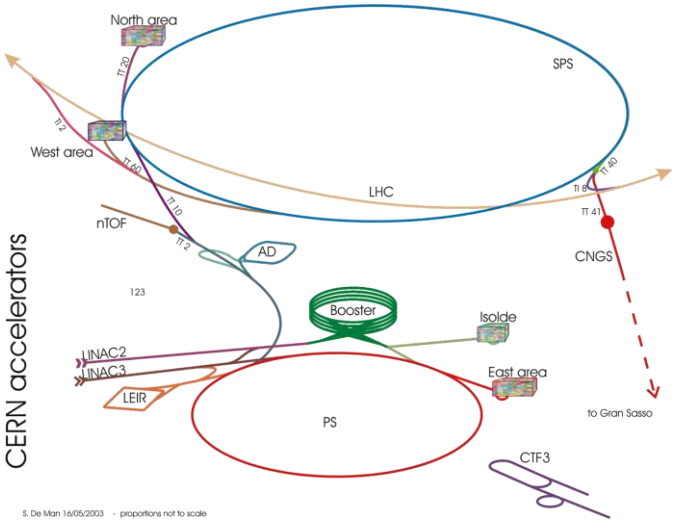
HIE-ISOLDE linac upgrade

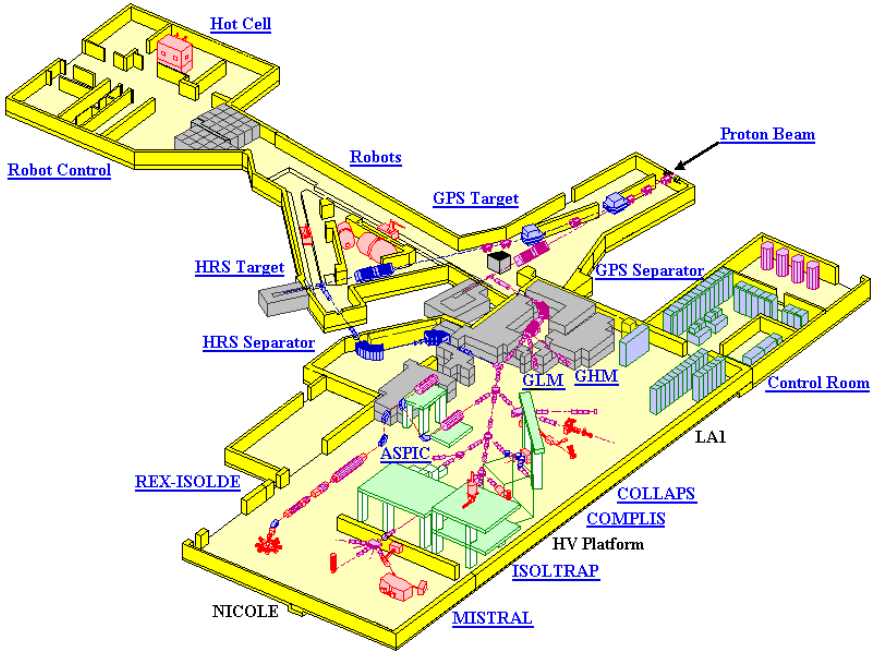
- **The REX and ISOLDE facilities**
- **HIE-ISOLDE linac**
- **HEBT and experimental stations**
- **Beam characteristics**

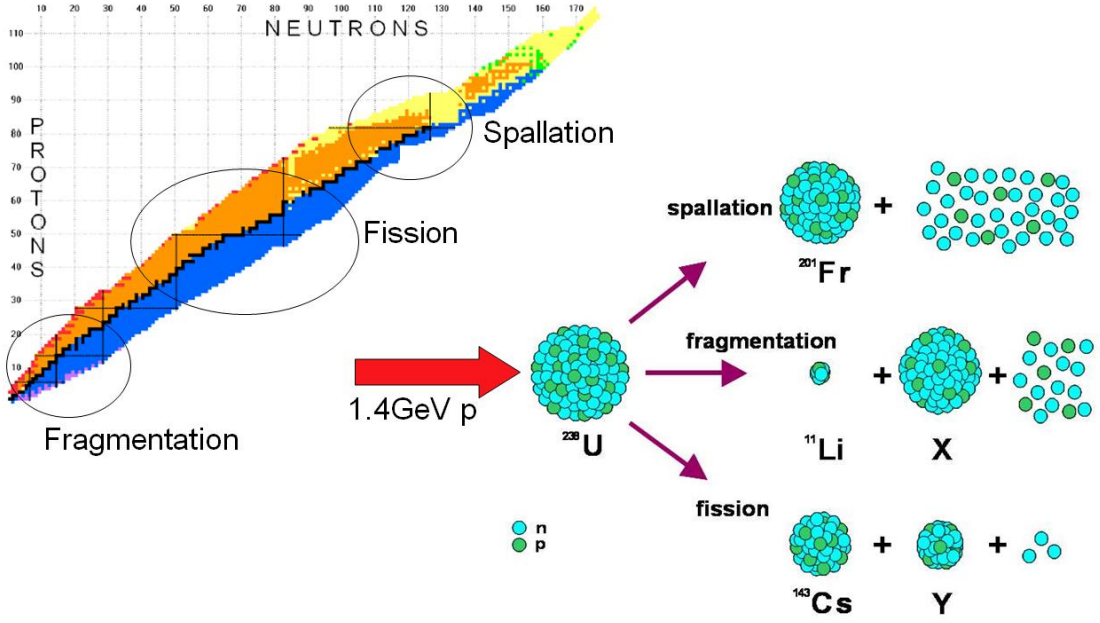
D. Voulot, BE/OP, *CERN*

On behalf of Matthew Alexander Fraser; Fredrik Wenander; Brennan Goddard and the HIE-ISOLDE project team

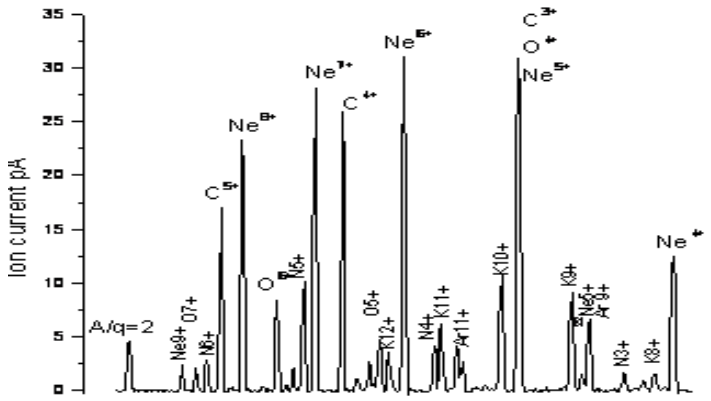
ISOLDE overview







REX-Isolde overview



* charge breeding
* 1+ ions to n+

MASS SEPARATOR

REXEBIS

Optional stripper

9-GAP RESONATOR

7-GAP RESONATORS

IH

Rebuncher

RFQ

ISOLDE beam

Experiments

3.0 MeV/u

2.2 MeV/u

1.2 MeV/u

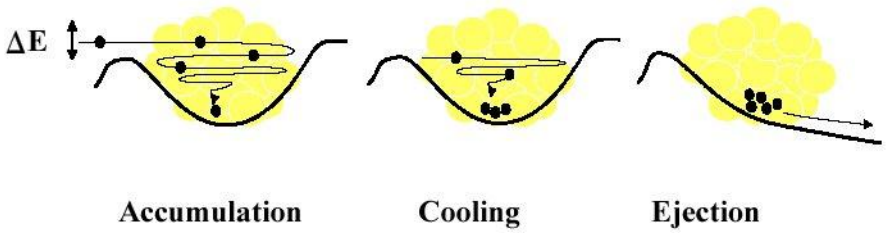
0.3 MeV/u

60 keV

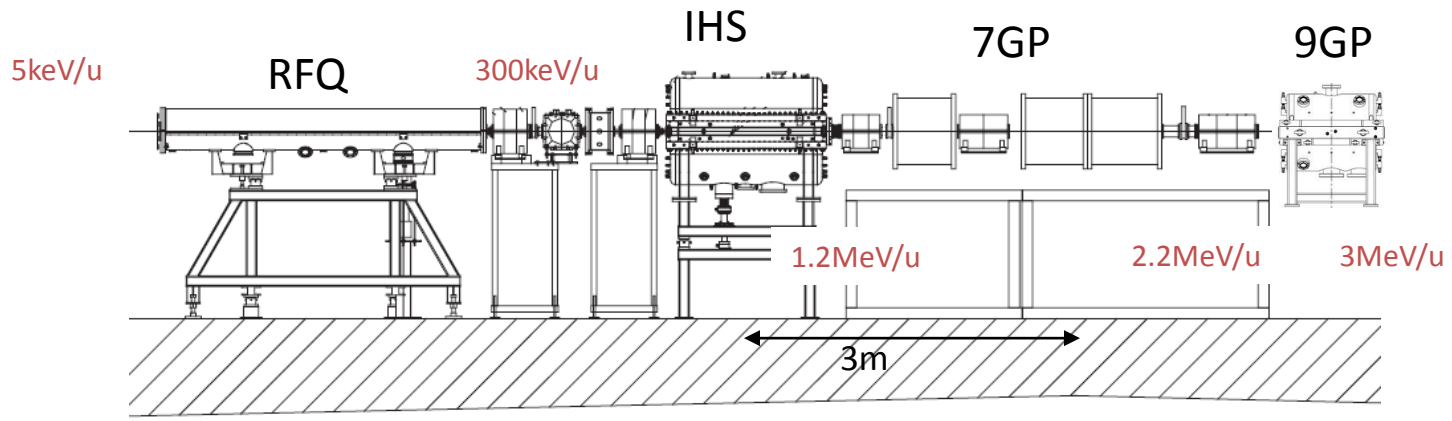
REXTRAP

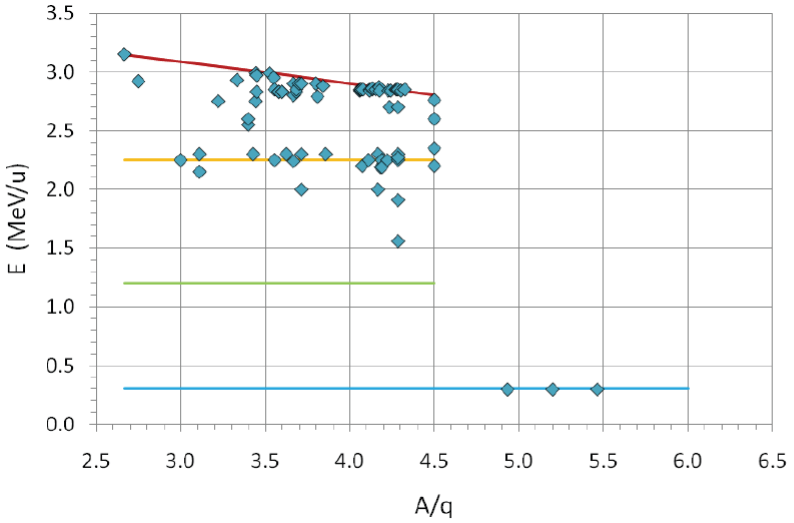
* 6 cavities
* 300 keV/u to 3 MeV/u

* longitudinal accumulation and bunching
* transverse phase space cooling



REX linac





9-gap IH

7-gap 3

IHS

RFQ

Linac:

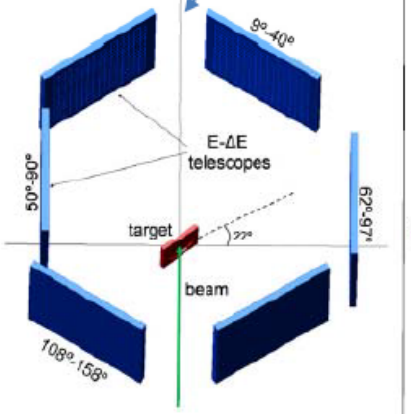
Length	11 m
Freq.	101 MHz (202 MHz for the 9GP)
Duty cycle	1ms 100 Hz (10%)
Energy	max. 3 MeV/u
A/q	2.0 - 4.5
Trans.	90% (lower for highly charged beams)

Present experimental program at REX-ISOLDE

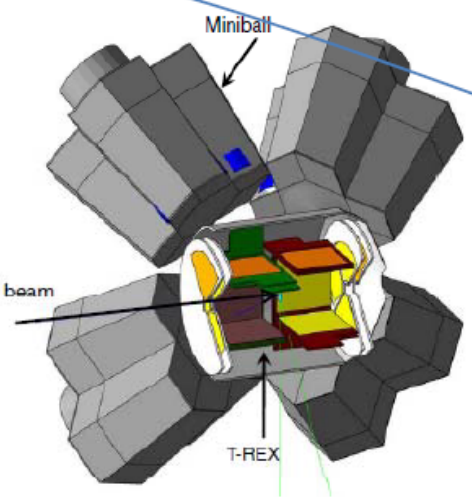
Focus of experimental program at REX-ISOLDE:

- Coulomb excitation
- few-nucleon transfer reaction studies
- fusion evaporation studies
- light particle elastic scattering

} using radioactive beams
Z=3 to 88, up to 3 MeV/u



Setup for scattering experiments of light nuclei, e.g. ^{11}Be



T-REX silicon barrel detector with Miniball germanium array for few-nucleon transfer reaction experiments

Miniball
Low-multiplicity Ge array + Si pixel particle detectors for Doppler correction

2nd beam line
Mobile experiments, e.g. scattering chamber

β-NMR experiment
Test to produce polarized beams using tilted foils method

REX physics reference: P Van Duppen and K. Riisager, J. Phys. G: Nucl. Part. Phys. 38 024005 (2011)

Miniball reference: 'The Miniball at REX-ISOLDE', J. Van de Walle., EPJ to be published

ISOLDE Statistics 2011

ISOLDE Shifts (8h):

Scheduled: 471.5

Delivered: 329.5 (+134 for machine development and test)

REX-ISOLDE: 147 (45%)

Category	Percentage
Nuclear structure using reactions	28%
Nuclear structure from ground-state properties and beta-decay	22%
Nuclear astrophysics	1%
Fundamental interactions	3%
Solid-state physics	12%
Biophysics and medicine	4%
total INTC and LOI RIB shifts	**71%**
Target and ion source development and Coordinator's reserve	29%

HIE-ISOLDE

A general upgrade of ISOLDE: High Intensity and Energy

- High intensity: upgrade of target area, separators and charge breeder (design study)
- High energy: HIE-LINAC
  - R&D activities for the linac (started in 2008)
  - Approved CERN project 2010
  - 5.5 MeV/u (stage 1) 2015 / 10 MeV/u (stage 2) 2016-2018
  - 36.5 MCHF, 50% financed through external collaboration

Motivations

Superconducting linac => “array of small independent resonating cavities, equipped with their own small RF amplifier “

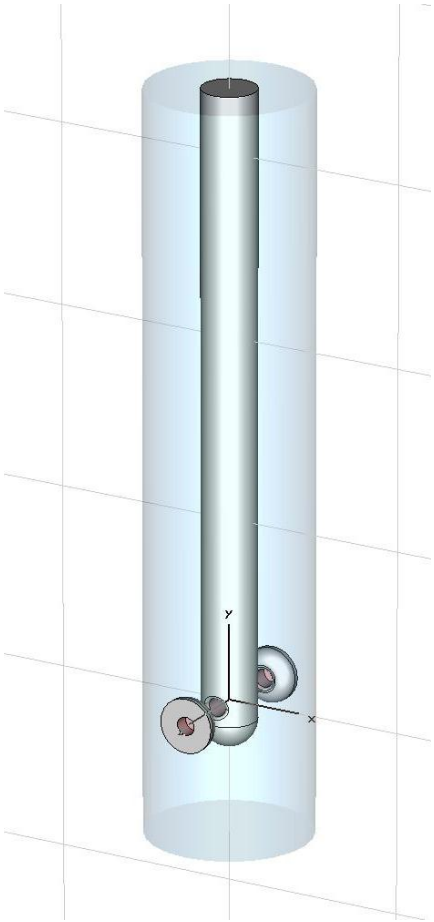
-> No high power amplifier (< 10W of RF diss. In the cavity)

-> High accelerating gradient (6 MV/m)

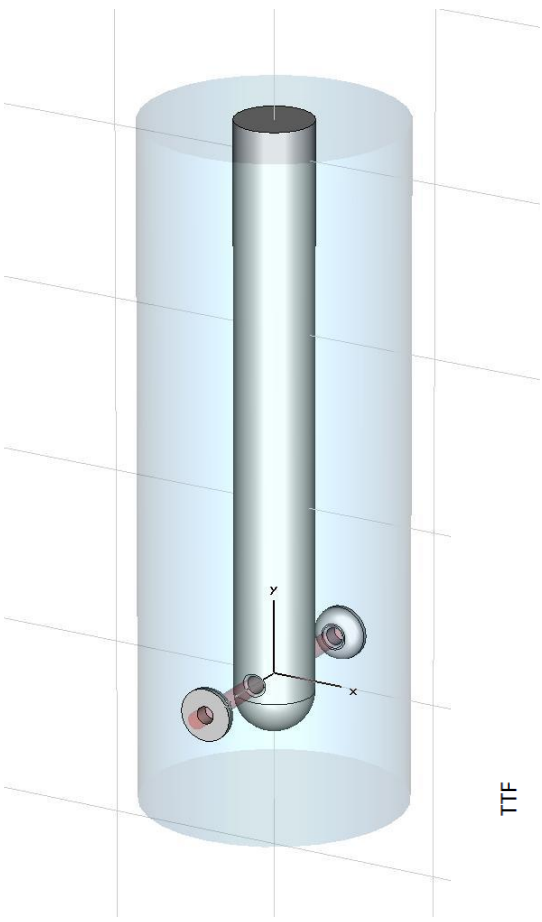
-> Short + independent cavities = high flexibility

-> CW operation

SC quarter-wave cavities

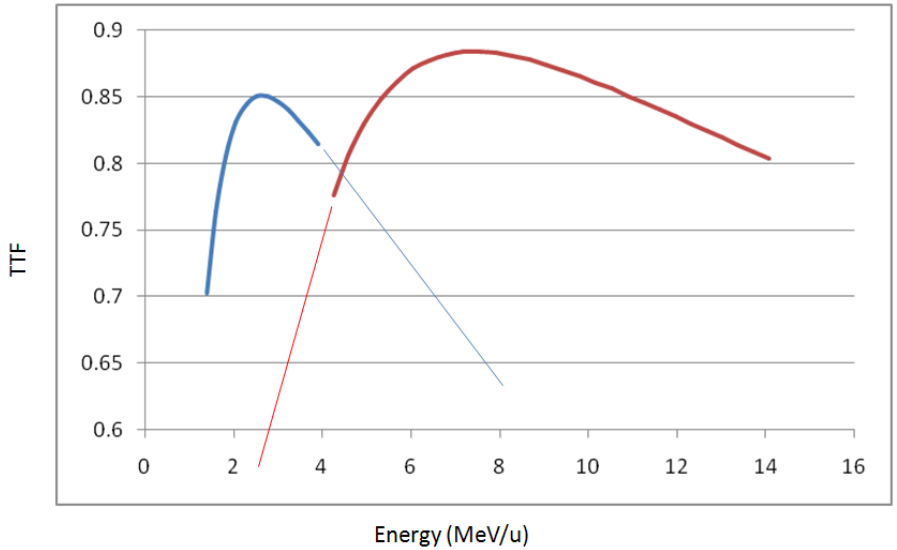


Low β

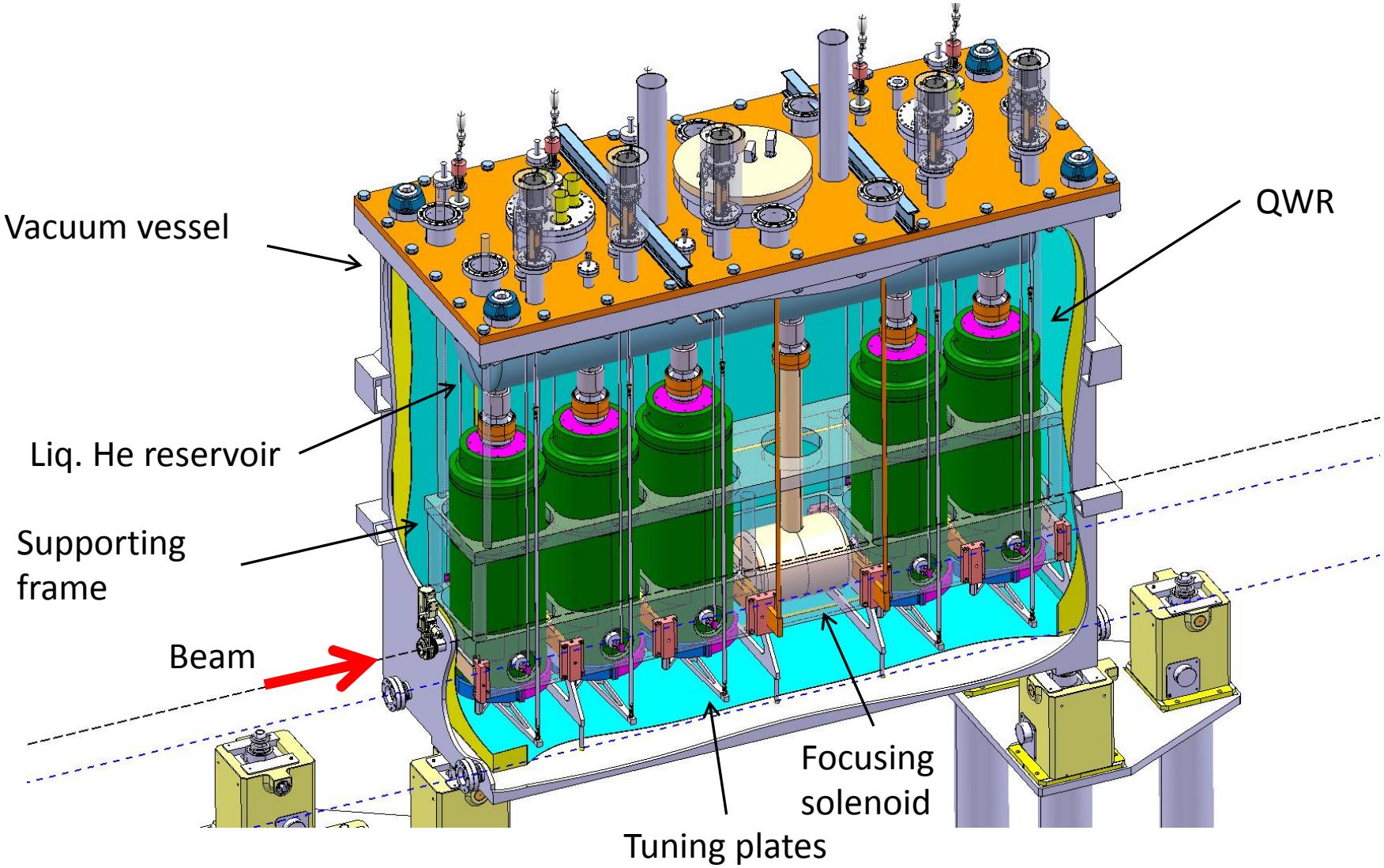


Highβ

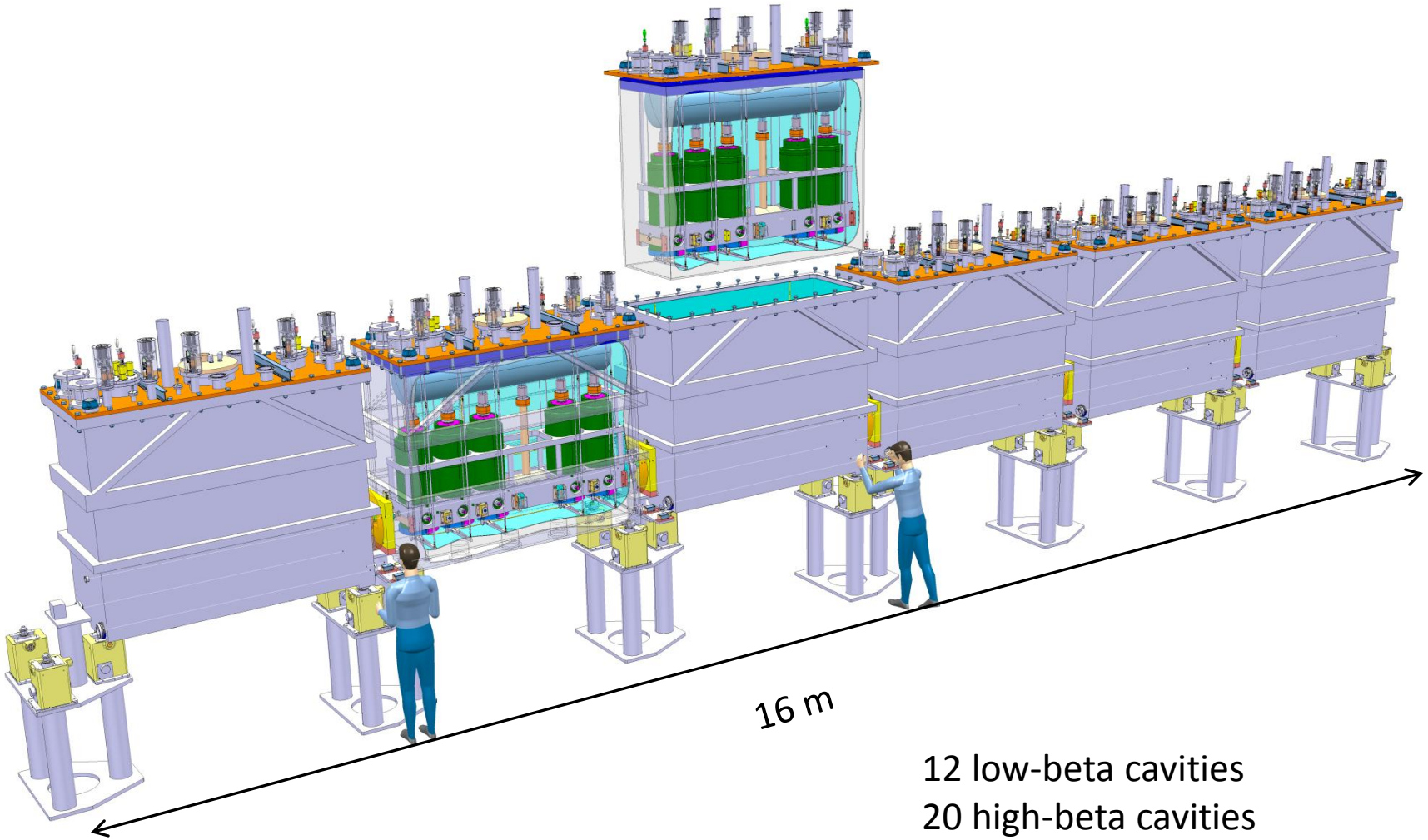
f (MHz)	101.28	101.28
β 0	6.3%	10.3%
Gradient Ea (MV/m)	6	6
Inner Cond. Diam (mm)	50	90
Outer Cond Diam (mm)	195	300
Mechanical Length (mm)	215	320
Gap length (mm)	50	85
Beam Apert. Diam. (mm)	20	20
Rsh/Q (Ohm)	564	548
Q0 min for 6 MV/m at 7W	$3.2\ 10^8$	$5\ 10^8$
TTF max	0.85	0.9
No. of cavities	12	20



HIE High-beta Cryomodule

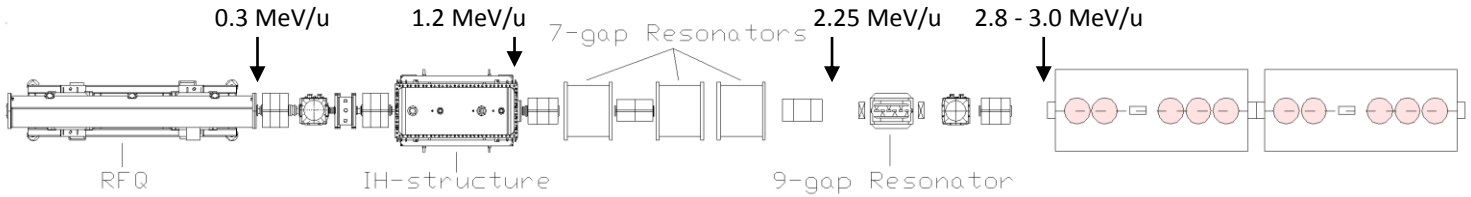


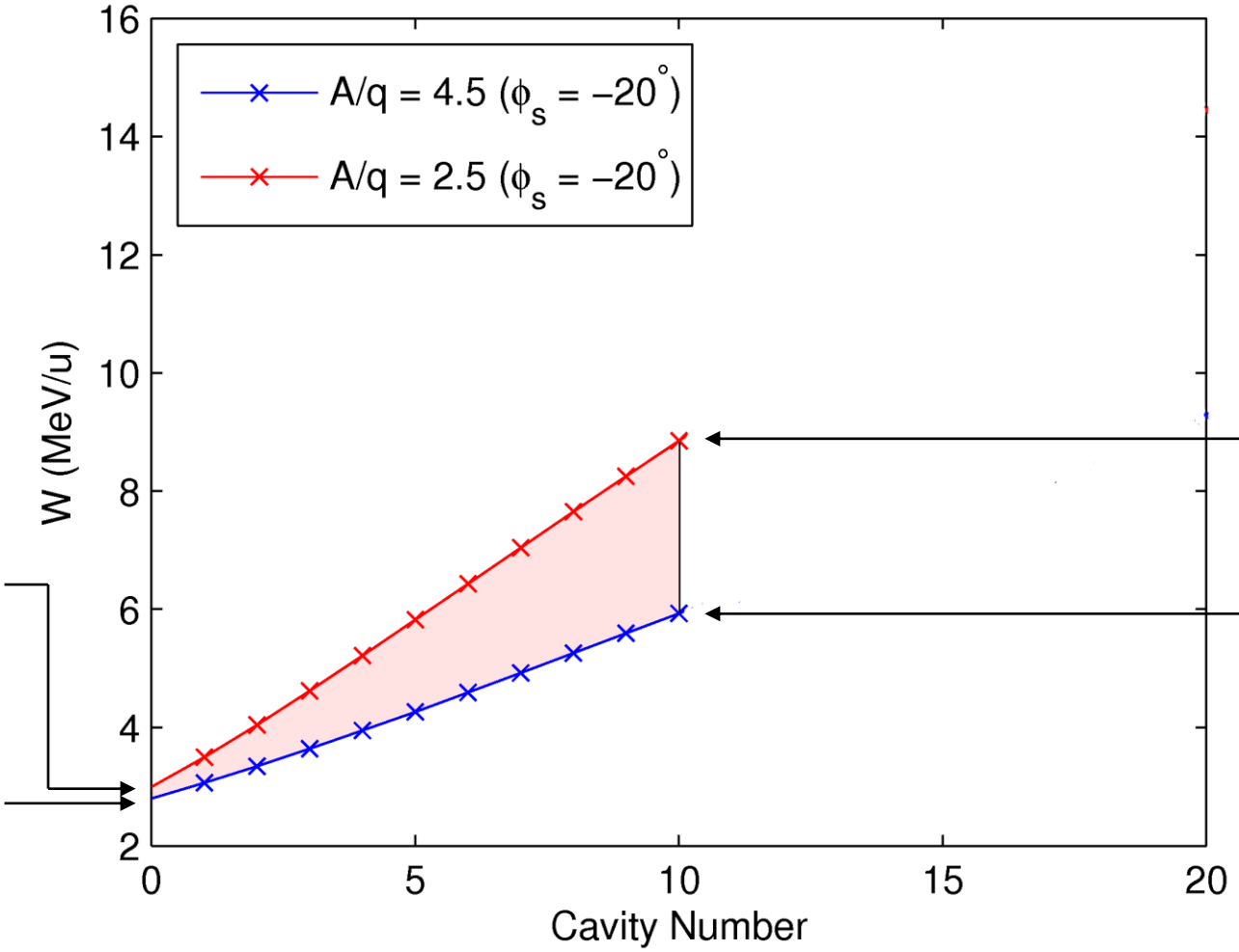
HIE linac (Stage 2b)



12 low-beta cavities
20 high-beta cavities
39.6 MV accelerating voltage

Energy RANGE: STAGE 1





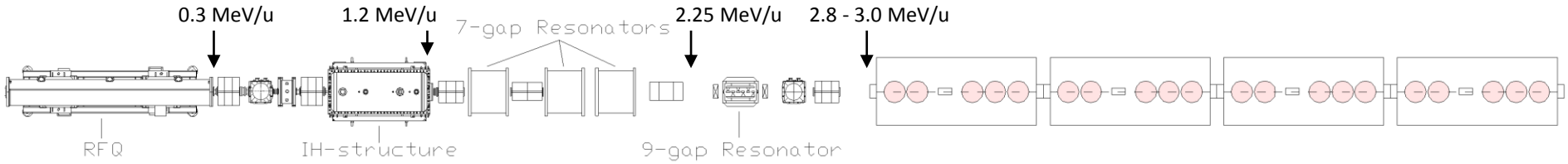
A/q = 2.5
W = 3.0 MeV/u
$\beta\gamma$ = 0.080

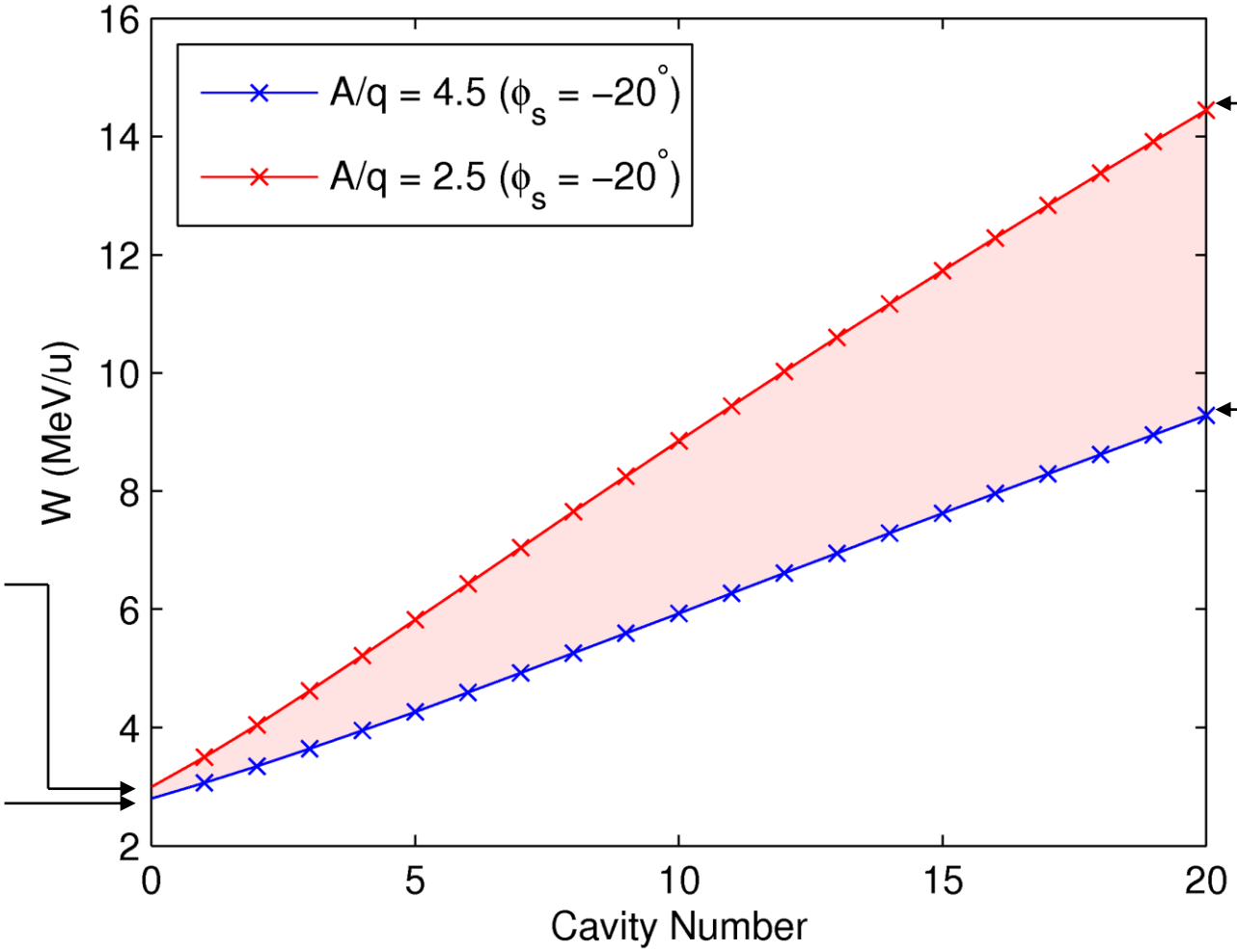
A/q =4.5
W = 2.8 MeV/u
$\beta\gamma$ = 0.0773

A/q = 2.5
W = 8.8 MeV/u
$\beta\gamma$ = 0.136

A/q =4.5
W = 5.5 MeV/u
$\beta\gamma$ = 0.109

Energy RANGE: STAGE 2a





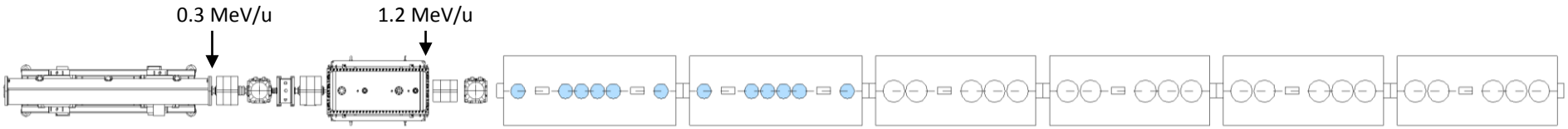
A/q = 2.5
W = 14.5 MeV/u
$\beta\gamma$ = 0.177

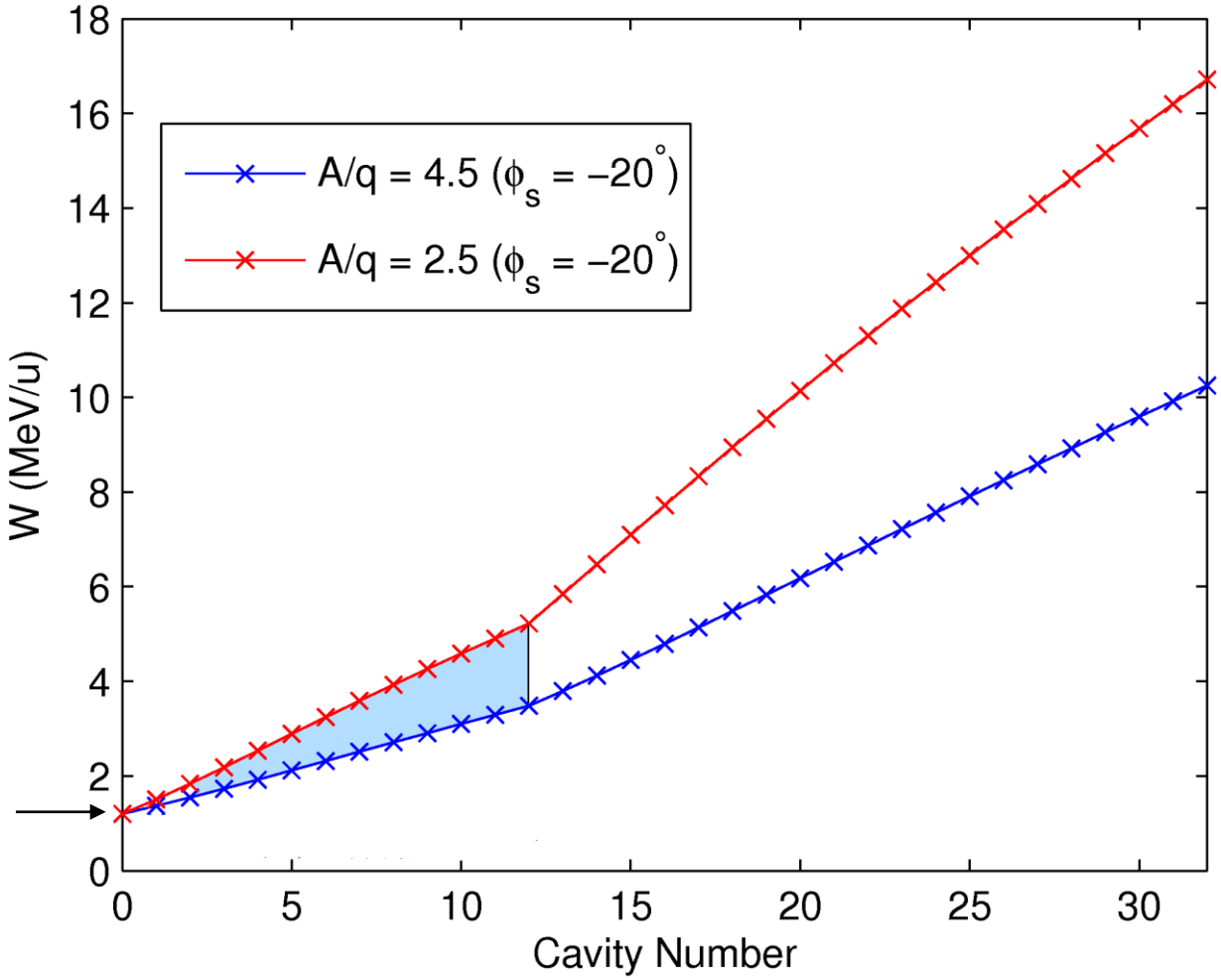
A/q =4.5
W = 9.3 MeV/u
$\beta\gamma$ = 0.140

A/q = 2.5
W = 3.0 MeV/u
$\beta\gamma$ = 0.080

A/q =4.5
W = 2.8 MeV/u
$\beta\gamma$ = 0.0773

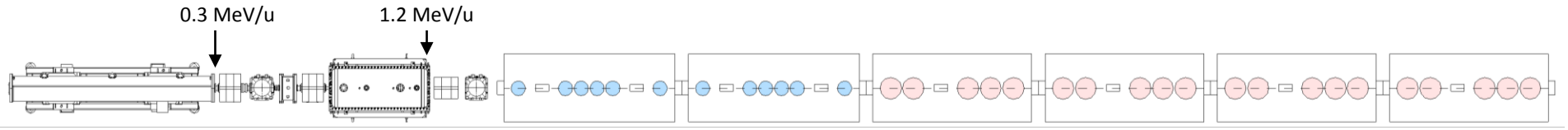
Energy RANGE: STAGE 2b

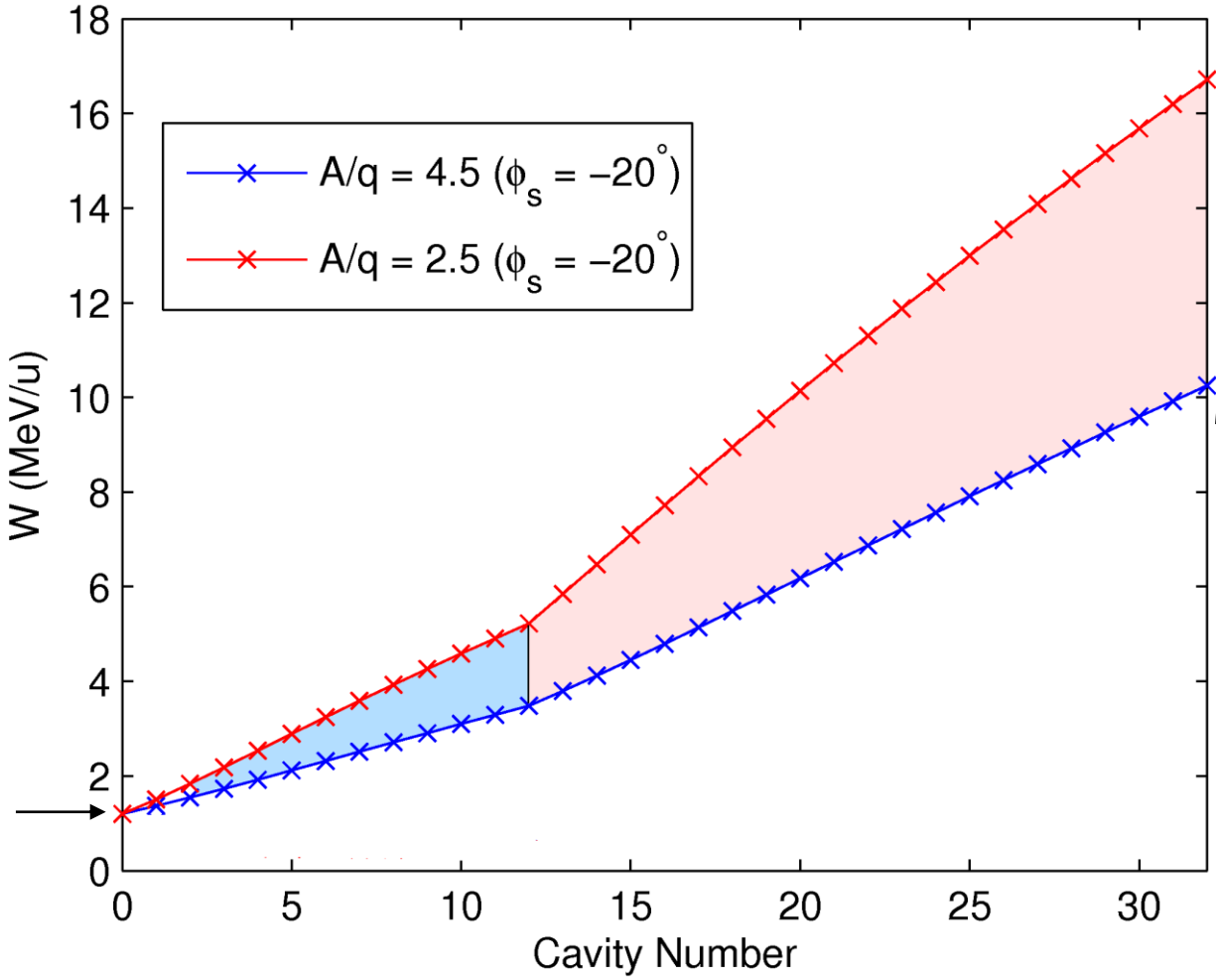




2.5 < A/q < 4.5
W = 1.2 MeV/u
$\beta\gamma$ = 0.051

Energy RANGE: STAGE 2b





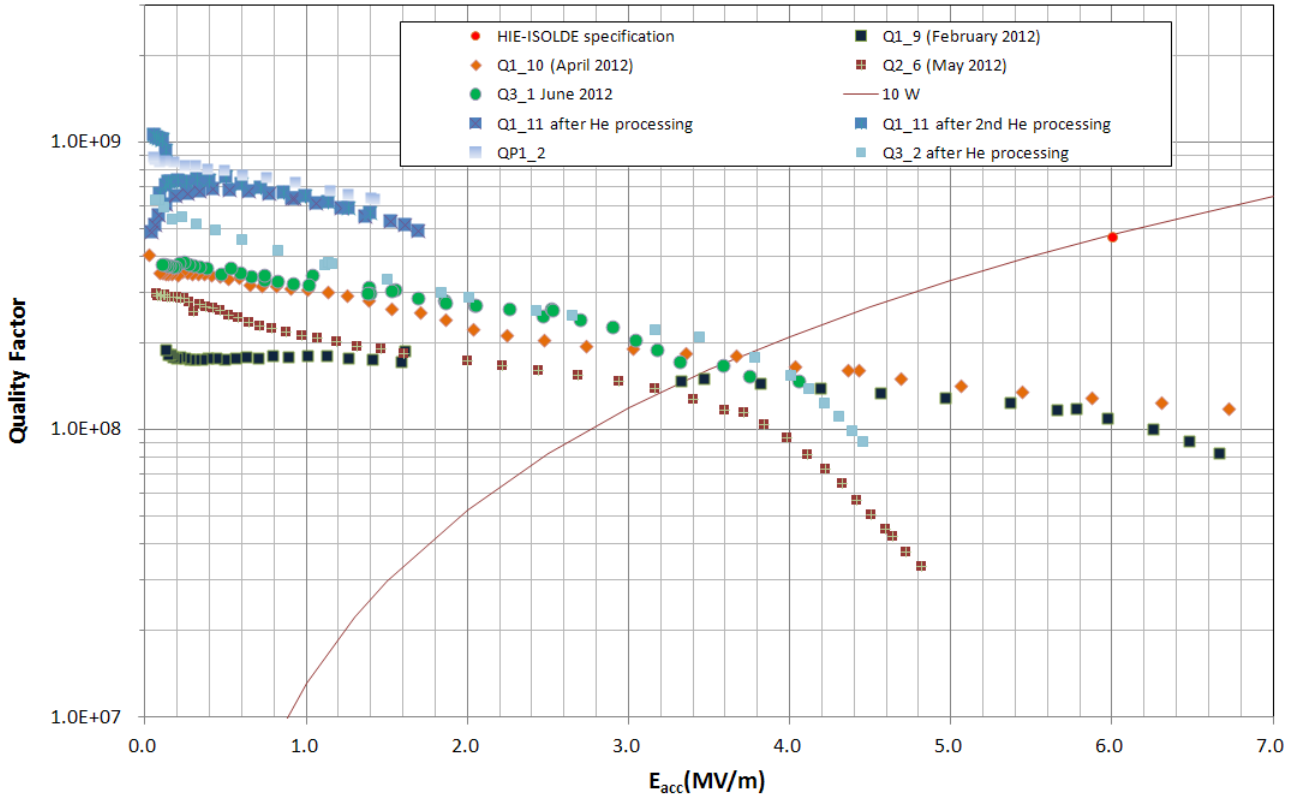
A/q = 4.5
W = 16.8 MeV/u
$\beta\gamma$ = 0.187

A/q = 4.5
W = 10.2 MeV/u
$\beta\gamma$ = 0.147

Highest rigidity:
W = 10 MeV/u
A/q = 4.5
$B\rho$ = 2 Tm

2.5 < A/q < 4.5
W = 1.2 MeV/u
$\beta\gamma$ = 0.051

HIE-REX Cavity: Nb sputtered on Cu



Beam characteristics

Characteristic	Value (for A/q = 4.5)
Particle type	Heavy (radioactive) ions (A < 238)
Mass-to-charge state (A/q) acceptance	2.5 < A/q < 4.5
Transverse emittance (normalised) (mm.mrad)	0.07 (rms) and 0.3 (90%)
Longitudinal emittance (π ns keV/u)	0.35 (rms) and 1.5 (86%)
Energy (MeV/u)	0.3 – 10
Average Beam Current	~ few particle per sec – 1 nA
Maximum rigidity (T.m)	2.05
Macro-pulse length (ms)	< 2
Repetition rate (Hz)	< 50

REX time structure

Protons from PSB → (A)

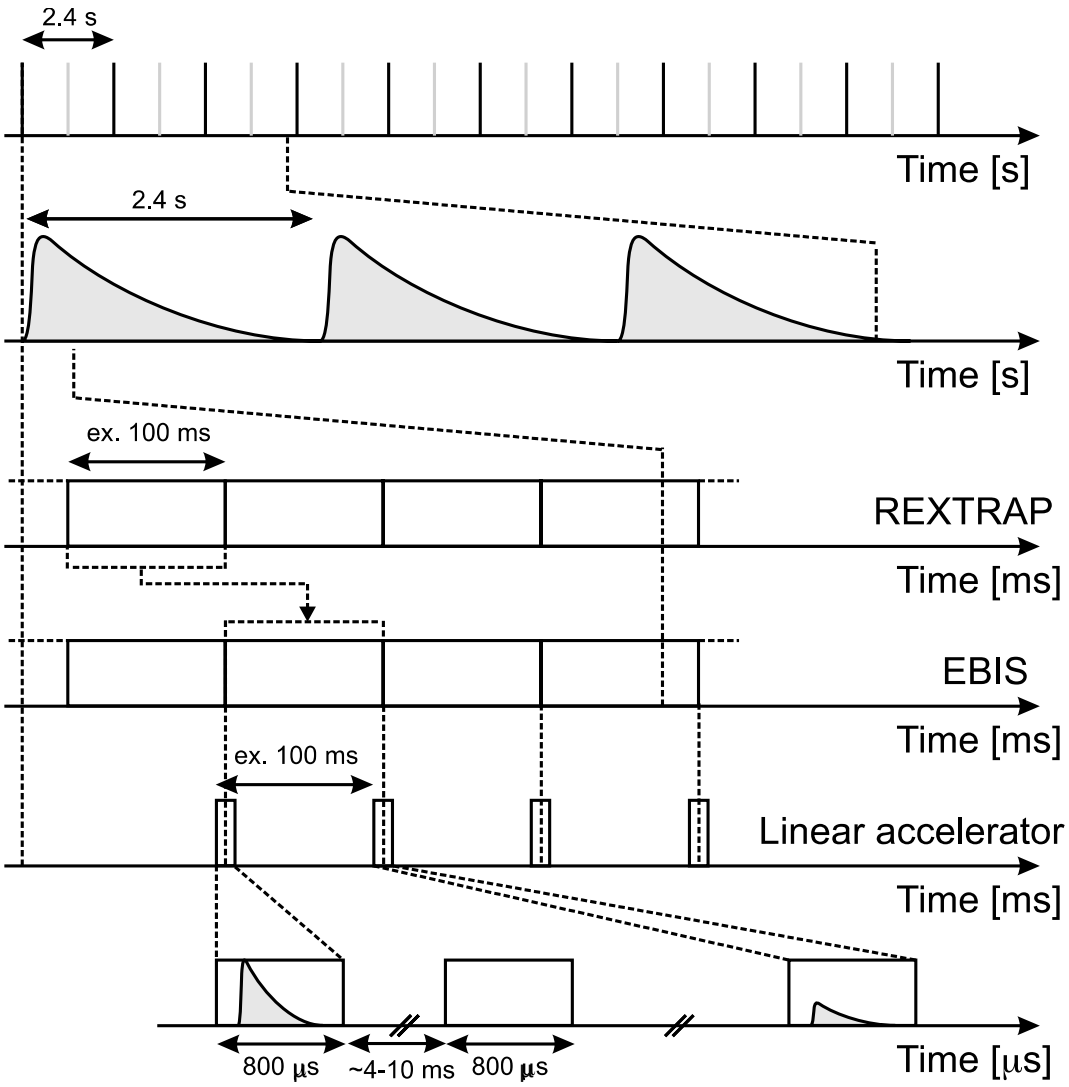
RIBs released from ISOL target → (B)

Accumulation/cooling/macro bunching (up to 100 Hz) → (C)

Charge breeding → (D)

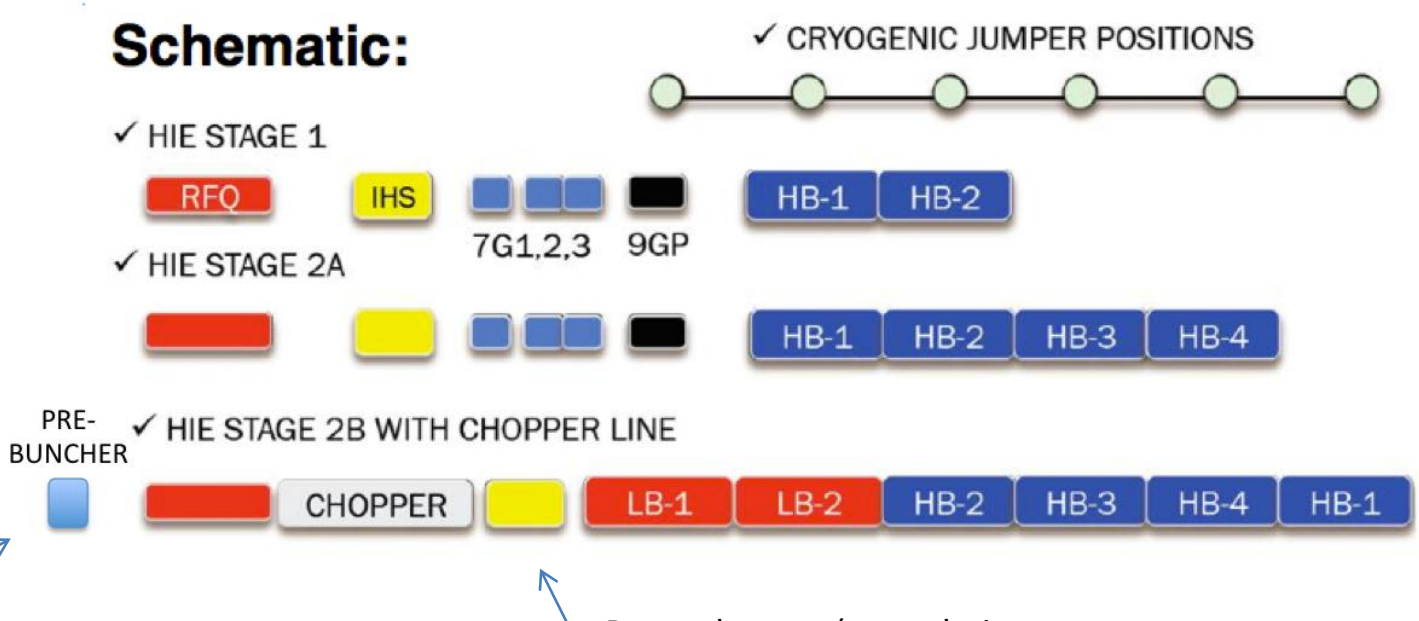
Duty cycle of linac matched to charge breeder/ion source → (E)

Micro-bunching of EBIS beam pulse by RFQ at 101.28 MHz → (F)



Chopper-buncher

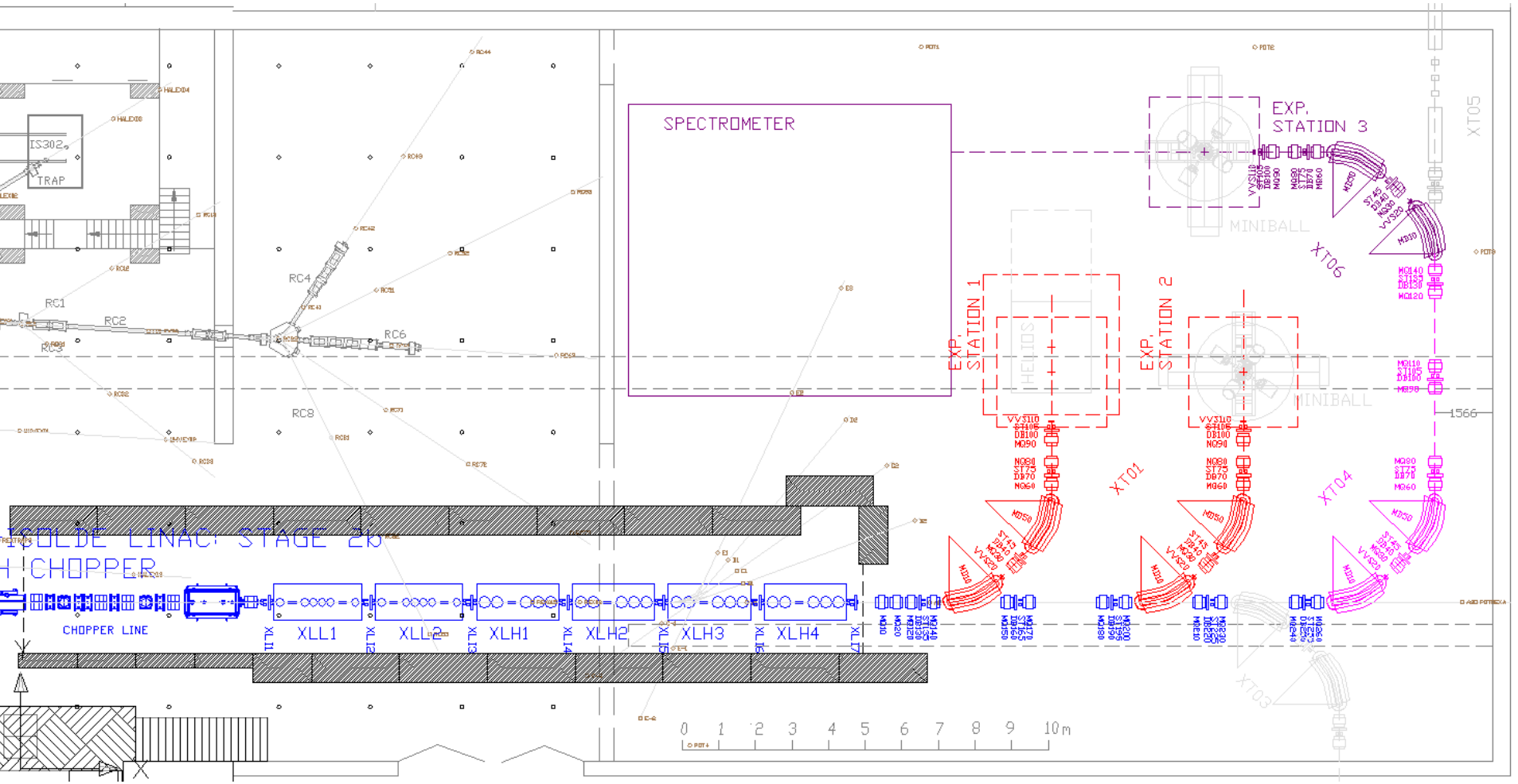
Goal: increase natural bunch spacing from ~10 ns (101.28 MHz) to ~100 ns for physics with TOF systems



Multi-harmonic pre-buncher operating at $f_0/10$ to 'squeeze' several bunches in one

Beam chopper (meandering line or sine-wave) pulsed in phase with the beam to remove particles from empty bunches

High Energy Transfer lines and experimental stations



HEBT: SPECIFICATION FOR TARGET PARAMETERS

Transverse Beam Parameters*

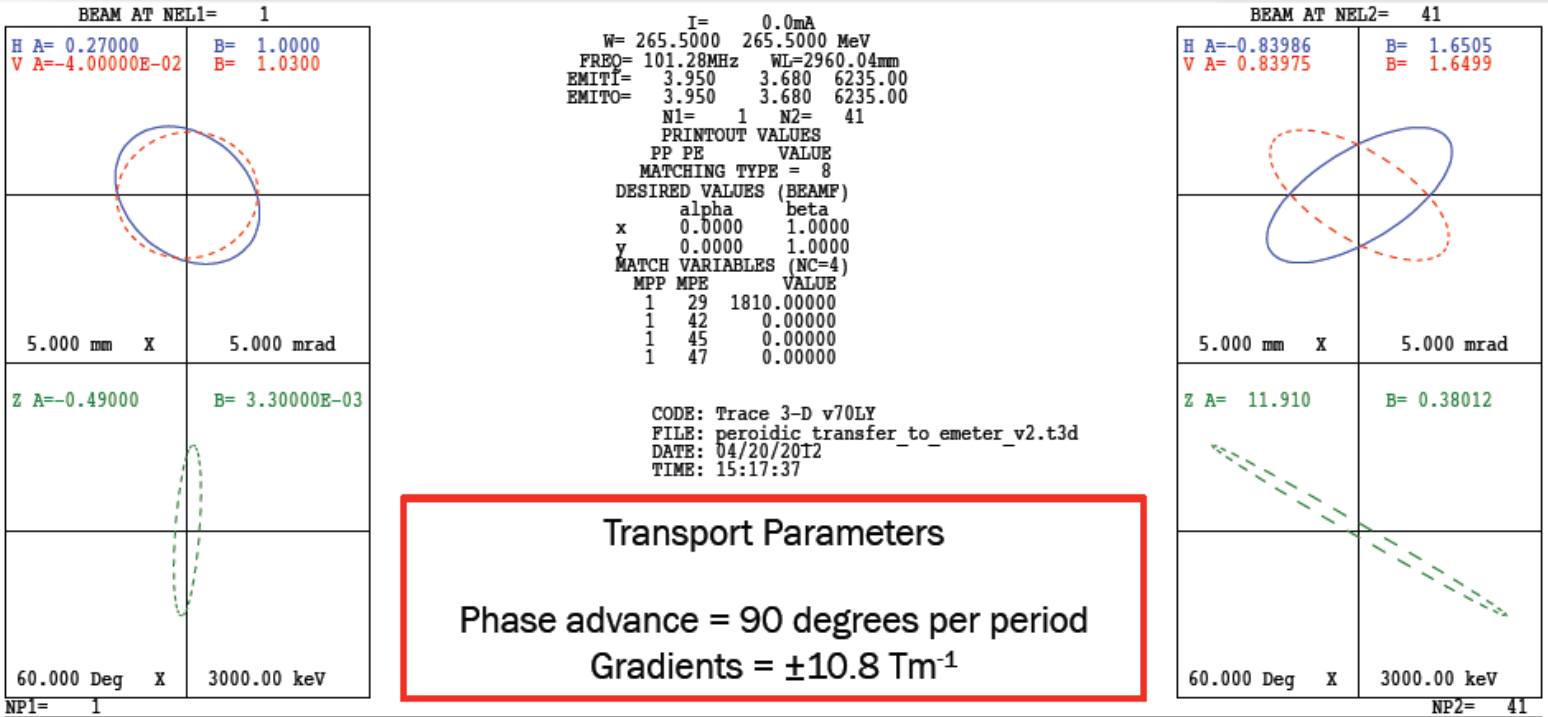
Energy (MeV/u)	Spot Size (mm) (FWHM)	$\varepsilon_x = \varepsilon_y$ (π m mrad) (norm, RMS)**	$\beta_x = \beta_y$ (m)
5.5	2	0.09	<0.9
10	2	0.09	<1.5
0.3	5	0.09	<1.2

Longitudinal Beam Parameters*

Energy (MeV/u)	Bunch Length (ns) (FWHM)	Energy Spread (%) (FWHM)
5.5	<2 ns	<0.1
10	<2 ns	<0.1

* Minutes of the Meeting of the HIE-ISOLDE Physics Coordination Group, 6th May 2011.
** Beam divergence specification consistent with assumed emittance.

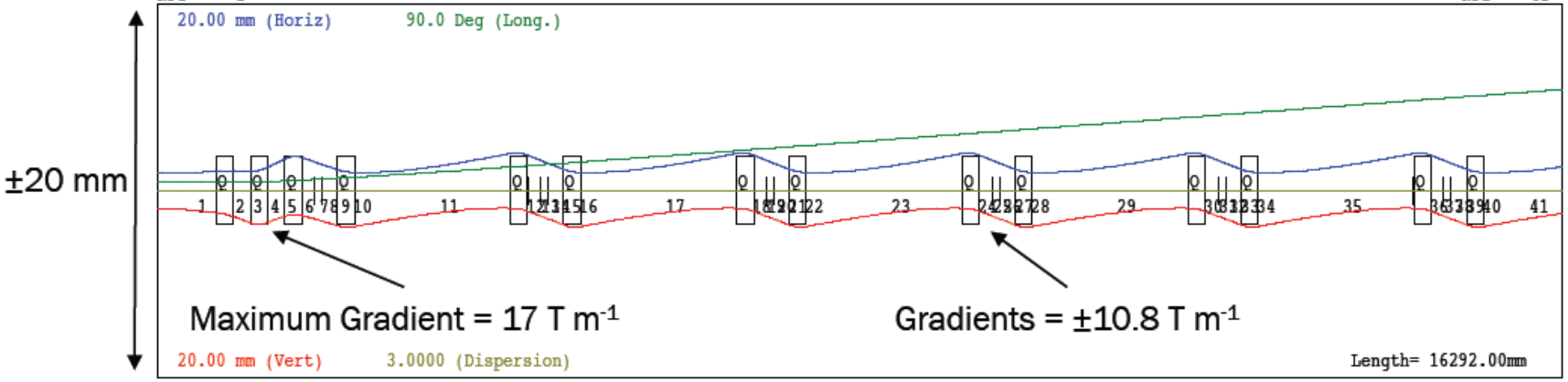
HEBT BEAM OPTICS: PERIODIC TRANSPORT
EXAMPLE: A/Q = 4.5, W = 5.5 MEV/U



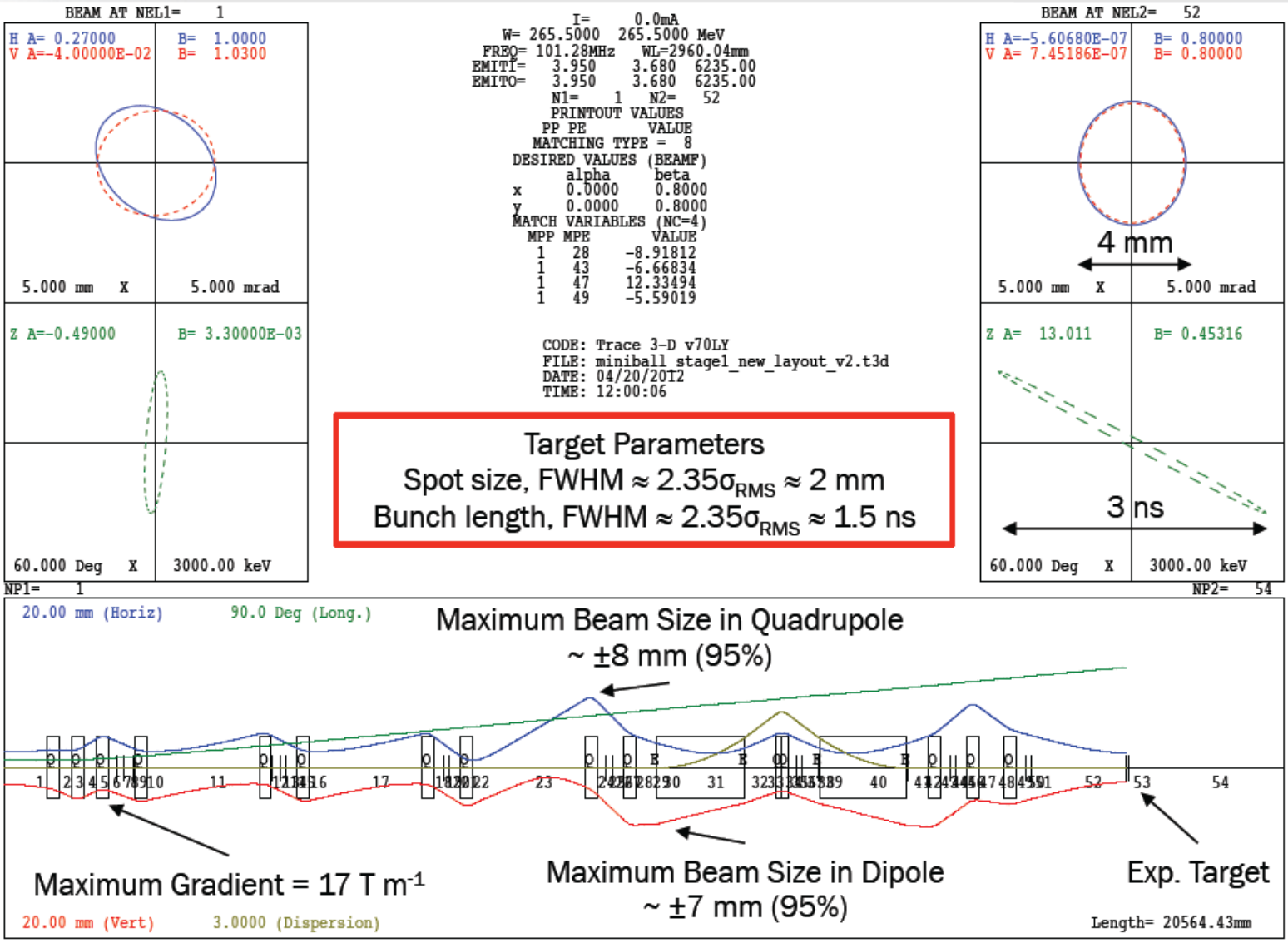
Transport Parameters

Phase advance = 90 degrees per period

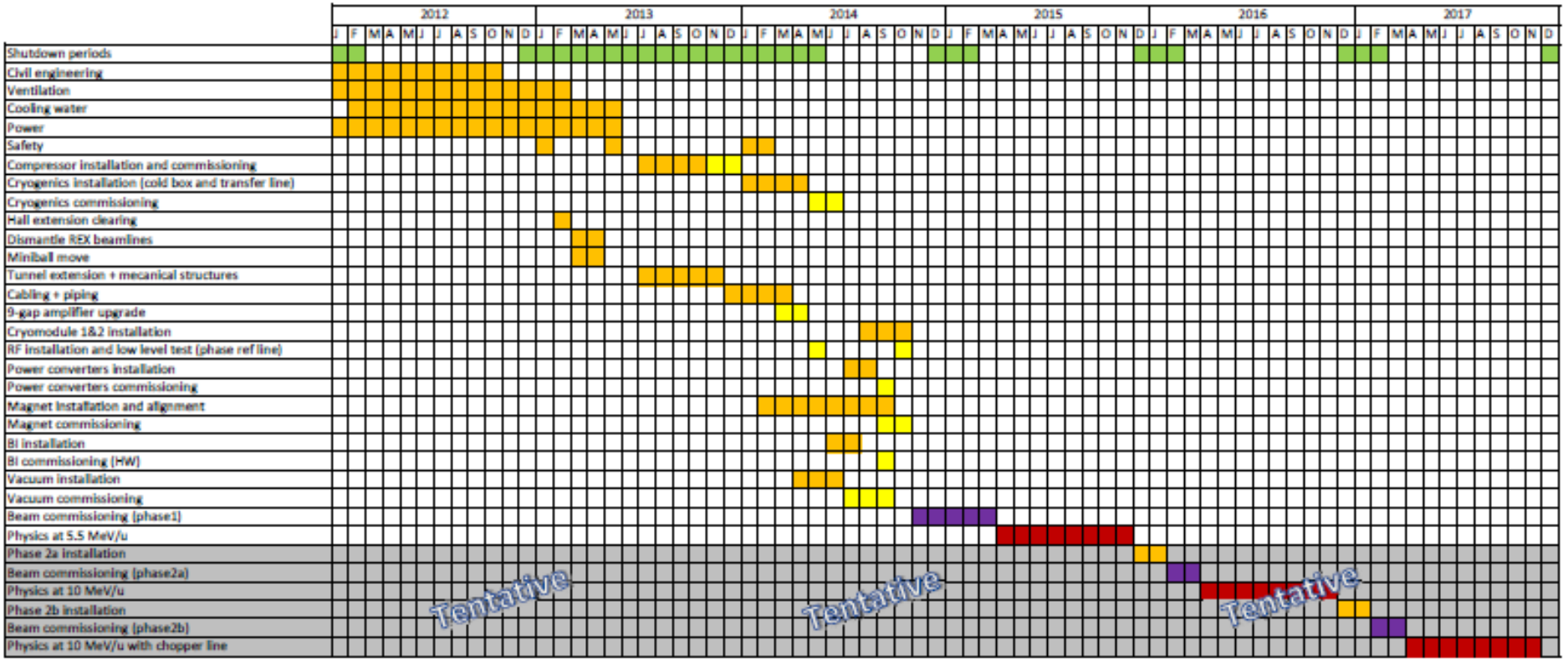
Gradients = ±10.8 Tm^{-1}



HEBT BEAM OPTICS: EXP. STATION 1
EXAMPLE: A/Q = 4.5, W = 5.5 MEV/U



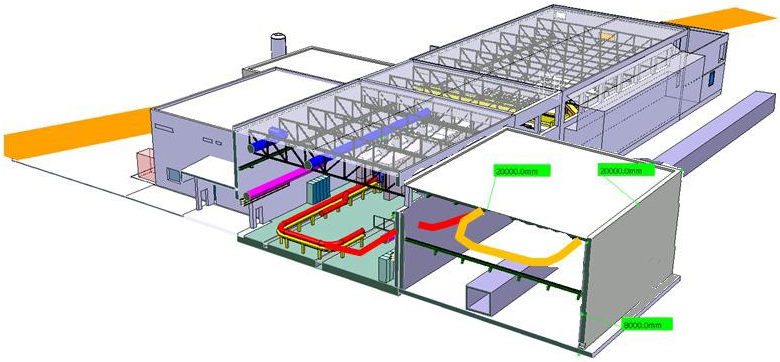
HIE Schedule



TSR@ISOLDE

- Heavy-Ion Storage Ring + HIE-ISOLDE
  - No background
  - No energy straggling
  - Cold beam/Smaller beamsize
  - Reduced dead time/CW beam
- Approved by research board May 2012
- Aiming for start-up in 2015 as an experiment, integration as CERN facility towards 2018

TSR at MPIK Heidelberg

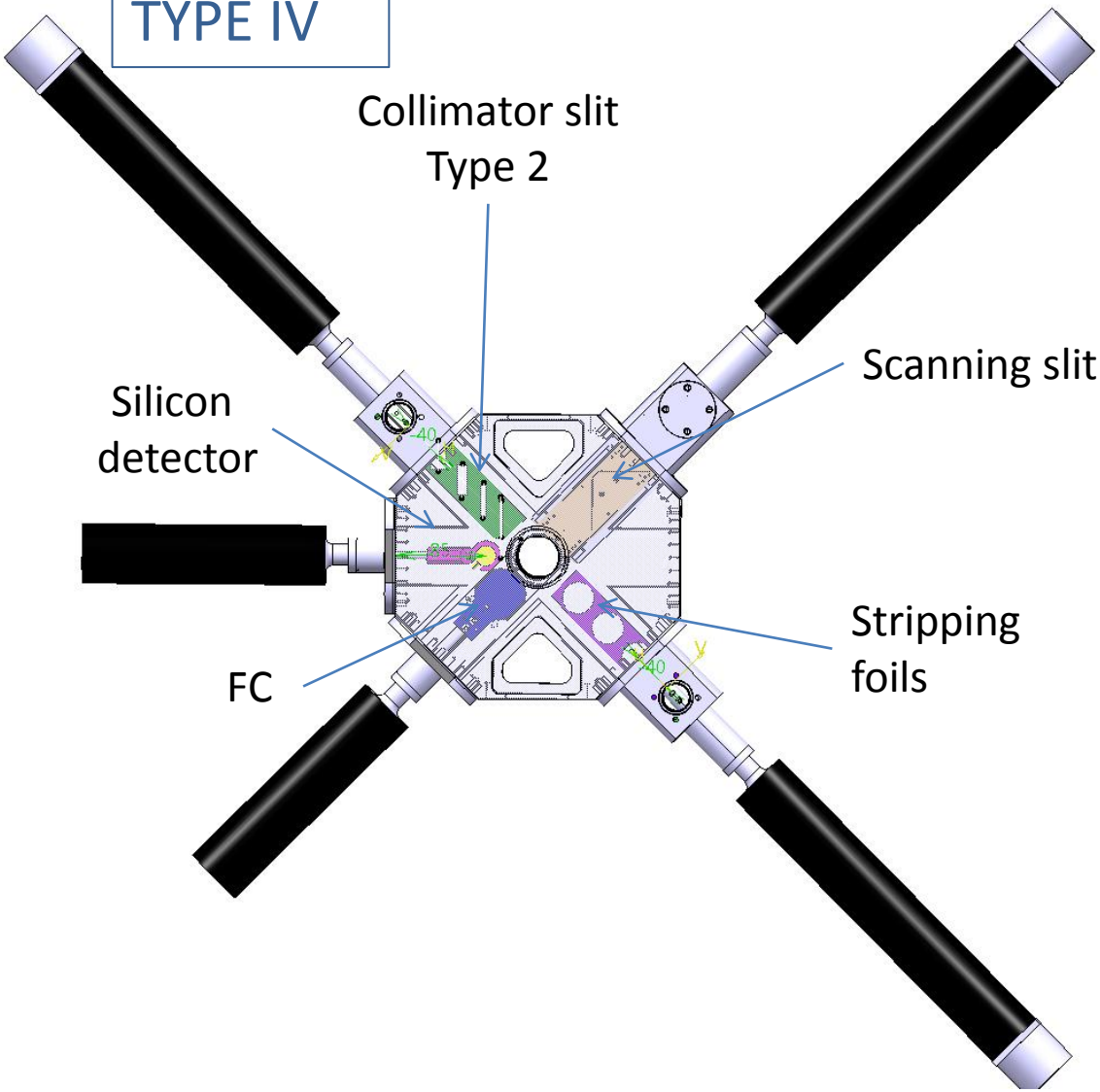


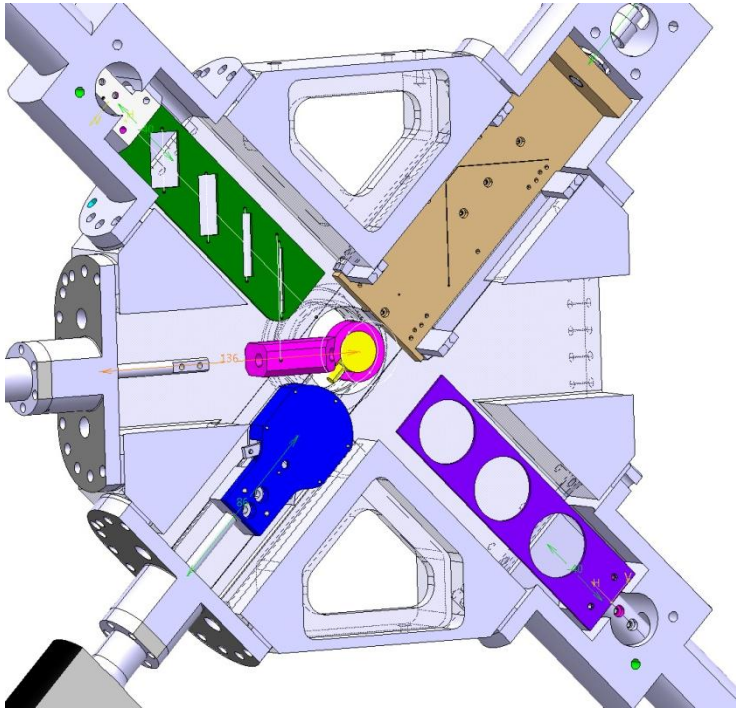
Possible TSR installation

Spare slides

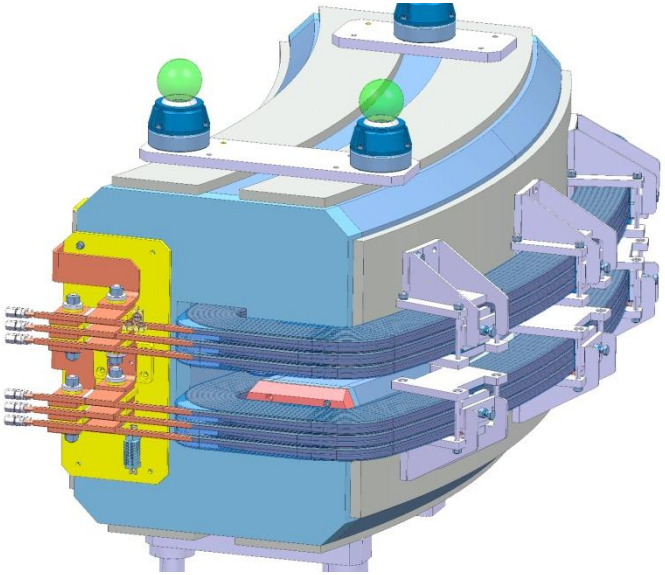
Diagnostic box

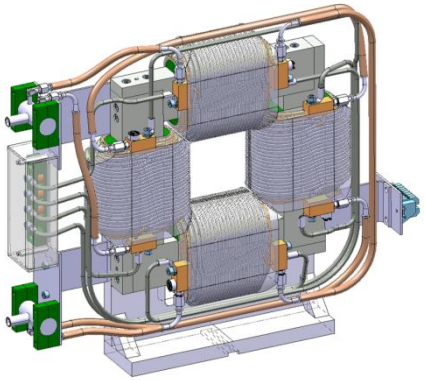
TYPE IV

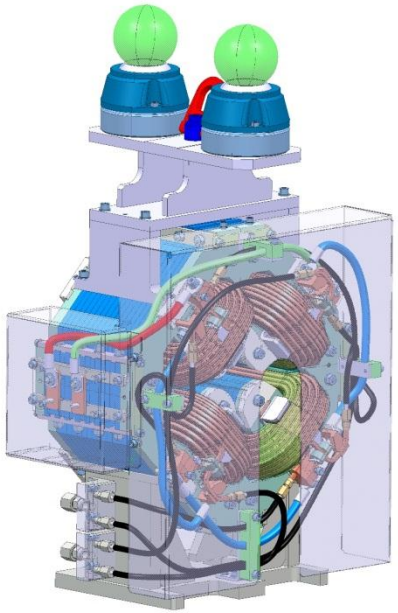




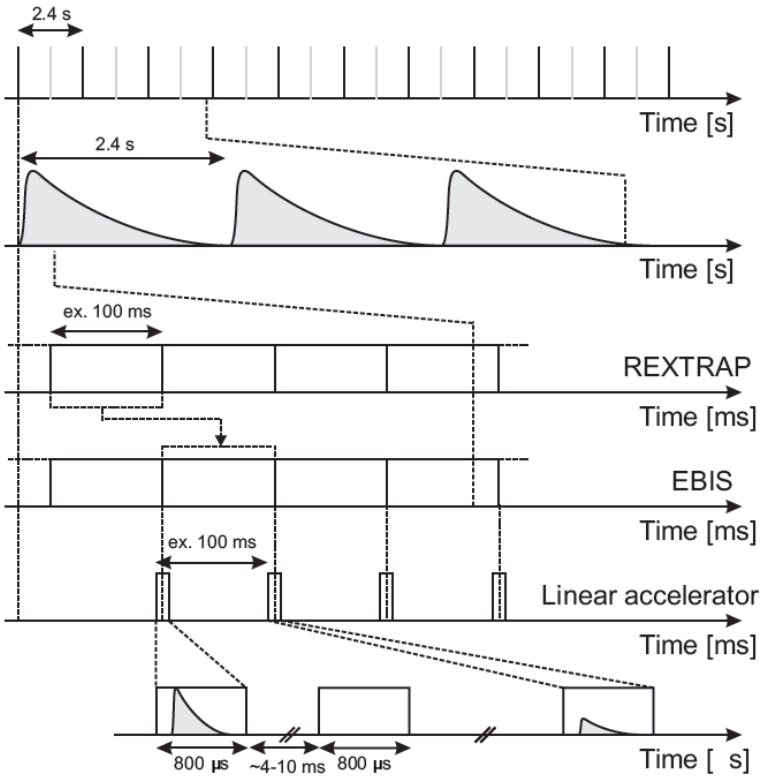
Magnets – present designs

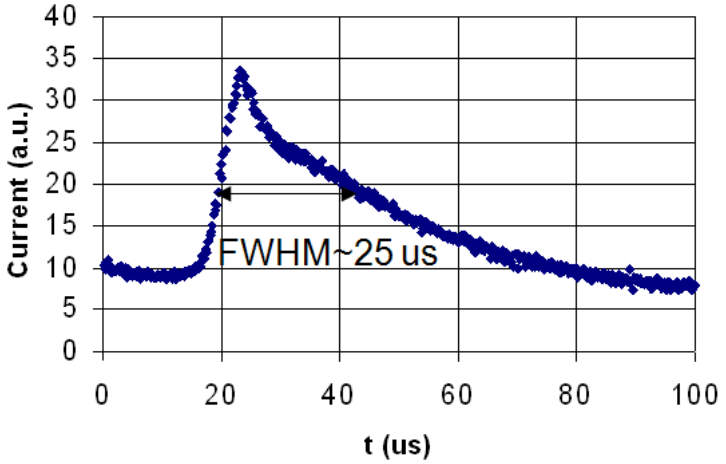




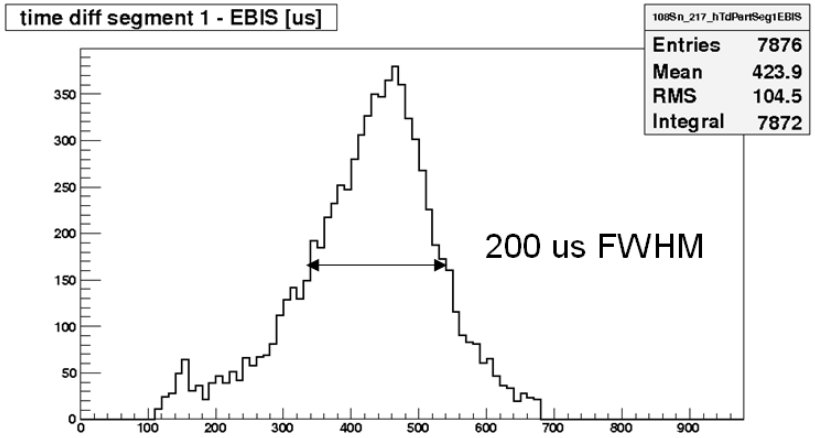


Slow extraction





normal extraction, 14N4+, measured in front of linac



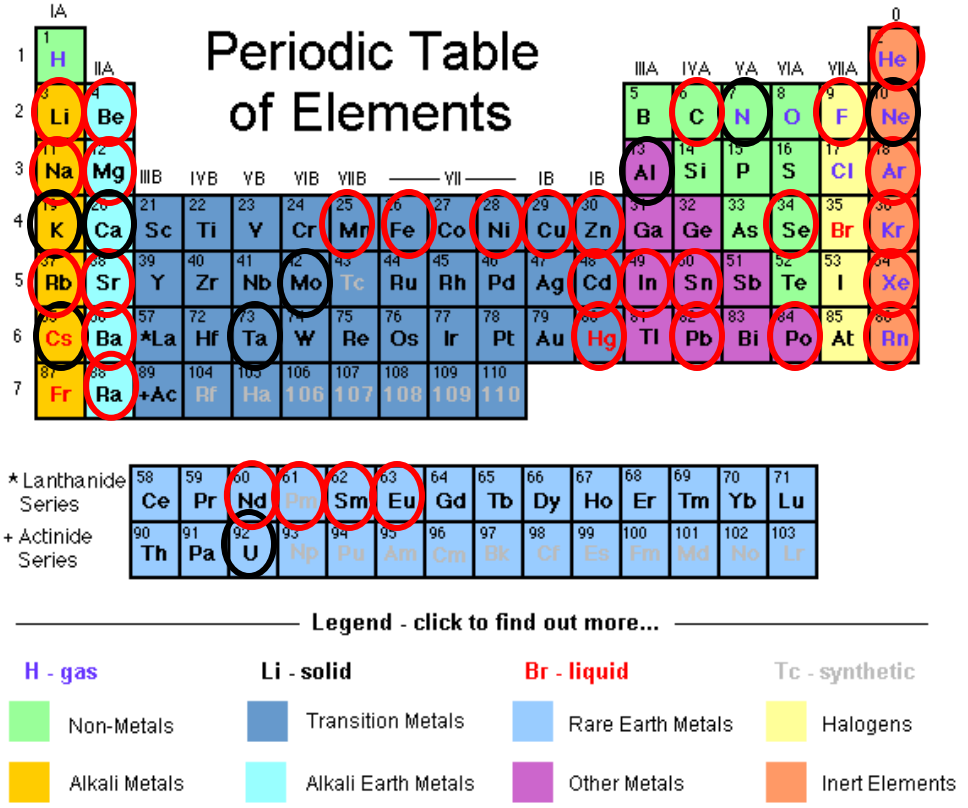
Slow extraction, 108Sn, measured at Miniball

- Bunched beam = high instantaneous rate -> dead time
- Good signal to noise ratio

REX beam collection

2001-2012

^{6}He
^{8,9,11}Li
^{10,11,12}Be
^{10}C
^{17}F
^{21,24,25,26,27,28,29,30}Na
^{28,29,30,31,32}Mg
^{44}Ar
^{61,62,63}Mn
^{61,62}Fe
^{66,68}Ni
^{67,68,69,70,71,73}Cu
^{72,74,76,78,80}Zn
^{70}Se
^{72,88,92,94,96}Kr
^{93,95,97,99}Rb
^{96,98}Sr
^{100,102,104,122,123,124,126,128}Cd
^{108}In
^{106,107,108,109,110}Sn
^{138,140,142,144}Xe
^{140,142,148}Ba
^{140}Nd
^{148}Pm
^{140,142,153}Sm
^{156}Eu
^{182,184,186,188}Hg
^{186,188,190,192,194,196,198}Pb
^{196,198,200,202,206}Po
^{202,204,208,220,221}Rn
^{224}Ra



>100 radioactive isotopes of 31 elements

A selection of stable elements charge bred