0				
	XGS32	231-255	29-32	1.10-1.15	11.0-11.5	755-850	9.5-10.7	1194-1990	15.0-25.0				
	XGS32H	231-255	29-32	1.10-1.15	11.0-11.5	755-858	9.5-10.8	≥1990	≥25.0				
	XGS33M	238-255	29.9-32	1.12-1.17	11.2-11.7	318-836	4.0-10.5	398-1194	5.0-15.0				
	XGS33	238-255	29.9-32	1.12-1.17	11.2-11.7	820-860	10.3-10.8	1194-1990	15.0-25.0				
	XGS33H	238-255	29.9-32	1.12-1.17	11.2-11.7	843-868	10.6-10.9	≥1990	≥25.0				

15000 magnet blocks ordered (~13000 effectively used)

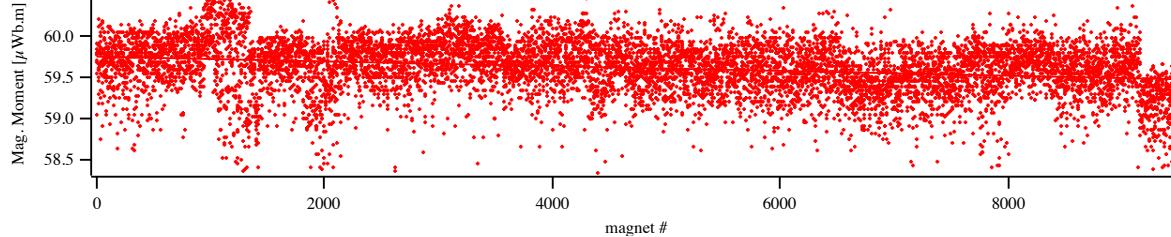
- 6 tons of material
- 2 main types of PM blocks + 1 for field adjustment (¼ block)
- Two batches: delivery September 2016 & December 2016
- Thermal stabilization @ 120 C



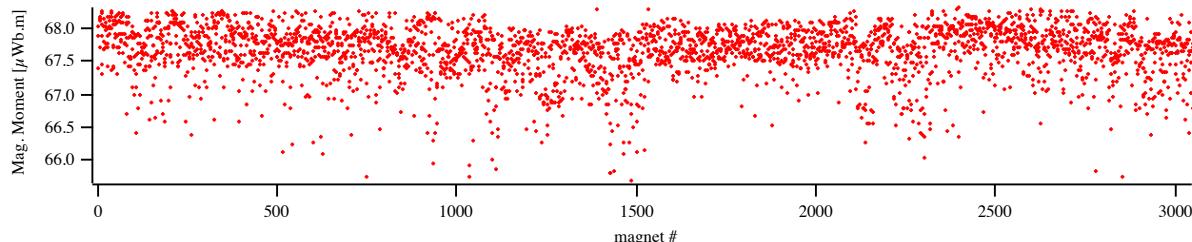
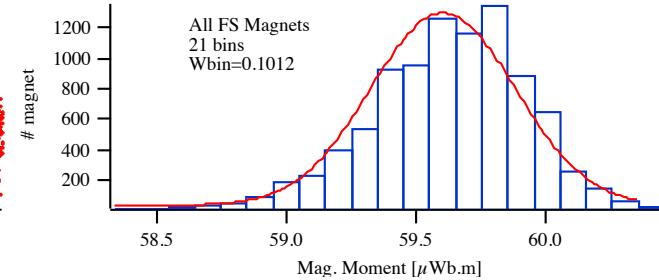
- Low temperature coefficients
- High radiation hardness
Resistance to radiation induced demagnetization

MAGNET BLOCKS DATA

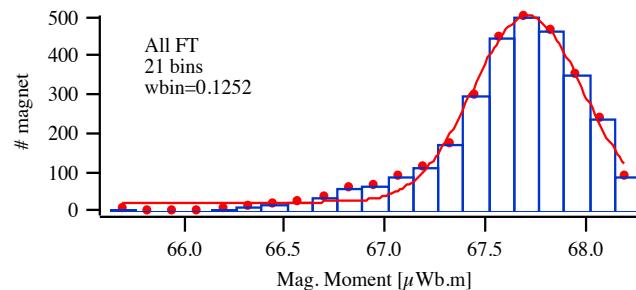
Measured magnetic moments



Magnet type FS: (max-min)/avg=3.5 %, stdev/avg=0.52 %



Magnet type FT: (max-min)/avg=3.9 %, stdev/avg=0.57 %



Use of magnet sorting

DL CONSTRUCTION: DONE IN-HOUSE

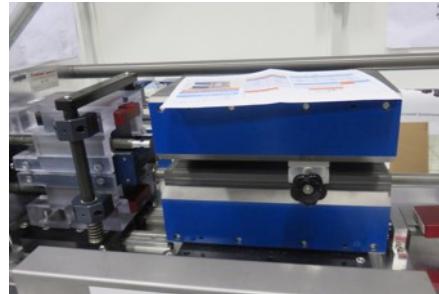
Magnet blocks (Magsound,)



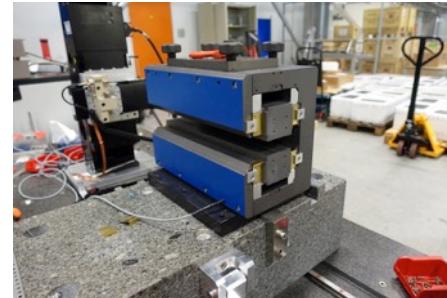
Machined empty modules
AMF (UK), CECOM (It)



Magnet block insertion in modules
(dedicated tools)



Magnetic measurement & field tuning
(stretched moving wire)



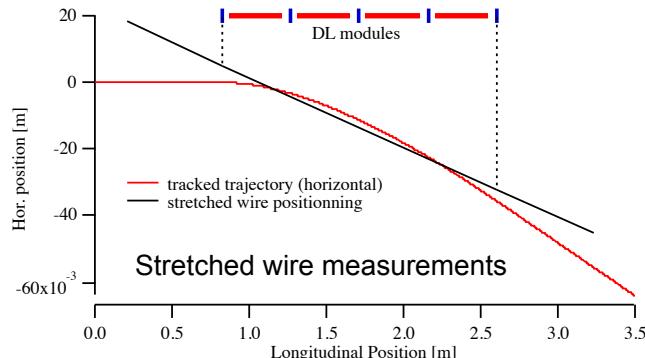
Magnetic measurements of full DL & final field tuning
(stretched moving wire)



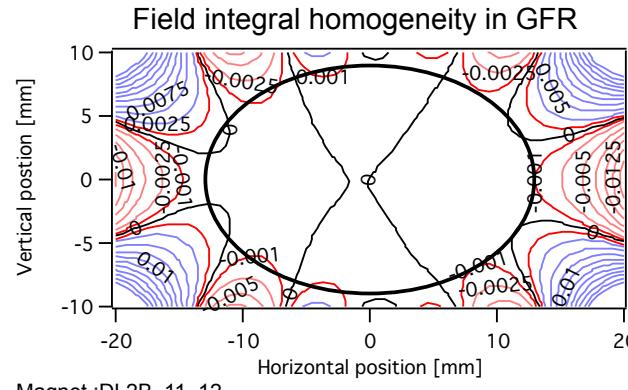
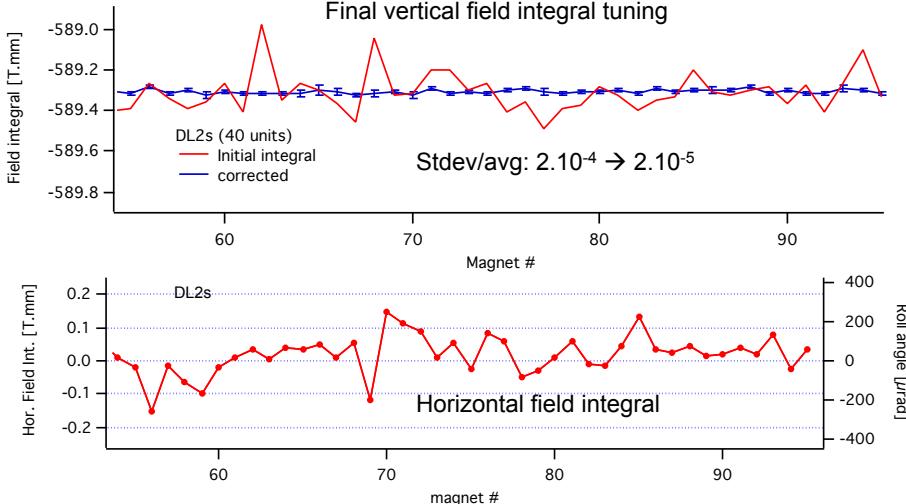
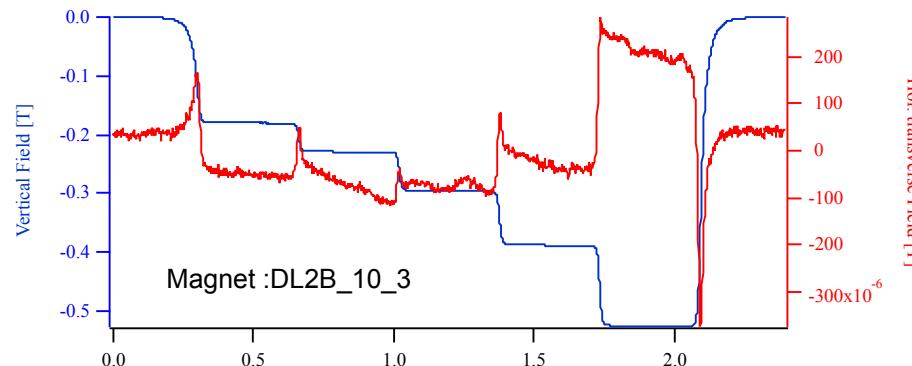
Modules assembly

MAGNETIC MEASUREMENTS

Field integrals measurements

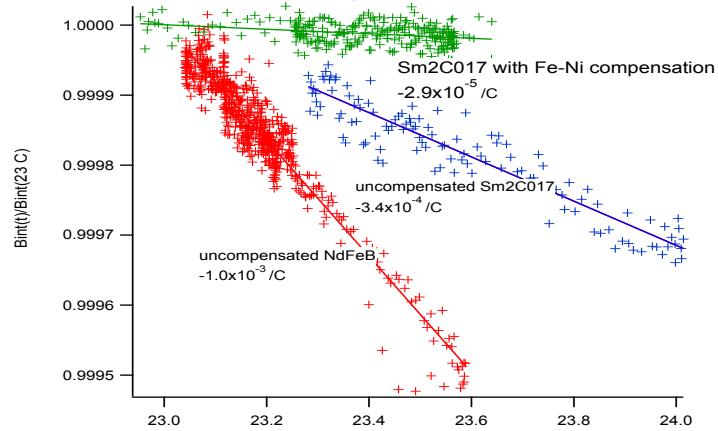


Local field measurements
(pre-series only)



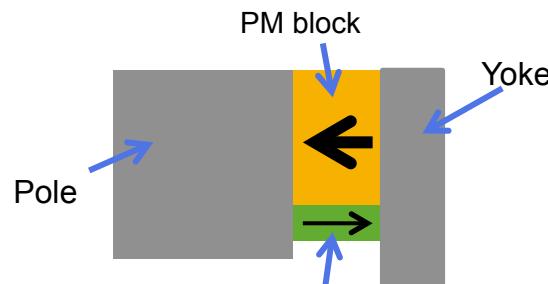
TEMPERATURE STABILITY

- Dominated by PM material temperature coefficient
- Can be compensated by passive FeNi shunts

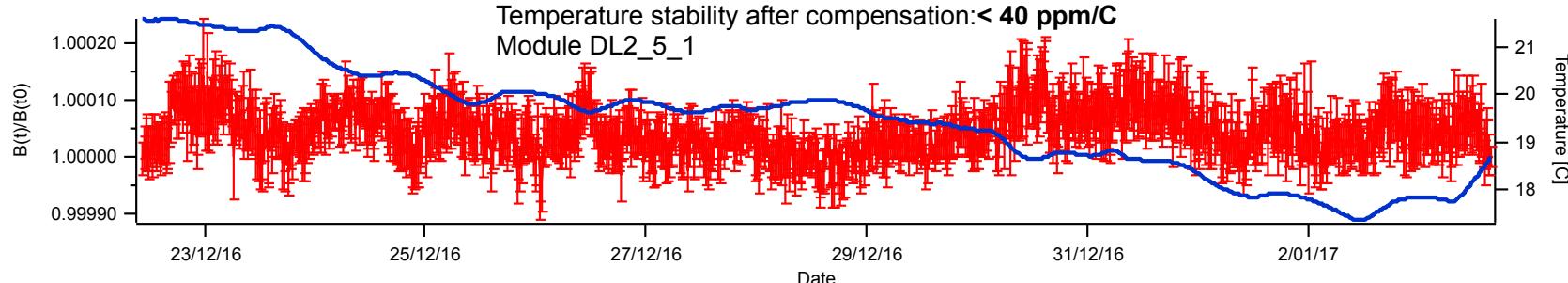


Field integral measurements on PM DL modules NdFeB, Sm₂Co₁₇

Material	$C_T = dB/B/dT$
Sm ₂ Co ₁₇	$-3.3 \cdot 10^{-4}$
Nd ₂ Fe ₁₄ B	-10^{-3}



Special FeNi shunt , thickness 0.8 mm to 4.5 mm depending on module type
(Thermoflux 55/100 G, curie temperature ~ 55 C, ~ -2%/C)



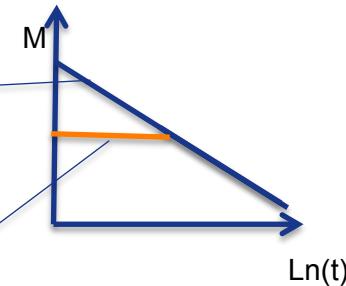
TIME STABILITY

$$\frac{\Delta M}{M_0} = -\frac{s}{M_0} \ln(t/t_0) = -\lambda \ln(t/t_0) = \frac{\Delta B}{B_0}$$

t : time elapsed since t_0

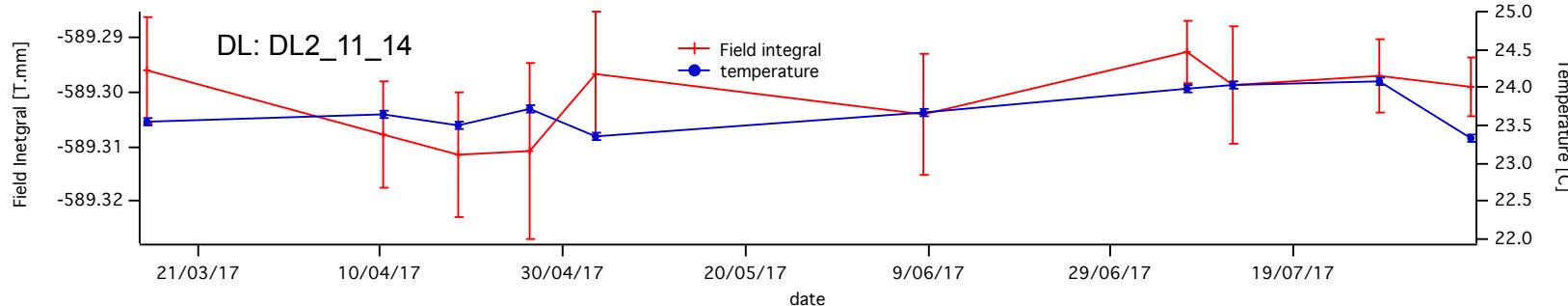
S: Magnetic viscosity

S depends on temperature, working point in magnet



- Magnet blocks thermally stabilized after manufacture (120 C)
- Reverse field in magnet blocks ~ 0.4 T , intrinsic coercivity is 2200KA/m (2.7 T)
- Need to be investigated

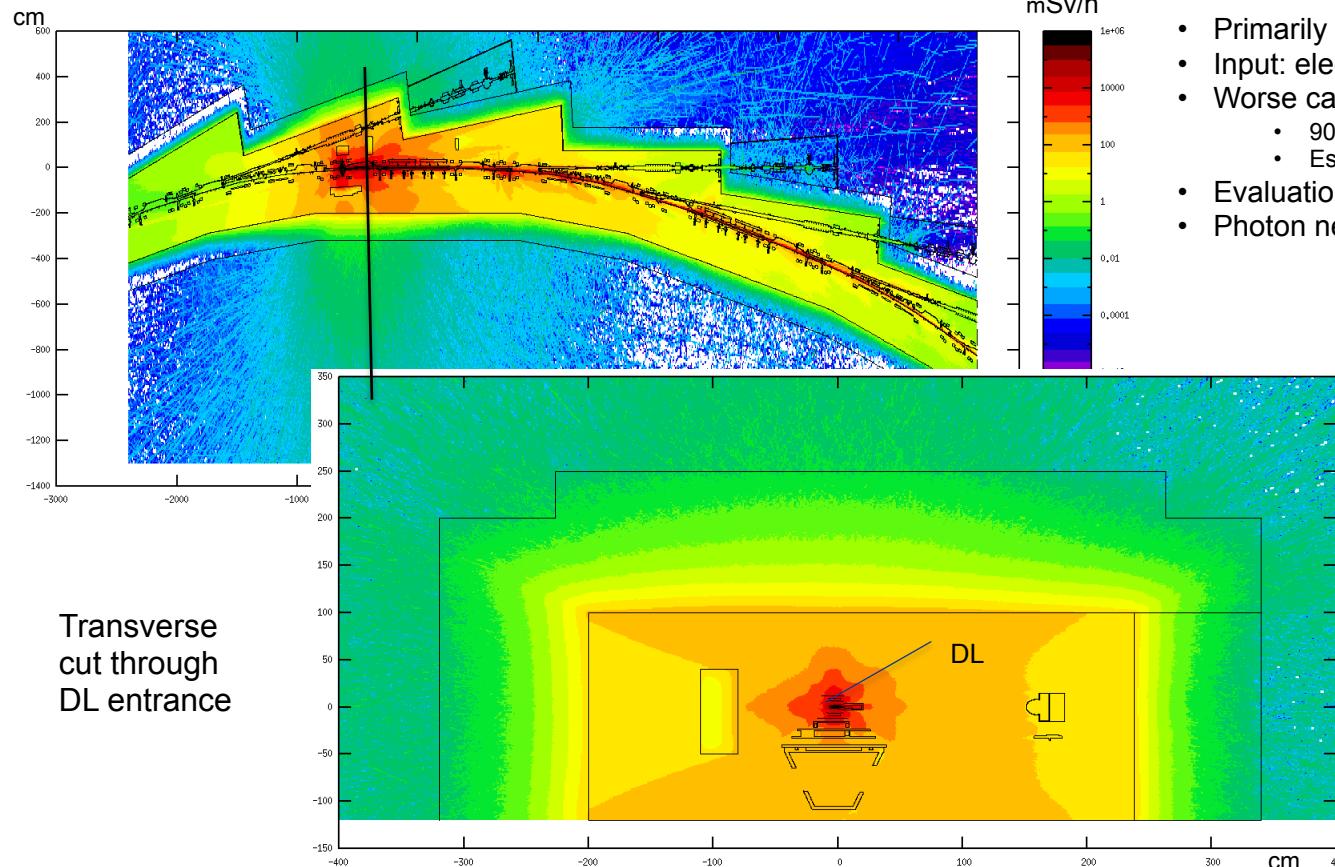
No visible change vs time after 6 months from assembly
(measurements will continue at least for the next 6 months)



RADIATIONS IN PERMANENT MAGNETS

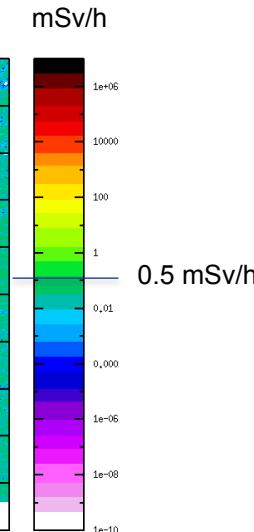
ESRF storage ring: 6 GeV,

Critical place is at the DL behind the electron beam collimator

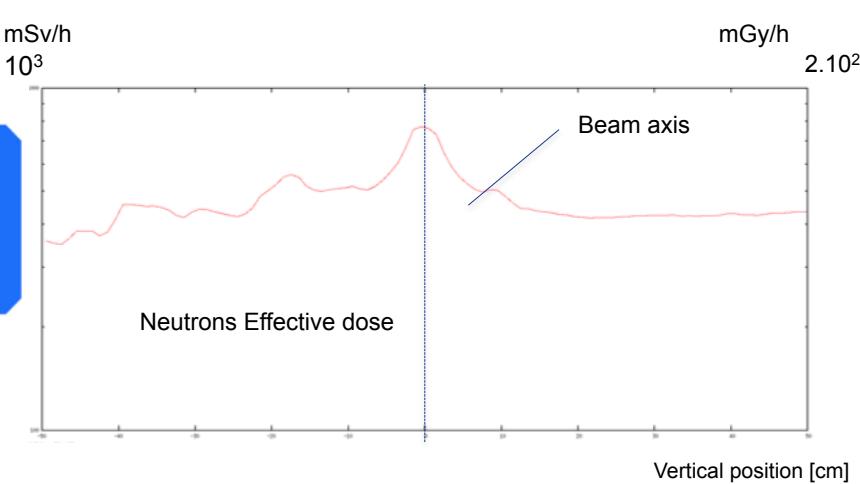
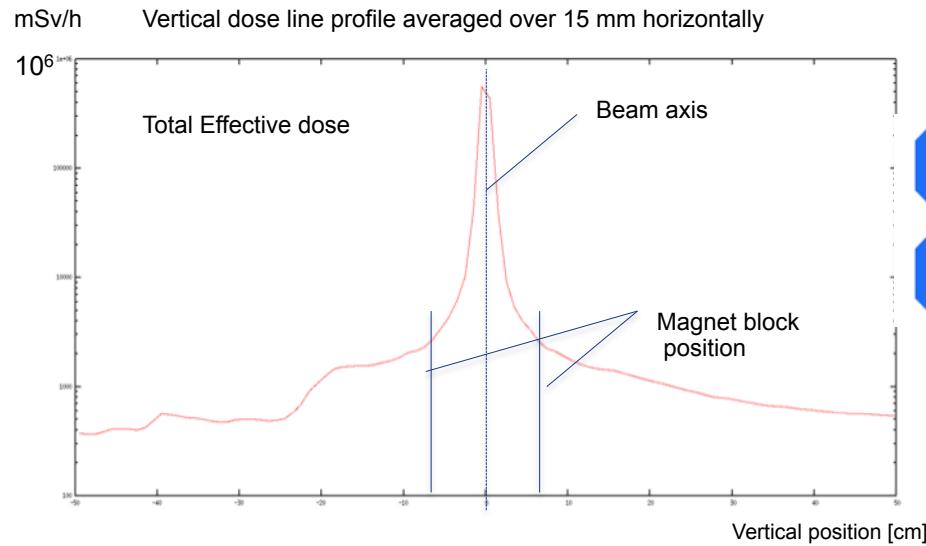


FLUKA simulations

- Primarily done for safety requirements
- Input: electron losses due to Touschek effect
- Worse case:
 - 90 mA 16 bunchs
 - Estimated 1.8 H lifetime in EBS
- Evaluation of radiations in DL
- Photon neutron dose in permanent magnets



RADIATIONS IN PERMANENT MAGNETS (CONT'D)



In present storage ring $\text{Sm}_2\text{Co}_{17}$ permanent magnets used in low gap undulators: In-Vacuum undulators

- Magnetic gap 6 mm
- Neutron doses at PM blocks are $\sim 1 \text{ Gy/h}$ derived from beam loss measurements
- No visible demagnetization of permanent magnet material after 15 years of operation ($< 0.2 \%$)

Magnetic stability vs radiations should be enough for 20-25 years operation

STATUS & SUMMARY

Status

- 102 out of 132 DLs constructed (28 August 2017)
- Production completed before mid October 2017



Summary

- Methods and technics for a large scale production of PM dipoles have been developed
- Simple magnetic structures, no electrical power
- Segmented (modules) approach for DLs has interesting flexibility
- $\text{Sm}_2\text{Co}_{17}$ material is the most suitable to ensure long term magnetic stability
- Magnetic measurements with stretched moving wire very efficient and reliable