Experience on spoke cavity development and future plan at IHEP

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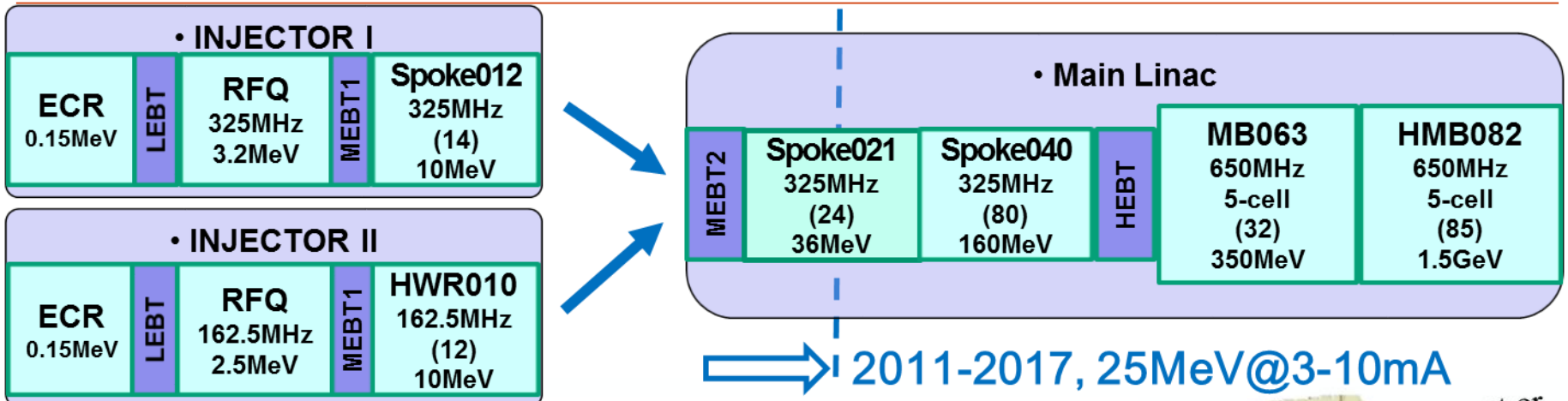
On behalf of colleagues in IHEP SRF group

Institute of High Energy Physics (IHEP)

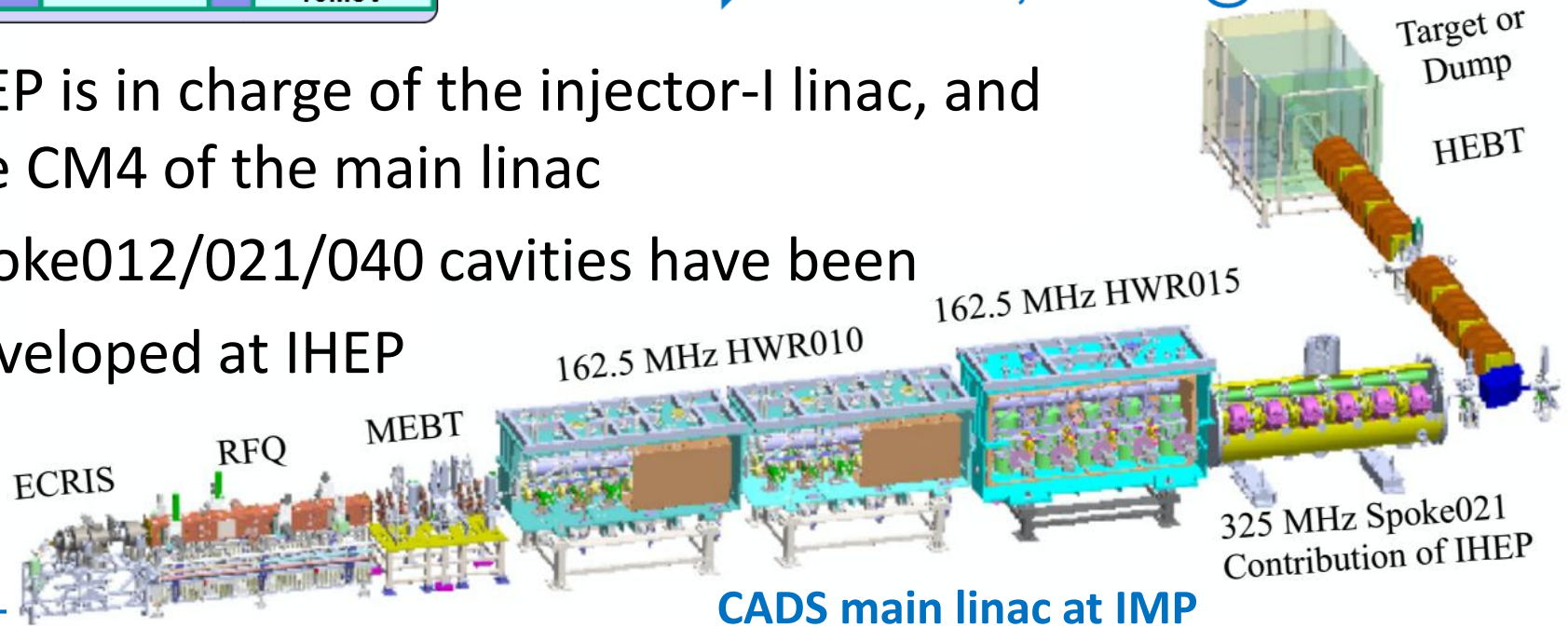
Outline

- Introduction to CADS linac
- Development of spoke cavities
- Cryomodule commissioning and operation
- Future plans

Introduction to the CADS linac



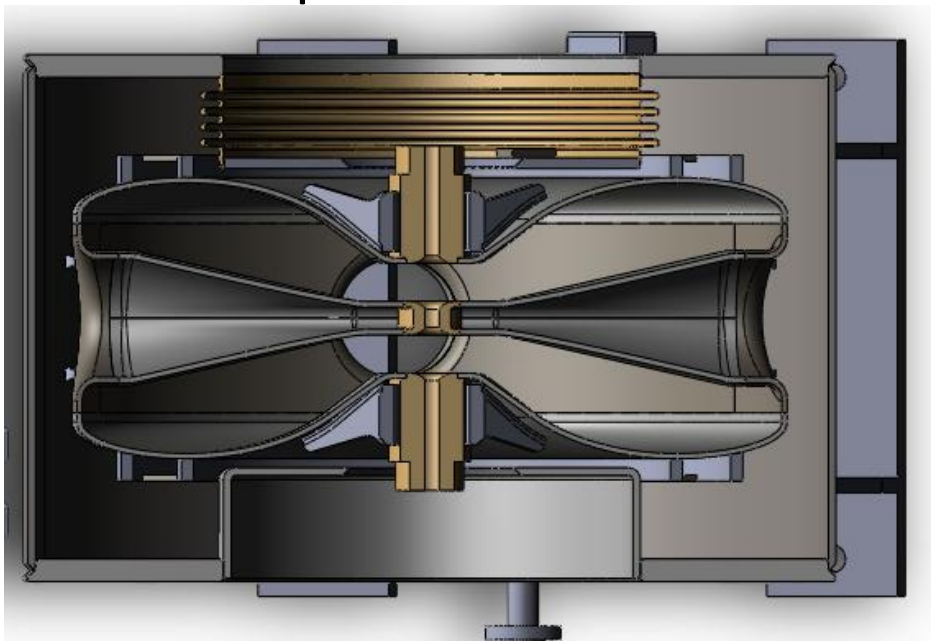
- IHEP is in charge of the injector-I linac, and the CM4 of the main linac
- Spoke012/021/040 cavities have been developed at IHEP



CADS main linac at IMP

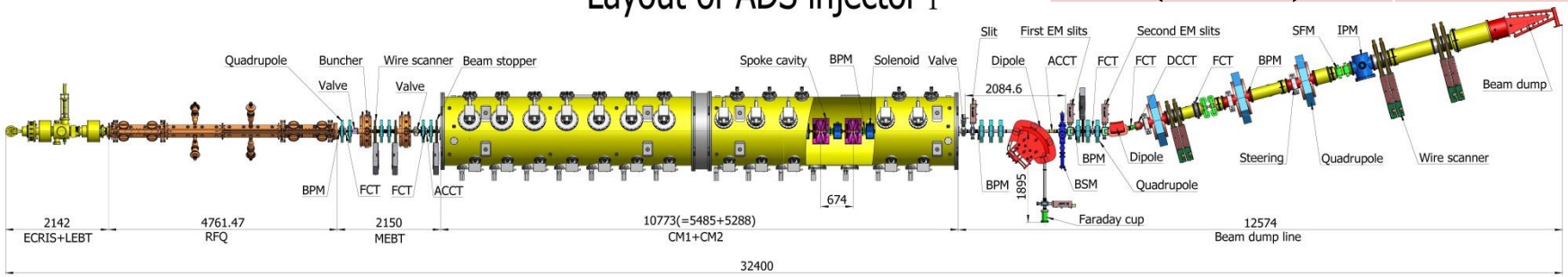
Spoke012 cavity

14 cavities in 2 CM. Beam commissioned with 2mA CW proton from 3.2MeV to 10MeV



	Spoke 012
β_0	0.14
Aperture-mm	35
Ep/Eacc	5.0
Bp/Eacc-mT/(MV/m)²	6.9
G-Ω	60
R/Q-Ω	150
df/dp [Hz/mbar]	-40
df/dp [Hz/mbar] (measured)	-130~-83
LFD [Hz/(MV/m)2]	-13

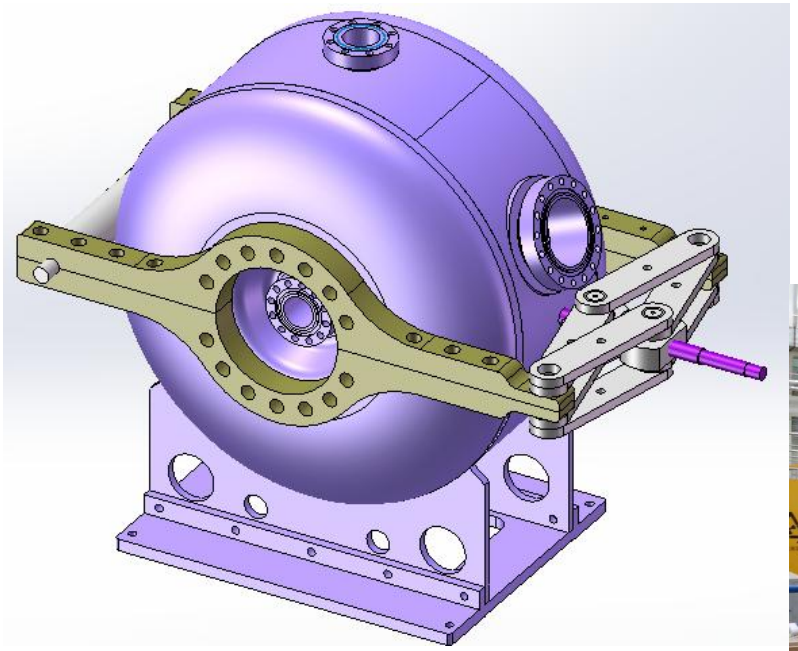
Layout of ADS injector I



Spoke021 cavity

- 6 cavities in one CM. developed in IHEP, Assembled in IMP. Beam commissioning is on going.

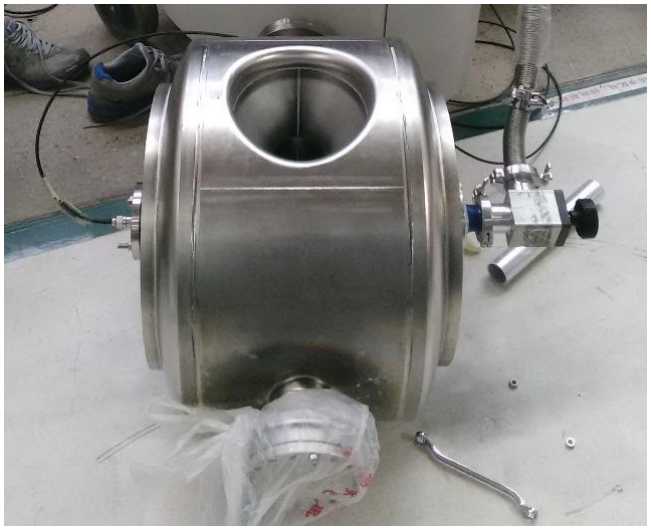
	Spoke 021
β_0	0.24
Aperture-mm	40
Ep/Eacc	4.4
Bp/Eacc-mT/(MV/m)^2	9.4
G-Ω	71
R/Q-Ω	191
df/dp [Hz/mbar]	-6
df/dp [Hz/mbar] (measured)	<-10

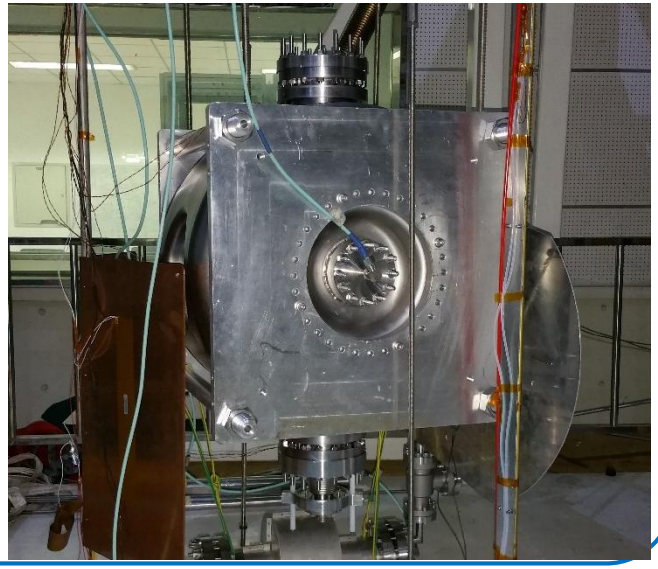


Spoke040 cavities

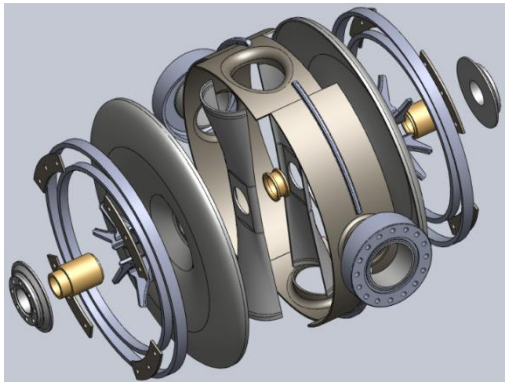
- It was proposed to use 72 Spoke 040 cavities in the future ADS linac
- Two type of Spoke040 cavities have been fabricated and exceeded design target in vertical test

	Spoke 040-1	Spoke 040-2
Freq. [MHz]	325	650
β_0	0.46	0.40
Aperture [mm]	50	50
E_p/E_{acc}	3.9	3.6
B_p/E_{acc} [mT/(MV/m)]	9.2	8.8
Geometry factor [Ω]	104	91
R/Q [Ω]	265	246





Fabrication of IHEP spoke cavities



LHe vessel ← Single cavity test

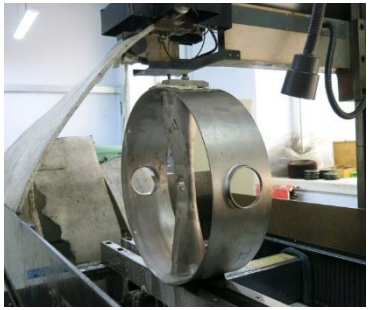
Design → Fabrication → Post processing → Assembly

Certification from vendor
Eye inspection

Material

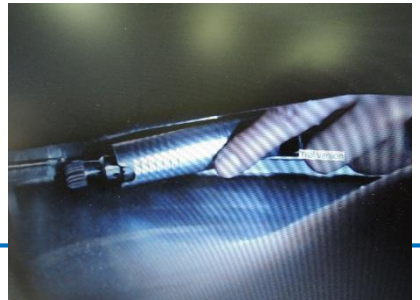
Technology

Deep drawing, annealing, machining, frequency control, grinding, EBW



Defect inspection and grinding before final EBW, size control, frequency control

Quality control



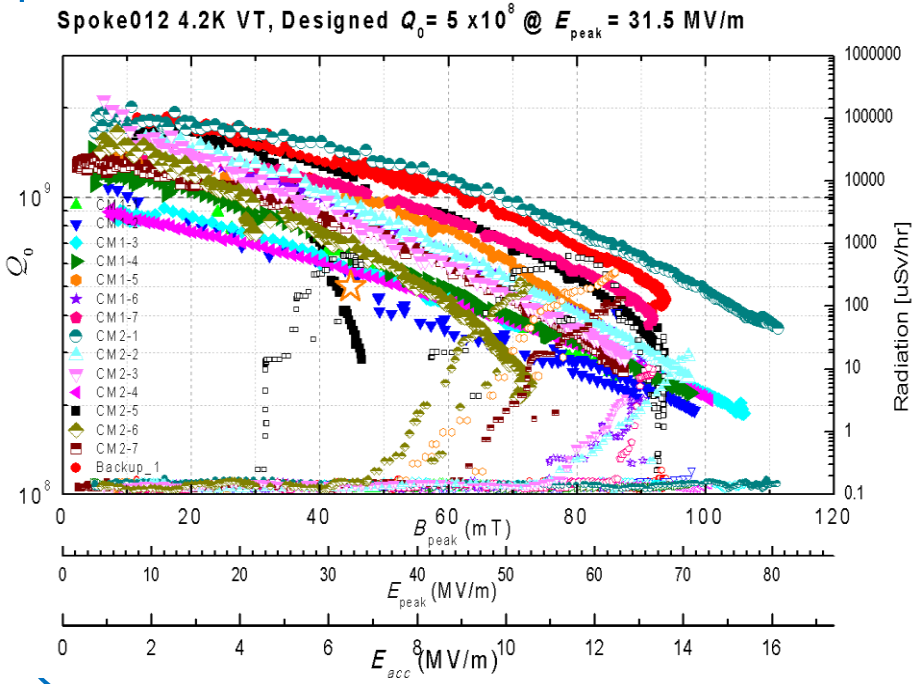
Post processing of Spoke cavities

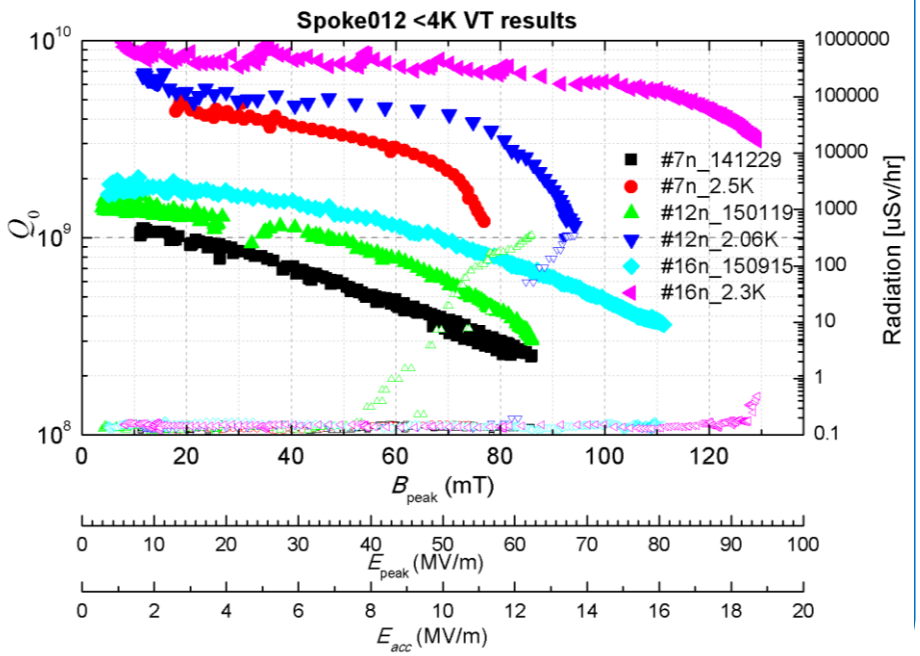
- BCP in Ningxia OTIC; re-HPR and clean assembly in IHEP

Ultrasonic
↓
BCP120 um
↓
800C 2hr
↓
BCP30 um
↓
HPR
↓
120C 48hr
↓
Vertical test
↓
Vessel weld
↓
650C 3hr
↓
BCP30 um
↓
HPR
↓
String assembly

VT results of the spoke012 cavities

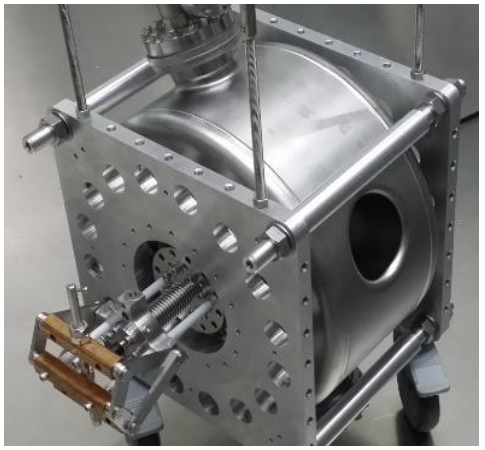
- MP conditioned in 1 hour with variable coupler
- Eacc increased by 2 MV/m with better cooling
- 120C baking increases Q_0 by about 50-100%
- At 2K, Q0 is 6 times higher, Bp~125mT achieved.

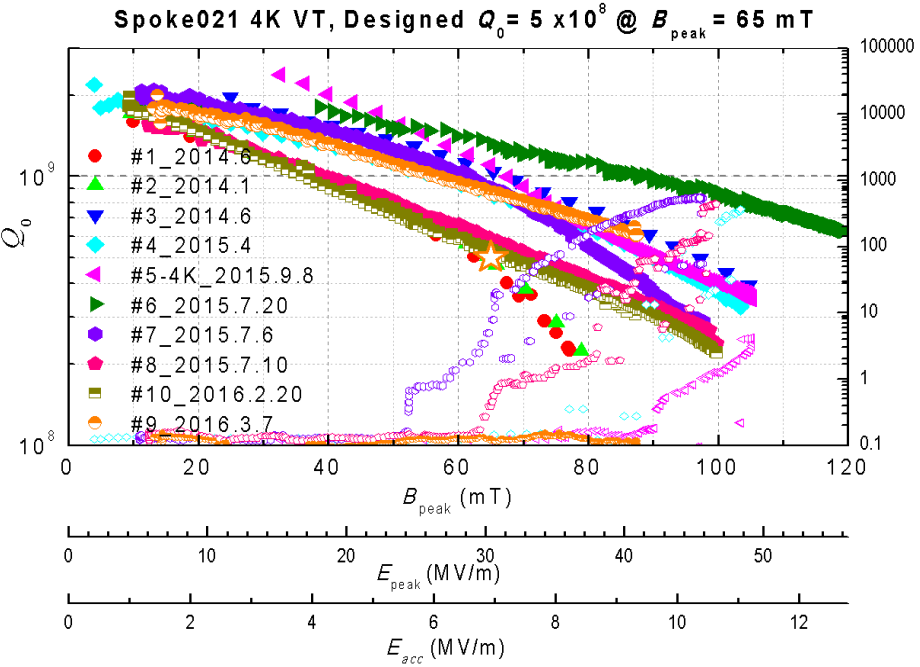


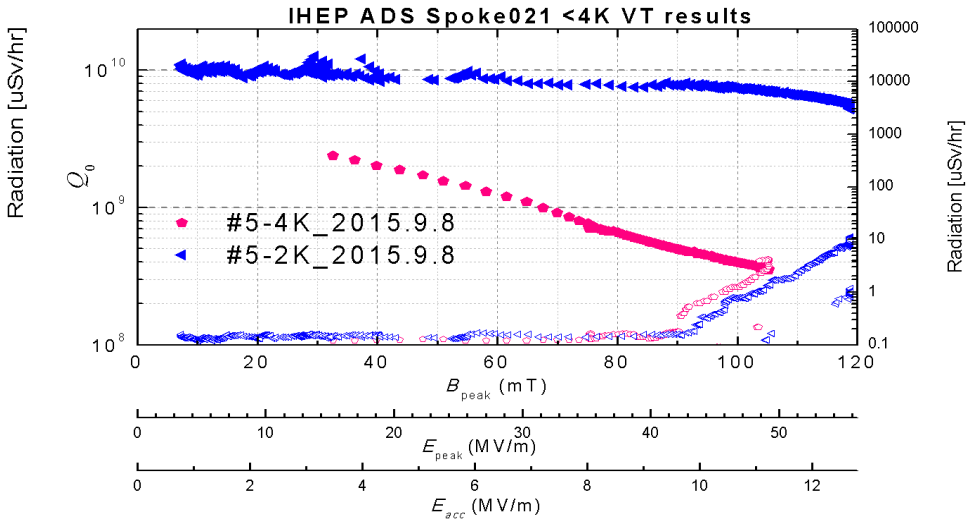


Spoke021 testing results

- MP conditioned in 1 hour
- Design target consistently exceeded
- Bp of 120mT and Rres of 7nΩ achieved at 2K







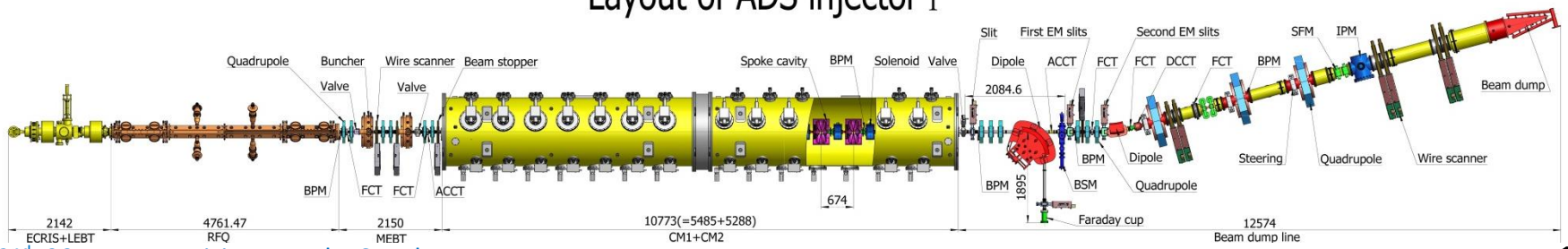
Outline

- Introduction to CADS linac
- Development of spoke cavities
- Cryomodule commissioning and operation
  - Measurements on cryomodule
  - Problems and improvements
- Future plans

Injector-I commissioning

- 2015.1.13, TCM was installed in the tunnel
- 2015.1.26, TCM reached 2K
- 2015.4, TCM was commissioned, CM1 installation started
- 2015.8.1, CM1 was installed in the tunnel
- 2015.8.28, CM1 reached 2K
- 2015.9.11-11.20, CM1 was commissioned
- 2016.3.20, CM1 and CM2 were connected in the tunnel
- 2016.6-2017.1, CM1 and CM2 were commissioning

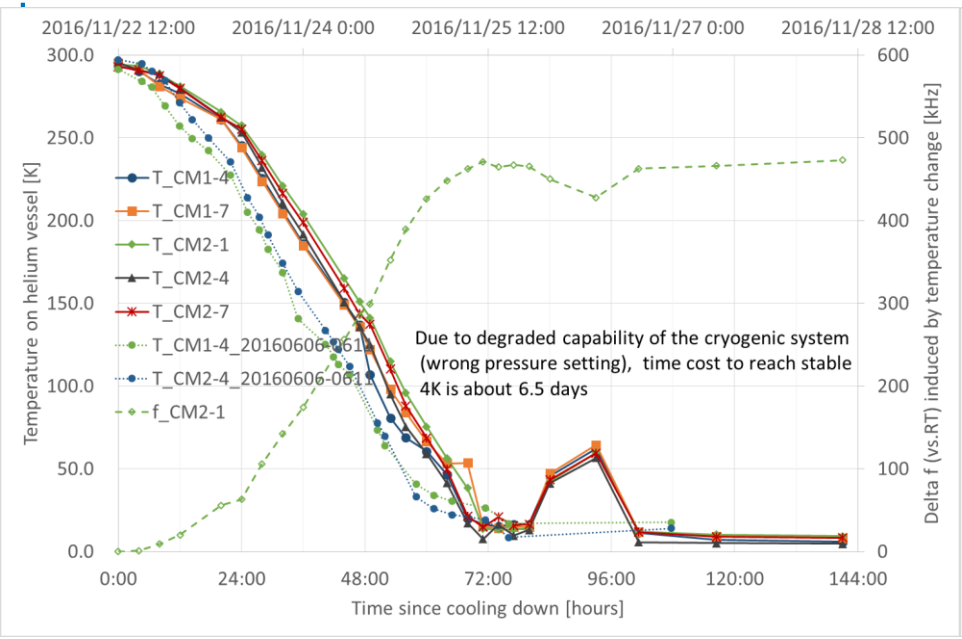
Layout of ADS injector I

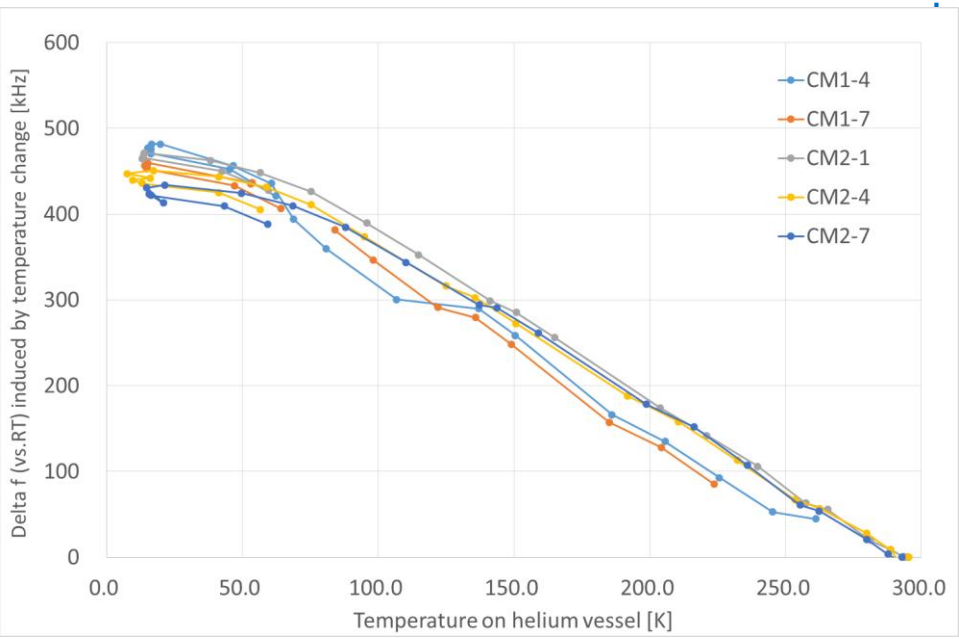


CM1&CM2 cooling down

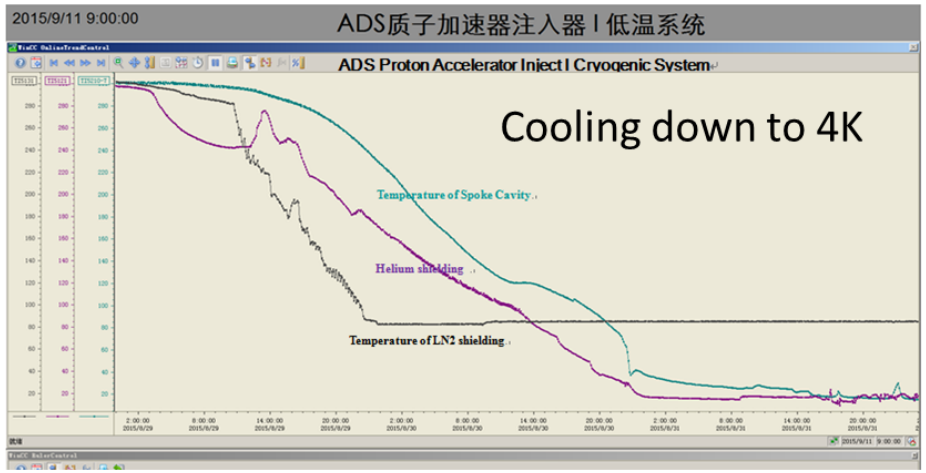
- It takes about 5-6.5 days to reach 4K stable operation
- Measured df/dp is about -130Hz/mbar for CM1 cavities, and -83Hz/mbar for CM2 cavities; LFD is about -13Hz/(MV/m)2; Q0 is not measured yet.

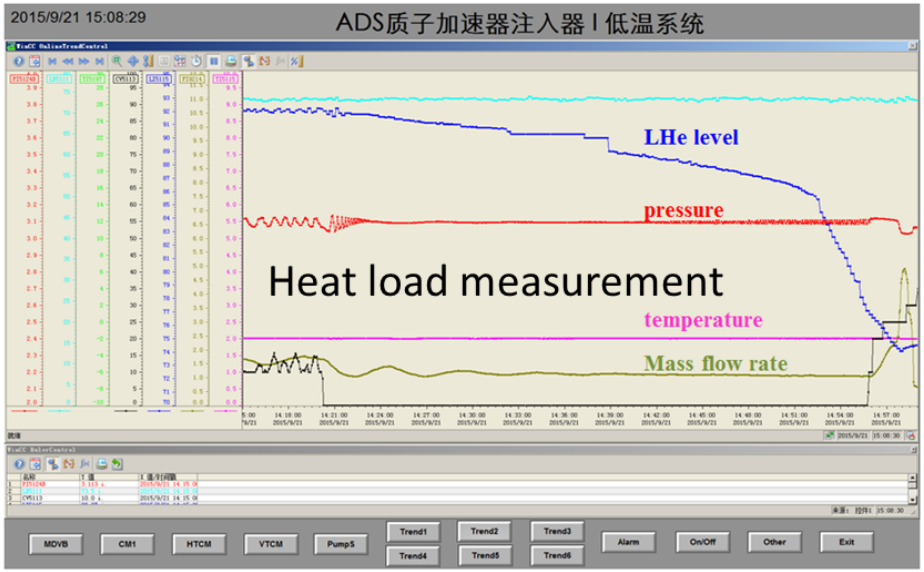
Cavity_ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
df_4KvsRT [kHz]	546	523	540	462	509	557	496	408	428	511	323	572	519	553
df/dp [Hz/mbar]	-157	-129	-134	-150	-131	-119	-91	-66	-47	-96	-82	-75	-97	-119
LFD [kHz]	-14	-12	-11	-13	-12	-10		-13	-13	-9	-10	-12	-9	-16



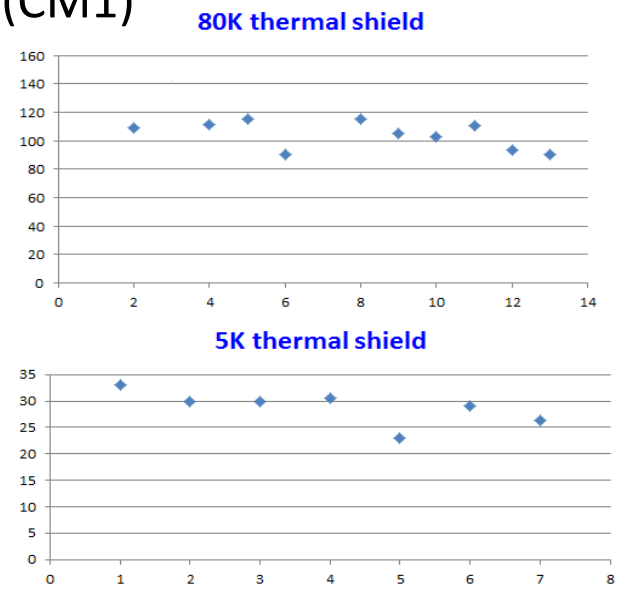


Static heat load of the CM1



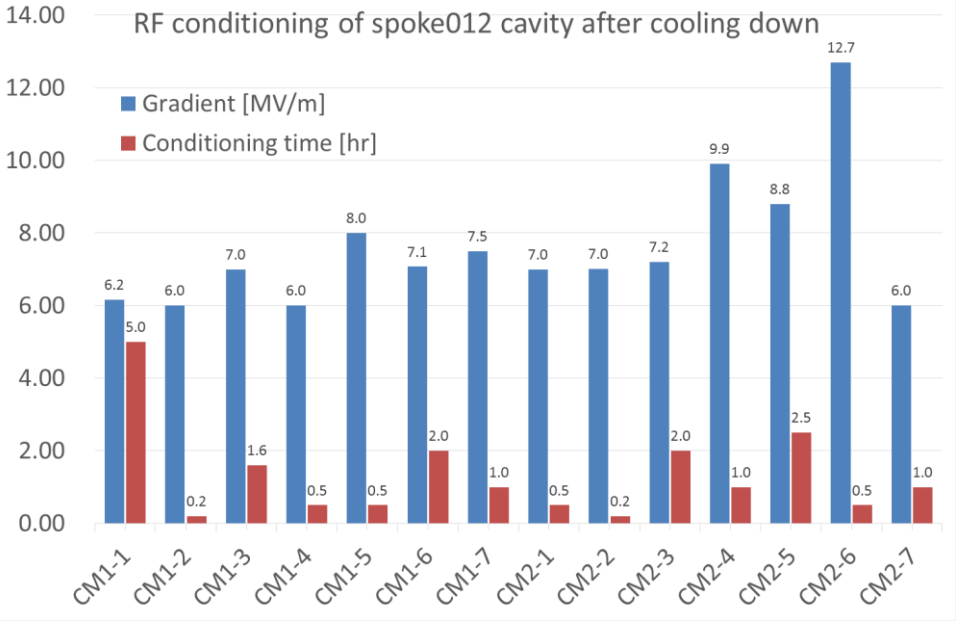


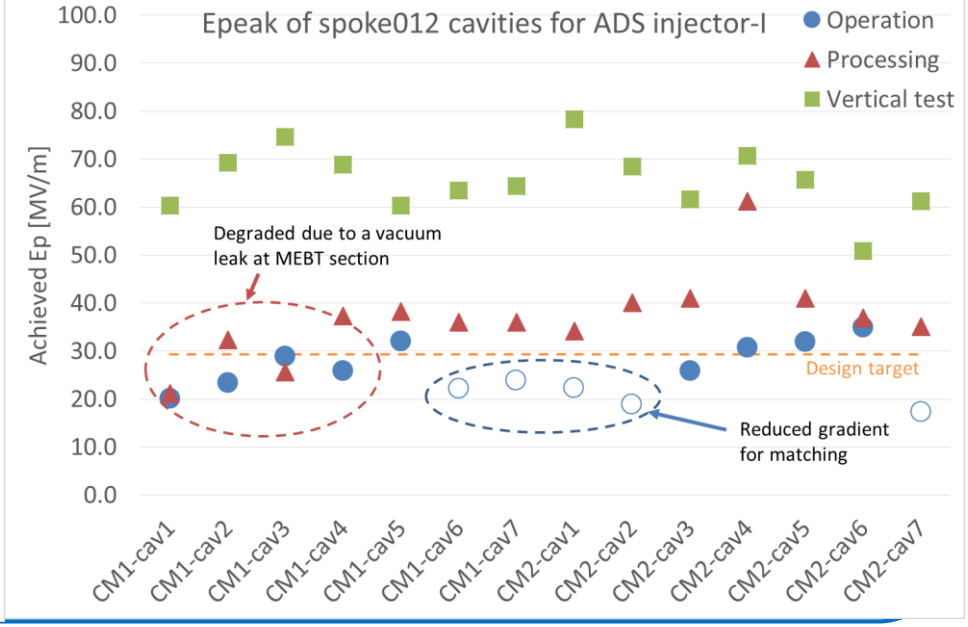
- The maximum temperature difference on thermal shields were less than 40K during cooling down
- Heat load of 30W measured by liquid level and mass flow rate agree in 7%
- LHe pressure stability was improved from ±0.6 mbar (TCM) to ±0.05 mbar (CM1)



Cavity conditioning

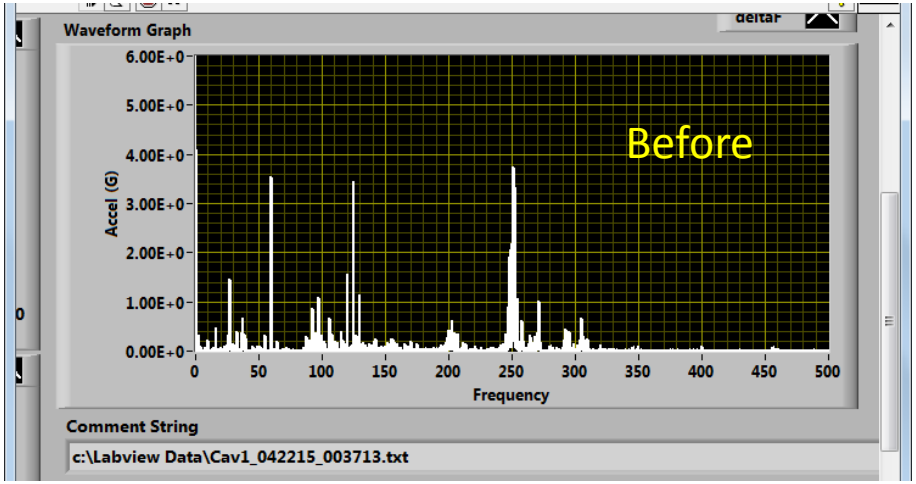
- Cavity conditioning at 4K typically takes 1-2 days
- Cavity was conditioned to 8MV/m before beam operation (FE for cav 1-4#, administrative for Cav5-14#)
- On beam operation of 10MeV mode, average cavity gradient is 6MV/m, i.e. Ep~27MV/m

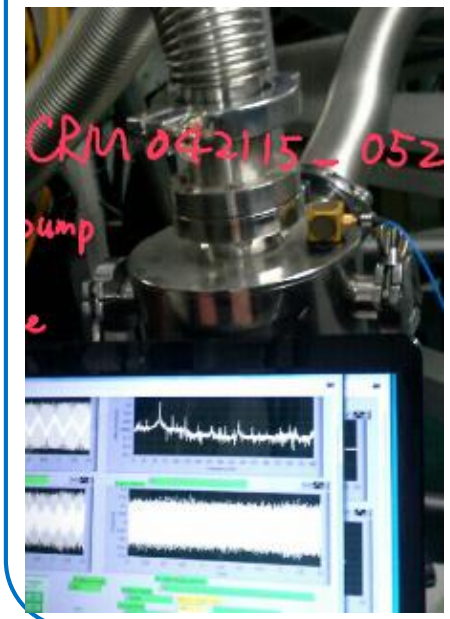


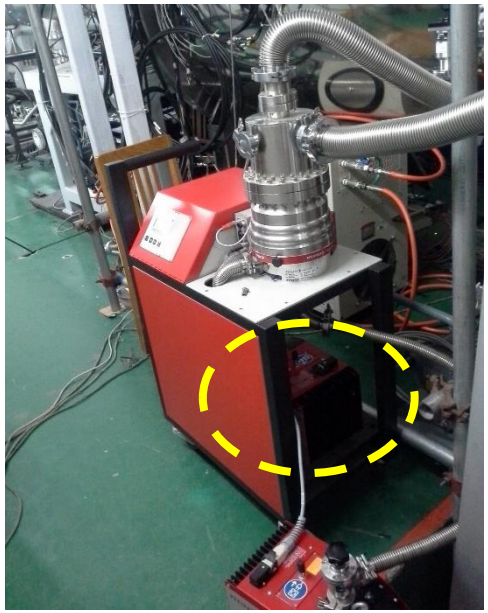


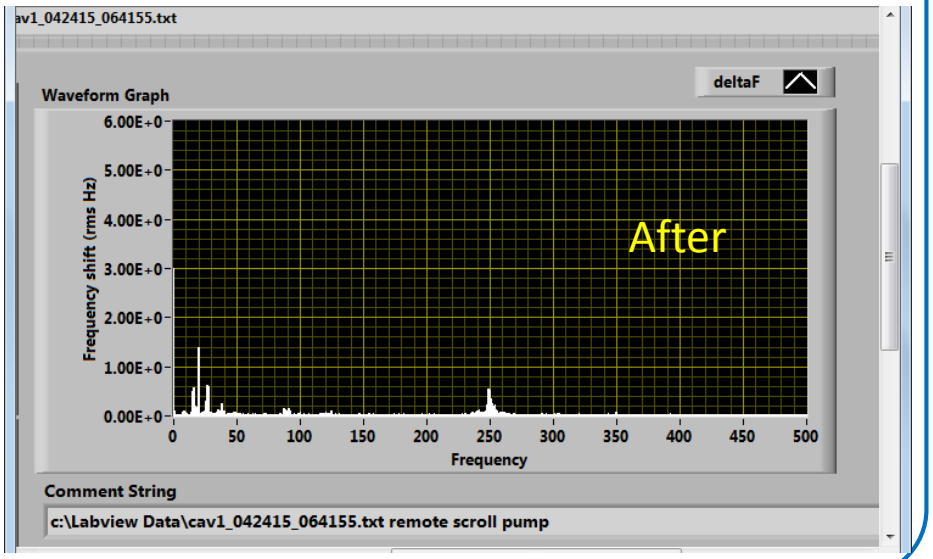
Problem: high noise level

- Vibration was measured by accelerometer
- Microphonics was reduced by one magnitude, by removing the scroll pump from the cart.



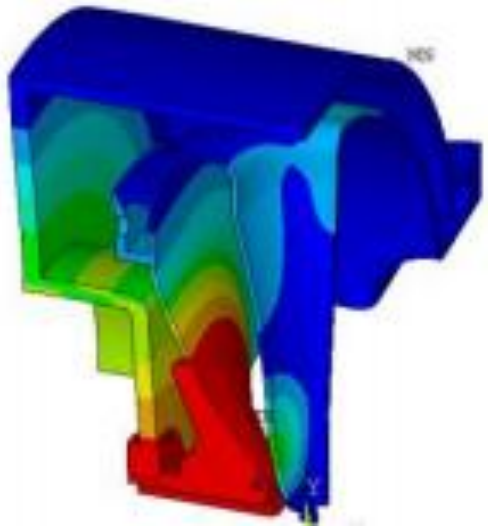






Problem: too high df/dp

- Problem: way too huge df/dp (-130 than -40Hz/mbar)
- Mainly by deformation of beam pipe
- Solution: adding stiffeners to He vessel, and stronger TIG welding



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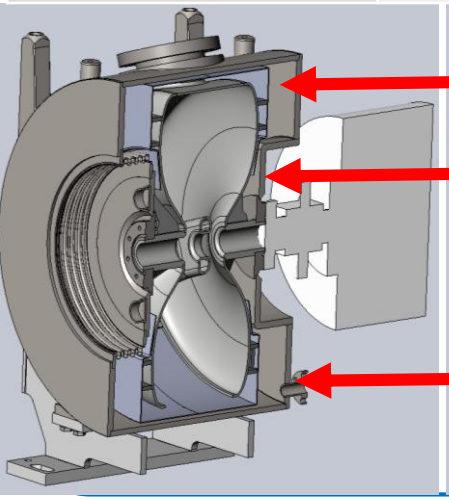
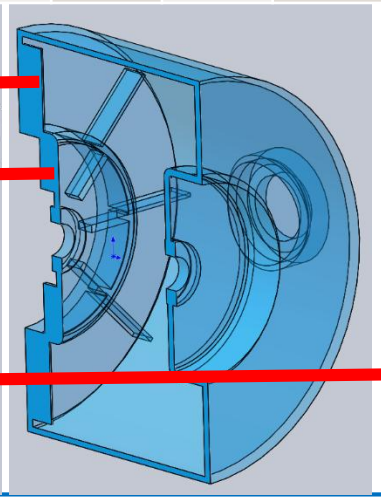
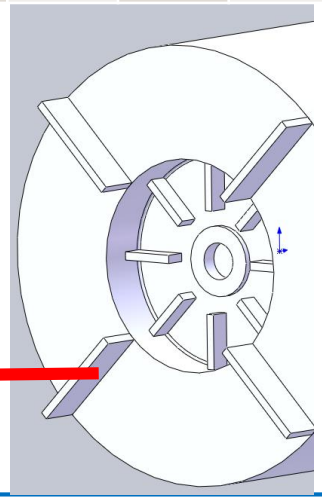
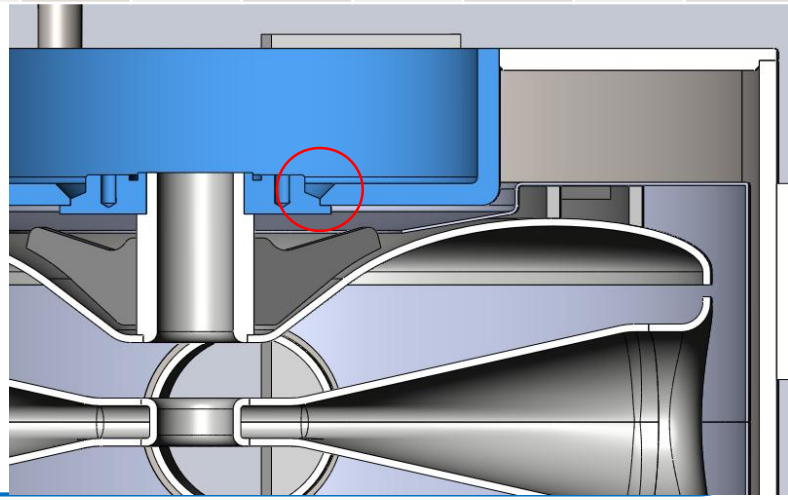
df/dp [Hz/mbar]	-157	-129	-134	-150	-131	-119	-91	-66	-47	-96	-82	-75	-97	-119
LFD [kHz]	-14	-12	-11	-13	-12	-10		-13	-13	-9	-10	-12	-9	-16







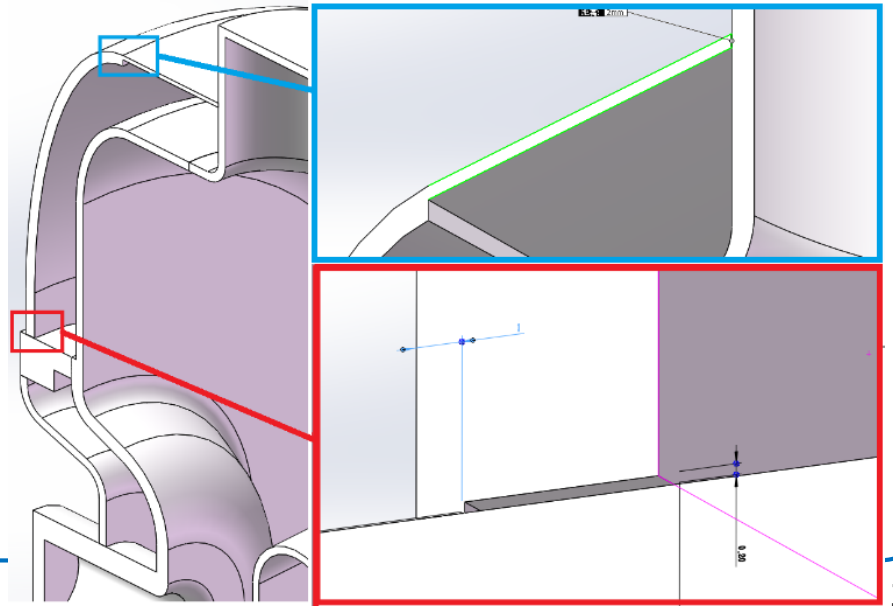


Un-expected high df/dp on Spoke021

- Improved design for df/dp ~ 10Hz/mbar
- Unexpected high df/dp in production phase
- df/dp is extremely sensitive to the depth of one weldment, which was switched from EBW to TIG
- Re-weld with EBW solved the problem

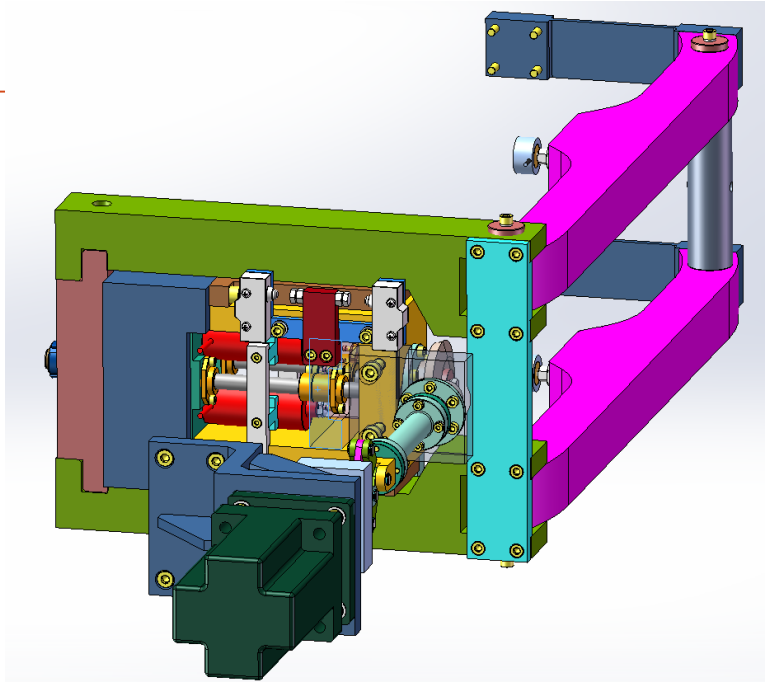
df/dp [Hz/mbar]	Before	After
021-5#	-60	0
021-6#	-40	-13
021-7#	-58	-12
021-8#	-82	-9
021-9#	-67	-15
021-10#	-65	-11

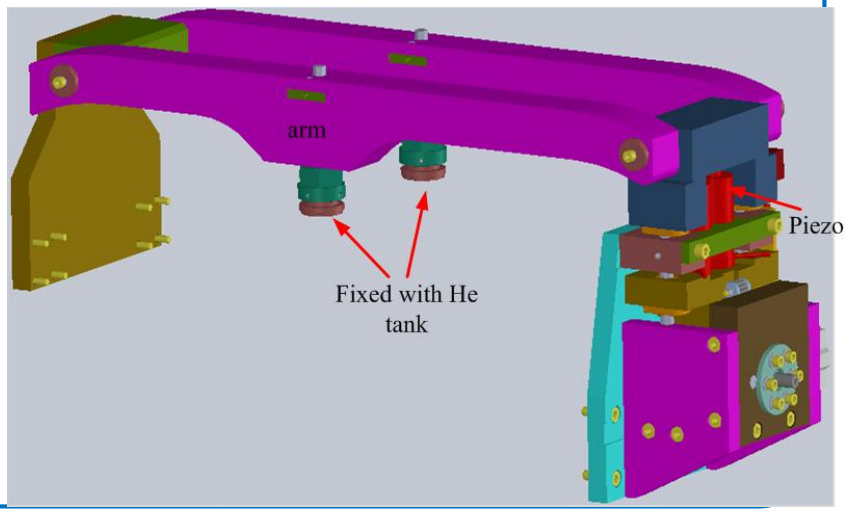
Weld depth[mm] (slide fit 0.2mm)	df/dp [Hz/mbar]
5	-1.0
4	-6.5
3	-16.2
2	-32.7
1	-64.4



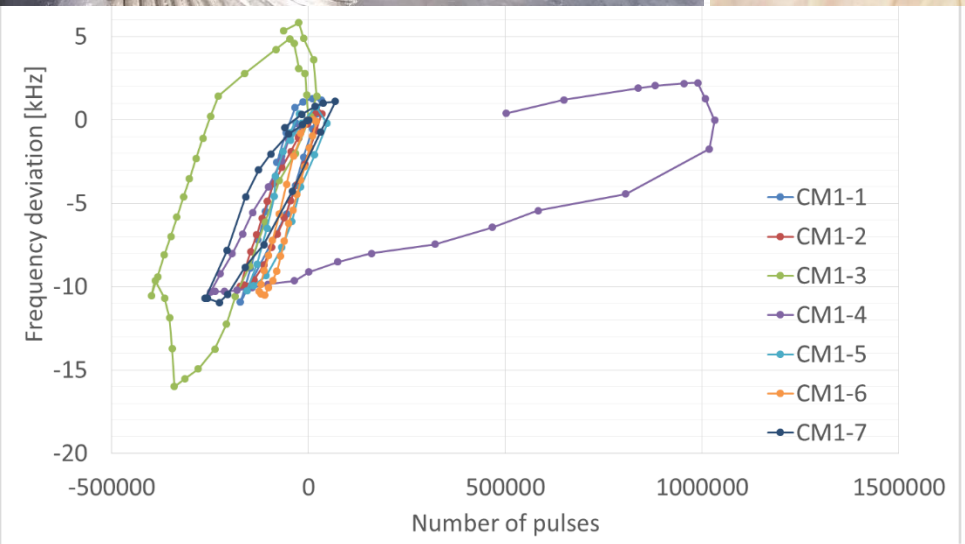
Tuner issue

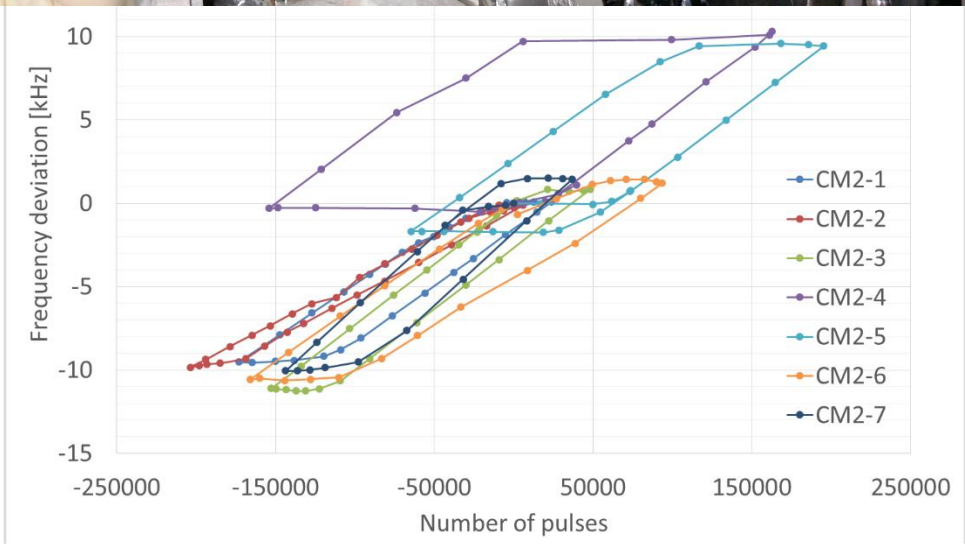
- Switch from pushing to pulling help reduce df/dp
- Severe backlash and overshoot possibly caused by gears and joints
- They were replaced from service port, which helped more or less





Tuner issue (2)

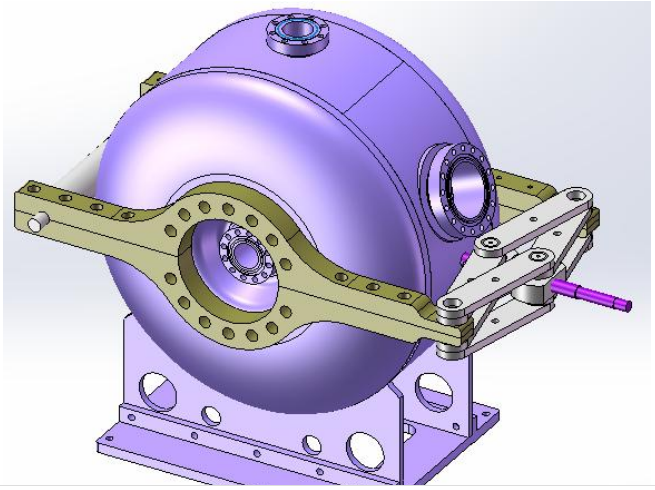


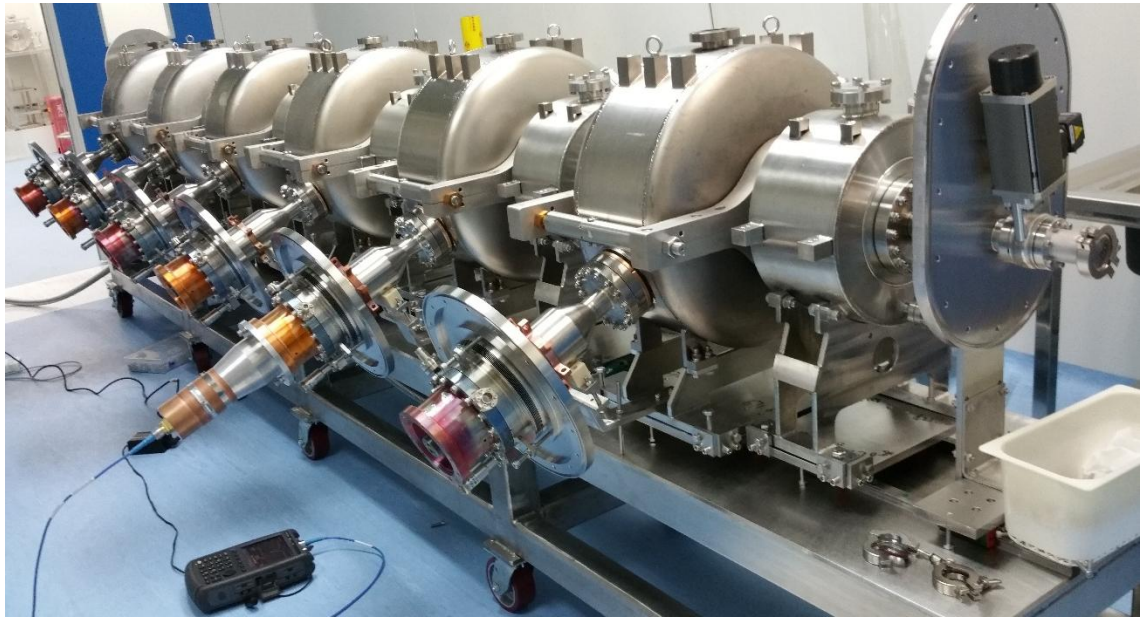


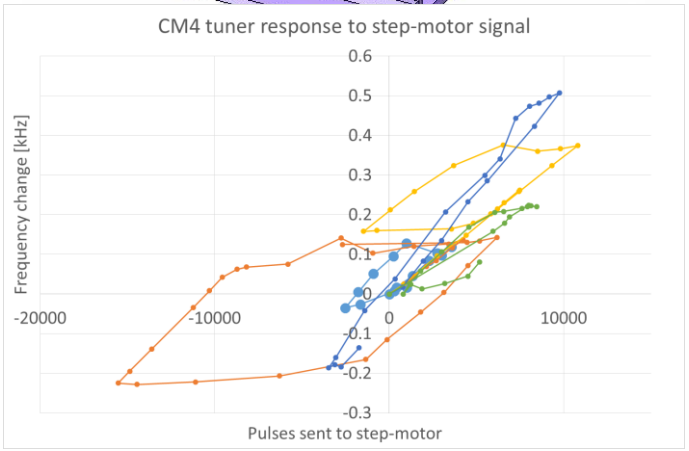
	CM1-1	CM1-2	CM1-3	CM1-4	CM1-5	CM1-6	CM1-7	CM2-1	CM2-2	CM2-3	CM2-4	CM2-5	CM2-6	CM2-7
Overshoot [Hz]	55	105	5200/ 2995	1120/ 215	500	155	117.5	35	0	102	123	104.5	139	27.5

Further improvement on CM4 tuner

- The tuner were re-designed to eliminate loose gears and joints.
- The overshoot was under-control







	CM4-1	CM4-2	CM4-3	CM4-4	CM4-5	CM4-6
Overshoot [Hz]	9	21		10	0	2

Outline

- Introduction to CADS linac
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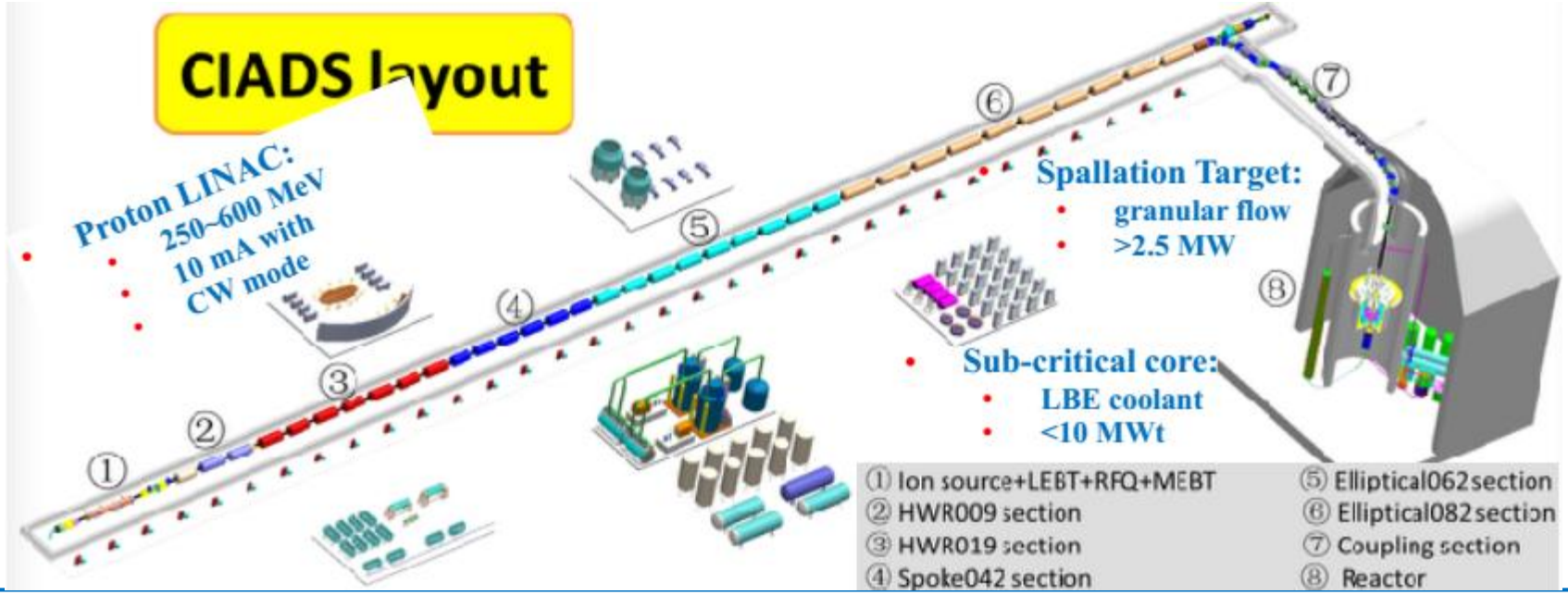
- Future plans

Future project: CIADS

- Approved by Chinese government in Dec. 2015
- Budget: >1.8B CNY
- In collaboration of IMP, IHEP, and many other institutes
- IHEP will continue spoke cavities R&D and production under the scope of CIADS project



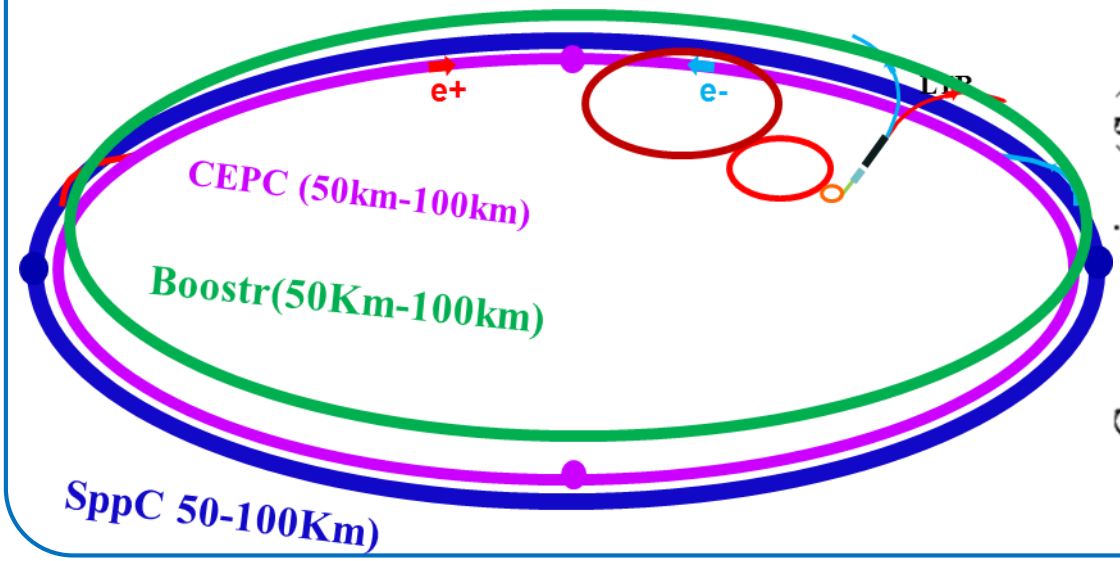
Future project: HEPS

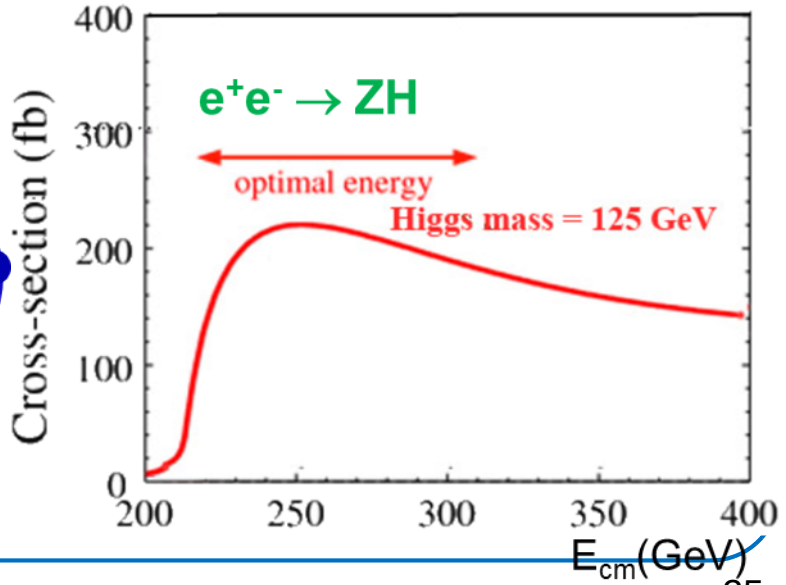
- High Energy Photon Source will be built in Beijing by IHEP from 2018 to 2024
- Budget: 4.8B CNY

Booster	
Circumference	432 m
Beam energy (inj./ext.)	0.3 / 6 GeV
Beam current	10 mA
Energy loss per turn	4.6 MeV
Beam power	~50 kW
Storage ring	
Circumference	1295.6 m
Beam energy/current	6 GeV / 200 mA
Energy loss per turn	2.5 MeV
Beam power	500 kW
Bunch length (inj./op.)	2.8/32 mm

Future project: CEPC

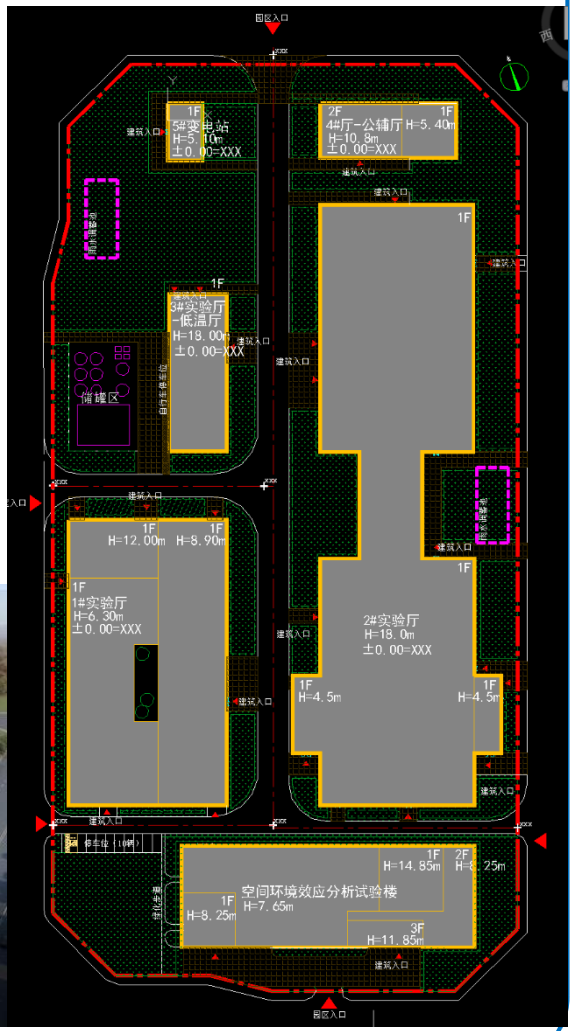
- Proposed by IHEP, pre-research in progress
- Circular electron-positron collider at 2 x 120GeV
- ~600 SRF cavities at 650MHz needed
- Operation specification: Q_0>2e10@E_{acc}=16MV/m
- VT specification: Q_0>4e10@E_{acc}=22MV/m





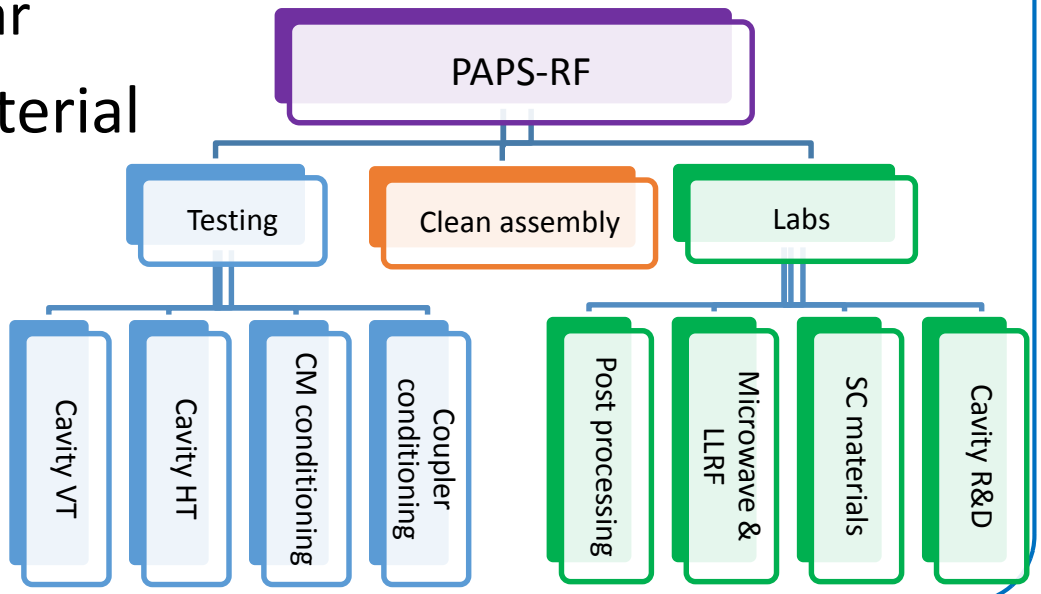
PAPS project for the future projects

- “Platform of Advanced Photon Source Technology R&D” project supported by Beijing Gov.
- Budget: 500M RMB
- Construction: 2017.5-2020.6
- Consist of 7 systems:
  - SRF system
  - Cryogenic system
  - Magnet technology
  - Beam test
  - X-ray optics
  - X-ray detection
  - X-ray application



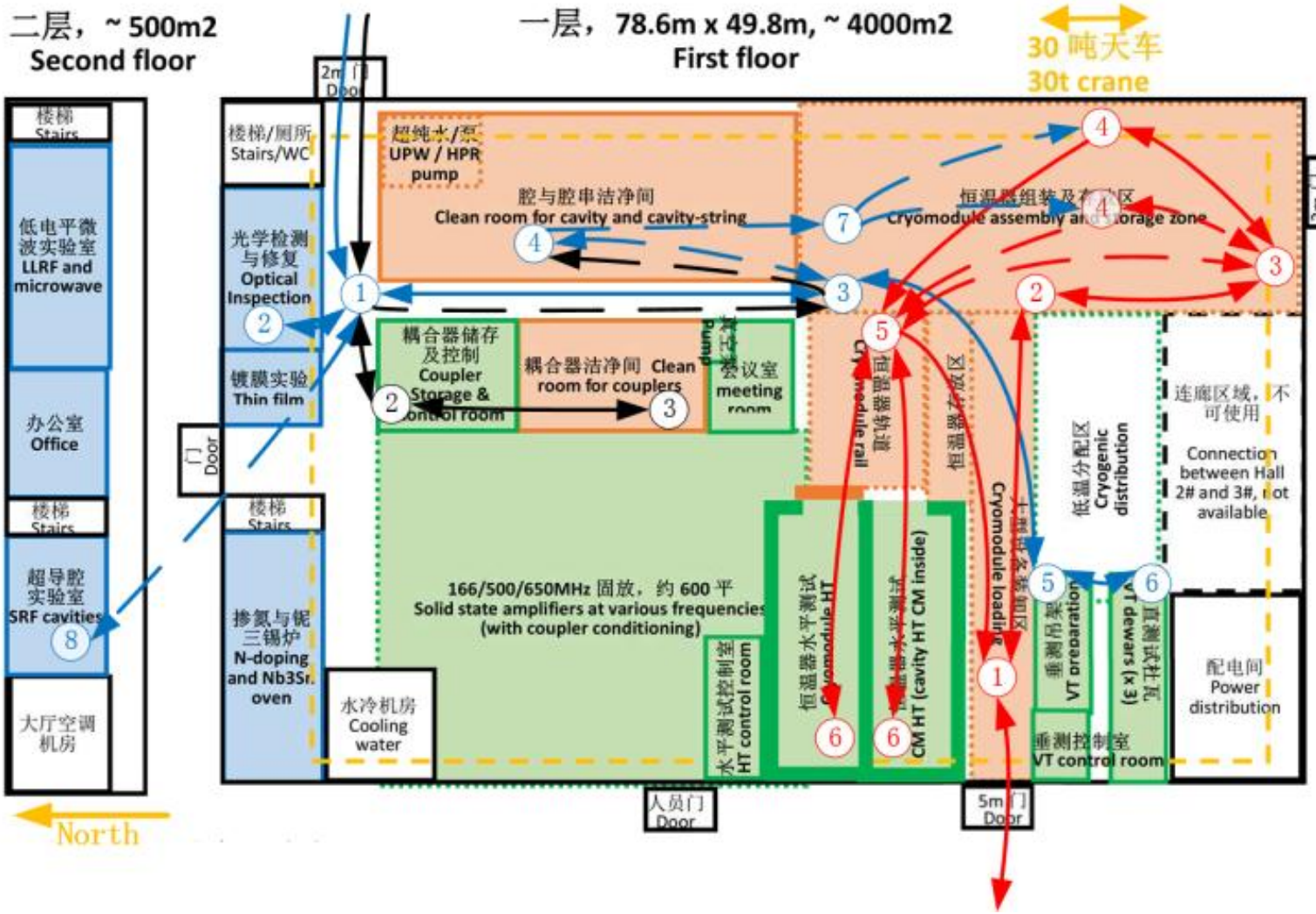
SRF facility to be built

- The SRF facility is part of the PAPS-RF system
- It will do post-processing, clean assembly, and all tests for mass production of cavities, couplers, and cryomodules.
  - Compatible of 166MHz, 500MHz, 650MHz, and 1.3GHz
  - 200-400 cavities (couplers) per year
  - ~20 cryomodules per year
- Support R&D on new material and new technology
- Total area of 4500 m^2
- Cryogenic system: 300W @ 2K



Layout of the SRF facility

- 3 VT dewars
- 2 HT caves
- 500m^2 CR
- FPC aging in CR ISO7
- Optic inspec.
- Pre-tuning
- Furnace
- Nb_3Sn oven
- Nb-Cu sputtering
- T-mapping
- Second sound
- ……



ESS&IHEP possible collaborations

- Joint development in hardware/software/application for Spoke cavities testing.
- Joint development in hardware/software/application for Elliptical cavities testing.
- Short to middle term visit for the commissioning of the joint-developed hardware /software/applications.
- Knowledge and expertise exchange of Test stand setting up and operation.
- Data and information sharing.

Thanks for your attention!