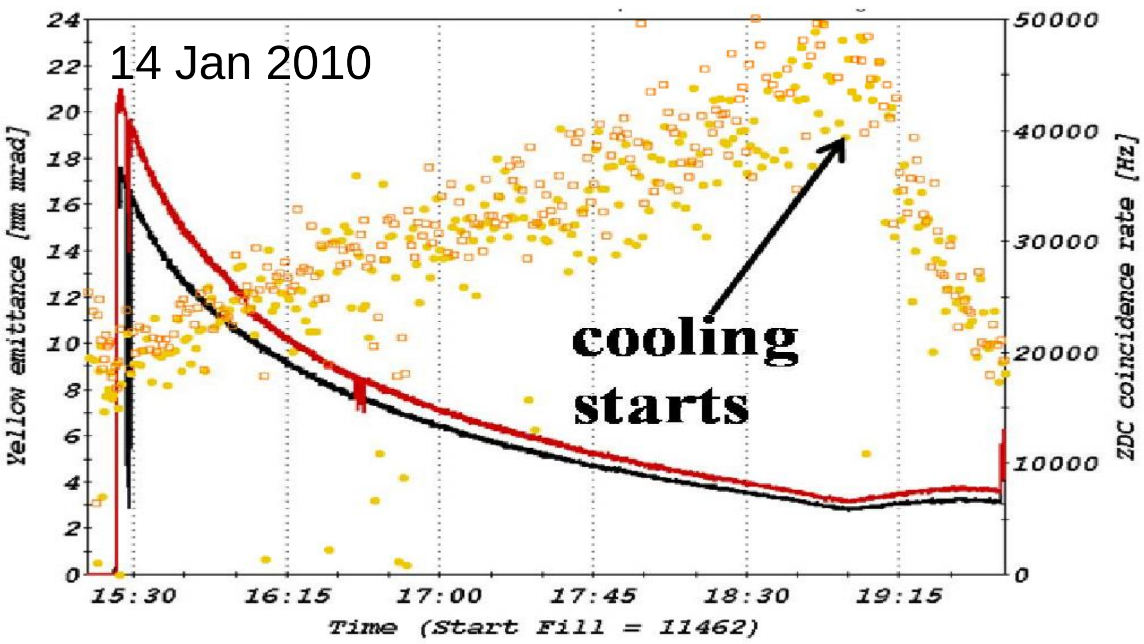
IBS and cooling in RHIC, HE-LHC active emittance control

W. Fischer and M. Blaskiewicz

1st vertical stochastic cooling in RHIC



BROOKHAVEN NATIONAL LABORATORY

15 October 2010

High-Energy LHC, Malta

Content

1. LHC active emittance control
   - HE LHC damping times
   - Maximization of integrated luminosity

1. IBS and cooling in RHIC
   - Measurements and simulations for IBS
   - Au^{79+} beam dynamics with stochastic cooling

High Energy LHC parameters (from F. Zimmermann)

[R. Assmann et al, “First thoughts on a higher energy LHC”, CERN-ATS-2010-177]

	Nominal LHC	High energy HE-LHC	
beam energy [TeV]	7	16.5	
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1.0	2.0	
luminosity lifetime [h]	23	13	
events per crossing	19	76	
# bunches / beam	2808	1404	
bunch population [10^{11}]	1.15	1.3	
Luminosity leveling	no	yes: $e_{x,y}$	
initial transverse normalized emittance [mm]	3.75	3.75 (x) 1.84 (y)	2.59
number of IPs contributing to tune shift	3	2	
maximum total beam-beam tune shift	0.01	0.01	
IP beta function [m]	0.55	1.0 (x), 0.43 (y)	0.6
full crossing angle [mrad]	285 (9.5 $s_{x,y}$)	~180 (12 s_{x0})	
longitudinal SR emittance damping time [h]	12.9	0.98	
horizontal SR emittance damping time [h]	25.8	1.97	
initial long. IBS emittance rise time [h]	61	64	
initial hor. IBS emittance rise time [h]	80	80	
initial ver. IBS emittance rise time [h], (k=0.2)	~400	~400	

Means of active emittance control during stores

Assume that initial beam parameters have been adjusted to acceptable values.

1. Adjust strength of active cooling (currently not an option in LHC)
   change of gain, power, average "system on" time
   changes equilibrium emittance

2. Increase transverse emittance
   random dipole kicks θ [M. Syphers, Handbook]

$$\frac{d\varepsilon}{dt} = \frac{f_0}{2}(\beta\gamma)\beta_0\theta_{rms}^2$$

3. Use x-y coupling to equalize transverse emittances
   when operating at beam-beam limit, maintains same bb parameter in both planes
   works well in RHIC without and with active cooling

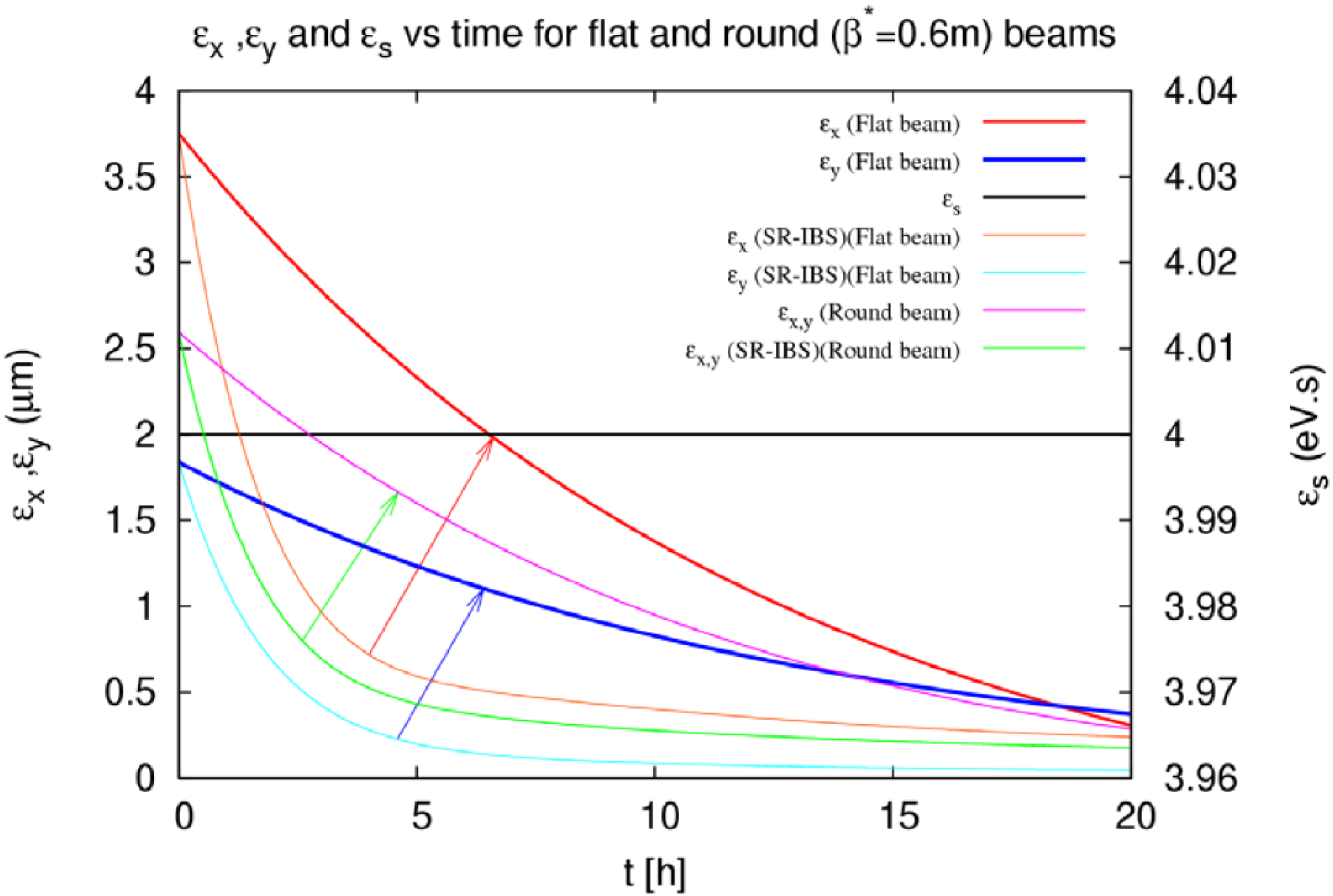
$$\varepsilon_x = \varepsilon_y \quad \Rightarrow \quad \xi_x = \xi_y$$

4. Increase bunch length to reduce peak currents
   random phase kicks $\delta\varphi$ [M. Syphers, Handbook]

$$\frac{d\varepsilon_s}{dt} = \frac{f_0}{2}\frac{E_0}{\omega_{rf}}\sqrt{-\frac{\beta e V_{rf}\cos\varphi_s}{2\pi h\,\eta E_0}}\,(\delta\varphi_{rms})^2$$

HE LHC emittances without and with heating

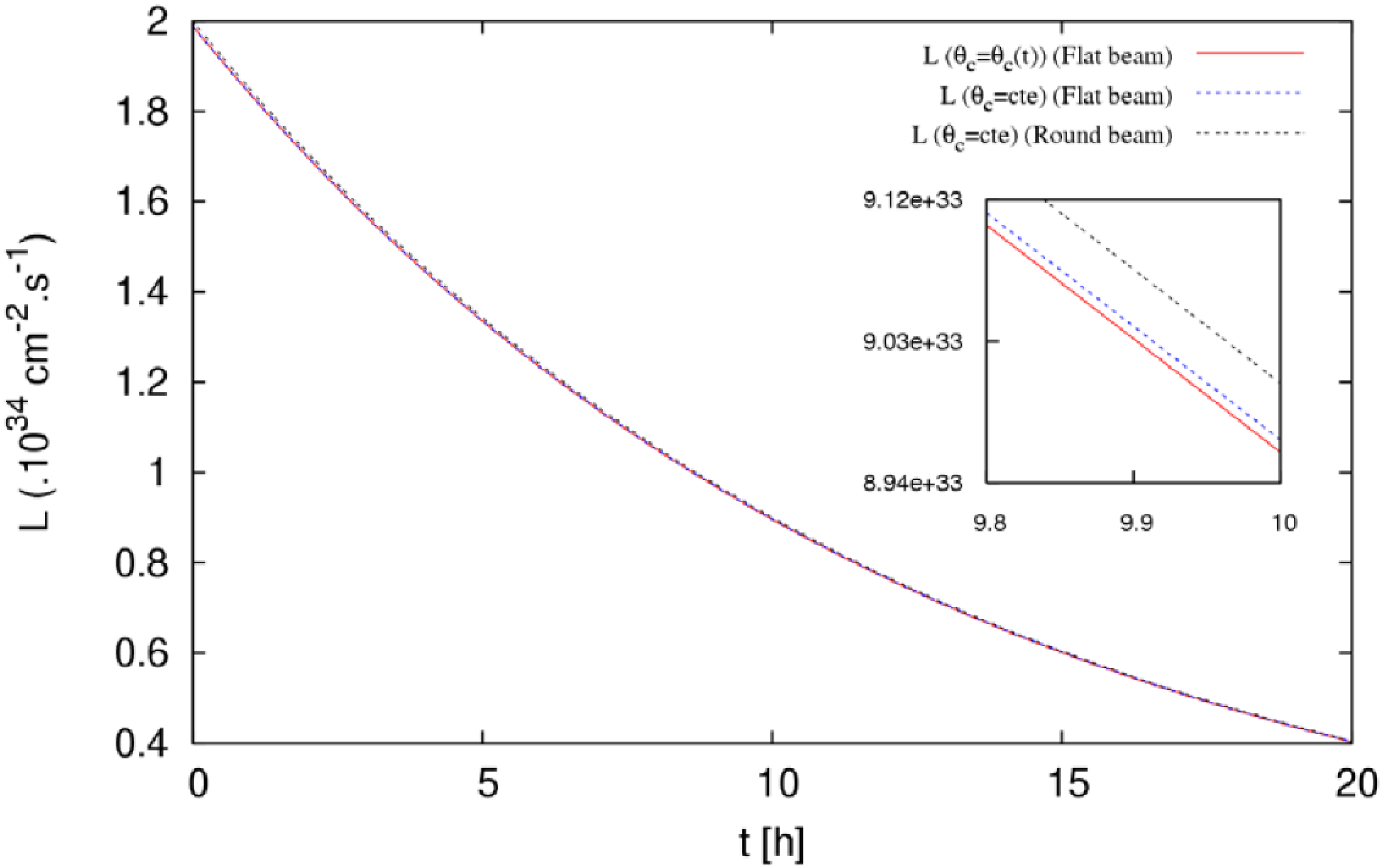
Heating condition: $\xi = 0.01$ (constant)
Constant crossing angle $\theta \sim 180$ mrad.



Courtesy of O. Dominiguez, F. Zimmermann, in CERN-ATS-2010-177.

HE LHC emittance without and with heating

Heating determined by: $\xi = 0.01$ (constant)



Same luminosity with round and flat beams.

Courtesy of O. Dominiguez, F. Zimmermann, in CERN-ATS-2010-177.

HE LHC luminosity with round beams

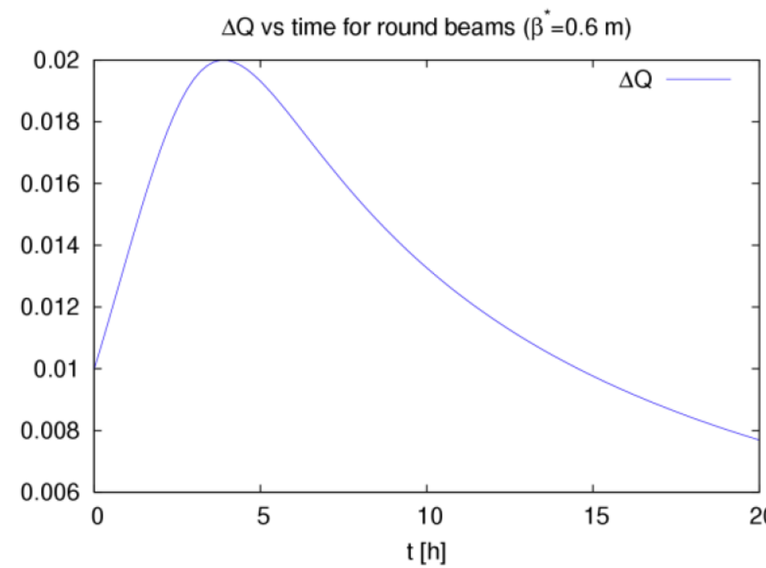
$$L = \frac{f_c \gamma}{r_0} \frac{N \xi}{\beta^*} F\left(\frac{\sigma_s}{\beta^*}, \theta \right)$$

f_c	collision frequency
γ	Lorentz factor
r_0	classical proton radius
N	bunch intensity (N_1=N_2=N)
ξ	beam-beam parameter
β^*	envelope function at IP
F	correction factor for hourglass and crossing angle θ

- Larger beam-beam parameter ξ allows for larger luminosity, or smaller *N* (and stored energy) for same luminosity
- Assumed beam-beam parameter (ξ_{tot} = 0.01) is conservative, smaller than SppS, Tevatron, RHIC
- May be increased beyond 0.01 (and even further with electron lenses)

ξ evolution without heating, max = 0.02, $\int Ldt$ + 15 %) ➔ .

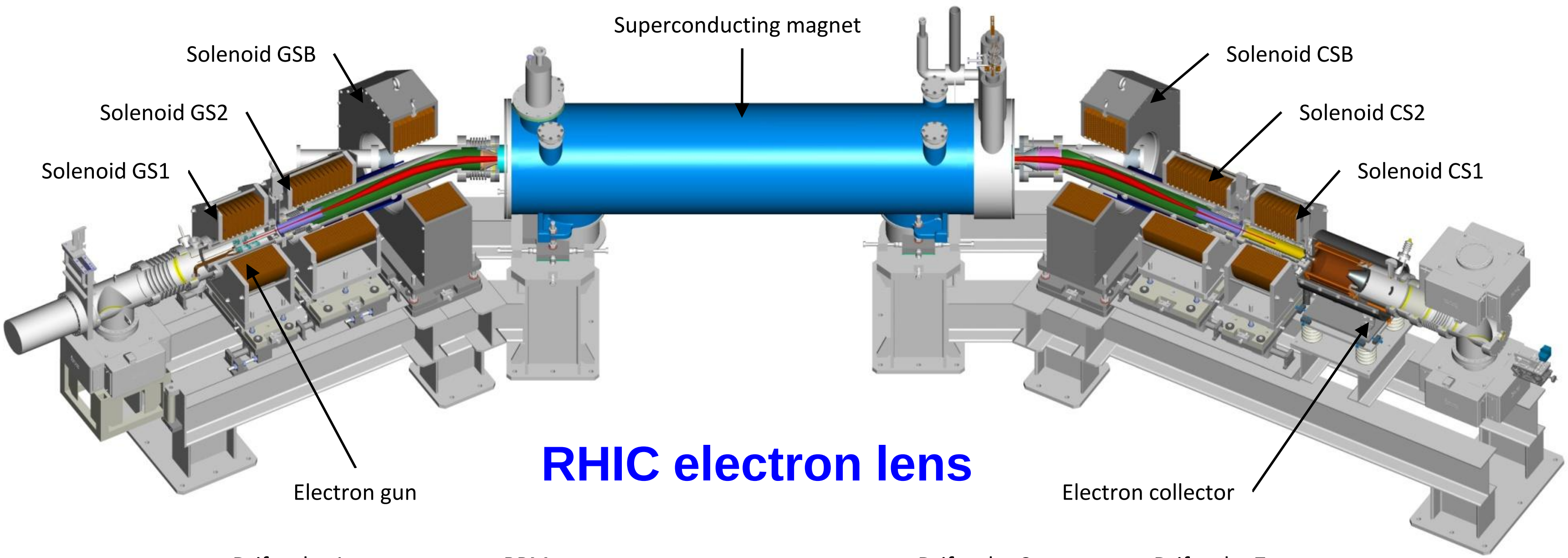
(max = 0.035 for flat beams, $\int Ldt$ + 20 %



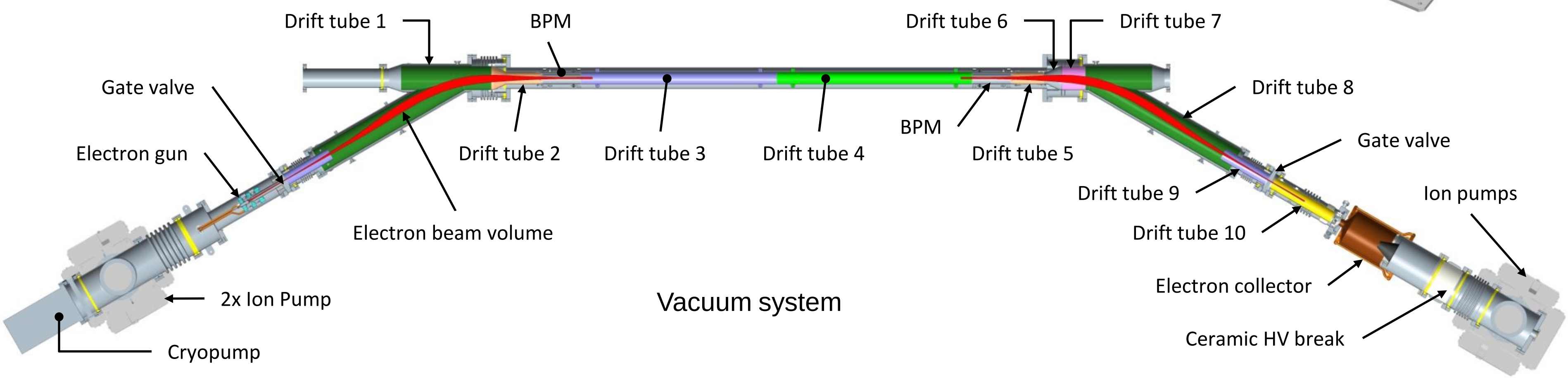
Courtesy of O. Domininguez, F. Zimmermann in CERN-ATS-2010-177.

2 Tevatron electron lenses in operation (not operationally used for HOBBC).

2 RHIC electron lenses for head-on BB compensation under construction.



RHIC electron lens



Vacuum system

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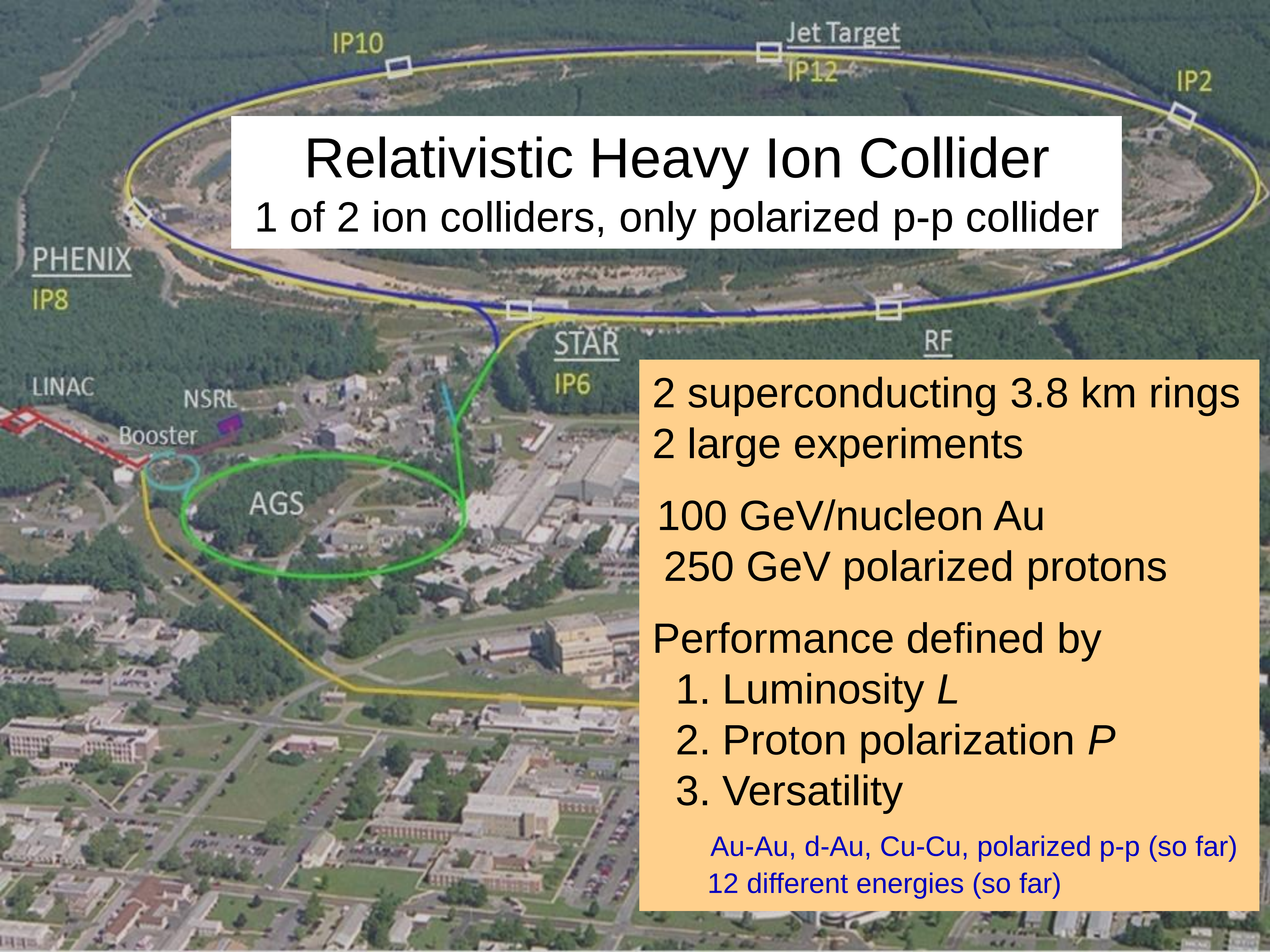
Relativistic Heavy Ion Collider

1 of 2 ion colliders, only polarized p-p collider



2 superconducting 3.8 km rings
2 large experiments

100 GeV/nucleon Au
250 GeV polarized protons

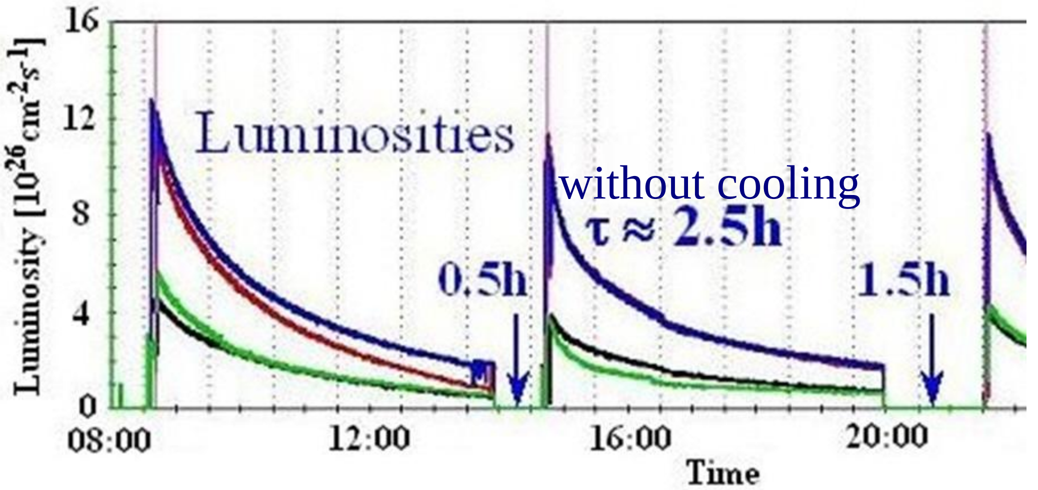
Performance defined by

1. Luminosity *L*
2. Proton polarization *P*
3. Versatility

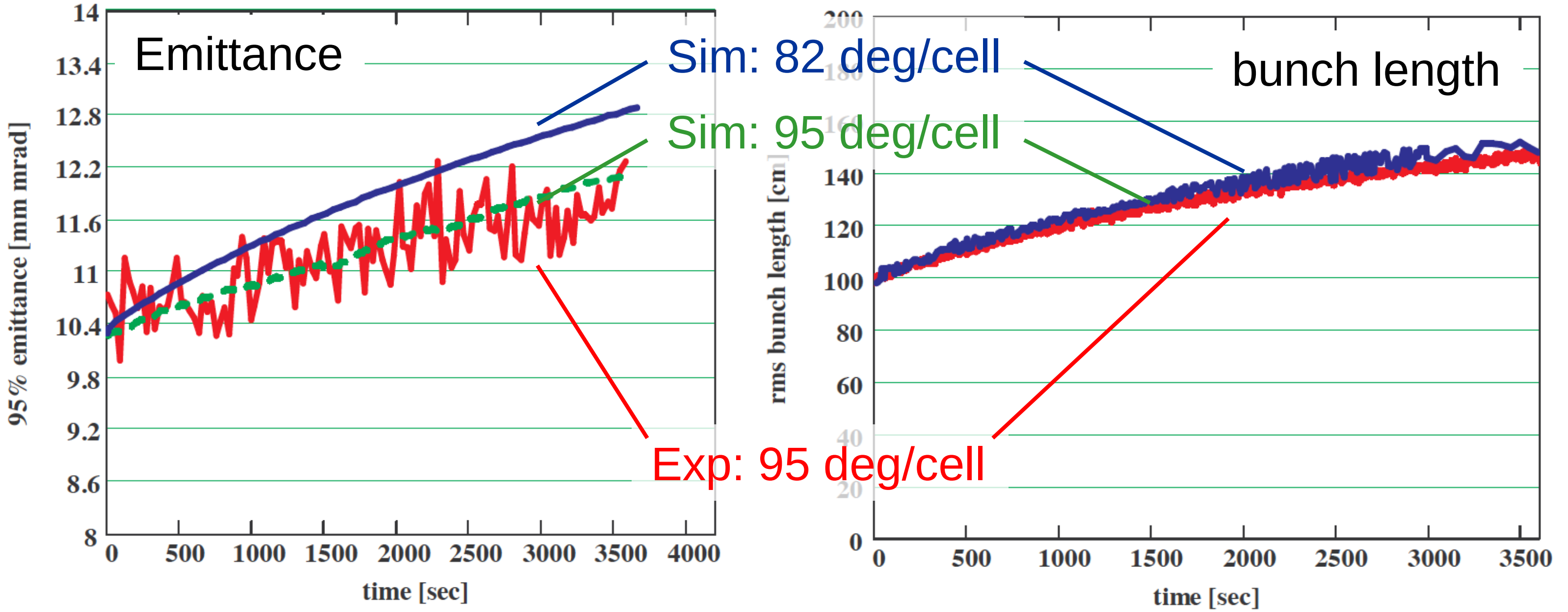
Au-Au, d-Au, Cu-Cu, polarized p-p (so far)
12 different energies (so far)

Intrabeam scattering in RHIC

IBS leads to debunching and transverse emittance growth of heavy ion beams



Comparison of measured and simulated $\varepsilon(t)$ and $\sigma_s(t)$ [A. Fedotov et al., proceedings HB2008.]

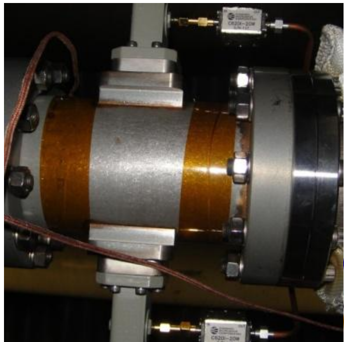


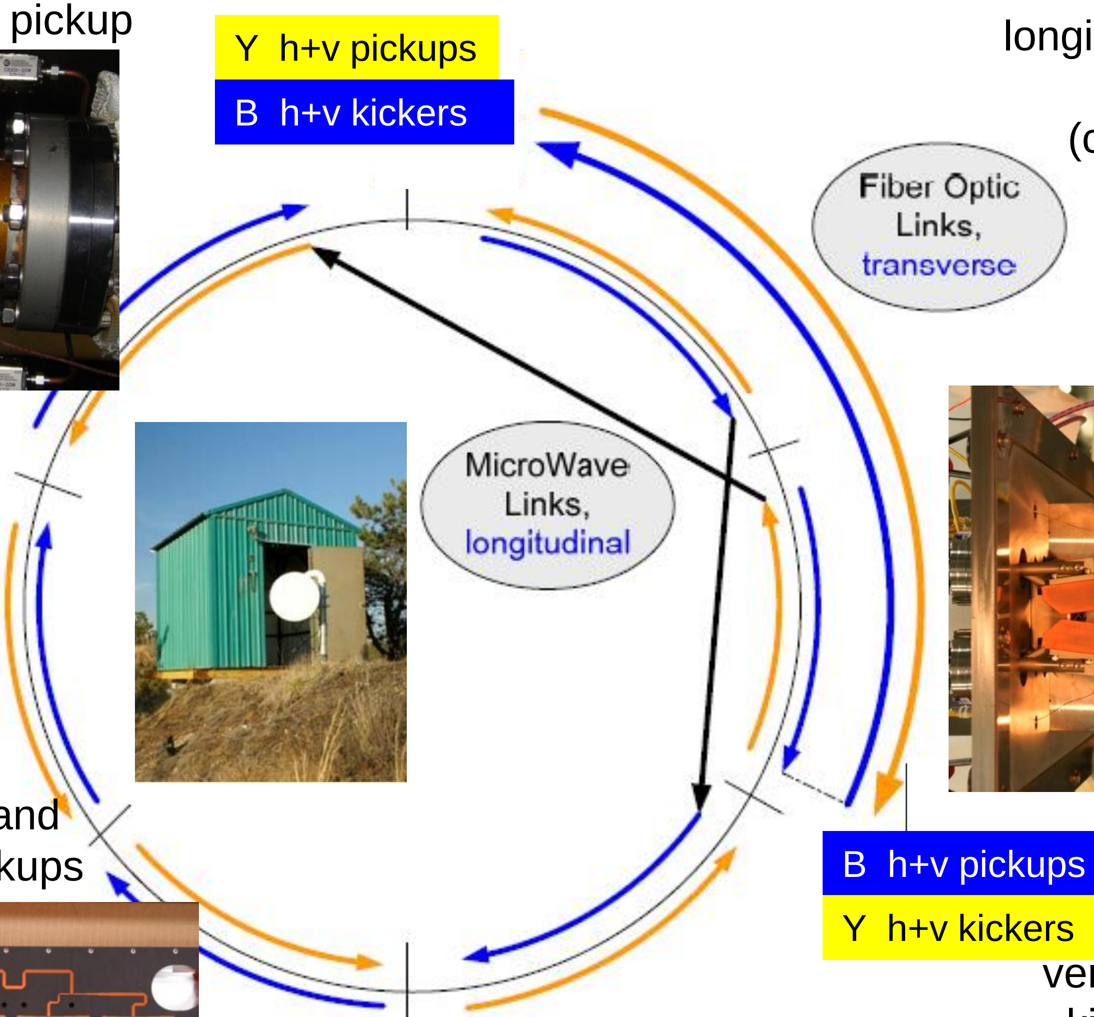
Beam: Au^{79+},100 GeV/nucleon, 95 deg/cell, N_b=0.92x10^9

Simulation: BETACOOL

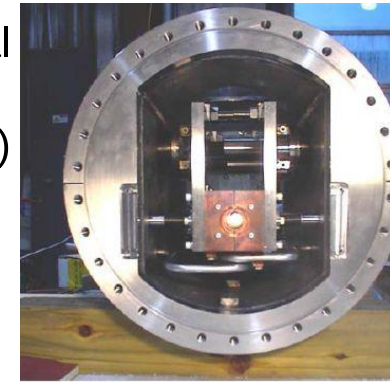
RHIC – 3D stochastic cooling for heavy ions

longitudinal pickup

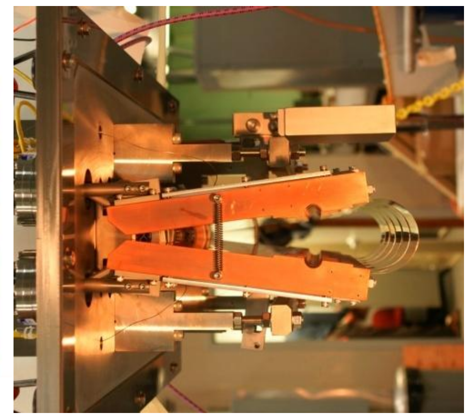




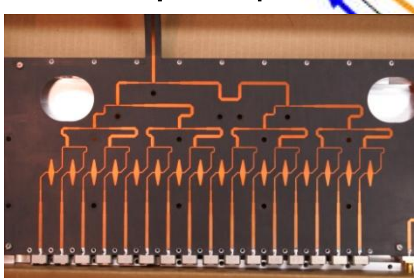
longitudinal kicker (closed)



horizontal kicker (open)



horizontal and vertical pickups



vertical kicker (closed)

5-9 GHz, cooling times ~1 h

M. Brennan, M. Blaskiewicz, F. Severino, Phys. Rev. Lett. **100** 174803 (2008); PRST-AB, PAC, EPAC

RHIC – bunched beam stochastic cooling for heavy ions

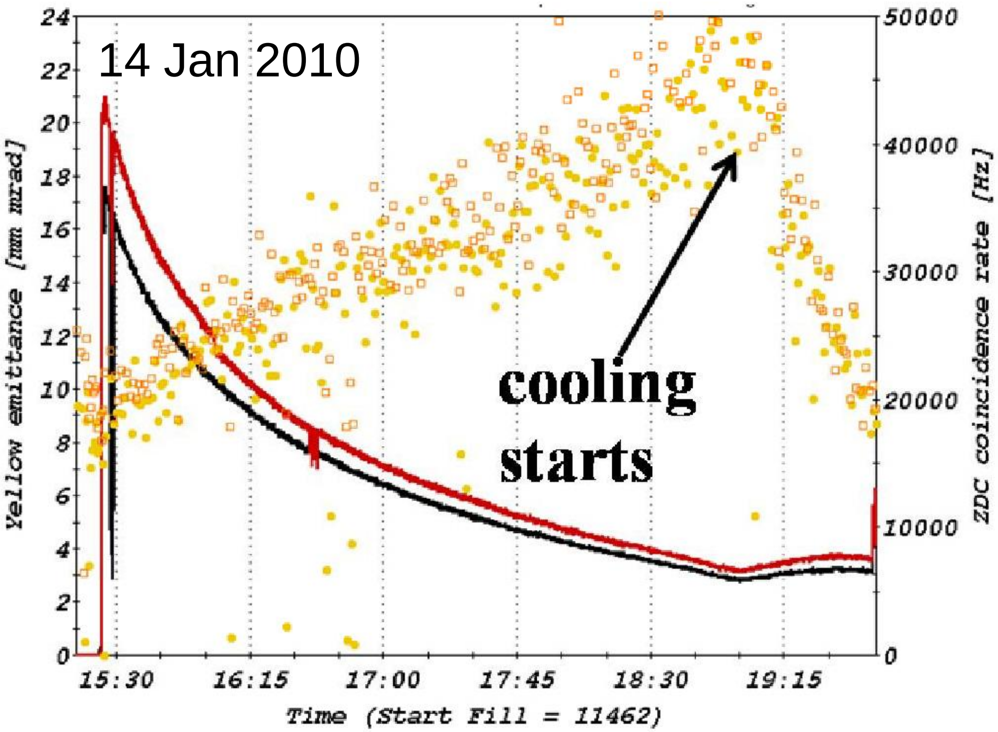
- Longitudinal cooling since 2007
- First transverse (vertical) cooling in 2010

M. Brennan
M. Blaskiewicz
K. Mernick et al.

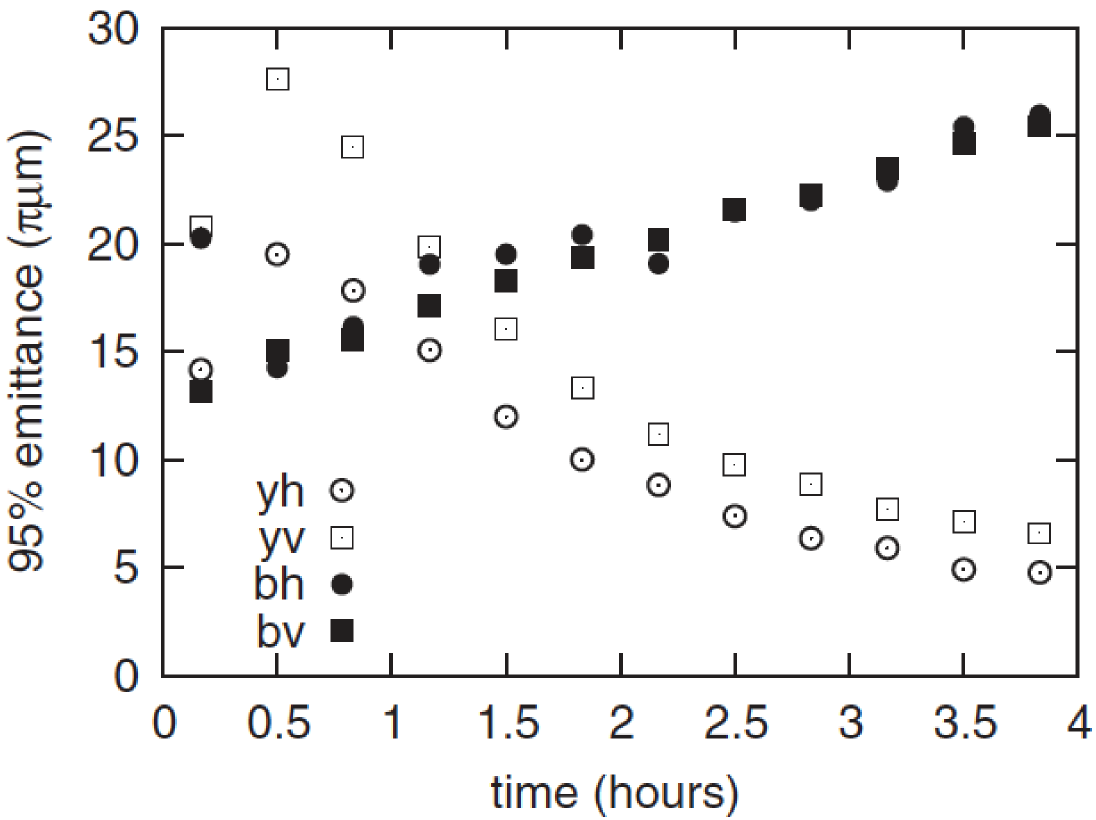
- **So far stochastic cooling increased average store luminosity by factor 2**
- **Expect another factor 2 with full 3D cooling**

Issues being addressed:

- Vacuum leaks at feedthroughs
- Mechanical motion of long. kickers
- Cross-talk between Blue and Yellow vertical system (addressed by 100 MHz shift in Blue)
- Construction, installation, and commissioning of horizontal systems



RHIC Au beams with vertical stochastic cooling



Blue emittances without vertical cooling

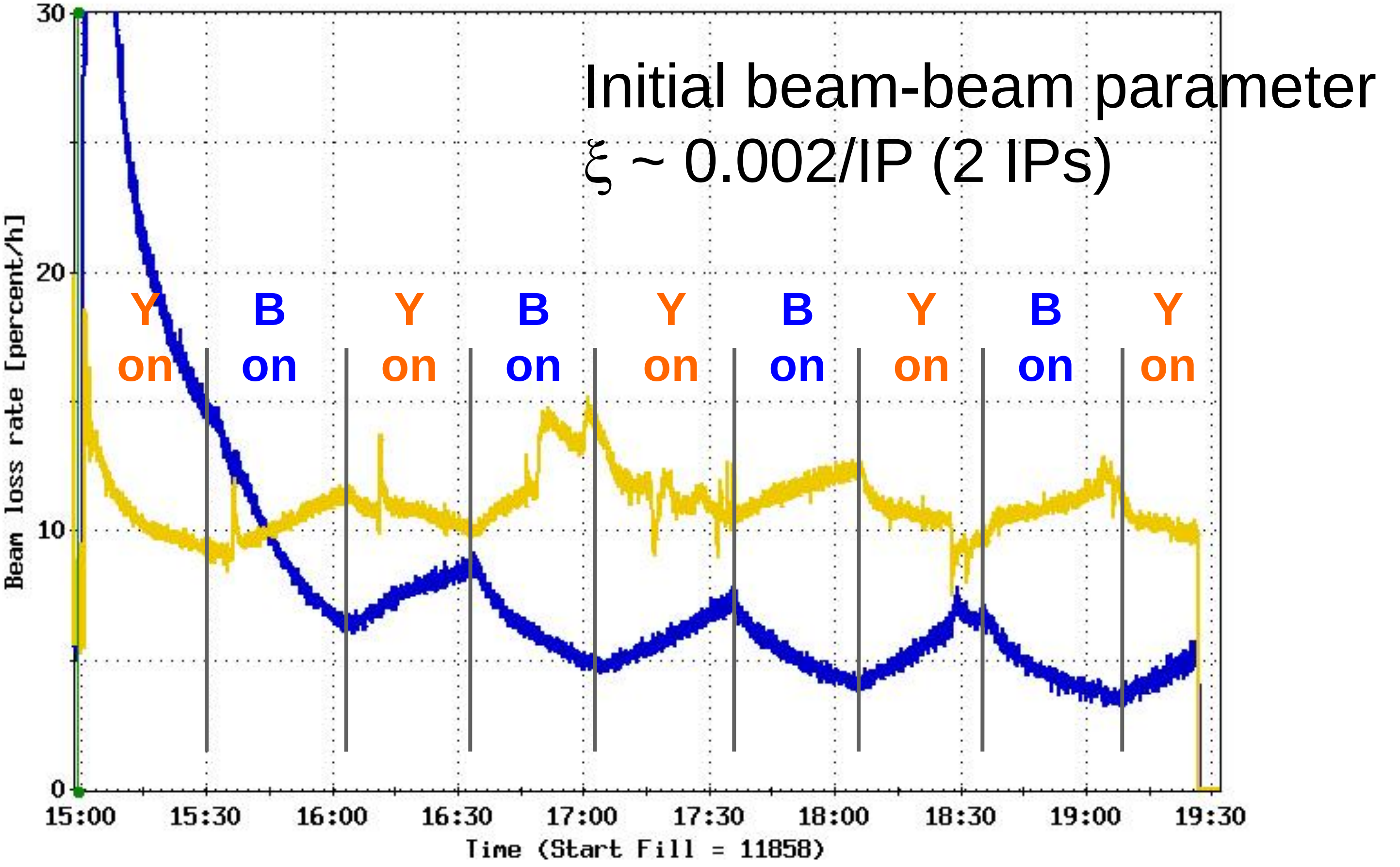
Yellow emittances with vertical cooling

Emittance measurement with Ionization Profile Monitor (IPM).

[M. Blaskiewicz, J.M. Brennan, and K. Mernick, PRL 105, 094801 (2010).]

Cooling only one beam

Because of Blue-Yellow cross talk of vertical cooling systems in 2010, only one beam could be cooled at the time. Loss rate of other beam increased as a result (from unmatched beam sizes at the IP).



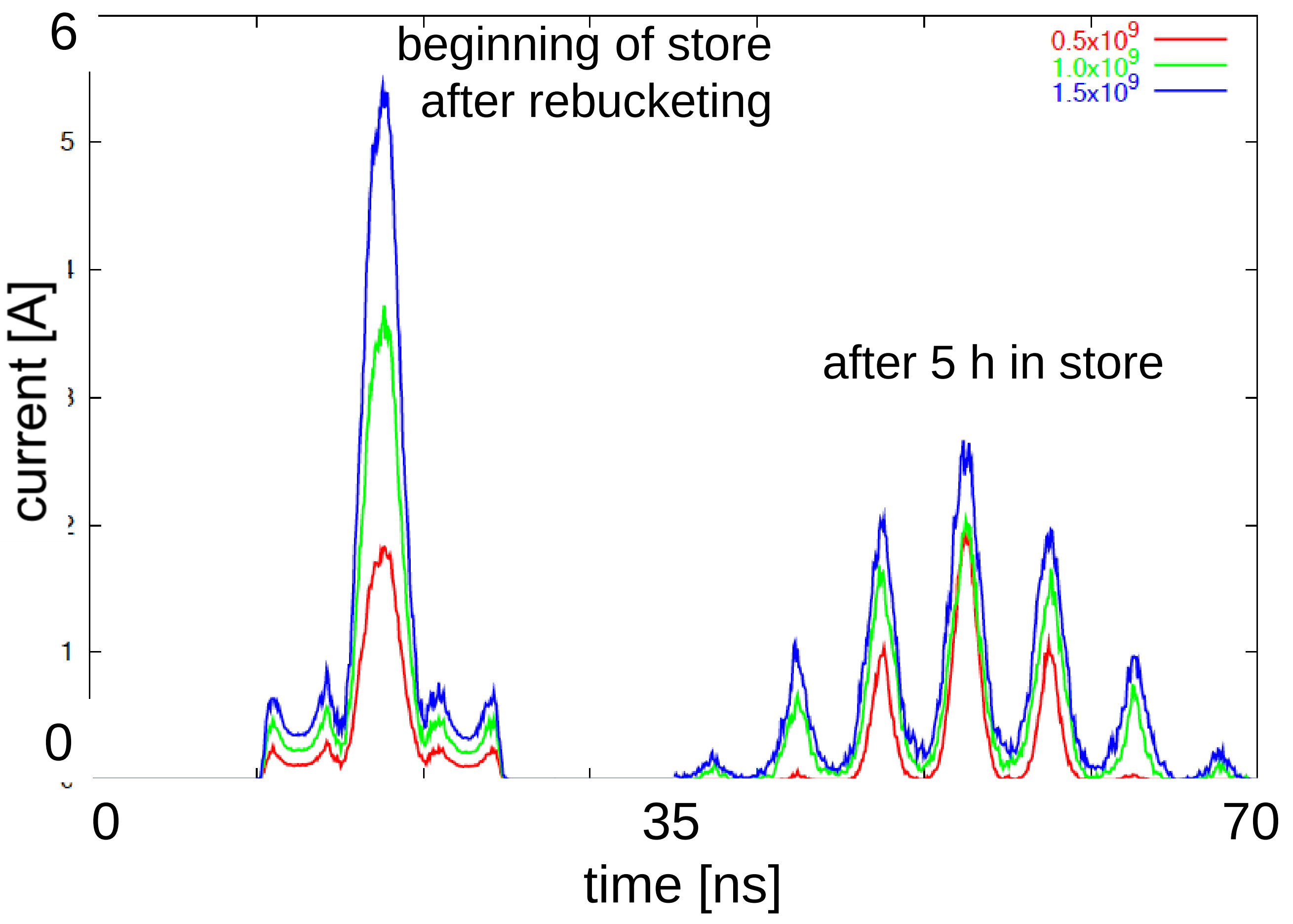
HE LHC: Adjust heating to maintain same emittances in both beams.

(Known effect from SppS, HERA, RHIC.)

RHIC store evolution with 3D stochastic cooling

Simulation by M. Blaskiewicz

Longitudinal profiles with h_1 = 360 (360 kV) and h_2 = 7x360 (4 MV)

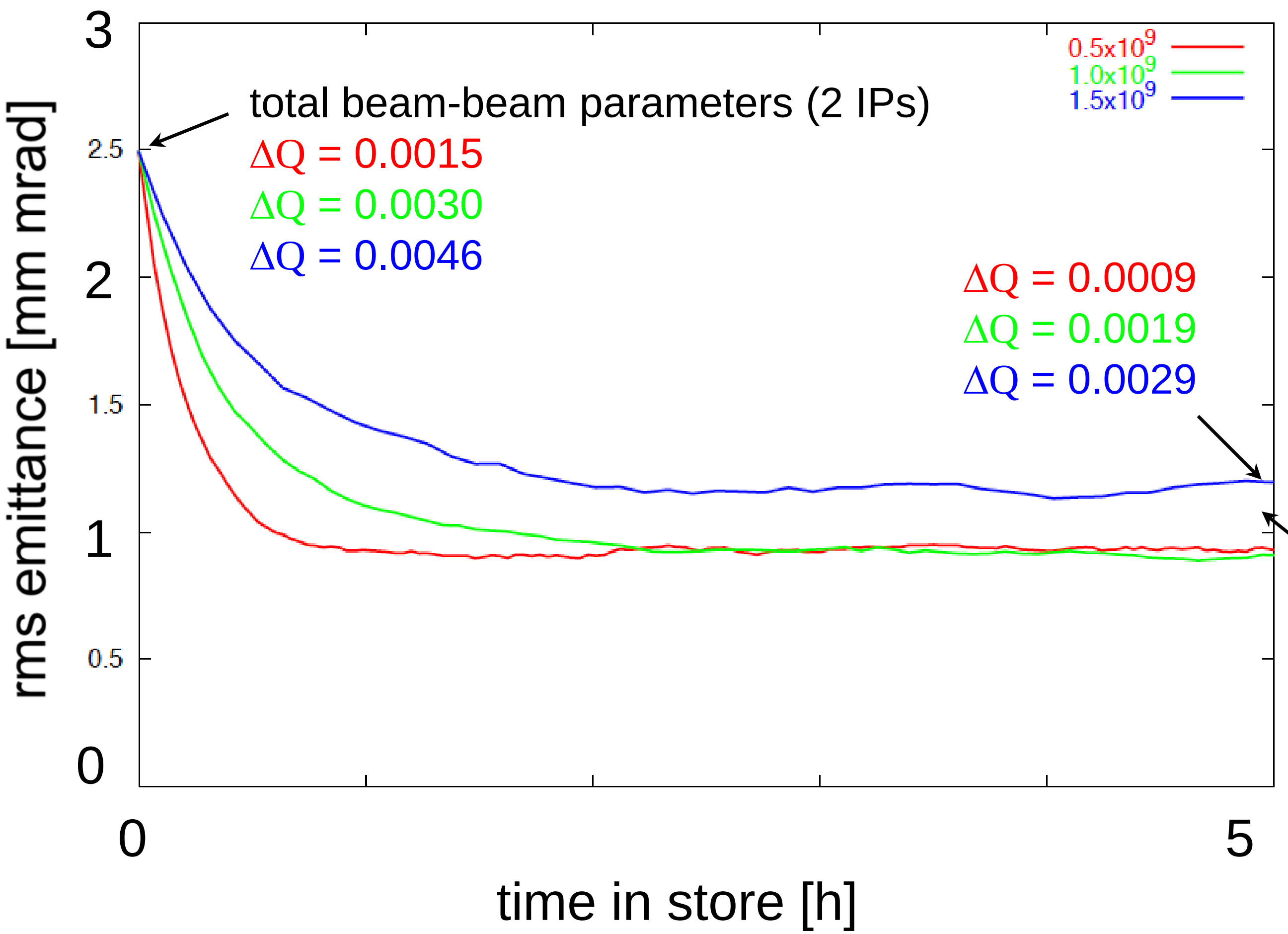


Au beam with
N_b = 0.5x10^9
N_b = 1.0x10^9
N_b = 1.5x10^9

Simulations have matched observable cases so far.

RHIC store evolution with 3D stochastic cooling

Simulation by M. Blaskiewicz



Au beam with
$N_b = 0.5 \times 10^9$
$N_b = 1.0 \times 10^9$
$N_b = 1.5 \times 10^9$

Expect ~3x larger ΔQ with 56 MHz SRF (under construction)

Then closer to LHC.

Summary

LHC

- LHC damping times of 1h (long.) and 2h (transv.) much shorter than IBS growth times (>50h)
- Heating required to maintain constant beam-beam parameter $\xi \sim 0.01$ (increase in ξ allows for more luminosity or a reduction in intensity)

RHIC

- Observations and simulations of IBS induced emittance growth generally agree well, evolution of with stochastic cooling predictable.
- With cooled Au beams not yet operating at beam-beam limit (need new 56 MHz SRF to reduce debunching, >= 2013)
- Even at relatively small beam-beam parameters, equal cooling in both beams (= equal heating in HE LHC) is necessary to maintain good beam lifetimes