Status of CIADS Project

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Outlines

- **Motivation and Roadmap**
- **Specifications and Challenge of CIADS**
- **Design Conception of Driven Linac**
- **Design Conception of Spallation Target**
- **Progress of Demo Facility**
- **Summary**

Nuclear Power Development in China

Nuclear energy is an inevitable strategic option to meet China energy demand in the future

- China is the largest energy consumer in the world and coal is the major resource for electricity production (79% in 2011)
- China claim that the CO_2 emissions will reach a peak around 2030 while Paris Climate Agreement.
- Nuclear power is a relatively clean energy without green-house gas emission

Current status of China nuclear power

- 22 nuclear power reactors in operation, 18.056GWe (6^{th} in the world)
- Produced electricity: 104.8TW.h, 2.1% share in 2013, (5^{th} in the world)
- 27 reactors under construction, 26.756GWe, (1^{st} in the world)

The planned NP development in China (2011-2020)

- By 2015, the installed capacity reaches 40GWe and 18GWe under construction
- By 2020, the installed nuclear capacity will be increased to 58GWe (~7%), and 30GWe are under construction

By 2050, 350~400GWe (~20%), comparable with the total NP capacity in the world (375GWe in 2014).

Important Issues for Sustainable NP Development

- **Management and safe disposal of nuclear waste**
- Fuel supply (Uranium~100 years for LWR)
- Inherent safety

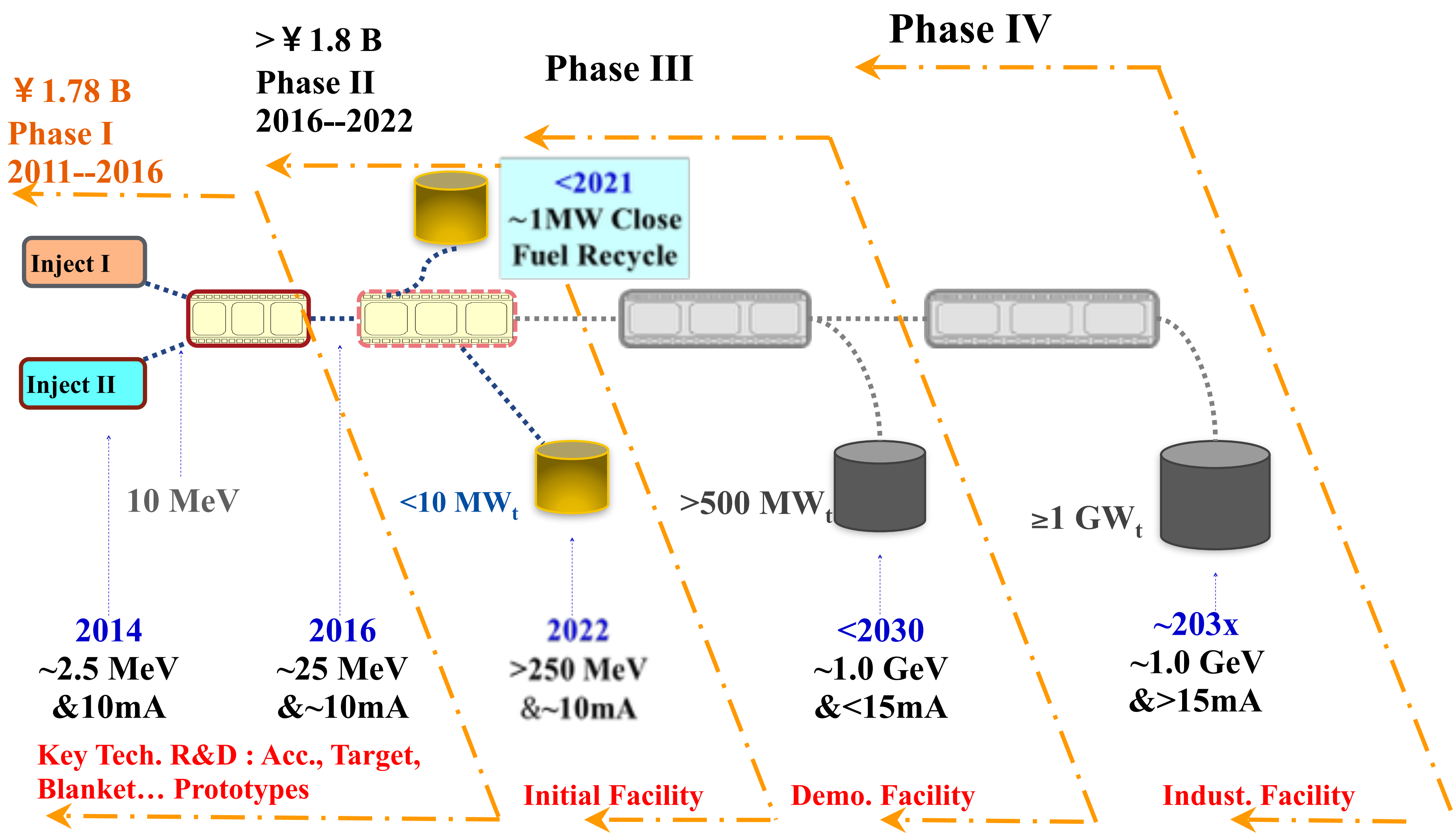
Global distribution of Uranium resources (Uranium 2014)

"The ADS has the advantage that it can burn pure minor actinides while avoiding a deterioration of the core safety characteristics."

— ADS and FR in Advanced Nuclear Fuel Cycles – A Comparative Study, NEA/OECD, 2002

Accelerator Driven Sub-critical Reactor and Accelerator Driven Recycle of Used Fuel are promising path to resolve the problems.

ADS/ADANES Roadmap in China



Project CIADS (2016-2022)

China Initiative Accelerator Driven System (CIADS)

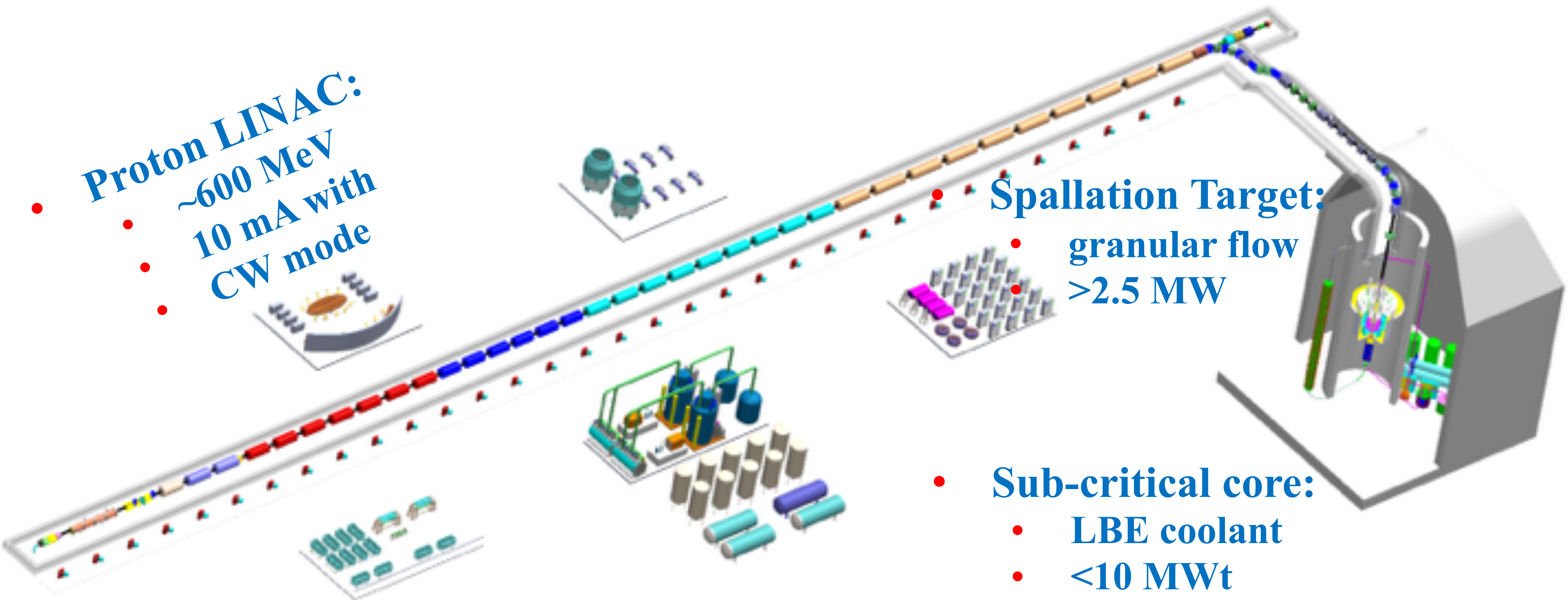
- Approved in Dec. 2015, CD0
- Leading institute: IMP
- Budget: >1.8B CNY (Gov. and Corp.)
- Location: Huizhou, Guangdong Prov.
- Contribution Partners:
  IHEP, CASHIPS, CIAE, CGN

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

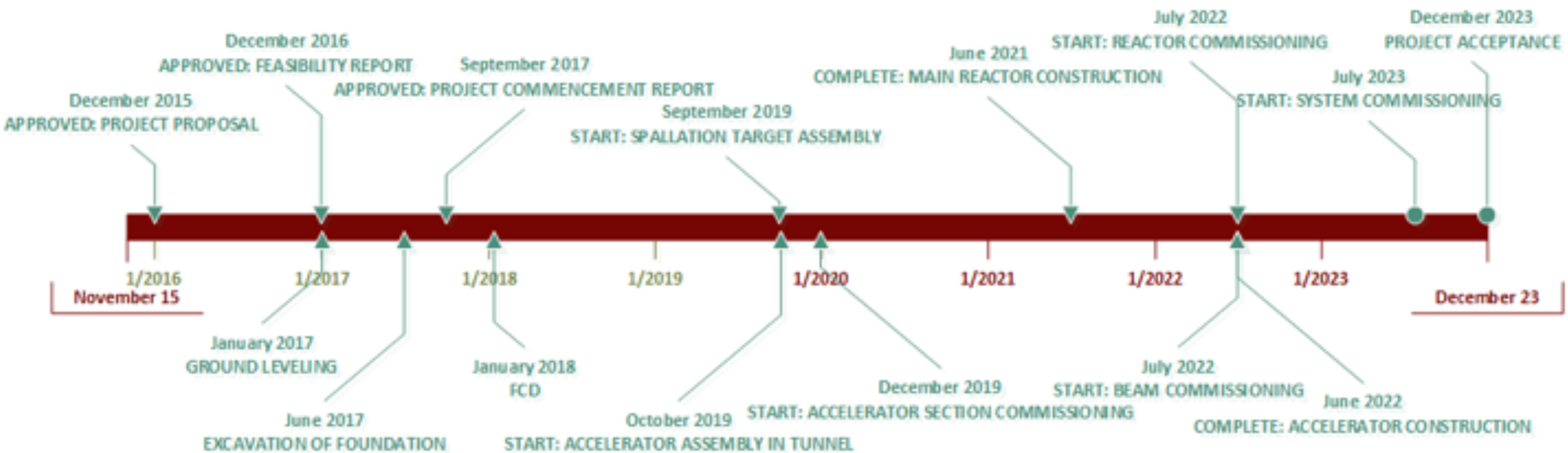
中广核 CGN

Hefei Institutes of Physical Science
Chinese Academy of Sciences



- Proton LINAC:
  - ~600 MeV
  - 10 mA with
  - CW mode
- Spallation Target:
  - granular flow
  - >2.5 MW
- Sub-critical core:
  - LBE coolant
  - <10 MWt

Plan of CIADS



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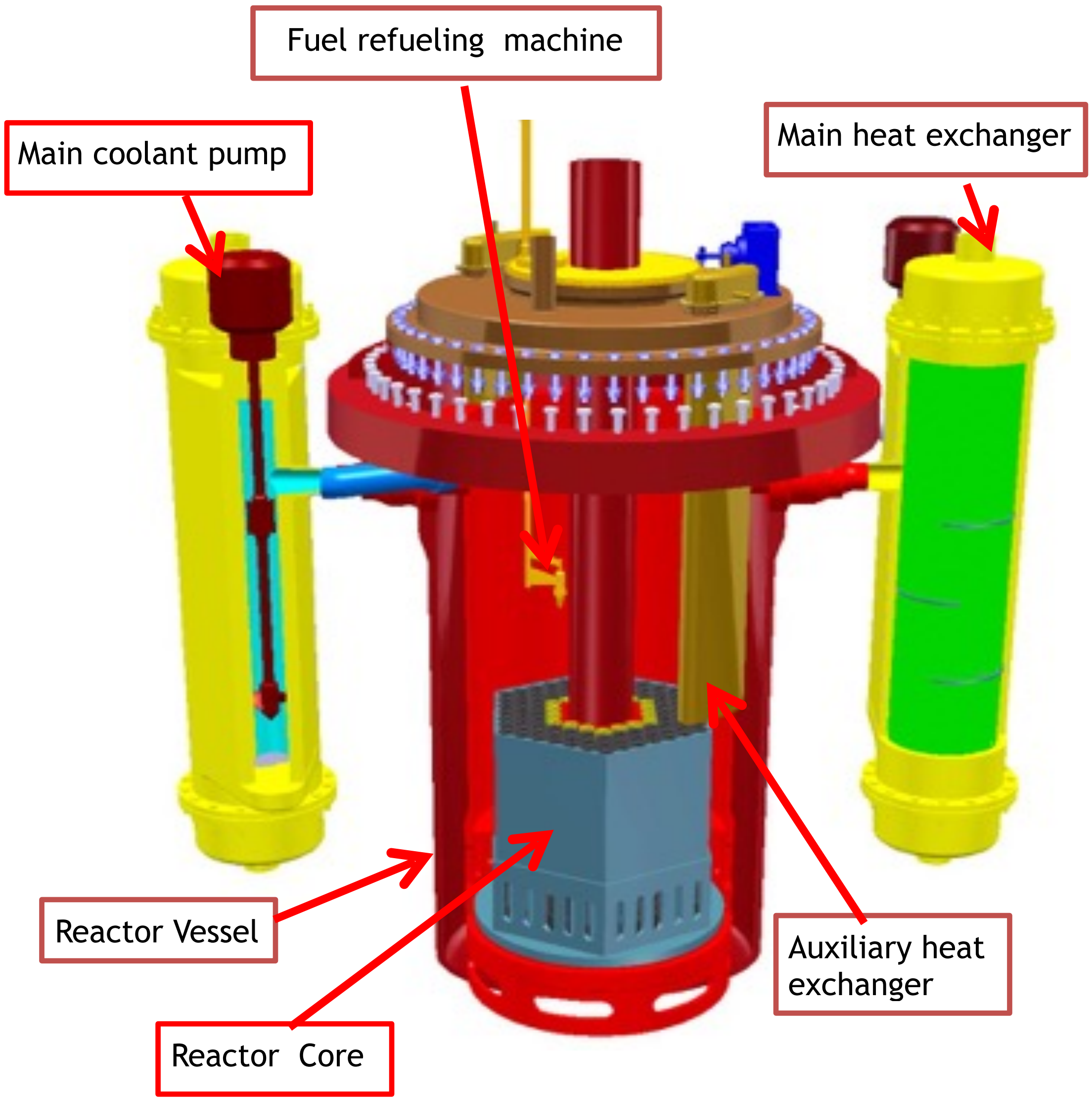
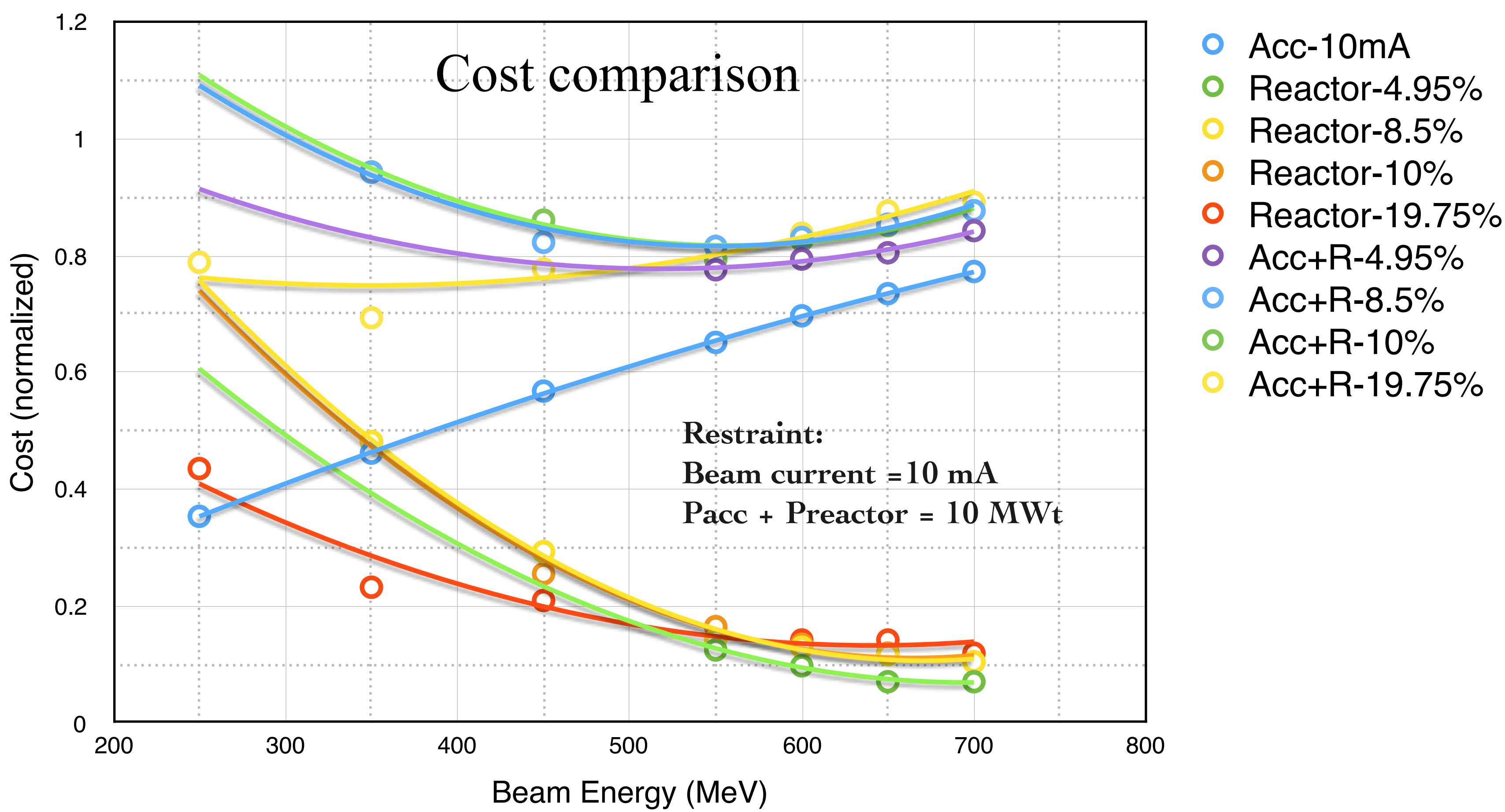
Layout of subcritical reactor



reactor configuration

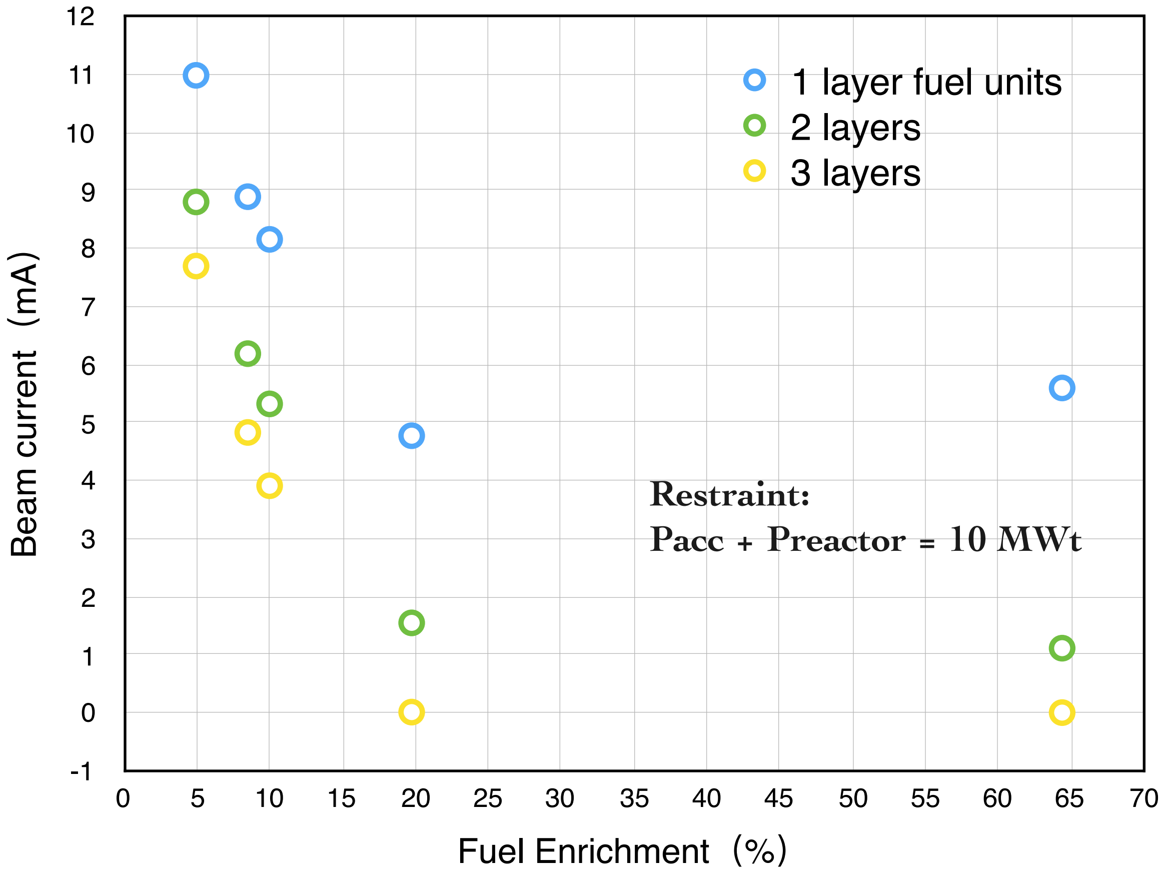
Core	4.95%	19.75%
Type of fuel	UO2 (4.95%)	UO2 (19.75%)
Diameter of central tube	42.8cm	42.8cm
Thickness of central tube	3.6cm	3.6cm
Number of fuel assemblies	18	72
Number of dummy assemblies	90	36
Number of control rods	None	None
Height of activity region	60cm	60cm
Equivalent diameter of activity region	124.61cm	80.80cm
Material of cladding	15-15Ti	15-15Ti
Material of structure	316L	316L
Uranium loading	4.202t	1.05t

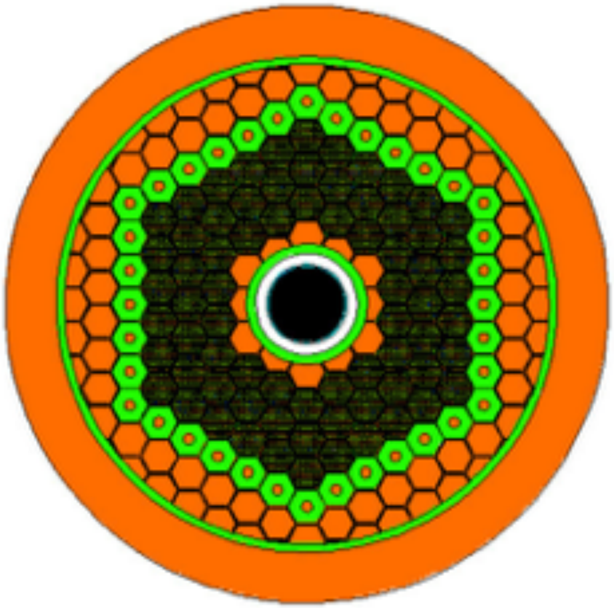
Selection of top level specifications



To different enrichment fuel, there is optimized beam energy if the total power of driven accelerator and sub-critical reactor is fixed. At around 550 MeV, the facility cost is independent of fuel enrichment and lowest.

Selection of Top level specifications

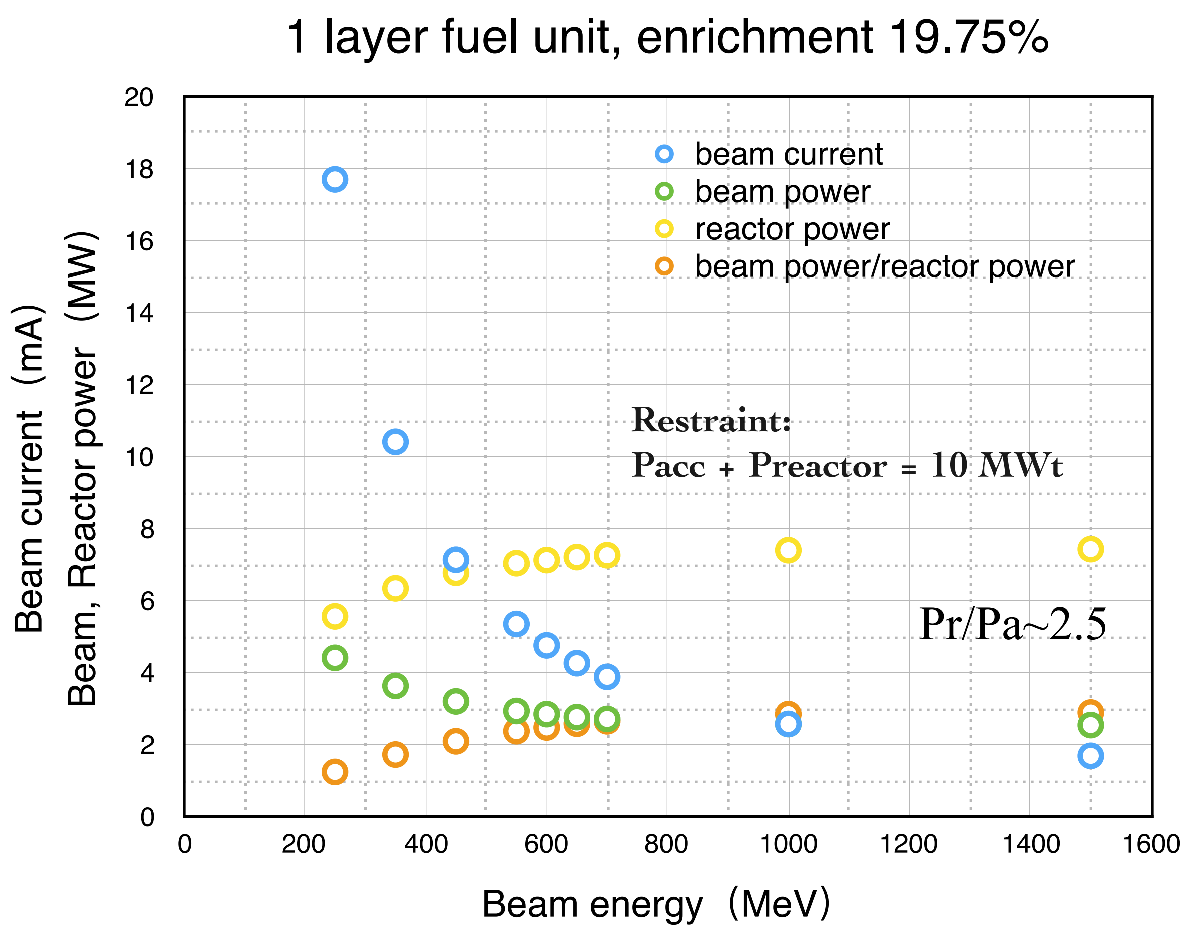


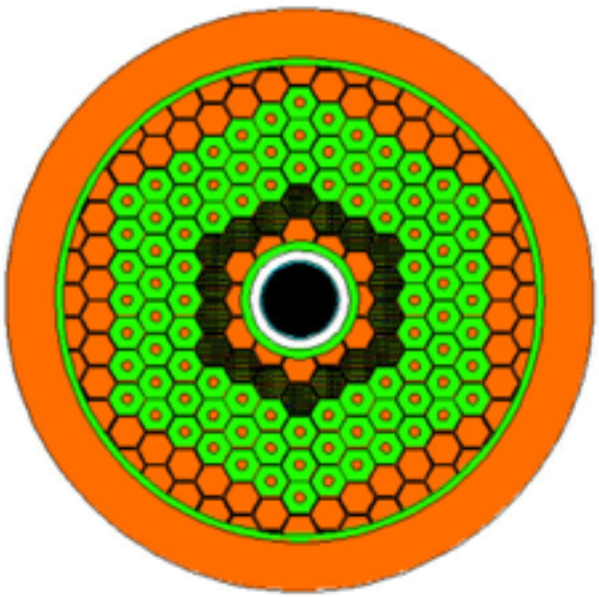


sub-critical reactor core
(61 rods in each fuel unit)

the dark ones are fuel-units and green ones are dumb-units. It takes the driven beam of 600 MeV. The beam current is reduced with fuel enrichment rapidly. The enrichment of 19.75% is a better value.

Selection of Top level specifications





sub-critical reactor core
(61 rods in each fuel unit)

Top level specifications:

Sub Reactor: fuel enrichment 19.75%, one layer with 18 units, power 7.14 MWt

Driven Linac: beam energy 600 MeV, current 4.78 mA, power 2.86 MWt

Target: sustained power ~2.5 MWt

Challenge of CIADS

- **First high power, CW beam, full SC proton accelerator**
  Highest CW beam power 6 MW, 10mA/CW@600MeV
  (2.3mA@600MeV, PSI; 1.0mA@1GeV, SNS; 2.5mA@2GeV, ESS)
- **First Sub-critical Core with LBE coolant**
  No sub-critical nuclear reactor is operated with power by now
- **High power spallation target**
  Highest power 6MW towards industrial scale
  (PSI, SNS: ~1.4MW; ESS will be 5MW; Industrial need >10MW)
- **First integrated Accelerator Driven Sub-critical Reactor System**
  physic's and engineering issues of interaction of three systems
  (low energy, low current beam coupled experiment)

CIADS will be the first platform to investigate the issues on construction and operation, Long-term R&D is necessary.

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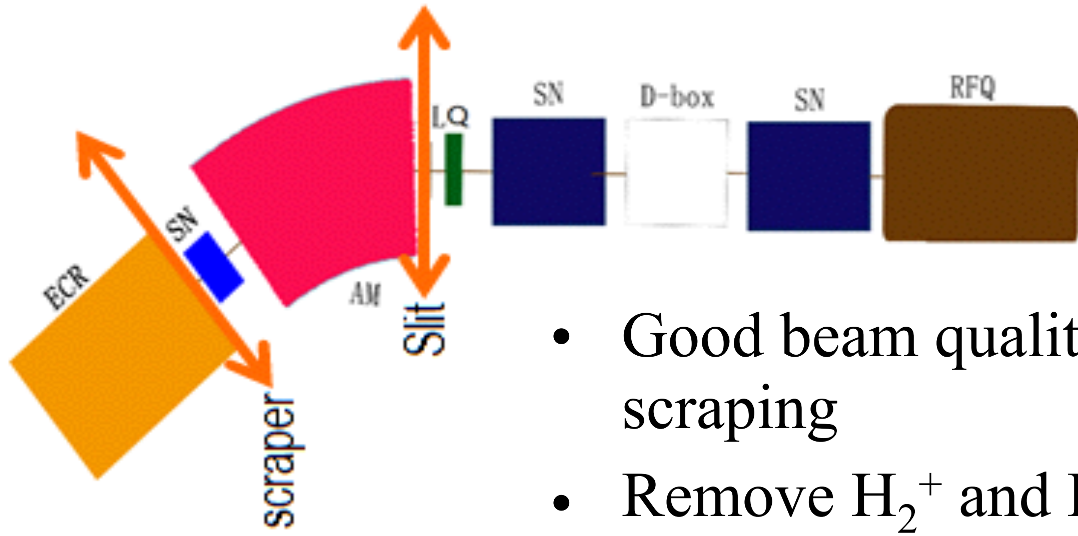
Design conception of driven linac

- Room temperature front-end (the most important part)
  - Ion source: dual, hot spare, higher frequency (14 GHz)
  - LEBT: bending H2+ H3+, trans. collimation, matching, fast chop
  - RFQ: small long. acceptance, lower frequency, compromise
  - MEBT: insulation of RT to SC, enough diagnostics, additional collimation
- Superconducting Linac (one injector)
  - beta selection: less cavity, minimize RF power, moderate gradient
  - failure compensation: 25% overhead, whole linac
- HEBT and coupling
  - chromatic aberration
  - trans. collimation: smaller acceptance than referential segment
  - long. collimation?
  - raster or crossover scanning?

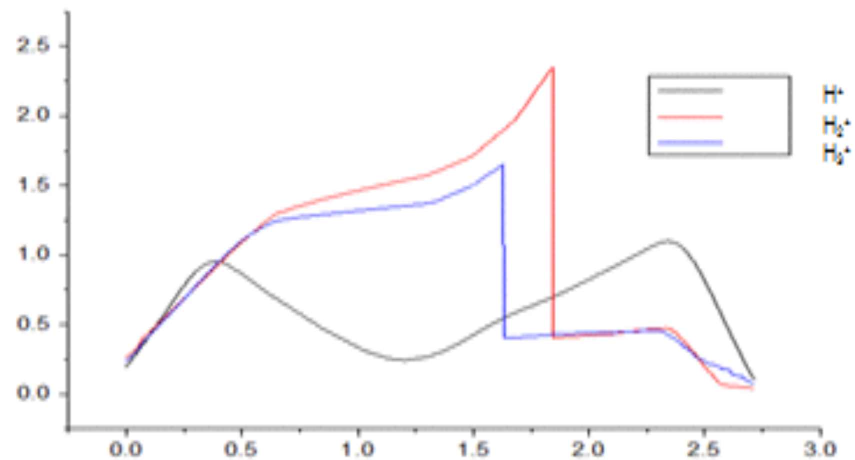
LEBT design



scrap the outer particles with large radius and angle

- Good beam quality through spot-source scraping
- Remove H_2^+ and H_3^+ by bending magnet in case of losing in RFQ

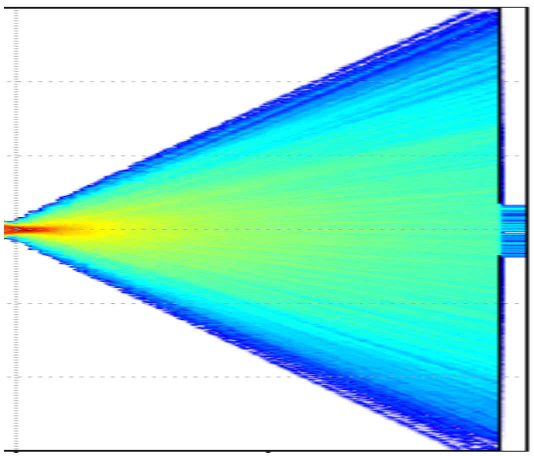
Ions	H^+
Energy (keV)	35
Beam current (mA)	10
Emittance rms_norm. (pi.mm.mrad)	0.186

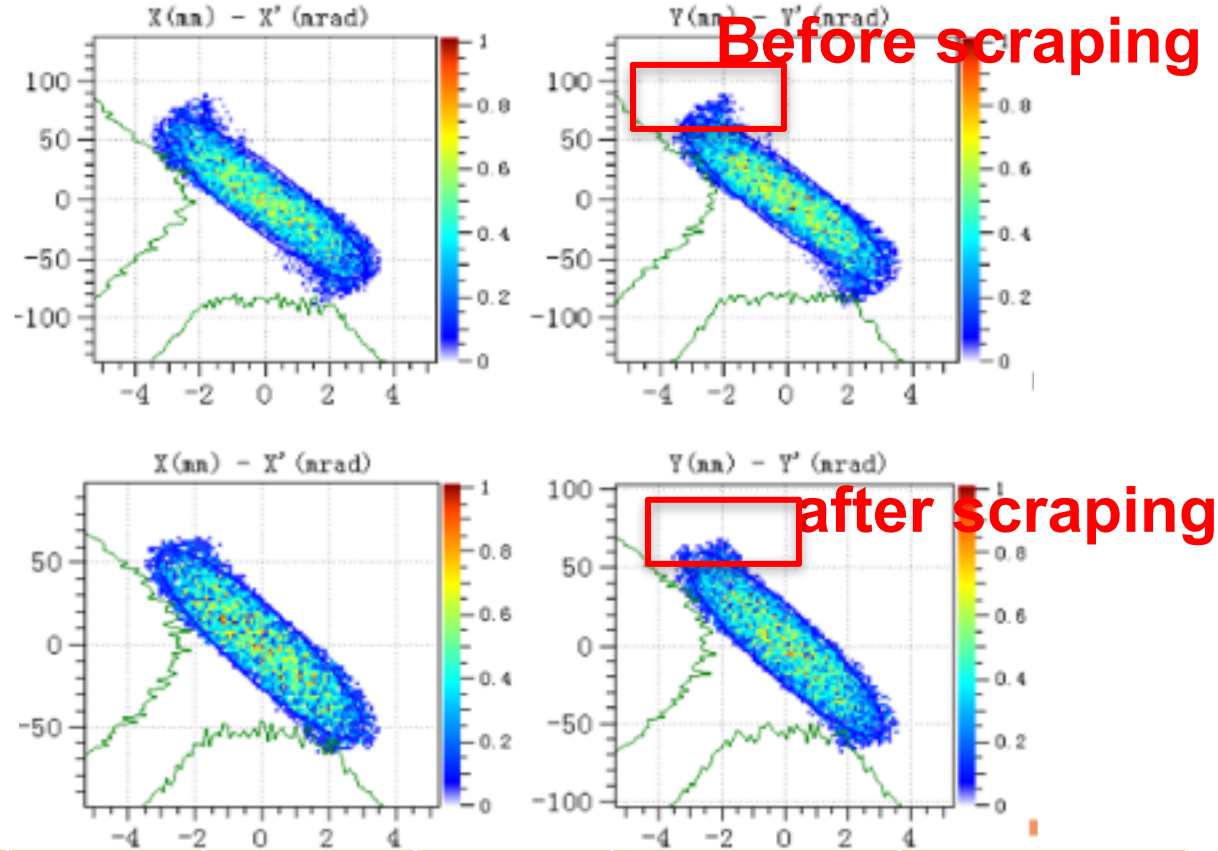


Simulation of spot-source collimation

Consideration：

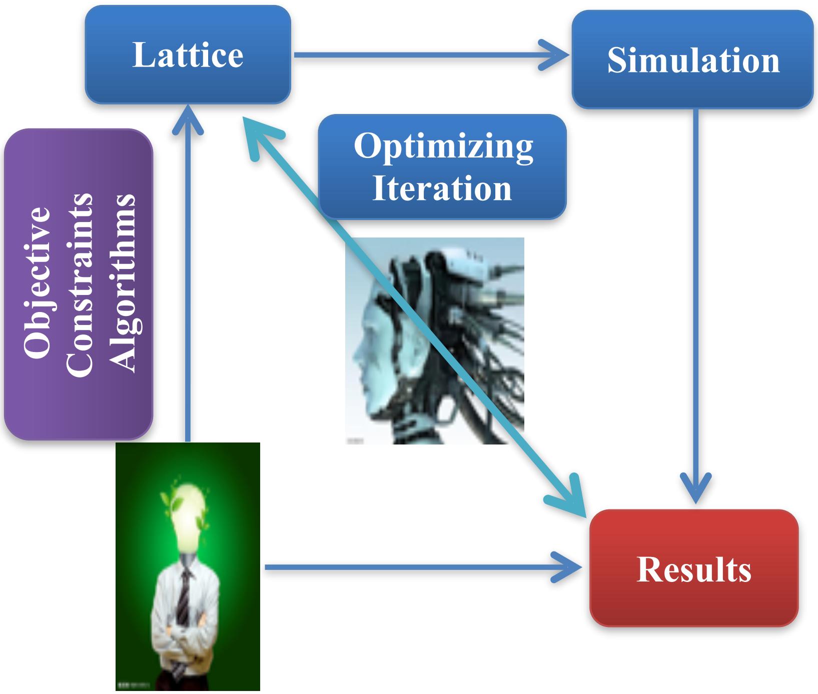
Scraping tail particles to reduce emittance growth caused by aberration effect





	X Alaph	X bata	Y Alaph	Y bata	X emittance	Y emittance
Before scraping	1.9282	0.1009	1.9895	0.1043	0.2176	0.2199
After scraping	1.9168	0.1146	1.9932	0.1186	0.1772	0.1787

Optimization of SC linac



Variable:
Geometric beta

Algorithm:
Particle Swarm Optimization

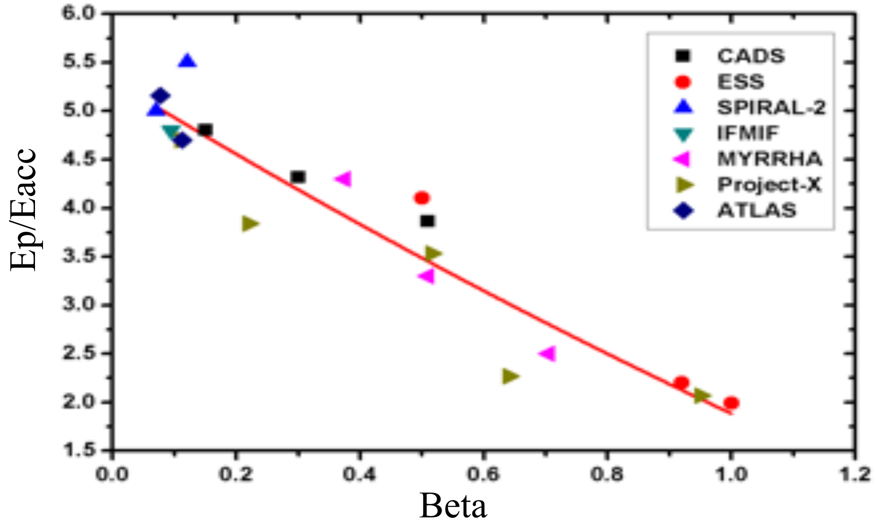
Constraints:
TTF continuous
Energy gain continuous

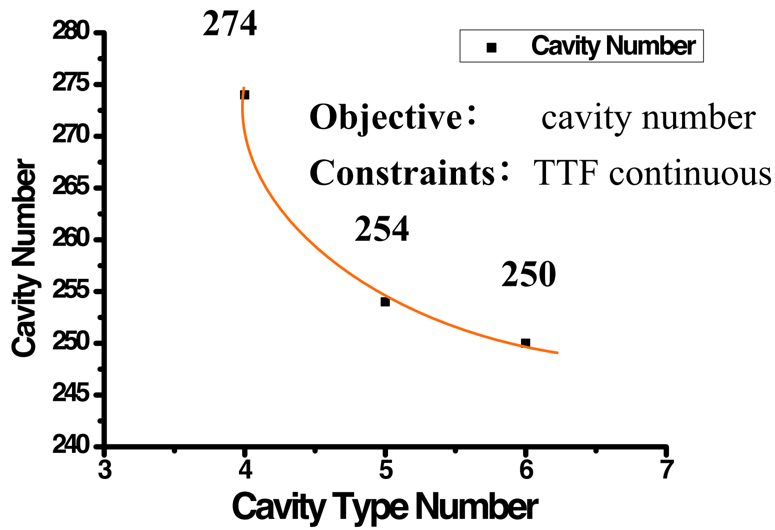
Objective:
Cavity number
Normalization power

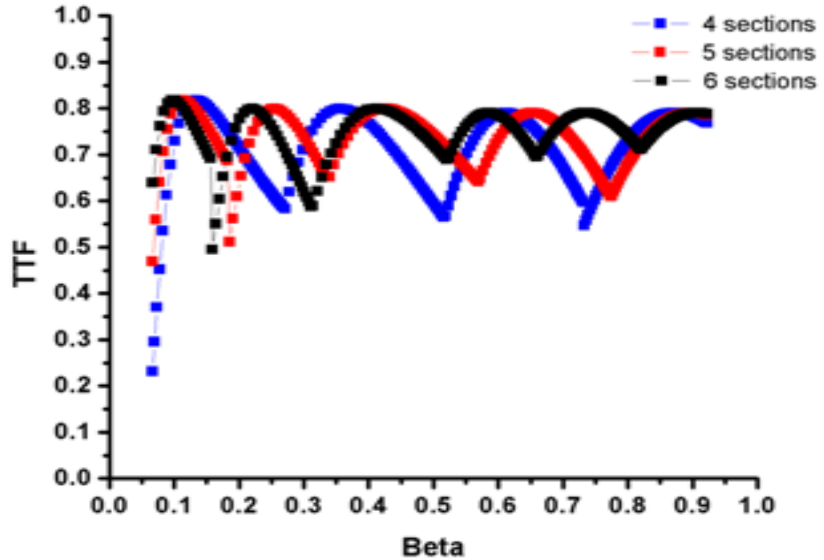
Cavity Family			
Cavity Type	HWR	Spoke	Ellip
Frequency(MHz)	162.5	325	650
Gap Number	2	3	5
Epeak(MV/m)	25/32	32	35

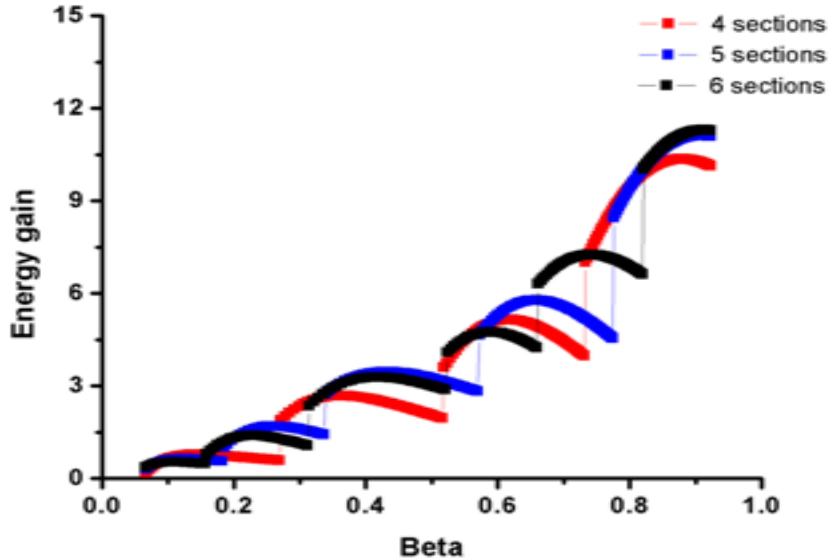
Input energy: 2.1 MeV
Output energy: 1.5 GeV

Optimization of SC linac





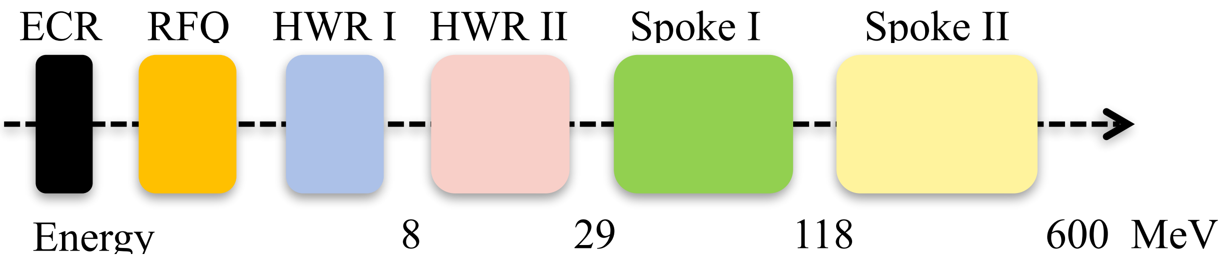




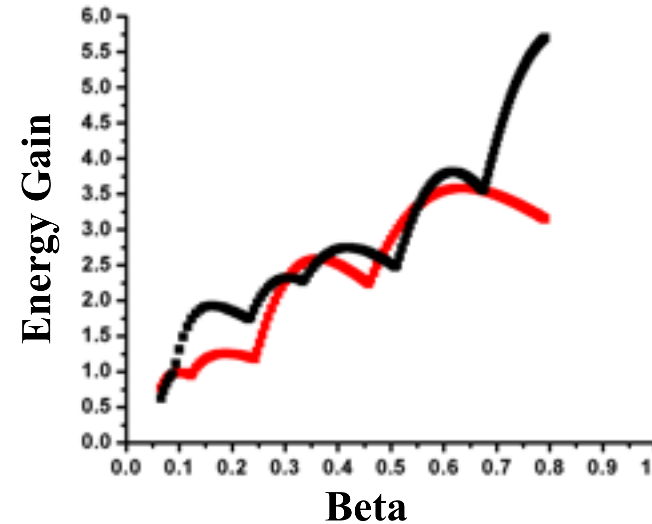
Two options for CIADS

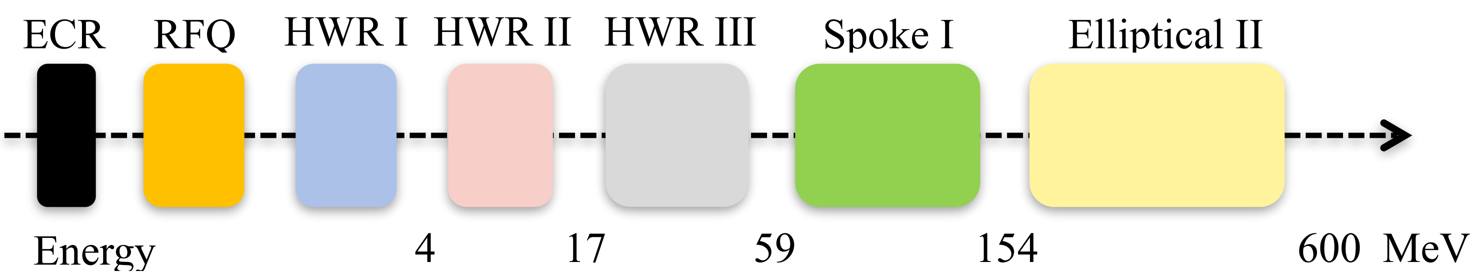
	Number	Cav1	Cav2	Cav3	Cav4	Cav5	Cav6	
Optimized for 600MeV d-spoke	164	0.09	0.19	0.36	0.63			$Beta_{opt}$
		0.76	0.15	0.33	0.58			$Beta_g$
		162.5	162.5	325	325			Frequency
		140	279	460	811			L (mm)
		0.526	1.1	2.71	6.09			Vacc(MV)
		3.73	3.96	5.89	7.51			Eacc(MV/m)
		7.25	29.24	117.77	600			$Energy_{out}$
Optimized for 1.5 GeV Cut at 600MeV	148	0.10	0.15	0.30	0.42	0.62	0.82	$Beta_{opt}$
		162.5	162.5	325	325	650	650	Frequency
		2	2	2	3	5	5	Gaps
		166	240	387	533	690	922	L (mm)
		0.84	1.59	2.90	4.39	7.65	12.92	Vmax(MV)
		0.63	1.19	2.18	3.29	5.74	9.69	Vacc(MV/m)
		3.77	4.98	5.63	6.18	8.32	10.50	Eacc (MV/m)
		4.2	17.0	59.3	154.3	336.8	600	$Energy_{out}$

Two options of lattice for 600MeV



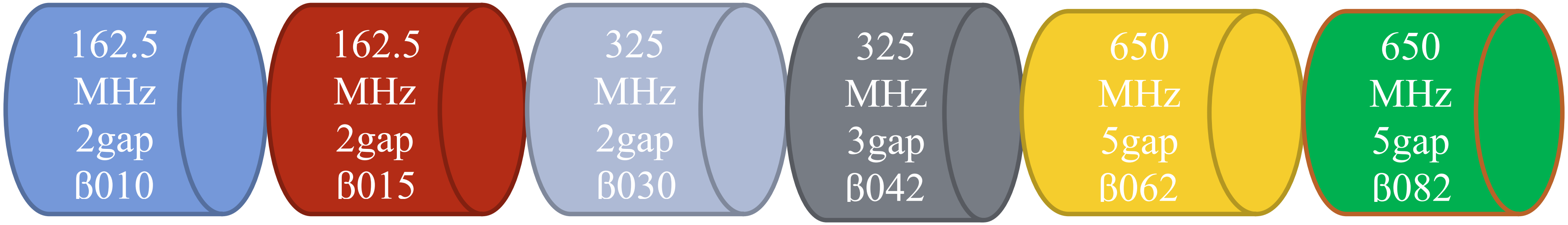
Section	HWR I	HWR II	Spoke I	Spoke II
Betaopt	0.09	0.19	0.36	0.63
Frequency (MHz)	162.5	162.5	325	325

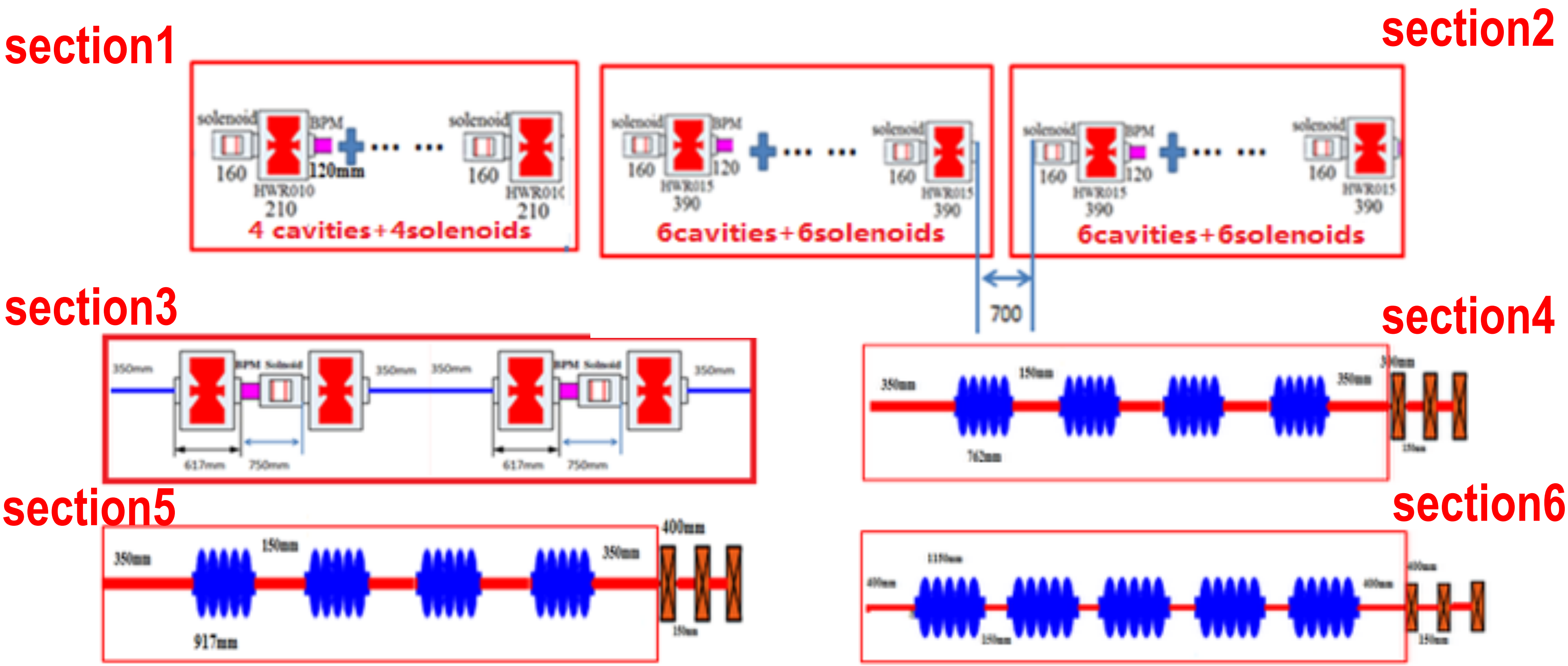




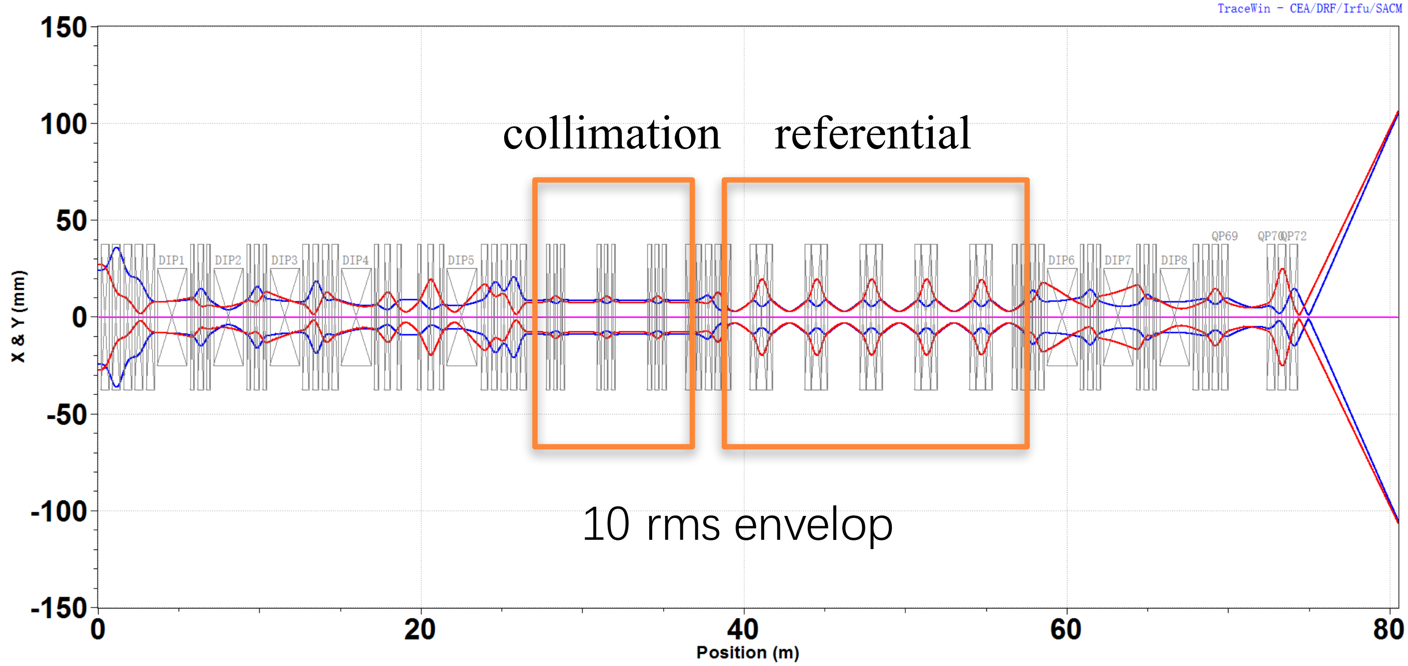
Section	HWR I	HWR II	HWR III	Spoke I	Ellip I	Ellip II
Betaopt	0.10	0.15	0.30	0.42	0.62	0.82
Frequency (MHz)	162.5	162.5	325	325	650	650

Period in each cryomodule

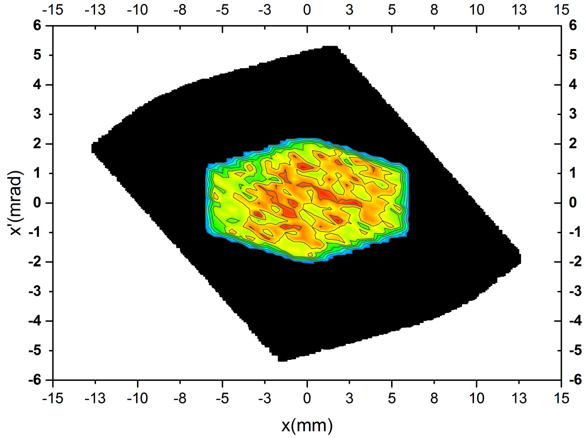


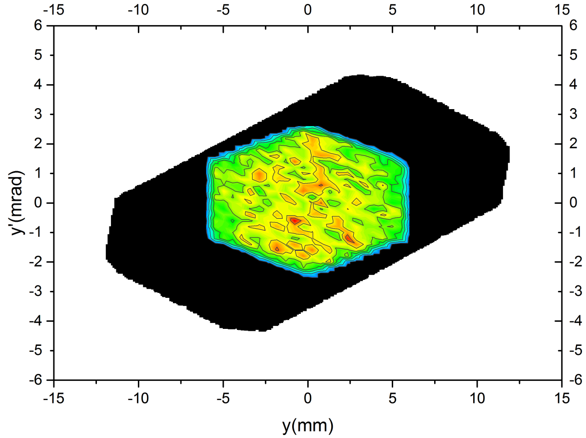


Design conception of HEBT

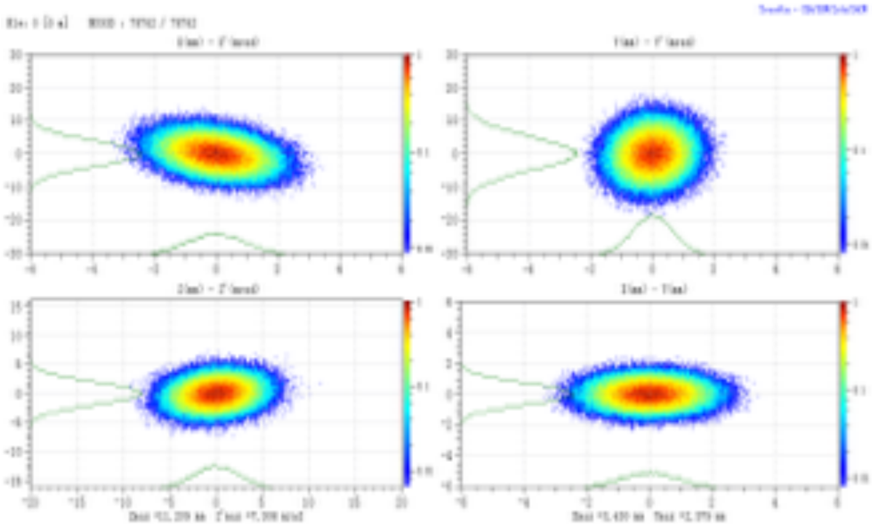


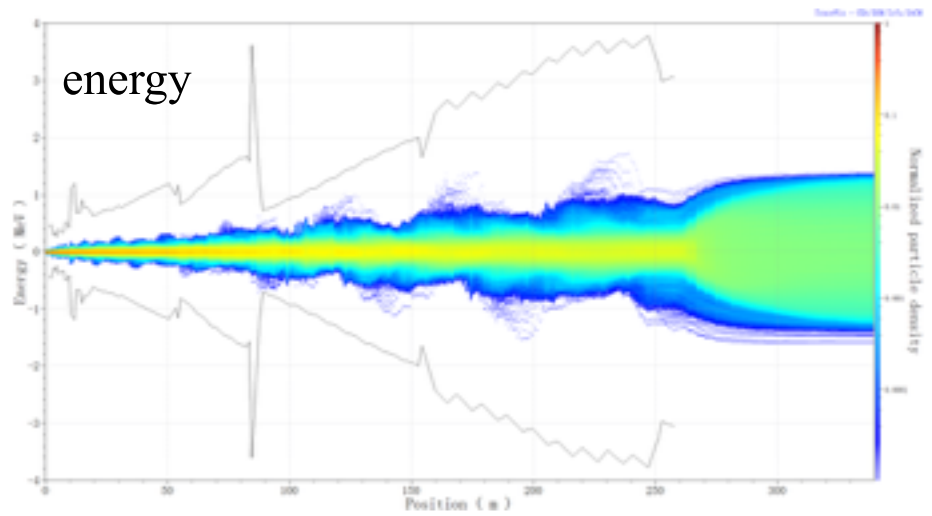
Emittance exit collimator with
Acceptance of referential



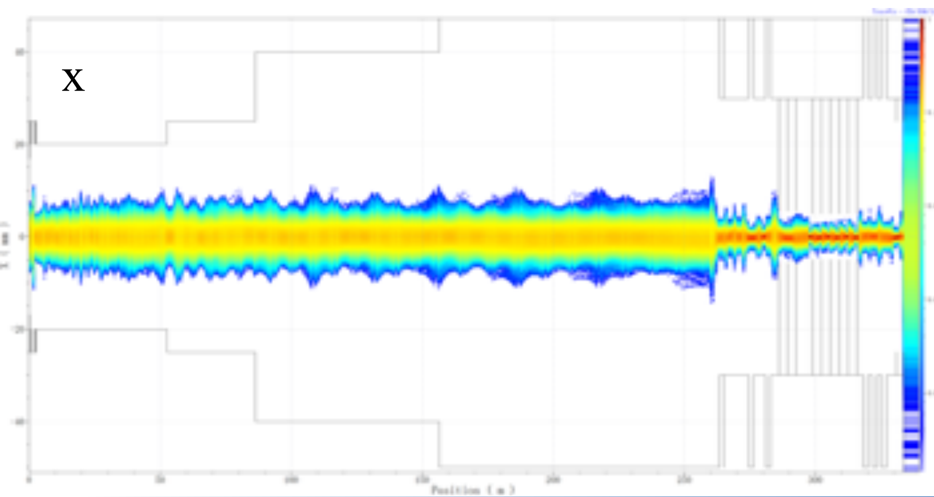


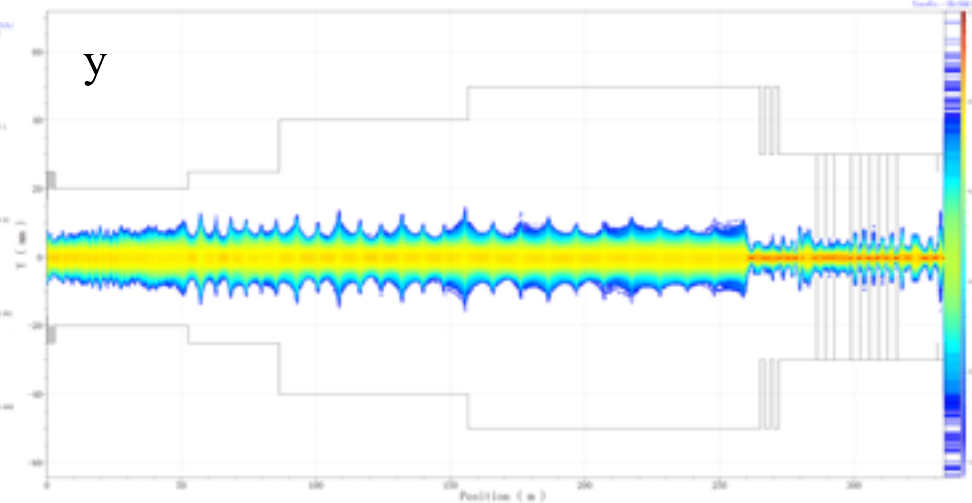
End to end simulation (RFQ to Target)



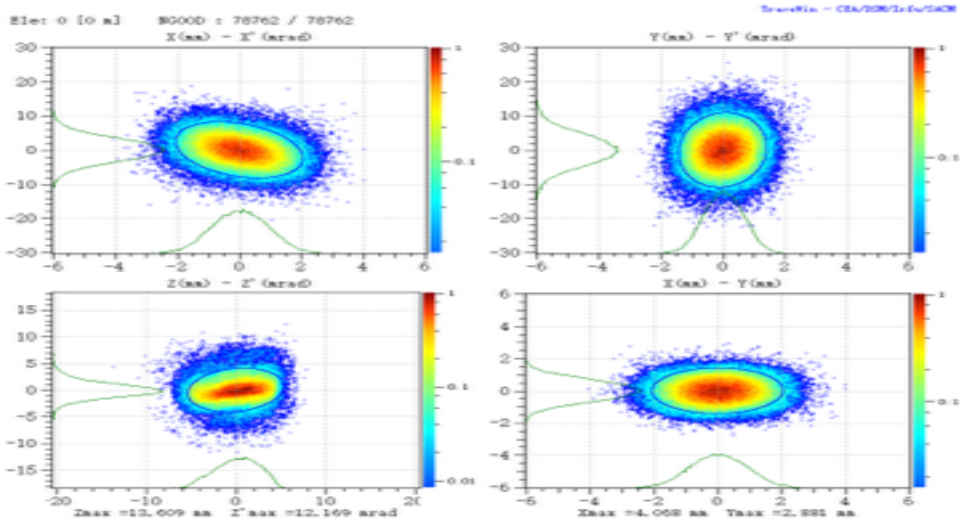


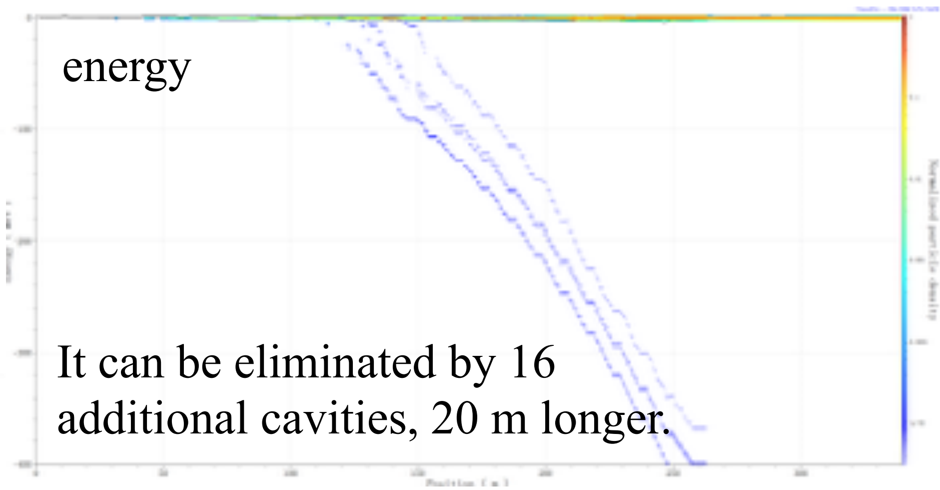
Initial 4 sigma/t and 5 sigma/L distribution, rms emittance growth 75%, no loss



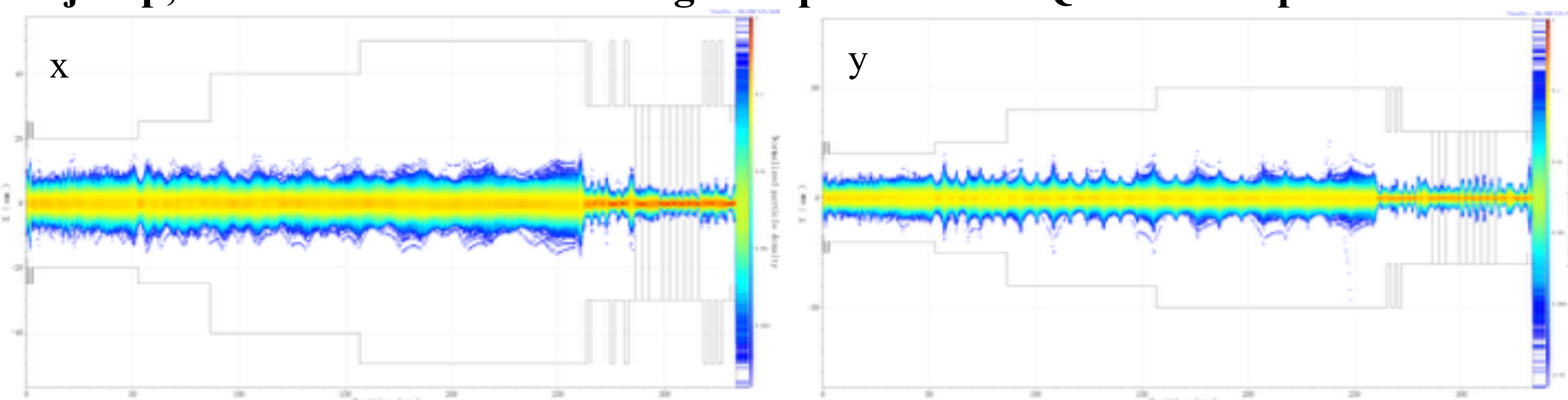


End to end simulation with RFQ output

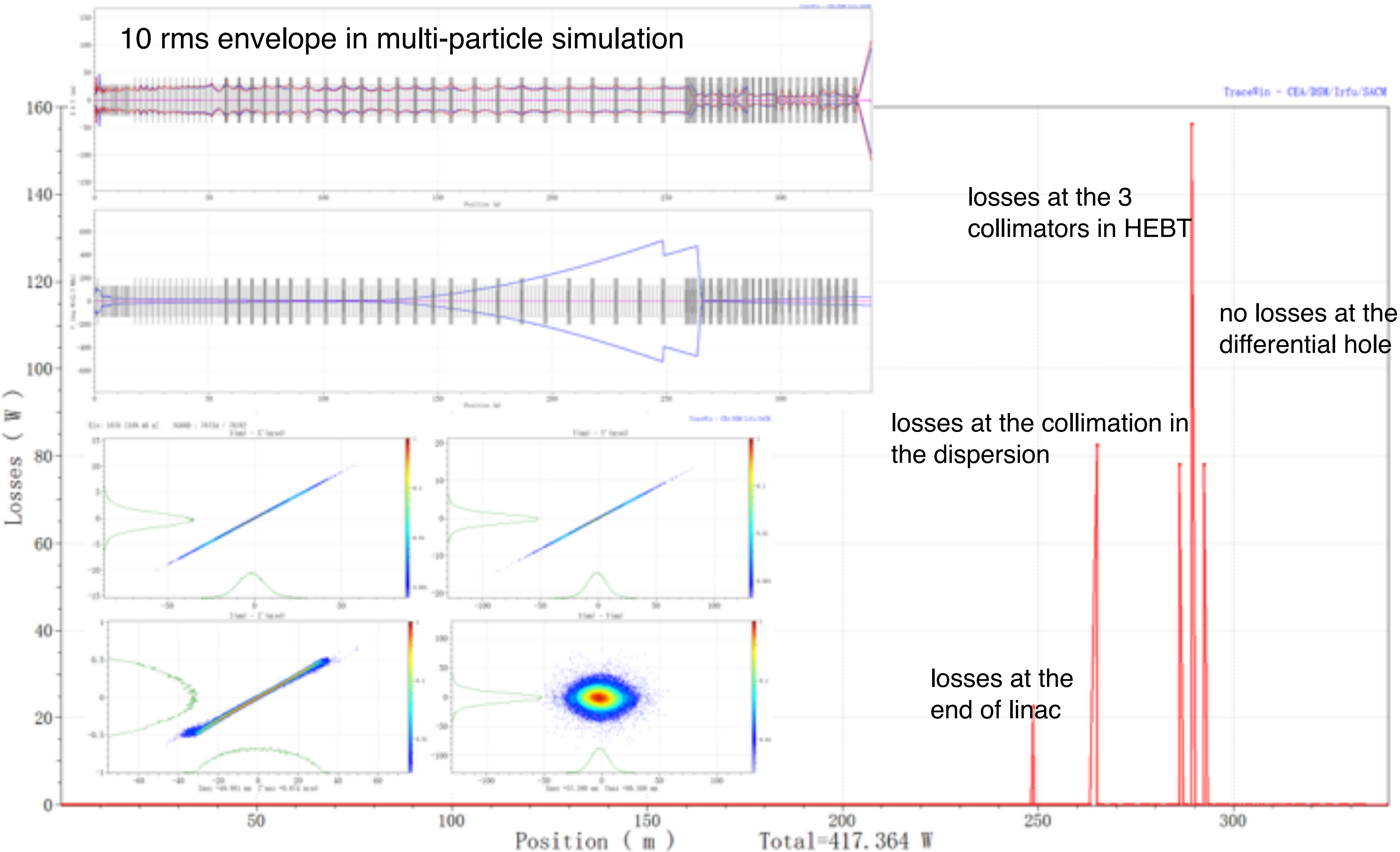




Particles distribution exit from present RFQ, long. loss happens at frequency jump, final trans. loss. Small long. acceptance of RFQ will be helpful.



Beam loss position



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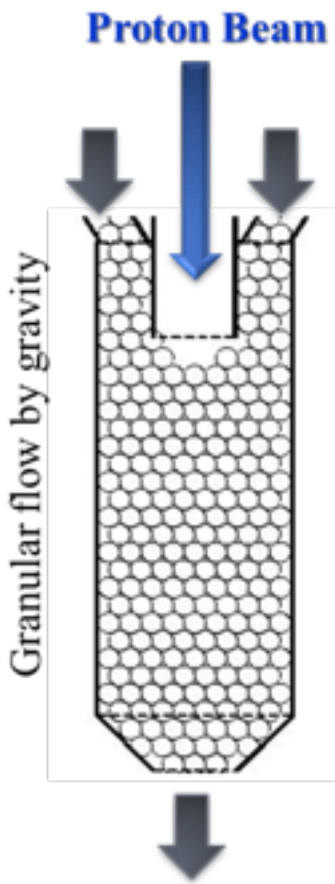
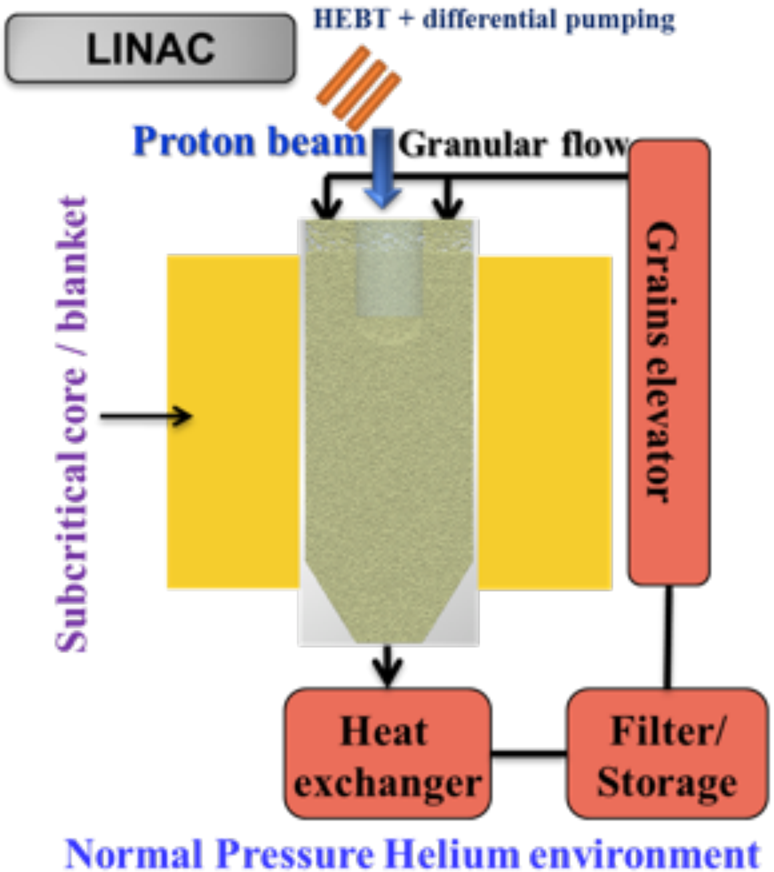
Granular Target Conception

Sand Clock

Time proportional to the outflow of the sand shows the stability of the granular flow.

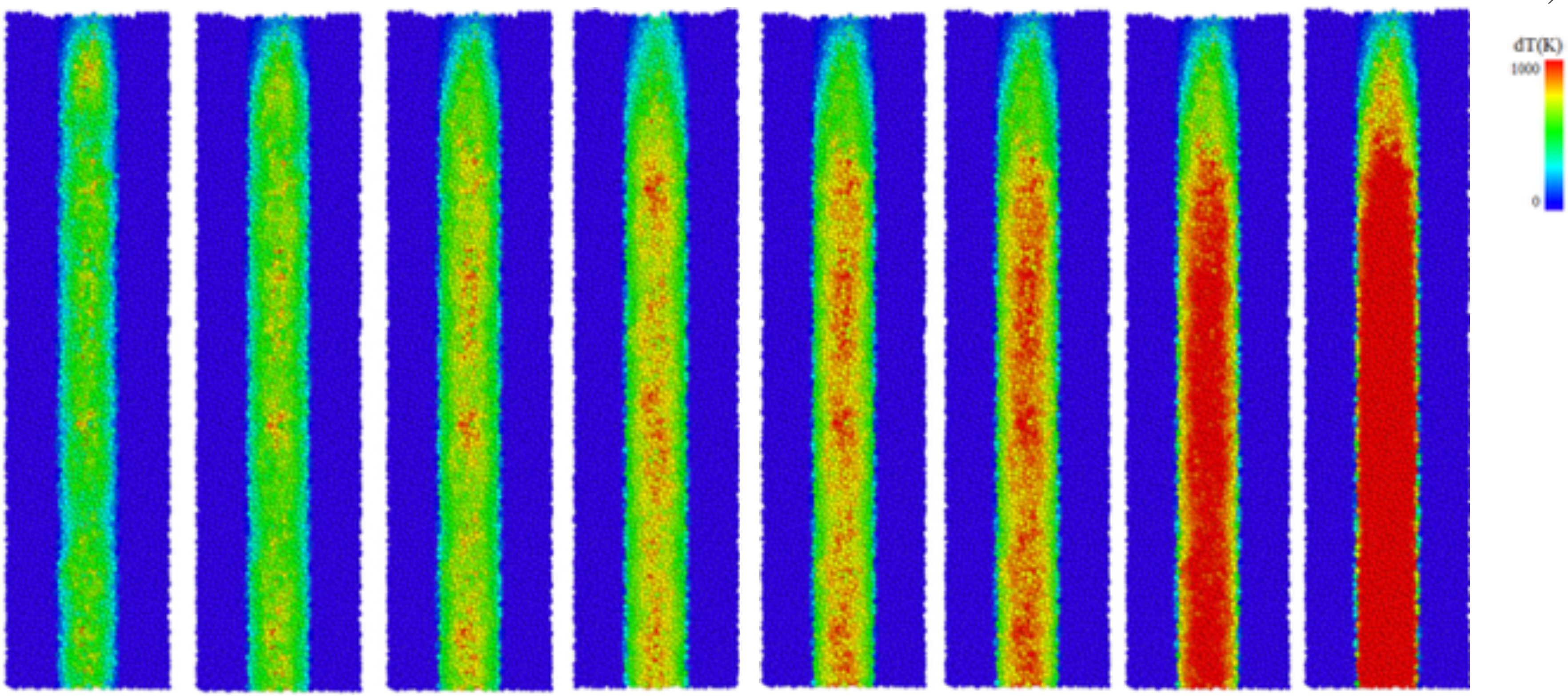




- In principle, it can stands for tens of MW beam power
- Increasing flexibility to use other target materials to increase the neutron yields

Large Scale Simulation with EDM

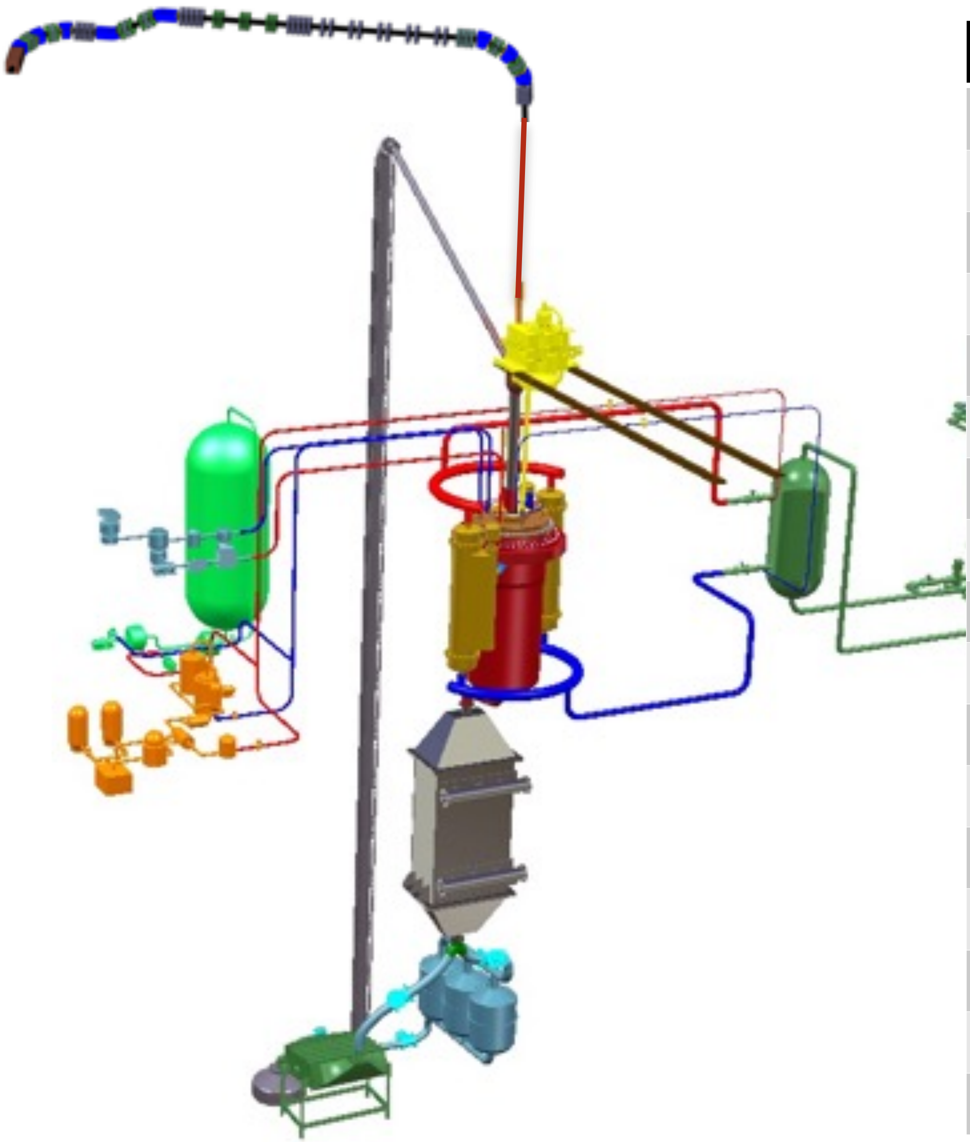
55.8 70.7 82.0 87.6 94.8 102 121 156 (K)



250 350 450 550 600 700 1000 1500(MeV)

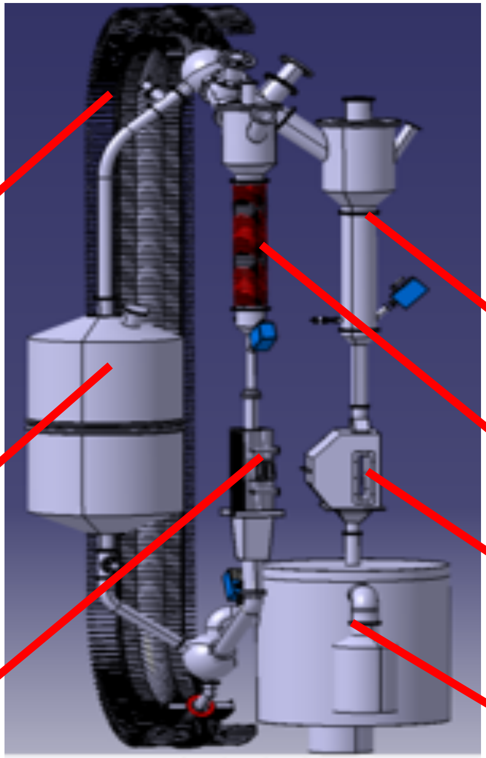
Granular: tungsten alloy, diameter=280mm, mass_flux=233kg/s, speed=0.5m/s
Beam: diameter=50mm, current=10mA, uniform distribution in 3D, CW

Layout of granular target and reactor



	parameters
ion	proton
beam energy	250 ~ 600 MeV
beam current	<= 10 mA
beam spot on target	~10 cm
granular material	tungsten alloy
Granular size	~1 mm
average temp. at entrance	250℃
average temp. at exit	<500℃
average speed of fluid	<0.5 m/s
structure material of tube	alloy
loop material	316L/TZM/SIMP
energy of leak neutron	~2.5 MeV
neutron yield	> 2 n/p
pressure of He	<0.5 MPa
heat exchange	~2.5 MW
mass flux	<200 kg/s
leakage of He	<10-5 Pa·m3/s

Test platform of granular target



Challenge of granular target:

- corrosion and erosion
- lifting
- heat exchange with water
- reduce the highest temp.
- clean dust
- radiation damage
- fluid detection

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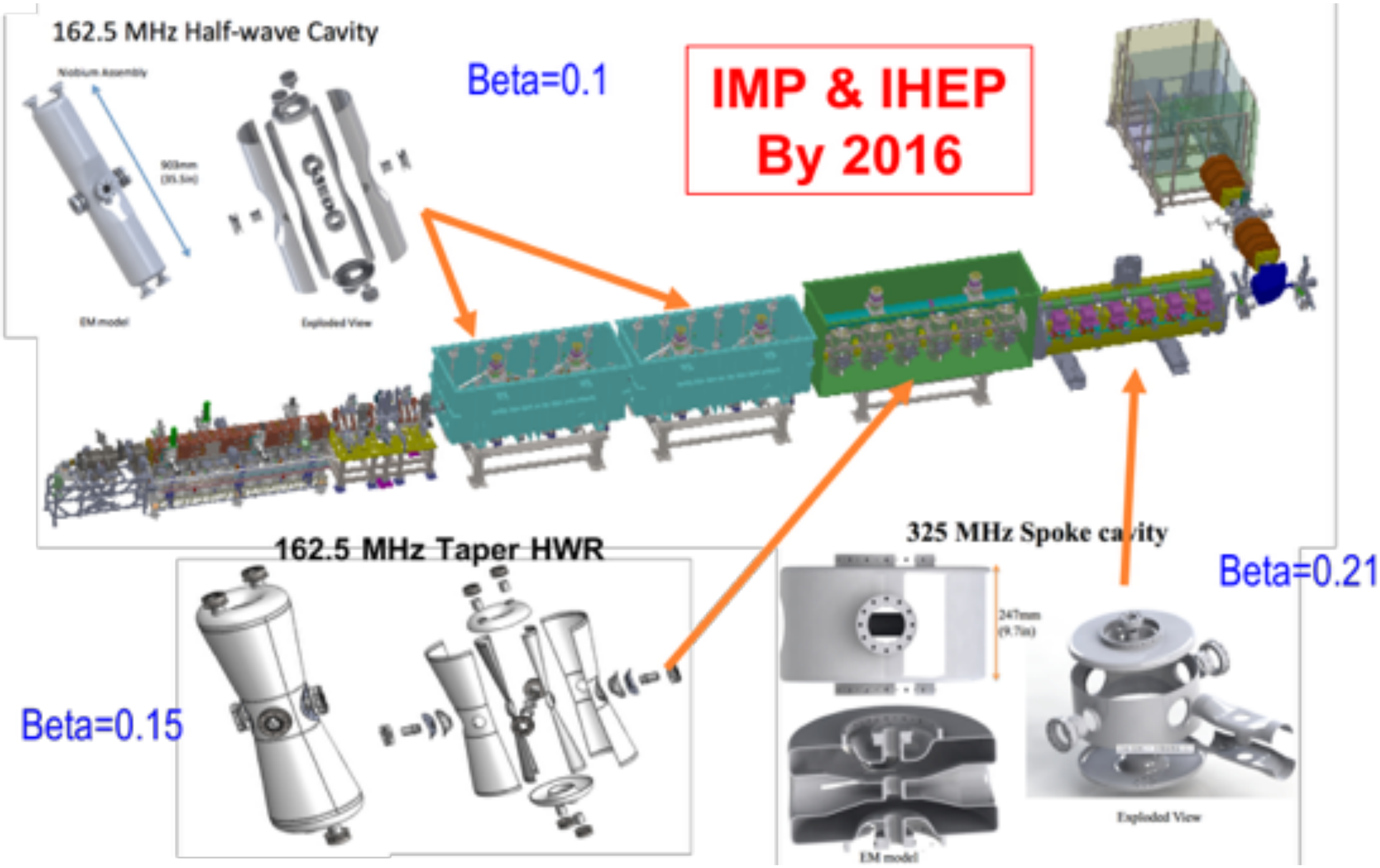
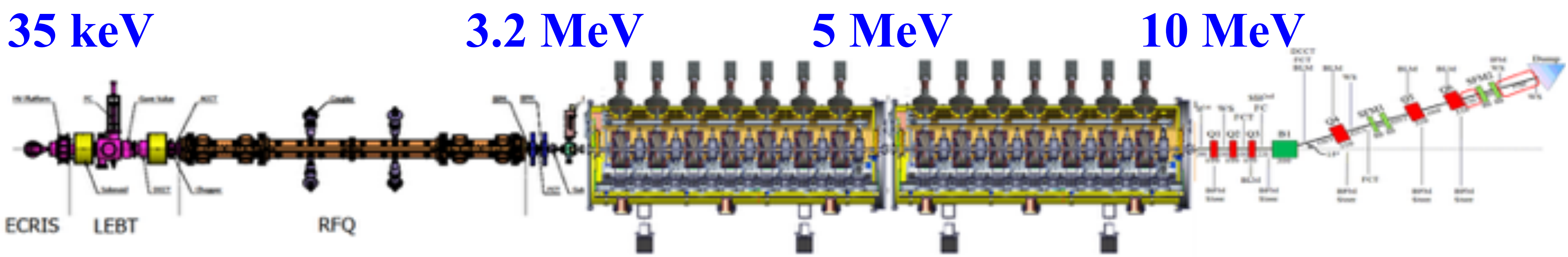
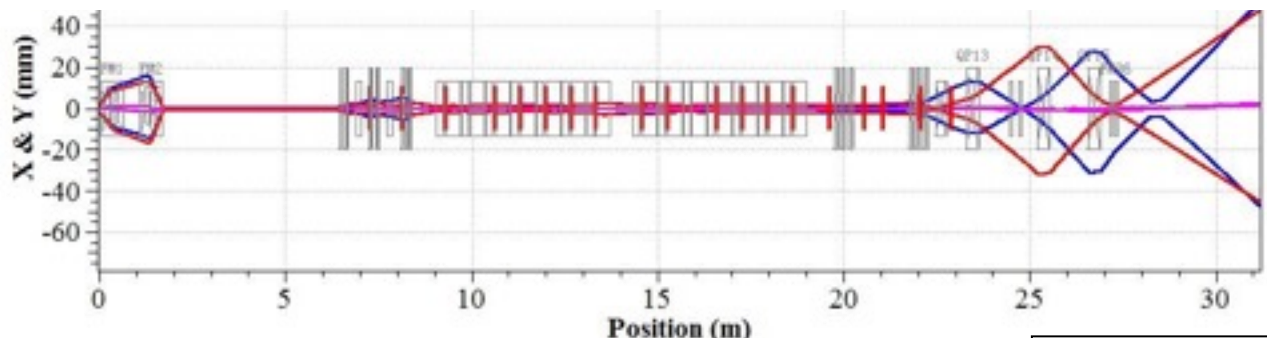
Demo facility of C-ADS at Lanzhou

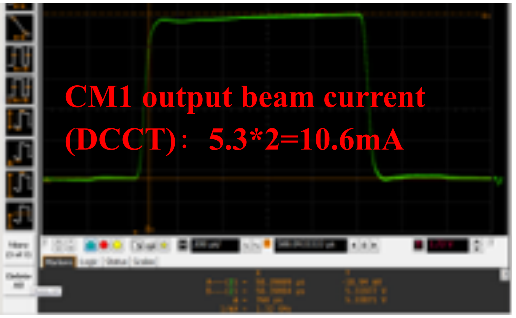


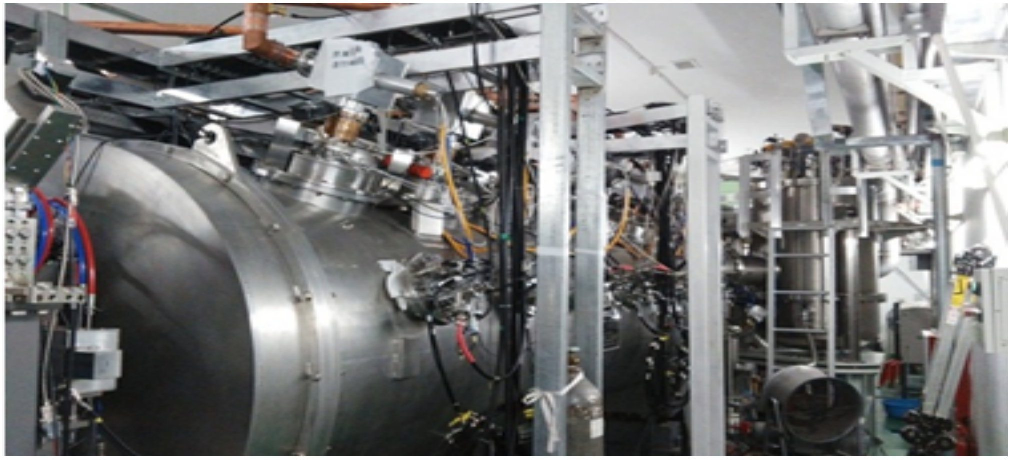
Beam: 25 MeV, 10 mA, CW, 250 kW
Target: tungsten granular, windowless, vacuum differential
Lifter: mechanical

Commissioning of Spoke linac at IHEP



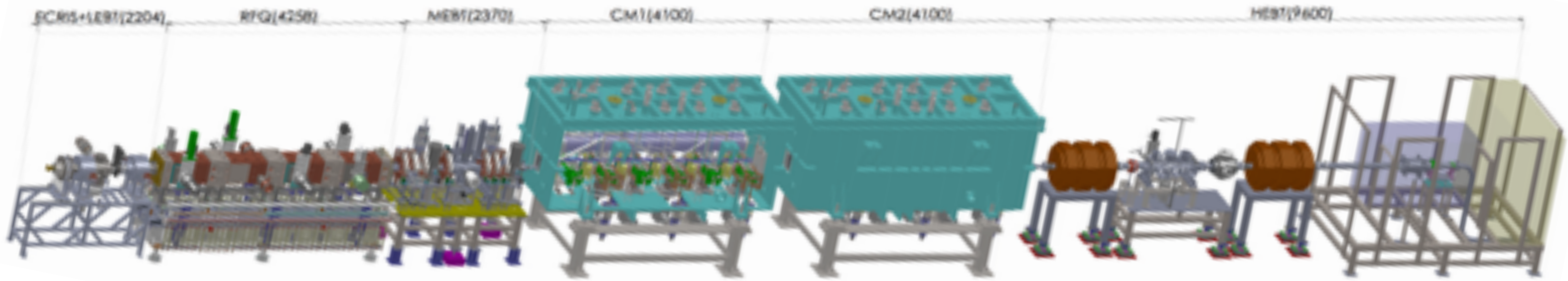






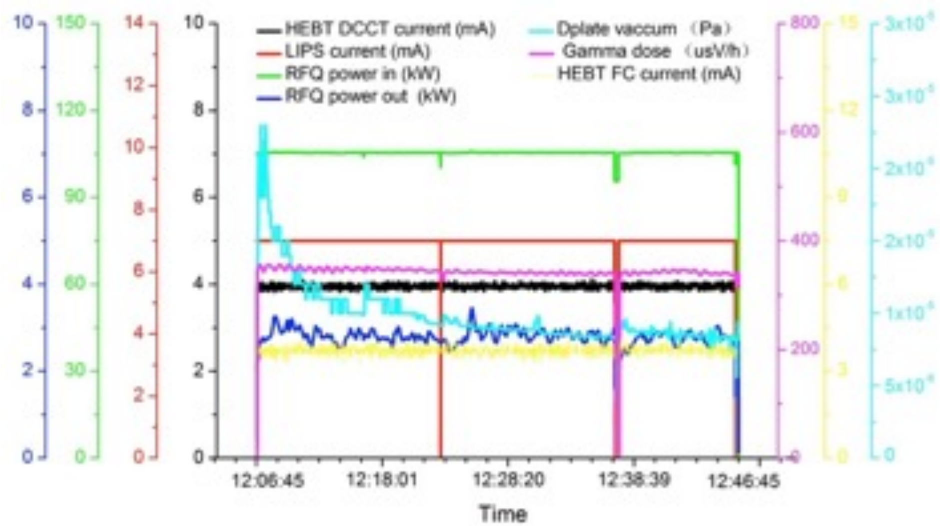
- Beam duty factor: 2‰ (2Hz/1ms)
- CM 1 output energy with 7 cavities : Eout=6MeV
- CM1 transmission: 100%
- RFQ+CM1 transmission: 88.4%
- Output current: 10.6mA

Commissioning of HWR linac at IMP



- **June 6, 2015, 5.2MeV, 10.2mA, pulse； 5.3MeV/2.7mA/CW/14kW；**
- **Nov. 28, 2015, 4.6MeV/4mA/CW/18kW/40min；**
- **Jan. 2, 2016, 4MeV/1.7mA/CW/6.8kW, 450min;**

10 MeV linac is conditioning



history record of 4.6MeV/4mA/CW/40min

Summary of operation of HWR linac

Operation 2014.06.06 - 2016.01.15			
	total beam time (hours)	CW (hours)	
RFQ- 2.1 MeV	1390	59	837h in 2014
TCM1- 2.5 MeV	208	22	Removed on April 27, 2015
TCM6- 5 MeV	400	20	To Mainten on Jan. 15, 2016

More details on beam commissioning will be presented by Dr. Zhijun Wang and Weiping Dou tomorrow.

Outlines

- Motivation and Roadmap
- Specifications and Challenge of CIADS
- Design Conception of Driven Linac
- Design Conception of Spallation Target
- Progress of Demo Facility
- **Summary**

Summary

- CIADS was approved in Dec. 2015.
- The top level parameters of CIADS has been updated.
- The design optimization of driven linac is on going. A code base on PSO was developed.
- The granular target will be employed to sustain 6 MW beam power. The V&V platform is under construction and will be ready by the year.
- The demo facility including 25 MeV linac and granular target is constructing at IMP. The 5MeV/4mA/CW beam has been proved at IMP. The 25 MeV will couple with granular target in 2017.

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……

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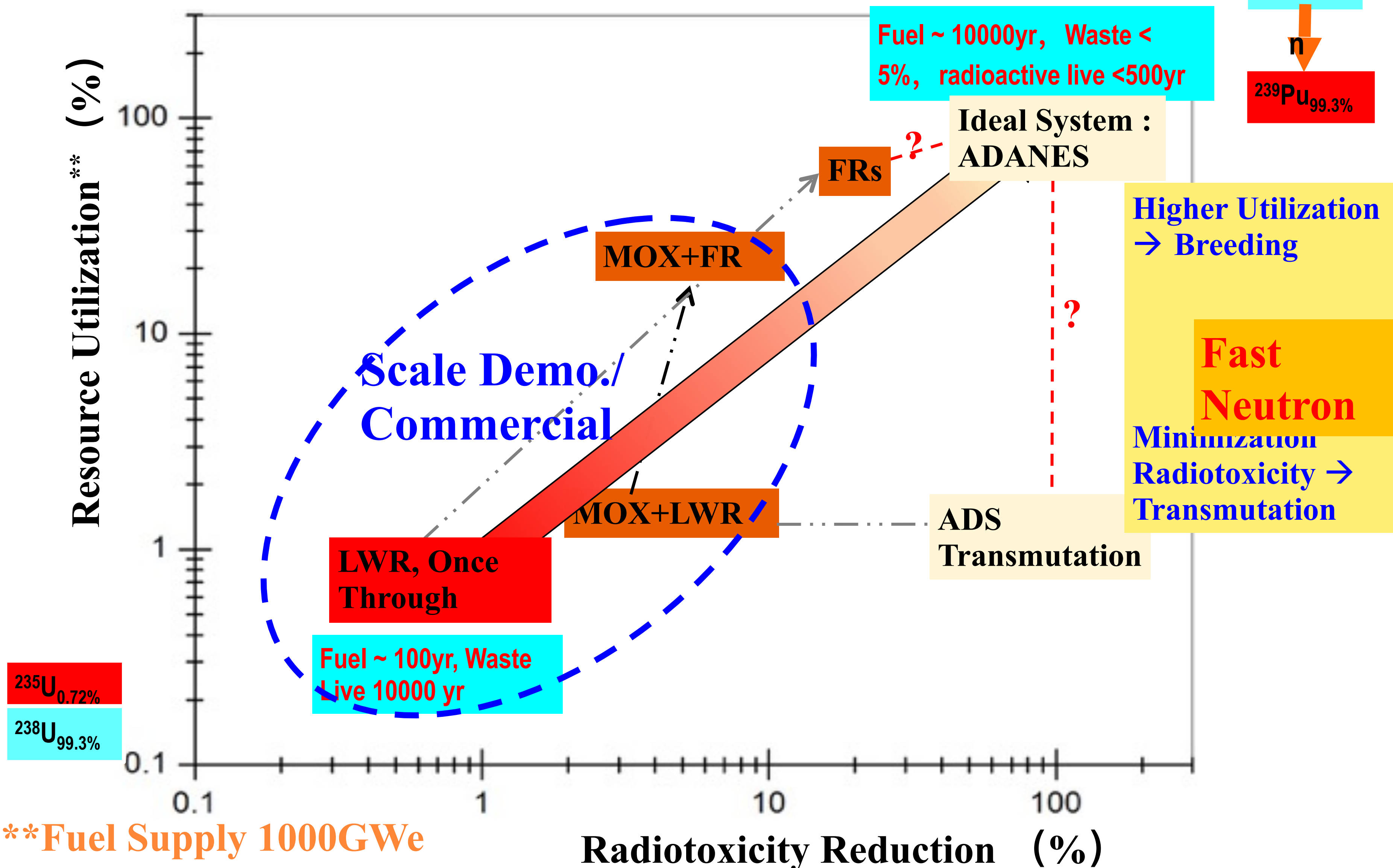
HIT, PKU, SINAP,……

Welcome Collaboration!

Nuclear Fission Energy Status



**Fuel Supply 1000GWe