10th Workshop on Hadron Physics in China

Weihai

26/07/2018

Introduction of HIAF and Nuclear Research Centre in Huizhou

Wenlong Zhan, IMP/Chinese Academy of Sciences

Outline

- **High Intensity HI Accelerator Facility**
  - **Introduction of HIAF**
  - **Upgrade for HIAF-CDR1 (Approved By Gov.)**

Motivation

National Scientific Facilities in 12-5(2011→)

- Total:16
- 7 Fields
  - Energy: 2（1）
  - Biology: 2
  - Earth & Env.: 3
  - Material: 3
  - Space & Astr.: 2
  - Part. & Nucl.: 2（1）
  - Eng. & Tech.: 2
- Physics & Related 7+4
- International Research Facility

Field	Facility
Energy	CIADS
	燃气轮机科学研究设施
Biology	Transform Medical Research Infrastr.
	动物表型与遗传机制分析研究设施
Earth & Environment	Seabed Observatory Network
	Atmosphere Simulator
	Precise Gravity Research Infrastruc.
Material	R&D of High Energy SRL
	Extreme Experiment Infrastructure
	2nd Phase SSRL
Space & Astronomy	Space Simulation Facility
	Astronomy Observer in Antarctica
Particle & Nuclear	LHAASO
	HIAF
Engineering & Technology	Future Network Research Infrastruc.
	大型低速风洞建设

HIAF (CDR1 Approved by Gov.)

E_{B1}: 0.8 AGeV, 3×10^{10}ppp $^{238}U^{35+}$
1.75AGeV, 7.5×10^{10}ppp $^{78}Kr^{19+}$
2.6AGeV, 1.0×10^{11}ppp $^{16}O^{6+}$

HIAF-I: 2018-2024

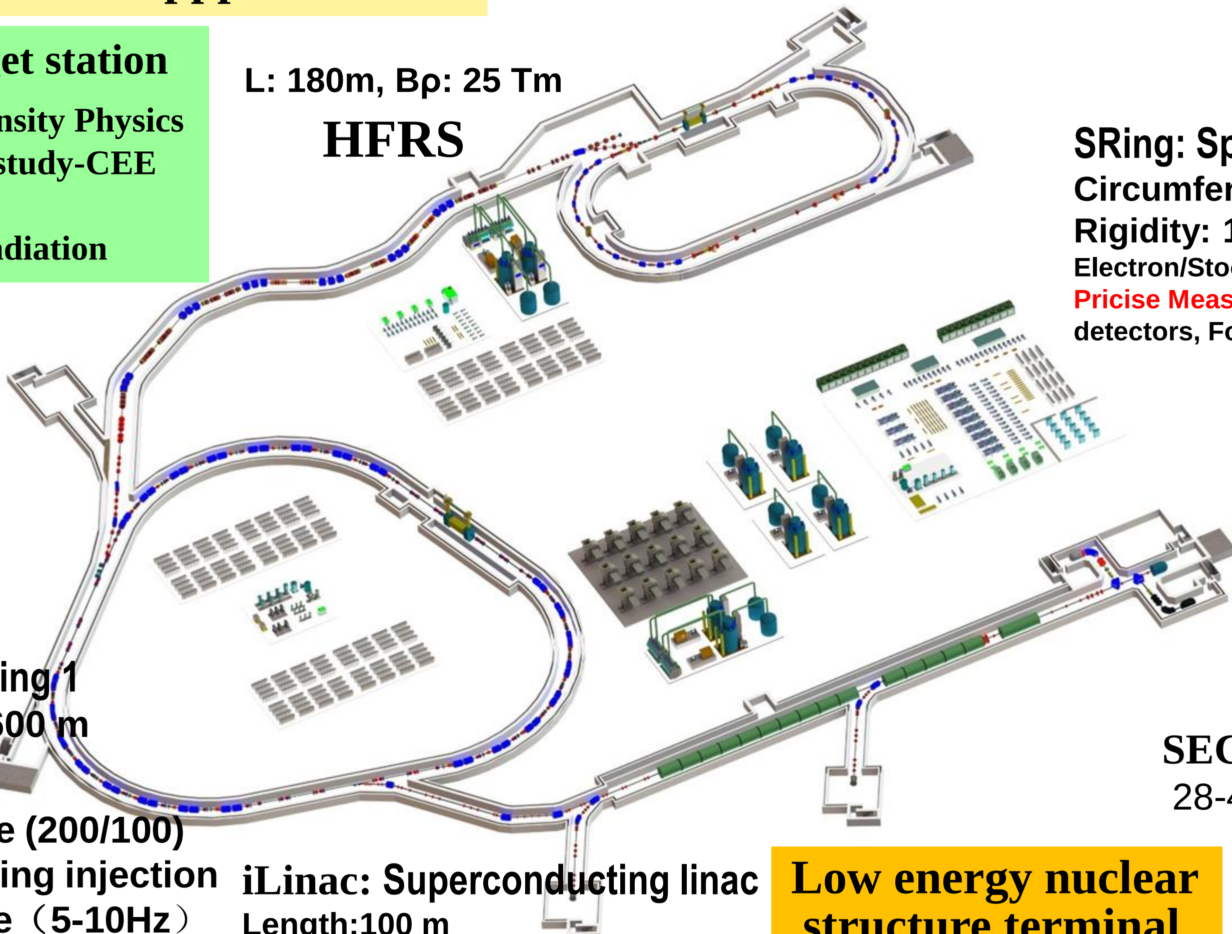
Budget: 1.5+1.2 B CNY, approved

External target station

- High Energy Density Physics
- Nuclear Matter study-CEE
- Hypernuclear
- High energy irradiation

L: 180m, Bρ: 25 Tm

HFRS



SRing: Spectrometer ring
Circumference: 273m
Rigidity: 13-15 Tm
Electron/Stochastic cooling
Pricise Measurement by Two TOF detectors, Four operation modes

BRing1: Booster ring 1
Circumference: 600 m
Rigidity: 34 Tm

Large acceptance (200/100)
Two planes painting injection
Fast ramping rate（5-10Hz）

iLinac: Superconducting linac
Length:100 m
Energy: 17~22 MeV/u($U^{35+ \sim 46+}$)

Low energy nuclear structure terminal

SECRAL and FECR
28-45GHz,1.0emA(U^{35+})

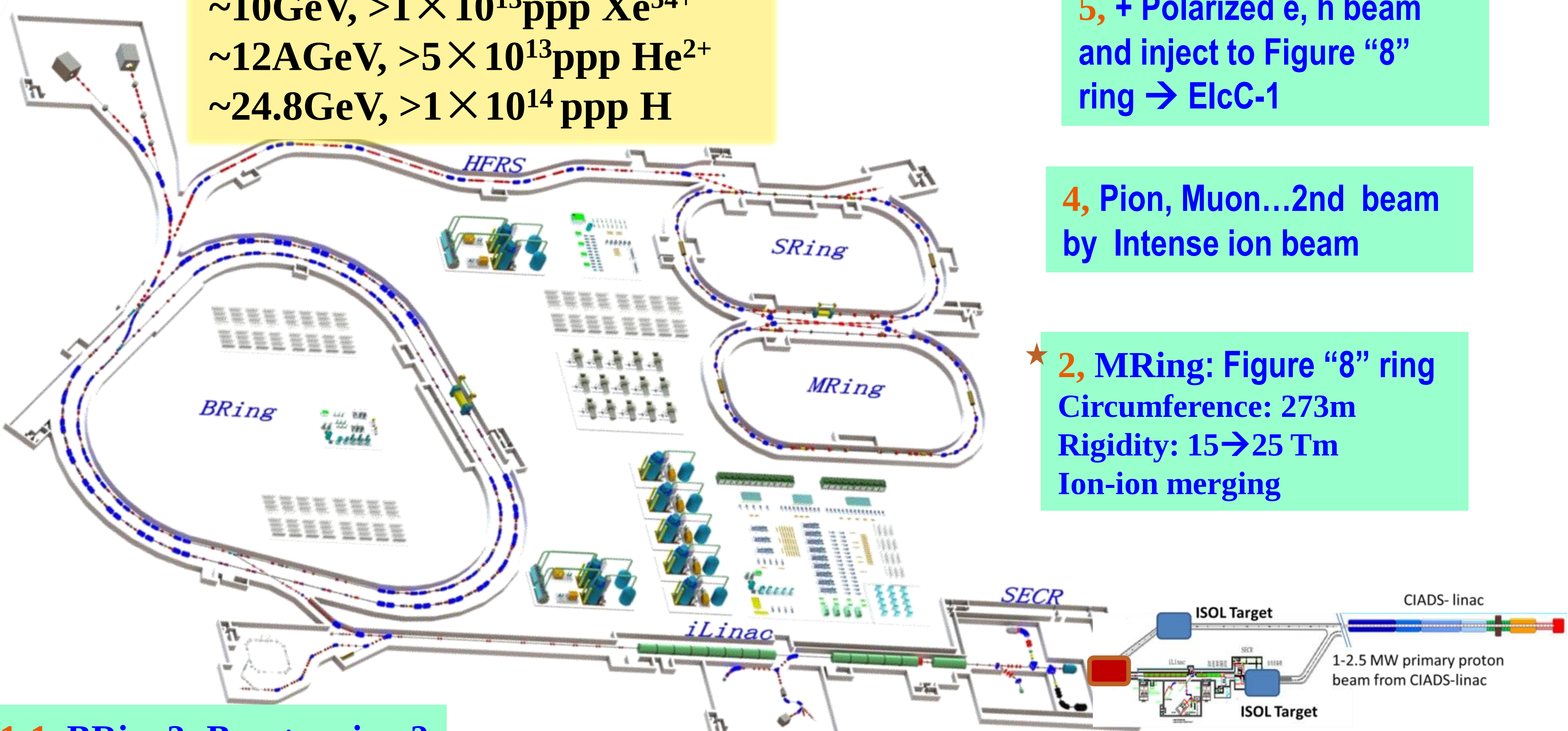
HIAF-CIADS Upgrade

E_{B2}: >9AGeV, 1×10^{12}ppp U^{92+}
~10GeV, >1×10^{13}ppp Xe^{54+}
~12AGeV, >5×10^{13}ppp He^{2+}
~24.8GeV, >1×10^{14} ppp H

HIAF-U

5, + Polarized e, h beam and inject to Figure “8” ring → EIcC-1

4, Pion, Muon…2nd beam by Intense ion beam



★ 2, MRing: Figure “8” ring
Circumference: 273m
Rigidity: 15→25 Tm
Ion-ion merging

★ 1-1, BRing2: Booster ring 2
Circumference: 600 m
Rigidity: 86 Tm

Beam stacking
Superconducting

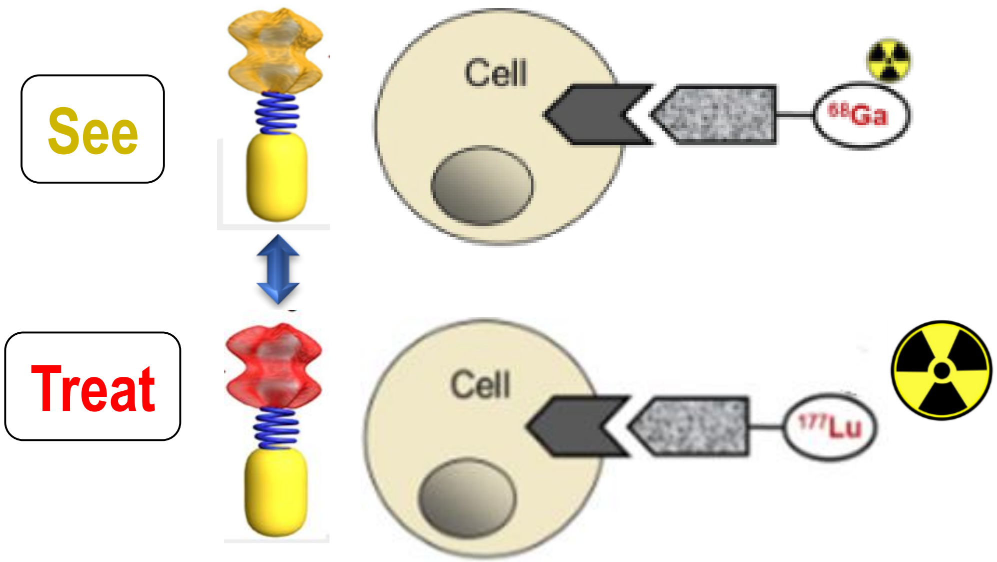
★ 1-0, iLinac: Superconducting linac
Energy: 100~150 MeV/u($U^{35+\sim46+}$)

★ 3, ISOL machine
HIAF+CIADS linac

1-0, Higher HI-SCL Energy and Intensity

- **HI-SCL Energy from 17~22AMeV to ~100AMeV**
  - **Beam Intensity Gain ~ 3, duo to:**
    - **Increasing HI charge stripping efficiency for heavier HI**
    - **Higher injection efficiency by reducing charge-spacing limit**

- **Medical Isotope Production for Targeted Tumor Treatment**
  - **Imaging →**
  - **Drug →**



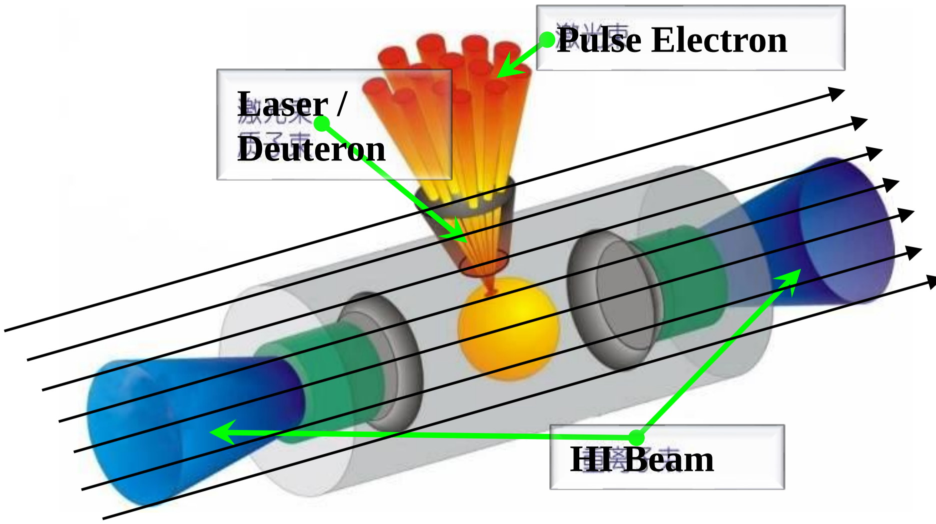
^{11}C, ^{18}F, ^{64}Cu, ^{44}Sc, ^{68}Ga, ^{72}As, ^{76}Br, ^{86}Y, ^{123}I, ^{124}I, ^{99m}Tc, ^{89}Zr, ^{111}In, ^{152}Tb…

β： ^{177}Lu, ^{90}Y， ^{123}I, ^{125}I, ^{131}I, ^{188}Re
α： ^{223}Ra， ^{211}At， ^{225}Ac， ^{213}Bi…

- **Treat What You See (molecular imaging & treatment)**

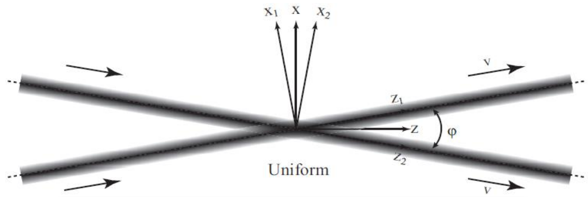
1-1, Higher Intense Ion Beam of HIAF

- **HI-RCS (5~30Hz) + BRing2(~1Hz):**
  - **Higher ions accumulation (4D painting gain >150) CW→ Pulse**
  - **higher efficiency of charge stripping between two ring**
  - **higher energy (34Tm→86Tm) of system**
- **Improvements:**
  - **Luminosity on (internal) target exp.**
  - **2nd beam Intensity**
    - **RIB**
    - **Meson beam…**
  - **Pulse beam >100kJ/ppp**
- **HEDM Research more power**
- **…**

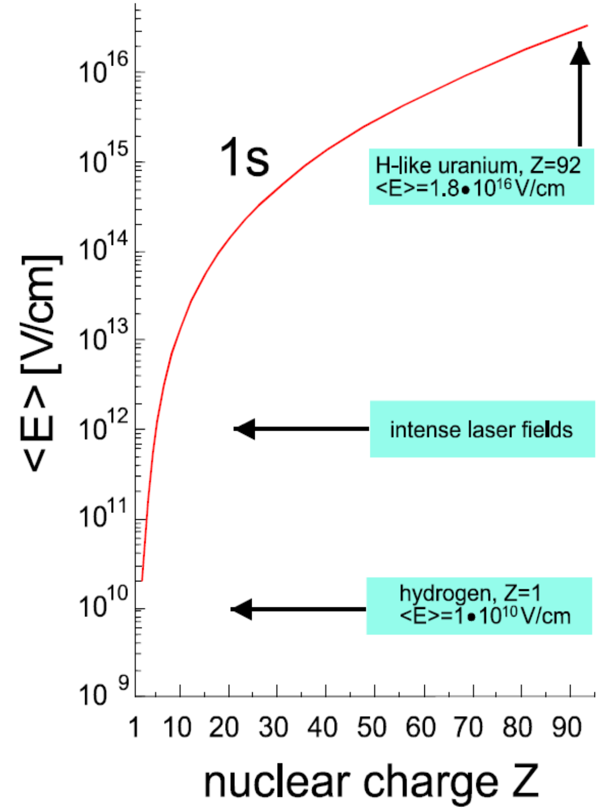


2, Merging Beam High Accuracy Experiment

- **Complete the Figure 8 ring and provide merging exp.**
- **Researches**
  - **RIB, HI direct reaction:**
    - **E_{cm} < 10MeV/u**
    - **Luminosity: <$10^{24\sim29}$/cm^2.s**
  - **QED Validation under Ultra-high E-field:**
    - **a, Vacuum Excitation e-pair;**
    - **b, Super-Critical Atom**
    - **$U^{92+} + U^{92+} \rightarrow$ Ec > 2*10^{16} V/cm**
    - **Collision Time >$10^{-21\sim-19}$ sec.**
    - **E_{cm} 5~8 MeV/u (R_{min}~30fm) could be tuned by changing E_{lab} of U**
    - **Luminosity: ~$10^{\sim26}$/cm^2.sec**

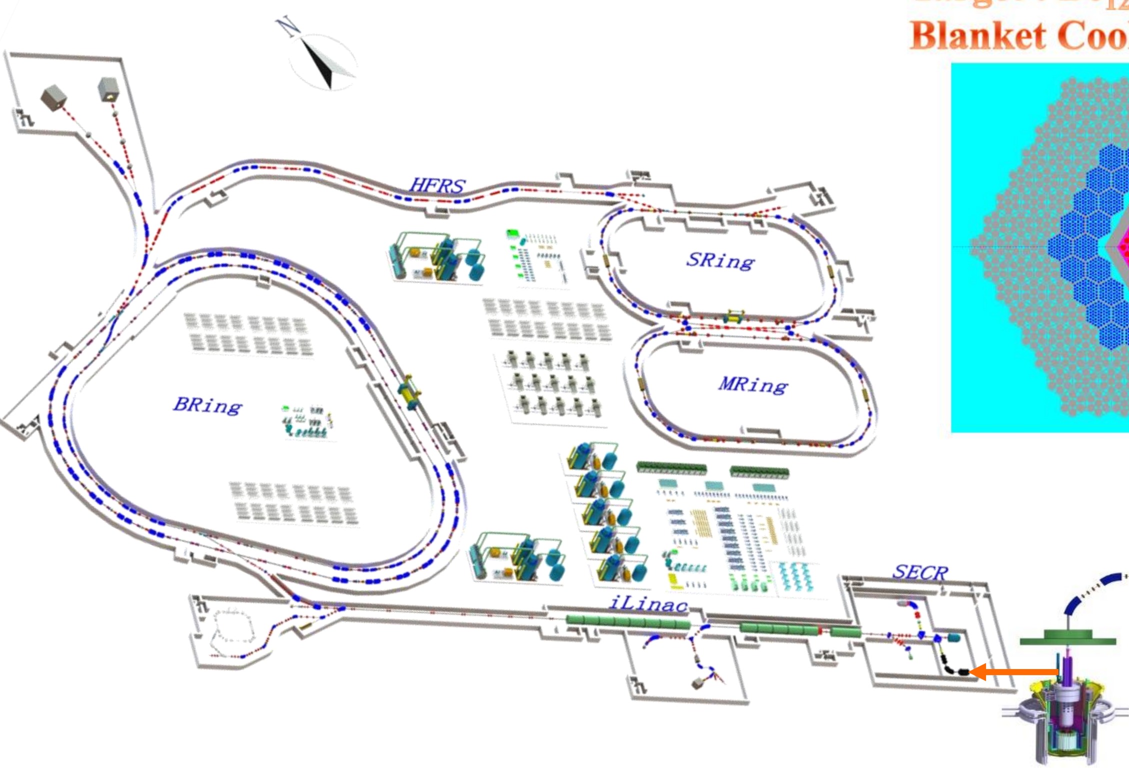


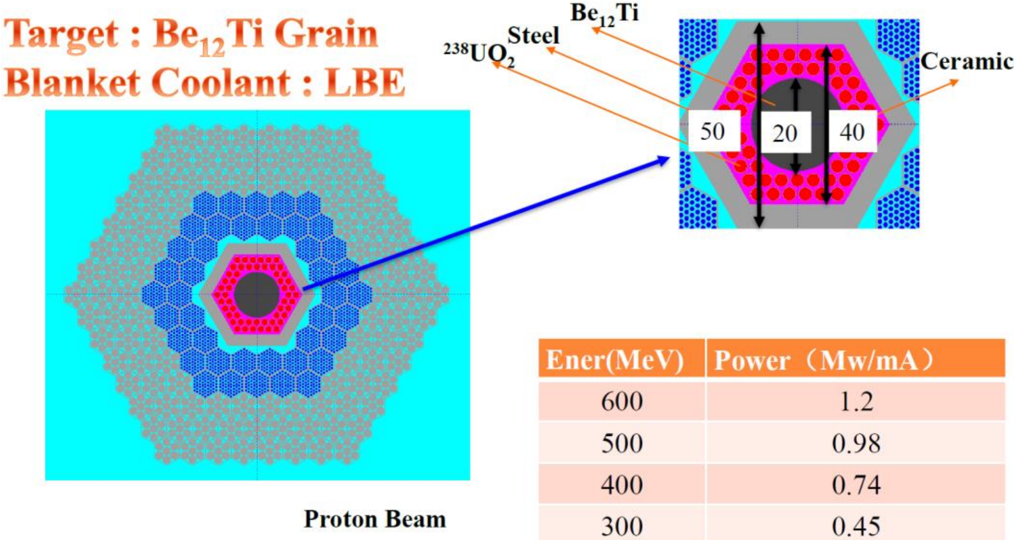
$$L = \frac{N^2 v}{2\sqrt{\pi}\gamma\sigma_y C^2} H$$



3, Integration of HIAF + CIADS

- **HIAF+CIADS(ADANES) → >2.5(10s')MW ISOL Target, RIB by Extracting RI (ex. Kr, Xe) from CIADS's Target and Inject to HIAF Complex**

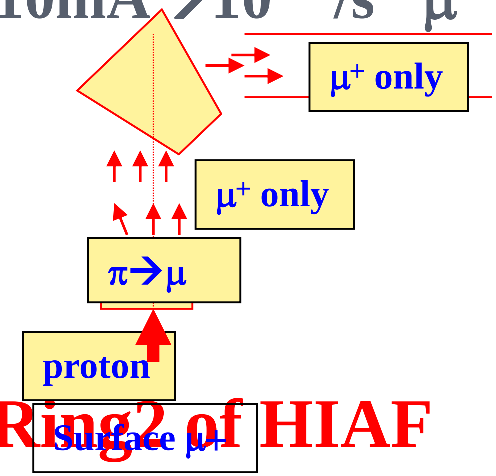




Ener(MeV)	Power（Mw/mA）
600	1.2
500	0.98
400	0.74
300	0.45

4, 2^{nd} Meson's and anti-Proton Beams (Intensity Frontier)

- **2^{nd} DC μ Beam driven by intense proton of CIADS**
  - "ISOL" Type (surface muon), 1.0~1.5GeV&10mA→$10^{\sim 12}$/s μ^+ (>10 time than existing Setups)
  - Research Topics:
    - $\mu^+ \rightarrow e^+\gamma$ (→$10^{-15\sim-16}$), μ^+ g-2, ...
    - Application: μSR, tomography, condense matter, …



- **2^{nd} Pulse Beams (>3GeV/c π, μ, k) from HI-BRing2 of HIAF**
  - "In Flight" ~$10^{12\sim10}$/ppp 2^{nd} Beam/ $10^{10\sim9}$ in Ring (10*μ Campus)
  - Research Topics:
    - Mu2e, μ g-2, …
    - Neutrino: υ_μ oscillation, precise measurement…
    - κ Rare Decay, nuclei EDM,…
    - large scale tomography…

- **2^{nd} Pulse anti-Proton Driven by 86 Tm Intense proton / Hi ?**

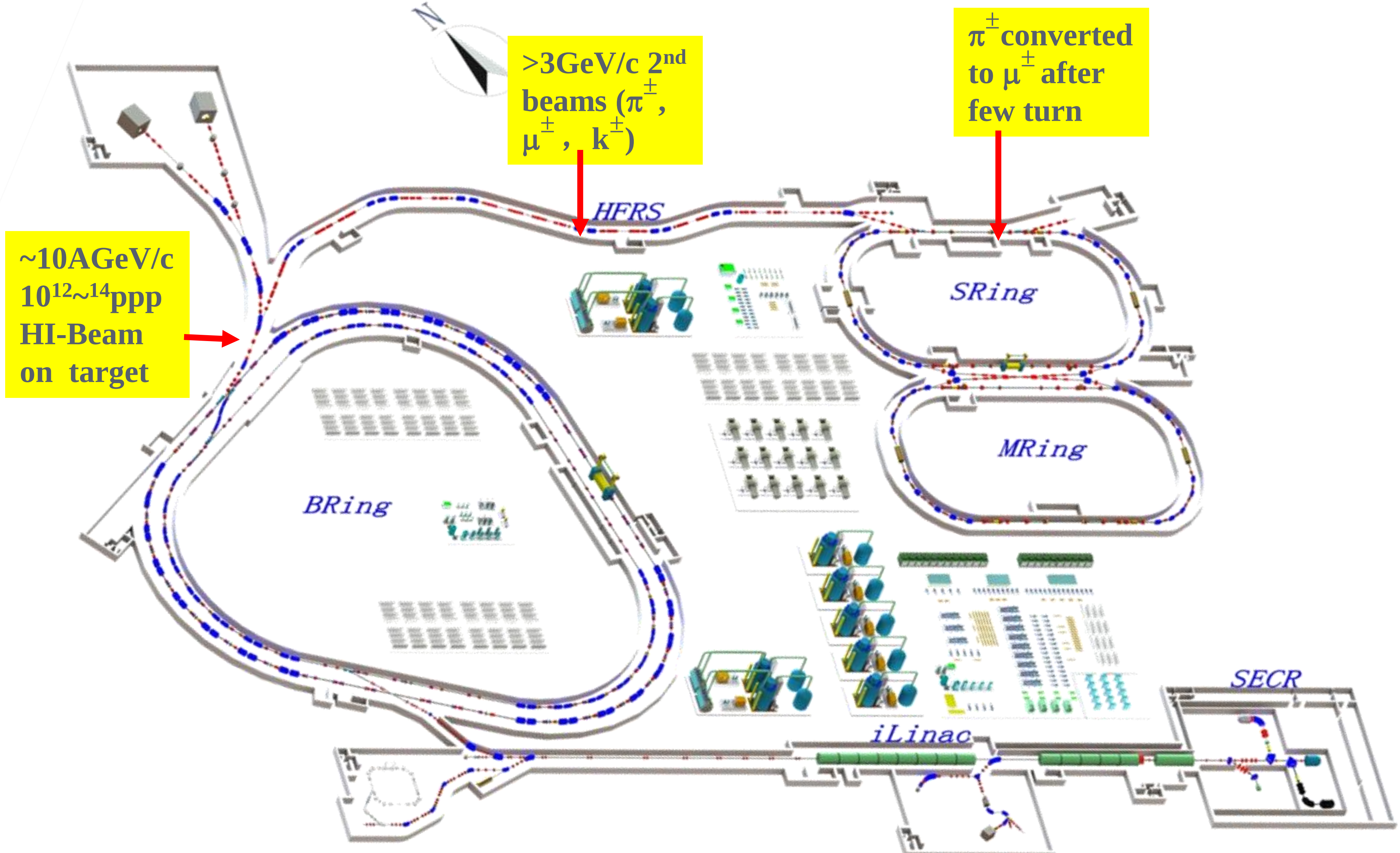
4, 2nd Muon (& Neutrino) Beam Driven by HI

- **System Optimizing: (higher eff. as intense pulse HI beams)**
  - $E_{ring} \propto q^2/A$ [Bρ = 86Tm → ~10AGeV for A~100]
  - $Gain_{Yield}$: $\propto A_p^{2/3}$ (~4AGeV)→ ~20

(π⁻enhanced) $\propto A_p$ (~10AGeV)→136 (>8 * muon campus)

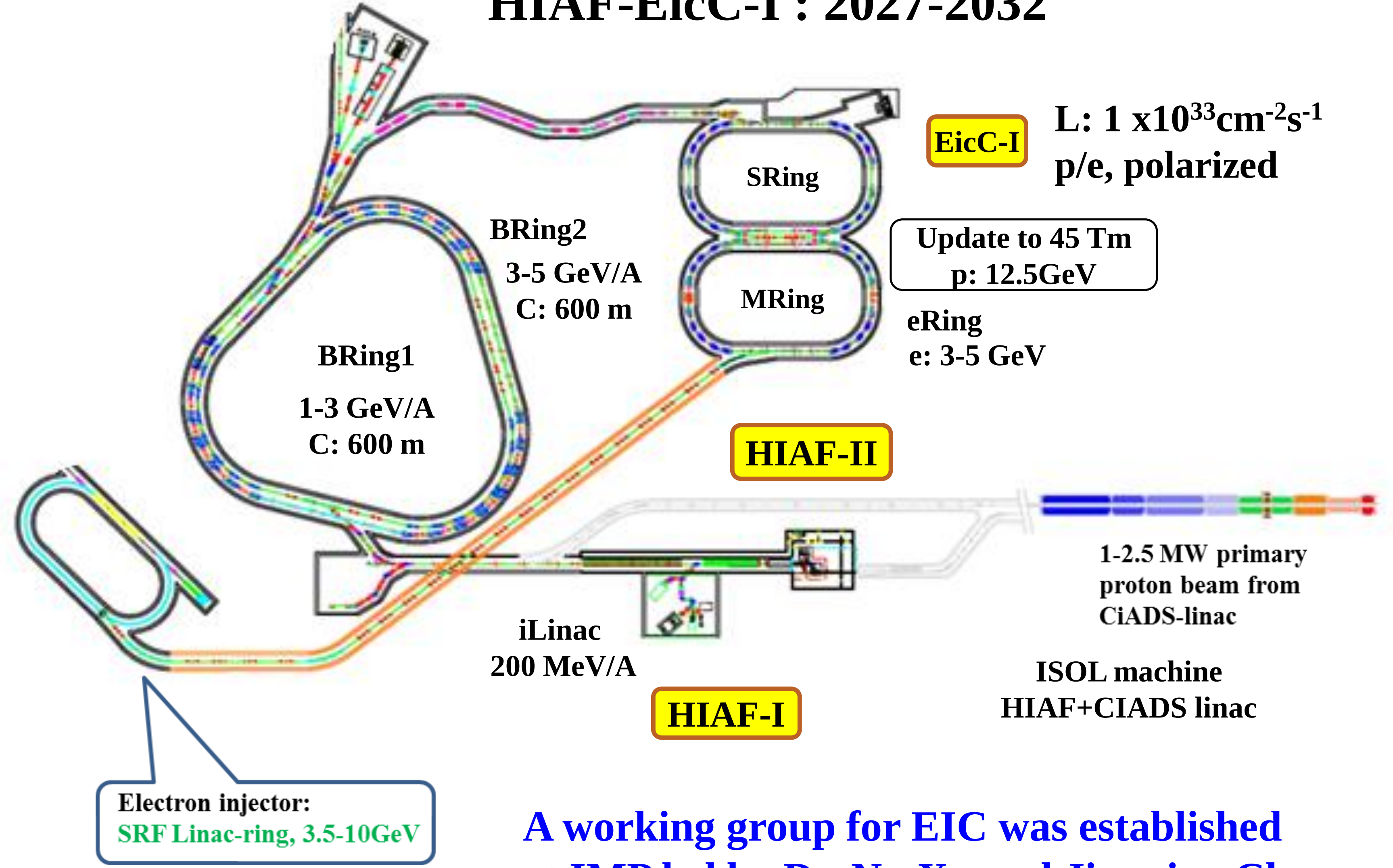
  - $Gain_{Yield}$: Granular Target →1.1 ~ 1.5
- **Further R&D:**
  - Optimizing primary reaction system (Energy, Proj., Target…)
  - Separator : HFRS (180m) or New design
  - Storage : Ring of Figure 8 (accelerate?) / TSR, Beam Acceptance
  - Detector System
- **Advantages of Comparing Proton Driven**
  - ~10AGeV HI effective for Pionisation of reaction system
  - In Flight → E_μ >3GeV easy to clean 2nd beam and inject to Ring

Dream: In-Flight Muon Beam → Muon Factory



5, HIAF- EicC-I (Cover Sea Quark)

HIAF-EicC-I : 2027-2032



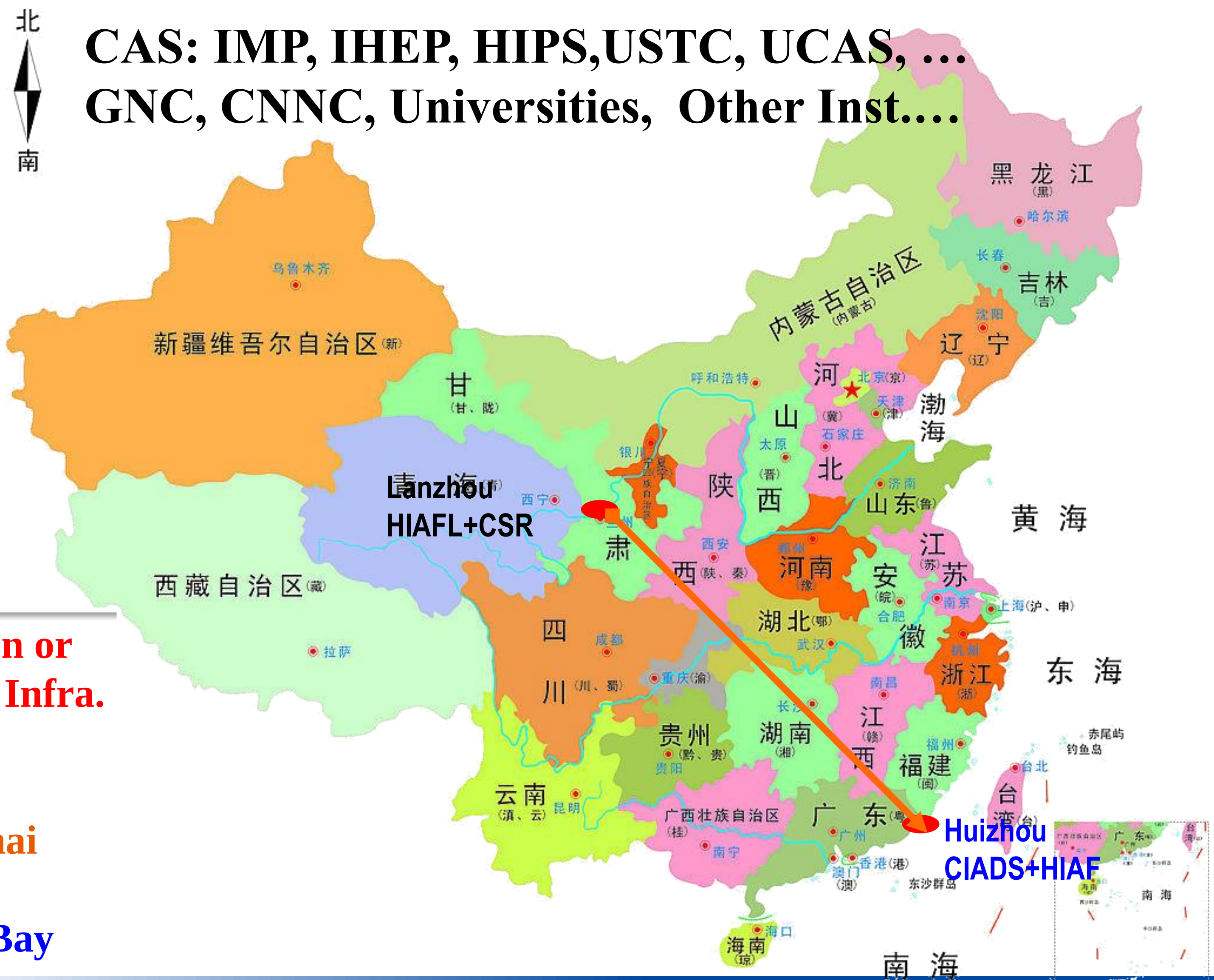
A working group for EIC was established at IMP led by Dr. Nu Xu and Jianping Chen.

Outline

- **Overview of New Research Centre**
  - **Introduction of New Centre**
  - **Chinese Initial Accelerator Driven System (CIADS)**
  - **Further Developments**

Research Center in Huizhou, China

CAS: IMP, IHEP, HIPS,USTC, UCAS, …
GNC, CNNC, Universities, Other Inst.…



Innovation or Research Infra. Center:

1, Beijing
2, Shanghai
3, Hefei
4, Great Bay

Opportunity of Research Center in Greater Bay

- Genome Bank
- Daya Bay (Neutrino Measurement θ_{13})
- Super-Computer (TianHe-2)
- Chinese Spallation Neutron Source
- JUNO (On Going)
- High Intensive HI Accelerator Facility (Starting in 2018)
- Chinese Integrate Accelerator Driven System (same above)
- Light Source (proposing by local gov.)
- Gravitation Research Facility (proposing by Univ. Zhongshan and will be Supported by Shenzhen Local Gov.)
- Nuclear Fuel Research Facility

Researches on Intense Beam at CIADS+HIAF

I. Nuclear Physics

- Nuclear Structure & Nuclear Astrophysics
- Nuclear Matter, Hadron Nuclear Physics

II. Foundation Physics

- Ultra-high E_Field QED, HEDM
- π, μ, κ meson rare decay, meson-nucleon reaction, neutrino, Potential： EIcC-1,...

III. Nuclear Energy (ADANES)

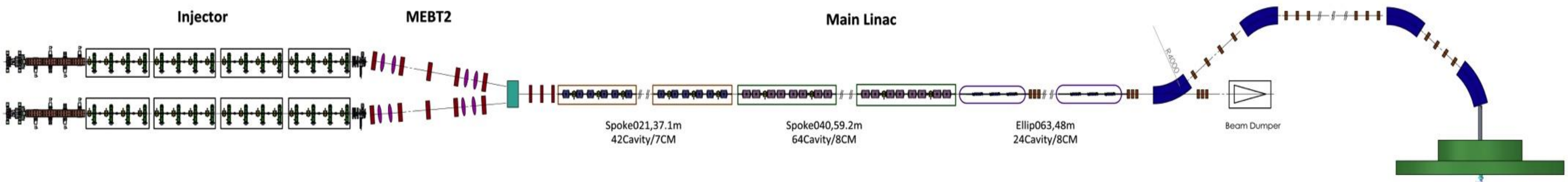
- CIADS → ADANES Burner + Convert UNF → Recycle Fuel

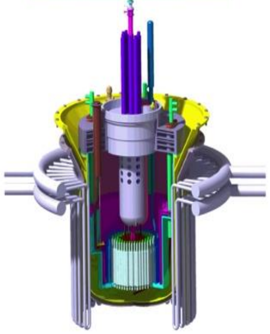
IV. Nuclear Fuel Research base on Accelerator

- High Flux Neutron Source (~14MeV 10^{16}n/cm^2.s, >60dpa)
- Intensive Ion Irradiation (speed up material pre=selection)

V. Tumor Treatment: hadron therapy and medical Isotopes

Chines Initial Accelerator Driven System (CIADS)





☐ CIADS Main Parameters:

- **High CW Power (>2.5MW, >500MeV) SC-LINAC**
- **High Power (>2.5MW) Spallation Target**
- **Sub-Core (<10MW$_{th}$)**
- **Coupling all Components → Full System (~10MW)**

☐ CIADS Time Schedule :

- **6 years （2018—2024）**

ADANES Summary

Energies 10(7);944
July 2017

- Accelerator Driven Burner (CIADS→ADB)

Transmutation + Breeding + Generation Burning

1, AD Starter + Long Refueling (16~36y) FR

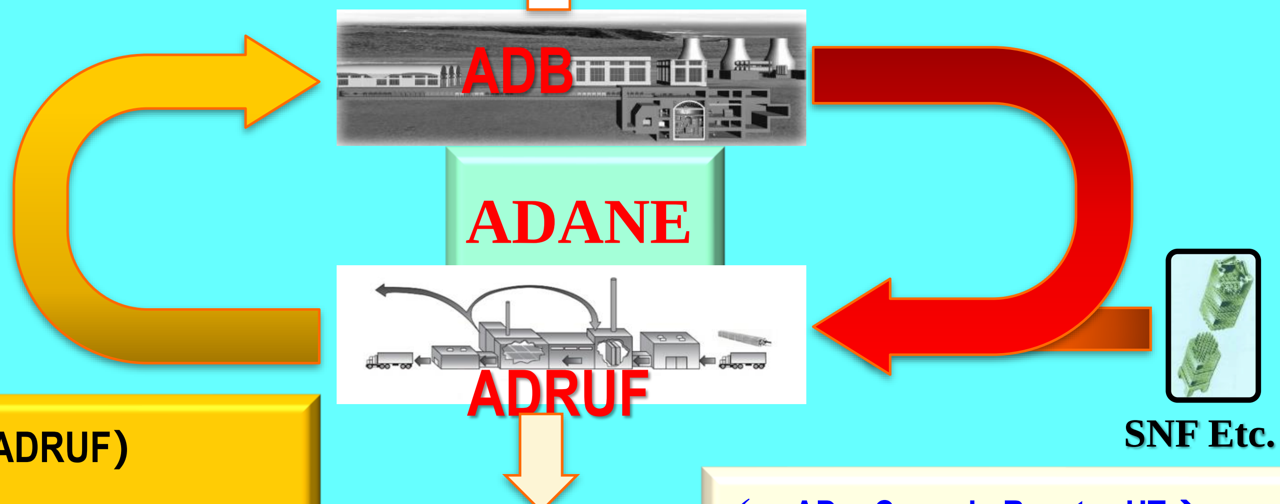
2, Burning ~50% FP Recycle UNF (Raw Fuel)

- Feature: Low Carbon→Clean

Fuel Close within Station

✓ Resource Utilizing>95%→10000y,
"Waste" <FP(4%) & <500y

Electricity



- AD Recycle Used Fuel (ADRUF)

AD Simplify Process → Removing >50% FP (<4%UNF),

Converting as Recycle UF (Dry, Less Contamination)

1, Dry Process(Gas + Volatile + Separate + Extracting)

2, HT, Long Live Fuel Device + Core Component

3, Irradiating Setup for Recycle UF, Core Components

<"Waste":
Gas + Volatile FP
+RE FP

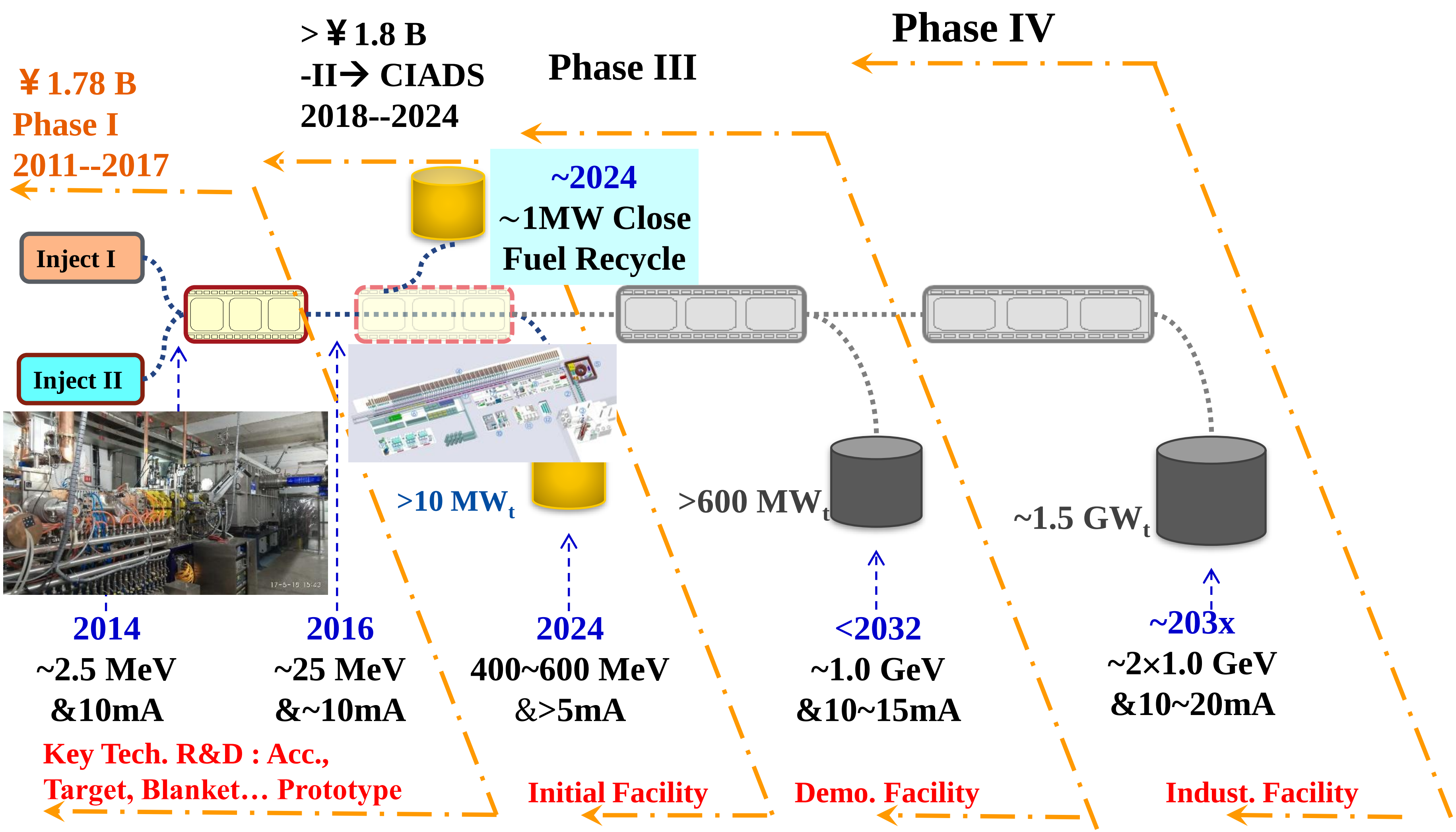
✓ AD + Ceramic Reactor HT→
Coherence Safety

✓ Waste Low Dose, Heat → Dry Storage

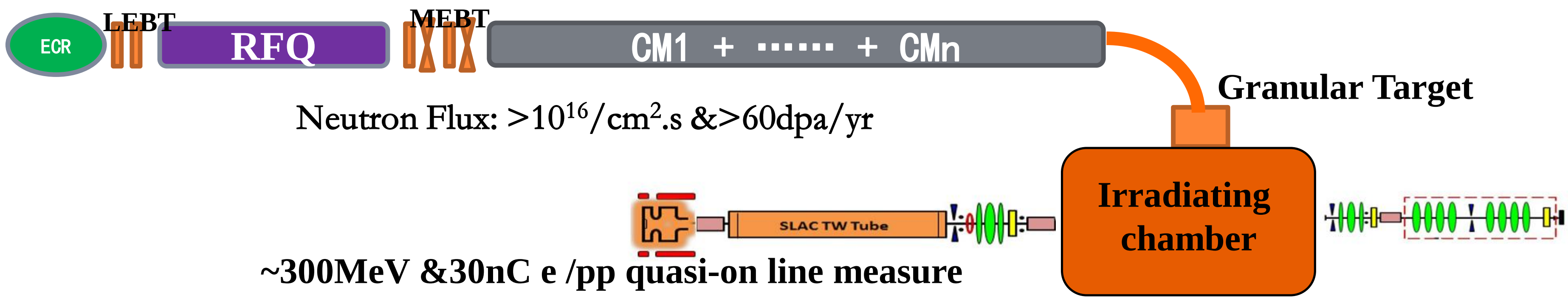
✓ Higher Cost Effective

✓ Anti-Proliferation in Principle

ADS/ADANES Roadmap in China



Nuclear Fuel Research Facility



➢ Main Goals

1, Fission Fuel & Recycle Fuel Verified

- Fuel Devices Test
- Recycle Fuel Transmutation, Breeding rate …

2, Fusion Fuel Sustainable: 14MeV (n, 2n), $^{6}Li(n, T)^{4}He$

3, Irradiation of Materials (Filtered by Ion beam, final, by Neutron)

- Cladding （SiC_f/SiC…)
- Core Structure、Window (Oxide + Carbide Ceramics…)

➢ Main Facilities

1，High Flux Neutron Source (Similar as Fusion Neutron Spectrum)

2，Intense light Ion Accelerator (~1dpa/d → >80MeV&1mA He)

3，Short Pulse Electron Quasi-online Imaging (~300MeV&30nC <1ns)

4，Associate Test Bench with hot cell

Research Capabilities at New Center

- **Feature:**
  - **Multidisciplinary Research Complexes (CIADS+HIAF-U)**
  - **Integration of CIADS+HIAF-U**
  - **Intense Primary Ion Beam & 2nd Beams**
  - **Highest Spallation Neutron**

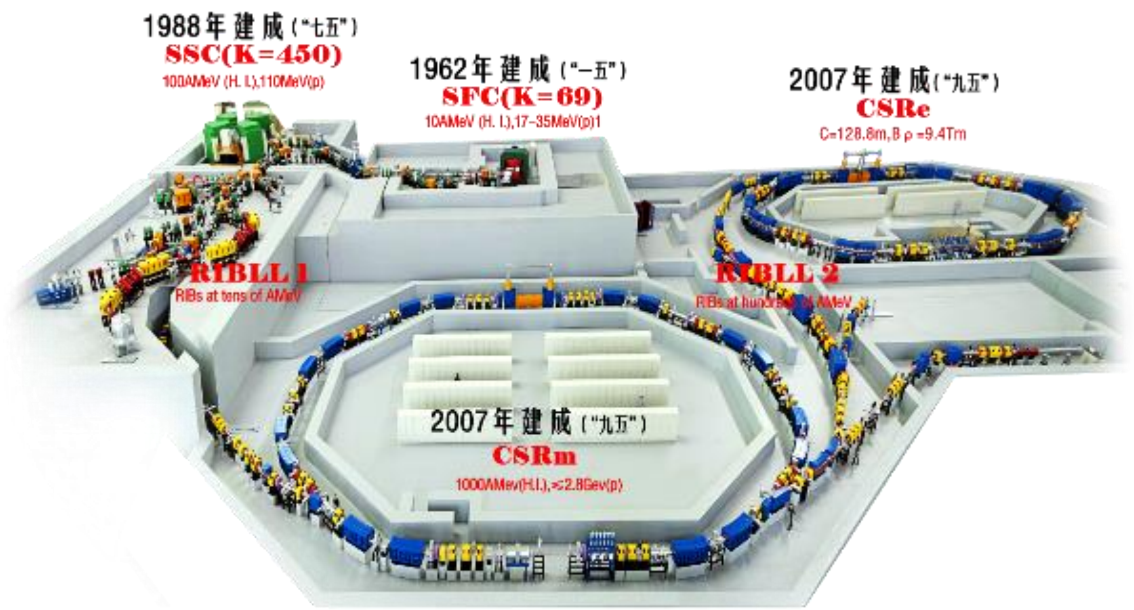
	HIAF+ + CIADS (~2025)	HIAF-U + ADANES (<2032)
HI	<1000 MeV/A <$10^{10\sim12}$pps	Heavy species close to 9~12AGeV, 10^{13}pps(A~100)
Proton	>500MeV&5mA ~10GeV/C&$10^{\sim13}$ppp	<1.5GeV&10mA ~25GeV/C&$10^{\sim14}$ppp
RIB	In Flight + ISOL?	In Flight +ISOL
Spallation Neutron &Flux	>2.5MW&$10^{14\sim15}$ n/cm^2.sec	>10MW&$10^{15\sim16}$ n/cm^2.sec
2nd Meson beam	?	π, μ, κ…
EIC	Polarized Proton Booster, ERL R&D	???

Outline

- **Status of New Research Centre**
  - **HIRFL+CSR R&D**
  - **ADS/ADANES R&D**
  - **…**

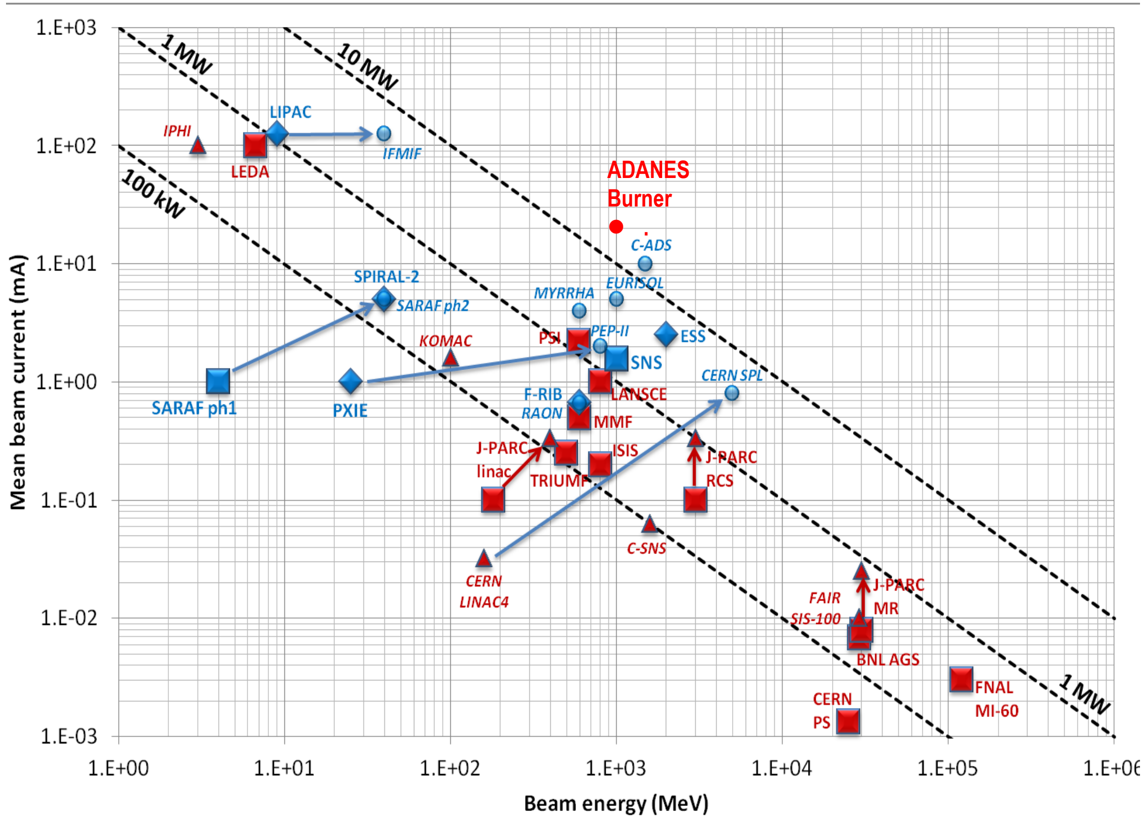
HIAF R&D (Detail Presentation by other talks)

- **Ion Source → LEAF**
- **SC-LINAC→ ADS Key Tech. R&D**
- **Synchrotron → HIRFL-CSR, Cancer Therapy**
- **E-Cooling → HIRFL-CSR, Pulsed electron cooling R&D**
- **Experiment Setup→**
  - HIRFL-CSR
  - BEPC
  - RHIC-STAR
  - Dark Matter Satellite



Challenge of SCL for CIADS/ADANES

- **Scale**
  - **Transmutation Demo**
  - **Industrial transmutation**
  - **Industrial Power Generation (IPG)**

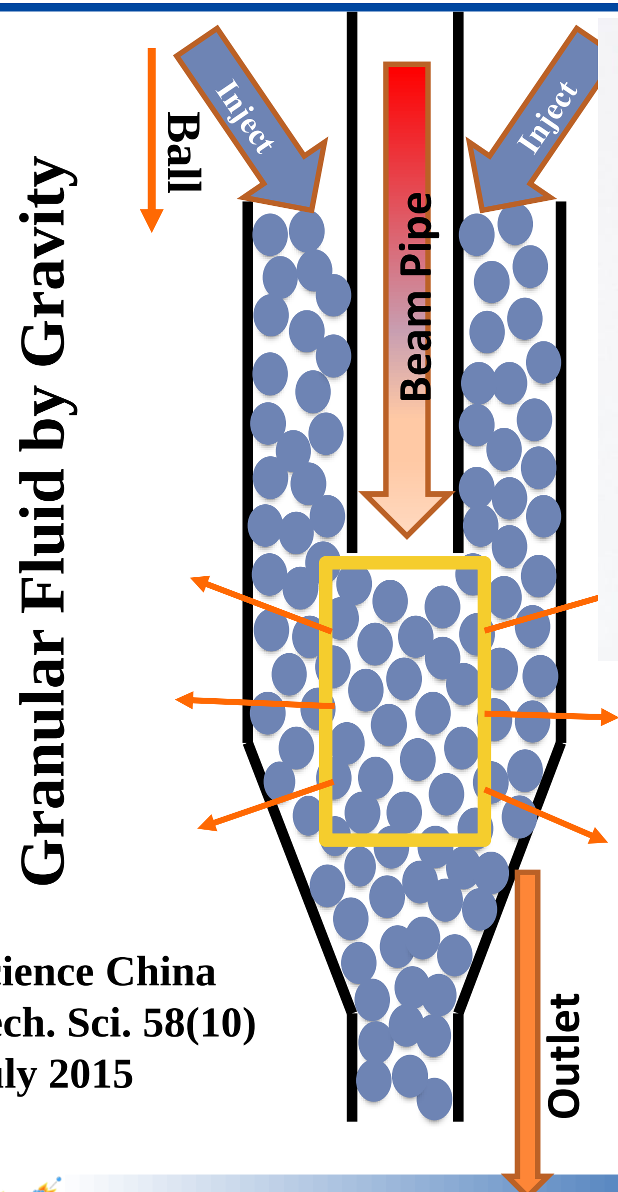


- **Mean Beam Power (IPG) : 10~20MW**
  - **Energy : ~1GeV**
  - **Mean current : 10~20mA**

- **Beam Strips & Availability（IPG）**

t < 1 sec.	1 < t < 10 sec.	10s < t <5 min.	t > 5min.	Availability
< 25000/yr.	< 2500 / yr.	< 250 / yr.	< 3 / yr.	> 85%

Principle of Granular Fluid Spallation Target

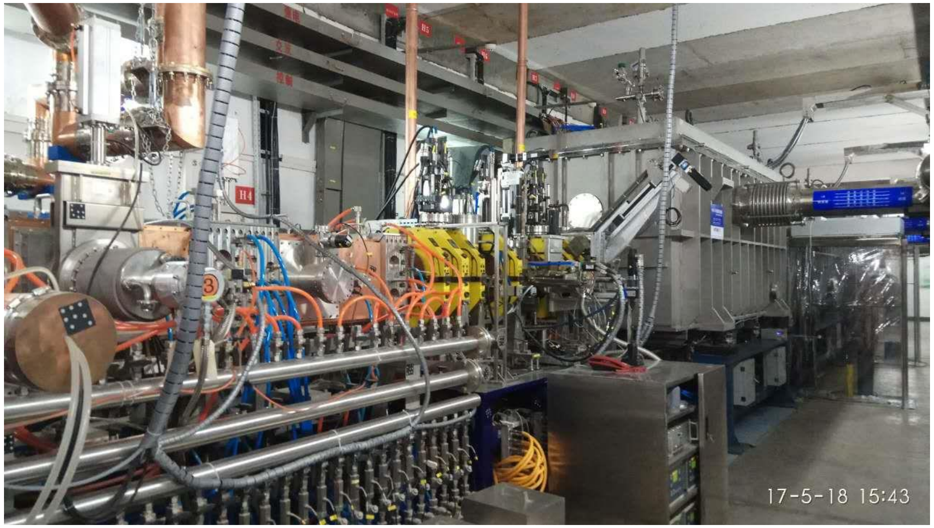


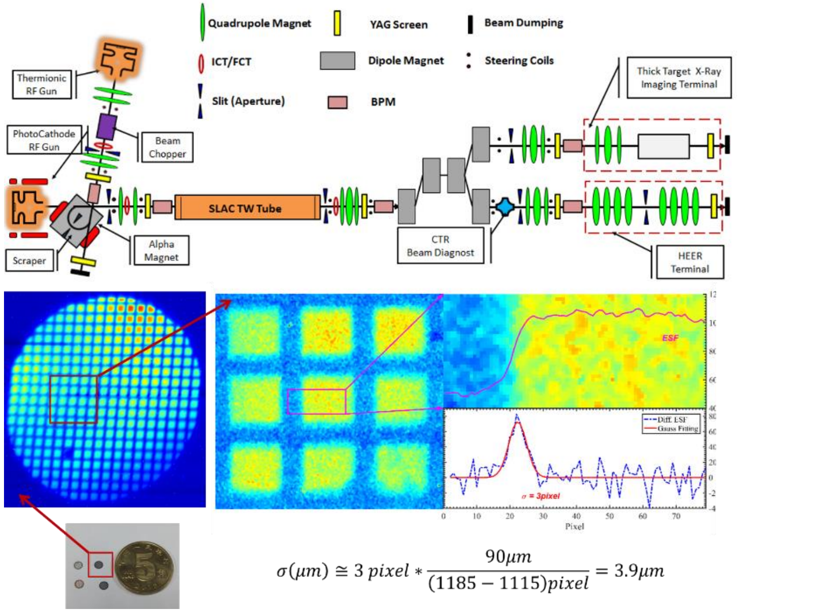
- Granular fluid operate stable as sand clock
- Target heat removing off line and grain update on line simply
- Higher target power capacity: 10~100 MW
- Dissipation the shock wave induced by beam trip, and relieve short beam trip (<10s) requirement of system
- Useful for 2nd beam
- Dust handling require
- High cost effective

Science China Tech. Sci. 58(10) July 2015

CIADS R&D (Detail Presentation by other talks

- **25MeV SCL（Prototype）**
- **Granular high power target and useful for 2^{nd} beams (new)**
- **High energy pulse electron imaging quasi-in line (new)**

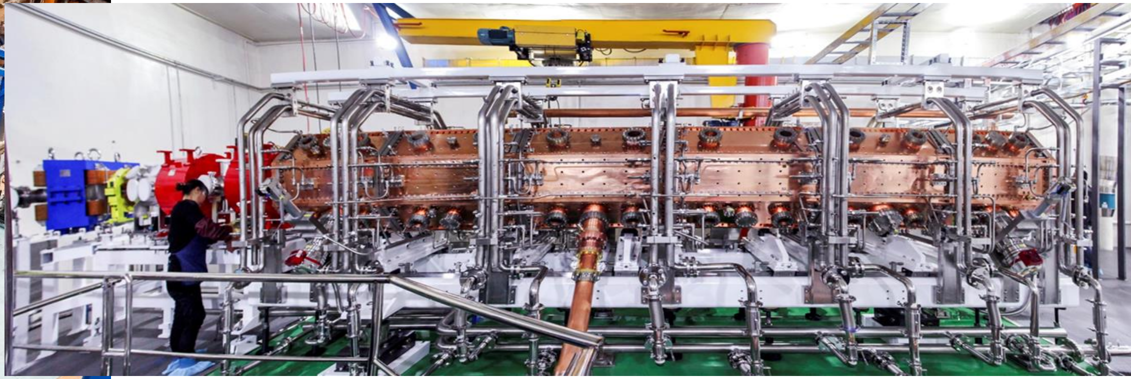




$$\sigma(\mu m) \cong 3\, pixel * \frac{90\mu m}{(1185-1115)pixel} = 3.9\mu m$$

HI RFQ Development

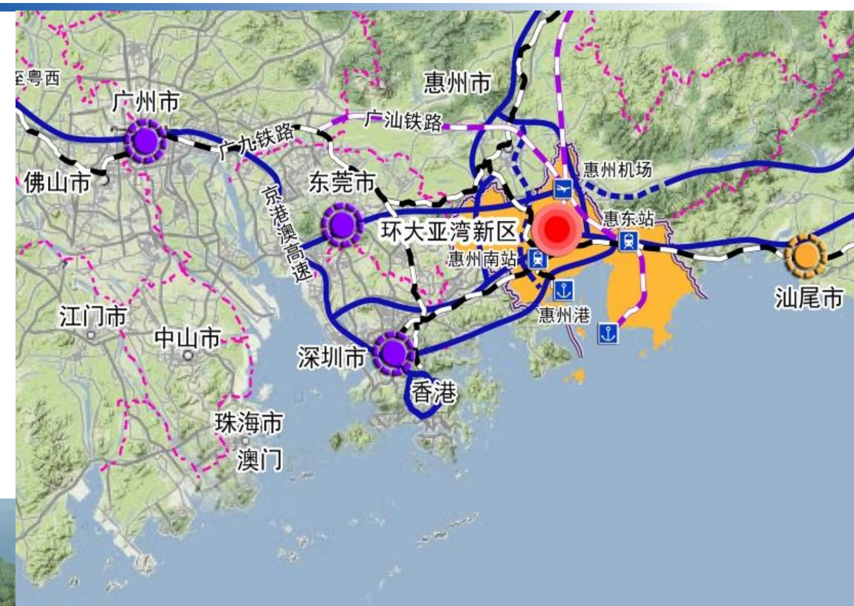
- **RFQ (Q/A=1/2) → H_2^+ , D, ^{4}He, ^{6}Li, ^{12}C…**
- **Commissioning >3.3MeV&10mA by H_2^+**
- **replaced the proton ion source of 25 MeV SCL to accelerate ions >15AMeV**

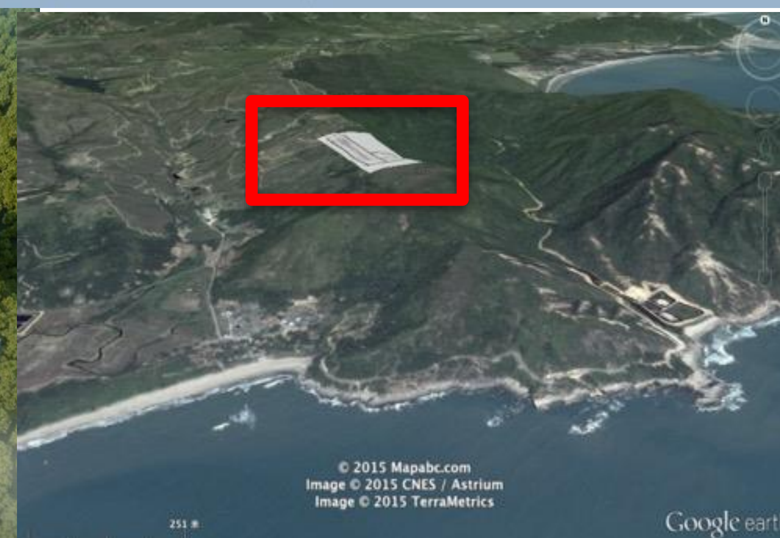


0.5 MeV/A 81.25 MHz,
CW $^{238}U^{35+}$, 1 emA, 2015-2018

ADANES Sites（Huizhou, Guangdong）

- **Pre-Civil Infrastructure Started 2017**
- **Projects Starting in mid of 2018**

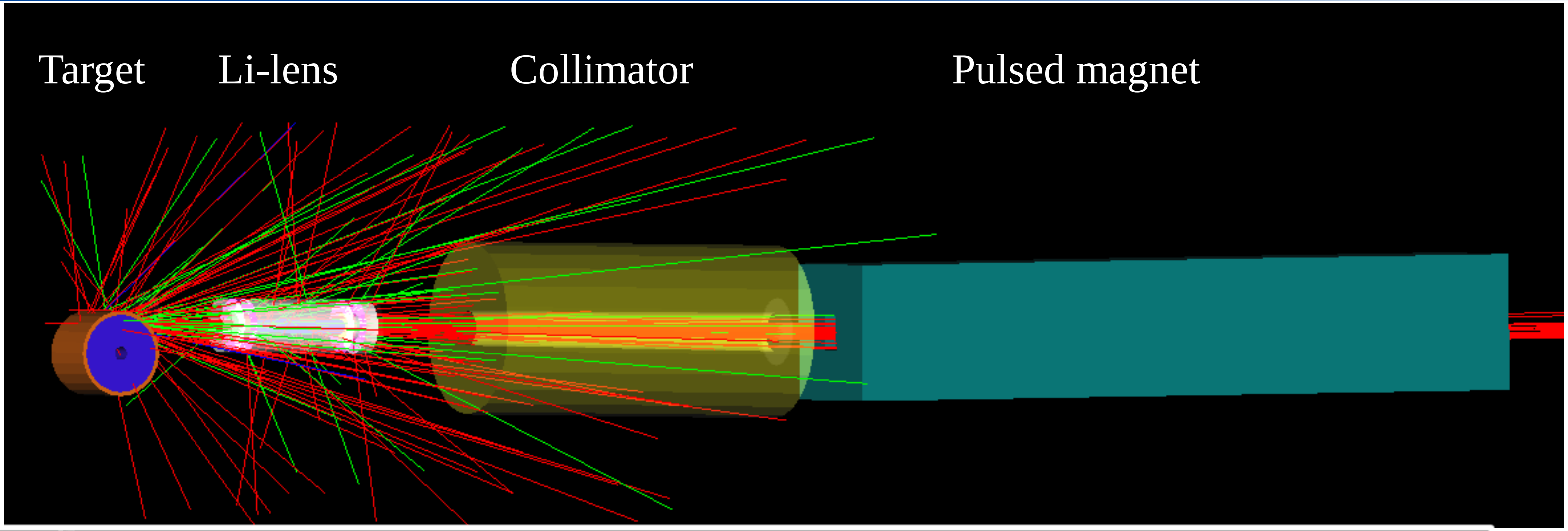




THANKS FOR ATTENTION

Welcome to Collaboration !

HIAF- Muon Beam vs Muon Campus



HIAF – Muon Beam

Parameter	^{136}Xe
Nucleon on target(POT) per pulse	**~136*10^{13}**
Pulse width	**100~150ns**
Number of pulses	**1**
Cycle length	**?**
Frequency	**0.5~1 Hz**
Incoming beam momentum	**>10AGeV/C**
Selection momentum	**>3 GeV/c**

Muon Campus

Parameter	Value
Protons on target (POT) per pulse	10^{12}
Pulse width	120 ns
Number of pulses	16
Cycle length	1.4 s
Frequency	12 Hz
Incoming beam momentum	8.89 GeV/c
Selection momentum	3.1 GeV/c