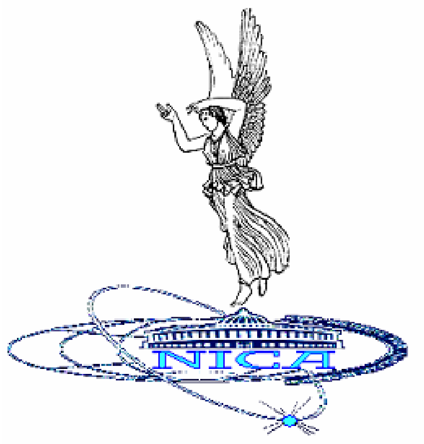
Nuclotron-based Ion Collider fAcility

I.N.Meshkov for NICA Working Group



Scientific Workshop Dedicated to
The Centenary of V. I. Veksler's Birth
and
the 50th Anniversary of
Commissioning the Synchrophasotron

Dubna, October 10-12, 2007

Contents

1. Introduction: "The Basic Conditions" for the Project development and some consequences

Development of the JINR basic facility for generation of intense heavy ion and polarized nuclear beams aimed at searching for the mixed phase of nuclear matter and investigation of polarization phenomena at the collision energies up to $\sqrt{s_{NN}} = 9$ GeV/u,
i.e. $^{238}U \times {}^{238}U$ *) in the energy range $1 \div 3.5$ (5) GeV/u.

The required average luminosity is $L_{average} = 1 \cdot 10^{27}\ \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$

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*) Changed to Au x Au recently

1. Introduction: "The Basic Conditions" for the Project development and some consequences (Contnd)

The Conditions:

1. Minimum of R & D

2. Application of existing experience

3. Co-operation with experienced research Centers

4. Cost – as low as possible
5. Realization time – 4 – 5 years

1. Introduction: "The Basic Conditions" for the Project development and some consequences (Contnd)

The Choice of Uranium nuclei as the basic particle for the project development allows us to meet all the necessary conditions for realization of

an ion-ion collider in a wide range of colliding nuclei

from p↑ to U.

1. Introduction: "The Basic Conditions" for the Project development and some consequences (Contnd)

The Concequences:

Choice of an existing building for dislocation of the collider

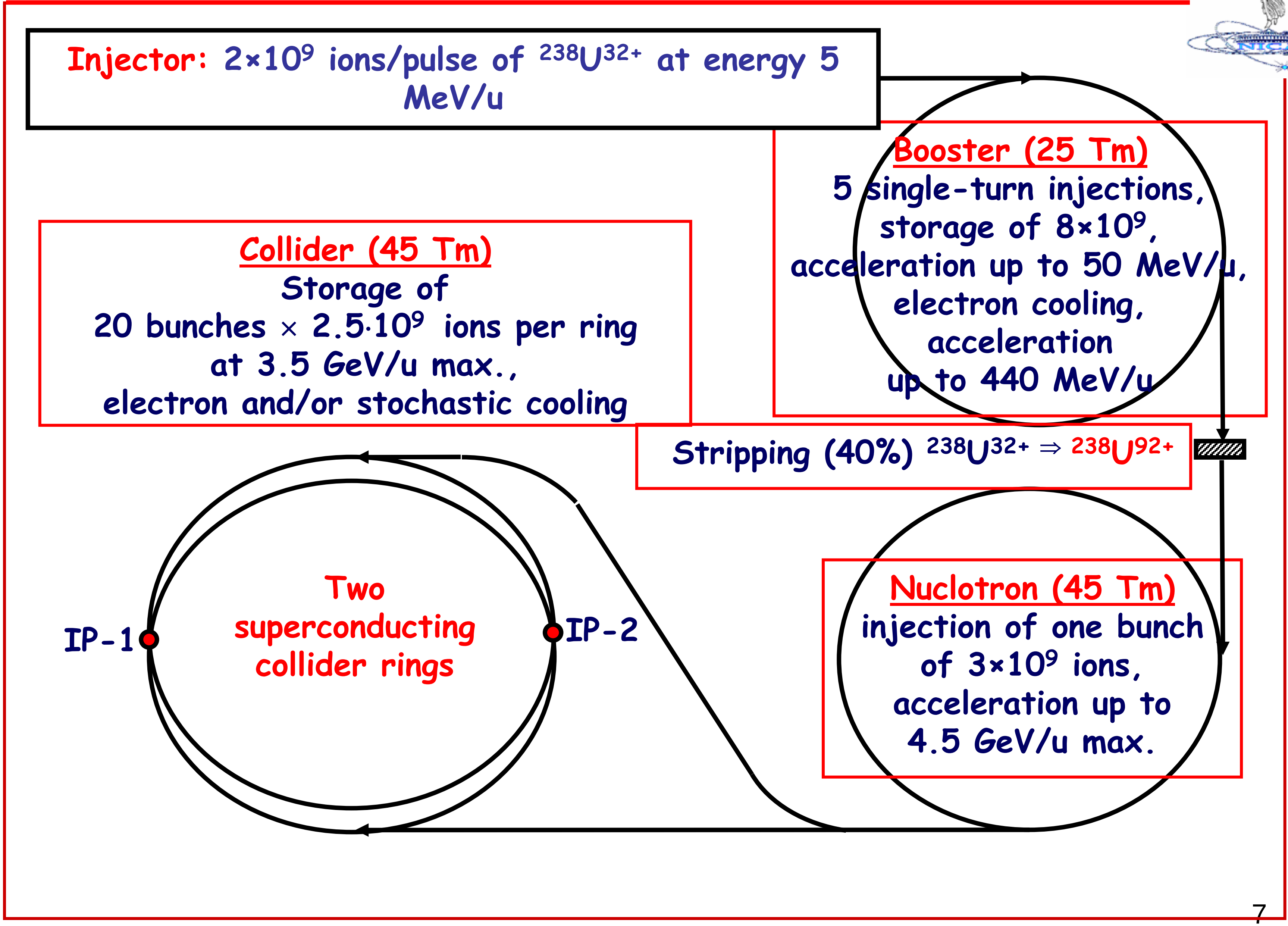
Collider perimeter is limited by ~ 250 m

Luminosity

High beam intensity,
multibunch regime,
low beta-function in Interaction Point,

……………………………………………………

2. NICA Scheme



Injector: 2×10^9 ions/pulse of $^{238}U^{32+}$ at energy 5 MeV/u

Booster (25 Tm)
5 single-turn injections,
storage of 8×10^9,
acceleration up to 50 MeV/u,
electron cooling,
acceleration
up to 440 MeV/u

Collider (45 Tm)
Storage of
20 bunches $\times$ $2.5\cdot10^9$ ions per ring
at 3.5 GeV/u max.,
electron and/or stochastic cooling

Stripping (40%) $^{238}U^{32+} \Rightarrow {}^{238}U^{92+}$

Two
superconducting
collider rings

IP-1

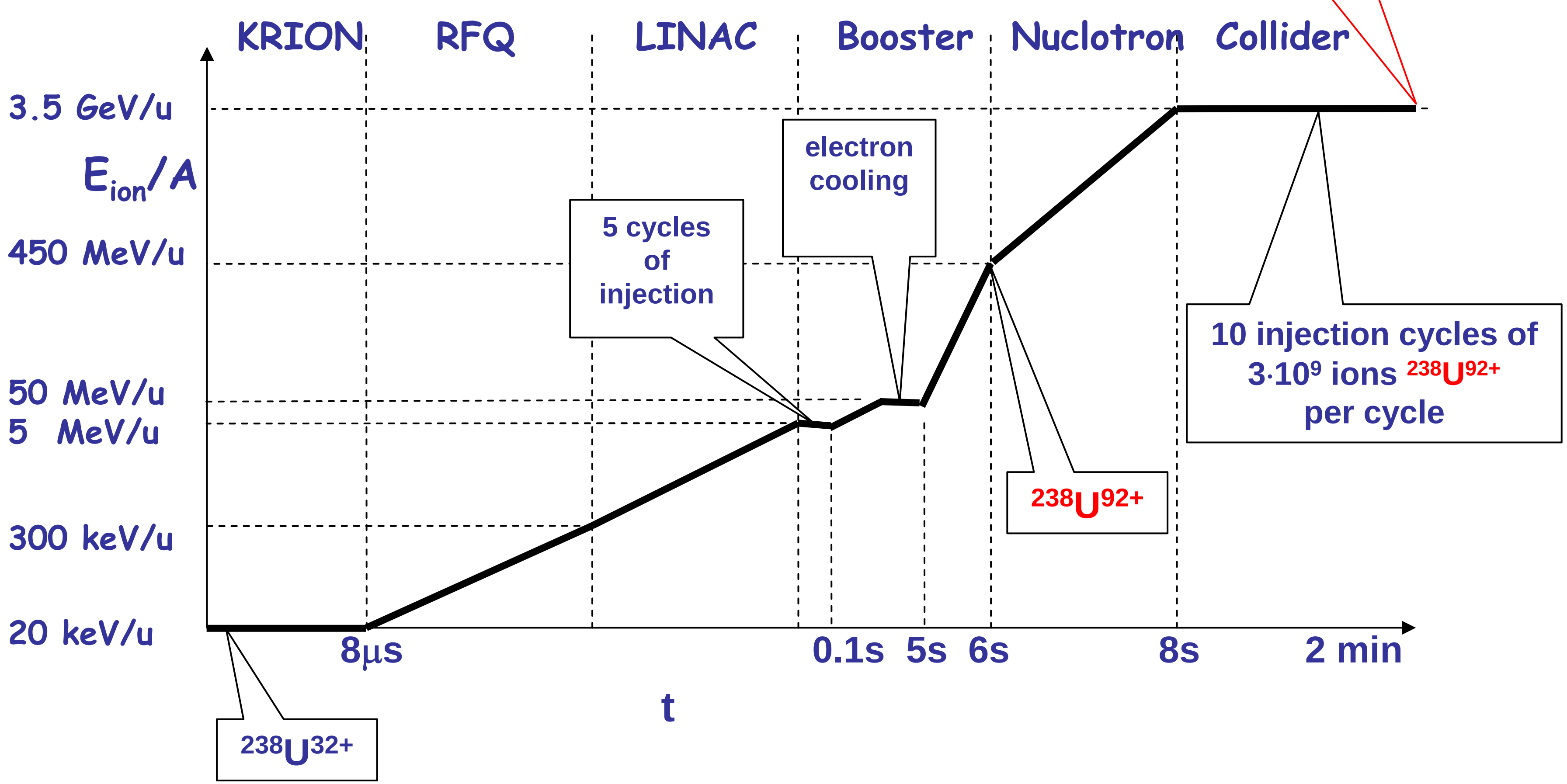
IP-2

Nuclotron (45 Tm)
injection of one bunch
of 3×10^9 ions,
acceleration up to
4.5 GeV/u max.

2. NICA scheme (Contnd)

$2 \times 3 \cdot 10^{10}$ ions of $^{238}U^{92+}$

Time Table of The Storage Proces



electron cooling

5 cycles of injection

10 injection cycles of $3 \cdot 10^9$ ions $^{238}U^{92+}$ per cycle

$^{238}U^{92+}$

$^{238}U^{32+}$

3. Collider General Parameters

Ring circumference, [m]	251.2
Bρ min/max (U92+), [T·m]	**14.6/45**
Ion kinetic energy, [GeV/amu]	1.0 ÷ 4.36
Dipole field, [T]	1.95 ÷ 5.5
Long straight sections number / length, [m]	2 x 48.3
Short straight sections number / length, [m]	4 x 9.66
Vacuum, [pTorr]	100 ÷ 10
RF harmonics amplitude, [kV]	70 150

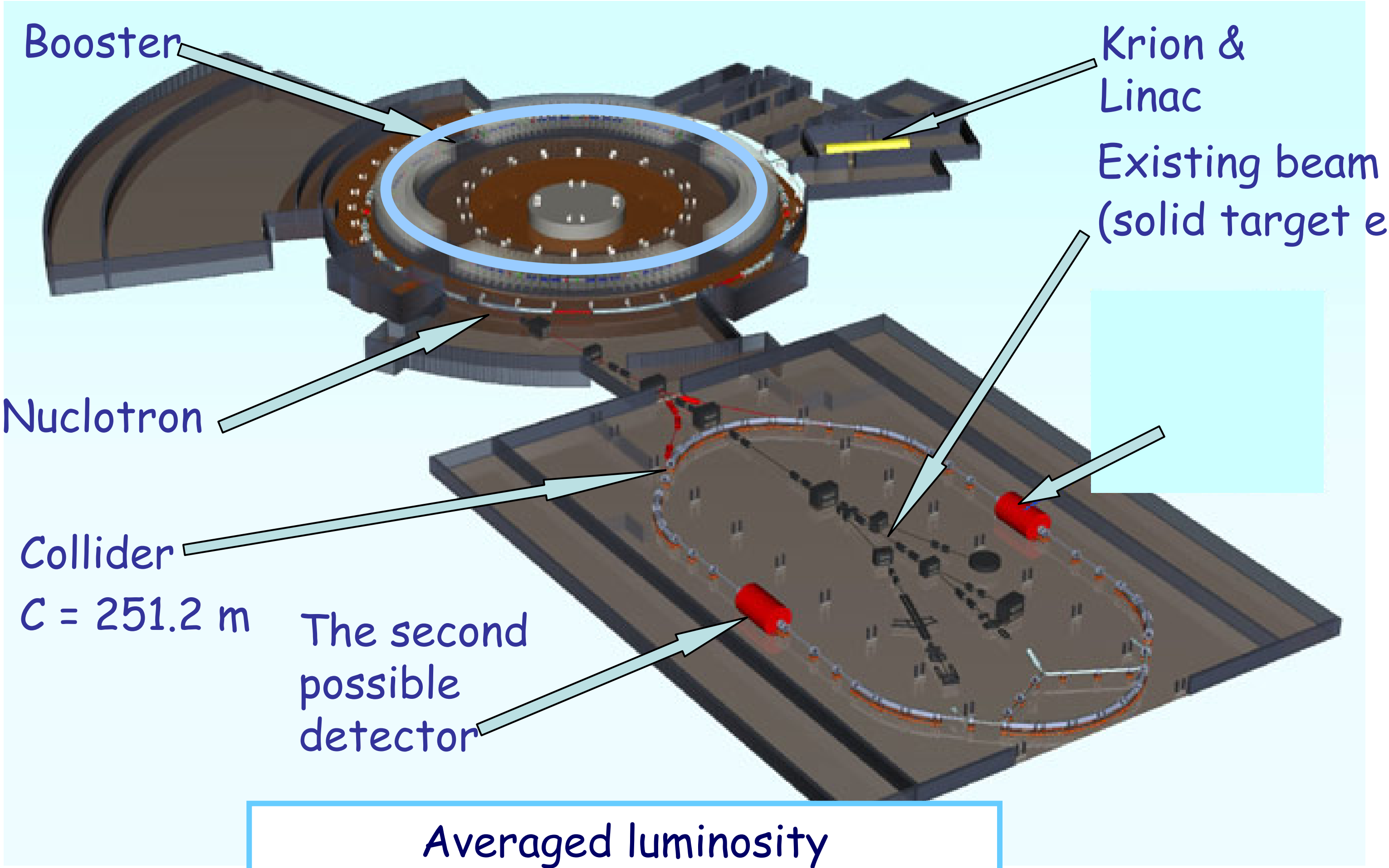
3. Collider General Parameters (Contnd)

Beam parameters and luminosity

Particle number per bunch, $N_{ion/bunch}$	3.0×10^9
Bunch length, m	0.33
Bunch nu	
Interbu	
Horizon	
Moment	
IBS life time [sec]	50 (to be increased)
Beta function at interaction point, β^*	0.5
Laslett tune shift, ΔQ	0.05
Beam-beam parameter	**0.009**
Peak luminosity (at 3.5 GeV/u), $[cm^{-2}s^{-1}]$	$\mathbf{2\times10^{27}}$
Average luminosity (at 3.5 GeV/u), $[cm^{-2}s^{-1}]$	$\mathbf{(1\div1.5)\times10^{27}}$

To cool, or not to cool?

4. NICA Layout



Booster

Krion &
Linac

Existing beam lines
(solid target exp-s)

Nuclotron

Collider

C = 251.2 m

The second
possible
detector

Averaged luminosity

$1.3 \cdot 10^{27}$ cm$^{-2} \cdot$s^{-1} ($^{238}U^{92+} \times {}^{238}U^{92+}$)

5. Collider Luminosity Limitations

1) Multibunch regime – storage and exchange “bunch by bunch”.

2) Bunch number is limited by parameters of
the injection/extraction system:
at realistic kicker pulse duration ~ 100 ns one can
have ⊙ 10 bunches/ring if $C_{collider}$ = 250 m.

3) Bunch intensity is limited by space charge effects:

“Lasslett tune shift” ⇒ ΔQ = 0.05 for $N_{ion/bunch} = 3 \cdot 10^9$, l_{bunch} = 0.33 m

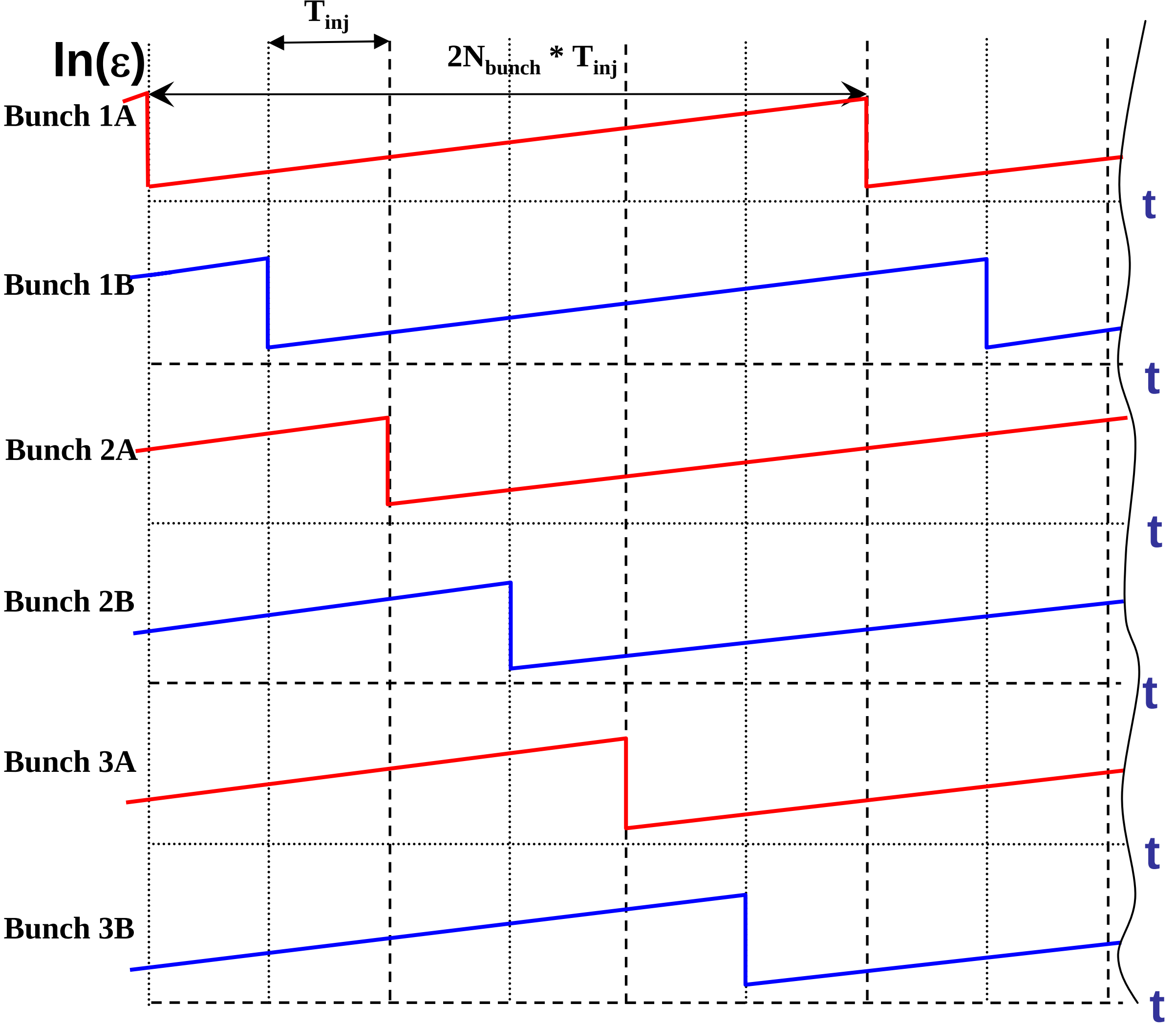
Beam-beam effect ⇒ ξ = 0.009 at the same bunch parameters ,

……

4) Ion life time and average luminosity

Ion storage – equilibrium regime (exchange of bunches "one by one")

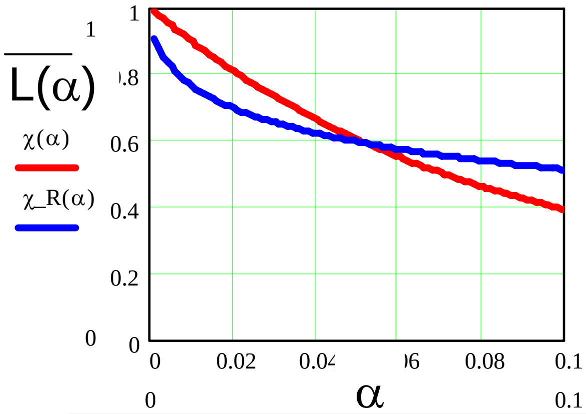
– bunch emittanse growth:



Average luminosity:

$$\overline{L} = L_{peak}\cdot\chi(\alpha),$$

$$\alpha = T_{inj}/\tau_{life}$$

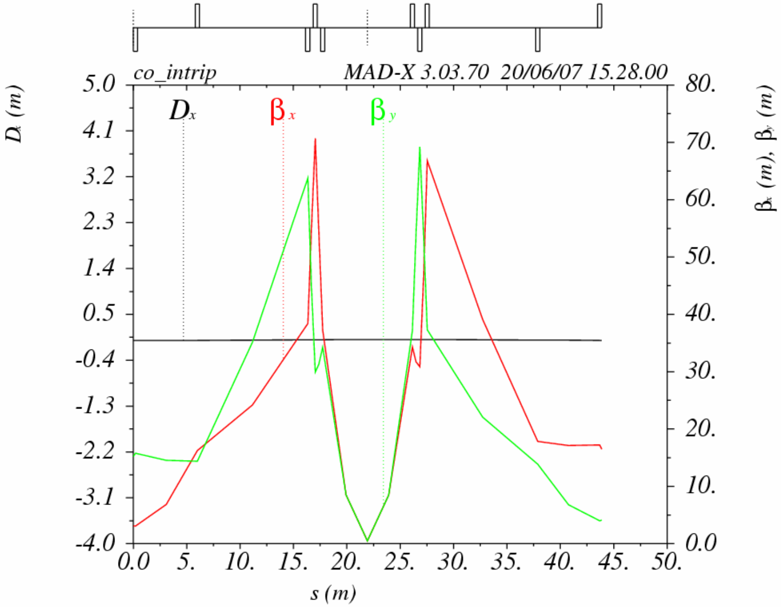


$$\boxed{\varepsilon(t) = \varepsilon_{min}\cdot exp\left(t/\tau_{life}\right)}$$

$$\boxed{\varepsilon(t) = \varepsilon_{min}\cdot\sqrt{1+t/\tau_{life}}}$$

5) Min β-function and hourglass effect

Optics & lattice function at IP



At l_{bunch} = 2 x 16.5 cm and β* = 50 cm we have

$$\frac{L}{L_{peak}} \geq \frac{\varepsilon_{min}}{\varepsilon_{max}} \sim \frac{\beta_{min}}{\beta_{min} + \frac{l_{bunch}^2}{\beta_{min}}} \sim 0.9$$

5. Collider Luminosity Limitations (Contnd)

6) Collider beam bunch length

$$l_{bunch} = 33 \text{ cm}$$

How to get it?

5. Collider Luminosity Limitations (Contnd)

6) Collider beam bunch length

The scenario of the short bunch formation:

1/ from injector ⇒ to booster, adiabatic capture in acceleration,

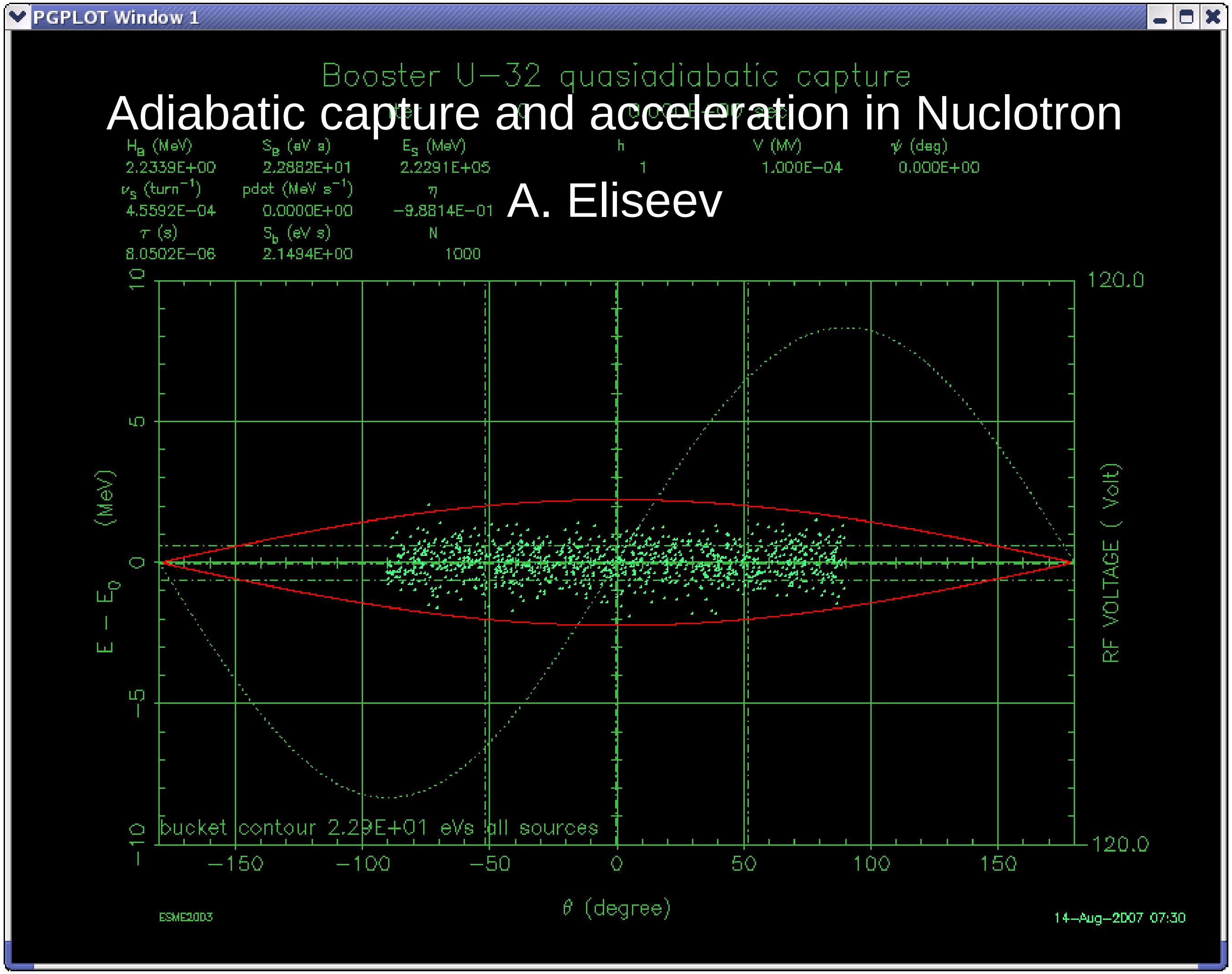
2/ from booster ⇒ to Nuclotron, adiabatic capture in acceleration,

3/ RF phase jump and “overtun” in phase space by “fast” increase of RF voltage,

4/ short bunch from Nuclotron ⇒ to collider.

5. Collider Luminosity Limitations (Contnd)

6) Collider beam bunch length (Contnd)



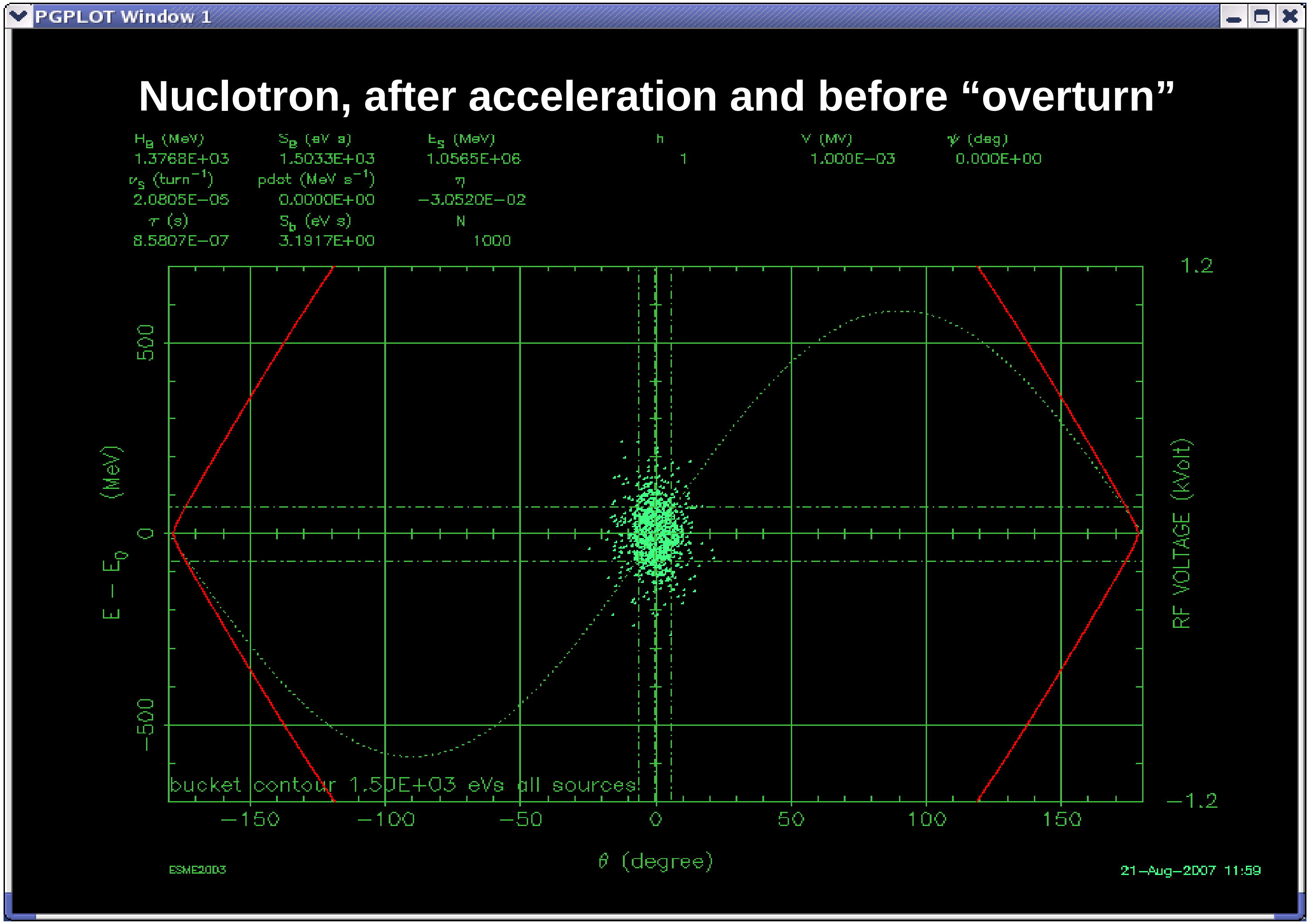
```
H_B (MeV)        S_B (eV s)        E_s (MeV)          h          V (MV)        ψ (deg)
2.2339E+00       2.2882E+01        2.2291E+05         1          1.000E-04     0.000E+00
ν_s (turn^-1)    pdot (MeV s^-1)   η
4.5592E-04       0.0000E+00        -9.8814E-01
τ (s)            S_b (eV s)        N
8.0502E-06       2.1494E+00        1000
```

Adiabatic capture and acceleration in Nuclotron

A. Eliseev

5. Collider Luminosity Limitations (Contnd)

6) Collider beam bunch length (Contnd)

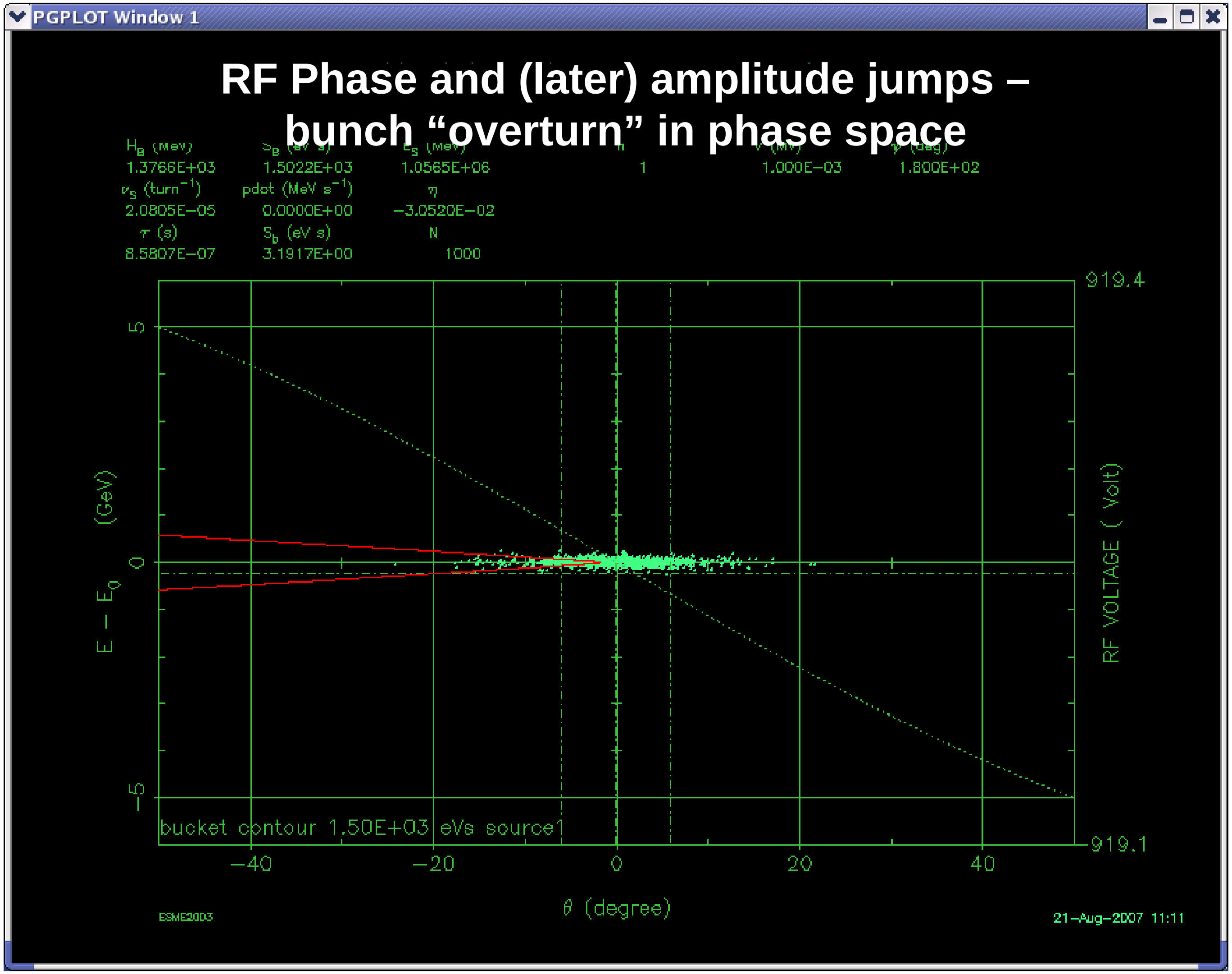


Nuclotron, after acceleration and before “overturn”

```
 H_B (MeV)      S_B (eV s)      E_s (MeV)               h            V (MV)        ψ (deg)
 1.3768E+03     1.5033E+03      1.0565E+06              1            1.000E-03     0.000E+00
ν_s (turn^-1)  pdot (MeV s^-1)      η
 2.0805E-05     0.0000E+00     -3.0520E-02
  τ (s)         S_b (eV s)          N
 8.5807E-07     3.1917E+00        1000
```

5. Collider Luminosity Limitations (Contnd)

6) Collider beam bunch length (Contnd)



RF Phase and (later) amplitude jumps – bunch "overturn" in phase space

```
 H_B (MeV)     S_B (eV s)     E_s (MeV)            h           V (MV)       φ (deg)
 1.3766E+03    1.5022E+03     1.0565E+06           1           1.000E-03    1.800E+02
ν_s (turn^-1)  pdot (MeV s^-1)    η
 2.0805E-05    0.0000E+00    -3.0520E-02
   τ (s)       S_b (eV s)         N
 8.5807E-07    3.1917E+00        1000
```

bucket contour 1.50E+03 eVs source1

ESME2003

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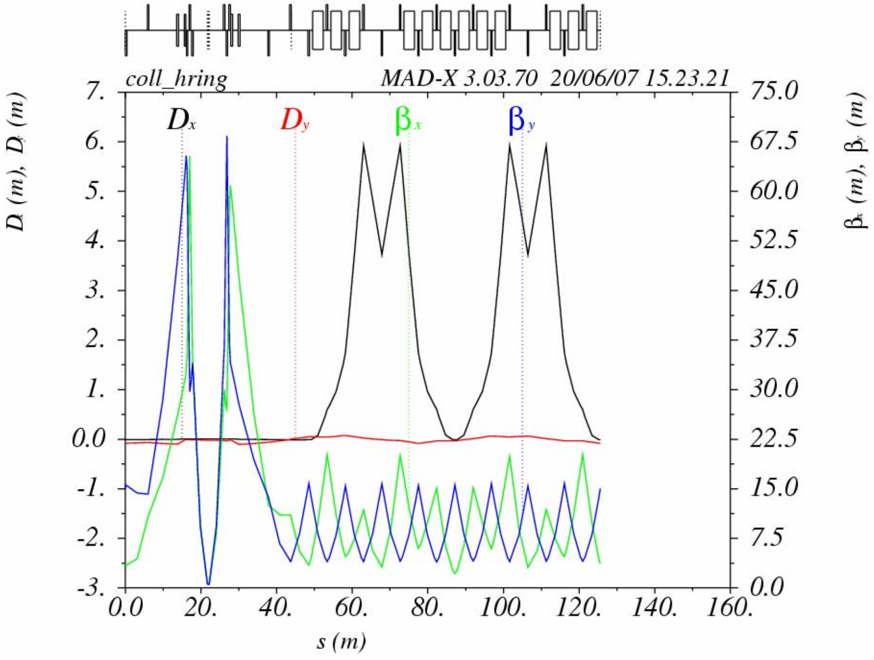
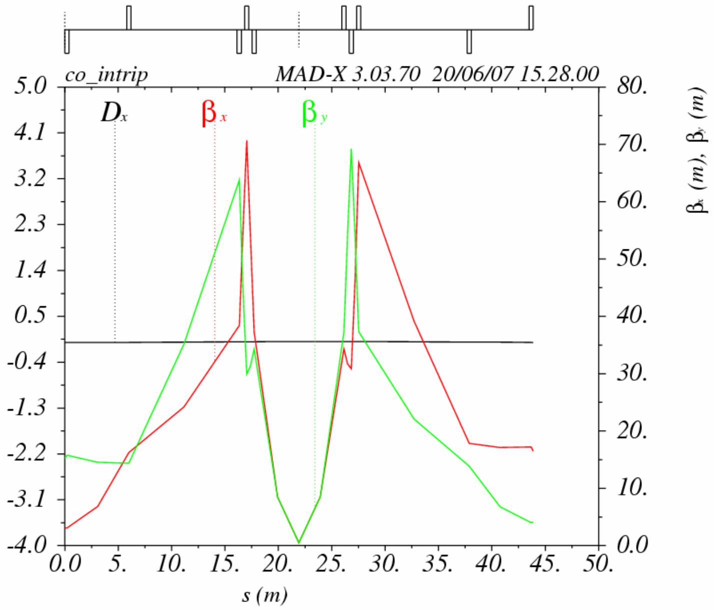
6. Collider ring optics and lattice functions

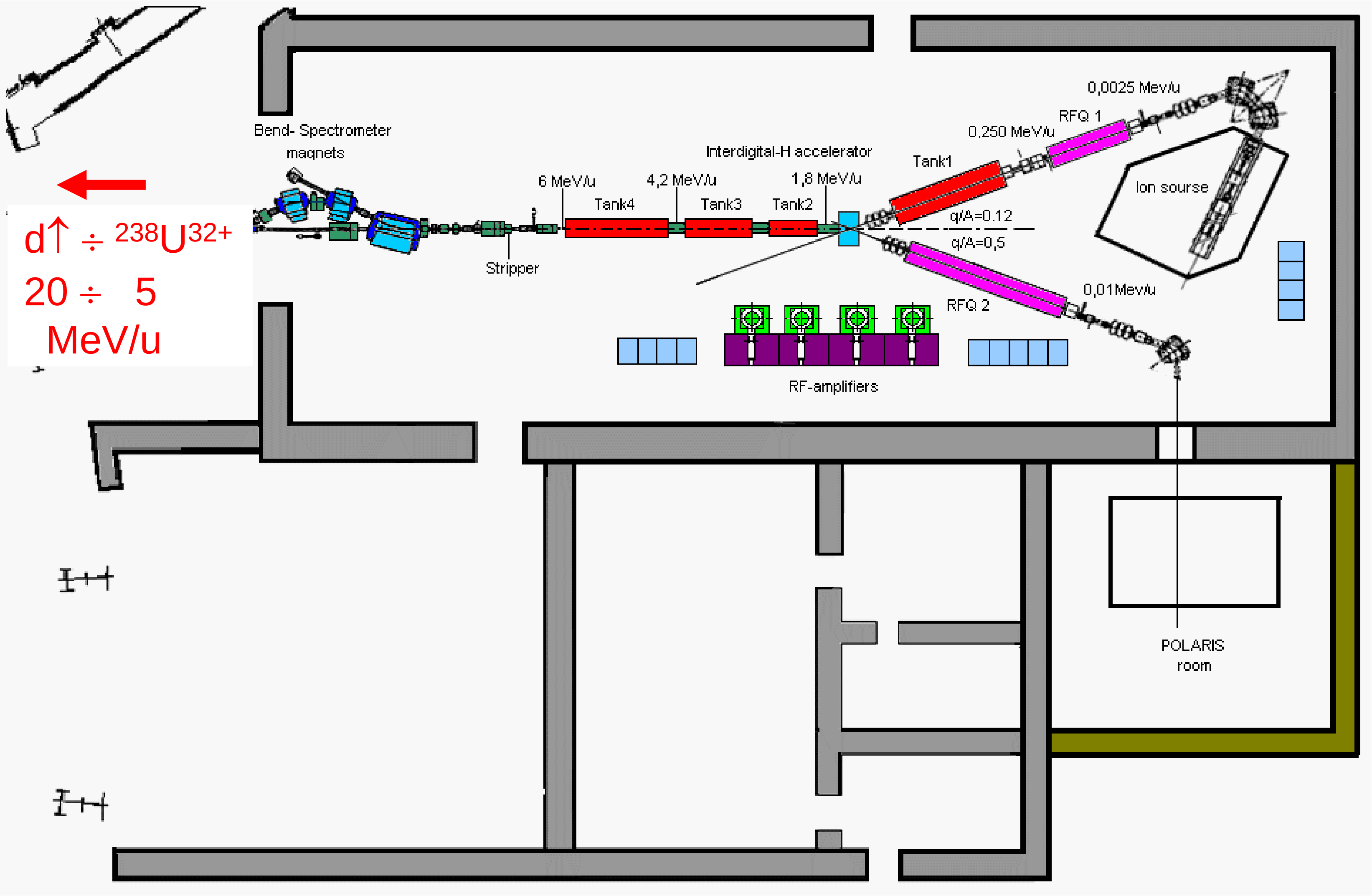
Superperiod and a bit longer…



Optics & lattice function at IP



7. Injector: Ion Source + Preinjector + Linac



d↑ ÷ $^{238}U^{32+}$

20 ÷ 5 MeV/u

Ion Source

Magnetic field 1.5 T ⇒ 3.0 (6.0) T,

ion number increase

Ion kind	Au30+ (U30+)		
Electron energy, E_e	25 keV		
Ionization factor, $j\tau$	6×10^{19} cm^{-2}		
Dependence of ion number on magnetic field	Version 1 $N_{e/i} \propto B$	Version 2 $N_{e/i} \propto B^2$	Version 3 $N_{e/i} \propto B^3$
Ionization time, τ Repetition rate	0.03 s 30 Hz	0.015 s 60 Hz	0.0075 s 120 Hz
Pulse width, t	8×10^{-6} s	8×10^{-6} s	8×10^{-6} s
Ion number per pulse, N_i	1×10^{9}	2×10^{9}	4×10^{9}
Ion current, I_i	0.6 mA	1.2 mA	2.4 mA

7. Injector: Ion Source + Preinjector + Linac (Contnd)

Ion Source (Contnd)

Ion Sources comparison

Ion source	KRION, Au^{30+}	ECR, Pb^{27+}
Peak ion current, mA	1.2	0.2
Pulse duration, μs	8	200
Ions per pulse	2×10^{9}	1×10^{10}
Ions per μsec	2.5×10^{8}	5×10^{7}
Norm. rms emittance	0.15÷0.3	0.15÷0.3
Repetition rate, Hz	60	30

Crucial parameter: Ions per μsec!

Thus, KRION has very significant advantage!

Preinjector + Linac

Injector concept

KRION suspended up to 200 kV

RFQ preaccelerator

Linac (unique design, “H-wave” type)

Parameters

Ions	$d\uparrow \div {}^{238}U^{32+}$
Energy at exit	5 MeV/amu
Length	25 m

Negotiations at IHEP (Protvino)

21-22 June 2007

August 2007: an agreement achieved

October 2007: project development has been started!

8. Booster

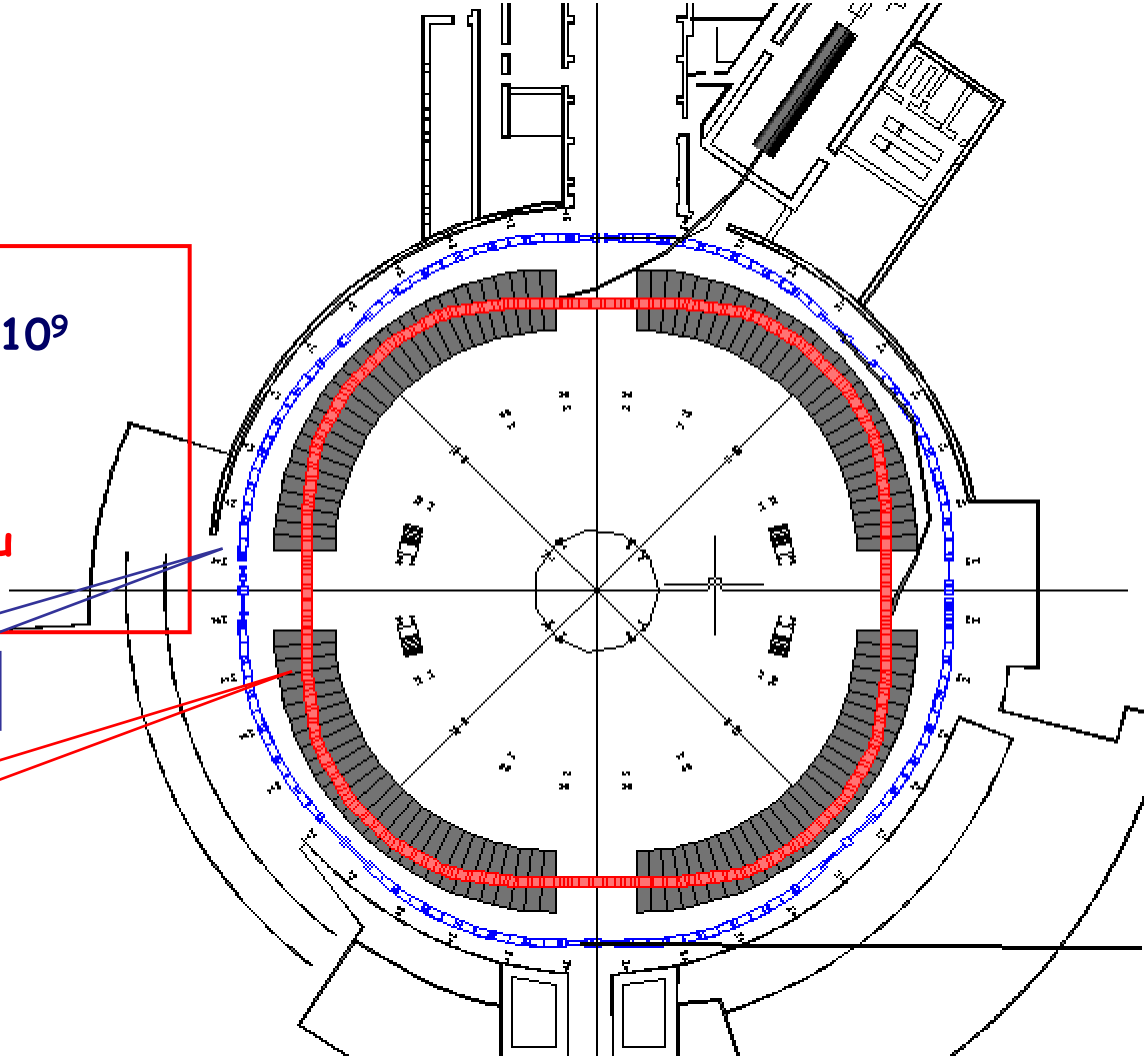
“Warm” booster

on basement

of The Synchrophasotron

$B\rho$ = 25 T·m, B_{max} = 1.8 T

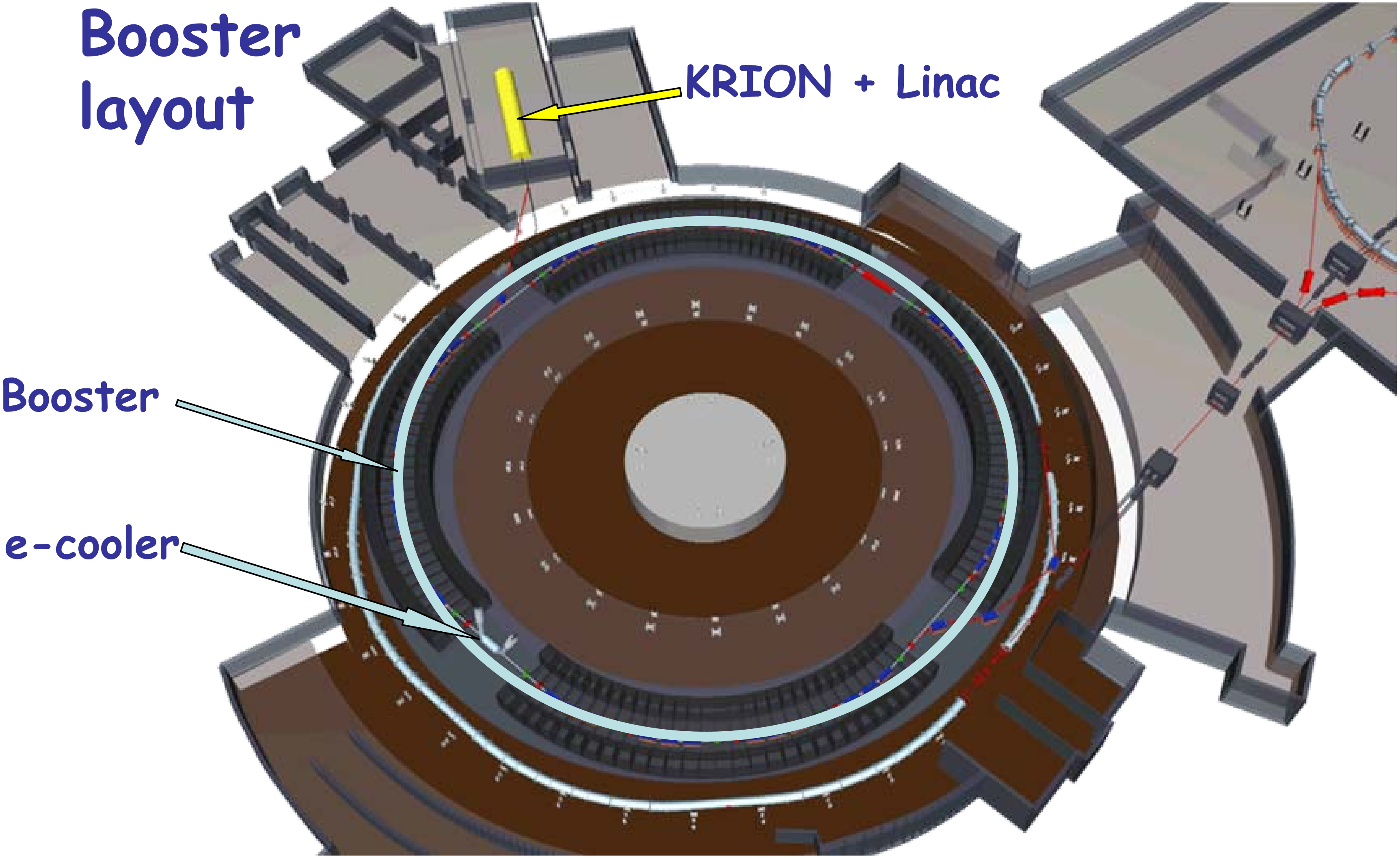
1) 5 single-turn injections of 8×10^9 $^{238}U^{32+}$
2) electron cooling
3) bunching
4) Acceleration up to 440 MeV/u
5) Extraction & stripping



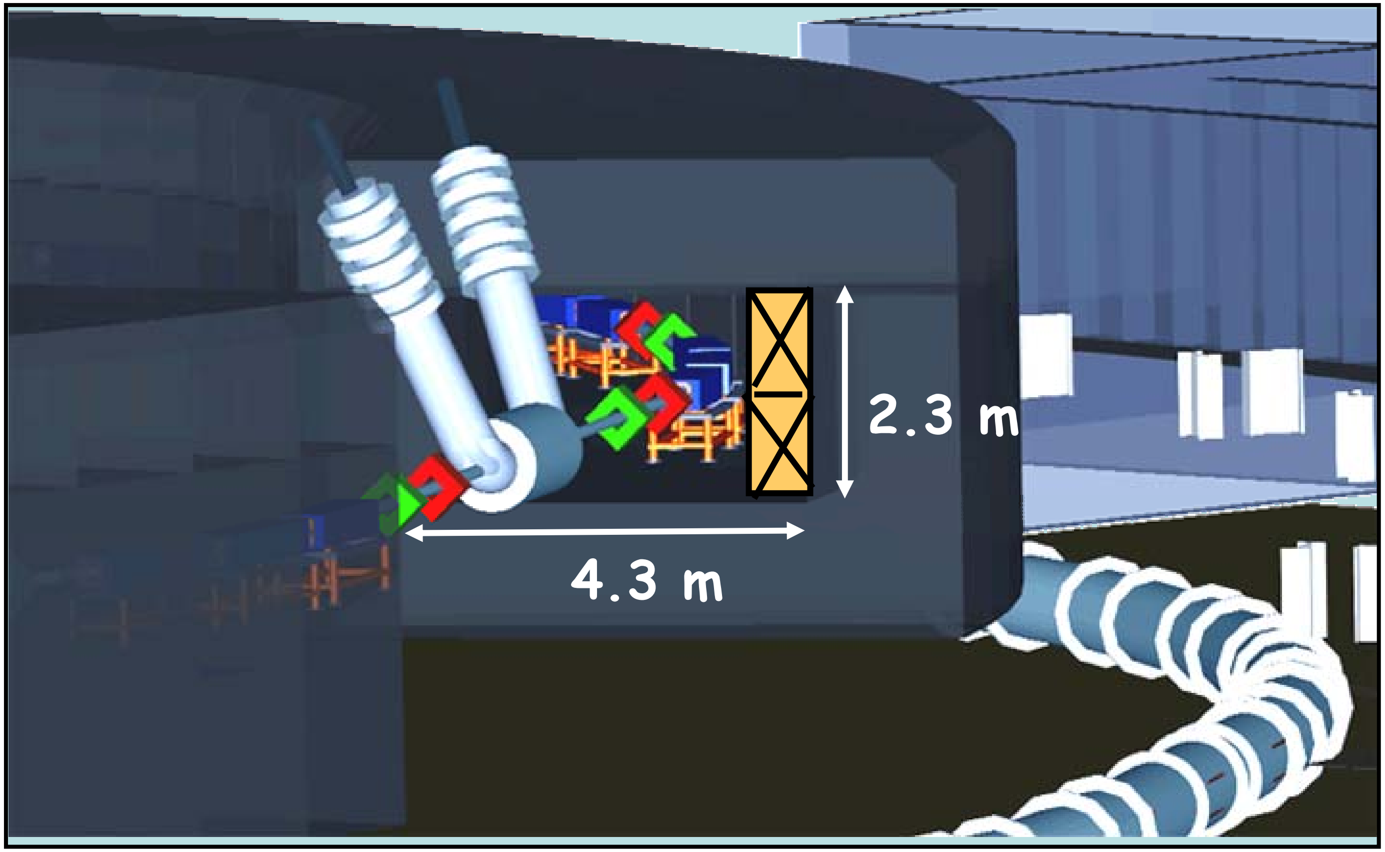
8. Booster (Contnd)

Main Booster parameters	
Circumference	210 m
Injection energy U^{30+}	5 MeV/u
Maximum energy U^{30+}	440 MeV/u
Maximum dipole field	1,8 T
Vacuum	10^{-11} Torr

8. Booster (Contnd)



Booster Location in "The Belly" of The Synchrophasotron



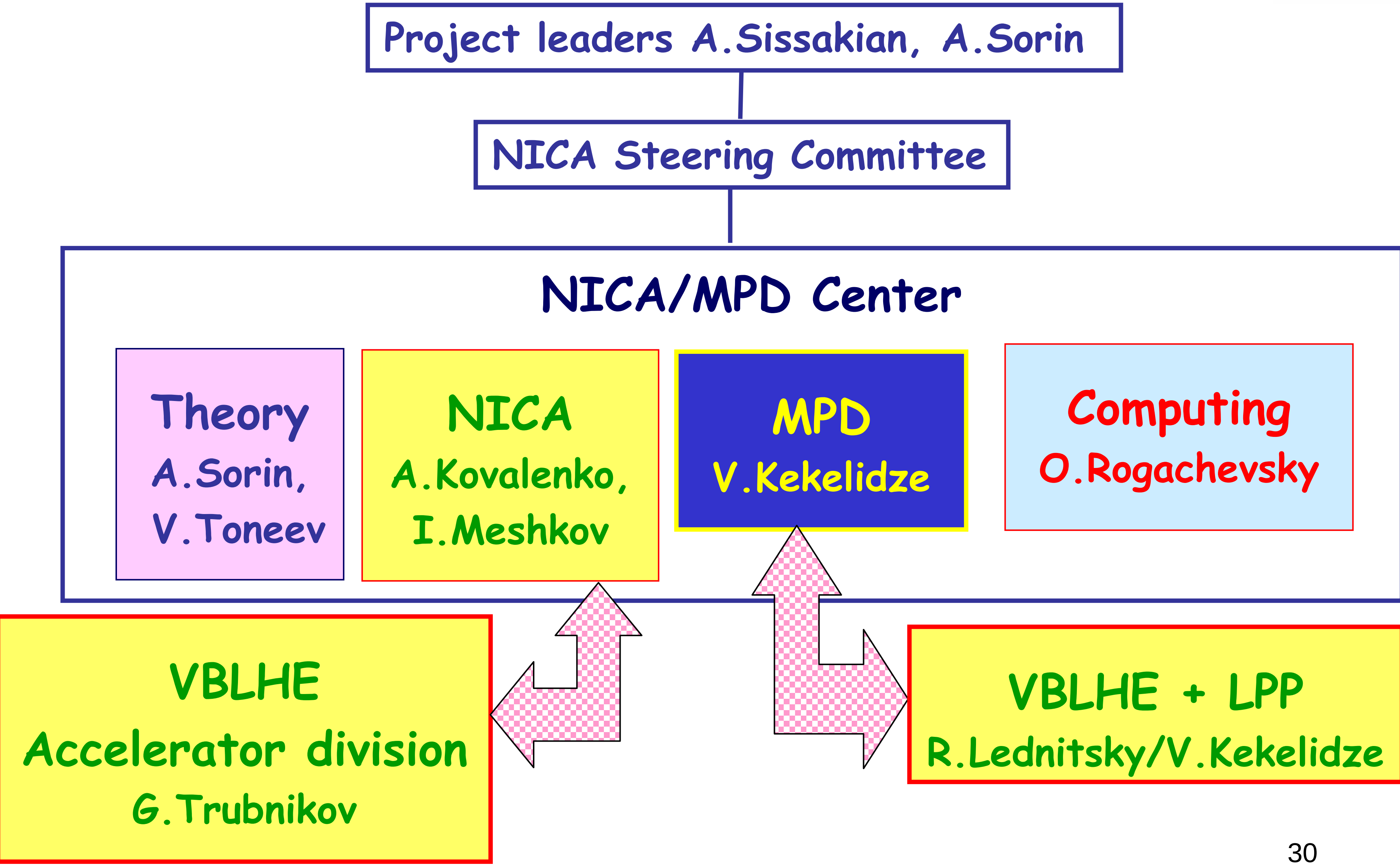
9. Cost Estimate ($M)

But! Infrastructute ⇒ ~ 17 !

KRION + HV “platform”	0.25
Injector (IHEP design)	10
Booster	8
Collider	2 x 10
Total	**~ 40**

One year budget of JINR

10. Project Work Organization



Project leaders A.Sissakian, A.Sorin

NICA Steering Committee

NICA/MPD Center

Theory
A.Sorin,
V.Toneev

NICA
A.Kovalenko,
I.Meshkov

MPD
V.Kekelidze

Computing
O.Rogachevsky

VBLHE
Accelerator division
G.Trubnikov

VBLHE + LPP
R.Lednitsky/V.Kekelidze

11. Project Milestones

Stage 1: 2006 - 2008

February 2006 – 1st Round Table ⇒ Physics of the mixed phase

October 2006 – 2d Round Table ⇒ Accelerator & Detector concepts

October 31, 2007 – CDR

November 2007 – start of TDR (or EngDR)

January 2008 – 3d Round Table

2008 – TDR completion,
beginning of the Booster manufacturing

11. Project Milestones (Contnd)

Stage 2: 2008 - 2012

- Design and Construction of NICA (Injector, Booster, Collider) and MPD detector
- Infrastructure development

Stage 3: 2010 – 2012

Facility and Detector assembling

Stage 4: 2013

Commissioning, beginning of operation

12. News from RHIC: Low-energy RHIC operation

A.Fedotov, BNL (Talk at COOL'07 September 14, 2007)

RHIC heavy ion collisions at $\sqrt{s_{NN}}$= 5-50 GeV/u

↓

Au beams in RHIC at $E_{kin} \approx 1.5 \div 24.0$ GeV/u
(Workshop at BNL, March 9-10, 2006):

"Can one discover the QCD critical point at RHIC?"

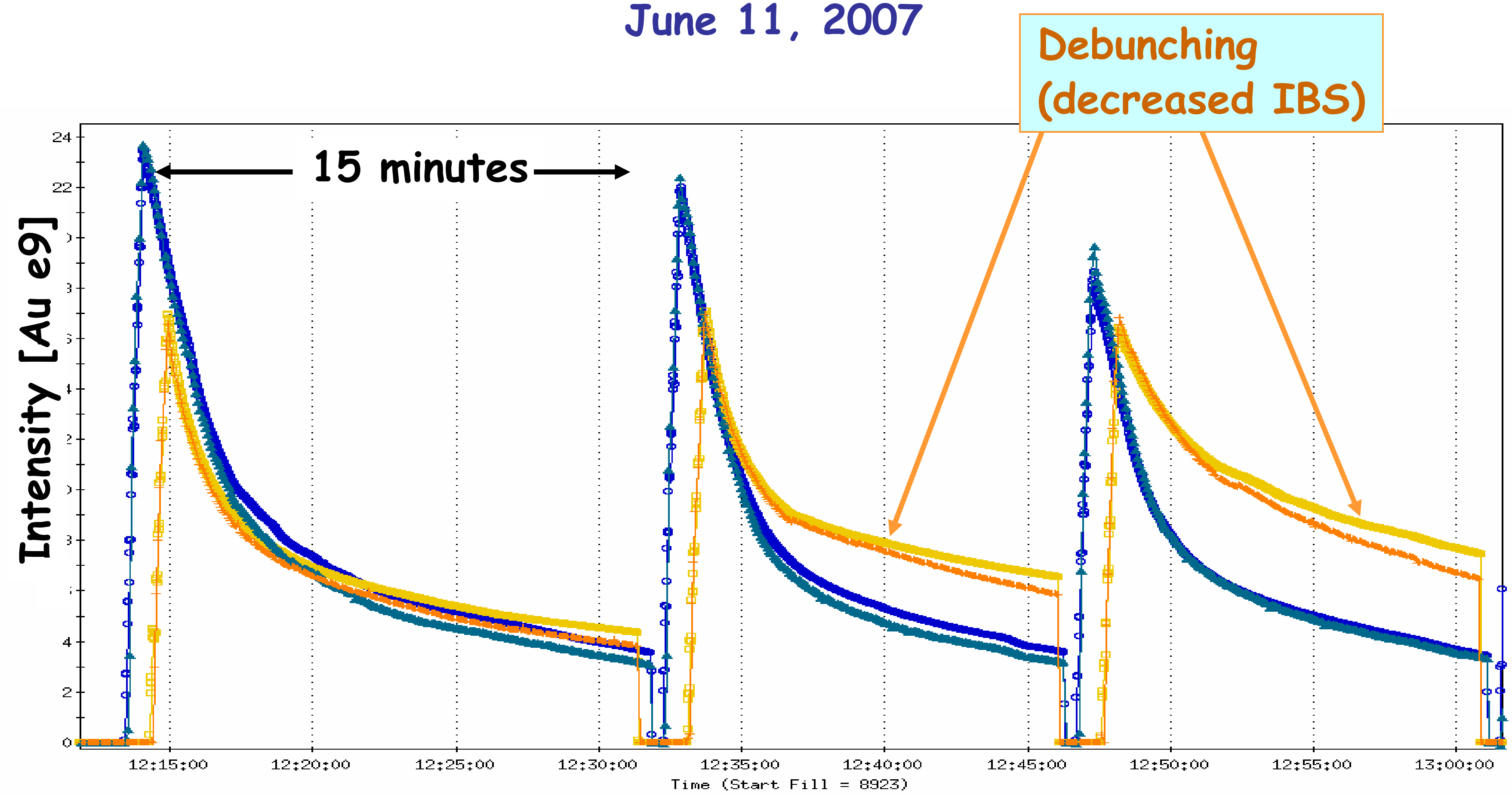
Suggested energy scan: $\sqrt{s_{NN}}$ = 5, 6.3, 7.6, 8.8,
12.3, 18, 28 GeV/u.

Two 1-day test runs were done in 2006 and 2007 at low-energies.

12. News from RHIC (Contnd)

Test Run at $\sqrt{s_{NN}}$ = 9.2 GeV/u (Ekin ≈ 3.5 GeV/u)

June 11, 2007



Debunching
(decreased IBS)

T. Satogata et al. PAC07

RHIC Low Energy Program Plans

RHIC low-energy operation is challenging:
RF acceptance, IBS, vertex, etc.

Tests of low-energy operation were successful:

- At $\sqrt{s_{NN}}$=9.2 GeV/n Beam-Beam Collisions rates of 100-700 Hz in STAR has been achieved;
- Peak luminosity was about 1.5×10E24 $cm^{-2} \cdot s^{-1}$

12. News from RHIC (Contnd)

RHIC Program Advisory Committee recommended 14 weeks operation in 2010:

- Obtaining minimum requested 5M events per energy point seems feasible.

- Obtaining higher statistic > 50M (already requested by some of the experiments) in the future may be produced with electron cooling in RHIC at these energies.

12. News from RHIC (Contnd)

Developments:

- No RHIC upgrades with e-cooler in RHIC is presently planned on this time scale… regardless the fact

- Concept of high energy electron cooler is under development at RHIC since ~ 2002.

- Application of transverse*) stochastic cooling of bunched beams on experiment energy is considered as a task of first priority.

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*) longitudinal stochastic cooling of bunched beams has been demonstrated at BNL in 2005.

13. NICA again

To cool! Why not?

If to cool ⇒ electron or stochastic cooling?
That's a question!

Our choice: stochastic cooling - longitudinal and transverse ones. Challenging, but promising:

$$\tau_{IBS} \geq 1000 \text{ sec!}$$

But - R&D is required!

13. NICA again (Contnd)

What further?

A fantasy, just a bit …

Asymmetric (by ion species) collider ⇒ $d\uparrow \times U$

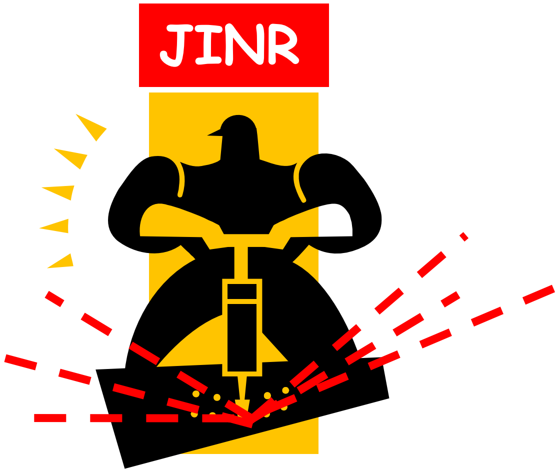
Electron-ion collider ⇒ DELSY facility!

$I_e = 10$ mA ⇒ $L \sim 2{\cdot}10^{30}$ $cm^{-2}{\cdot}s^{-1}$!

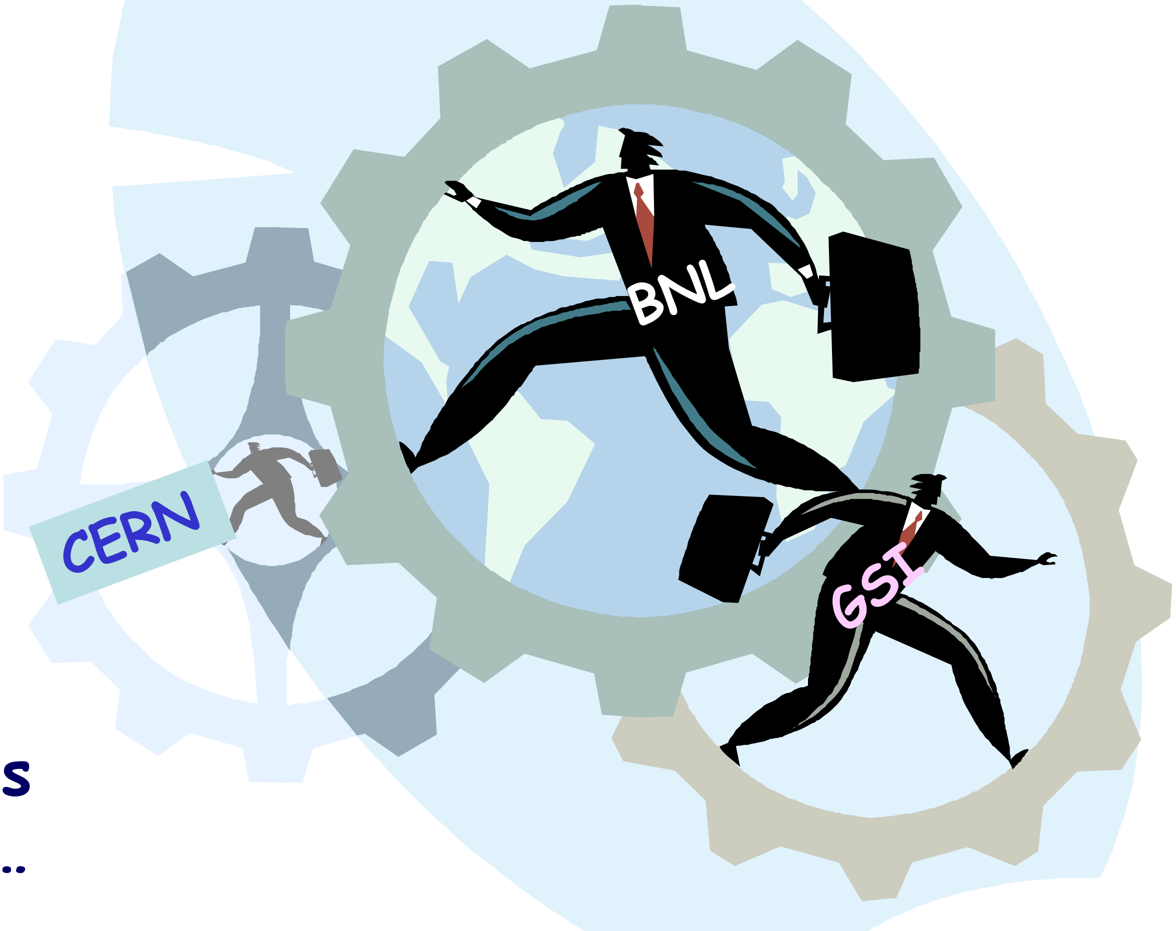
Conclusion

With NICA project JINR joins community of three labs, which perform (or plan to perform) studies of MP in excited nuclear matter,…

…the project will develop further …



…the pioneering ideas outspoken at JINR …



Conclusion

… and extend our knowledge…

… beyond "the horizon"…

Conclusion

Лучшая память об Учителе –
– его идеи, развитые его учениками.

Thank you for your attention