2010年度RCNP研究会
「重イオン蓄積リングの物理」

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重イオン蓄積リングのための施設拡張計画(案)

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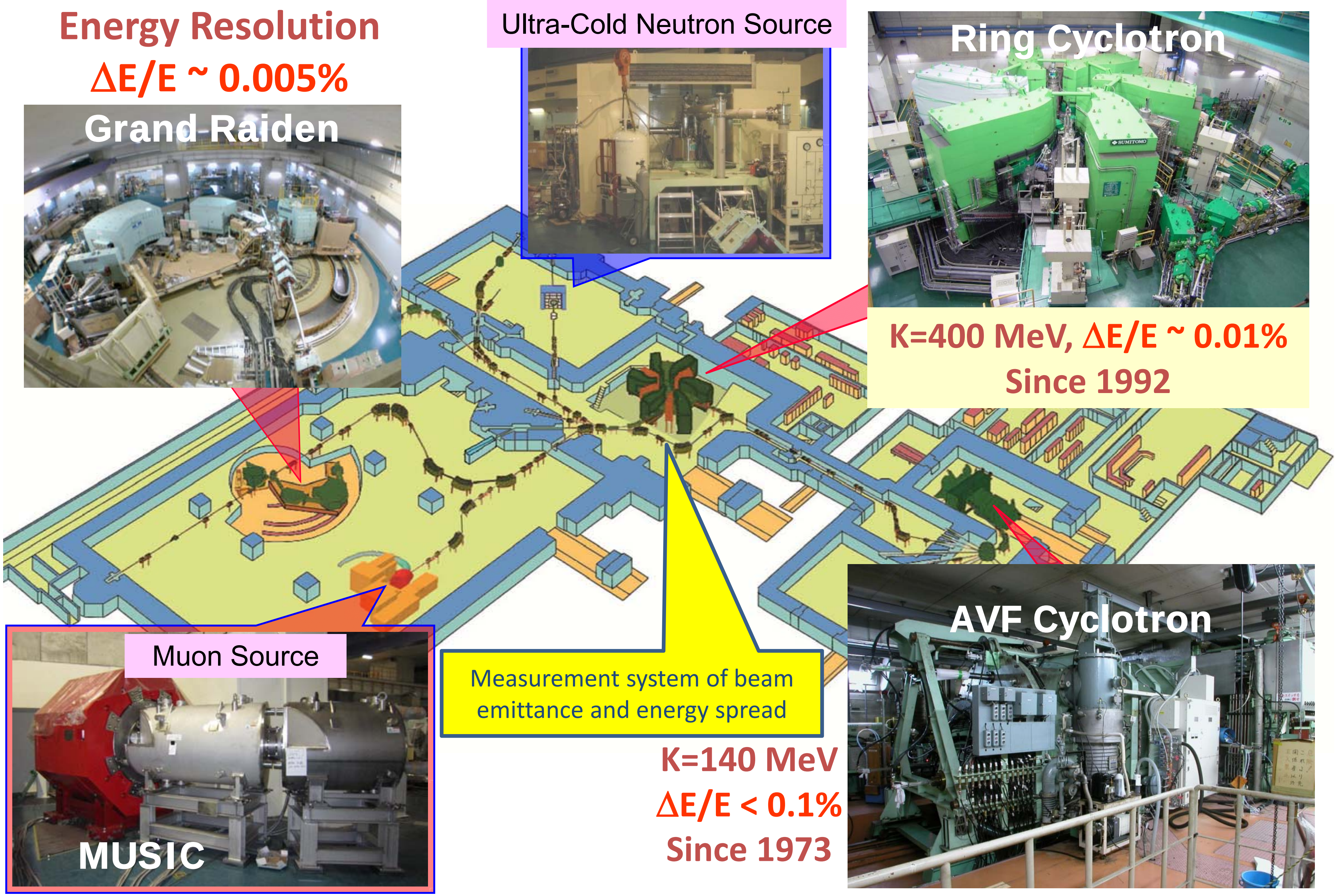
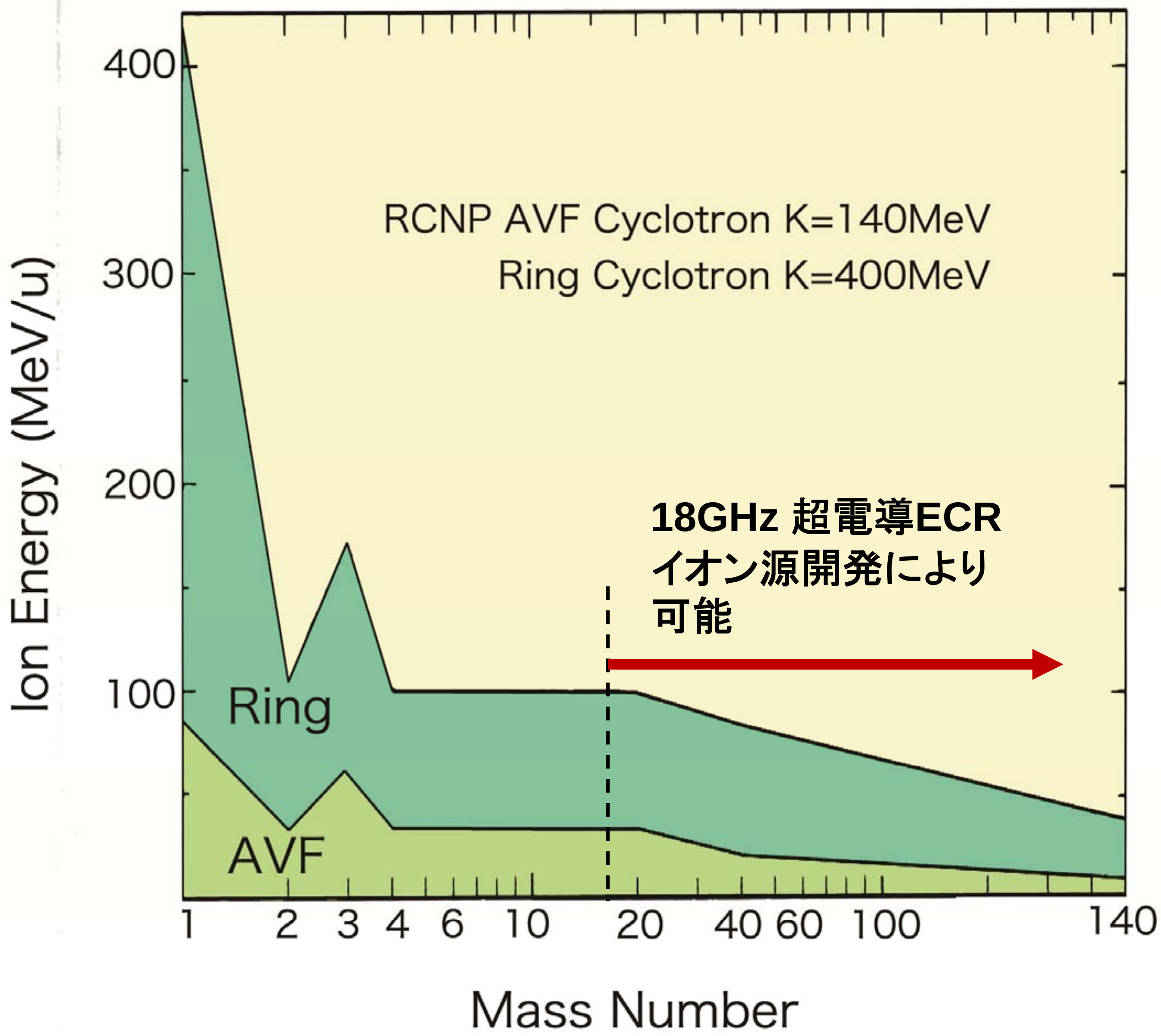
１．既存のサイクロトロン施設

Present RCNP Cyclotron Facility



既存サイクロトロンの加速エネルギー範囲



２．新入射器と重イオン蓄積リングの配置（案）

ビームに対する要求

※今回の研究会で明らかになってくるはずだが・・・

●一次ビームの利用
・軽イオン
・重イオン

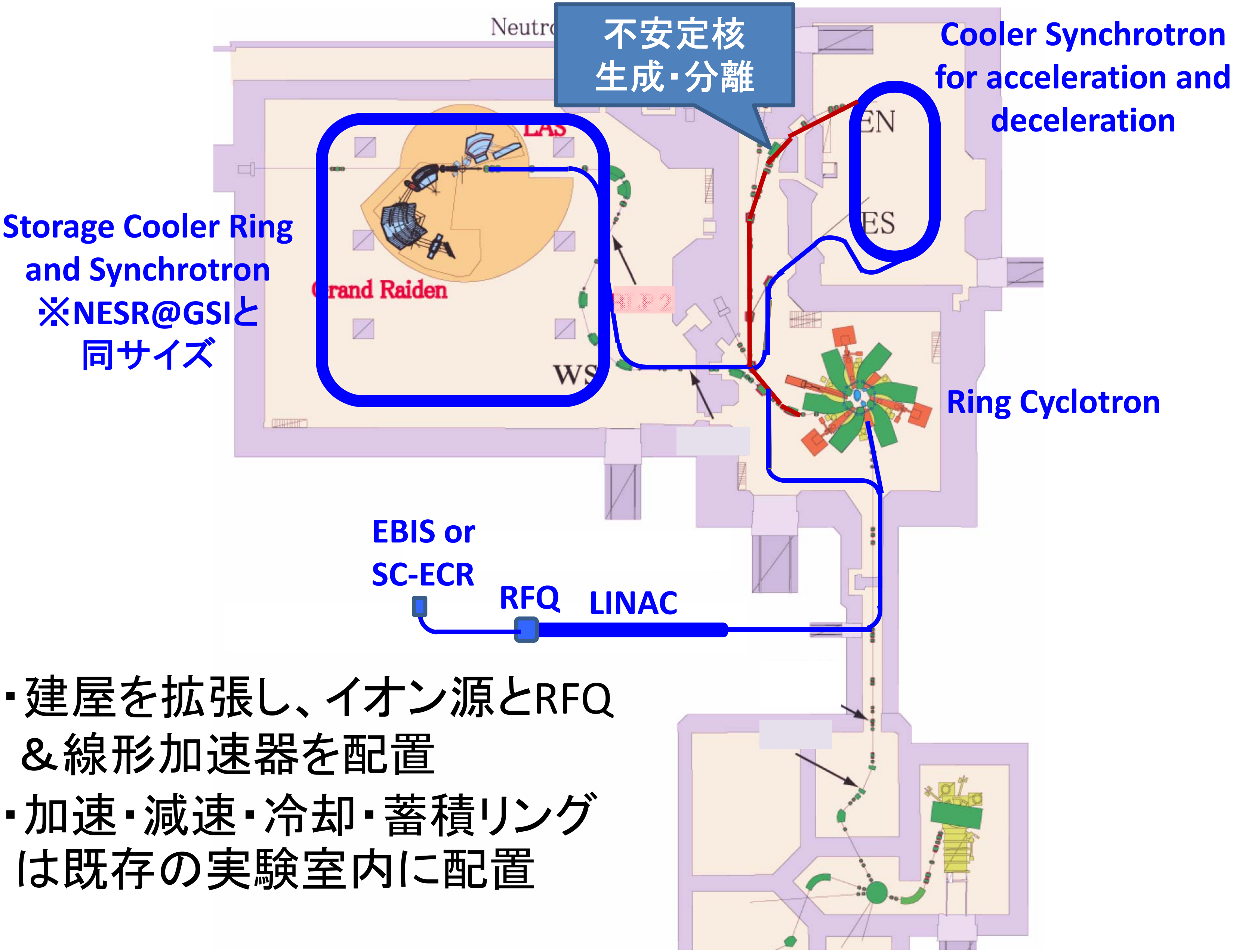
●二次ビーム（不安定核ビーム）の利用
・短寿命核
・比較的寿命の長い原子核

●標的
・リング内部
・外部

●既存の実験装置の利用
・Grand-Raiden

ビームの量と質は？
・ビーム強度
　蓄積
　再利用
・低～高エネルギー
　加速・減速
・運動量幅
　冷却
・低エミッタンス
　高輝度

Upgrade of the Accelerator Facilities



・建屋を拡張し、イオン源とRFQ
＆線形加速器を配置

・加速・減速・冷却・蓄積リング
は既存の実験室内に配置

３．新たなイオン源と入射器

粒子源と前段加速器

●GSI-UNILACのUpgrade計画の例

・28GHz SC-ECRの増設

既存の14GHz ECR(CAPRICE-type)も併用

・新低エネルギー輸送ライン

・High duty factorの新RFQとIH型ライナック

Duty factorの改善： 28% → 50%

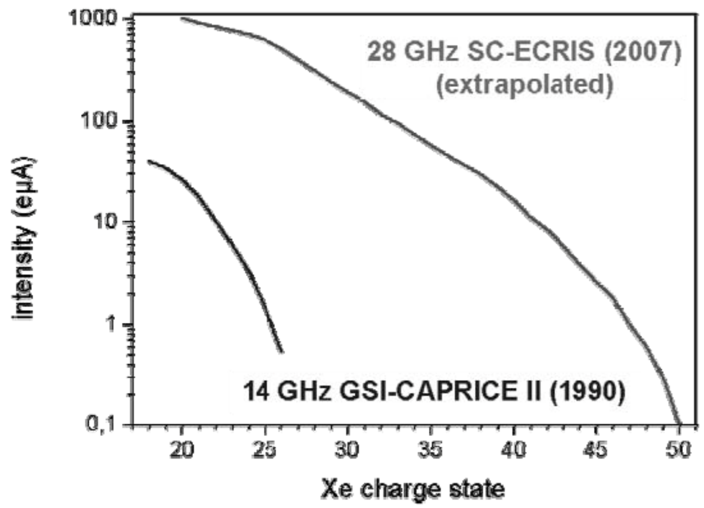


Fig. 5: Comparison of ECR-ion source types; mainly the increase of microwave frequency and the higher magnetic flux density (superconducting magnets) is responsible for the increased intensity of the sc-ECRIS-type ECR.

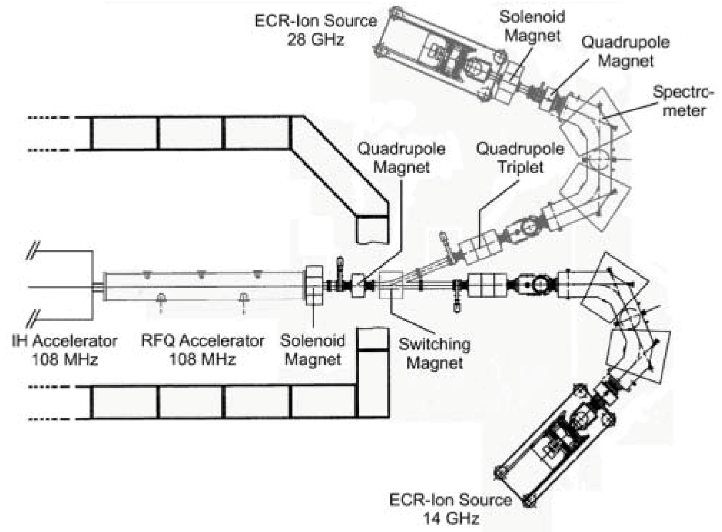


Fig. 6: Upgrade of the High Charge State Injector Front-end-System (schematic view); 28 GHz-ECR source, new LEBT, switching magnet and the new RFQ (in red).

高強度重イオン源

※詳細は依田氏の講演を参照

【参考１】RHIC用EBIS（BNL）［パルス型］

･イオン	He ～ U
･Q/M	1／6 ～ 1／2
･ビーム強度	＞1.5 emA
･繰り返し周波数	最大5 Hz
･パルス幅	10 ～ 40 μs
･エネルギー	15 ～ 20 keV/u

【参考２】28GHz SC-ECR（VENUS＠LBNL）［CW型］

･129Xe	25+ ～ 28+	223 ～ 88 μA
･209Bi	25+ ～ 30+	243 ～ 165 μA
	47+	2.4 μA
･238U	33+ ～ 35+	205 ～ 175 μA
	47+	5 μA

Upgrade of the GSI-UNILAC

- New CW-superconducting LINAC @ GSI
  - ・Increase of the duty factor 100%

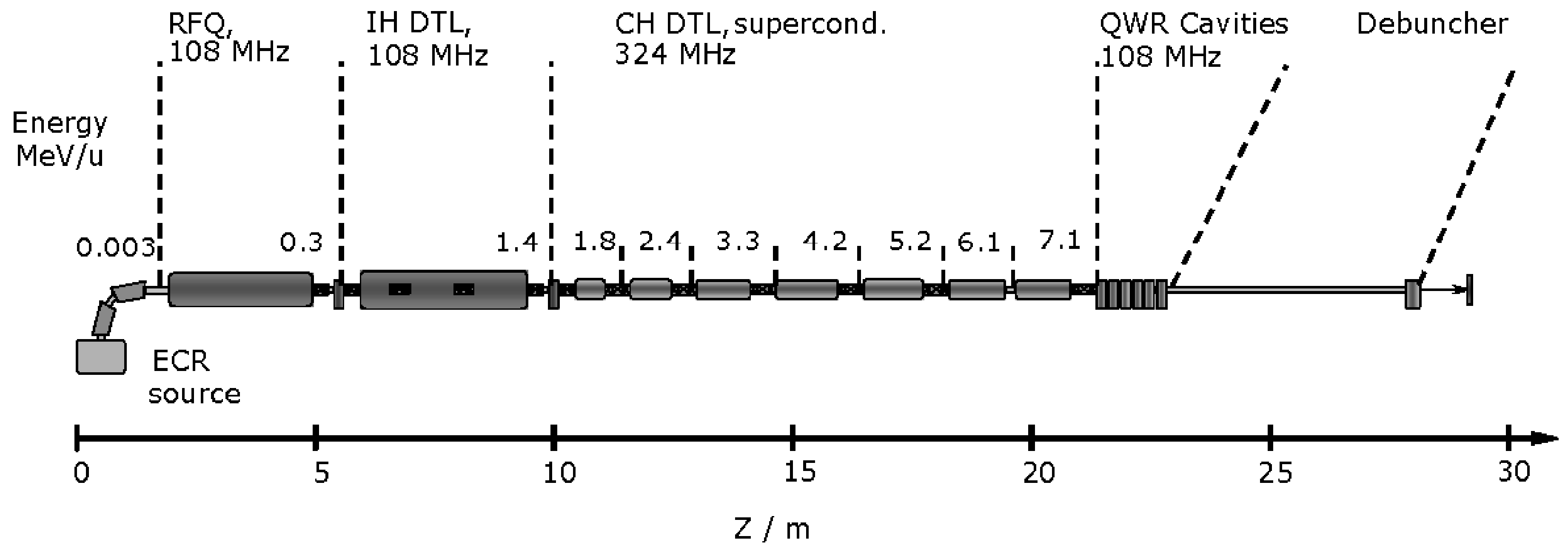


Fig. 7: Proposed layout of a cw-superconducting LINAC. [4]

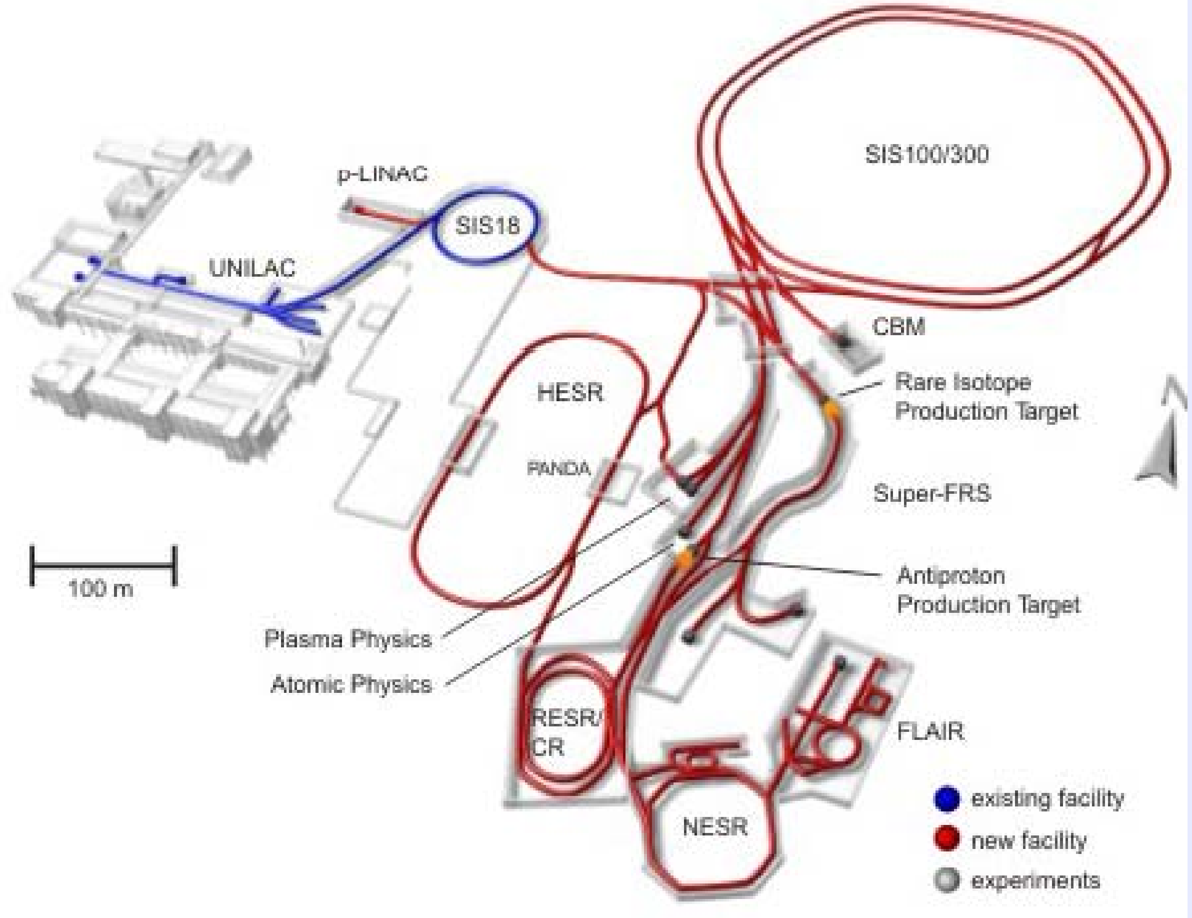
※CW化によりリングサイクロトロンへの入射効率も向上

４．加速･減速･冷却･蓄積リング

－GSIの例を踏まえて検討中－

FAIR Project at GSI

FAIR: Facility for Antiproton and Ion Research



SIS300	Synchrotron
SIS100	Synchrotron
CR	Collector Ring
RESR	Accumulator Ring
NESR	Experimental Storage Ring
HESR	High Energy Storage Ring

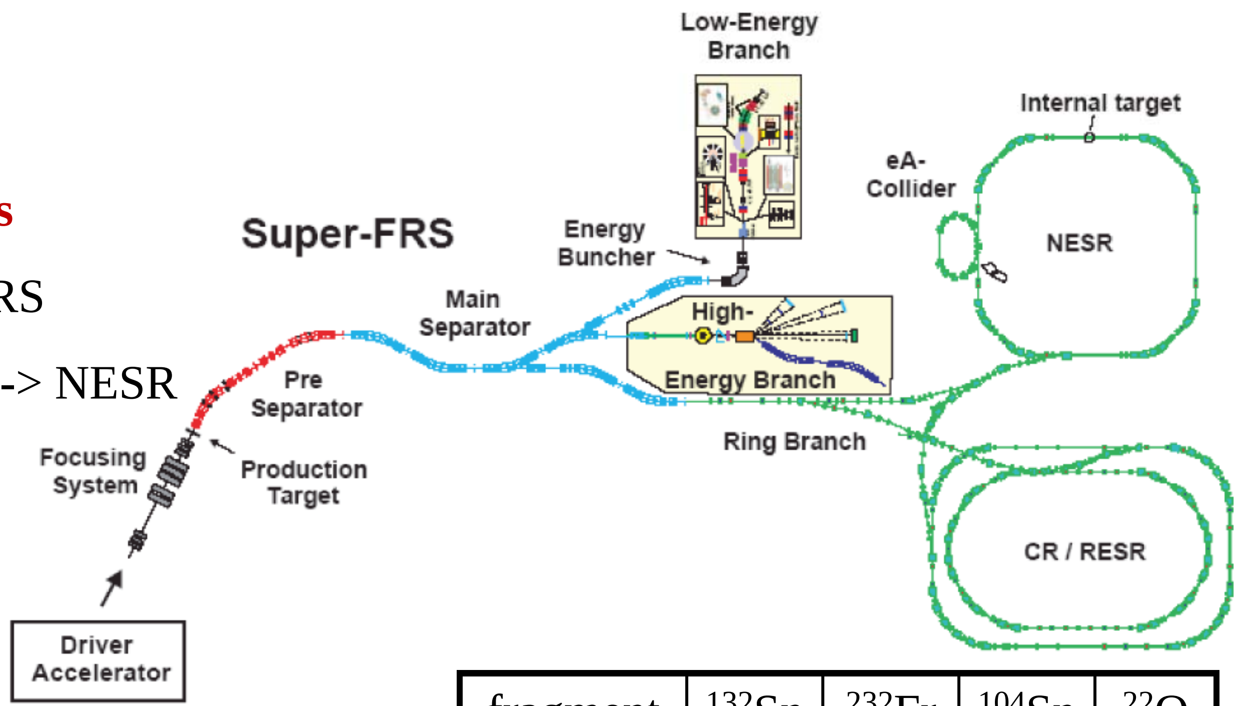
Ring	Circumference [m]	Beam rigidity [Tm]	Beam Energy	Features
Synchrotron SIS100	1084	100	U^{28+}: 2.7 GeV/u protons: 29 GeV	Fast pulsed superferric magnets 4 T/s, up to 2 T, bunch compression to ~60 ns for $5x10^{11}$ U ions, fast and slow extraction, $5x10^{-12}$ mbar operating vacuum
Synchrotron SIS300	1084	300	34 GeV/c for U^{92+}	Fast pulsed superconducting cosθ-magnets 1 T/s, up to 6 T slow extraction of ~$3x10^{11}$ U-ions per sec, 5·10-12 mbar operating vacuum
Collector Ring CR	211	13	U^{92+}: 0.74 GeV/u antiprotons: 3 GeV	Acceptance for antiprotons: 240 mm mrad: $\Delta p/p=\pm 3x10^{-2}$, fast stochastic cooling, isochronous mass spectrometer
Accumulator Ring RESR	245	13	U^{92+}: 0.74 GeV/u antiprotons: 3 GeV	Accumulation of antiprotons (pre-cooling in the CR), fast deceleration of short-lived nuclei (1T/s)
New Experimental Storage Ring	222	13	U^{92+}: 0.74 GeV/u antiprotons: 3 GeV	Electron cooling of radioactive ions and antiprotons, precision mass spectrometer, internal targets with atoms and electrons, electron-nucleus scattering facility, deceleration of ions and antiprotons (1 T/s)
High-Energy Storage Ring HESR	574	50	antiprotons: 14 GeV	Stochastic cooling of antiprotons up to 14 GeV, electron cooling of antiprotons up to 9 GeV; internal gas jet or pellet target

Rare Isotope Beam Facility

Primary beam: 5x10^{11} ions/s

Fragment separator: Super-FRS

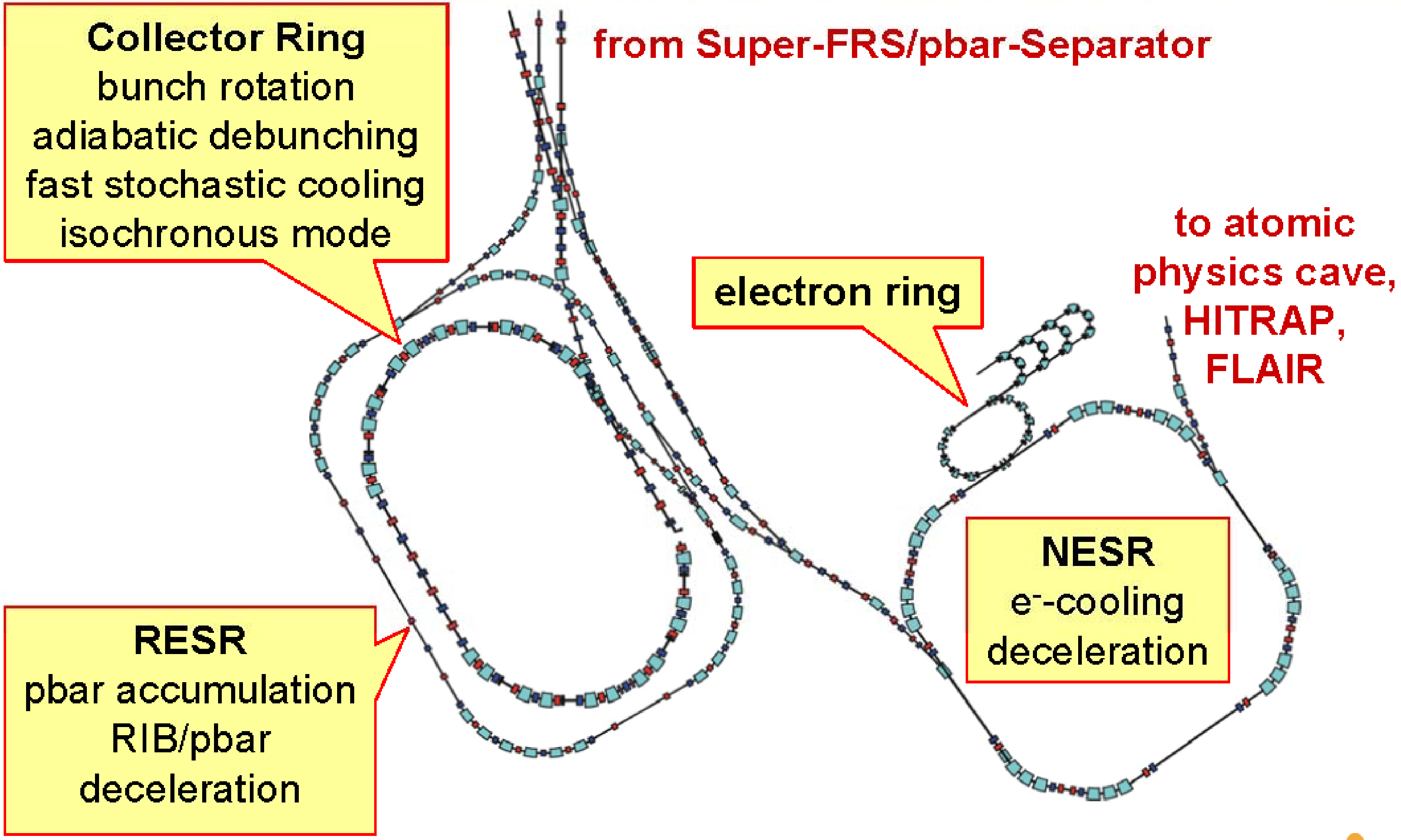
Ring Branch: CR -> (RESR) -> NESR



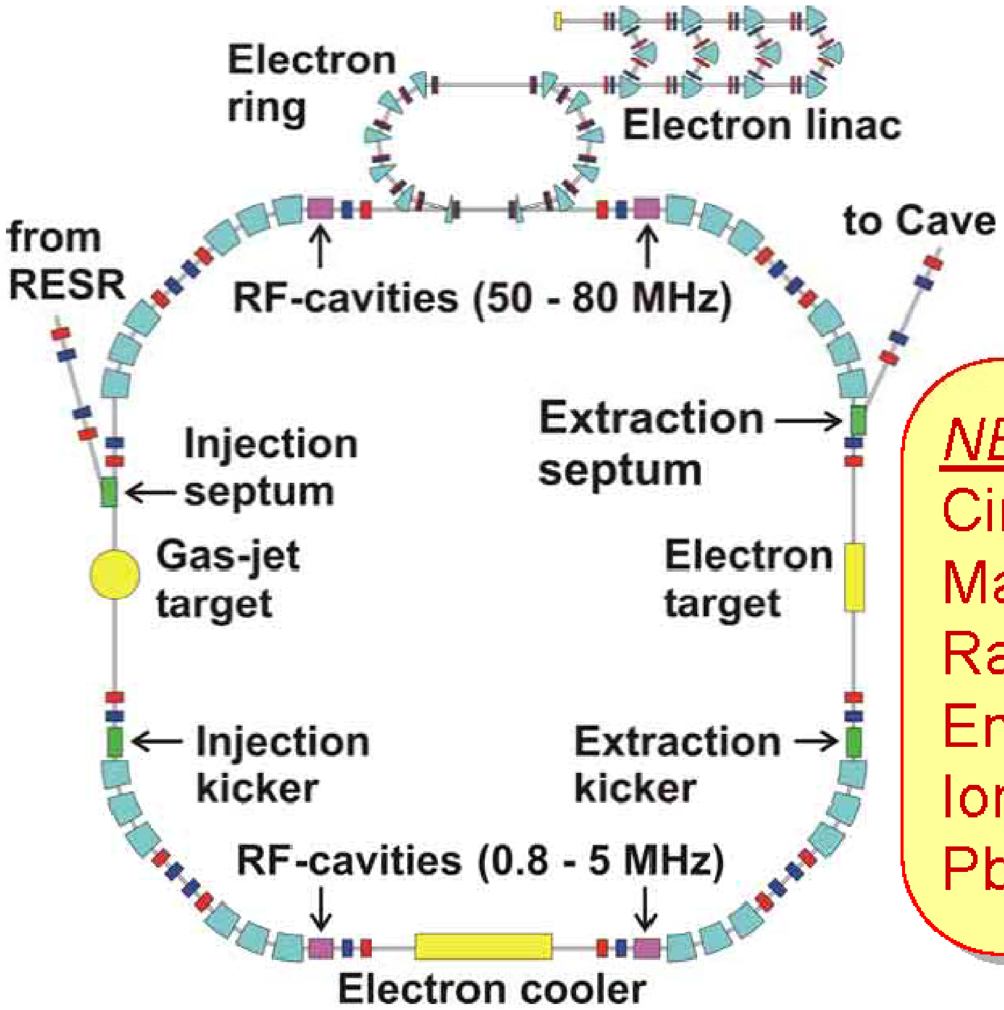
fragment	^{132}Sn	^{232}Fr	^{104}Sn	^{22}O
primary beam	^{238}U	^{238}U	^{124}Xe	^{40}Ar
T to MF7	0.24	0.46	0.79	0.52
T to CR	0.14	0.46	0.76	0.33
MF7/CR	0.59	0.99	0.96	0.63
$2\sigma_p/p$ [%]	3.05	1.21	1.47	3.03

	$B\rho_{max}$ [Tm]	Δp [%]	$\Delta\theta$ [mrad]	$\Delta\phi$ [mrad]	R
FRS	18	±1	±7.5	±7.5	1500
Super FRS	20	±2.5	±20	±40	1500

The Storage Rings



Layout of the NESR Lattice



Electron ring:

Circumference 45.22 m

Electron energy 200-500 MeV

NESR:

Circumference 218.75 m

Max. bending power 13 Tm

Ramp rate 1 T/s

Energy range:

Ions 4 – 840 MeV/u

Pbar 30 MeV – 3 GeV

NESR Parameters

Ring parameters

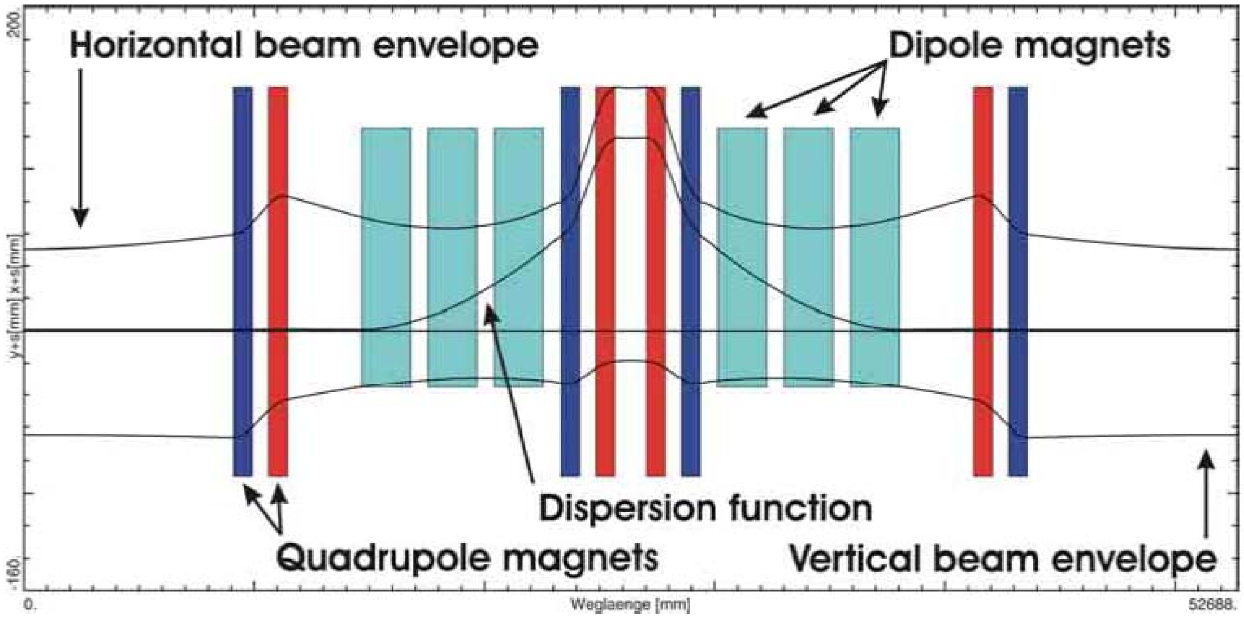
Horizontal/vertical acceptance [mm mrad]	160/100
Momentum acceptance [%]	±1.75
Horizontal/vertical tune	3.4/3.2
Transition energy	5.74
Maximum dispersion [m]	7.24

RI Beam parameters

Energy range (A/Z=2.7) (Ramp Rate 1 T/s) [MeV/u]	4 - 740
Cooling time constant (for U^{92+}-ions) [s]	0.3 - 0.5
Transverse emittance after cooling [mm mrad]	0.1
Momentum spread after cooling	$\pm 1 \times 10^{-4}$
Luminosity at internal gas target for ^{132}Sn [$cm^{-2}\ s^{-1}$]	6×10^{28}

Beam Envelopes and Dispersion Function

ε_x = 160 mm mrad, ε_y = 100 mm mrad, dp/p = 1 %



Maximum Dispersion 7.24 m

Luminosity at NESR

Nucleus	Production rate [1/spill]	τ incl. losses in NESR [s] at 740/100 MeV/u	L at 740 MeV/u [$cm^{-2}s^{-1}$]	L at 100 MeV/u [$cm^{-2}s^{-1}$]
^{11}Be	1×10^9	36/36	$> 10^{28}$	$> 10^{28}$
^{46}Ar	4×10^8	20/20	$> 10^{28}$	$> 10^{28}$
^{52}Ca	2×10^5	12/12	5×10^{25}	2×10^{25}
^{55}Ni	5×10^7	0.5/0.5	7×10^{25}	4×10^{25}
^{56}Ni	8×10^8	3800/1400	$> 10^{28}$	$> 10^{28}$
^{72}Ni	5×10^6	4.1/4.1	3×10^{26}	2×10^{26}
^{104}Sn	7×10^5	51/43	6×10^{26}	3×10^{26}
^{132}Sn	6×10^7	93/70	$> 10^{28}$	1×10^{28}
^{134}Sn	5×10^5	2.7/2.7	5×10^{24}	2×10^{24}
^{187}Sn	7×10^6	34/23	5×10^{24}	2×10^{24}

Assumption:

Beam intensity: 6×10^{11} ions/spill at Super-FRS target.

Target thickness: 10^{14} atoms/cm^2

重イオン蓄積リング

●NESR＠GSIと同等のリングにした場合