Beam Induced Pressure Rise in RHIC

Wolfram Fischer

Thanks to

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H. Huang, U. Iriso-Ariz, L. Smart, S.Y. Zhang

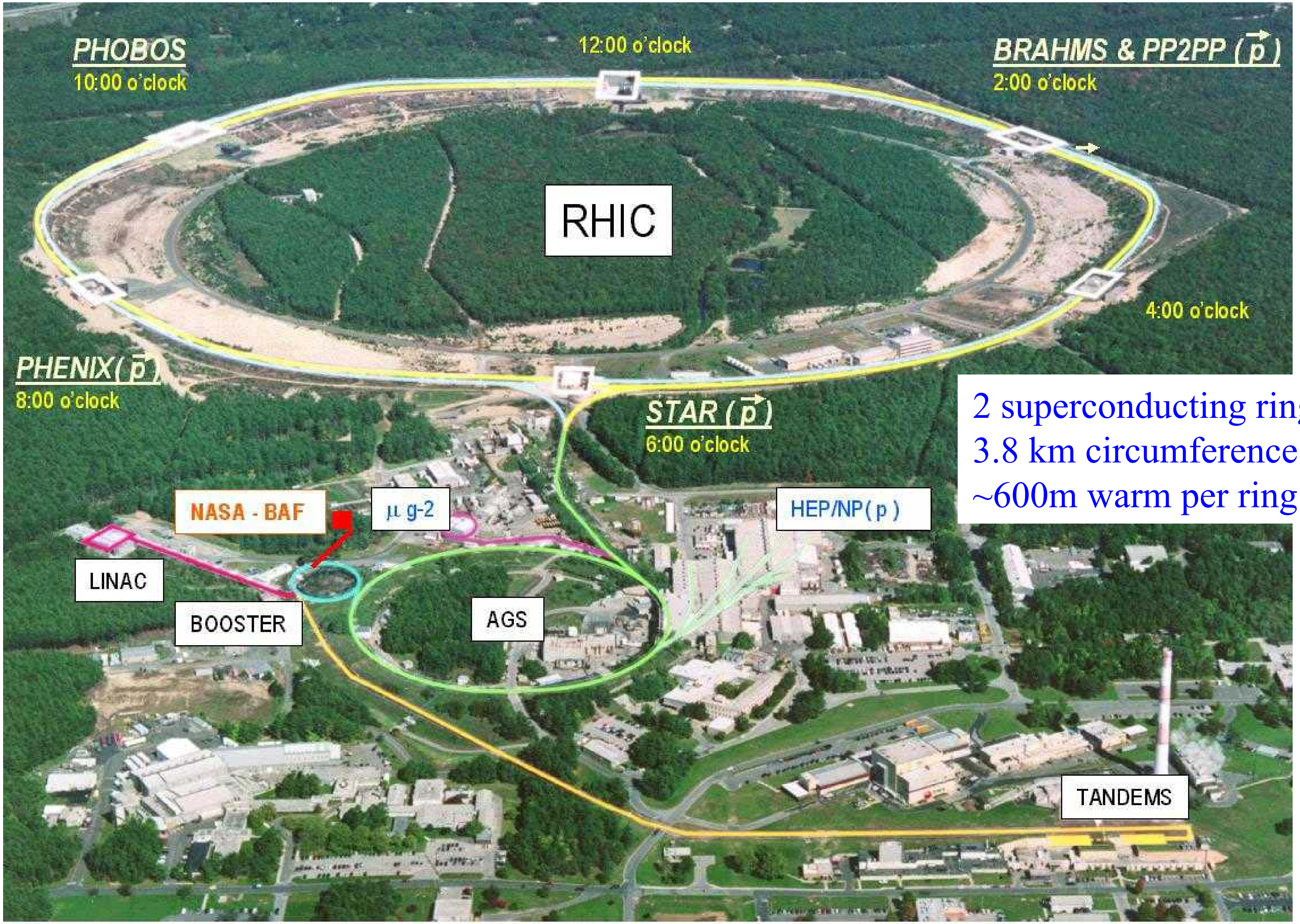
BROOKHAVEN NATIONAL LABORATORY

13th ICFA Beam Dynamics Mini-Workshop on
"Beam Induced Pressure Rise in Rings"
9 December 2003

Beam Induced Pressure Rise in RHIC

When filling RHIC with intense ion beams, pressure rises are observed that are high enough to cause experimental backgrounds or even prevent machine operation. Currently this is one of the most severe limitations in the quest for higher luminosity. Pressure rises were observed with all ion species in RHIC: gold, protons and deuterons. While electron clouds were clearly established as a source of beam induced pressure rises, the role beam loss induced desorption is still under investigation. We summarize the observations, the effect of corrective actions taken, and plans for further improvements.

1. Introduction
2. Vacuum test equipment
3. Observations
   - Injection
   - Transition
4. Counter measures
   - Solenoids
   - NEG coated pipes
   - Bunch patterns
   - Scrubbing
5. Summary



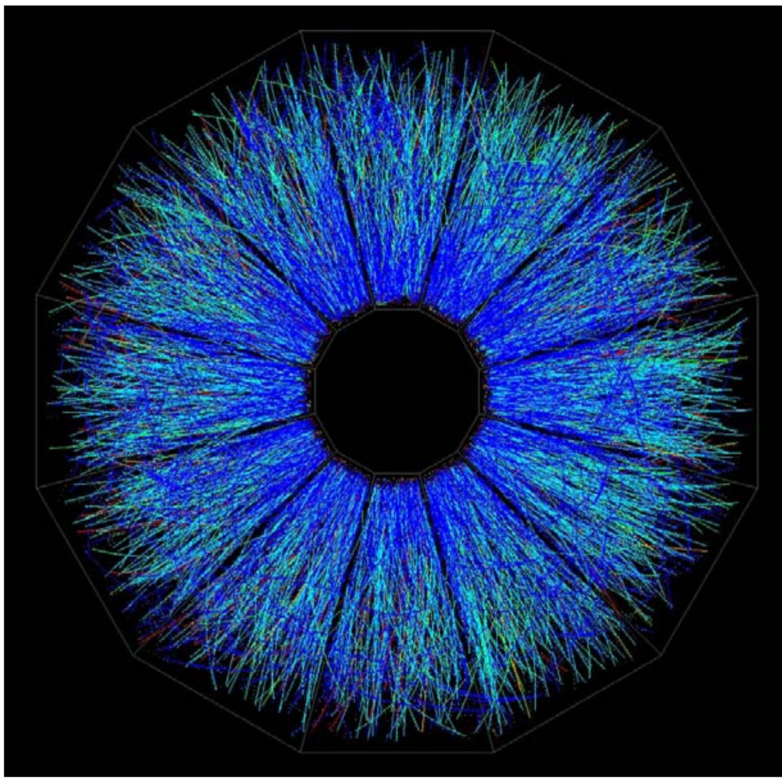
2 superconducting rings
3.8 km circumference
~600m warm per ring

- Four experiments (2 large, 2 small), different preferences
- More flexibility than at other hadron colliders
  - Variation in particle species, also asymmetric
    → So far Au+Au, d+Au, p↑+p↑, others possible
  - Variation in energy
    → Au+Au at 10, 66, 100 GeV/u
    → p↑+p↑ at 100 GeV (250 GeV planned in year after next)
  - Variation in lattice
    → Low β* in most cases (1-3 m)
    → Large β* for small angle scattering experiments (>10 m)
    → Polarity change in large experimental magnet about every 2 weeks
- Short runs (~30 wks/year), often with multiple modes
  - Significant amount of set-up time required
  - Difficult to achieve large integrated luminosity

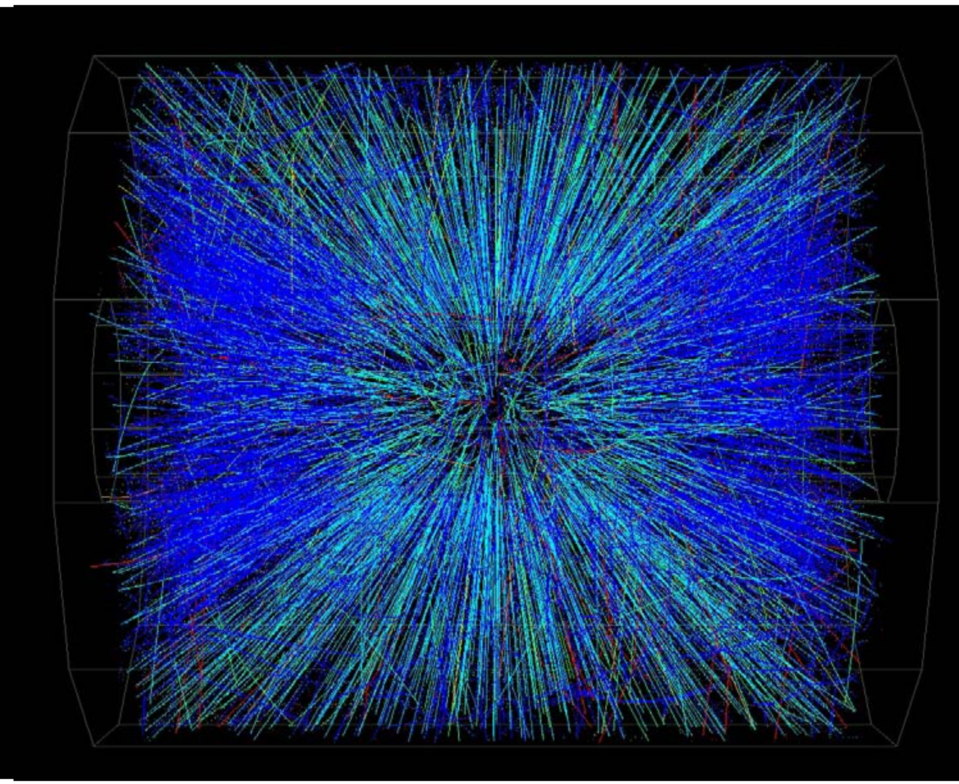
→ Further luminosity limitations hinder experimental programs (heavy ions <u>and</u> polarized protons)

Au+Au collision seen by the STAR detector

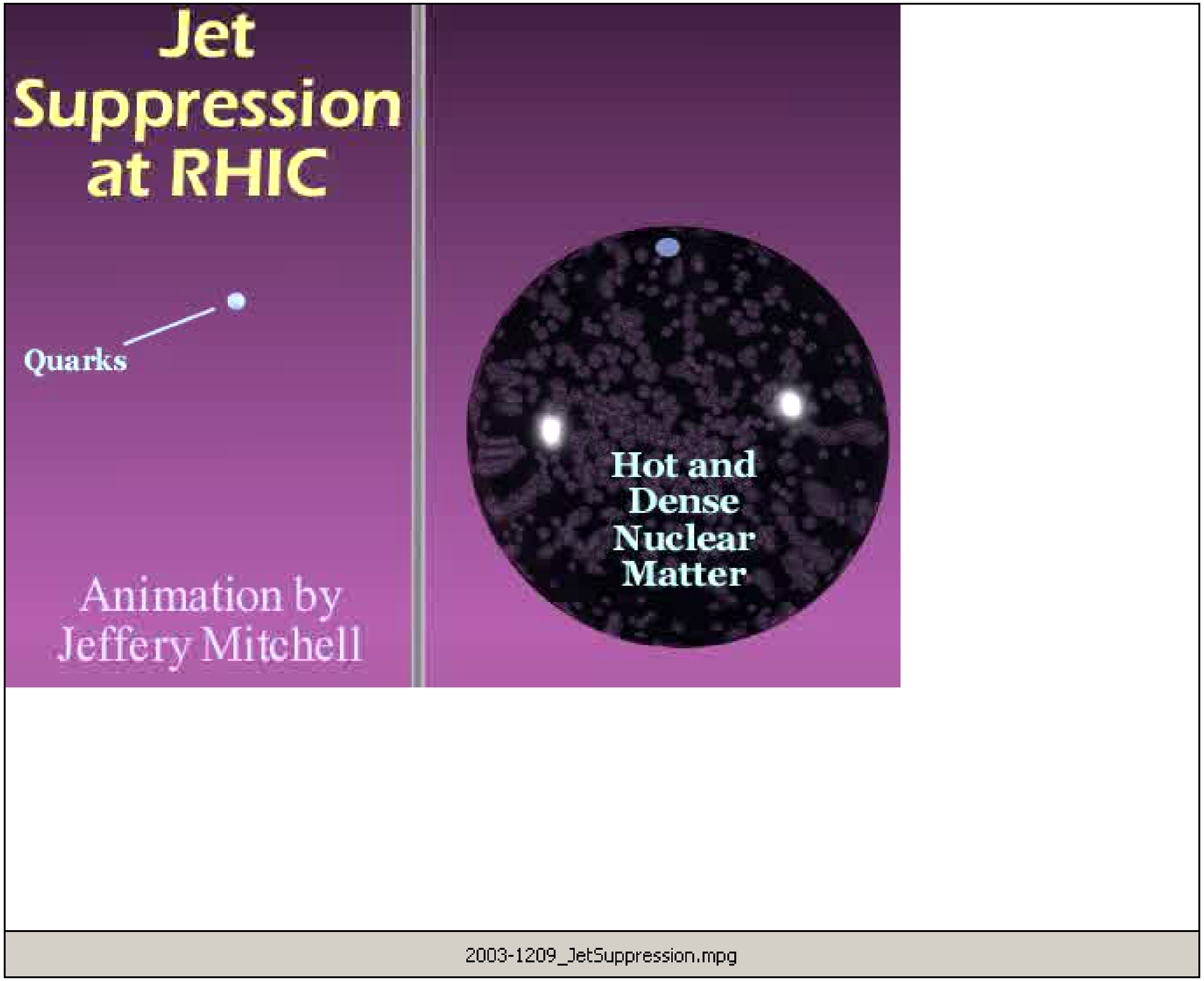
— a few thousand tracks —



along beam direction



sideways



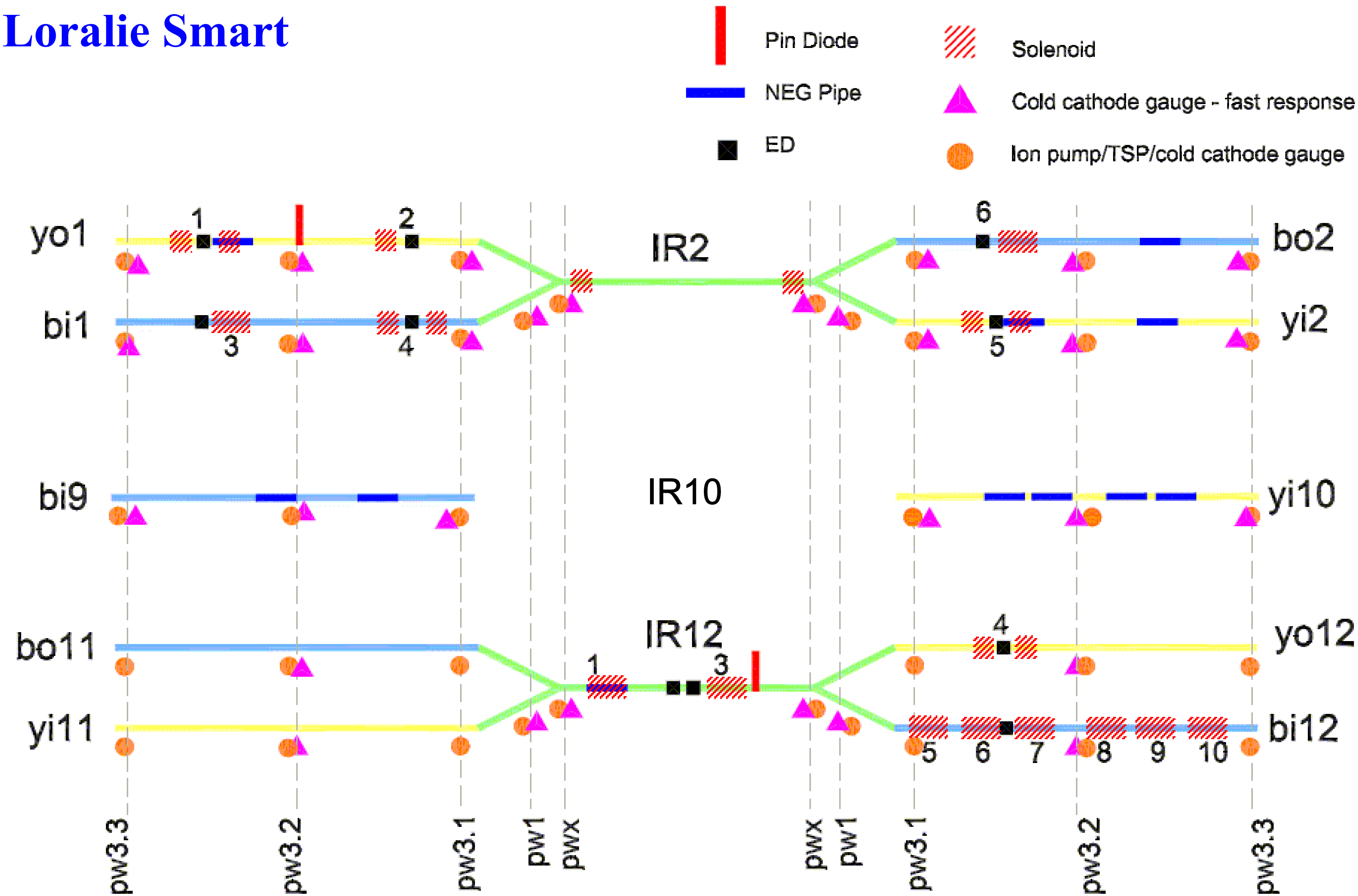
Mini video by Jeffrey Mitchell, PHENIX

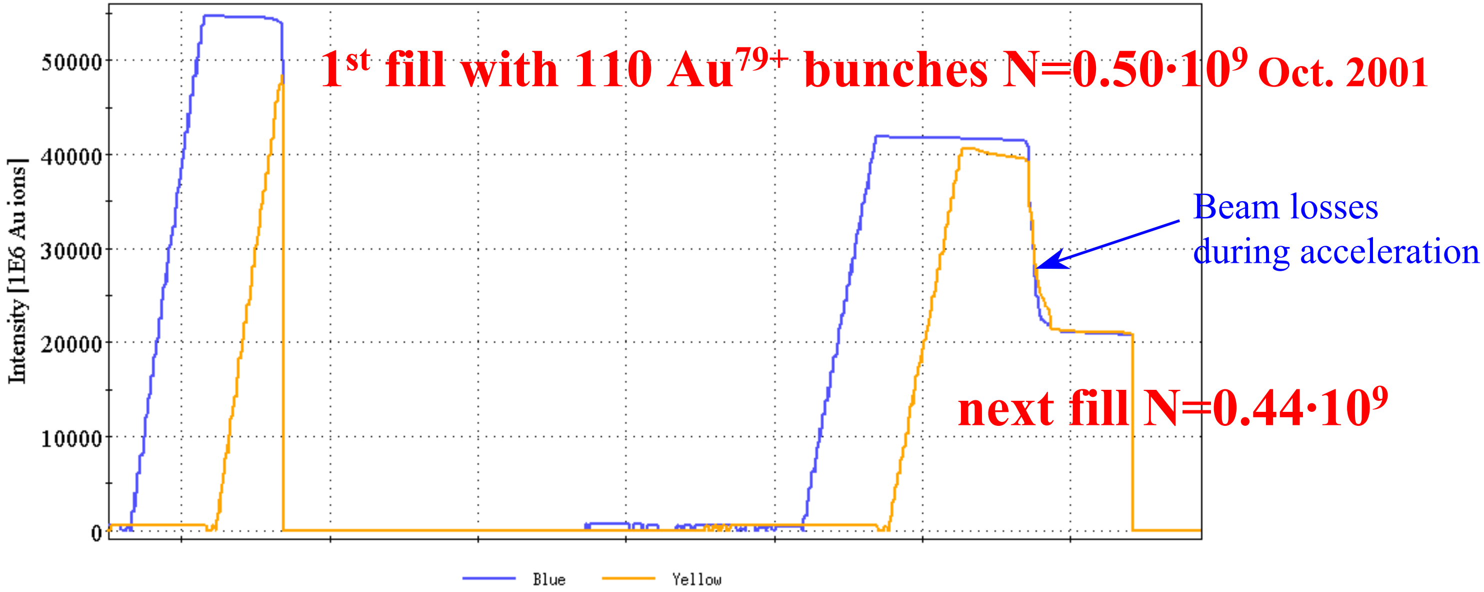
- d+Au similar to p+p
- Au+Au is different: High p_T particles are suppressed in collisions
- **Au+Au forms opaque state of matter that has not existed since shortly after the Big Bang (~13 billion years ago)**

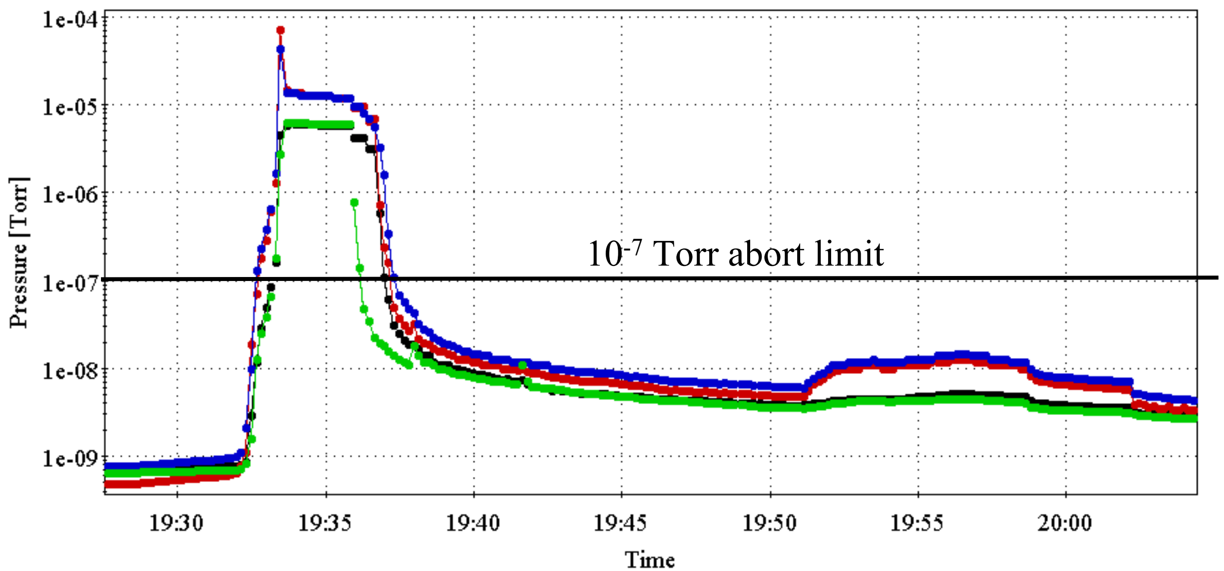
[not yet called QGP, quark-gluon plasma]

- Pressure gauges
- Residual gas analyzers
- 16 electron detectors
  - 11 RHIC e-detectors
  - 4 SNS e-detectors
  - 1 ANL e-detector
  - 1 Micro-channel plate
- 64m of solenoids
  - Maximum field: 6.8 mT [68 G]
- 60m of NEG coated pipes

Loralie Smart




1st fill with 110 Au79+ bunches N=0.50·10^9 Oct. 2001
Beam losses
during acceleration
next fill N=0.44·10^9
Intensity [1E6 Au ions]
50000
40000
30000
20000
10000
0
Blue
Yellow


Pressure [Torr]
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
10-7 Torr abort limit
19:30
19:35
19:40
19:45
19:50
19:55
20:00
Time

Pressure rise mechanisms considered so far

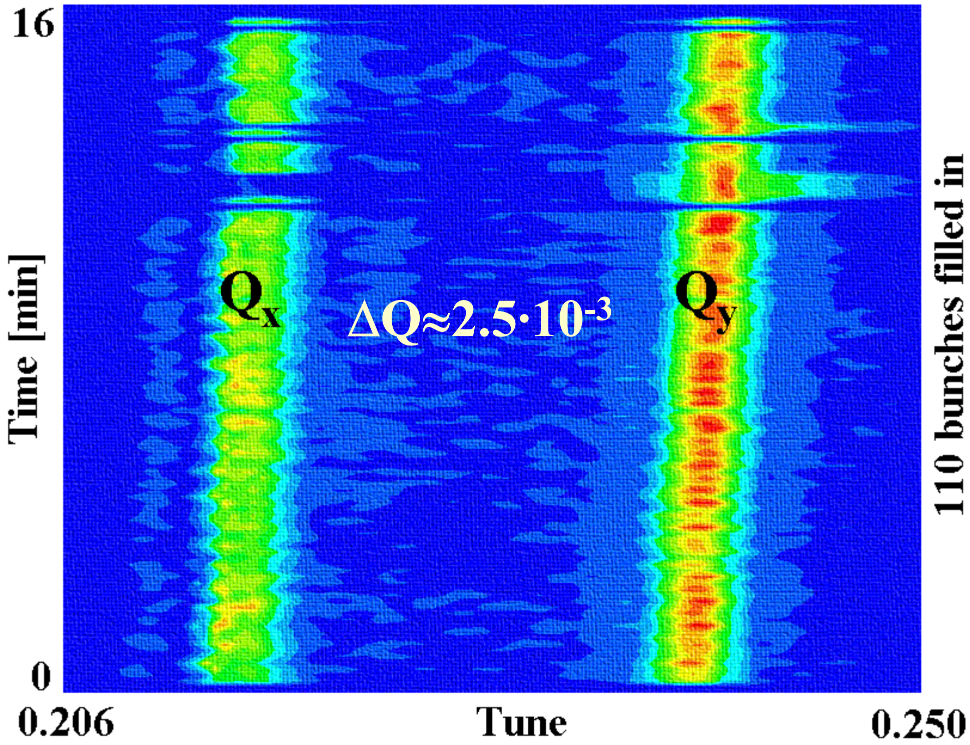
- Electron cloud → **confirmed, see later**
  - Coherent tune shift in bunch train
  - Electron detectors
- Ion desorption → **ruled out**
  - Rest gas ionization, acceleration through beam
  - Ion energies ~10eV
  - Effect too small to explain pressure rise at injection
- Beam loss induced desorption → **unclear, see later**
  - No reliable desorption coefficients
  - Need to have beam losses in all locations with pressure rise

[W. Fischer et al., "Vacuum pressure rise with intense ion beams in RHIC", EPAC'02]

	Au^{79+}	d^+	p^+
Pressure rise locations	only in warm beam pipes		
Injection			
Pressure rise observed	yes	yes	yes
E-clouds observed	no	yes	yes
Threshold, 108ns bunch spacing	$>0.6\cdot10^9$	$0.9\cdot10^{11}$	$0.9\cdot10^{11}$
Threshold, 216ns bunch spacing	$>0.8\cdot10^9$	$>1.3\cdot10^{11}$	$>0.8\cdot10^{11}$
Transition			
Pressure rise observed	yes	yes	N/A
Threshold, 108ns bunch spacing	no threshold		N/A
Threshold, 216ns bunch spacing	no threshold		N/A
E-clouds observed	yes with large losses	no	N/A

Indirect observation – coherent tune shift along bunch train

$33\cdot10^{11}$ p^+ total, $0.3\cdot10^{11}$ p^+/bunch, 110 bunches, 108 ns spacing (2002)



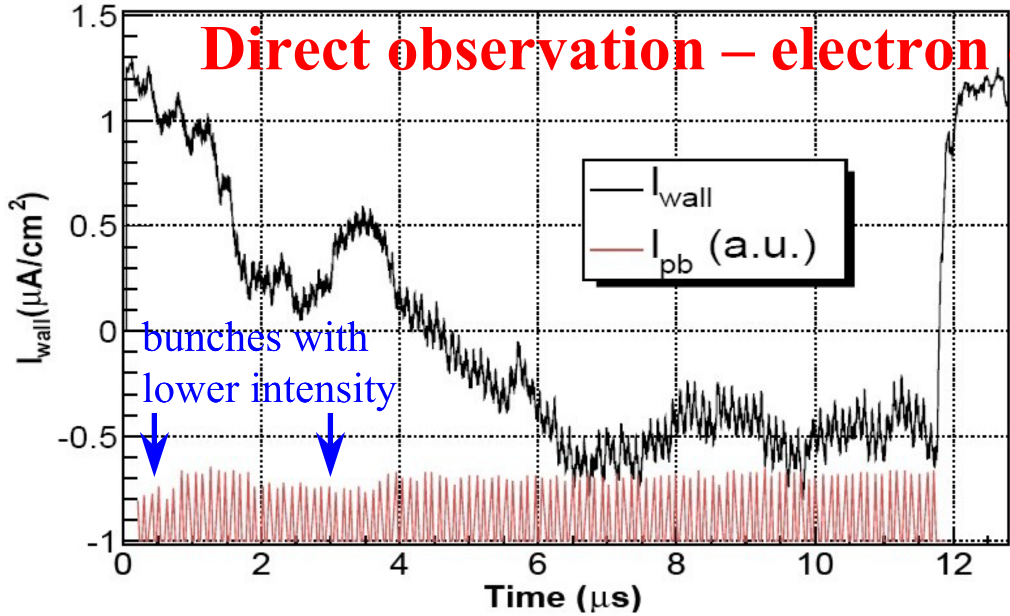
(1) From measured tune shift, the e-cloud density is estimated to be 0.2 – 2.0 $nC\cdot m^{-1}$

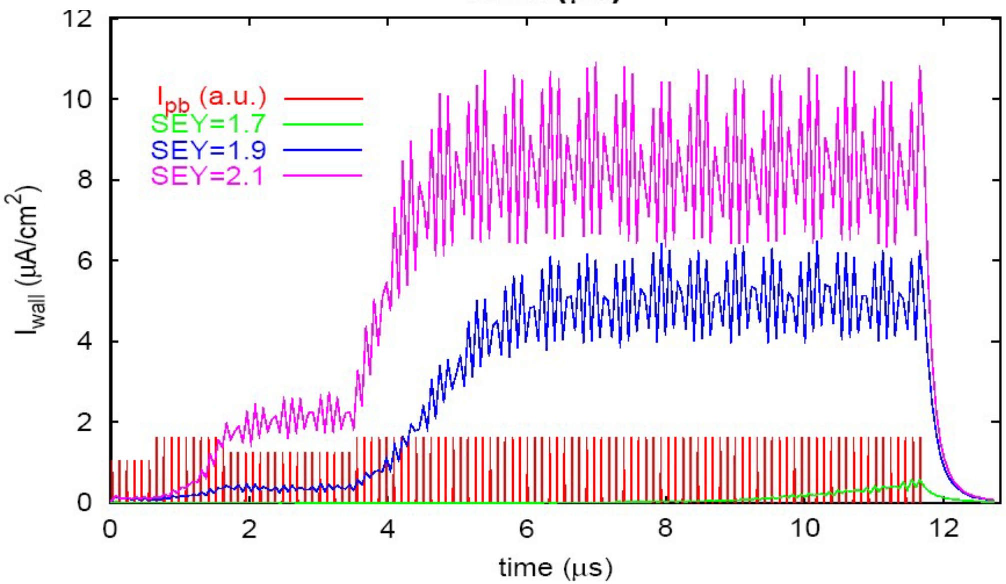
(2) E-cloud density can be reproduced in simulation with slightly higher charge and 110 bunches (CSEC by M. Blaskiewicz)

[W. Fischer, J.M. Brennan, M. Blaskiewicz, and T. Satogata, "Electron cloud measurements and observations for the Brookhaven Relativistic Heavy Ion Collider", PRSTAB 124401 (2002).]

Direct observation – electron detectors

U. Iriso-Ariz





Observation:

$88 \cdot 10^{11}$ p$^+$ total
$0.8 \cdot 10^{11}$ p$^+$/bunch
110 bunches
108 ns spacing

Simulation:

Variation of SEY$_{max}$: 1.7 to 2.1
Keep R=0.6
(reflectivity for zero energy)

Good fit for
SEY$_{max}$ = 1.8 and R=0.6

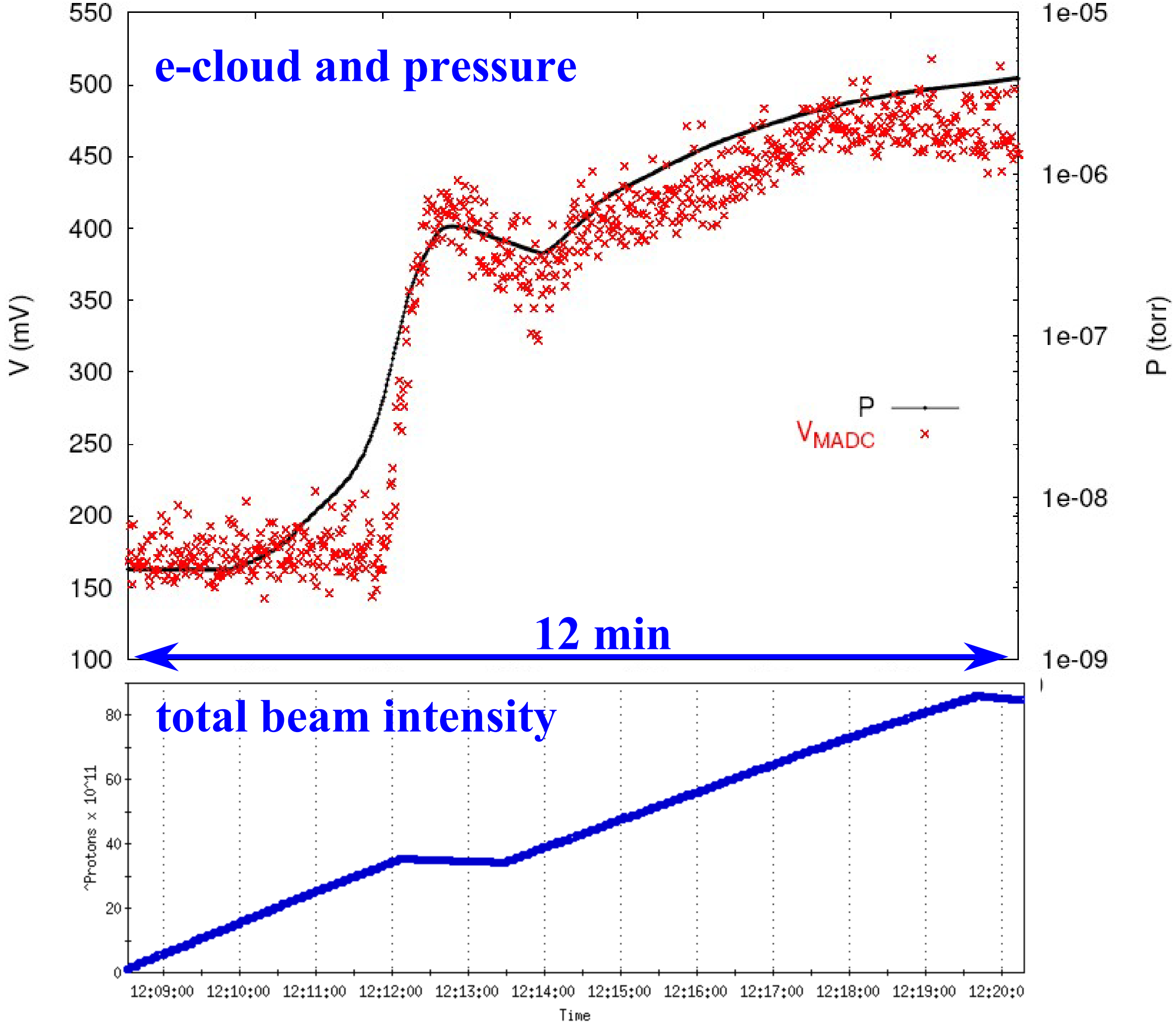
Code: CSEC by M. Blaskiewicz

[U. Iriso-Ariz et al. "Electron cloud and pressure rise simulations for RHIC", PAC'03.]

Electron cloud and pressure rise

86·10^{11} p^{+} total, 0.78·10^{11} p^{+}/bunch, 110 bunches, 108 ns spacing

U. Iriso-Ariz



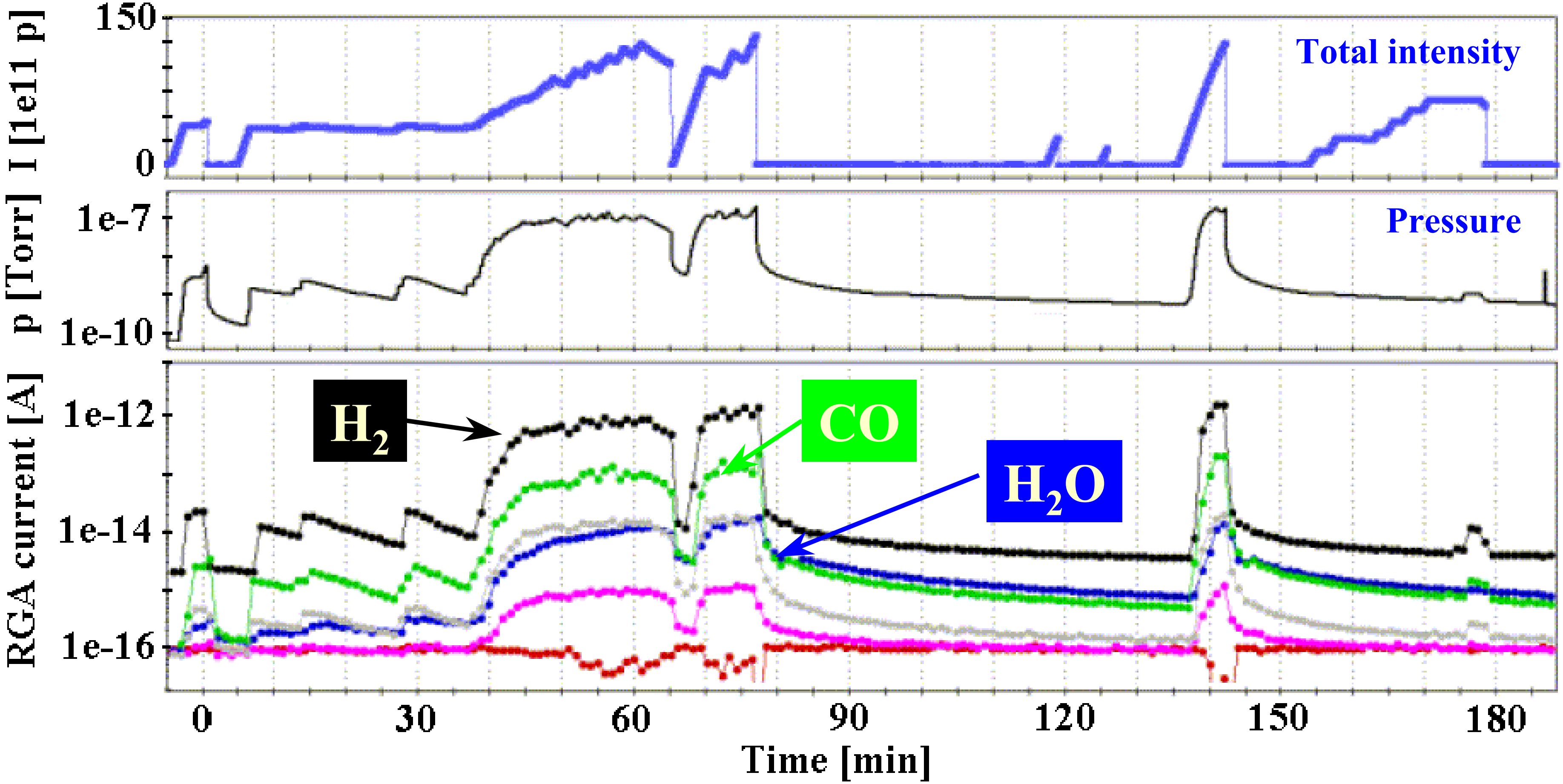
Clear connection between e-cloud and pressure at injection

Estimate for η_e assuming pressure caused by e-cloud: 0.001-0.02

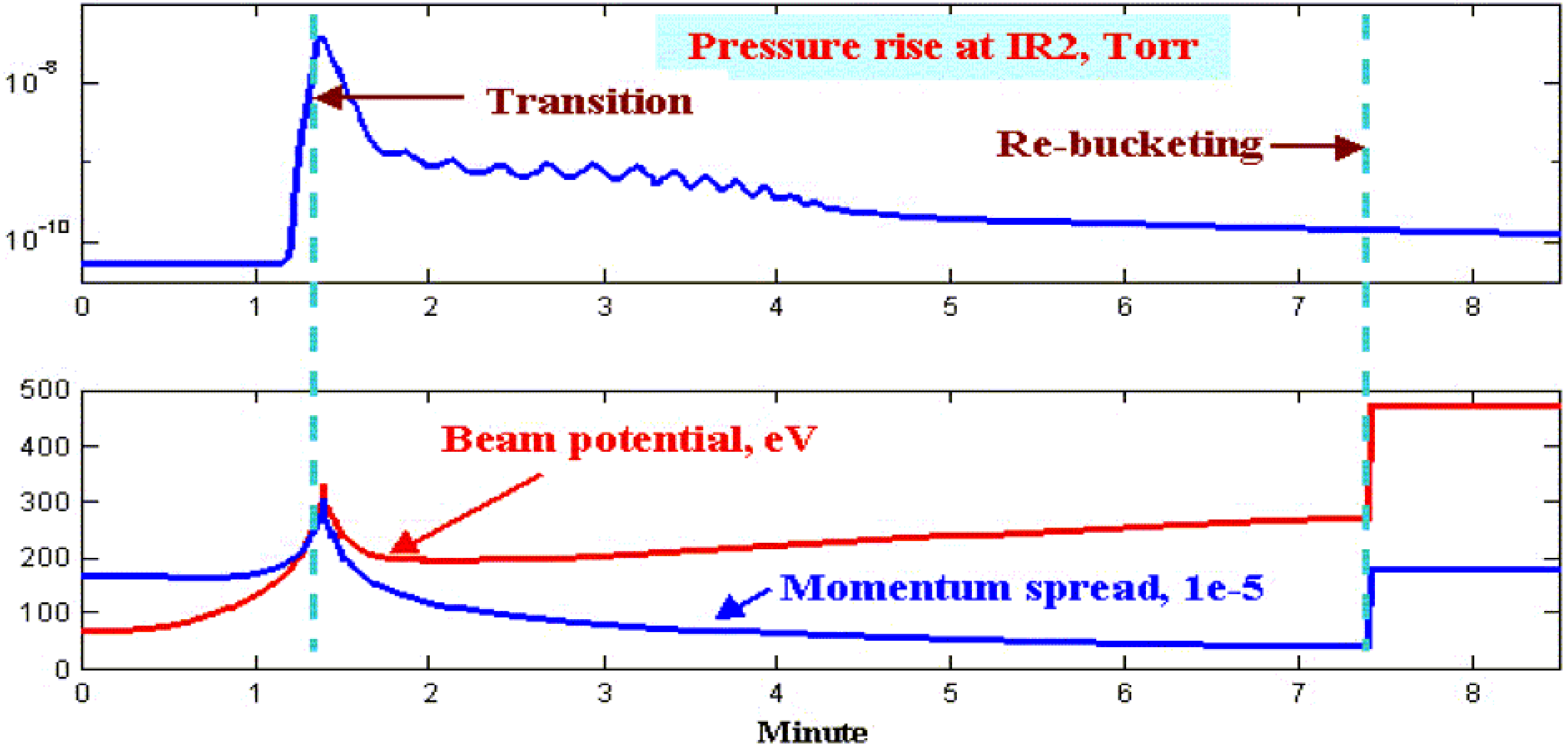
(large error from multiple sources)

[U. Iriso-Ariz et al. "Electron cloud observations at RHIC during FY2003", in preparation.]

Gas composition in IR12 during pressure rise **P. He**

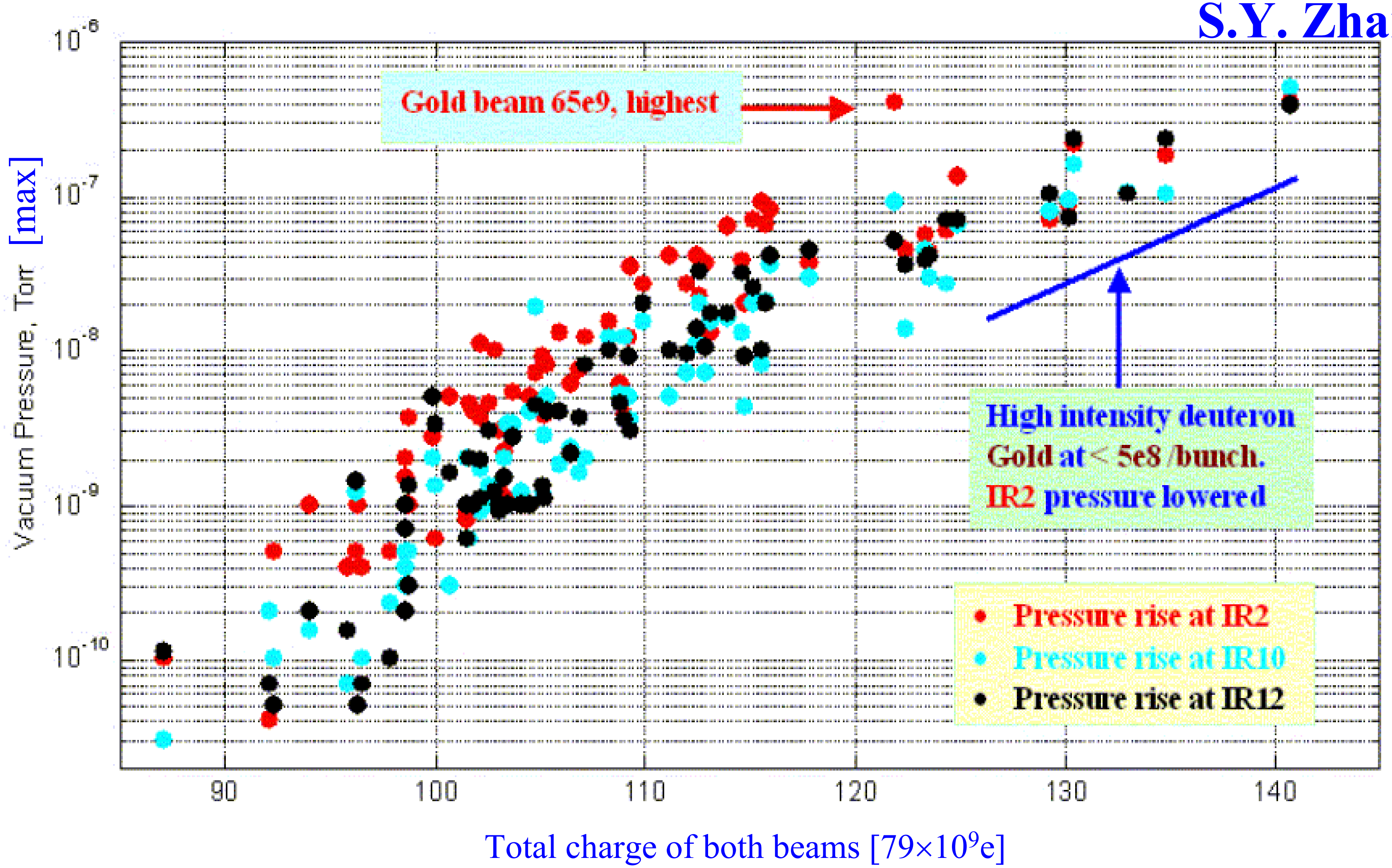


Pressure rise at transition (causes experimental background)
Transition:
- short bunches (4ns vs. 18ns at injection, → enhanced e-cloud)
- large momentum spread (possibly momentum scraping)



[S.Y. Zhang et al., "RHIC pressure rise and electron cloud", PAC'03 (2003)]

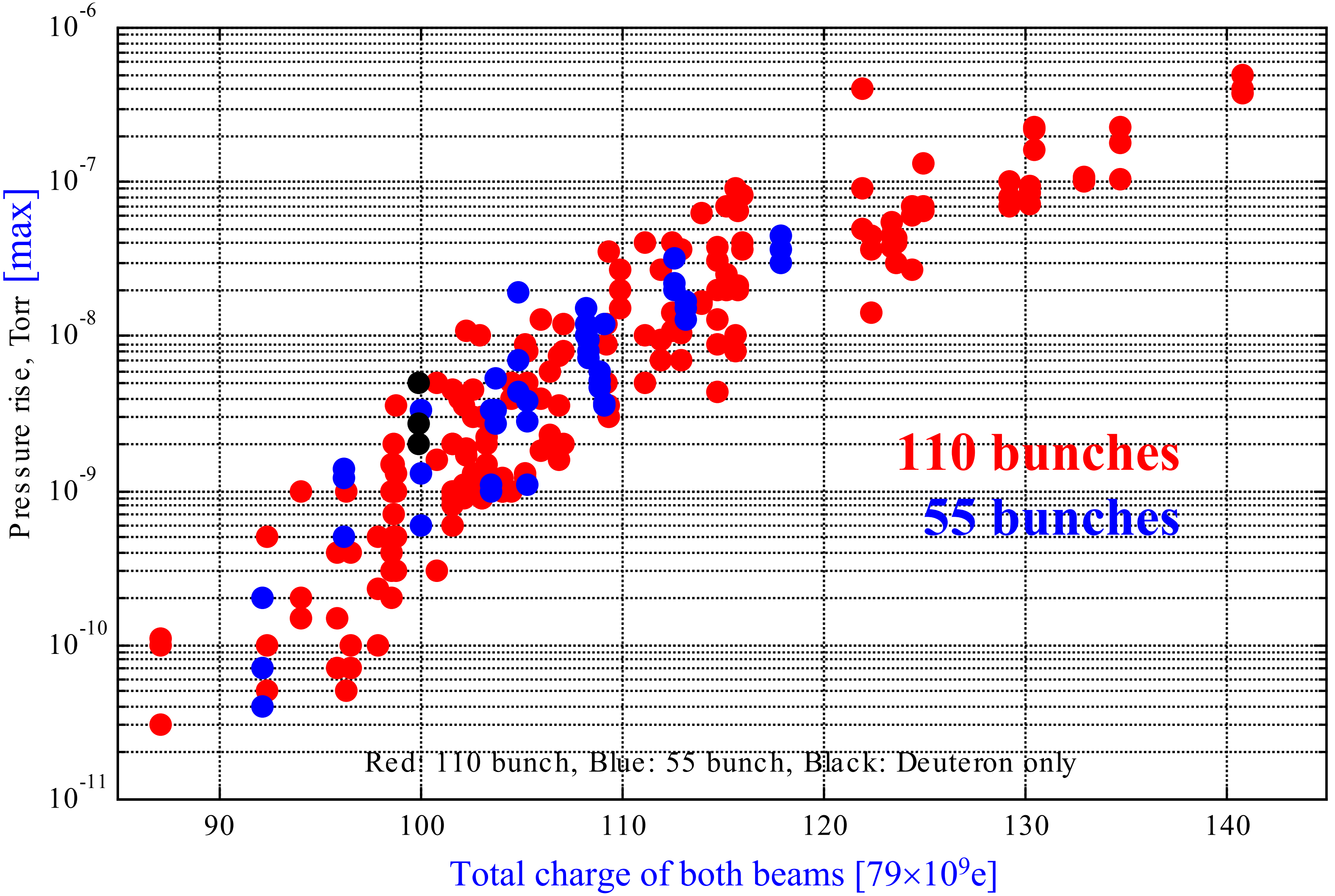
S.Y. Zhang



[S.Y. Zhang, "Experiment Background in RHIC Deuteron-Gold Run", BNL C-A/AP/107 (2003)]

Transition pressure rise not dependent on bunch spacing

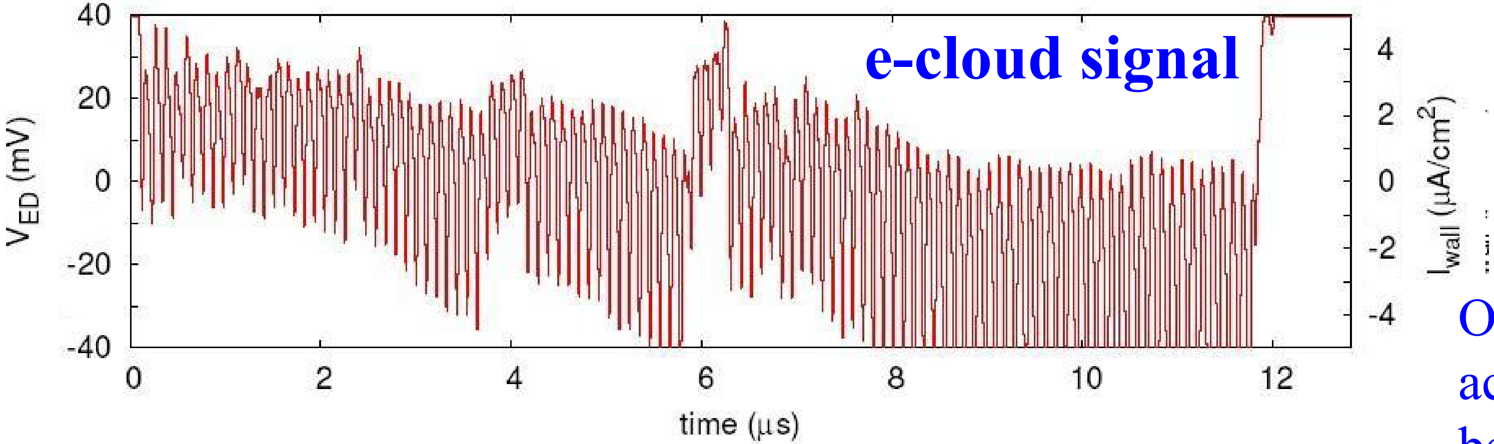
S.Y. Zhang

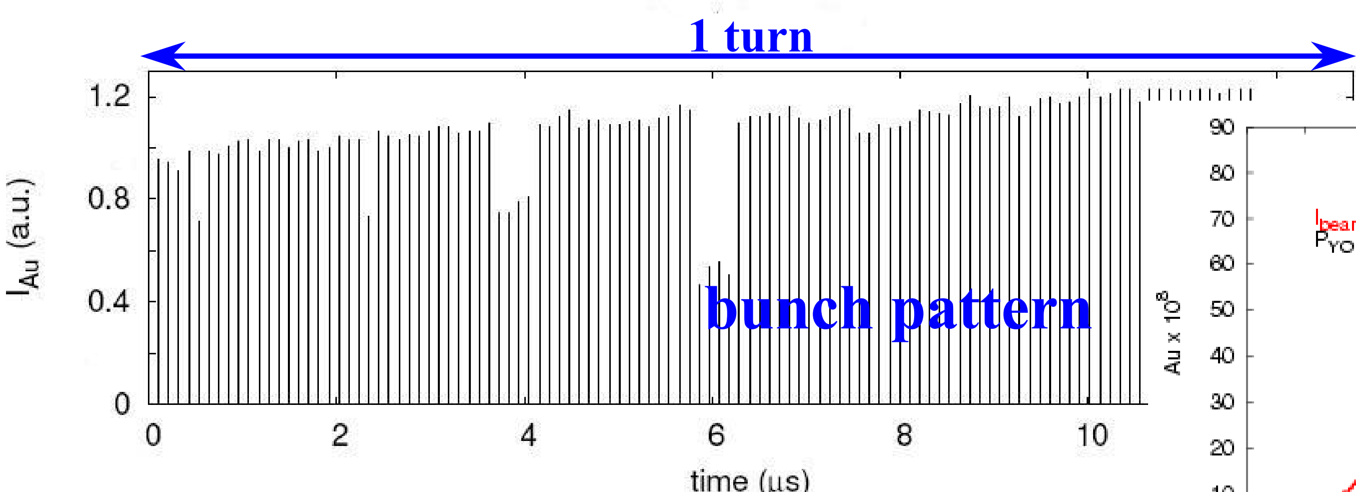


Only 1 direct e-cloud observation at transition, in conjunction with total beam loss

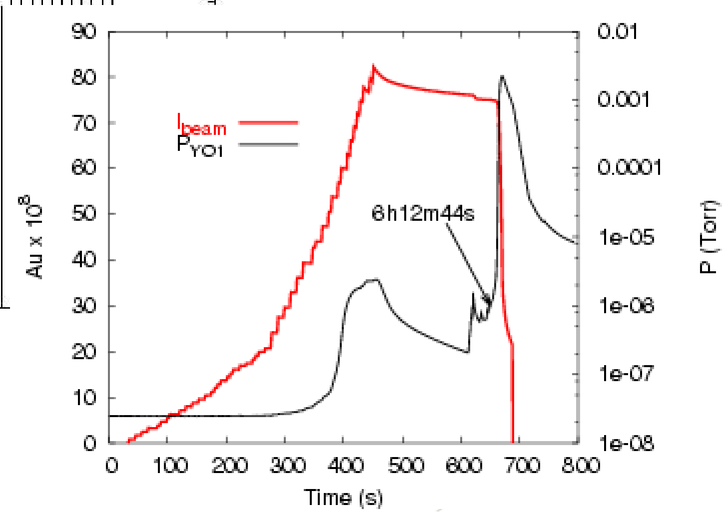
U. Iriso-Ariz

$82 \cdot 10^9$ Au^{79+} total, $0.75 \cdot 10^9$ Au^{79+}/bunch, 110 bunches, 108 ns spacing



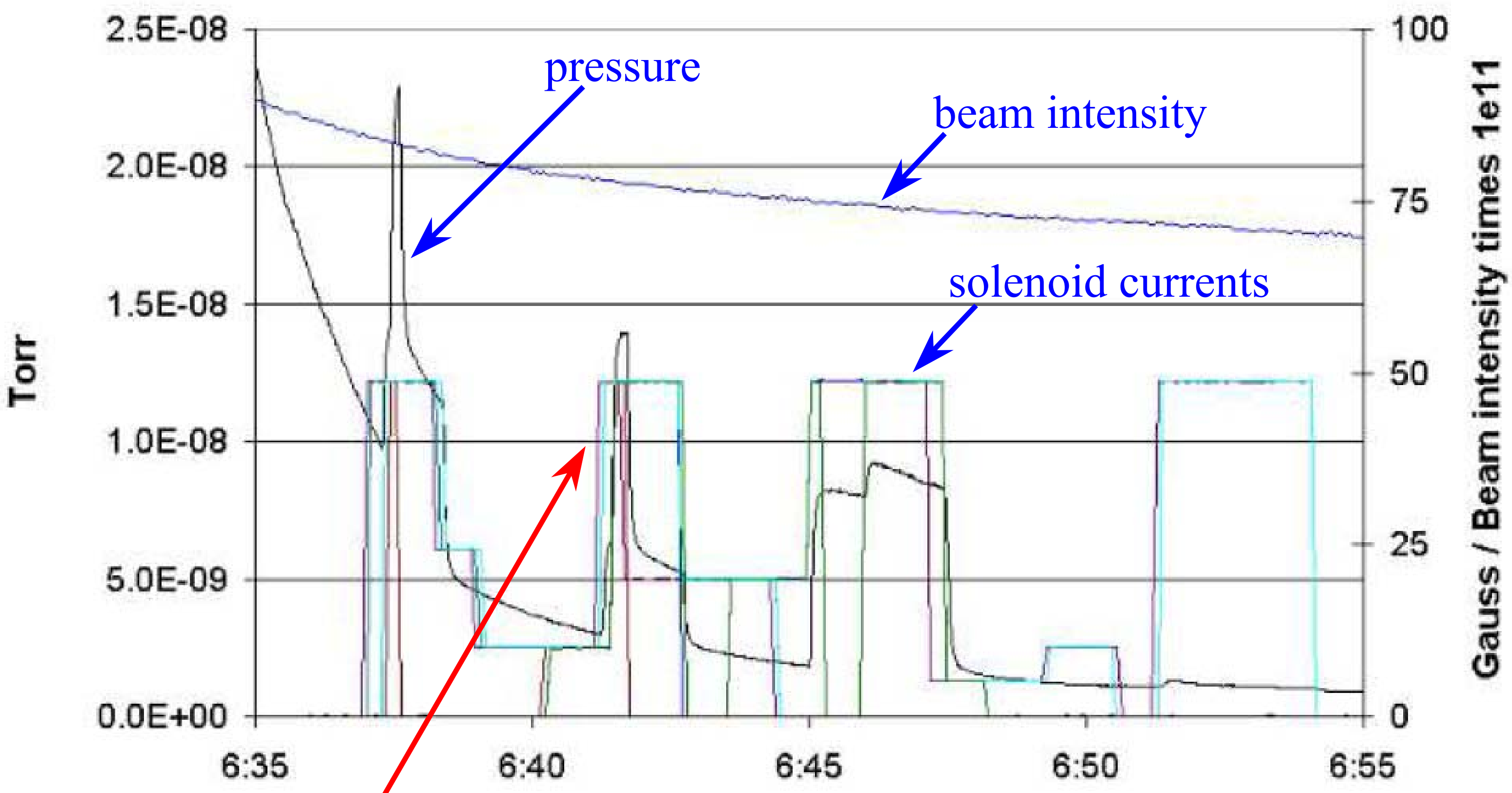


Only Au beam accelerated, all beam lost at transition



- In-situ baking (>95% of 700m/ring warm pipes baked)
  → Occasionally installation schedules too tight
- Solenoids (only against e-clouds)
  → Tested last year
- NEG coated pipes
  → Installed last shut-down
- Bunch patterns (only against e-clouds)
  → Tested last year
  → Implemented flexible bunch patterns for operation
- Scrubbing
  → Tested last year

- 50m of solenoids
  - Maximum field: 6.8 mT [68 G]
- Close to e-detectors and pressure gauges
- Solenoidal fields generally reduce e-cloud
  - Not in all cases completely
  - In some cases increasing fields increase pressure
- Solenoids have operational difficulties
  (routinely used in B-factories)
  - Many power supplies
  - Highest field (6.8 mT) not always best



pressure increase with increasing solenoid fields **U. Iriso-Ariz**

[U. Iriso-Ariz et al., "Electron cloud observations at RHIC during FY2003", BNL C-A/AP note in preparation (2003)]

H.C. Hseuh

- Installed 60 m of NEG coated pipes in selected warm regions
  - For evaluation purposes
  - To reduce background at Phobos
- NEG coated beam pipes
  - Coating done by SAES Getters, Milan, Italy
  - ~1μm sputtered TiZrV layer (30%–30%–40%)
  - Activated with 2 hrs baking at 250°C (can be done with 24 hrs at 180°C)
  - Expected speed of 300 $l \cdot s^{-1} m^{-1}$ with load of 1e-5 $Torr \cdot l \cdot cm^{-2}$ (based on CERN data)
  - Expected SEY of 1.4 (after activation) to 1.7 (saturation)

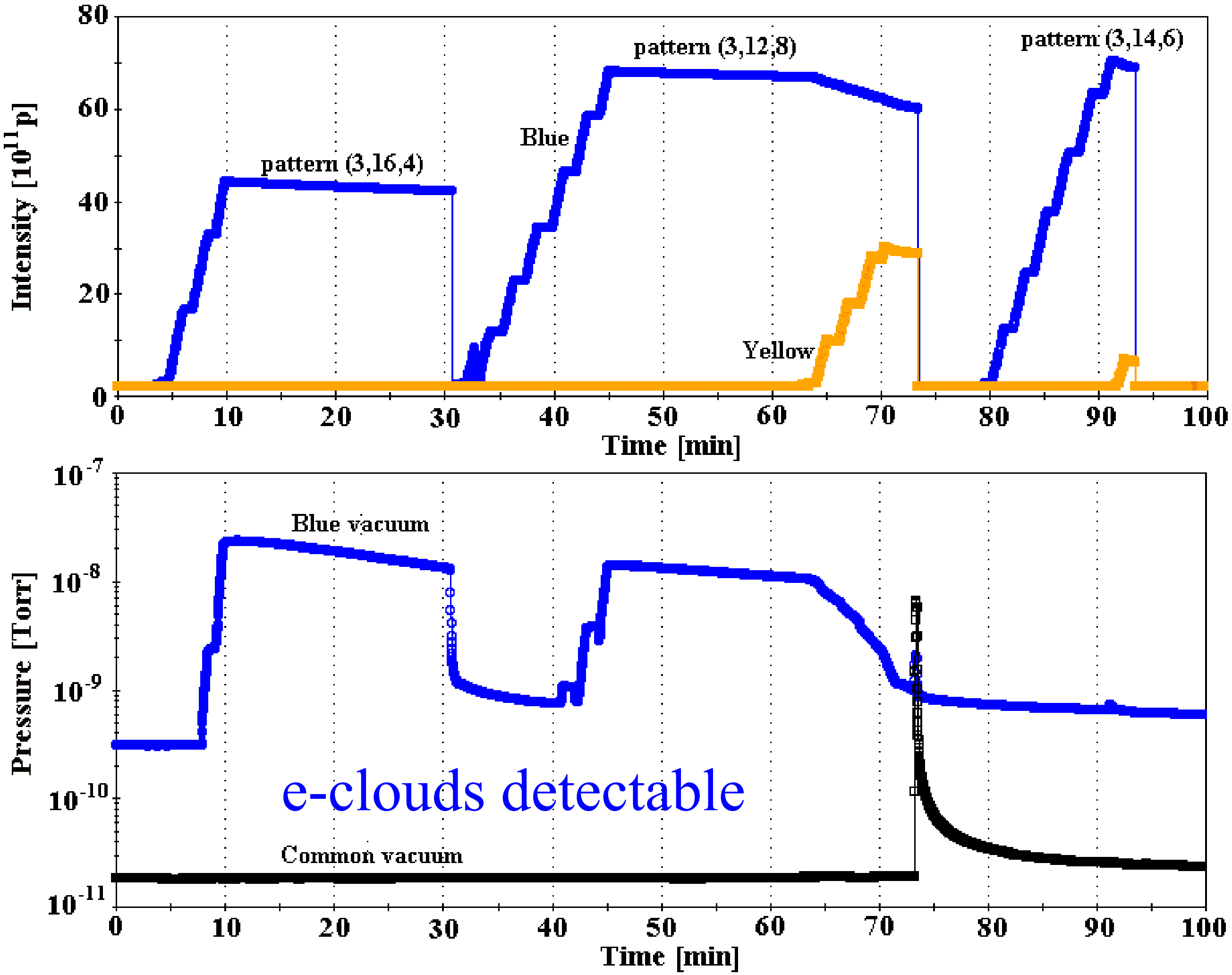
NEG coating setup at SAES Getters

- Need to evaluate in coming Run:
  - vacuum near NEG coated pipes
  - electron clouds near NEG coated pipes
  - desorption with beam losses on NEG coated pipes (pressure rises observed in Booster-to-AGS transfer line when beam loss on NEG surface)
- If NEG coated pipes suppress pressure rise, can replace large parts of warm beam pipes with NEG coated pipes (~700m per ring)
- NEG coating of experiments beam pipes (beryllium) may reduce background

- Question:
  How should one distribute n bunches along the circumference to minimize pressure?
  (→ larger n possible with optimum distribution)
- Notation for bunch patterns:
  (k_1,l_1,m_1) (k_2,l_2,m_2)…
  k – bunch distance measured in buckets
  l – no of bunches with spacing k
  m – no of missing bunches with spacing k
  repeat until abort gap is reached
- Example (2,2,1)(3,4,0) corresponds to
  1-0-1-0-0-0-1-0-0-1-0-0-1-0-0-1-0-0…

Beam test of 3 different bunch patterns

(6 trains with 16, 12 or 14 bunches – ring not completely filled)



Comparison of bunch patterns tested in RHIC at injection.

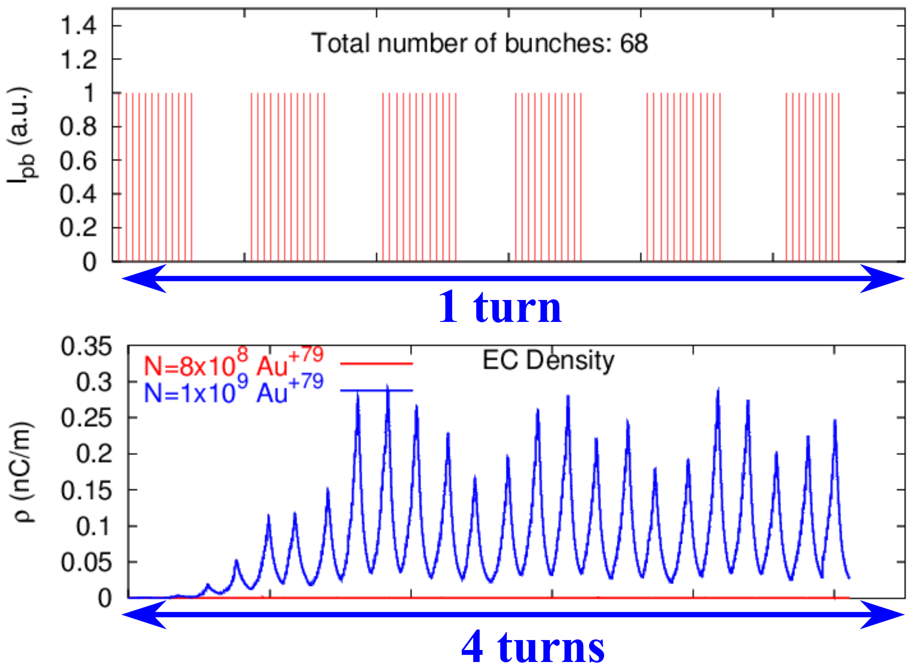
parameter	unit	reference case	fill no 1	fill no 2	fill no 3
bunch pattern	...	(6,1,0)	(3,16,4)	(3,12,8)	(3,14,6)
no of bunches	...	56	41	69	78
average bunch intensity N_b	10^{11}p	1.0	1.1	1.0	0.9
total intensity	10^{11}p	56.0	44.3	68.1	70.2
full bunch length	ns	...	16.5	17.6	34.2
pressure rise	...	...	yes	yes	no
luminosity scaling factor	...	1.00	0.88	1.23	1.13

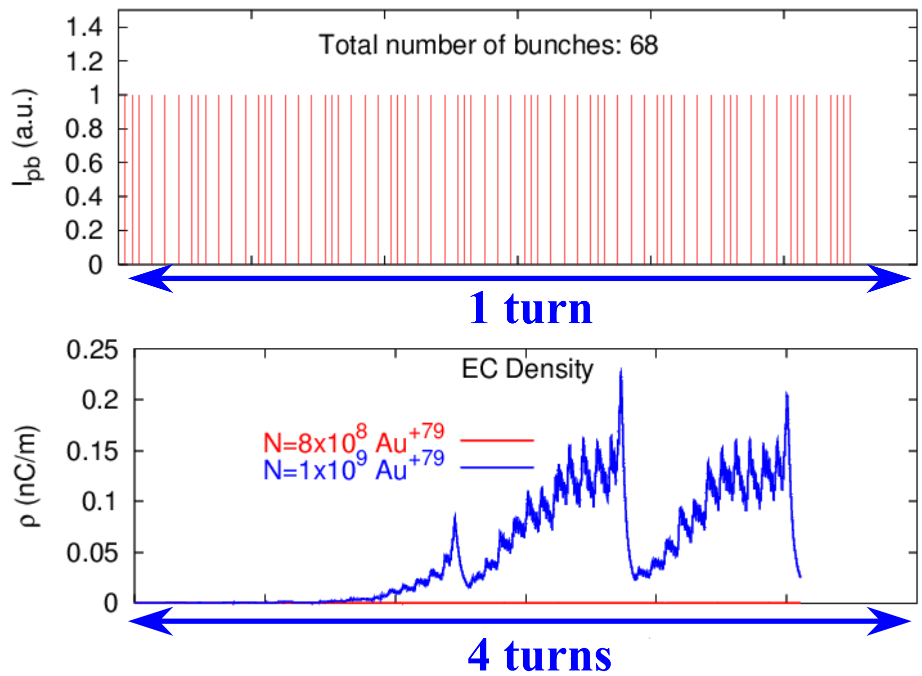
Longer bunches and larger intensity variations

→ Shorter trains (with 3 bucket spacing) give more luminosity with comparable vacuum performance (in limited data set)

Assuming e-cloud induced pressure rise, test bunch patterns in simulation, and observe e-cloud densities. **U. Iriso-Ariz**

5 cases tested with 68 bunches (20% more than now), all with same parameters close to e-cloud threshold (except pattern)





Code: CSEC by M. Blaskiewicz

Comparison of bunch patterns tested in simulations.

parameter	unit	case no 1	case no 2	case no 3	case no 4	case no 5
bunch pattern	...	(3,68,52)	(3,23,17)	(3,12,8)	(3,4,0)(6,8,0)	(3,2,0)(6,4,0)
no of bunches	...	68	68	68	68	68
bunch intensity N_b	10^9Au	1.0	1.0	1.0	1.0	1.0
total intensity	10^9Au	68.0	68.0	68.0	68.0	68.0
maximum line density ρ_{max}	nC/m	0.92	0.67	0.28	0.22	0.20
average line density ρ_{ave}	nC/m	0.30	0.14	0.10	0.10	0.09

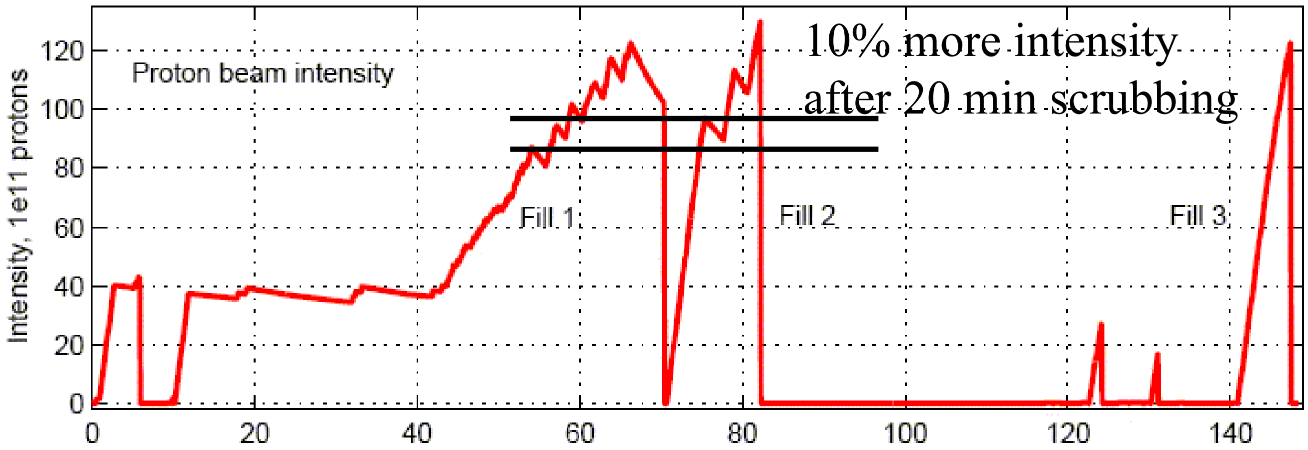
3 long trains,
3 long gaps

most uniform

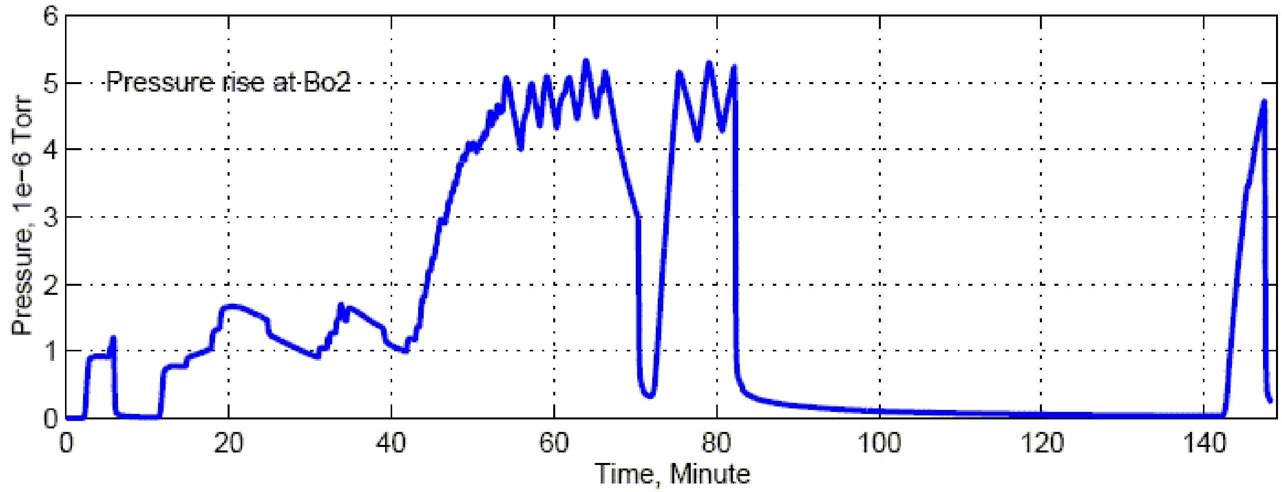
→ If pressure correlates with either maximum or average line density of an e-cloud, most uniform bunch patter is preferable
(in line with KEKB observations, and PEP-II as long as e-clouds are the dominant luminosity limit)

[W. Fischer and U. Iriso-Ariz, “Bunch pattern and pressure rise in RHIC”, BNL C-A/AP/118 (2003)]

High intensity beam tests → scrubbing visible
(~1.5e11 p/bunch, up to 112 bunches possible)



poor beam lifetime (large losses)



S.Y. Zhang

- Scrubbing effect more pronounced at locations with high pressures
  → removes bottle necks successively
- Based on observation, need hours – days of scrubbing, depending on intended beam intensity
- High intensity tests damaged BPM electronics in tunnel, may have adverse effect on silicon detectors in experiments
  → need to move BPM electronics into alcoves before further scrubbing (1/2 done)
  → evaluate dose for experimental silicon detectors

[S.Y. Zhang, W. Fischer, H. Huang and T. Roser, "Beam Scrubbing for RHIC Polarized Proton Run", BNL C-A/AP/123 note in preparation (2003)]

- Pressure rise observed with intense ion beams
  - With all species (Au^{79+}, d^+, p^+), in warm region only
  - At injection
    - Caused by e-clouds, other effects may contribute
    - Limits intensity and luminosity
  - At transition (Au^{79+}, d^+)
    - Cause not clearly identified
    - Causes experimental background
- Counter measures under consideration
  - Solenoids → works, maximum strength not optimum
  - NEG coated pipes → promising, preferred if test successful
  - Bunch patterns → promising, flexible patterns implemented
  - Scrubbing → works, damages remaining electronics in tunnel

- T. Roser, “RHIC status and plans”
- S.Y. Zhang, “AGS Booster issues”
- H.C. Hseuh, “Status and upgrade of RHIC beam vacuum system”
- S.Y. Zhang, “RHIC pressure rise observation and questions”
- P. He, “RHIC electron cloud and vacuum pressure rise characteristics”
- L. Wang, “Mechanism of electron multipacting with long proton bunches”
- H. Huang, “Proton beam scrubbing in RHIC”

1. P. He et al., "Improvement of RHIC warm beam vacuum for high intensity operation", PAC'03.
2. S.Y. Zhang et al., "RHIC pressure rise and electron cloud", PAC'03.
3. U. Iriso-Ariz et al., "Electron detectors for vacuum pressure rise diagnostics at RHIC", PAC'03.
4. U. Iriso-Ariz et al., "Electron cloud and pressure rise simulations for RHIC", PAC'03.
5. J. Gulotta et al., "RHIC electron detector signal processing design", PAC'03
6. S.Y. Zhang, H.C. Hseuh, and T. Roser, "NEG coating at RHIC", BNL C-A/AP/99 (2003).
7. S.Y. Zhang, "Experimental background in RHIC deuteron-gold run", BNL C-A/AP/107 (2003).
8. W. Fischer and U. Iriso-Ariz, "Bunch patterns and pressure rise in RHIC", BNL C-A/AP/108 (2003).
9. S.Y. Zhang, W. Fischer, H. Huang, and T. Roser, "Beam scrubbing for RHIC polarized proton operation", BNL C-A/AP/123 (2003).
10. U. Iriso-Ariz et al., "Electron cloud observations at RHIC during FY003", BNL C-A/AP note in preparation (2003).