INTRA-BEAM SCATTERING MEASUREMENTS IN RHIC

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European Particle Accelerator Conference
Paris
6 June 2002

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Motivation

- Intra-beam scattering limits beam and luminosity lifetimes in RHIC with gold beams

  - Longitudinal $\rightarrow$ debunching
    (THPRI073 – A. Drees, et al., "Abort Gap Cleaning in RHIC")

  - Transverse $\rightarrow$ emittance growth

- IBS will counteract electron cooling in RHIC
  (V. Parkhomchuk, I. Ben-Zvi, "Electron Cooling for RHIC", BNL C-A/AP/47, 2001)

- LHC heavy ion program — SPS at injection
  (D. Brand, L. Vos, CERN)

- IBS determines equilibrium beam size in linear collider damping rings
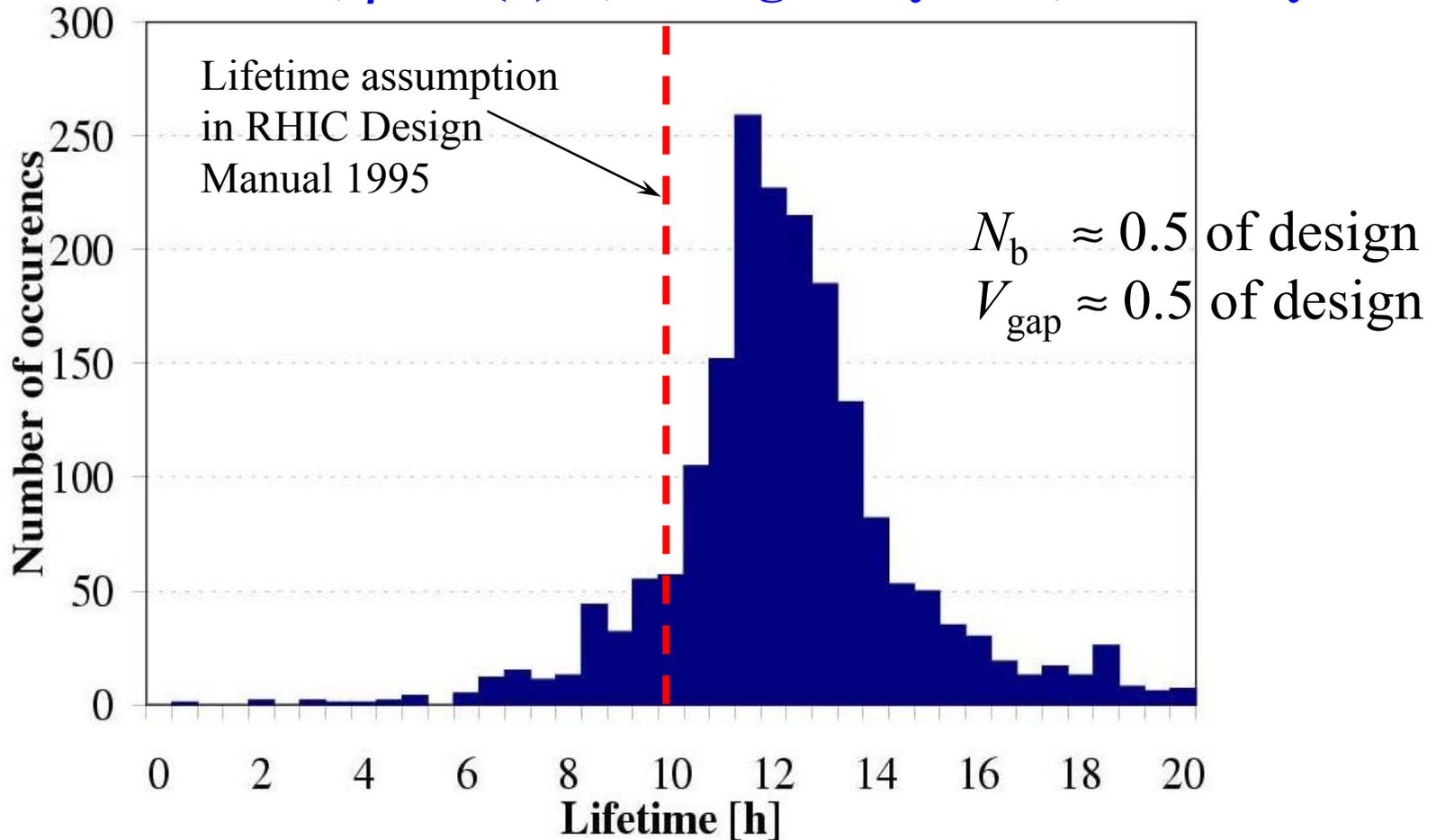 (K. Bane et al., ATF measurements, SLAC-PUB-8875, 2001)

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Debunching during store

Au^{79+} stores, β*=5m, N_b=0.25…0.4 · 10^9/bunch, storage rf system
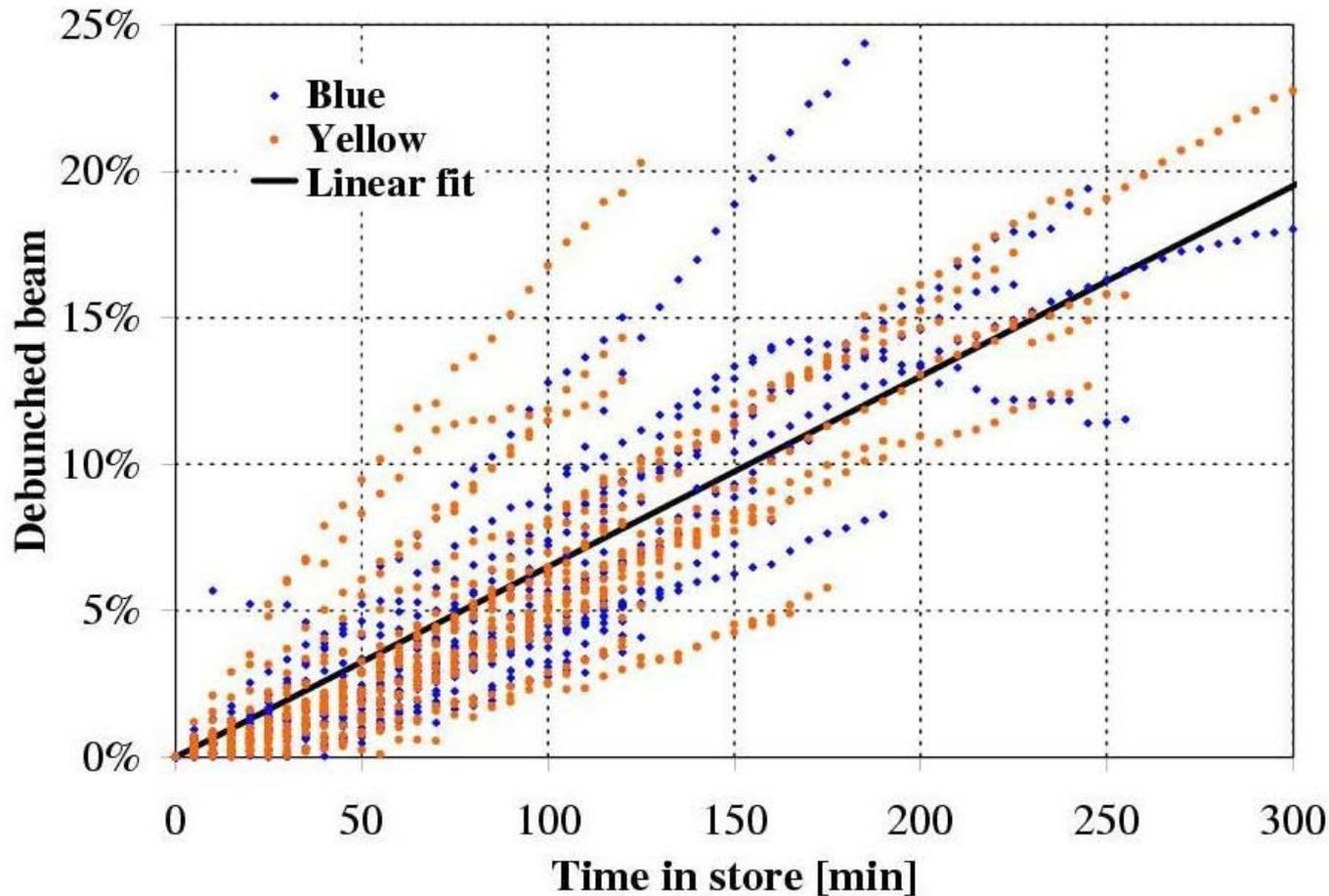
20% of beam debunched after 5 hours

Bunched beam lifetime

Au^{79+} stores, β^*=2(1)m, storage rf system, Blue only

Lifetime assumption
in RHIC Design
Manual 1995

$N_{\mathrm{b}} \approx 0.5$ of design
$V_{\mathrm{gap}} \approx 0.5$ of design

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Intra-beam scattering measurements

- Observe free expansion of bunches
  - Measure bunch length vs. time
  - Measure transverse emittance vs. time
- Measurements of
  - Au^{79+} beams at store and injection
  - p^+ beams at store
- Comparison with IBS simulations
  - 90 min at store   (typical store: 5 hours)
  - 15 min at injection (typical injection: 5 min)

RHIC parameters 2001/02

	unit	Au^{79+} injection	Au^{79+} store	p$^+$ store
relativistic γ	…	10.5	107	107
ions per bunch N_b	10^9	0.2 … 0.7		100
rms emittances $\varepsilon_{x,y}$	μm	2.0	2.5	3.5
rms bunch length	m	1.4	0.3	1.0
gap voltage V_{gap}	MV	0.3	3.0	0.3
		Accelerating rf system 28 MHz	**Storage rf system 197 MHz**	**Accelerating rf system 28 MHz**

Bunch length measurements

Turn number

Geometric phase [degrees]

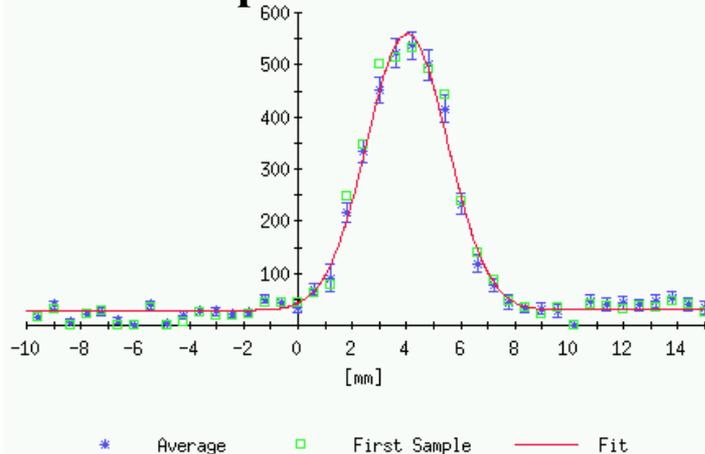145 ns
4 accelerating buckets
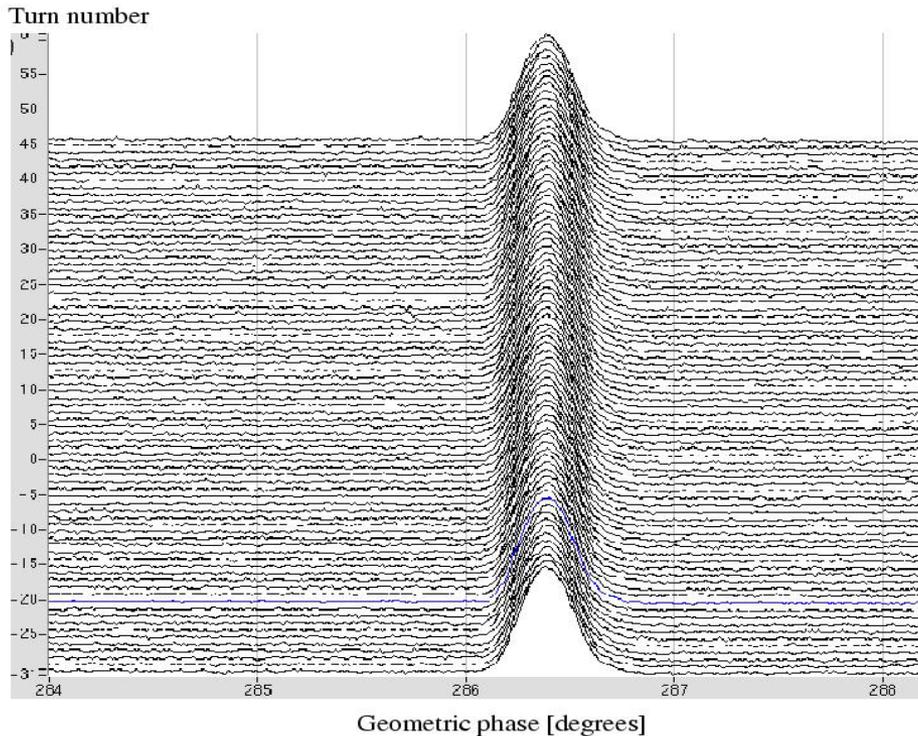
Wall Current Monitor

- **time resolution 0.25 ns**
  (buckets: 35 ns and 5 ns)
- **recording period 0.1…5 min**
- **used for:**
  - **bunched current**
  - **bunch length**
    (Gaussian fit)

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Transverse emittance measurements

Ionization profile and Gaussian fit
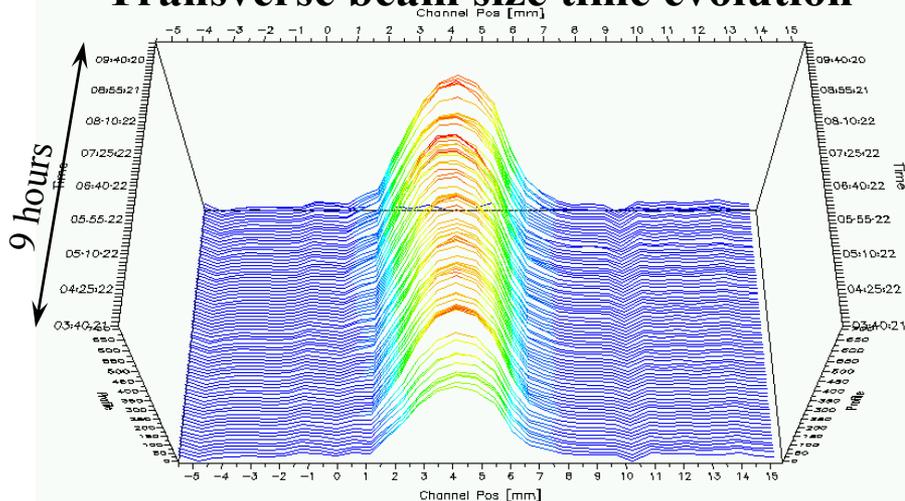

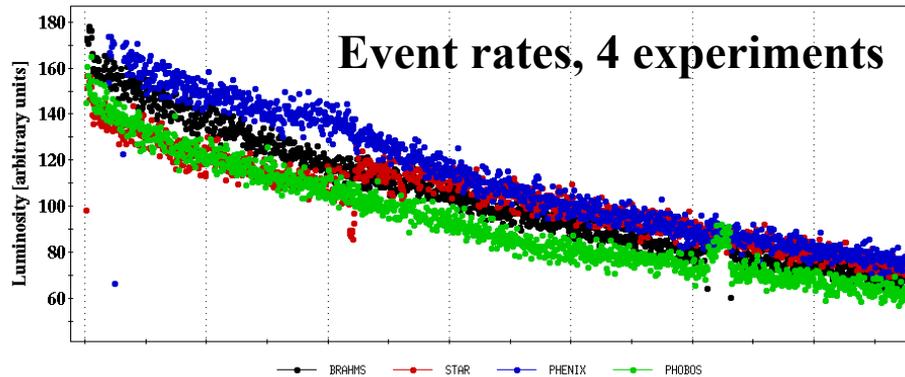## Transverse beam size time evolution

Ionization Profile Monitor

R. Connolly, S. Tepikian

- recording period 0.5…5 min
- not always reliable data
  - stray electrons
  - horizontal monitor position not optimal
  - small rest gas ionization with protons
- used:
  - at injection
  - calibration at store
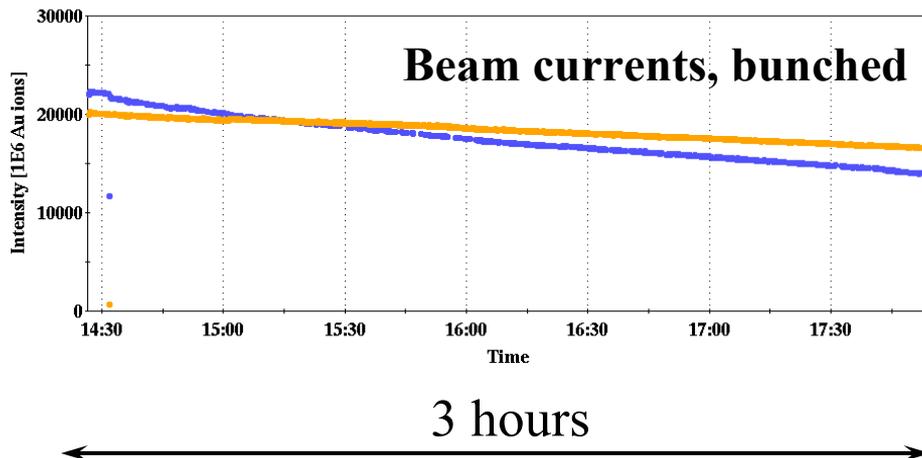
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Transverse emittance measurements — store

At store emittance derived from luminosity signal and bunched beam currents

- **assumes same emittances for both rings and planes**
- **allows to analyze all available store data**

Event rates, 4 experiments

BRAHMS   STAR   PHENIX   PHOBOS

Beam currents, bunched

3 hours

$$\varepsilon(t) = f \frac{N_B(t)N_Y(t)}{L(t)}$$

Determined with
- IPM data
- Measured beam-beam tune shift

- Used program by J. Wei
  (based on PAC'93 article, following work by
  Piwinski, Möhl, Sacherer, Martini, Parzen)

- Only FODO cells included

- Compact code, easy to simulate large number of cases (= individual measurements)

- Assume fully coupled beams ($\varepsilon_x=\varepsilon_y$),
  typical $\Delta Q_{min} \approx 0.01$ at injection and storage

- Beam loss explicitly included

- Analyzed 22 stores with 2420 bunches

- Intensity $0.2\ldots0.4 \cdot 10^9$ Au^{79+} ions per bunch

- Only stores with β*=5m considered,
  significantly larger Δε/ε with β*=2(1)m,
  suspect Yellow triplet errors

- Bunch length averaged over 55 bunches

- Each store simulated separately with
  - Measured initial average bunch length
  - Measured initial average emittance

Storage — above transition

Bunch length σ $\tau_{\sigma,meas} \approx 8h$

Transverse emittance ε $\tau_{\varepsilon,meas} \approx 6h$
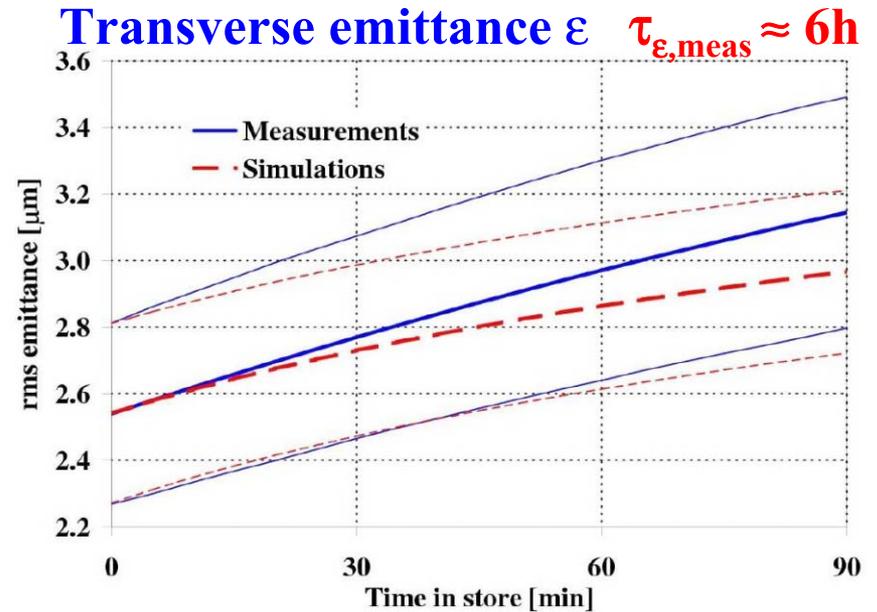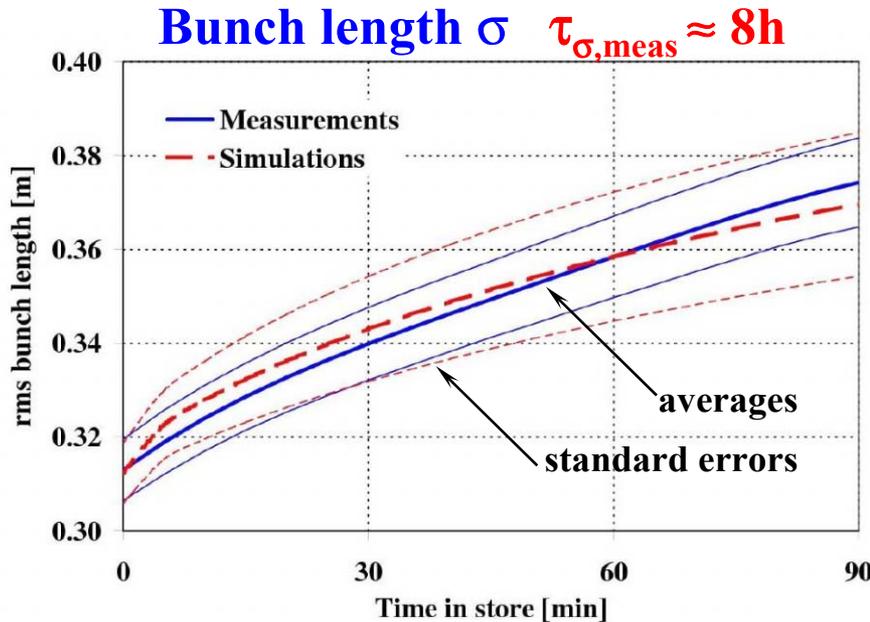
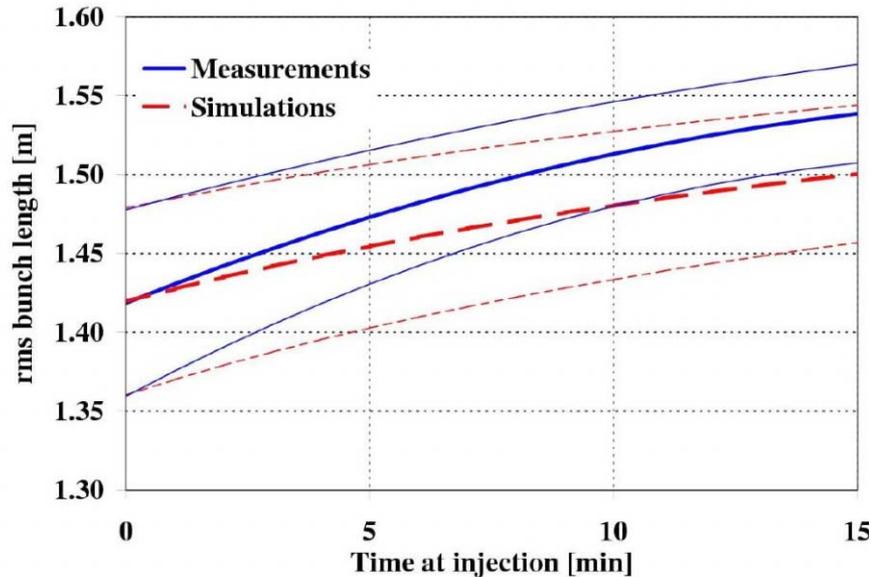| After 90 min	Δσ/σ	Δε/ε
Measured Au	20%	24%
Computed Au	18%	17%
Measured p		5%

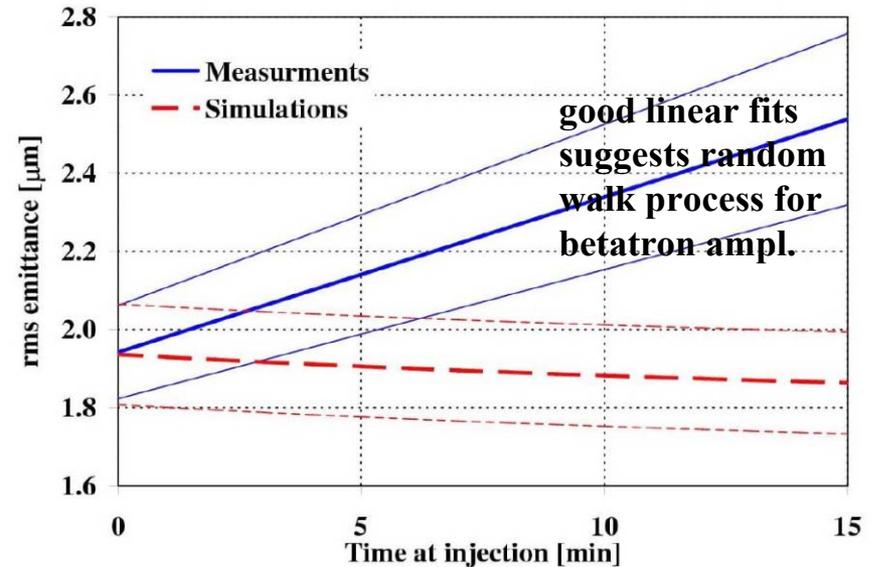- IBS growth rates smaller by factor 10
- Beam-beam stronger by factor 2

- Less data than at store

- 8 bunch length measurements, 7 transverse emittance growth measurements

- Intensity $0.4 \ldots 0.7 \cdot 10^9$ Au^{79+} ions per bunch

- Only 3 cases with longitudinal and transverse data at the same time

- All bunch length measurements simulated; if emittance not available, average substituted

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Injection — below transition

Bunch length σ $\tau_{\sigma,meas} \approx 3h$ **Transverse emittance ε $\tau_{\varepsilon,meas} \approx 1h$**

good linear fits suggests random walk process for betatron ampl.

After 15 min	$\Delta\sigma/\sigma$	$\Delta\varepsilon/\varepsilon$
Measured Au	8%	31%
Computed Au	6%	–4%

IBS measurements in RHIC — summary

- Intra-beam scattering limits beam and luminosity lifetimes in RHIC with gold beams
- Measured free expansion of beam
  - At store with Au^{79+} and p^+ (above transition)
  - At injection with Au^{79+} (below transition)
- At store good agreement with simulations:
  - Longitudinally without adjustments
  - Transversely after accounting for non-IBS growth, estimated with p^+ measurements
- At injection:
  - Longitudinally reasonable agreement (discrepancy may be due to transverse growth)
  - Transversely large growth observed, non-IBS

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