IPAC 2013 Conference – Shanghai, China

High power protons and heavy ions accelerators

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Overview

Outline

Sorry in advance ...

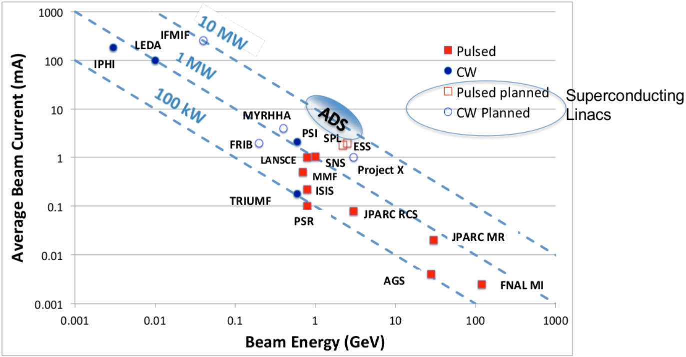
- This review is far from being exhaustive
- It is really speaker dependant
- It may look like a catalogue
- It focuses mainly on the oral contributions

All contributions are available on `www.jacow.org` or at `http://accelconf.web.cern.ch/accelconf/IPAC2013/`

Outline

1. Introduction
2. **High Power Proton Accelerators: issues and challenges**
   - Beam losses
   - High Power RFQ
   - Ion sources and low energy beam transport lines
3. High Power Proton Accelerators: a few projects
4. ADS program in China
5. Heavy Ions Accelerators
6. Novel Techniques and Challenges in Hadron Therapy

High Power Proton Accelerators
An overview...



Accelerators with MW beam experience

- PSI: 600 MeV cyclotron, 1.3 MW
- SNS 925 MeV superconducting linac, 1 MW
- LANSCE: 800 MeV copper linac, 800 kW

High Power Proton Accelerators Challenges & Issues

- **Beam losses**
  - Intra-beam stripping
  - Residual gas stripping
  - H^+ capture and acceleration
  - Dark current
- **Beam losses mitigation**
  - Low energy scraping
  - Mis-matched beams
- **High Power RFQ**
  - Gas desorption
  - Fast resonance control

M.A. Plum, **MOXBB101.**

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M.A. Plum, **MOXBB101.**

- **Beam diagnostics**
  - Non-interceptive (activation, power deposition...)
  - Accuracy (space charge)
  - Phase Space Beam tomography

M.G. Ibison, THOAB103.

- **Ion sources and low energy beam line**
  - Ion beam generation
  - Beam dynamics simulations with space charge compensation
  - Experimental results from beam commissioning (SPIRAL2, IFMIF, FETS, PKU...).
- **High power target**
  - Target development is needed to handle the beam power
  - Beam rastering.

P. Hurh, THPFI082 . **H.D. Thomsen, MOPEA005.**

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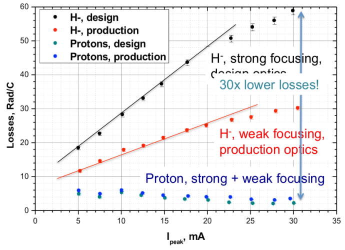
P. Hurh, **THPFI082 .**

H.D. Thomsen, **MOPEA005.**

Beam Losses

Intra-beam stripping

- H^- loss > H^+ loss ($\times 30$)
- Model in agreement with observations
- Seen in SNS and LANSCE



Residual gas stripping

- $H^- \to H^0$ or $H^- \to H^+$
- Cross section highest at low energy
- H^+ can be captured and accelerated !!
- SNS, LANSCE, J-PARC

Dark current

- Continuous current from SNS ion source
- Cure: reversing DTL phase

M.A. Plum, **MOXBB101.**

Beam Losses Mitigations

Beam losses due to tails/halo: low energy scrapping

- Horizontal scrapping in the 2.5 MeV SNS MEBT
- Up to 57% loss reduction by scraping 3-4%

Beam losses mitigation by matching

- *Conventional wisdom:* It is best to match the beam Twiss parameters at the lattice transitions
- What about real beam distributions that have different Twiss parameters for the core and the tails of the beam?
- Low-loss tune is mis-matched at beginning of SNS SCL.
- "Halo matching": IFMIF SRF linac (simulations)

P.A.P. Nghiem, **TUPWA004.**

High Power RFQ

Both SNS and J-PARC experienced resonance control and electrical discharge problems with their RFQ's

- Gas from ion source is absorbed by copper in RFQ
- Gas desorption possibly helped by ion beam striking the vanes
- A mild electric discharge is started, driven by the RF power
- Klystron power is increased to maintain field
- More RF power → more gas released → more discharges
- Vane temperature rapidly increases and throws RFQ out of resonance

Lessons learned and solutions

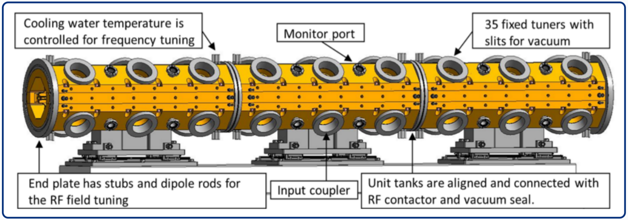
- Minimize gas flow from source to RFQ (minimize ion source gas pressure, use orifice between ion source and RFQ)
- Design the RFQ for high pumping speed and ensure adequate pumping
- To control the gas desorption instability at SNS, a control loop was added for the RF pulse length

High Power RFQ

J-PARC RFQ's

RFQ II: to improve the nominal one (discharges)

RFQ III: New modulation to go to higher beam power (50 mA)



H. Oguri, **WEYB101.**

T. Morishita, **THPWO034.**

LINAC4 RFQ commissioning

- RF Tuning
- 16-18 mA H^- beam (pulses of 200 μs) accelerated with 70% transmissions

O. Piquet, **THPWO004.**

C. Rossi, **THPWO082.**

Intense $H^-/H^+/D^+/$ ion beam sources are needed

- **H^-:** Pulsed beams – Surface or volume ion sources, with Cs.

Ex: SNS, Project X,ISIS, LINAC4, CSNS, J-PARC (75 mA/500μs pulses)

H^- ion source in PKU: **S.X. Peng, MOPFI034.**

- **H^+/D^+:** Pulsed or continuous beams – Mainly ECR sources.

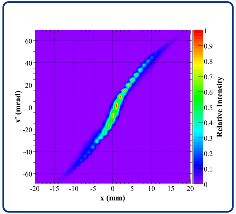
Ex: ESS, FAIR proton linac, SPIRAL 2, IFMIF, HIAF, MYRRHA.

H^+ at IMP Beijing for C-ADS: **L. Sun, WEOAB201.**

IFMIF Injector

An unprecedented **100 keV/140 mA cw D^+** beam has been extracted and transported.

R. Gobin, THPWO003.



Understand beam transport in LEBT with space charge compensation

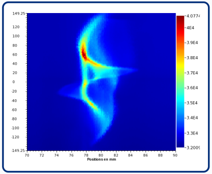
Studies on space charge compensation rate and characteristic time at FETS (RAL) and Los Alamos:

J.K. Pozimski, THPWA042.

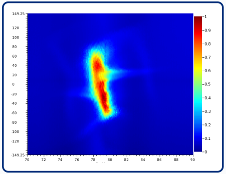
Y.K. Batygin, TUPWA066.

Beam commissioning of the Spiral2 injector:

D. Uriot, THPWO005.



Pressure: 1.0×10^{6} mbar

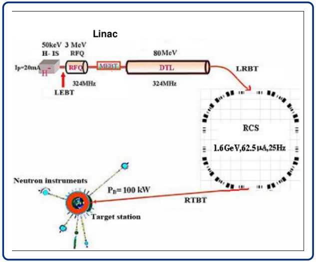


Pressure: 1.2×10^{5} mbar with Ar

Outline

China Spallation Neutron Source

Parameter	Value
Beam Power [kW]	100
Proton energy [GeV]	1.6
Beam intensity [μA]	15
Duty factor [%]	1
Linac type	DTL
Frequency [MHz]	324
RCS circumference [m]	228



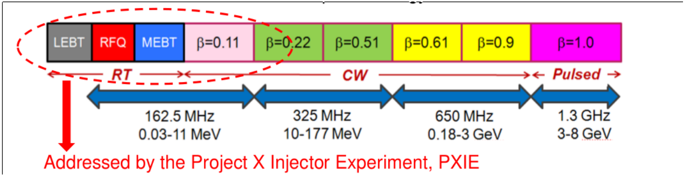
- An upgrade for 300 kW on target is foreseen (Spoke cavities)
- Budget: US$270M (accelerator, target, 3 instruments, buildings)
- End of project: 2018.
- Front-end will be installed before the end of 2013

S. Fu, FRXAB201.

Project X and PXIE

Project X is an Intensity Frontier accelerator providing MW-scale proton beam to many users quasi-simultaneously

- Acceleration in SRF from low energies
- Constant power in time scale >μs; adjustable structure of the bunch train
- Bunch-by-bunch chopping in MEBT and RF separation after acceleration to the required energy



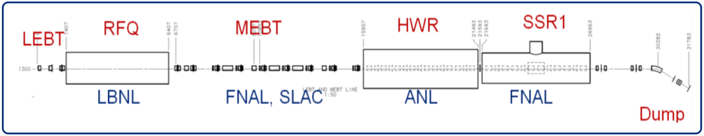
A. Shemyakin, TUOAB102.

Project X and PXIE

Parameter	Value
H^- energy [MeV]	25
Average Current [mA]	1
Linac type (low β)	HWR
HWR Frequency [MHz]	162.5
Linac type (high β)	SSR
SSR Frequency [MHz]	325

Goals

- Validate project X front end
- Demonstrate the bunch-by-bunch chopping
- Efficient acceleration of 1 mA beam in SRF to at least 15 MeV
- End of project: 2018.



J.-F.Ostiguy, **TUPWA054.**

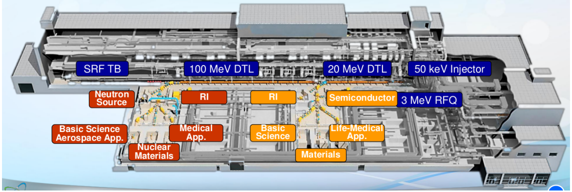
L. Ristori, **WEPWO055.**

KOMAC Accelerator Facility

KOrea Multi-Purpose Accelerator Complex, Gyeongju city

Parameter	Value
Beam Power [kW]	160
H^+ energy [MeV]	20 & 100
Duty Cycle [%]	8
Max. Current [mA]	20
Linac type	DTLs
Frequency [MHz]	350
Experimental lines	2×5

- Applications: biology, medical, space, radio isotope production, nuclear material tests, ISOL target testing.
- Total Budget: ≈ 314.3 k$
- Linac is under commissioning
- GeV upgrade for pulsed neutron source



Y. S. Cho, **WEOBB101**.

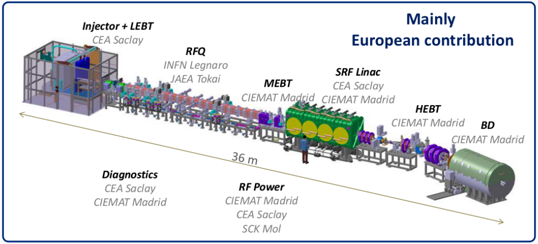
IFMIF – LIPAc

Linear IFMIF Prototype Accelerator Rokkasho, Japan

IPAC13

Parameter	Value
Beam Power [MW]	1.125
D^+ energy [MeV]	9
Duty Cycle [%]	cw
Max. Current [mA]	125
Linac type	HWR
Frequency [MHz]	175

- Demonstrate the feasibility of IFMIF 40 MeV
- Highest beam power
- Very space charge
- Injector commissioned in Saclay and sent to Japan
- Commissioning in 2016



J. Naster, TUOAB101.

N. Chauvin, THPWO006.

Outline

Nuclear Power Development in China

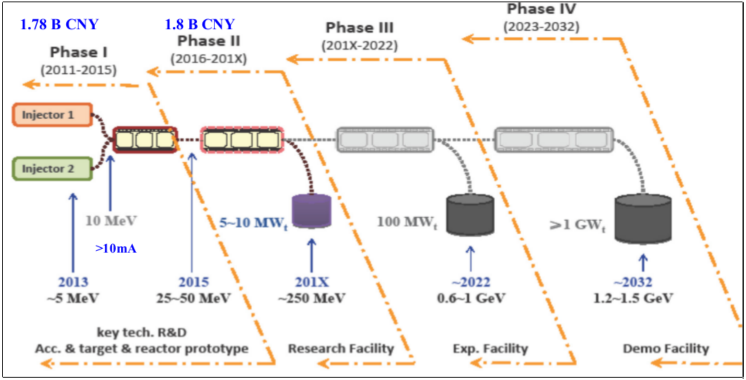
In 2013 in China...

- Operating 17 set reactors, 13.955 GWe (6th in world)
- Constructing 28 set reactors, 30.550 GWe (1st in world)
- Planned 49 set reactors, 56.020 GWe; (1st in world)

Possible extrapolation...

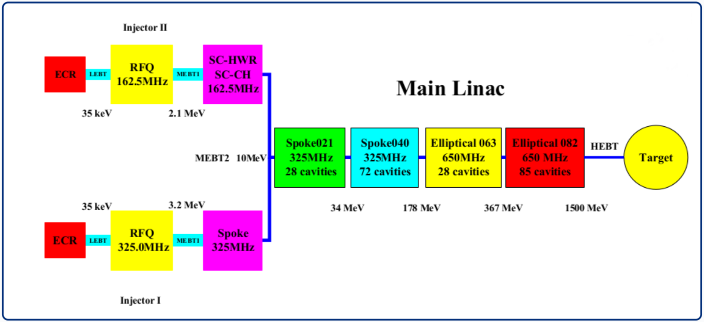
- 2020: ≈70 GWe NPP in operation and 30 GWe NPP under construction. more than 5% of NP to total installed power capacity
- 2030: ≈10% of NP to total installed power capacity
- 2050: more than 400 GWe NPP → **almost same as the total in the world todays!**

ADS road map in China



W. Zhan, MOXAB101.

C-ADS layout



- 10 mA H^+ beam intensity
- 15 MW beam on target
- Two front ends in development

Z.H. Li, THPWO043.

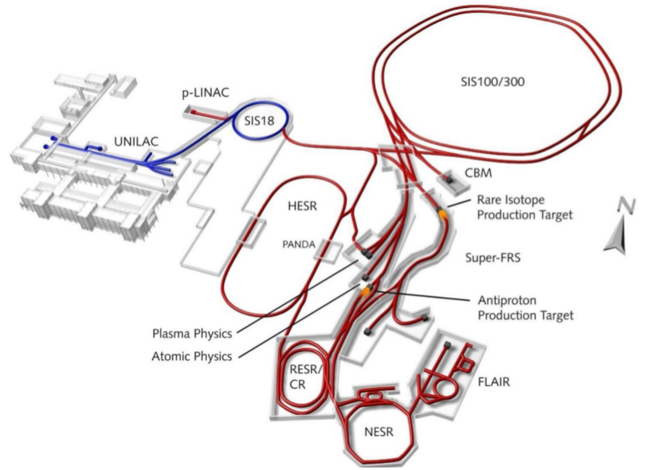
X. Wu, TUPWA059.

- Main linac cavities

S. Liu, TUPWA025.

Outline

FAIR facility
FAIR Layout

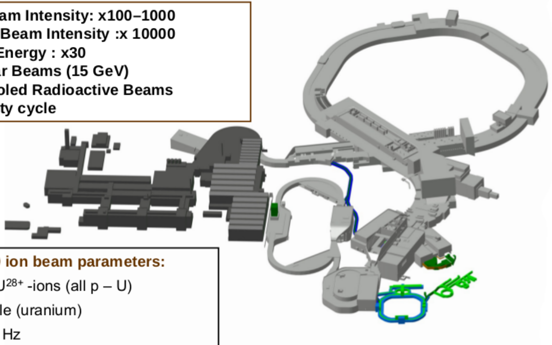


O. Kester, TUXB101.

FAIR facility

Beam parameters

- Primary Beam Intensity: x100–1000
- Secondary Beam Intensity :x 10000
- Heavy Ion Energy : x30
- Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Variable duty cycle



Some SIS100 ion beam parameters:

Ion species : U^{28+} -ions (all p – U)

N: $5x10^{11}$ /cycle (uranium)

Rep. rate: 0.5 Hz

Energy : 400 – 2715 MeV/u for heavy ions

Pulse length : 30 – 90 ns

FAIR physics program

- Nuclear Physics
- Plasma quarks Gluon
- Astrophysics
- Atomic and plasma physics

FAIR challenges

Injectors

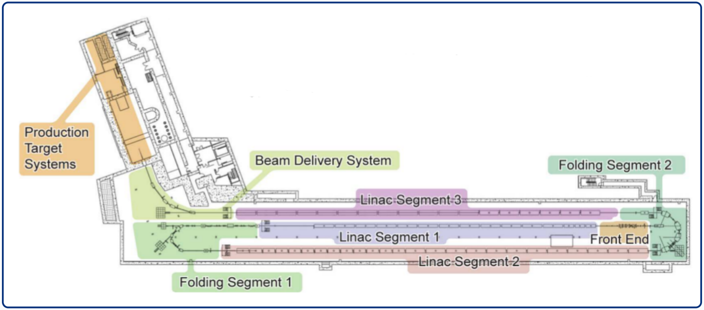
- UNILAC upgrade — **B. Schlitt**, **THPWO010.**
- p-linac — **G. Clemente**, **THPWO008 & THPWO009.**
- SIS18 high current upgrade

Other challenges

- SIS100 synchrotron — **P. Spiller**, **THPWO011.**
- Fast ramped magnets (sync.) — **S. Sattler**, **MOODB101.**
- Super-FRS developments — **H. Müller**, **THPME005.**
- FAIR storage rings — **O. Dolinskyy**, **TUPWO006.**

FRIB Driver Linac

Facility for Rare Isotope Beams



- 10-year DOE US $700 million project
- Dedicated to nuclear physics and nuclear astrophysics
- 400 kW heavy ion beams sent onto fragmentation target (short lived RIBs)

Y. Zhang, WOBB102.

FRIB Driver Linac parameters

	Linac Segment 1	Linac Segment 2	Linac Segment 3
Cavities QWR 80.5 MHz HWR 322 MHz	0.041 QWR 12 0.085 QWR 91 0.29 HWR 4	0.085 QWR 3 0.29 HWR 72 0.53 HWR 96	0.53 HWR 52
Cryomodules	Acceleration 14 Rebunching 3	Acceleration 24 Rebunching 1	Acceleration 6 Rebunching 1
Parameters of uranium beam	E_{IN} 0.5 MeV/u E_{OUT} 16.6 MeV/u q +33/+34 352 eµA (10.5 pµA)	E_{IN} 16.4 MeV/u E_{OUT} 147.8 MeV/u q +76 to +80 655 eµA (8.4 pµA)	E_{IN} 147.8 MeV/u E_{OUT} 202 MeV/u q +76 to +80 655 eµA (8.4 pµA)

- ECR ion sources are located at the ground level
- All the linac segments are in a tunnel 10 m underground
- Total beam path of the driver linac is about 520 m
- All ion beams can be accelerated to more than 200 MeV/u (power on target 400 kW)
- Tunnel designed and shielded for upgrade to 1 GeV proton (ISOL) or beam energy upgrade (above 400 MeV/u)

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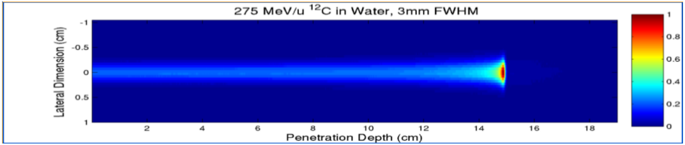
   - Introduction
   - Beam scanning
   - Heidelberg Ion Therapy Center
   - Challenges

Reduction of the Normal Tissue Dose



Entrance channel	Tumour
Low physical dose Low rel. biol. efficiency	High physical dose physics High rel. biol. efficiency

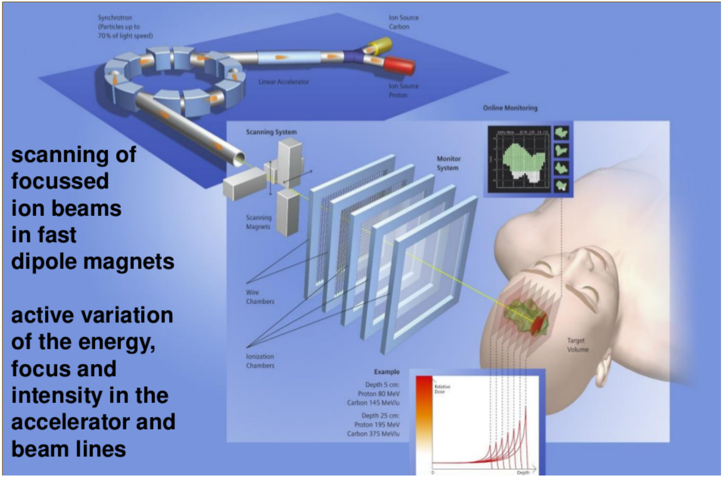
Target dose with hadrons ≈ 32 times lower than with conventional radiation

T. Haberer, THXB201.

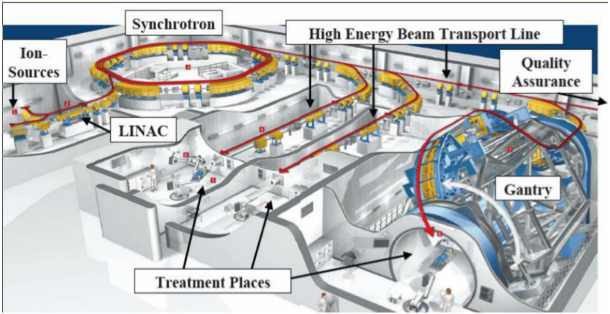
Rasterscan Method

scanning of focussed ion beams in fast dipole magnets

active variation of the energy, focus and intensity in the accelerator and beam lines



Heidelberg Ion Therapy Center



- Compact design 60m×70m
- Full clinical integration
- Rasterscanning only
- Protons/Helium modality
- Carbon/Oxygen modality
- > 1000 patients/year

Challenges

- Multi-vault design only adequate for large clinical centers
- Single or two-room designs would open a new market
- Cut investment via compact design (accelerator, beam lines, gantry) would help. To really change this setting, magnetic fields need to be more than doubled... Example: Dielectric Wall Accelerator A. Zografos, THOAB201.
- Minimizing the dose delivery time and increase the patient throughput. C. Schömers, WEPME010.
- **Anyhow, the beam quality (lateral scattering, fragmentation, ...) and finally the conformity of the dose distribution (typically via beam scanning) must not be compromised!**

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- **Anyhow, the beam quality (lateral scattering, fragmentation, ...) and finally the conformity of the dose distribution (typically via beam scanning) must not be compromised!**

Challenges

- Multi-vault design only adequate for large clinical centers
- Single or two-room designs would open a new market
- Cut investment via compact design (accelerator, beam lines, gantry) would help. To really change this setting, magnetic fields need to be more than doubled... Example: Dielectric Wall Accelerator **A. Zografos, THOAB201.**
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Thank you for your attention !