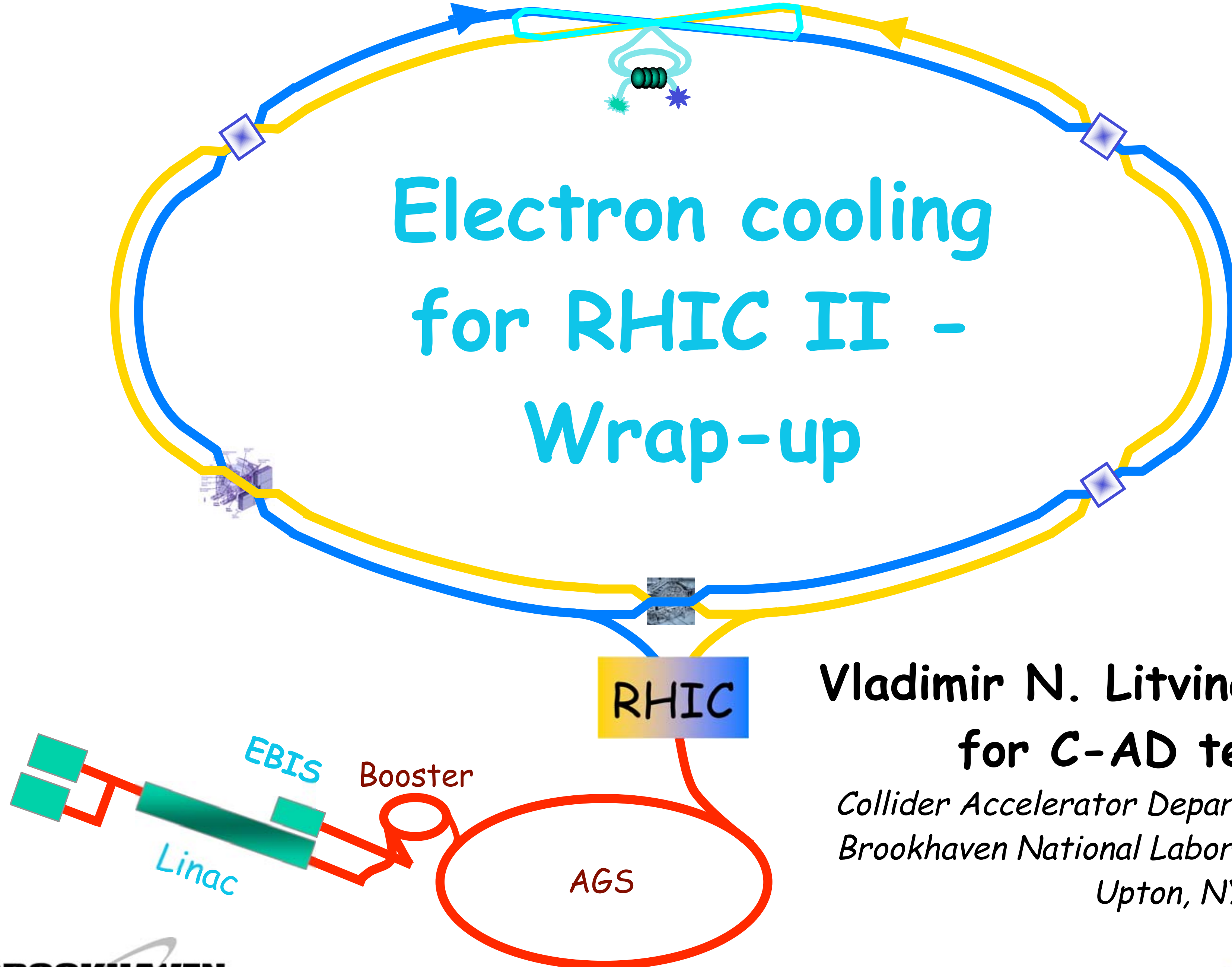
Electron cooling for RHIC II - Wrap-up



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RHIC

Outline

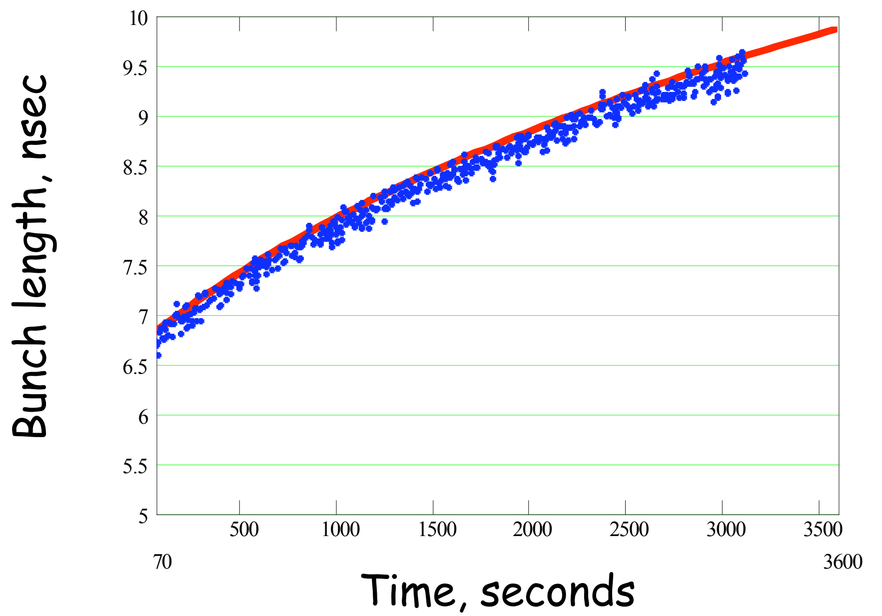
- Understanding of IBS at RHIC
- Face to Face comparison:
  - Electron cooling: classical (non-magnetized) vs. magnetized,
  - Requirements on the beam parameters
- Margins for errors :
  - Low IBS lattice of RHIC -> IBS / 2
  - Longer straights and larger β's -> Cooling x 2
  - Larger charges per bunch -> Cooling x 1.8
- R&D ERL - *a tool to learn*
  - Status of design, construction and assembly
  - Study plan
- Comments on using single ERL to cool two RHIC beams
- Conclusion

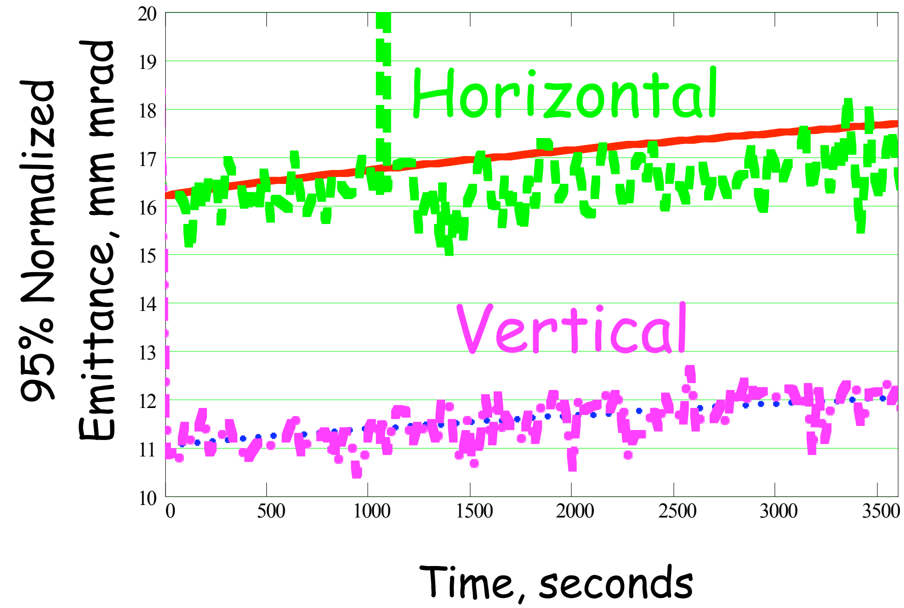
Understanding IBS at RHIC

- A set of dedicated comprehensive IBS measurements had been done during two RHIC runs using Au and Cu ions
- We plan to continue the IBS studies and also to finalize the development of low IBS lattice
- Our predictions are in good agreement with the measurements within uncertainty of the current instrumentation
- We know IBS rate with accuracy much better than ±50%
- New beam emittance measuring instrument is in the process of installation and test

IBS for run with Cu-ions

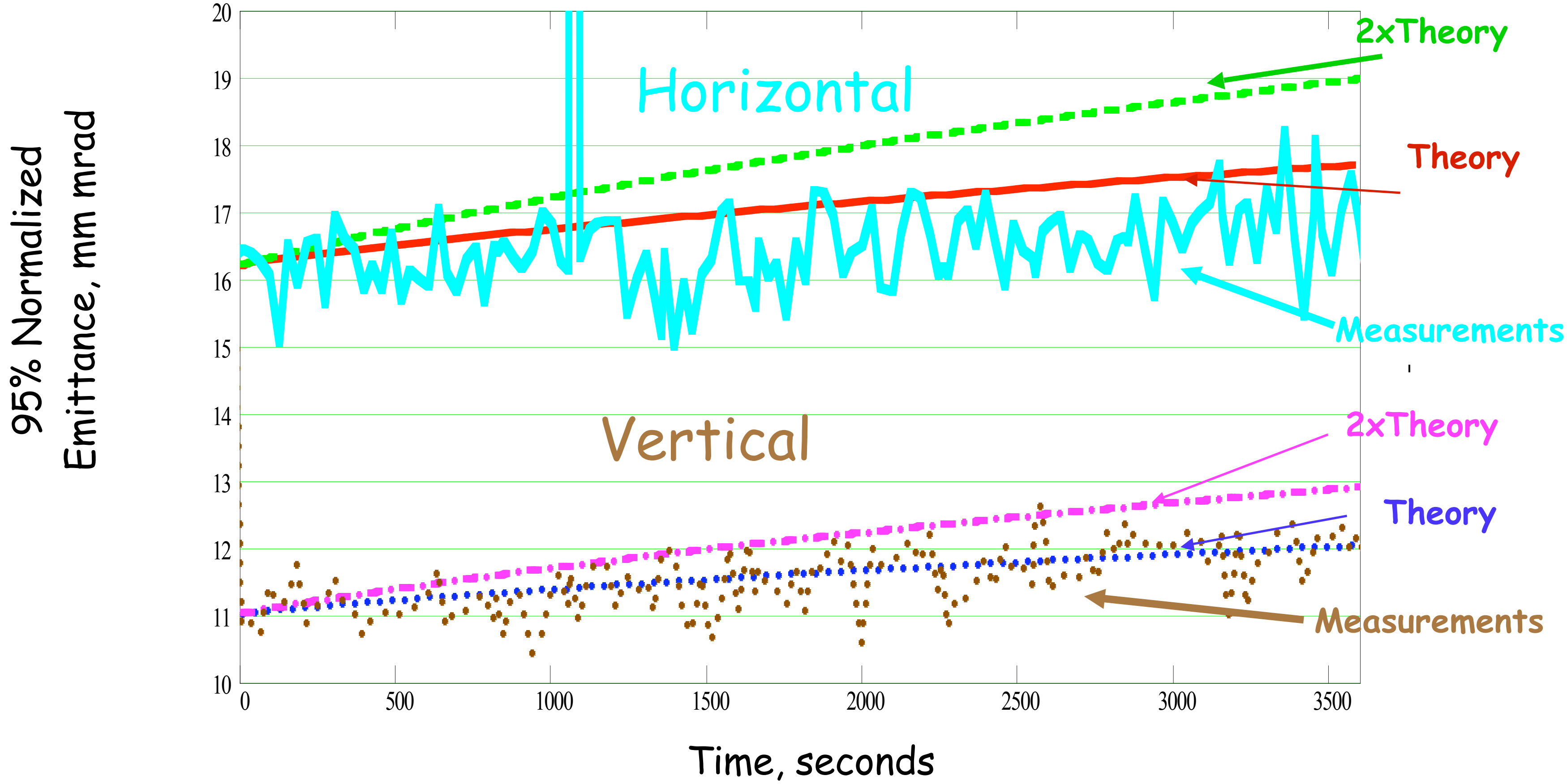
Theory = Martini's formalism of IBS





Very good agreement with theoretical predictions within resolution of IPM: for both yellow and blue rings, for six bunches with various intensities and various initial emittances

IBS for run with Cu-ions

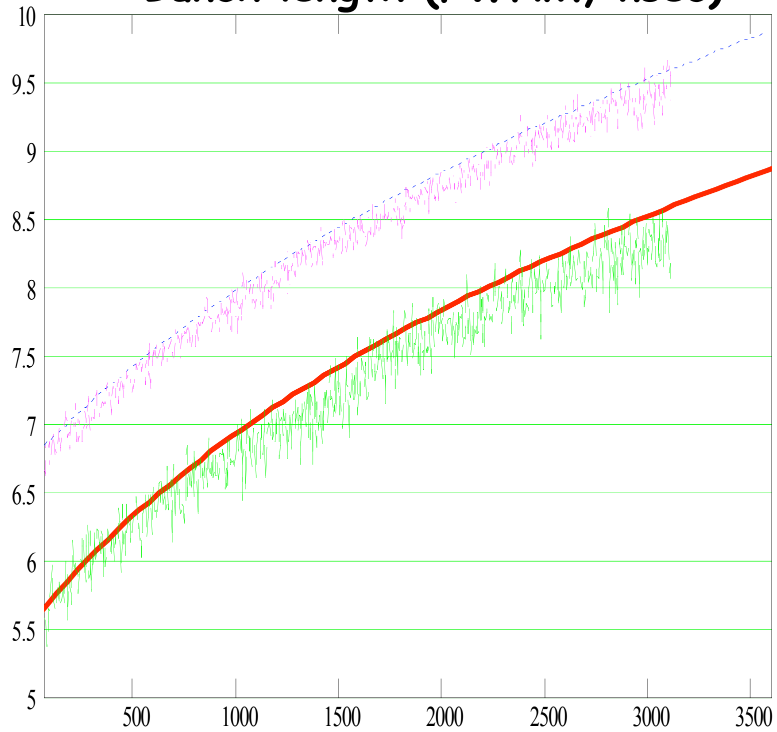


Doubling IBS growth does not fit with the experiment.

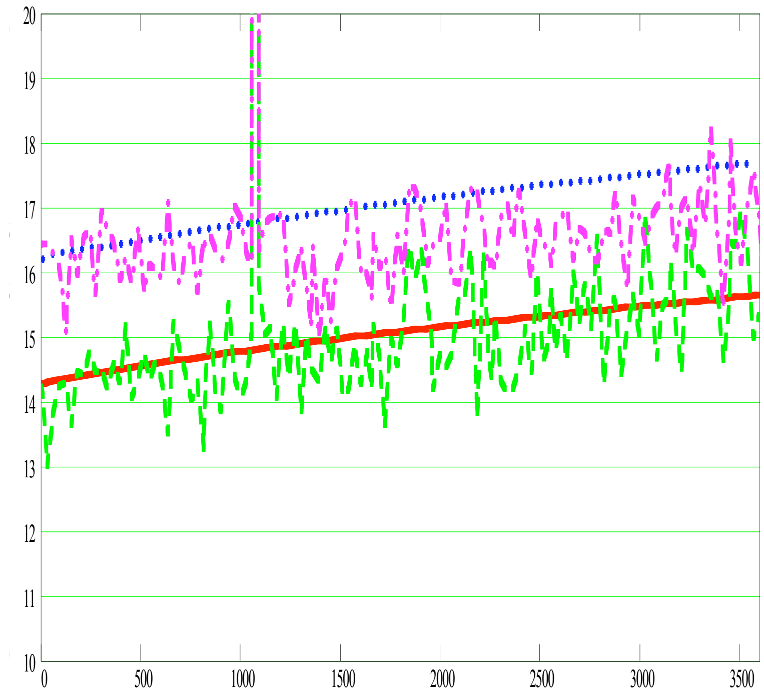
BLUE:

two intensities (N_{Cu}=2.9 10^9 and N_{Cu}=1.4 10^9 per bunch) – IBS measurements and simulations - 2005 run, Cu

Bunch length (FWHM, nsec)



95% Horizontal emittance, um



Theoretical IBS growth does fit with the experiment from reasonably well to very well

E-Cooling: classical vs magnetized

Parameter	Units	Classical (non-magnetized)	Magnetized
Ion's energy	Gev/A	100	100
Transverse normalized RMS emittance (initial)	mm · mrad	2.5	2.5
Relative RMS energy spread (initial)		$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$
Length of cooling section per ring	m	60	60
Ions β-function in the cooling section	m	**≥ 200**	**60**
Increase in average luminosity in 10 hour store	$7\ 10^{26}$ $cm^{-2}\ sec^{-1}$	X 10	X 10
Beam rep-rate	MHz	9.383	9.383
Special devices		**A wiggler with 0.001 T field (if needed)**	**60 meters of 2T-to-5 T solenoids, stretcher and compressor**

Main e-Beam parameters: classical vs magnetized

Parameter	Units	Classical (non-magnetized)	Magnetized
Electron beam energy	MeV	54	54
Electron beam current	mA	47	**186**
Charge per bunch	nC	5	**20**
Normalized beam emittance: Magnetized/ Normal	mm · mrad	0 / ≤ **5**	**1700** / **50**
Relative energy spread @ 54 MeV		≤ 10^{-3}	≤ 10^{-3}
Bunch length, RMS	cm	1	5
RF/bunch frequencies	MHz	703.75/9.383	703.75/9.383
Beam alignment in cooling section		BPMs each 1-2 m with 5-10 um resolution	Beam-based alignment using special coils

Margins for errors

- Low IBS lattice of RHIC
- Longer straights and larger β's

$$\textit{Cooling rate} \propto \sqrt{\frac{1+\alpha_x^2}{\beta_x} + \kappa\frac{1+\alpha_y^2}{\beta_y}} = \sqrt{\frac{1}{\beta_x^*} + \frac{\kappa}{\beta_y^*}}$$

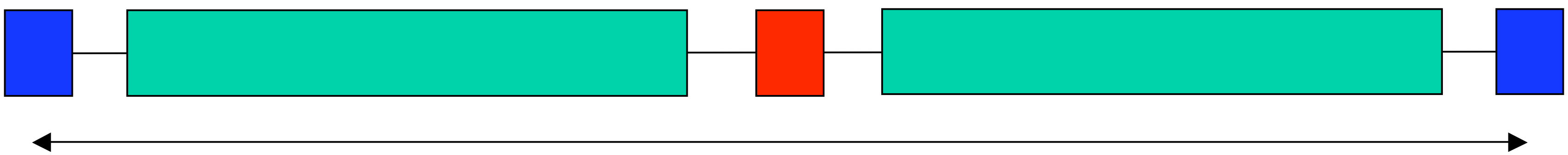
  - Increase of $\beta*$ from 200m to 800 m doubles the cooling rate and allows for either stronger IBS or half of ERL current
- Boosting charges per bunch to 10 nC (possible in our ERL design) is opportunity to X 1.8 increase of the cooling, if needed

Low IBS lattice of RHIC

The main contribution to the transverse IBS in RHIC come from the arcs, most of which comprised of FODO cells

There is a potential to increase strength of focusing and to reduce transverse IBS rate

$$\frac{d\varepsilon_x}{ds} = H(s)\cdot\frac{d\delta_E^{\ 2}}{ds};\qquad H(s) = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$$

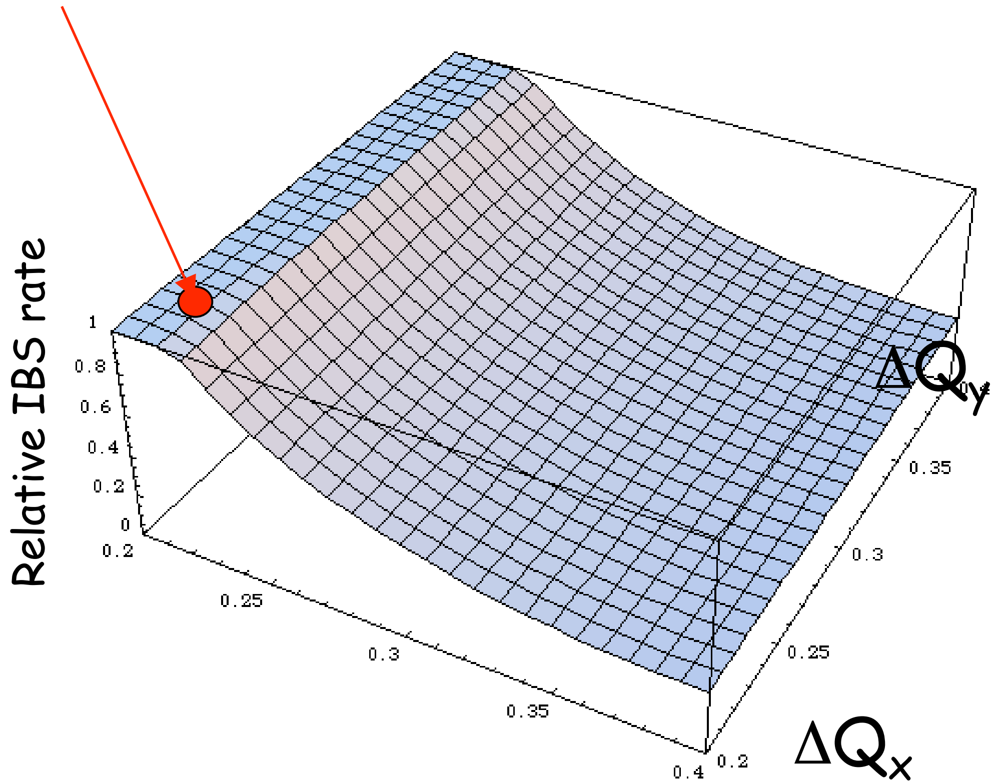


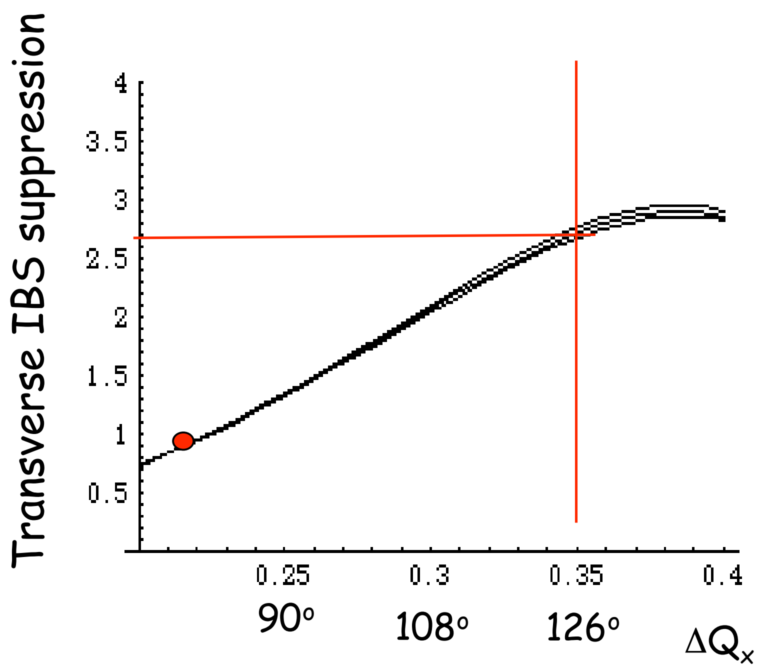
$$\frac{d\delta_E^{\ 2}}{ds} \propto \frac{N}{\sigma_s \sigma_r^{\ 2} \sigma_{r'}};\qquad H_{\mathrm{mod}}(s) = \frac{H(s)}{\sqrt{\beta_y(1+\alpha_x^{\ 2}) + \beta_x(1+\alpha_y^{\ 2})}}$$

- The arcs quadrupoles are set well below their limit: operate at ~4-4.5 kA,
- PS are capable of 5.6 kA, leads can stand 6.3-6.5 kA, quench limit is at 7 kA.

Low IBS lattice of RHIC

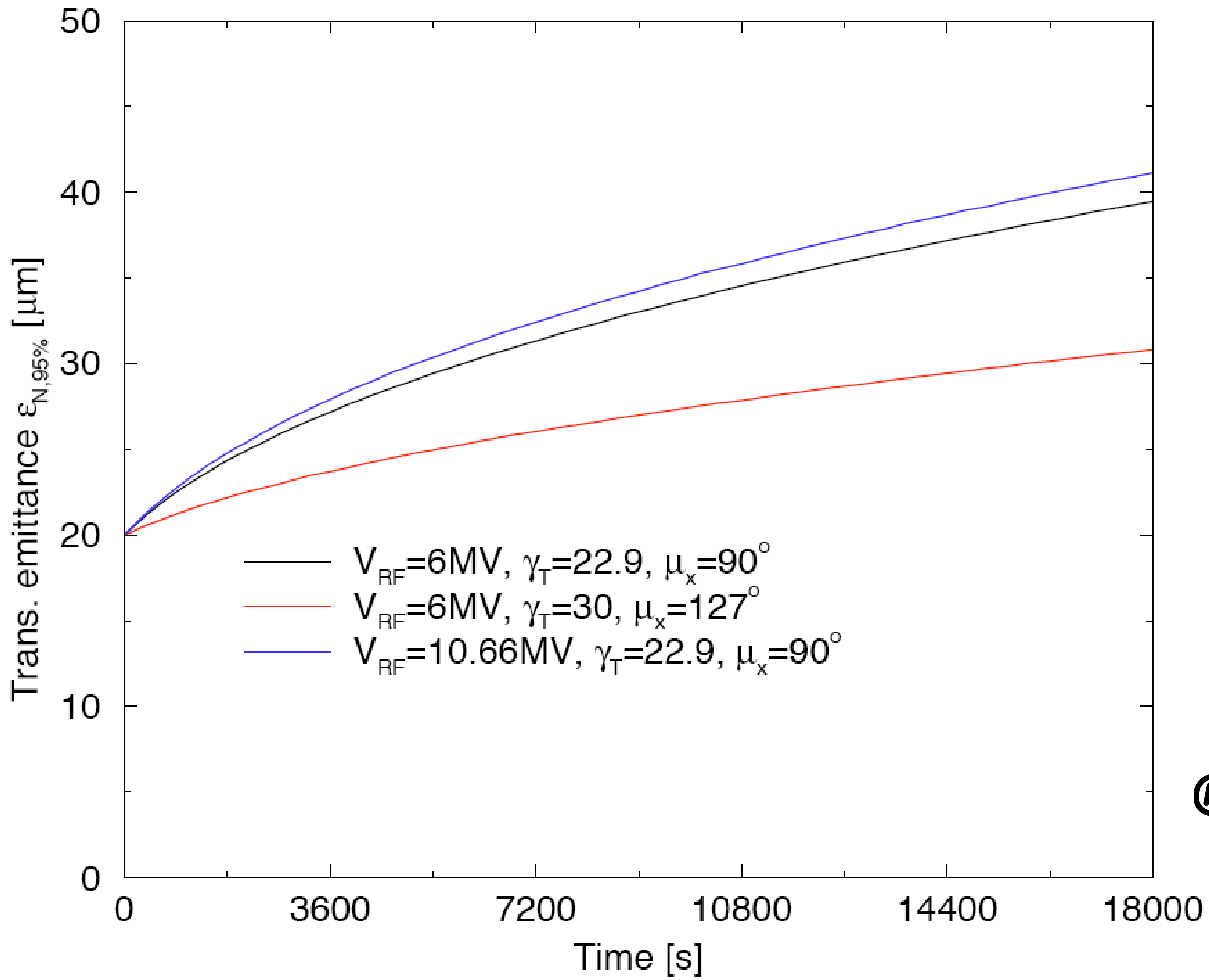
Present operating
Point : 82° per cell





NOTE: $\Delta Q_{x,y}$ are tune advances per one FODO cell

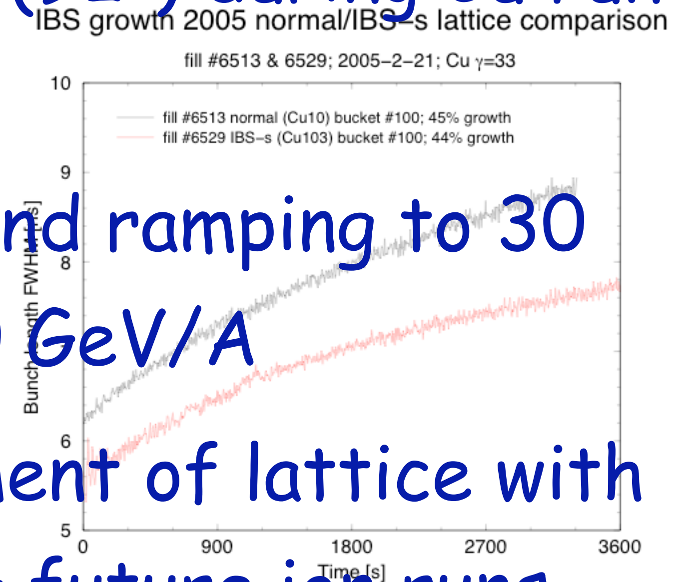
Low IBS lattice of RHIC



®J.Wie

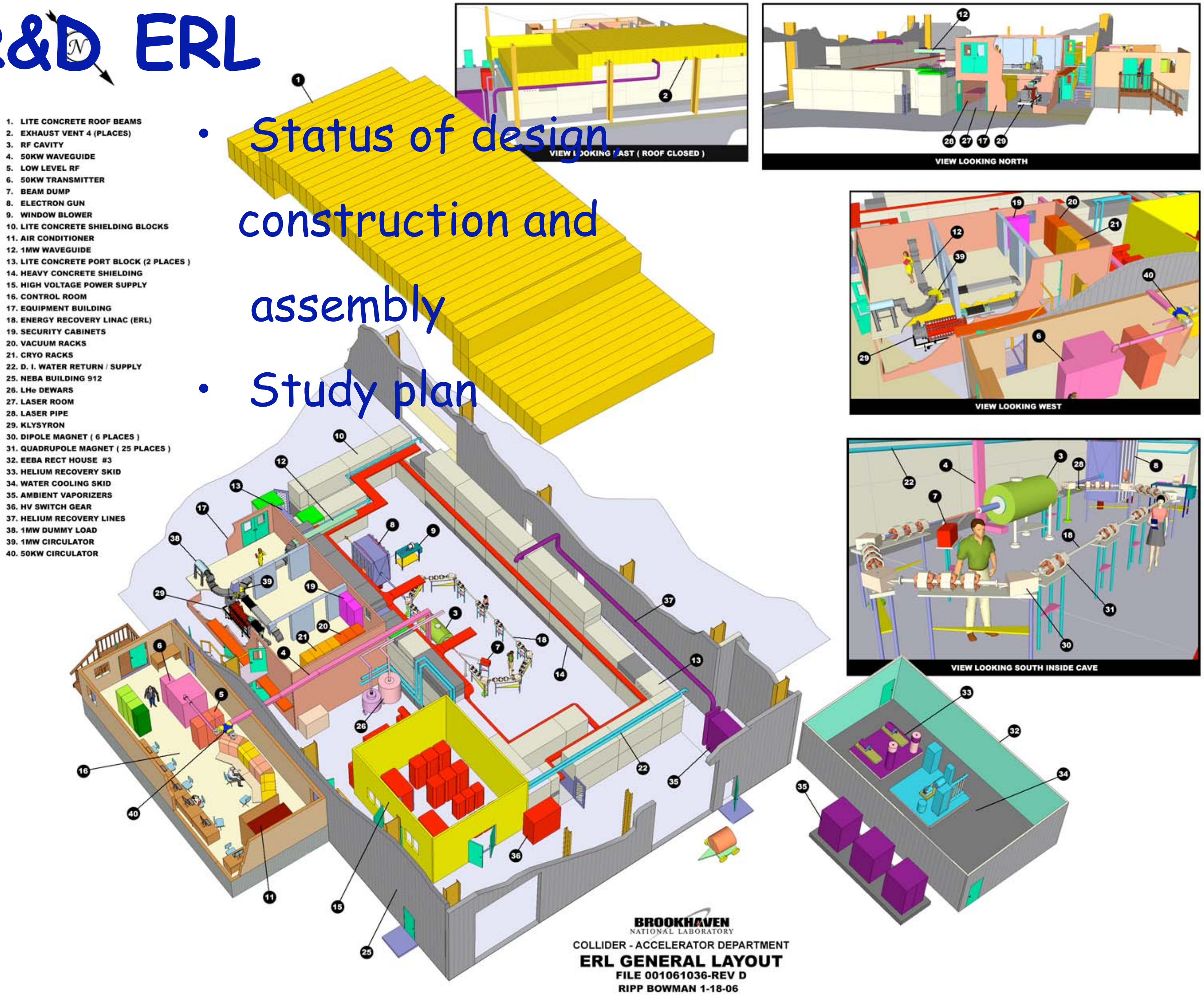
Low IBS lattice of RHIC

- Started experiments on developing RHIC lattice with reduced IBS (92°) during Cu run (2004-2005)
- Succeeded at injection and ramping to 30 GeV/A, did not reach 100 GeV/A
- Plan to continue development of lattice with large tune advance during future ion runs



R&D ERL

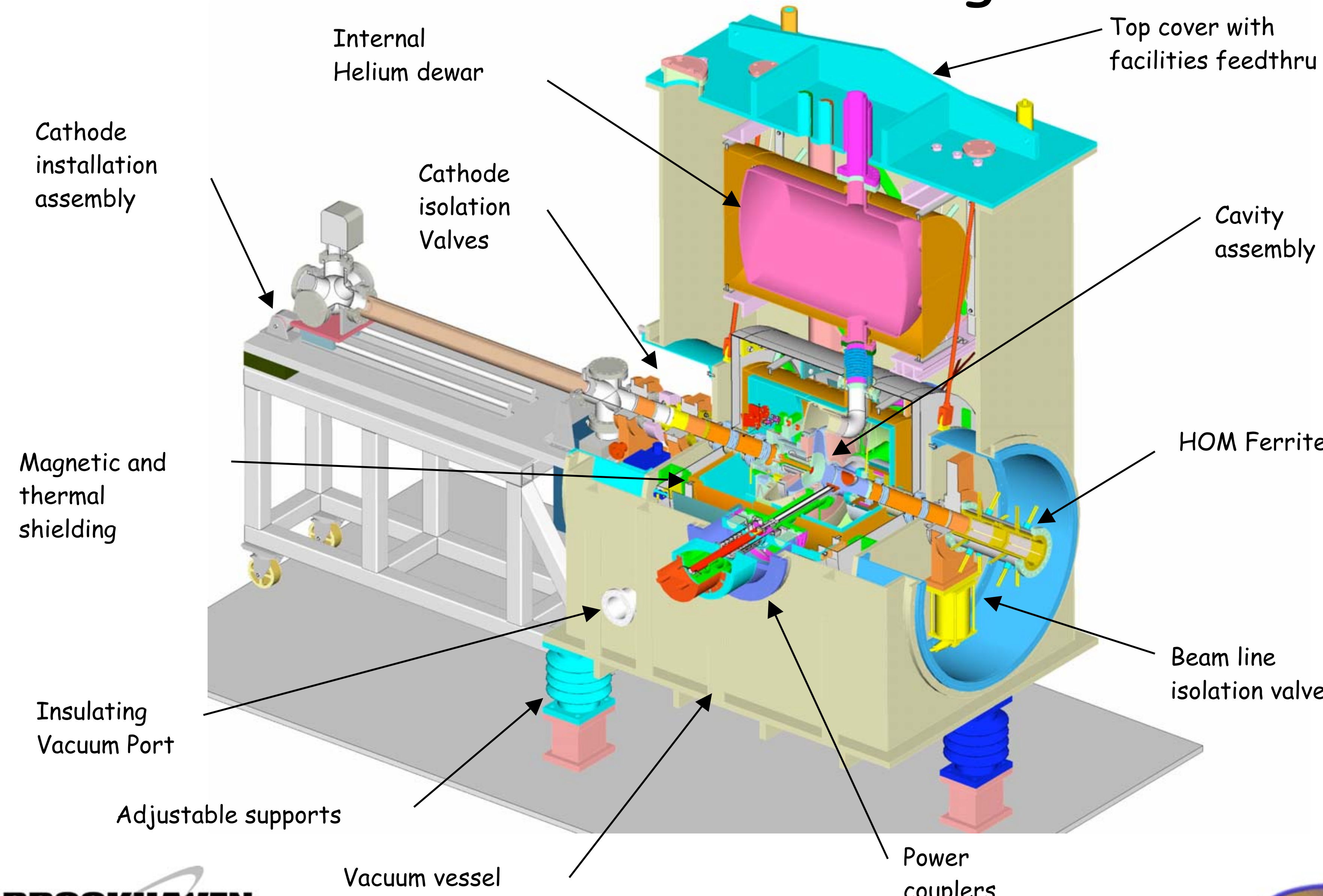
- Status of design, construction and assembly
- Study plan



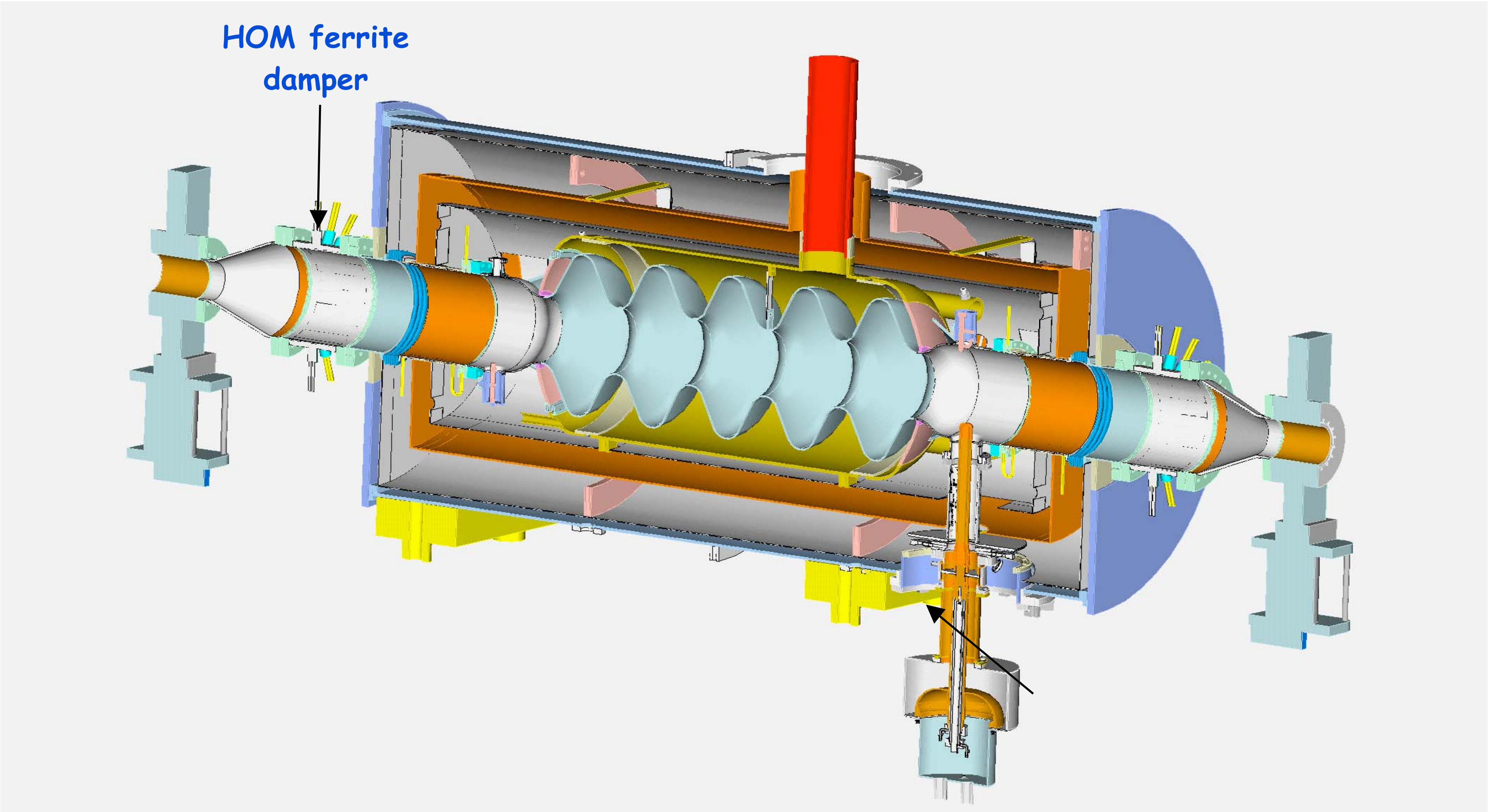
Status of design, construction and assembly

- The cave & infrastructure - close to completion
- RF systems - in or on their way
- Magnets - 80% designed and send for quotes
- SRF gun in an advanced design phase
- 5-cell cavity is in preparation for assembly
- Injection, supports, beam-dump are in preliminary design stage

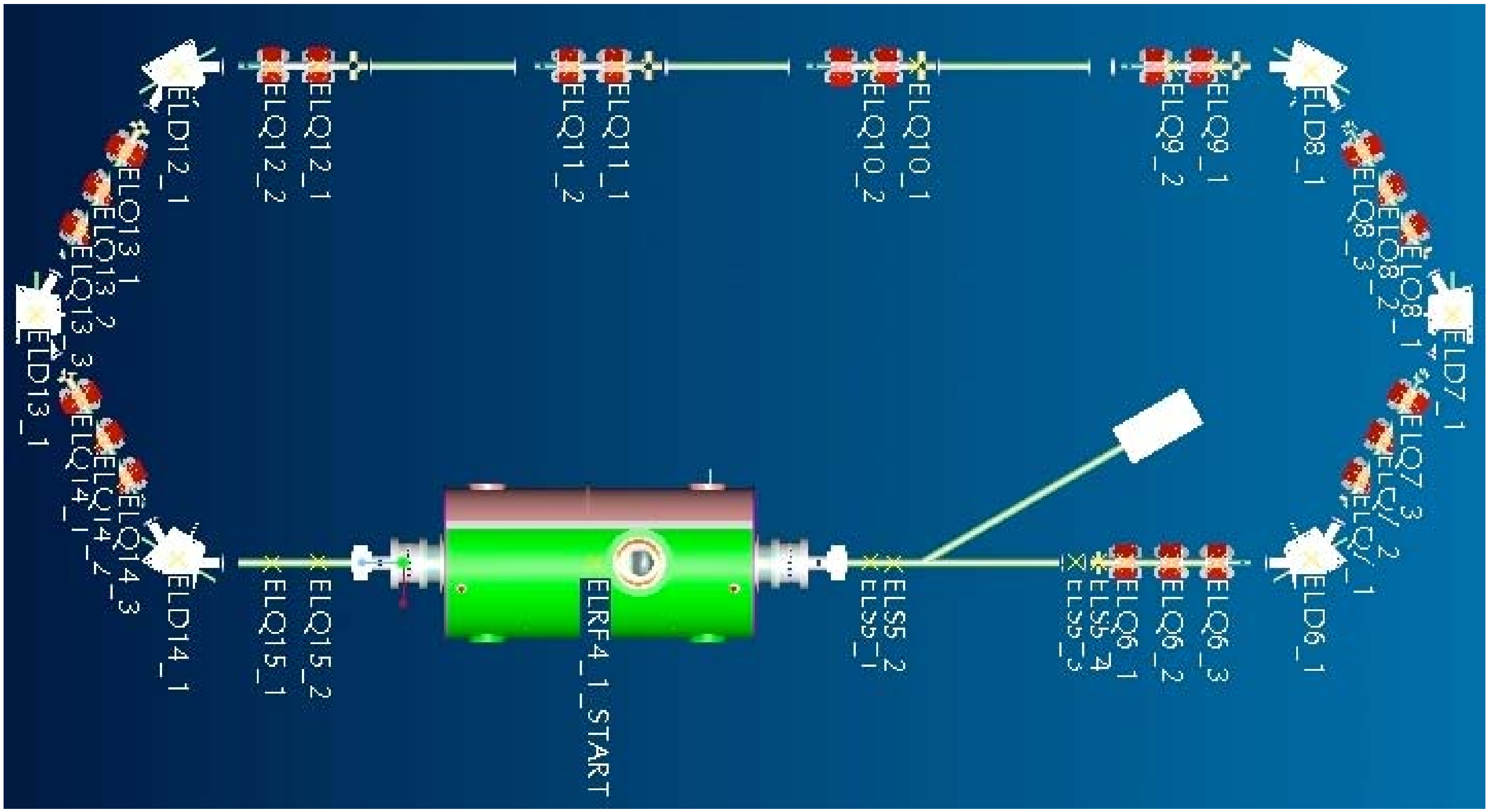
SRF Gun - General Arrangement



RF accelerators



R&D ERL loop and 5-cell cavity



R&D ERL: study plan

- Commission the SRF and verify its low emittance (few um mrad), high current (up to 0.5 A), high charge (up to 10 nC)
- Commission and verify emittance preservation in Zig-Zag merger system
- Commission 5-cell cavity, the loop and the beam dump with high energy acceptance, and commission the ERL
- Verify emittance and energy spread at 20 MeV
- Demonstrate e-beam losses as low as few ppm in ERL for operational current
- Study stability R_{56} range for longitudinal stability for achromatic lattice and its dependence on the beam current
- Attempt to reach TBBU threshold by increasing R_{12} and R_{34} within limits of the lattice

Effect on electron beam as a result of single interaction with ion beam and self-heating

The following effects were estimated by A. Fedotov:

1. Electron-electron interactions: < 1% growth in RMS momentum spread (at L=100m relative growth of RMS spread is 0.2%, i.e 2 10^{-5} in the value).
2. CSR: < 1% effect (upper limit estimate gives <10^{-3} level energy loss and energy spread).
3. Emittance increase due to collective interaction with ion beam – not expected to be a problem
4. Electrons scattering on ions (largest effect in the list): L=100 m interaction length results in 0.4% effect (2 10^{-5} in the value) in RMS momentum spread.

Conclusions

- **IBS in RHIC is well understood**
- **Both classical and magnetized cooling will work for RHIC**
- Classical (non-magnetized) cooling is definitely less expensive compared with magnetized cooling (60 m of 5T solenoids, stretchers, 20x large apertures, etc.)
- Classical (non-magnetized) cooling cools entire ion beam and prevent creation of dense core
- Parameters of electron beam seems to within reach for both systems, but are easier for the classical cooler, which can also allows using one ERL for both RHIC rings
- There is significant number of reserves in the system (such as IBS suppression lattice, etc), each providing a 2X margin of error
- **We are convinced that classical (non-magnetized) cooler is right choice for RHIC**