Institute of High Energy Physics
Chinese Academy of Sciences

CEPC Circular Electron Positron Collider

The Fabrication and Measurements of the Dual Aperture Quadrupole for CEPC

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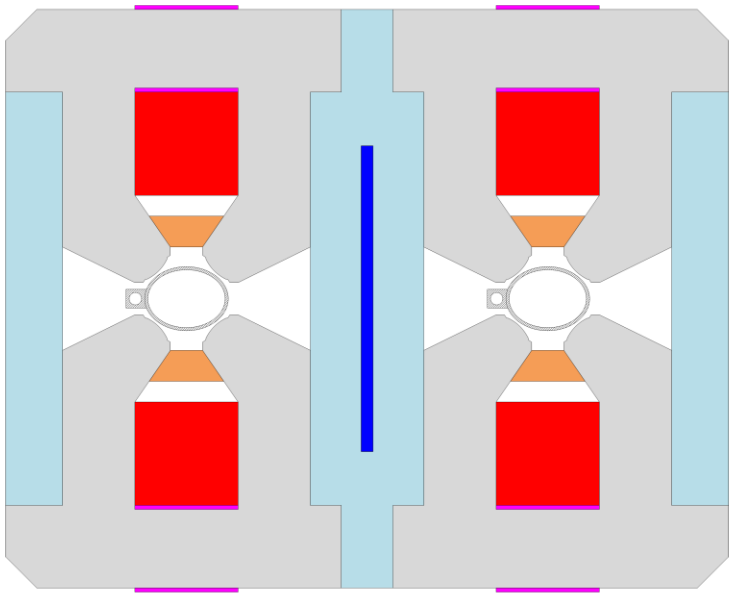
Outline

- Dual Aperture Quadrupole(DAQ) parameters and first prototype
- Preliminary field measurement results
- Optimization design
- Prototype modification and field measurement results
- Summary

DAQ parameters and first prototype

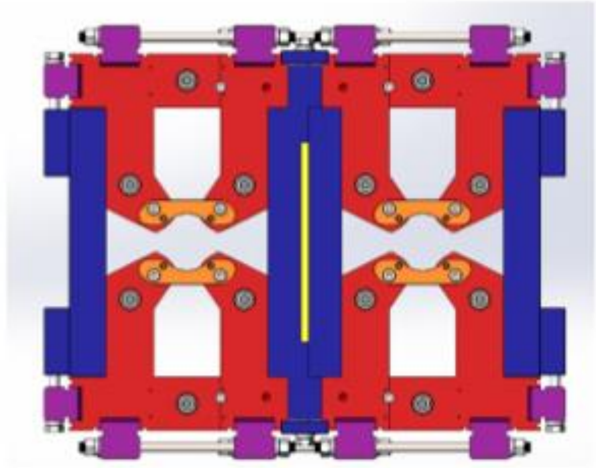
- Basic parameters of DAQ(dual aperture quadrupole)　　CDR,2018
  - Apertures：76mm
  - Beam separation：350mm
  - Gradient range: 3.2T/m@45.5GeV~12.8T/m@182.5GeV
  - Trim coil: ±1.5% gradient tapering
  - Field quality: 5×10^{-4}@Rref=12.2mm
- First F/D prototype features
  - DT4 compensation sheet
  - Trim coils located on the yoke, far from the midplane.
  - Hollow water cooled aluminum conductor.
  - Large leakage field at the outside and middle of the magnet.
  - Strong dipole field at the end.
  - With lead blocks for radiation shielding

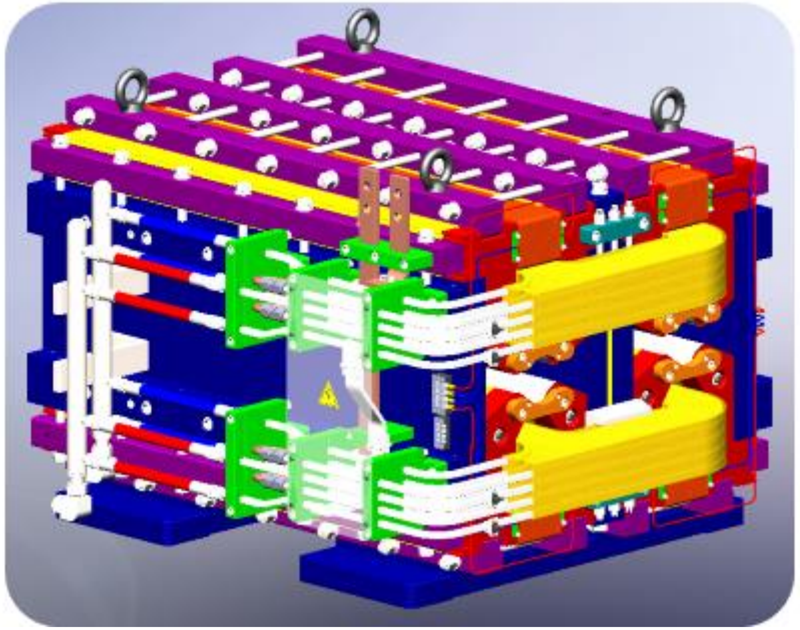


First F/D design

DAQ parameters and first prototype

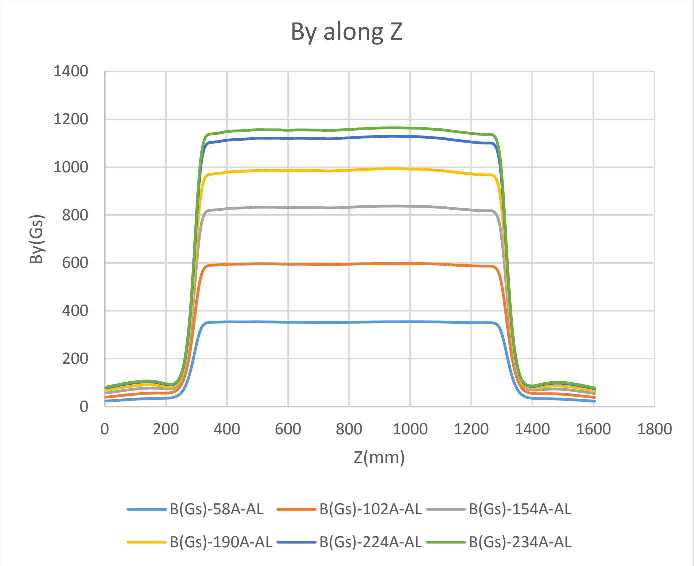
- The first prototype is a laminated one with DT4 compensate sheet in the middle.
- Complex mechanical structure:
  - The iron is divided into many blocks.
  - The poles are slender.
  - Difficult to control the tolerance.



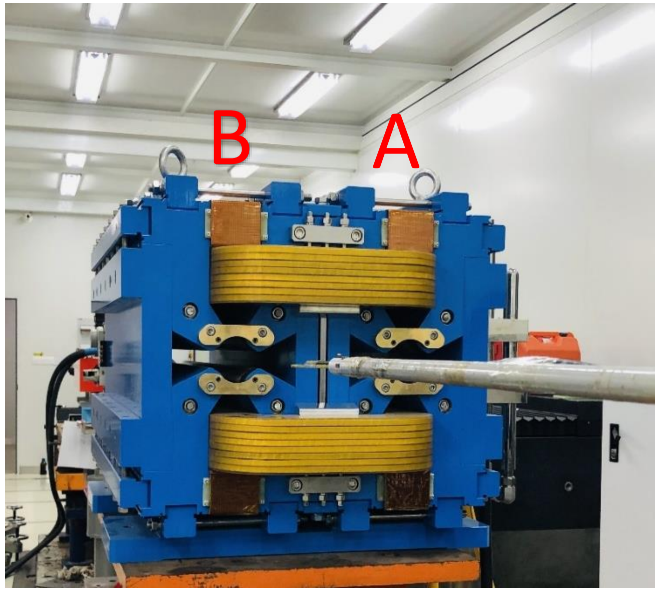


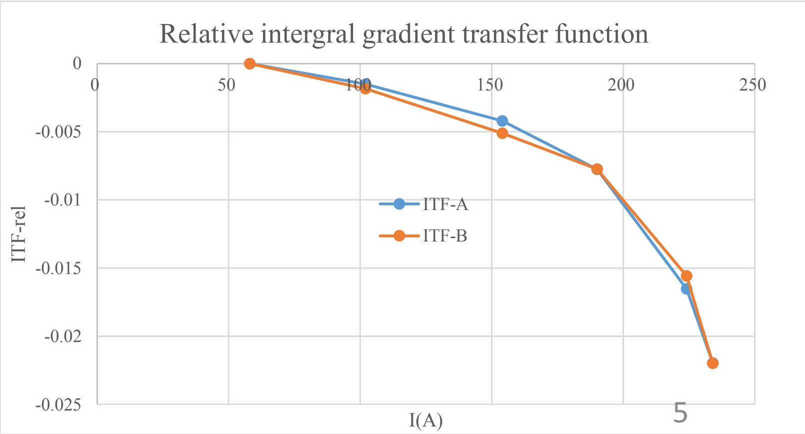
DAQ parameters and first prototype

- The first 1m long prototype was fabricated and tested by Hall.
  - Large edge field;
  - GL difference in two apertures: less than 0.5% (except 80GeV)
  - X0 center shift with energy;



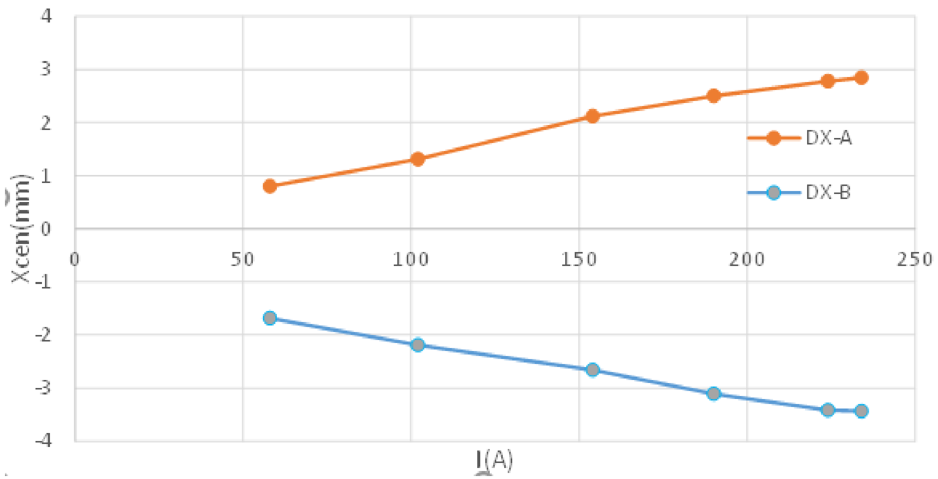
E(GeV)	I(A)	GL(T)-A	GL(T)-B	GL_A/GL_B-1
45	57.99	-3.36	3.35	0.40%
80	101.99	-5.91	5.88	**0.59%**
120	153.98	-8.89	8.85	0.49%
148	189.98	-10.93	10.89	0.40%
175	223.99	-12.77	12.73	0.30%
182.5	233.99	-13.27	13.21	0.40%



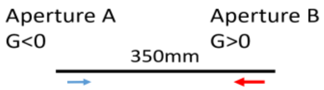


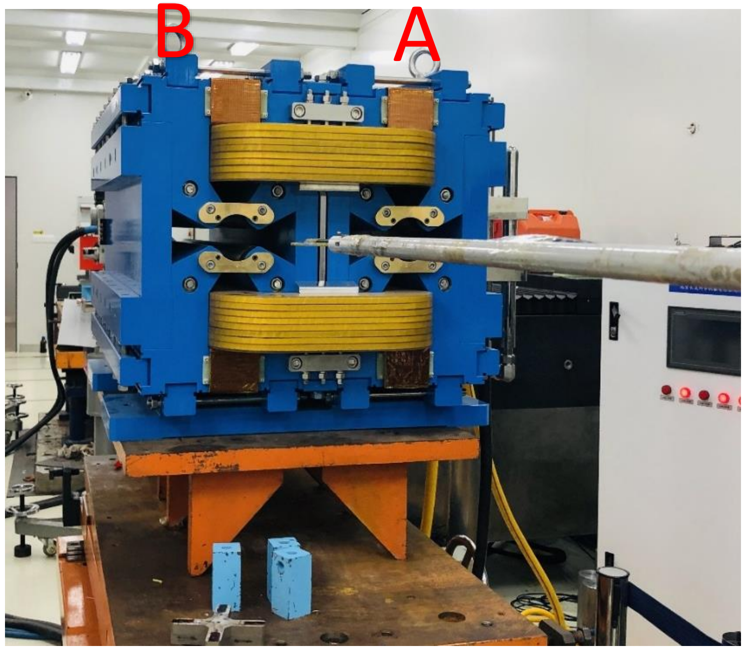
DAQ parameters and first prototype

- Problems with the first design
  - One DT4 sheet only can only work at one situation.
  - The DAQ magnet should work at four different energy cases and with trim coils.
  - The harmonics of b1 and b3 vary large at different field levels and with trim coils.



X0 shift with energy

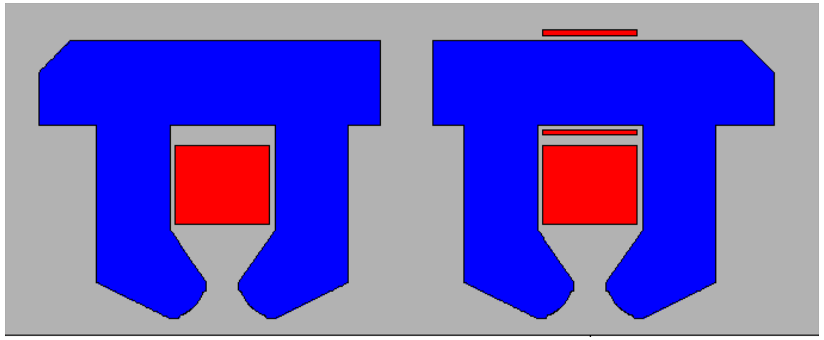




Prototype on the hall measurement bench

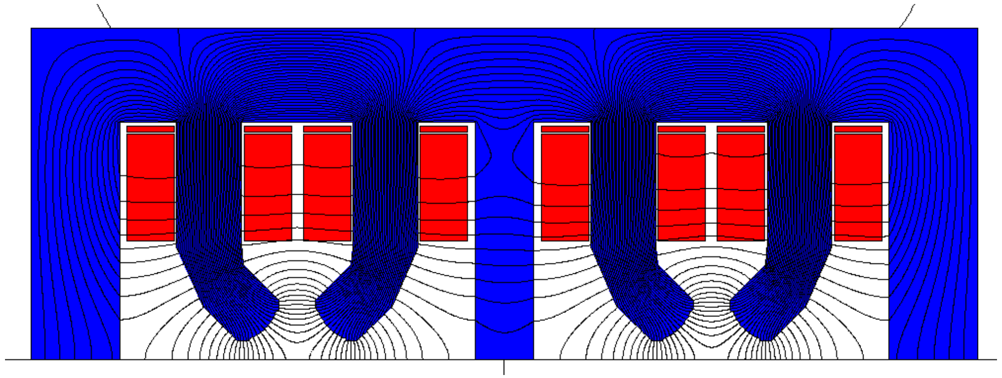
Alternative design schemes

- Two separate irons with common coils
  - ➢ Mechanical depart;
  - ➢ No X center shift with energy shift
  - ➢ Large and constant b1 and b3, and can compensate by iron shim;
  - ➢ Trim coils on the yoke, far away from the midplane.



Separate irons, no DT4 compensation sheet
2020 CEPC DAY

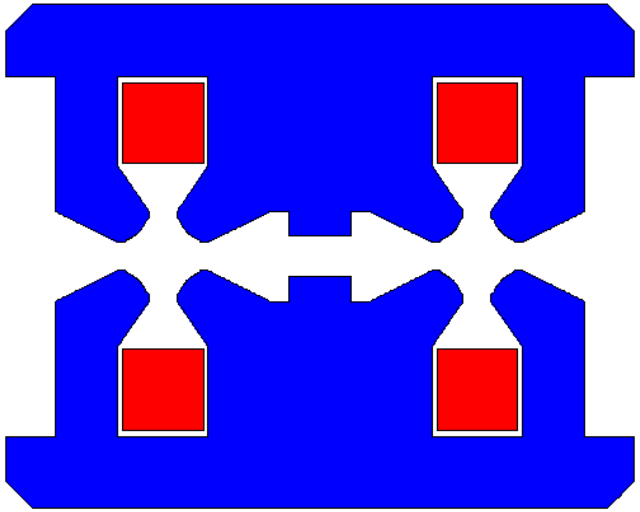
- Parallel iron with 8 main coils
  - ➢ Large power supply
  - ➢ Nearly no cross talk effect between two apertures.



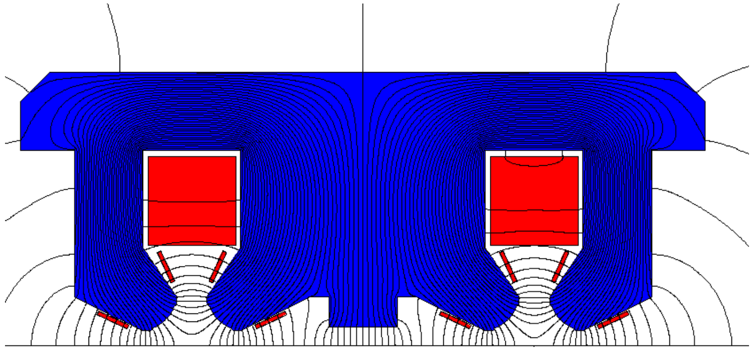
8 main coils, F/F design
2021 IAS

Optimization of the design

- With center shim, make the flux distribution symmetrical in a single aperture.
  - @120GeV: b1 and b3 reduced a lot.
  - No obvious shift at different energies.
  - Trim coils on the poles.
  - Strong cross talk between the two apertures.



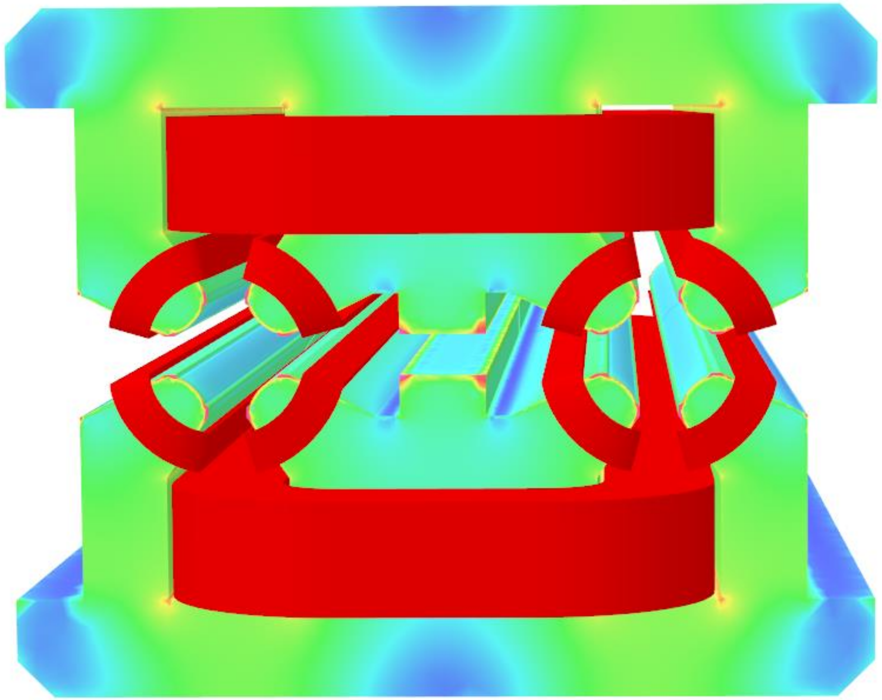
E=120GeV	origin		center shim	
n	Bn/B2-L	Bn/B2-R	Bn/B2-L	Bn/B2-R
1	1557.30	-1557.27	-13.51	13.53
2	10000	10000	10000	10000
3	126.14	-126.18	-1.11	1.06
4	0.52	0.52	0.51	0.53
5	1.70	-1.71	-0.02	0.01
6	-0.04	-0.03	-0.04	-0.03
B1(T)	-0.01622	-0.0162197	0.00014	0.00014
B2(T)	-0.1041546	0.1041547	-0.10411	0.10411
B3(T)	-1.31E-03	-0.0013143	0.00001	0.00001
G(T/m)	-8.537	8.537	-8.534	8.534
S(T/m2)	-17.654	-17.660	0.155	0.149



Optimization of the design

- With trim coils in 3D simulation
  - ➢ Little b1 & b3 variations in the energy range

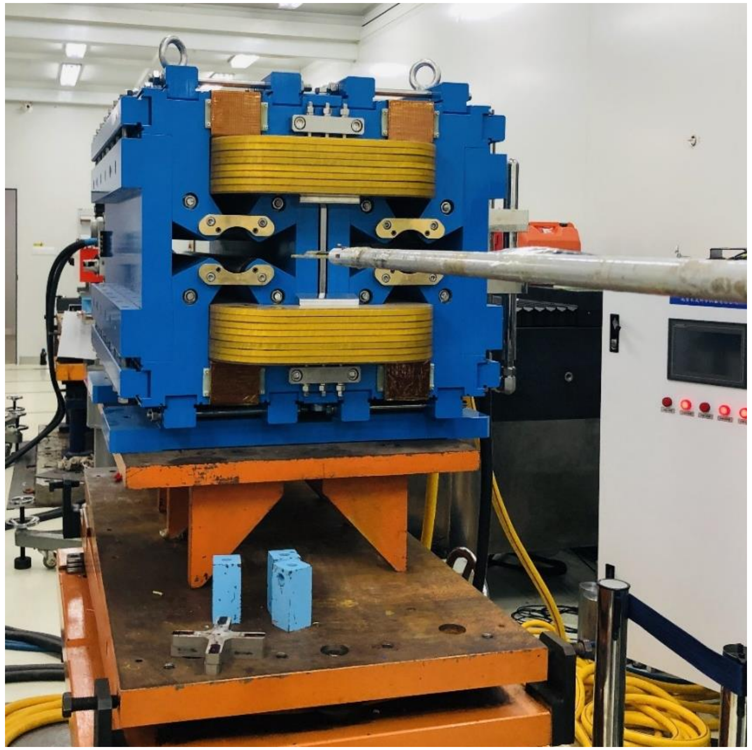
Trimcoil	45GeV		120GeV		182.5GeV		change
	AP_L	AP_R	AP_L	AP_R	AP_L	AP_R	
G(T/m)	-3.18	3.28	-8.39	8.64	-12.68	13.05	
b3	9.63	-9.53	9.64	-9.72	10.52	-11.58	-2.05
b4	0.53	0.41	0.54	0.42	0.56	0.43	
b5	0.11	-0.12	0.11	-0.12	0.12	-0.14	
b6	-0.34	-0.31	-0.35	-0.31	-0.36	-0.33	
x0(mm)	0.2937	-0.2834	0.2936	-0.2807	0.2841	-0.2560	0.0274
Beam sep		-0.5770		-0.5743		-0.5401	0.0369

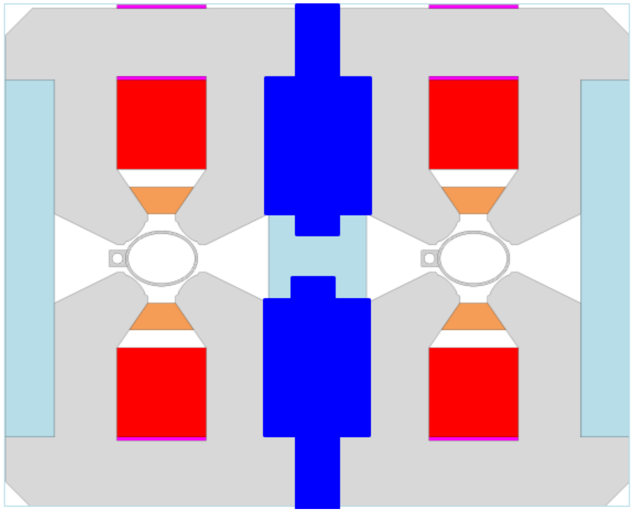


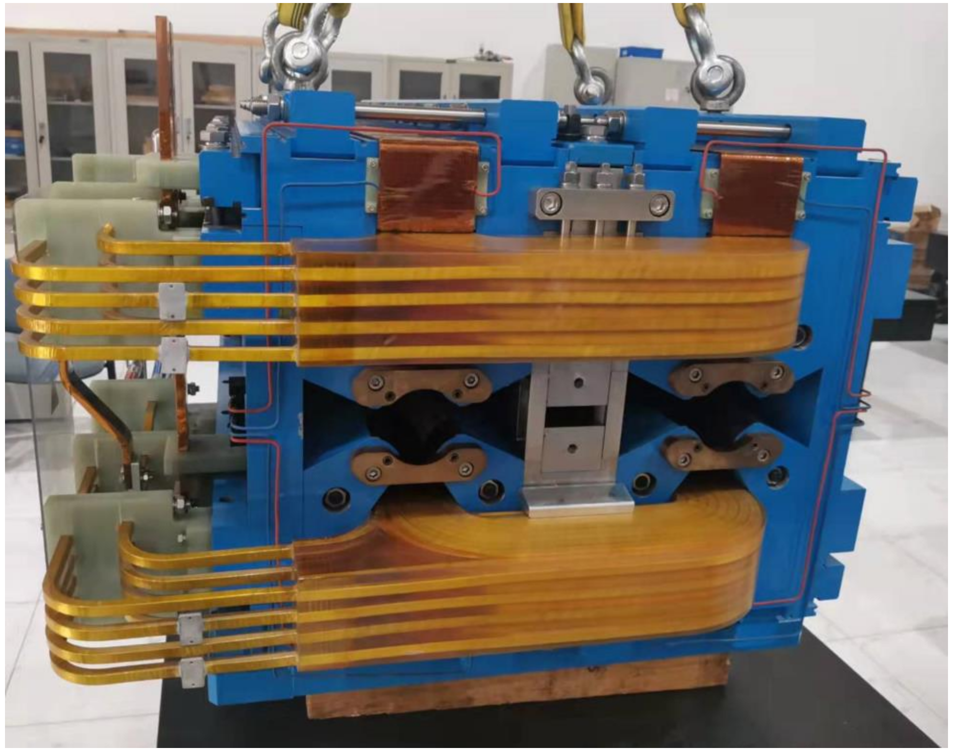
DAQ simulation shows that the F/D scheme can meet the requirement.

Modified DAQ-1m prototype

- 1m long prototype modification
  - DT4 iron in the middle instead the sheet and stainless steel.

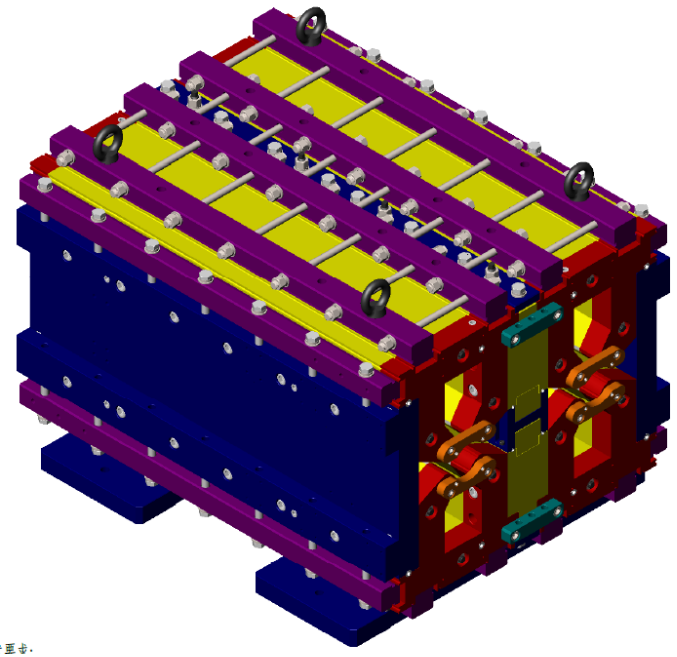




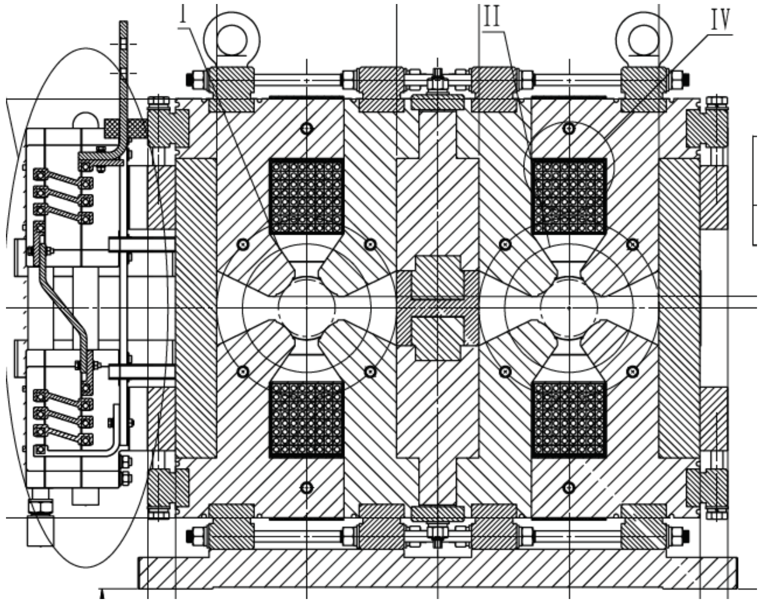


Prototype modification and field measurement results

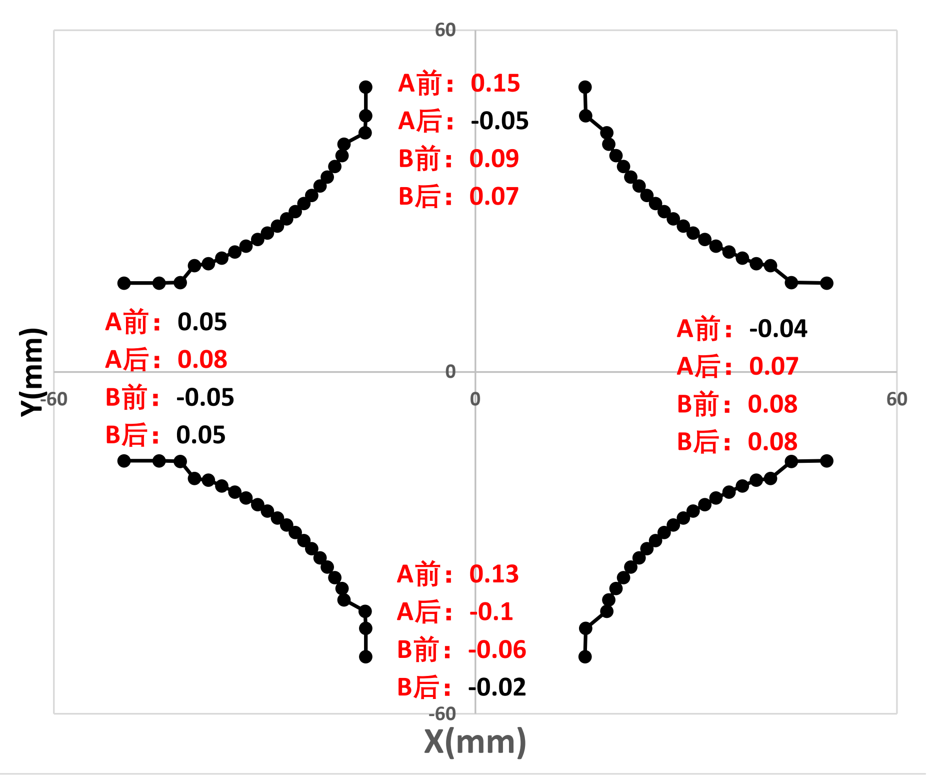
- Magnet assembly errors （tolerance:±0.05mm)
  - ➢ Complex structure: laminated, with trim coils and shared main coils
  - ➢ Large magnet blocks, long iron length, slender poles.
  - ➢ The final assembly is out of tolerance.



Iron model



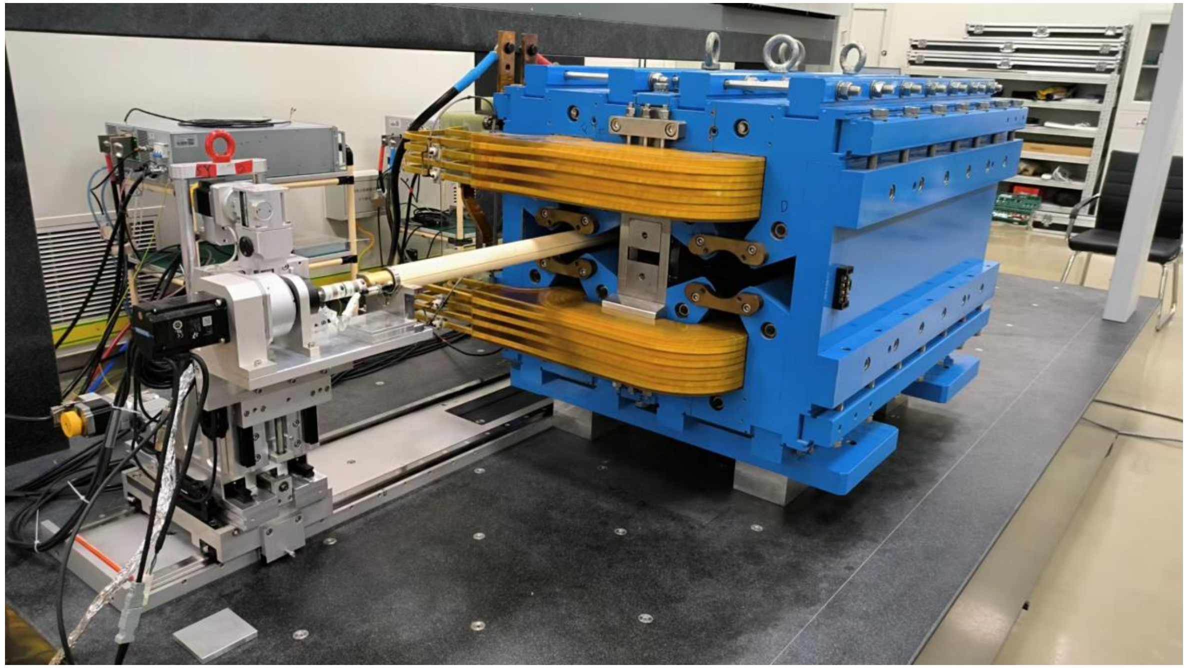
Cross section of DAQ



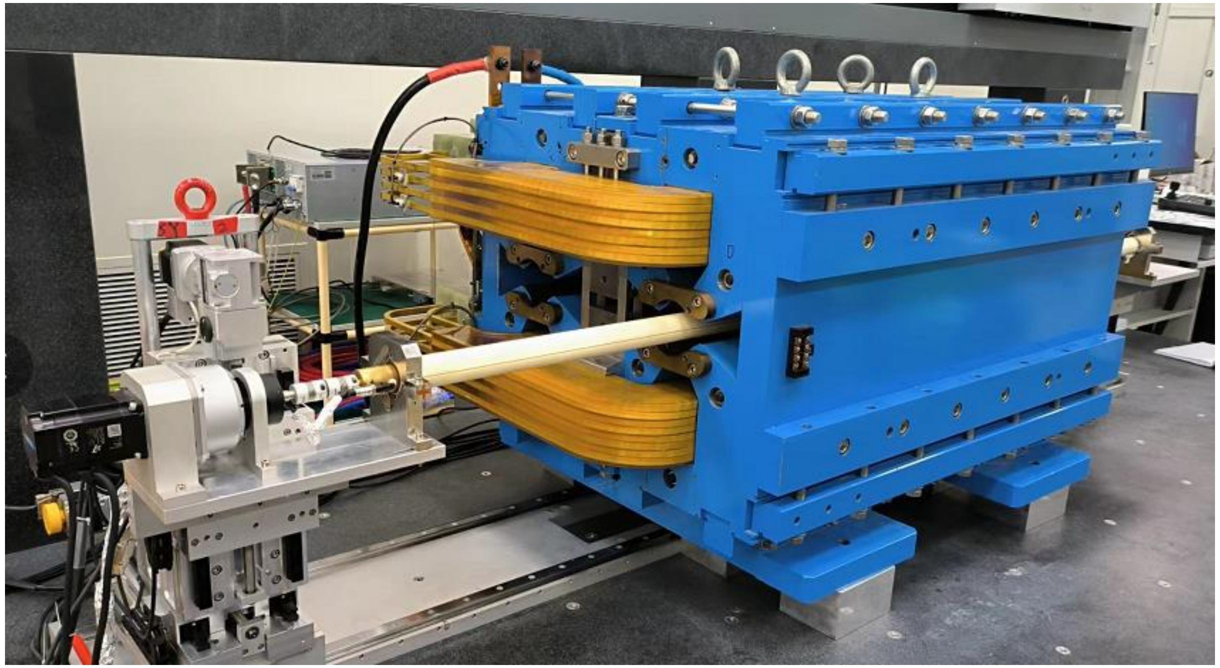
Gap between poles

Prototype modification and field measurement results

- Field measurements with rotating coil measurement system
  - Aperture A: F polarity
  - Aperture B: D polarity



Aperture A

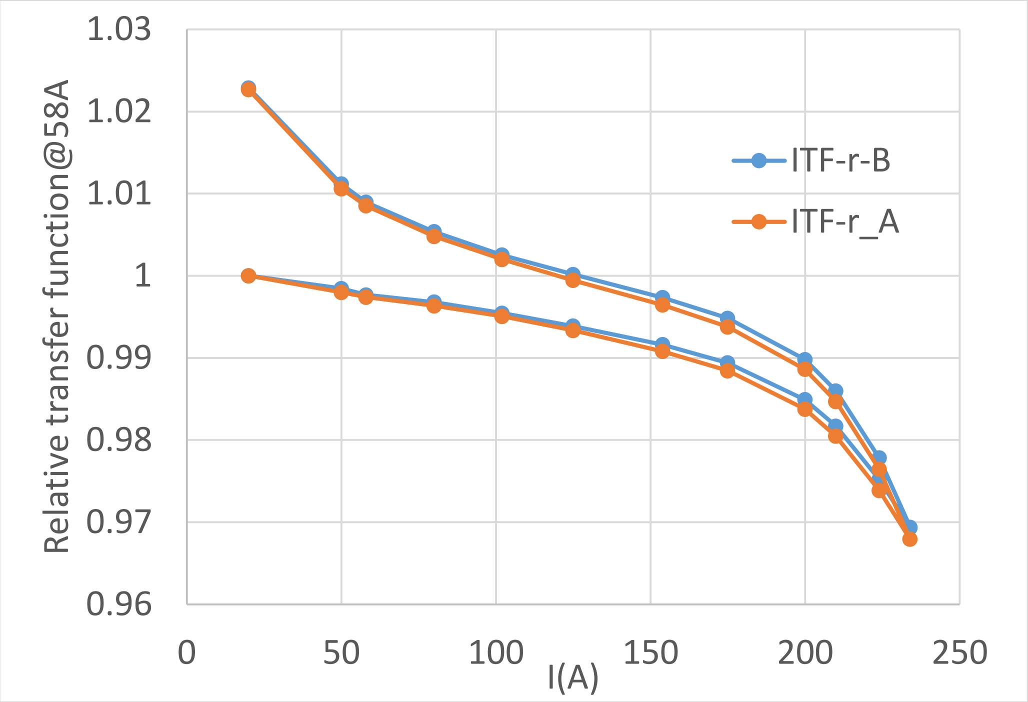


Aperture B

Prototype modification and field measurement results

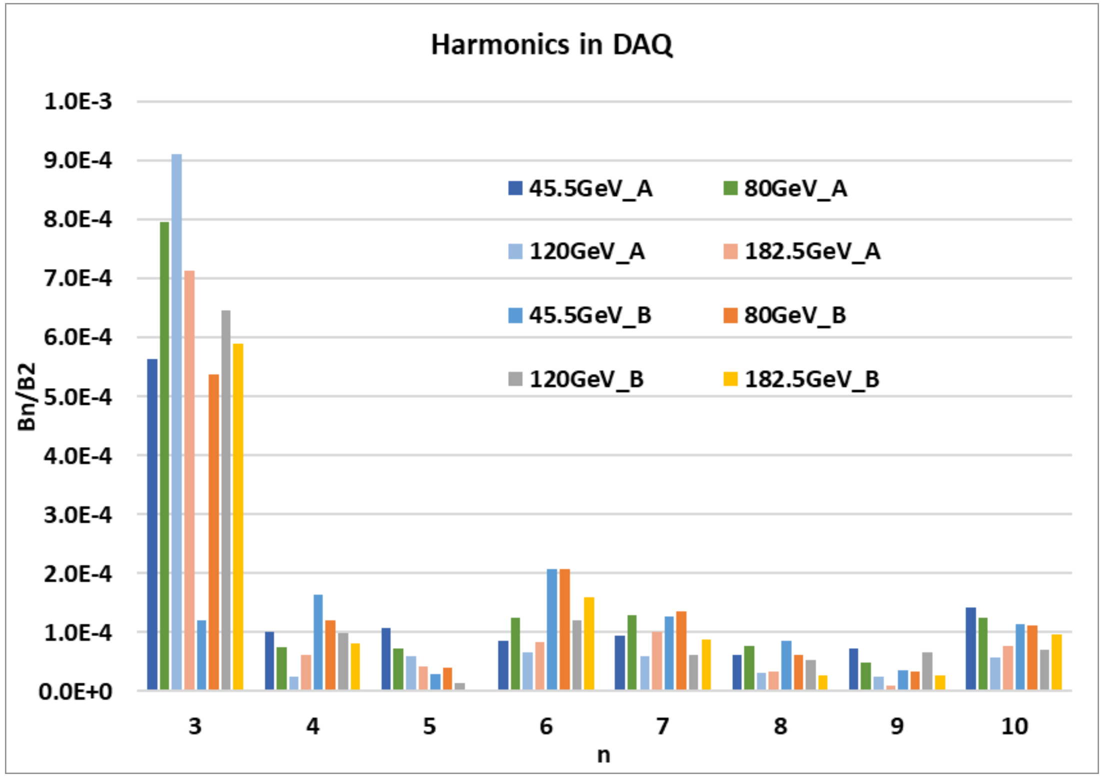
- RCS results—Integral transfer function
  - GL difference in two apertures： <0.2%
  - Similar transfer function in two apertures.
  - The efficiency is about 97.8%, not saturated.

E(GeV)	Ireal(A)	PHI2_A	PHI2_B	BL_A/BL_B-1
45.5	57.99286	0.02407	0.024025	0.19%
80	101.9951	0.042234	0.042161	0.17%
120	153.9915	0.063491	0.063409	0.13%
182.5	233.9919	0.094249	0.094182	0.07%



Prototype modification and field measurement results

- Harmonics:
  - ➢ Higher harmonics: less than 3 units, except sextupole component.
  - ➢ Possible reasons:
    - Large mechanical assemble errors;
    - Iron deformation;
    - Cross talk effect is not compensated completely.
  - ➢ Possible solutions:
    - Adjust the compensate blocks.
    - Magic finger to adjust the field.

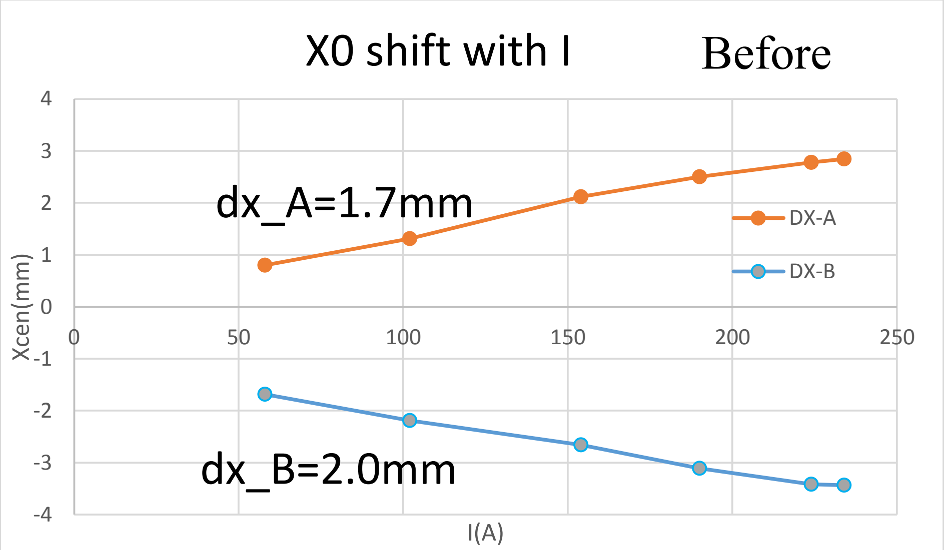


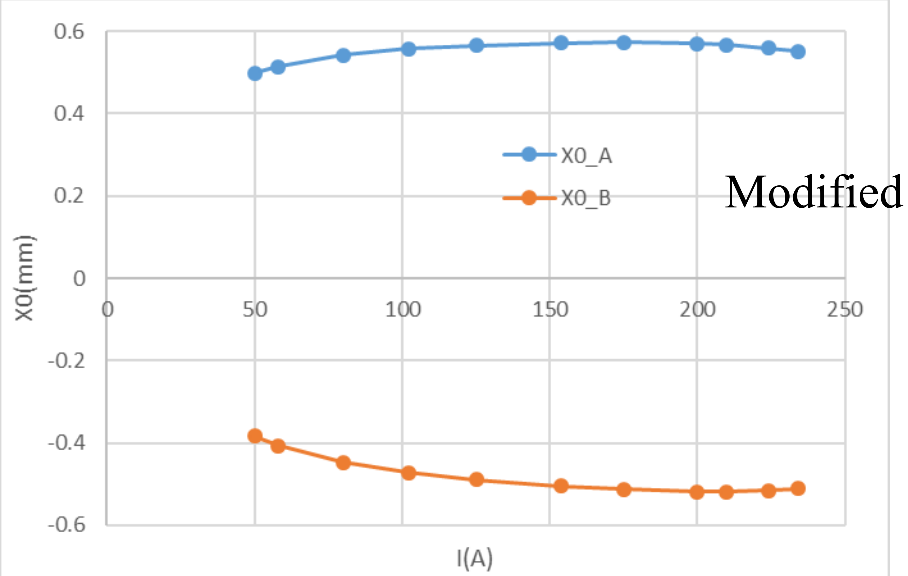
Prototype modification and field measurement results

- Shift of magnetic center with energy
  - X0_A varies 0.056mm， X0_B varies 0.105mm
  - Possible reason: incomplete compensation; iron properties different.

  - Y0_A varies 0.04mm
  - Possible reason: Busbars' location.

E(GeV)	Ireal(A)	X0_A(mm)	Y0_A(mm)	X0_B(mm)	Y0_B(mm)
45.5	57.99286	0.514	0.174	-0.406	-0.078
80	101.9951	0.557	0.166	-0.472	-0.074
120	153.9915	0.571	0.157	-0.505	-0.069
182.5	233.9919	0.551	0.133	-0.511	-0.072
	max-min	0.056	0.040	0.105	0.009





Summary

- First prototype is a laminated one and composed by many blocks, whose strength and stiffness is weak. The design will be reviewed later, especially the mechanical design.
- After iron modification with center shim, X0 shifts is reduced by an order, which is agreed with the simulation results.
- New trim coils will add on the poles to taper the gradient in the two apertures.
- Further modification
  - Adjust the gap height of the center shim, to compensate the cross talk effect.
  - Add trim coils or use the correctors to adjust the x0 shift at different energies.

Thank you very much!