Undulator update

Radiators, Modulators, Phase shifters *et al*.

Kathrin Götze (FS-US Undulator group)
FLASH2020+ Progress Review Meeting, 18th October 2024

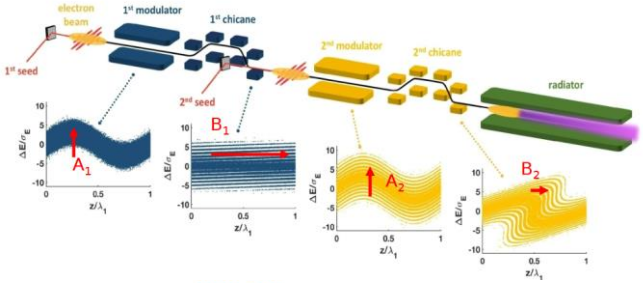
On behalf of the DESY undulator group and with thanks to colleagues at ZM1, ZM2, machine shop and FLASH

HELMHOLTZ

DESY.

Outline

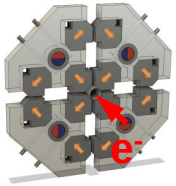
Radiation section



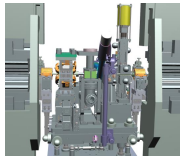
- General layout of the radiation section
- Modulators U84

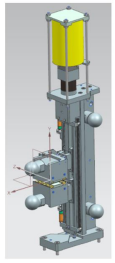
- Refurbished U32 undulators from sFLASH

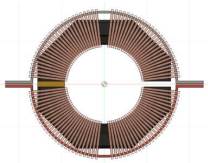
- Radiators (APPLE3)

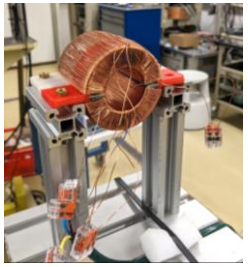


- Intersections: Phase shifters and corrector coils

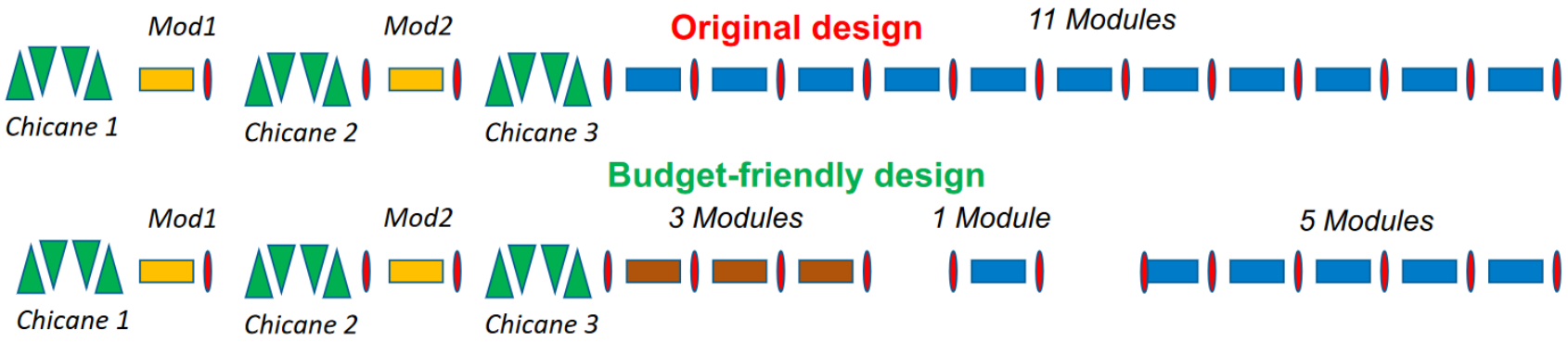








General layout of the radiation section



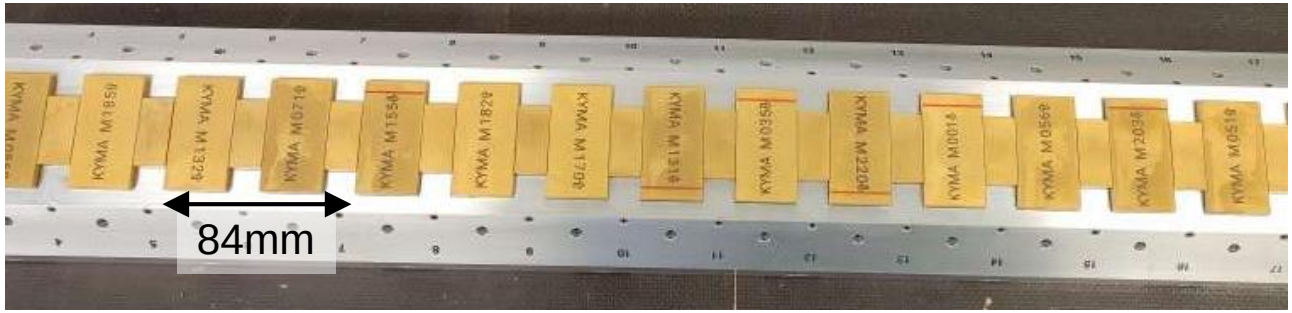
- 2 Modulator undulators with 84mm period length and hybrid (magnets&poles) structure.
- 6 (finally 11) radiator undulators of APPLE3 type. At least 3 for the restart in 2025.
- In the interim: 3 refurbished U32 undulators from sFLASH to increase the pulse energy at short wavelengths.

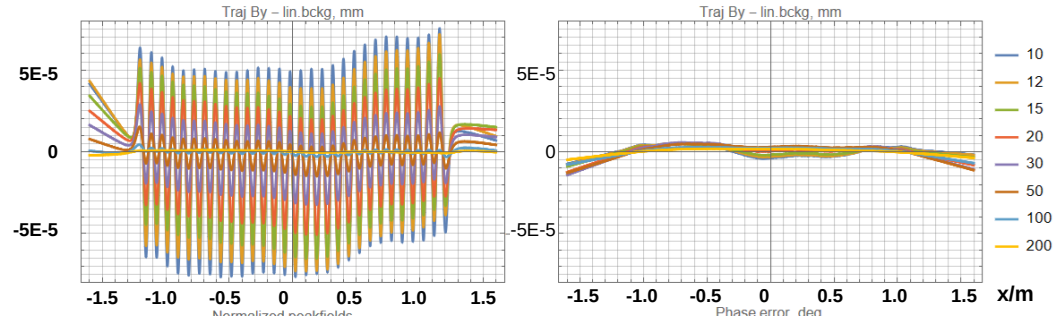
Figures: E. Ferrari, Progress Review Meeting 10/2023

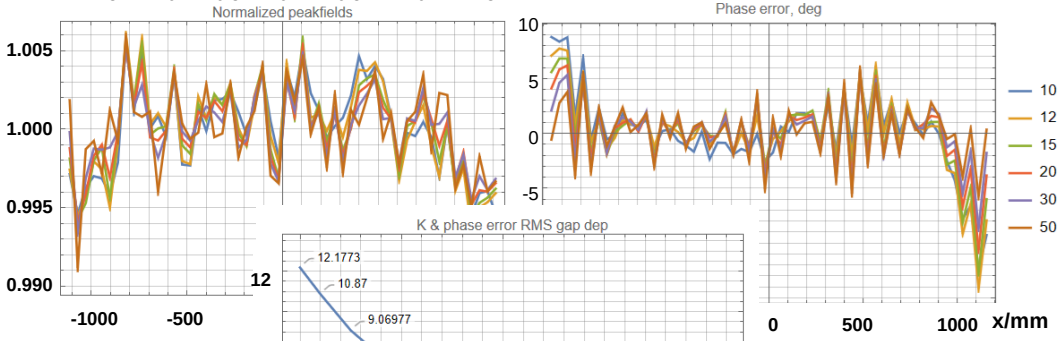
Modulators

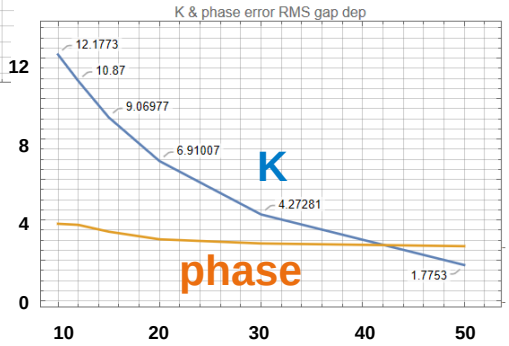
Two U84 planar undulators with hybrid structure (magnet and poles)

- Length = 2.5m
- Period = 84mm
- Min. gap = 9mm
- B_{max} = 1.8T
- Specs: K=11, achieved: K = 12.9









- Sorting of magnets based on novel Hall mapper reduces amount of pole tuning
  - ➢ Parameters were within specs without any pole tuning (straight trajectory, phase error <4°).
- Additional girder curvature spoiled phase error
- Strong fields
  - ➢ Strong forces
  - ➢ Reaching limits of sensor calibration

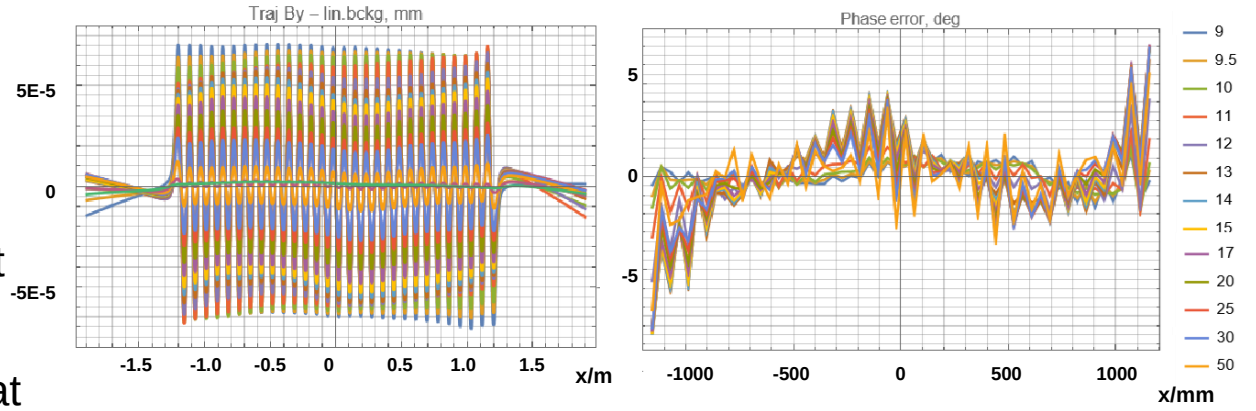
Modulators

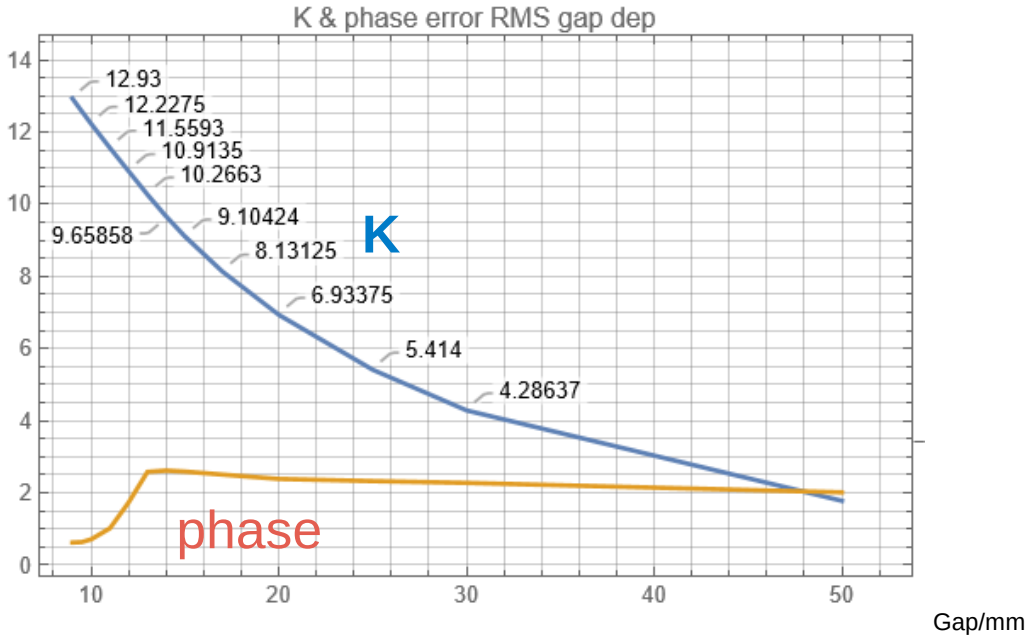
Two U84 planar undulators with hybrid structure (magnet and poles)

After tuning

- Trajectories further straightened
- 0.5deg RMS phase error at minimum gap
- Girder shape strikes back at intermediate gaps due to different gap dep.
- K = 12.9
- „Target" value was K_{target}=11 at 9.5mm gap, to reach 343nm at 1.4GeV
- Now at 1.35GeV: 343nm reached at K=10.6, or operating gap ~12.5mm

➢ Both Modulators tuned and close to ready.





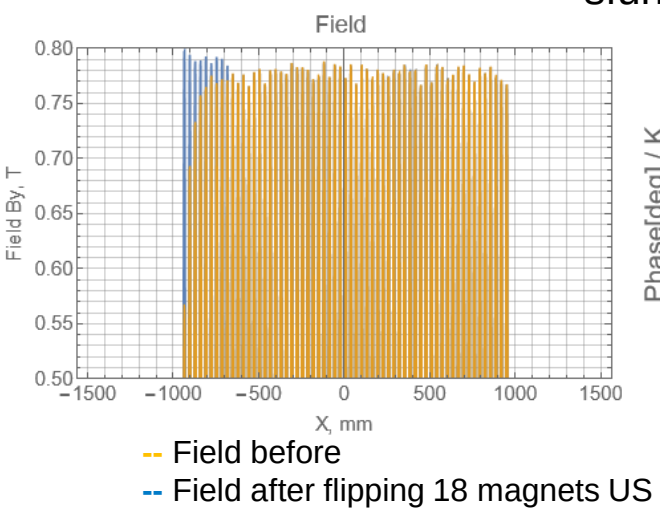
Refurbished U32s from sFLASH

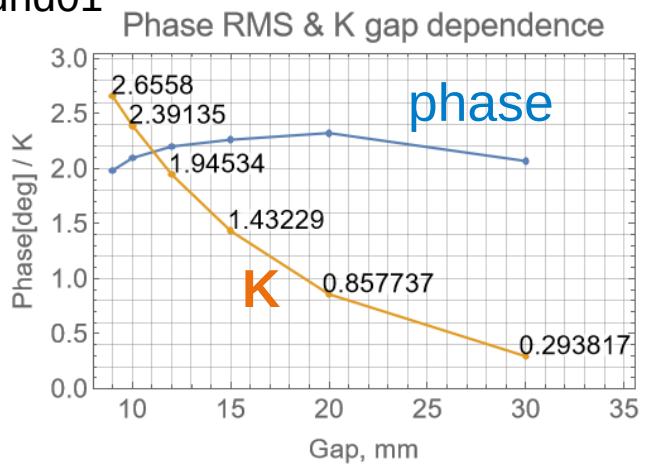
Three devices for the interim to increase pulse energy at short wavelengths.

- sfund01, sfund02 and sfund03 retuned.
- sfund01: Severe radiation damage (>10%) – flipped 18 magnet pairs and replaced end magnets upstream.
- K between 2.65 and 2.70 at min gap of 9mm
- Phase errors <3°
- Remaining kick errors: ±50 Gcm. Corrected in a feed-forward by small air coils.

➢ All three devices tuned and ready.

sfund01



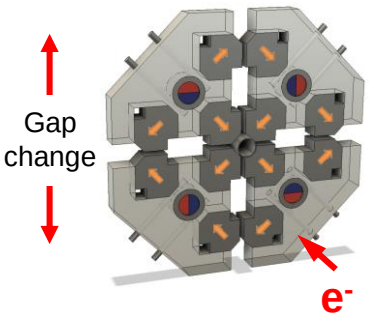


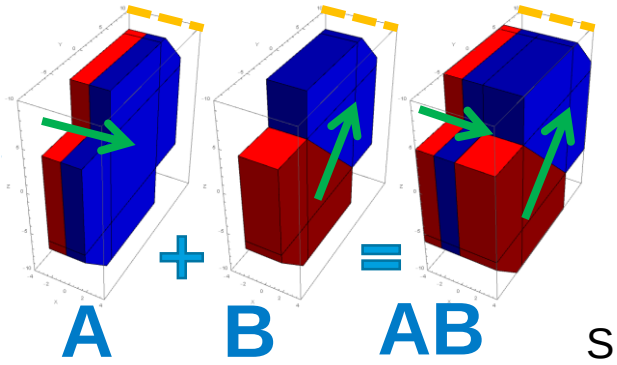
APPLE III Radiators

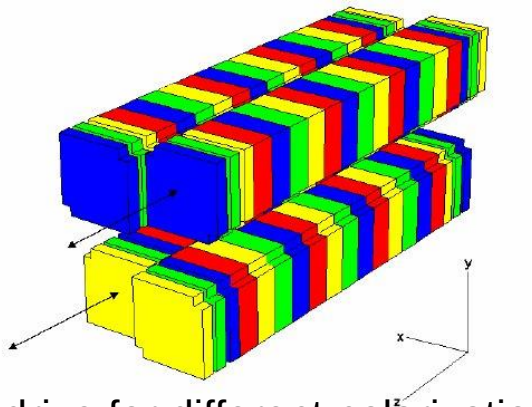
APPLE III devices with 35mm period length

- Users' wish: Variable Polarisation
- Experiments using circular dichroism for magnetism and chirality

➢ Flexible APPLE-III undulators

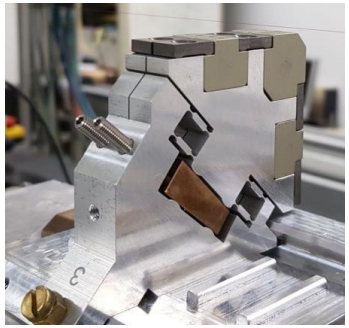


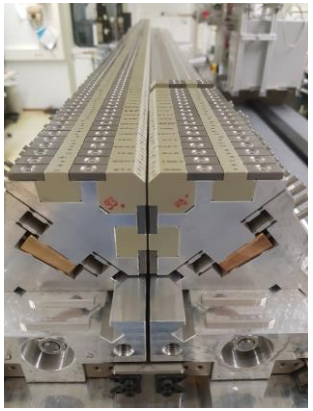




Shift drive for different polarization modes: vertical, left circular, horizontal, right circular

- APPLE III: highest field, less bulky, cost efficient
- Force reduction up to factor of 8
- Full period (35mm) keepers
- Correction by virtual shimming of keepers





FLASH2 Afterburner
17.5mm period length

Source shift drive: Hannon, F.E., *et al, Proceedings of EPAC*. 2004.

Radiators

6 APPLE III devices with 35mm period length

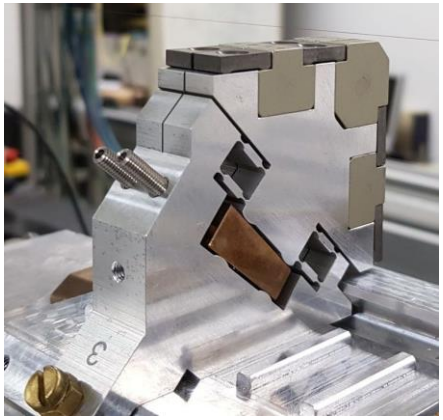
- Received support structures, all parts for shift drives and first batch of main and sub girders.
- ➢ Pre-assembly in progress, manual shimming, cooperation with ZMQS

- Magnets and keepers in production:
  - >1600 keepers plus endkeepers
  - >3300 function magnet pairs plus special end magnets for six devices
  - ~6600 compensation magnet pairs for six devices

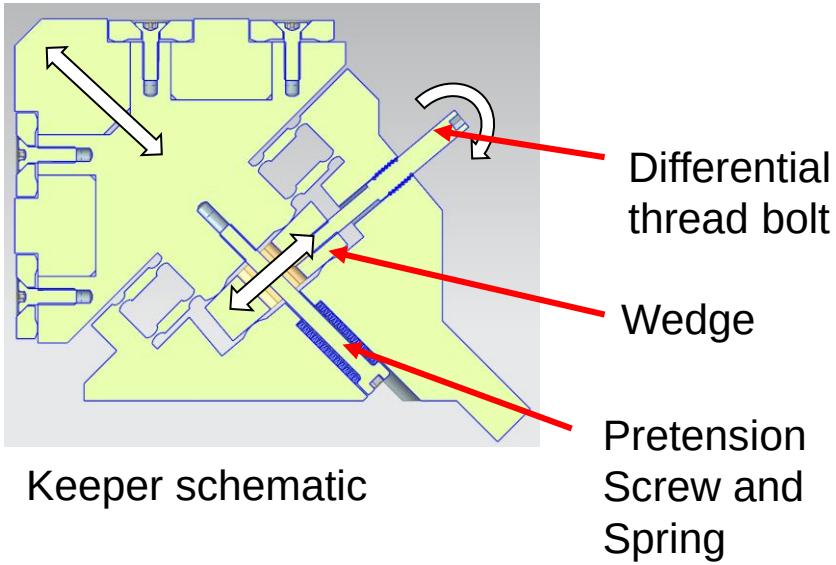
- Weekly meetings with suppliers

- First assembled batch (magnets in keepers) expected end of November.

Support structures



Keeper afterburner



Keeper schematic

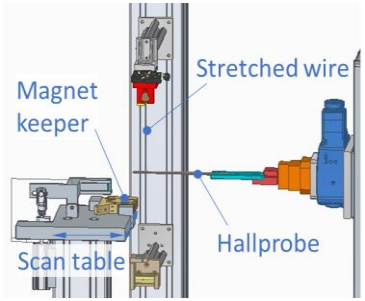
Radiators

6 APPLE III devices with 35mm period length

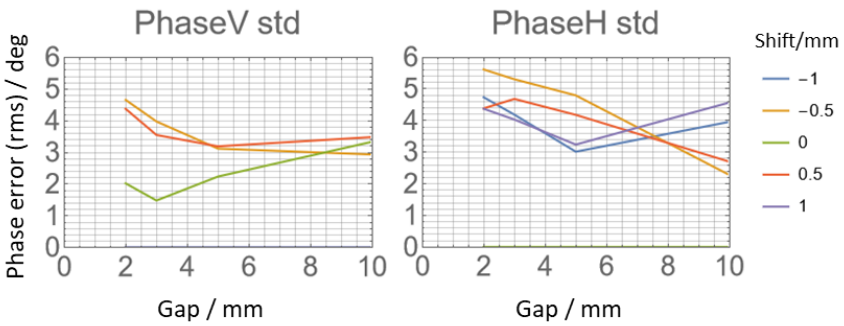
Once we received magnets assembled in keepers:

Stretched-wire measurements of all individual keepers → Sorting based on these data → Assembly onto girders/support structures → Measure and tune complete device with Hall probe and stretched-wire set-up

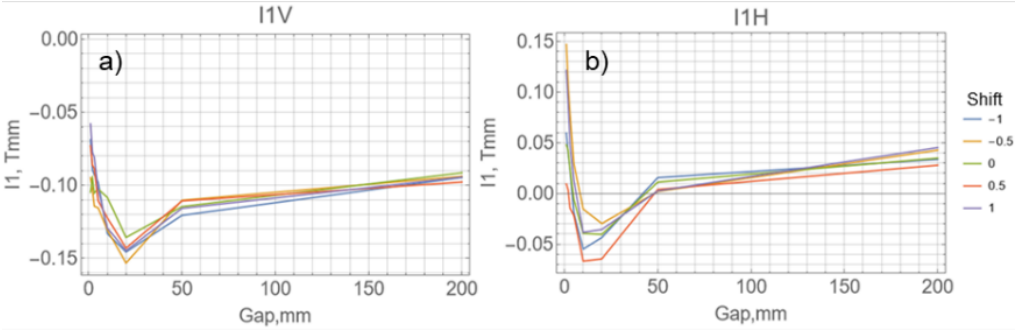
- Each step in a different lab – continuous work flow
- Experience from afterburner
- 2 labs for the final step of measuring and tuning



Final parameters afterburner



Phase error <6deg, little variation with shift mode

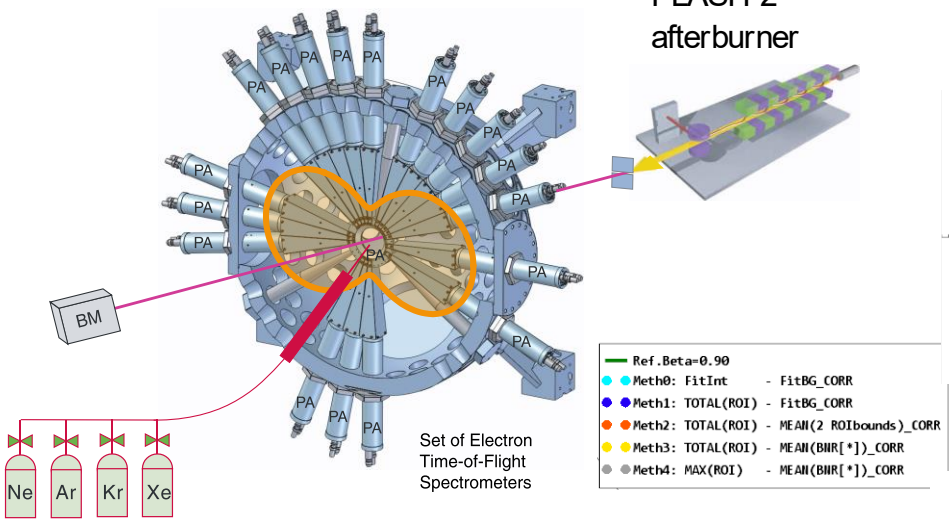


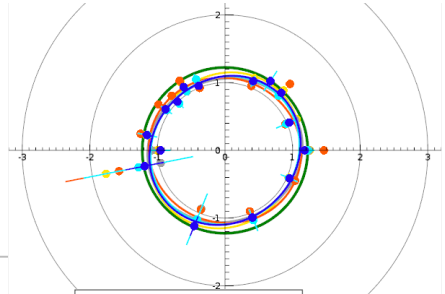
Remaining kick errors: ±50 Gcm +shift-dependent kick error of similar size. Corrected in a feed-forward by small air coils.

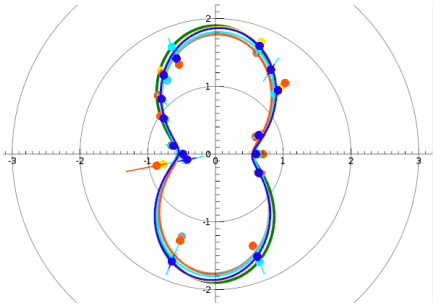
Radiators

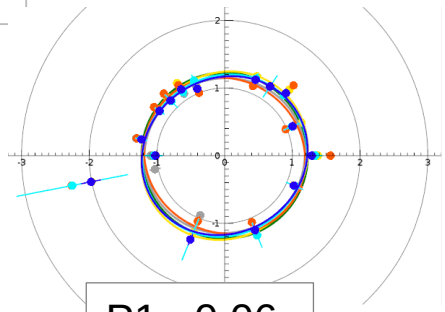
FLASH2 APPLE III afterburner in operation

E_{ACC} = 880 MeV
hv = 104.6 eV / 313.8 eV

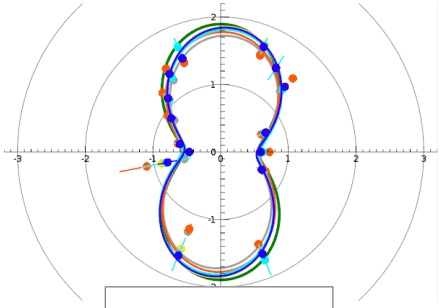



P1= 0.08


P1= 0.98

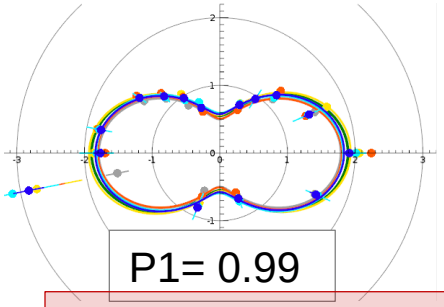

P1= 0.06

ABU shift = +/- 0.25


P1= 0.98

ABU shift = +/- 0.5

- Ball chamber instrument
- Measuring angular distribution of photoelectron emission of a certain photoelectron feature from 3rd harmonic


P1= 0.99

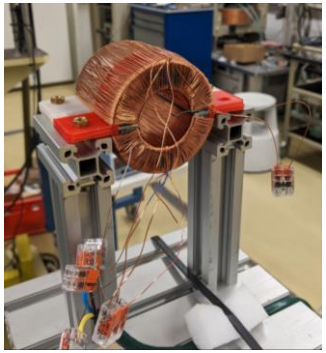
ABU shift = 0.0

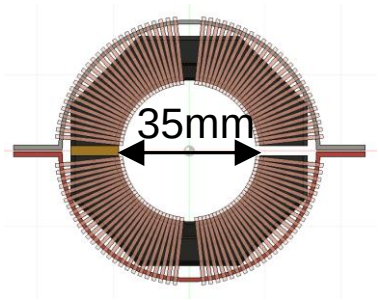
- Circularly polarized light down to 1.46 nm generated
- First successful user experiments

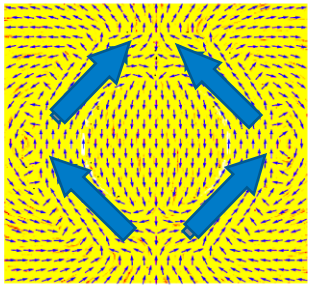
Courtesy M. Braune, K. Tiedke, J. Rönsch-Schulenburg and colleagues

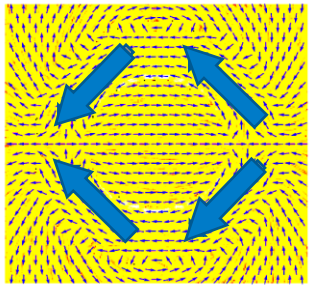
Steerer/corrector coils with variable field direction

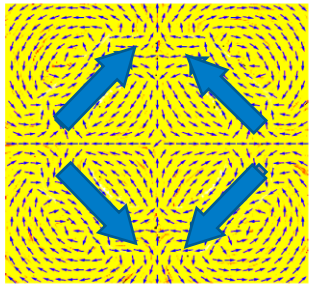
Ferrite enforced resistive coils (air-cooled)









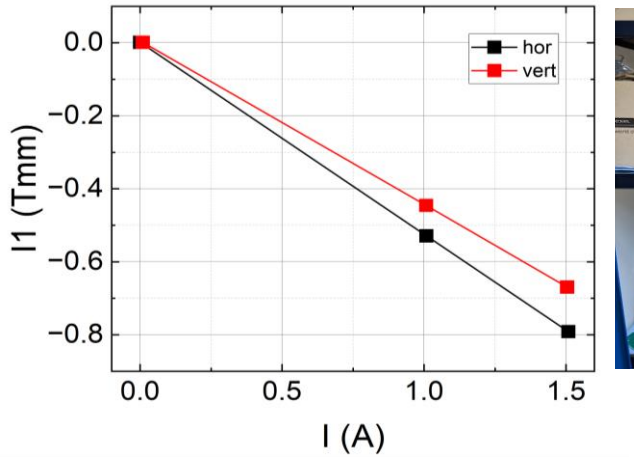


vertical **horizontal** **quadrupole**

Correct (gap dependent) kick up and down stream of undulators

- In-house design for stronger coils with slow feedback option
- Resistive, air-cooled coils
- Compact and cost-efficient design
- Ferrite-based – 0.55Tmm at 1A
- Four sub-coils per unit – variable field direction
- AC capability

➢ Series of 40 coils manufactured



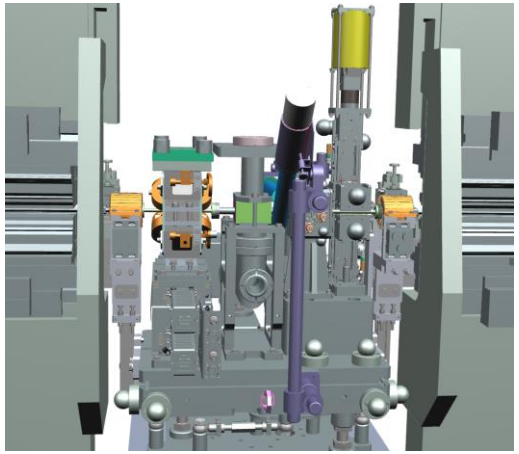
On-axis first field-integral as a function of current (hor/vert field).

Stored coils

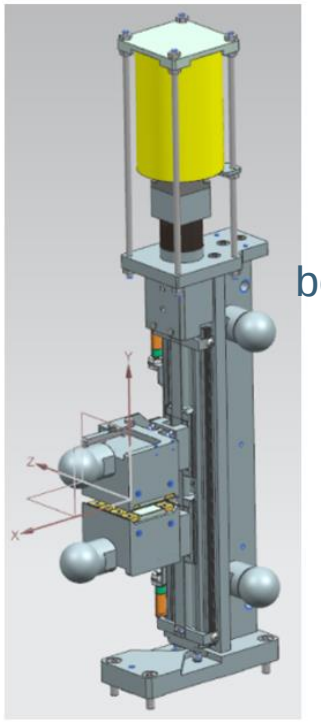
Phase shifters

Compact, permanent magnet-based phase shifters on intersections

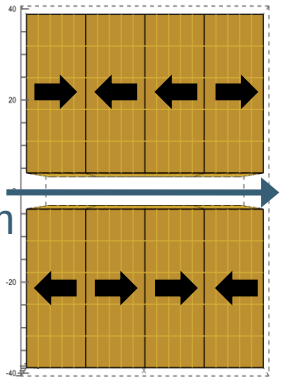
- Compact, permanent magnet-based design
- Pre-sorting allows for using lower quality, low price magnets
- Series of 10 phase shifters built and tuned
- <0.02Tmm (6µrad) on-axis kick remaining
- high uniformity within series



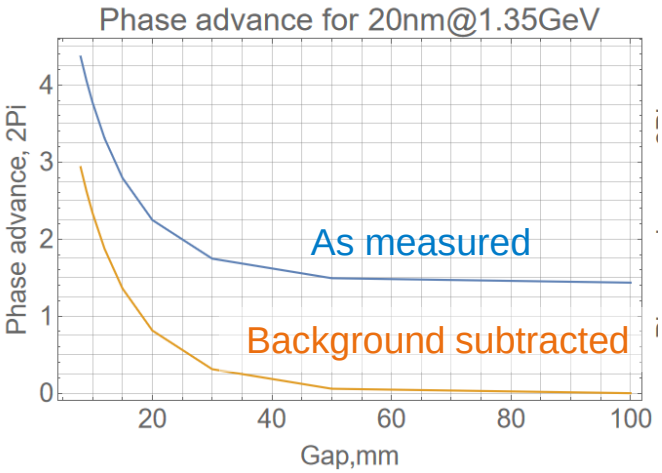
Intersection



Phase shifter

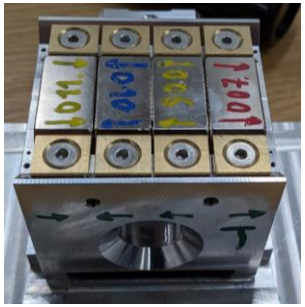


Magnetic set-up



➢ Phase advance as a function of gap.

All 10 phase shifters achieve at least **2.8*2π** for 20nm@1.35GeV.



Magnet blocks.
Size: 35x35x15mm^3

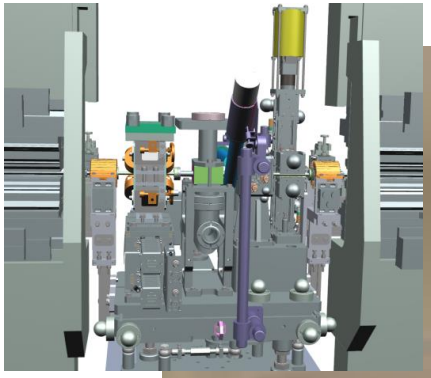
Phase shifters and corrector coils

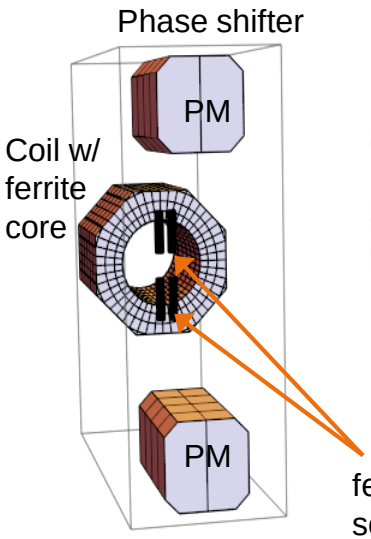
Managing cross-talk

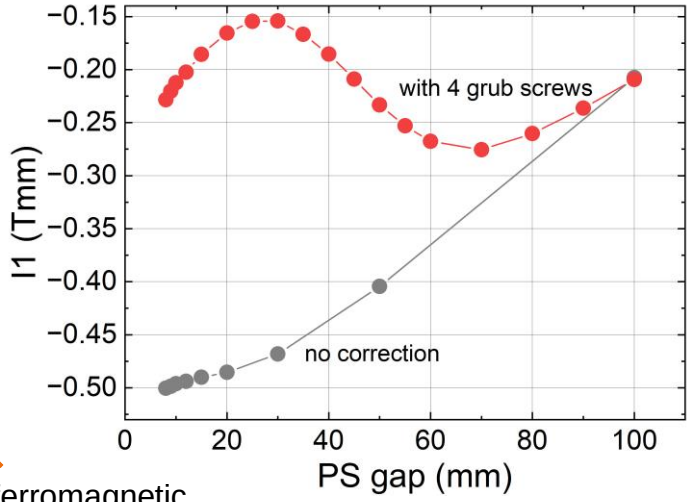
- Originally only 22mm distance between permanent magnets of phase shifter and ferrite enforced coils
- Strong, unwanted dampening of PS fringe fields due to cross-talk

➢ Increased the distance to 30 mm (max)

➢ Passive compensation by installing two sets of ferromagnetic screws above and below the beam pipe.

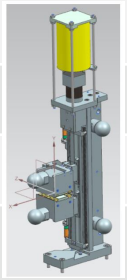






Summary and Outlook

- Radiation section with variable polarization for experiments using circular dichroism for magnetism and chirality → Flexible APPLE-III undulators
- Time and money are tight → 3 refurbished U32 undulators from sFLASH to increase the pulse energy at short wavelengths and 3 radiators for the 2025 restart, 3 more later.
- Magnet sorting based on Hall mapper data reduced time and need for tuning significantly.

Two U84 modulators		 Modulator
Three refurbished U32 undulators		 U32 undulators from sFLASH Radiator undulators (APPLE3)
Radiators		
Support structures		
Girders		*1st batch received, rest in production*
Keepers and magnets		*ordered, in production, 1st batch expected 11/2024*
Assembly, measurement, tuning		*will work in two labs, experience from afterburner*
Intersection		
10 Phase shifters & 40 Corrector coils		 
Manage cross talk		
Final measurements & correction tables		*Work in progress*

Thank you for your attention.

Contact: kathrin.goetze@desy.de • Tel: …4851