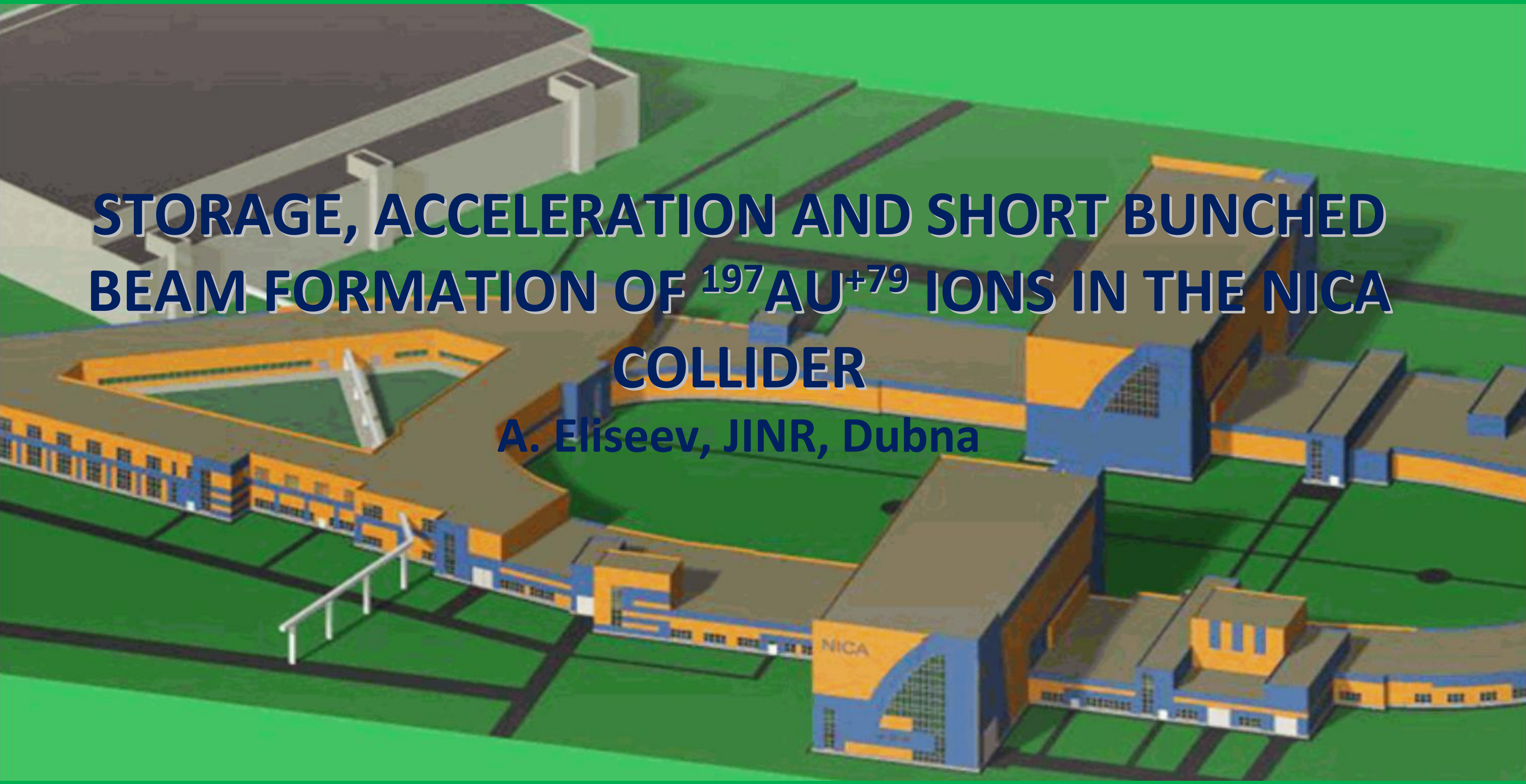
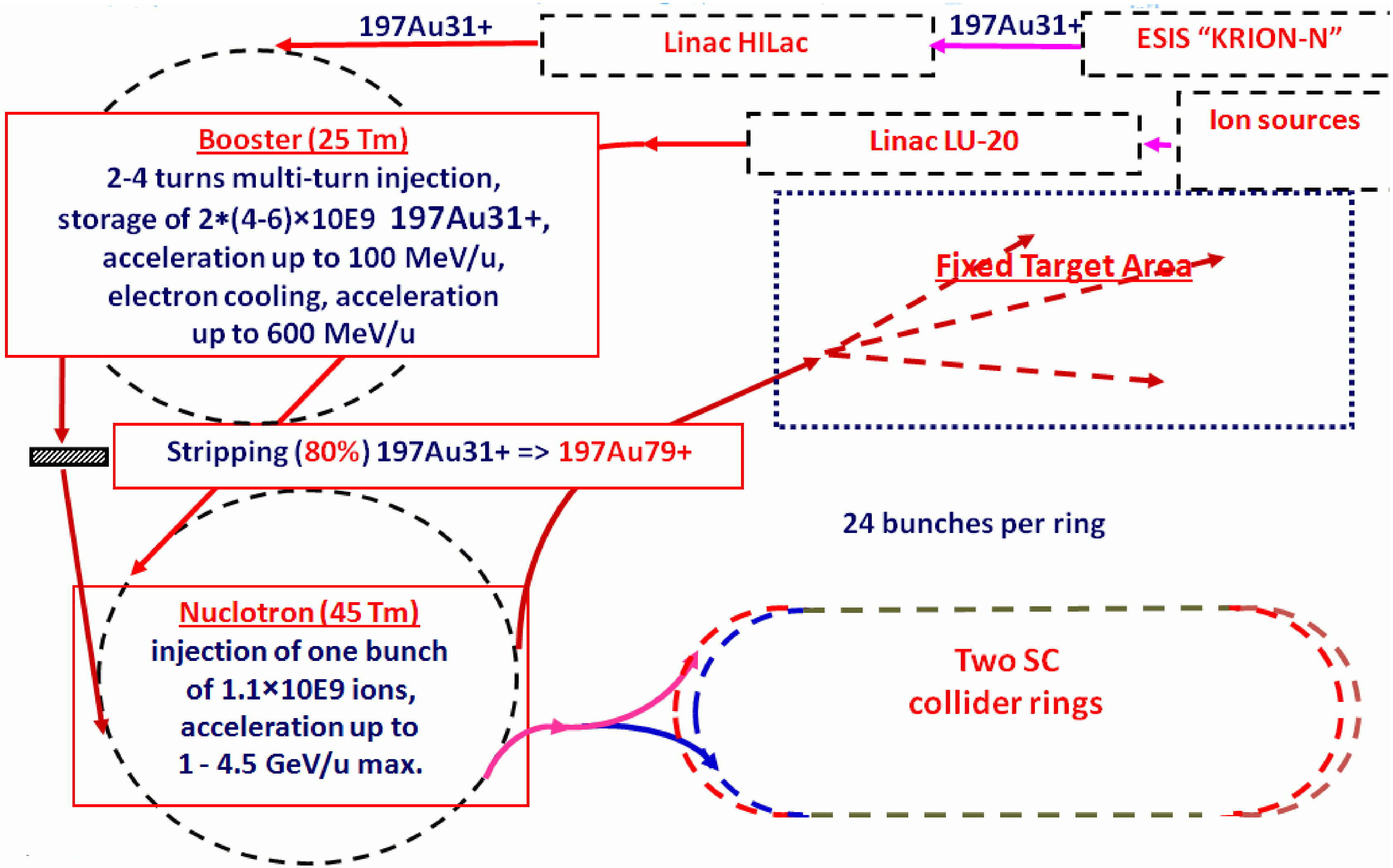
STORAGE, ACCELERATION AND SHORT BUNCHED BEAM FORMATION OF $^{197}AU^{+79}$ IONS IN THE NICA COLLIDER

A. Eliseev, JINR, Dubna



1. Facility general scheme



Longitudinal Bunch parameters after Nuclotron

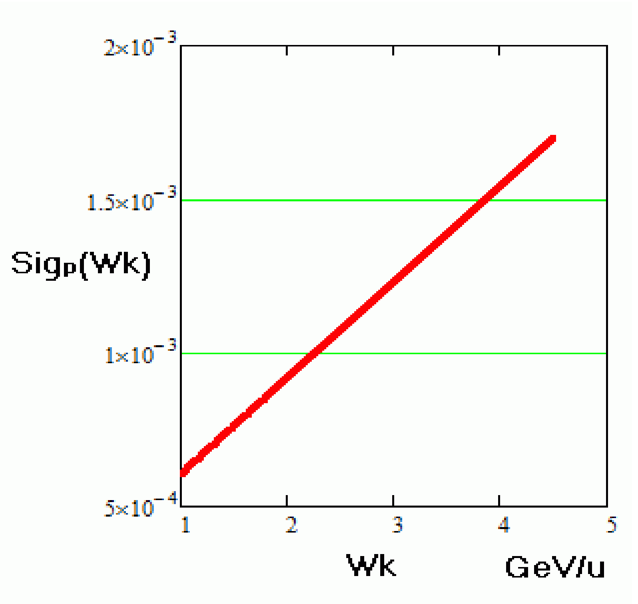
Before stripping foil - ε_{rms} **= 2.5 eV·s** (Au^{+31}).
After - ε_{rms} **= 3.2 eV·s** (Au^{+79}).

	1 GeV/u	1.5 GeV/u	2.5 GeV/u	3.5 GeV/u	4.5 GeV/u
σ_s (m)	4.5 ÷ 9	3.7÷ 7.4	2.8 ÷ 5.6	2.1 ÷ 4.2	1.7 ÷ 3.4
σ_p	$1.4 \cdot 10^{-4}$ ÷ $0.7 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$ ÷ $0.65 \cdot 10^{-4}$	$1.2 \cdot 10^{-4}$ ÷ $0.6 \cdot 10^{-4}$	$1.2 \cdot 10^{-4}$ ÷ $0.6 \cdot 10^{-4}$	$1.2 \cdot 10^{-4}$ ÷ $0.6 \cdot 10^{-4}$

Number of ions - **1÷2 10^9**
Maximum possible rms bunch length is **9 m**
Rms momentum spread is below **$2 \cdot 10^{-4}$** in the total energy range

NICA collider parameters

Ring circumference, m	503,04		
Number of bunches	24		
Rms bunch length, m	0.6		
Beta-function in the IP, m	0.35		
Betatron tunes, Qx/Qy	9.44/9.44		
Ring acceptance	40 π·mm·mrad		
Long. acceptance, $\Delta p/p$	±0.010		
Gamma-transition, γ_{tr}	7.091		
Ion energy, GeV/u	1.0	3.0	4.5
Ion number per bunch	$2.75 \cdot 10^8$	$2.4 \cdot 10^9$	$2.2 \cdot 10^9$
Rms dp/p, 10^{-3}	0.62	1.25	1.65
Rms beam emittance, h/v, (unnormalized), π·mm·mrad	1.1/ 1.01	1.1/ 0.89	1.1/ 0.76
Luminosity, $cm^{-2}s^{-1}$	1.1e25	1e27	1e27
IBS growthe time, sec	190	700	2500



Beam storage at the experiment energy

1. RF barrier bucket system (RF1)
   allowing storage of the required beam intensity

2 1^{st} narrow-band RF system (RF2)
   operating at harmonics of revolution frequency corresponding to the bunch number; it provides the beam bunching.

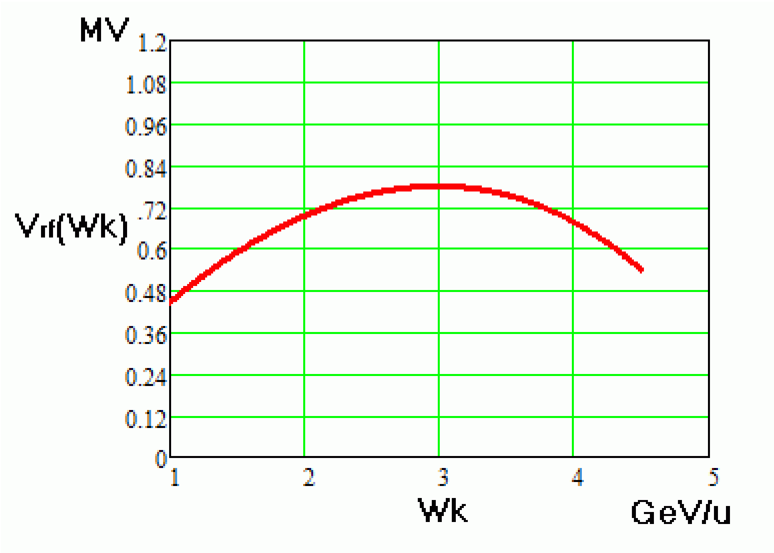
3 2^{nd} narrow-band RF system (RF3)
   operating at harmonics number larger than the 1^{st} one, that provides the bunch length necessary for collision experiments.

Choice of the RF3 harmonics number

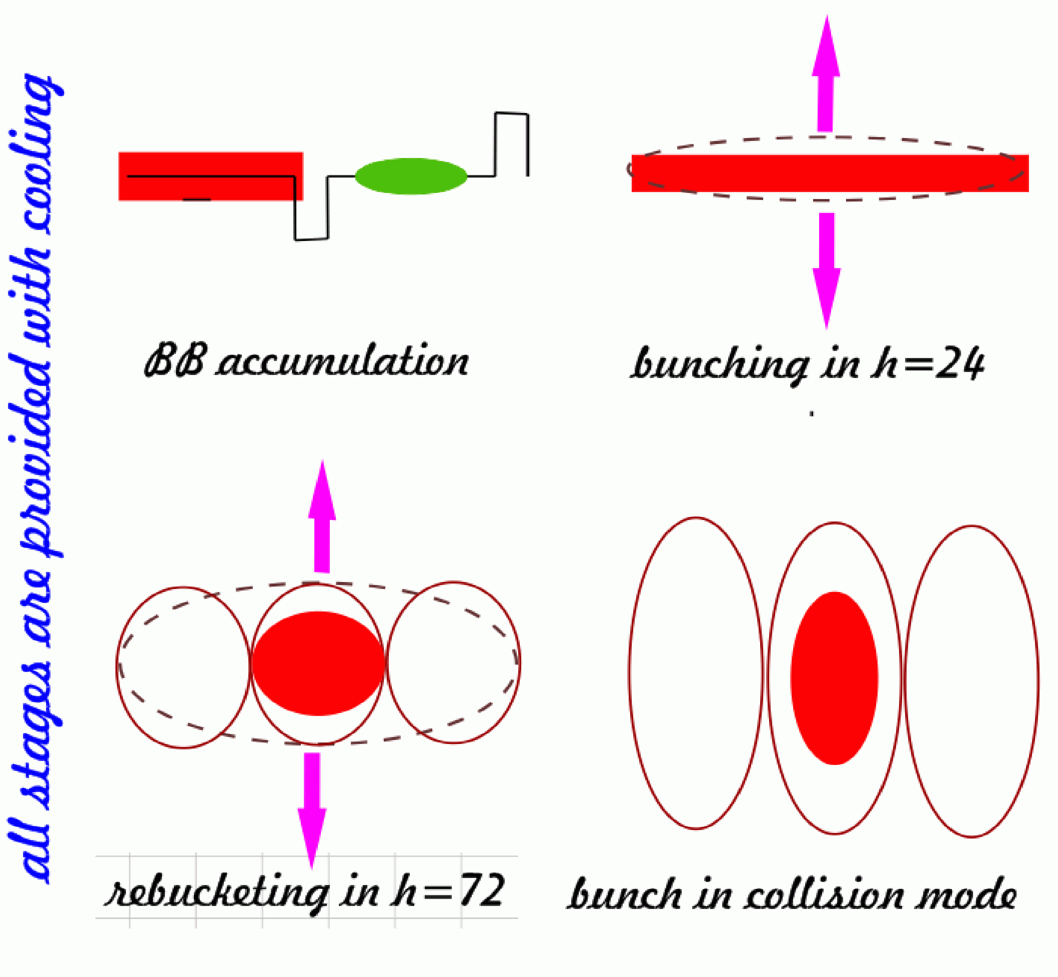
4.5 GeV/u, $\sigma_p = 1.7 \cdot 10^{-3}$

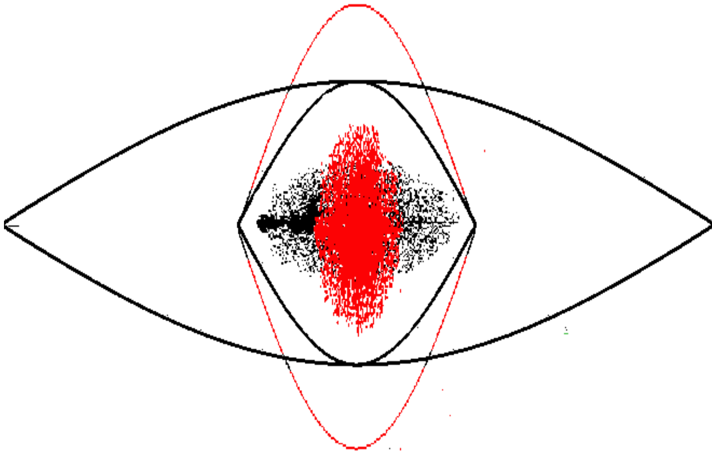
h3/h2	L_{bucket} in σ_s	V_{rf} (kV)	Hbucket in σ_p
1	±18 (±18.4)	1723 (325)	±11.46 (±11.7)
2	±9 (±9.2)	861 (162)	±5.73 (±5.85)
3	**±6**	**574**	**±3.82**
4	±4.5 (±4.6)	431 (81)	±2.86 (±2.92)
5	±3.6 (±3.7)	344 (65)	±2.29 (±2.33)

RF voltage at collision is defined now



RF cycle scheme in Collider





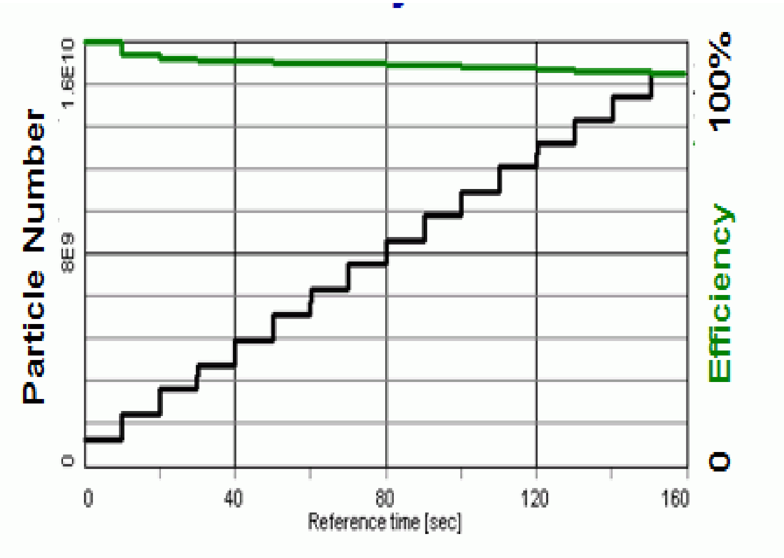
ESME simulation of rebucketing

Increase of accumulated particle number as a function of time

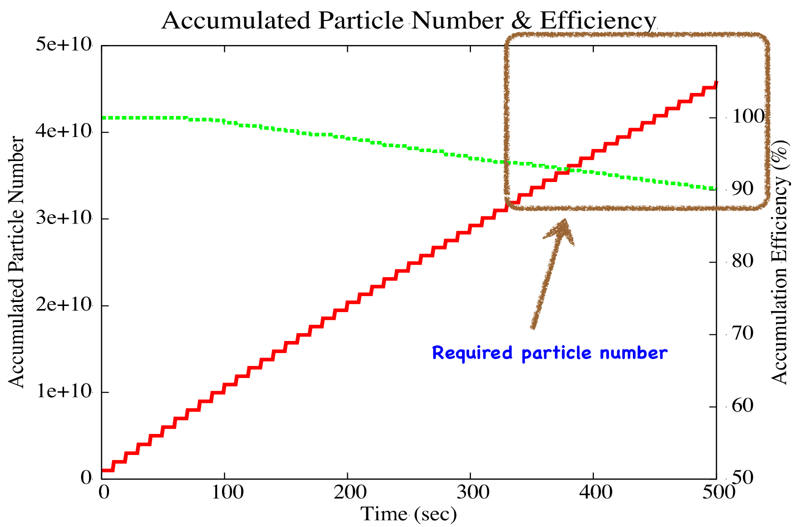
BETACOOL simulation (e – cooling). **E=1.5 GeV/u.** **Smirnov A.**

simulation of stochastic cooling. **E= 3.5 GeV/u.** **T. Katayama**

1.5 Gev/u



3.5 Gev/u



Accumulation process and its efficiency

E < 3 GeV/u:
Stacking with Electron cooling
Problem – cooling time strongly depends on energy and does not depend on bunching factor
The cooling power sufficient for experiment can be insufficient for effective stacking

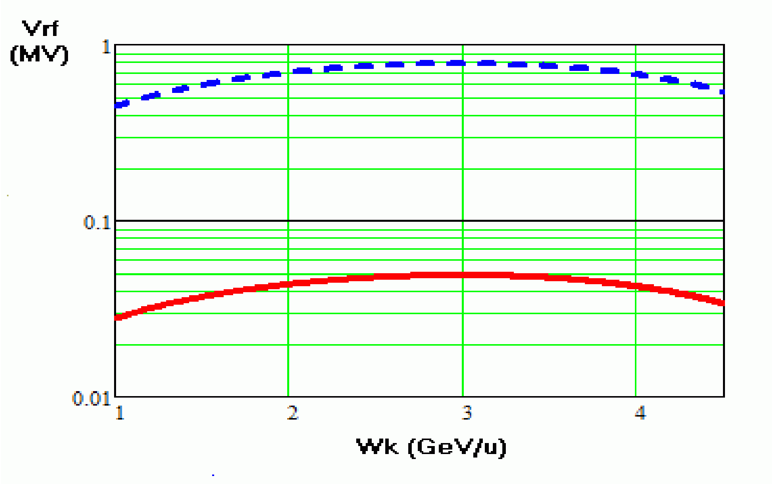
E > 3 GeV/u:
stacking with Stochastic cooling
The cooling time is proportional to the bunching factor
for “almost” coasting beam in BB the cooling times ~ 10 sec

RF2 voltage estimation

- At collisions the bunch **has to have** proper longitudinal emittance.
- Final emittance is lesser then starting one (after accumulation) by **5-13 times** over the whole energy range thus - **cooling**.
- Preparation of beam for collision occurs in two stages:
  - 1. Adiabatic voltage increase in RF2 (h=24). (Under cooling the bunch shrinks not only in its length but in emittance as well)
  - 2. Then the bunch length becomes short enough it is intercepted into RF3 (h=72). Adiabatic voltage increase is going on.

Question: What is the lowest possible voltage of RF2?

Answer: Emittance at interception must be equal to the final emittance and its length (±3σ) is just fitted into bucket of RF3.

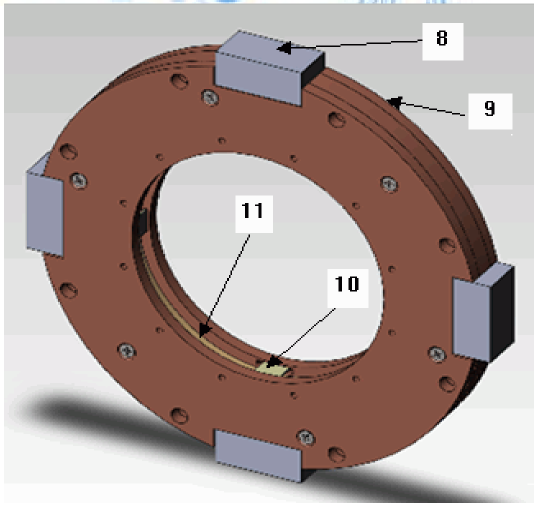


Although wide variety of scenarios is possible it is preferable to finish longitudinal emittance formation before RF3 starts working. In this case total voltage of RF2 can be limited by 50 kV.

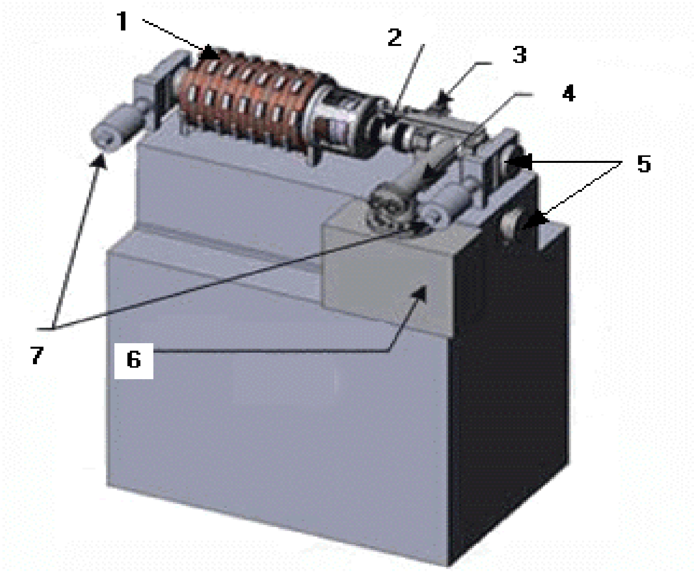
Main parameters of RF systems

	RF1	RF2	RF3
Frequency, MHz	BB	11.4-12.8	34.2-38.4
Total voltage amplitude, kV	**5 (2)**	**100 (50)**	**1000**
Voltage per resonator, kV	5	25	125
Number of resonators	1	4	8
Resonator length, m	0.8	1.1	1.1
Total length, m	**0.8**	**4.4**	**8.8**

Barrier Bucket cavity (preliminary design, BINP)



General view of BB station and design of a section of the inductive accelerator



1. **Induction accelerator. 2. Contactor within vacuum chamber. 3. Drive for contactor. 4. Manometric lamp. 5. Vacuum chambers. 6. Vacuum pump. 7. Gates. 8. Box of electronic keys. 9. Cover. 10. Excitation coil. 11. Amorphous iron coil**

Barrier pulse phase width – $\pi/6$ rad , voltage amplitude – ± 5kV.

14 rings from amorphous iron:

12 for rectangular barriers at 5 kV

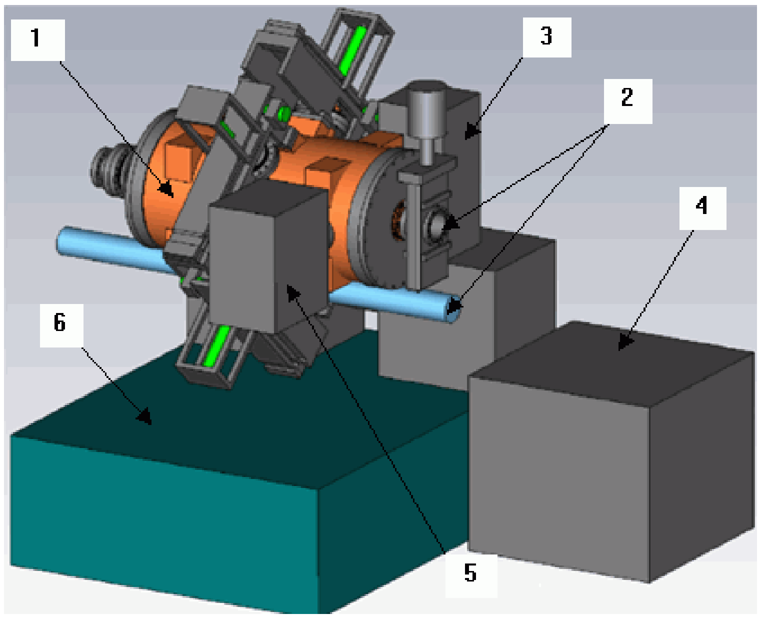
2 for acceleration at 300 V

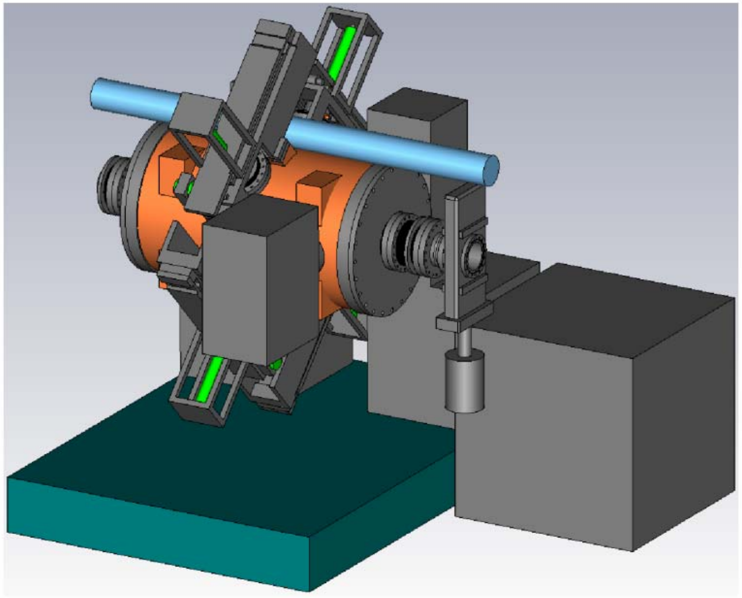
BINP team:

V.N. Volkov, E.K.Kenzhebulatov, G.Y. Kurkin, V.M. Petrov ….

RF2 and RF3 stations

General view of the accelerating resonators of RF2 and RF3 for the upper and lower collider ring





1. Resonator. 2. Vacuum chambers. 3. Generator. 4. Air cooling for generator. 5. Vacuum pump. 6. Stand

RF2 and RF3 stations

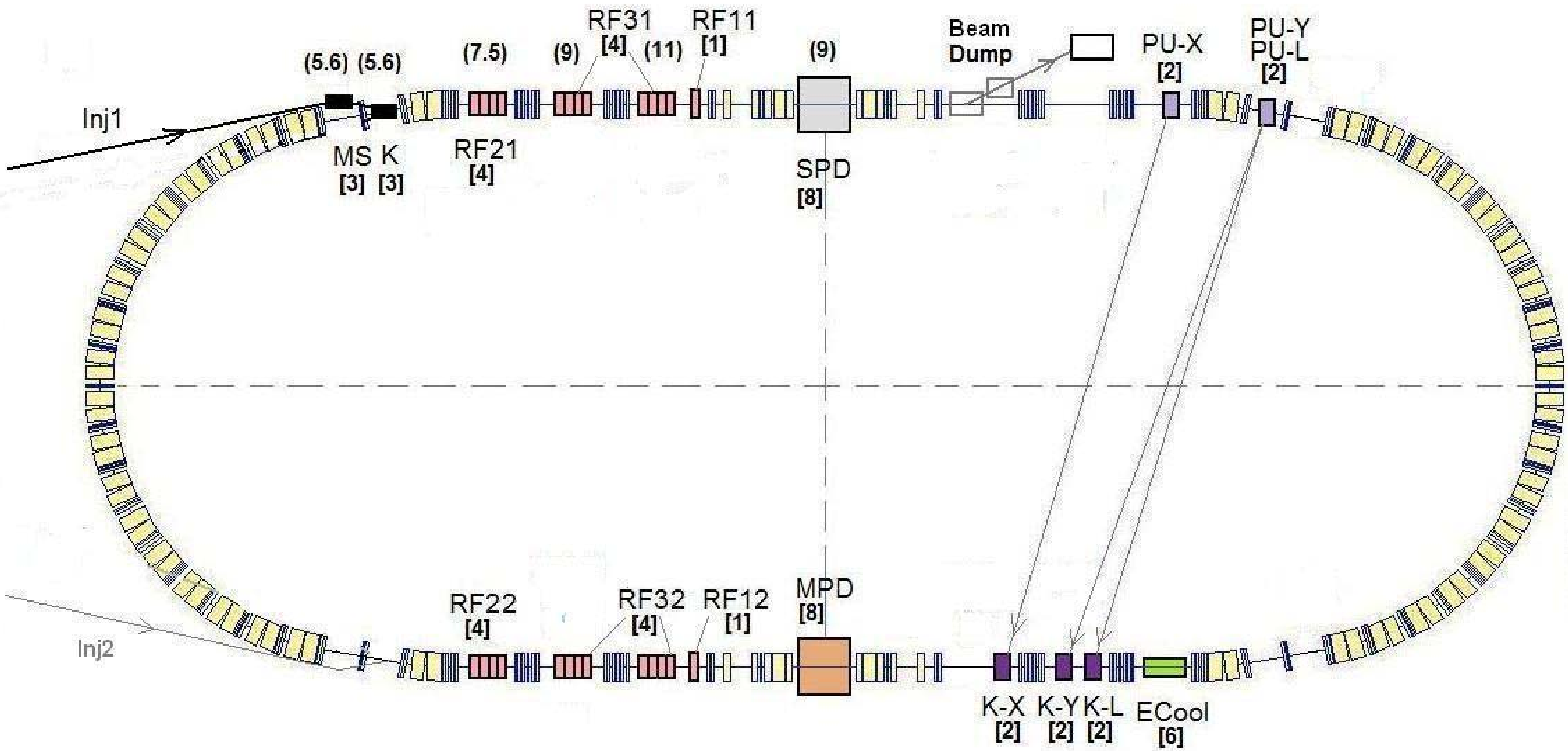
RF2

parameter	value
Working frequency	12.528 ÷14.088
quality	3570÷3750
Shunt impedance, kOhm	54.8 ÷65.0
Max. Voltage, kV	25
Max. power of RF losses, kW	4.8 ÷ 5.6
Dimensions, diameter/length, mm	520/760

RF3

parameter	value
Working frequency, MHz	37.584÷42.264
quality	5490÷5820
Shunt impedance, kOhm	252 ÷ 304
Max. voltage, kV	125
Max. power of RF losses, kW	32.1 ÷ 38.6
Dimensions, diameter/length, mm	520/760

Ring layout. Locations of RF1, RF2, RF3, e-cooler, stochastic cooler system.



Au(+79) ion mode

Acceleration in collider

Reasons for acceleration in the Collider:

- Significant dependence of the accumulation efficiency on the ion energy
- Saturation flux density of Nuclotron's magnets is about 1.8T while 4.5 GeV/u corresponds to 2.2 T.

1. Beam storage at small energy (below 2 GeV/u) with electron cooling
2. Slow acceleration (with RF1 (BB) or specialized RF0)
3. Bunching at the experiment energy

Design of BB resonator permits to create an accelerating "meander-type" voltage up to 300V amplitude. This implies acceleration rate at 0.024 T/s and acceleration time from 1 GeV/u to 4.5 GeV/u – 51 sec.

Conclusions

- 1. The presented scheme of the bunch formation based on three RF systems seems to be optimal.

- 2. The parameters of all RF systems are achievable with present-day technologies.

Thank you for attention