Electron cloud experiments, and cures in RHIC

Wolfram Fischer

M. Blaskiewicz, H.-C. Hseuh, H. Huang, U. Iriso, V. Ptitsyn, T. Roser, P. Thieberger, D. Trbojevic, J. Wei, S.Y. Zhang

BROOKHAVEN NATIONAL LABORATORY

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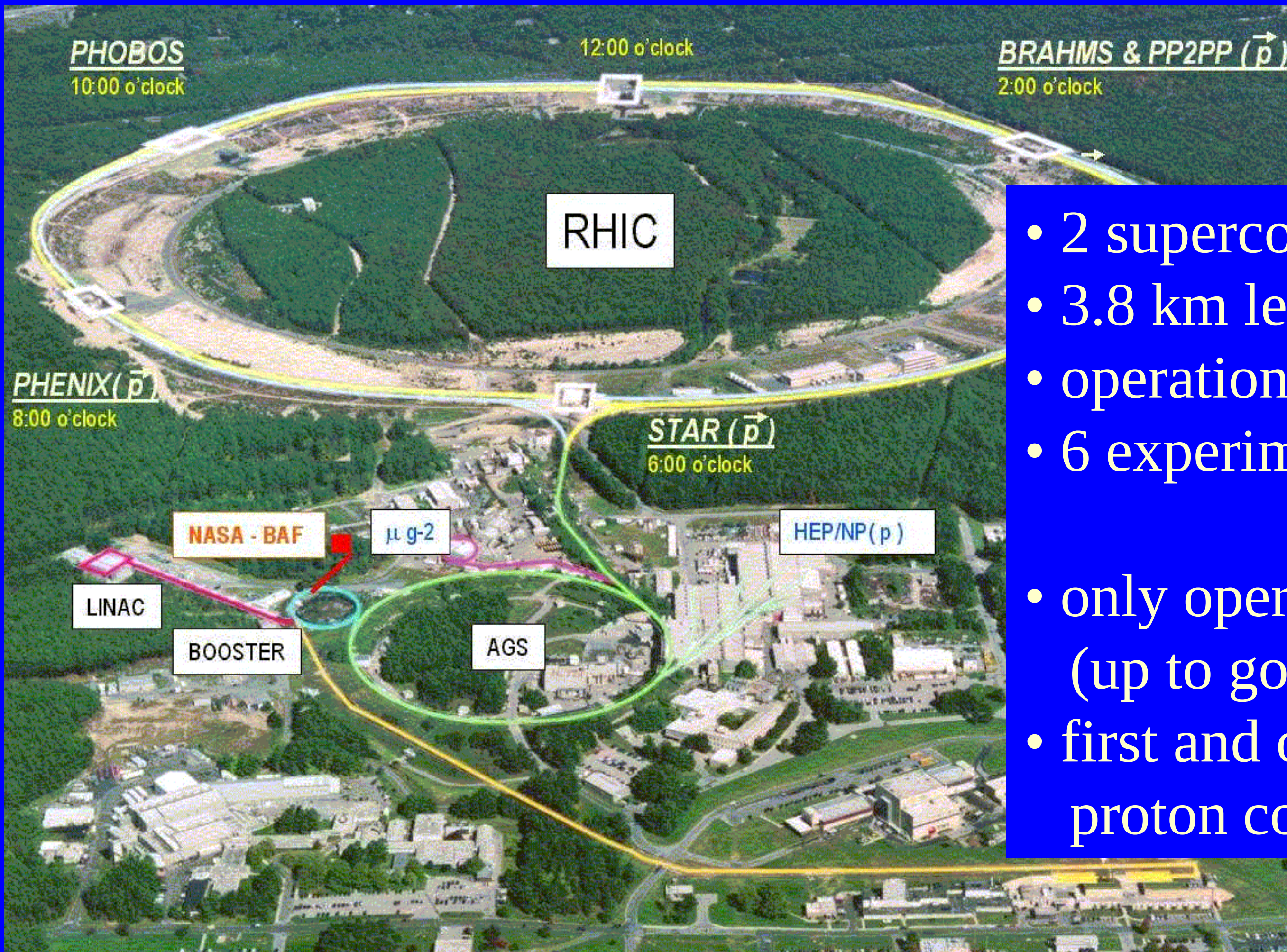
Outline

1. **E-cloud observations**
   dynamic pressure rise, tune shift, electrons, instabilities, emittance growth

2. **E-cloud cures**
   in-situ baking, NEG coating, bunch patterns, solenoids, anti-grazing rings, pre-pumping in cold regions, scrubbing

3. **Open problems**
   instabilities during transition crossing, emittance growth

Relativistic Heavy Ion Collider



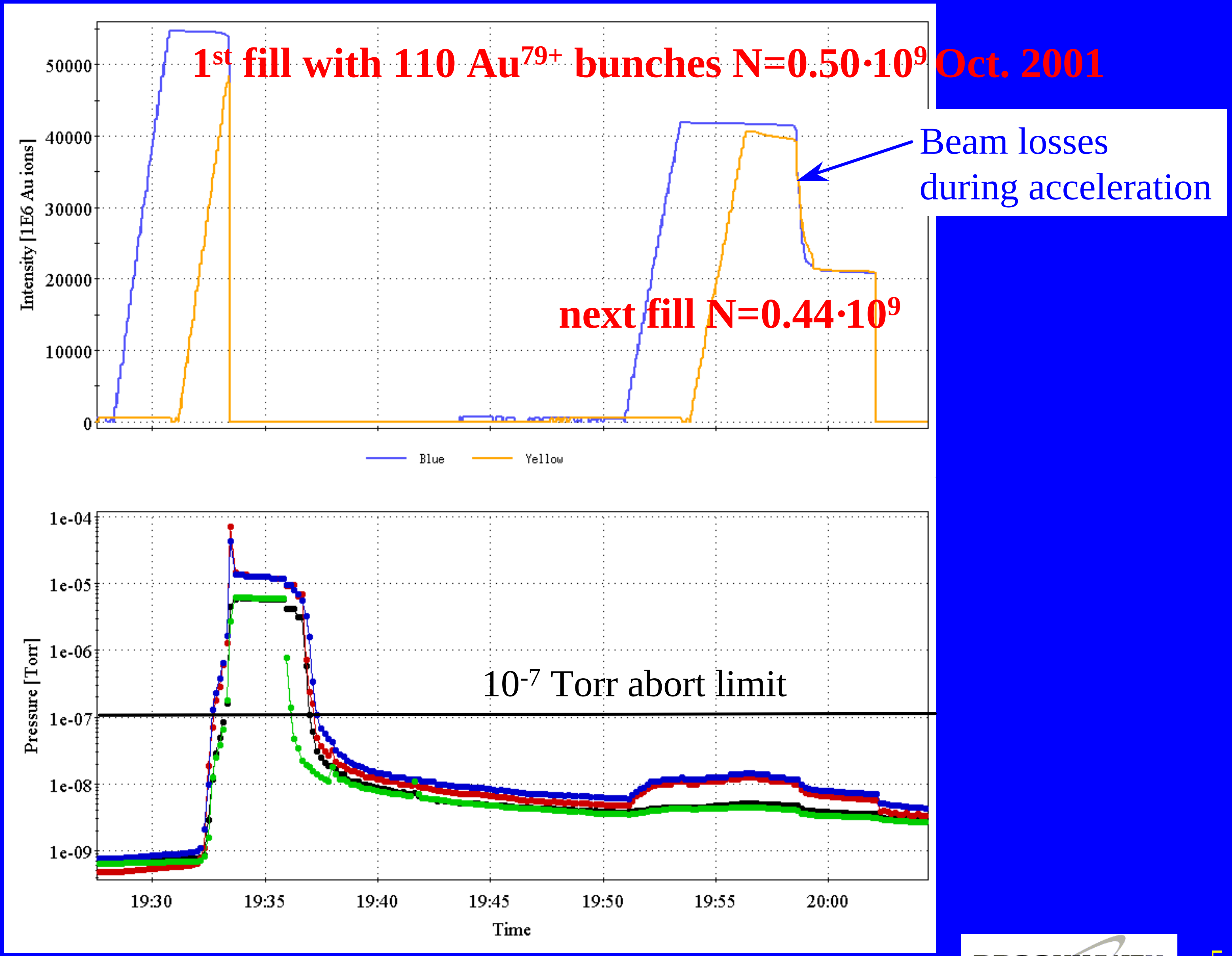
- 2 superconducting rings
- 3.8 km length
- operation since 2000
- 6 experiments so far

- only operating ion collider (up to gold 100 GeV/n)
- first and only polarized proton collider

E-cloud observations in RHIC

1. **Dynamic pressure rise**
2. **Tune shift**
3. **Electrons**
4. **Instabilities**
   - Beam instabilities
   - Pressure instabilities
5. **Emittance growth**

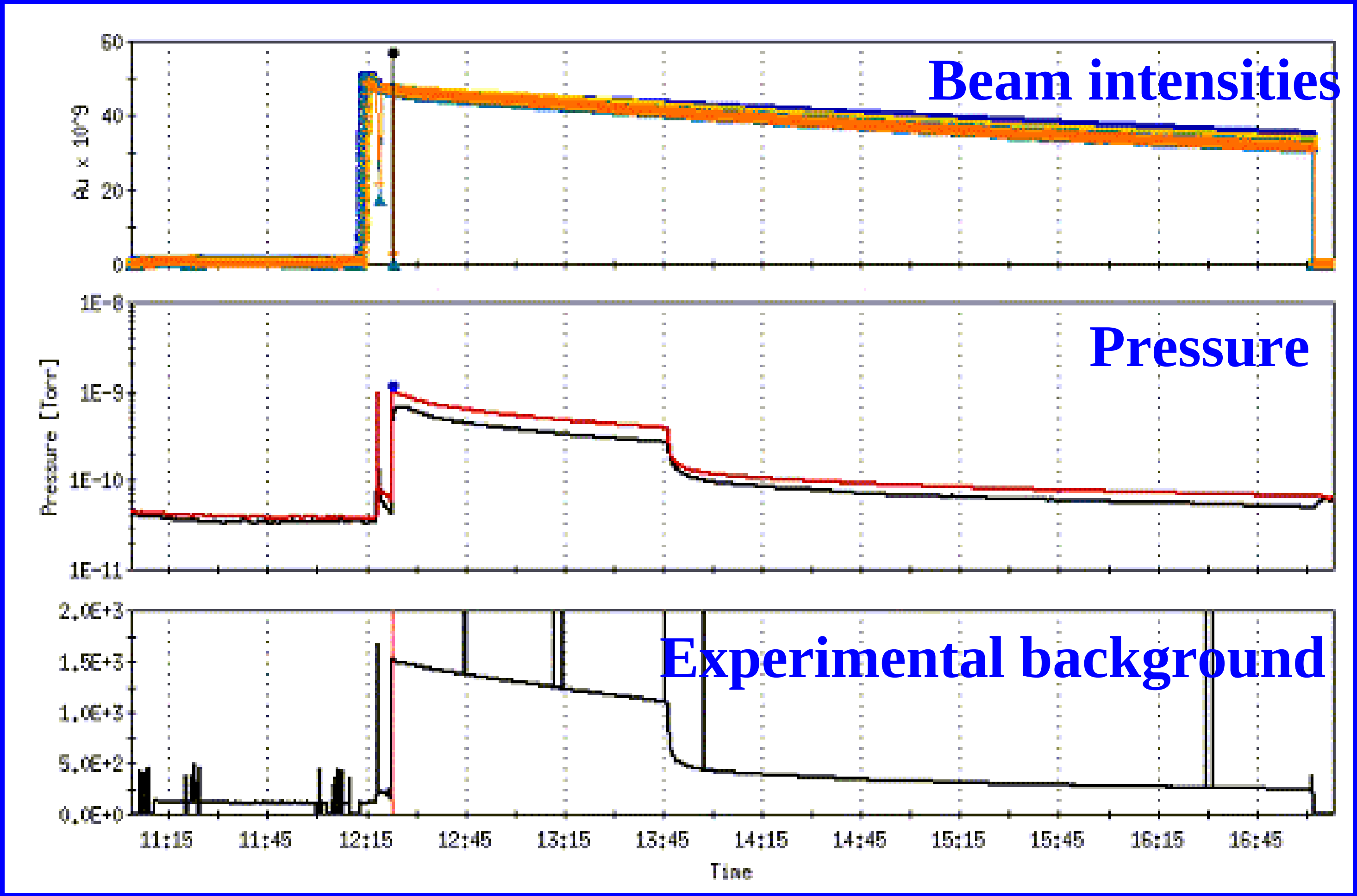
First pressure rise observation



Pressure rise mechanisms considered

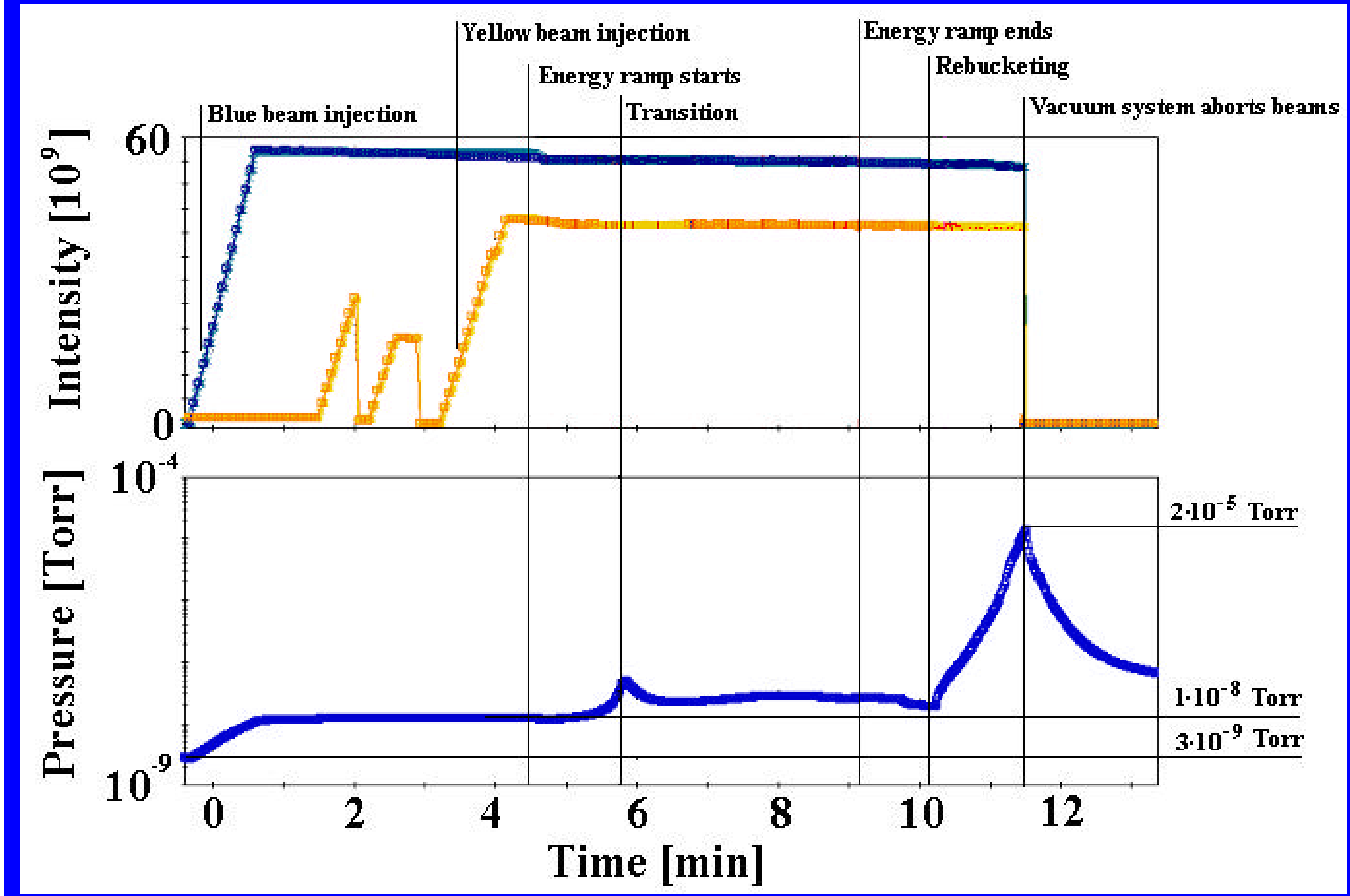
- Electron-impact desorption ® **dominating for operation**
  - Observed coherent tune shift in bunch train due to e-cloud
  - Electron detectors
- Ion-impact desorption ® **tolerable for operation**
  - Rest gas ionization, ion acceleration through beam
  - Ion impact energies at wall ~15 eV for Au, ~60 eV for p
  - Visible pressure rise, may lead to instability in unbaked regions (observed with Au only)
- Beam loss induced desorption ® **tolerable for operation**
  - Need large beam loss for significant pressure rise

Sudden pressure drop in experimental area (12m Be)



Can be understood with combined electron and ion cloud.
[U. Iriso and S. Peggs, PRST-AB 9, 071002 (2006).]

E-cloud observation: pressure instability



Pressure instability observed with growth times of 2-12 seconds.

Need:

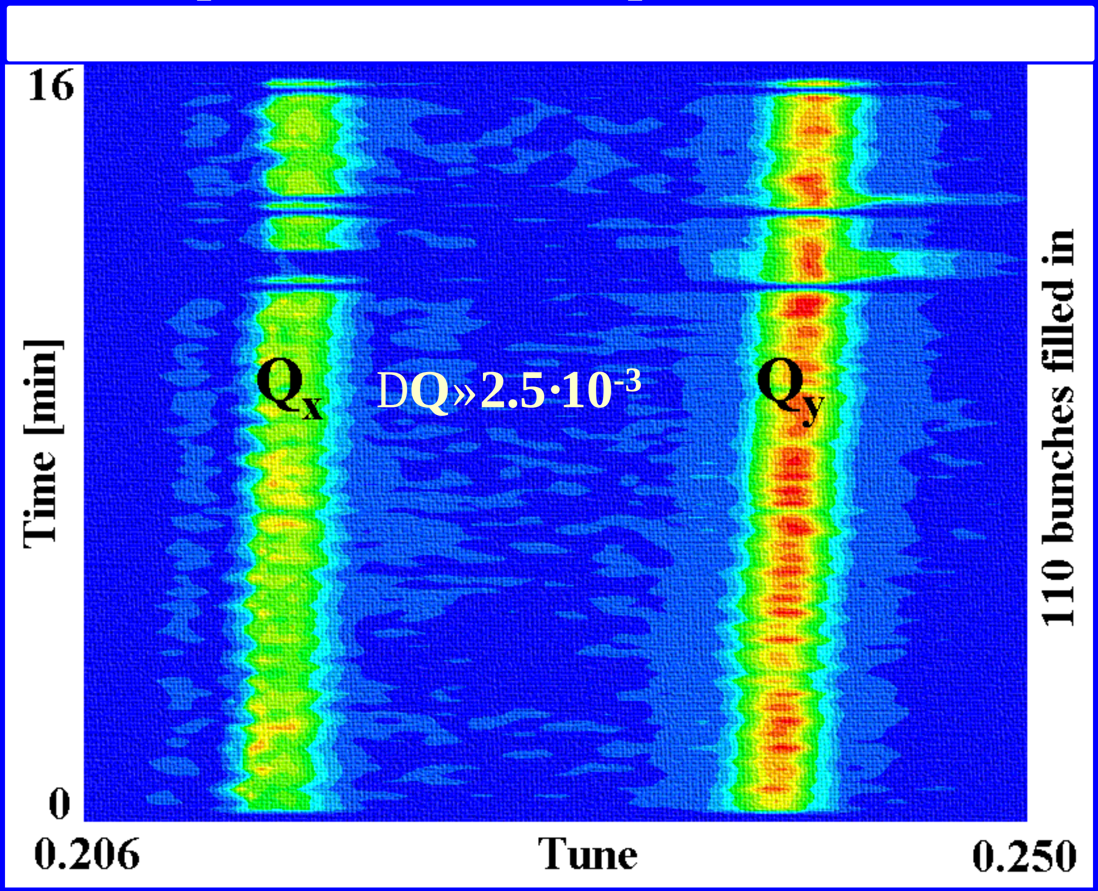
- Au^{79+}
  (large rest gas ionization)
- unbaked locations
  (large desorption)
- e-clouds
  (short bunches)

Calculations show possibility of pressure instability with heavy ion beam and heavy molecules (CO). Do not fully match.

[Calculations: W. Fischer, U. Iriso, and E. Mustafin, "Electron cloud driven vacuum instability", workshop proceedings HB 2004]

Electron cloud observation: tune shift

$33 \cdot 10^{11}$ p^+ total, $0.3 \cdot 10^{11}$ p^+/bunch, 110 bunches, 108 ns spacing (2002)

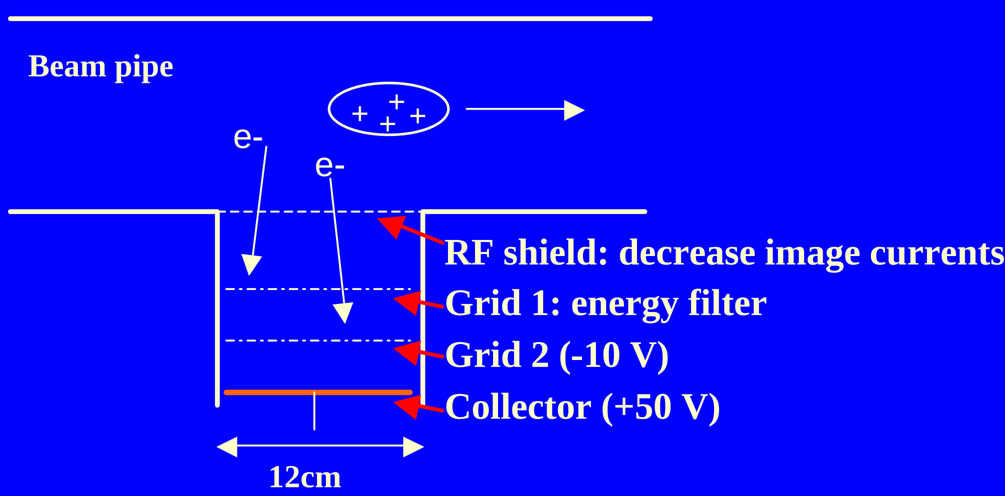


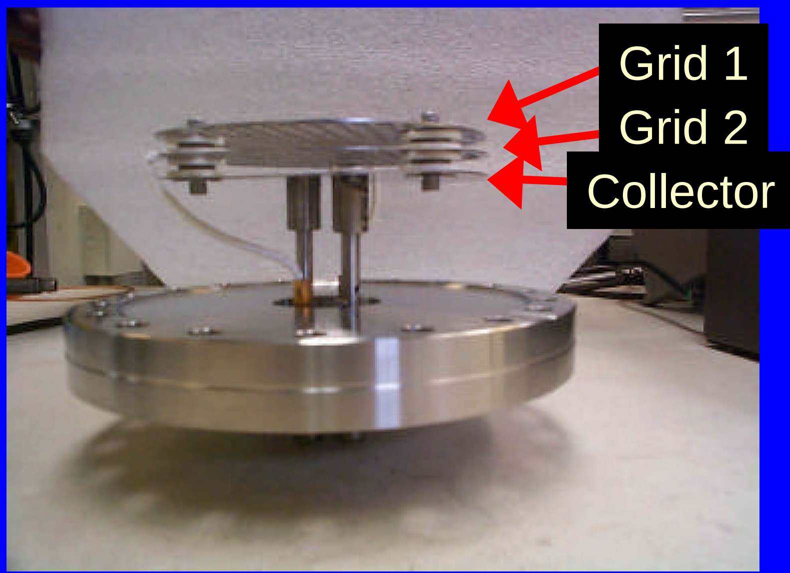
(1) From measured tune shift, the e-cloud density is estimated to be 0.2 – 2.0 nC·m^{-1}

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

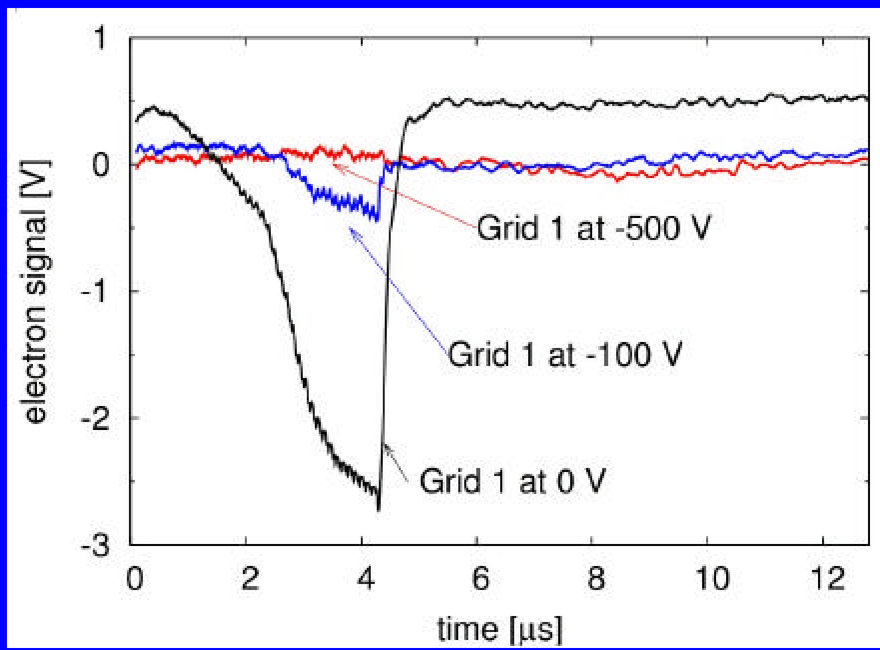
[W. Fischer, J.M. Brennan, M. Blaskiewicz, and T. Satogata, “Electron cloud measurements and observations for the Brookhaven Relativistic Heavy Ion Collider”, PRST-AB 124401 (2002).]

E-cloud observation: electron detectors



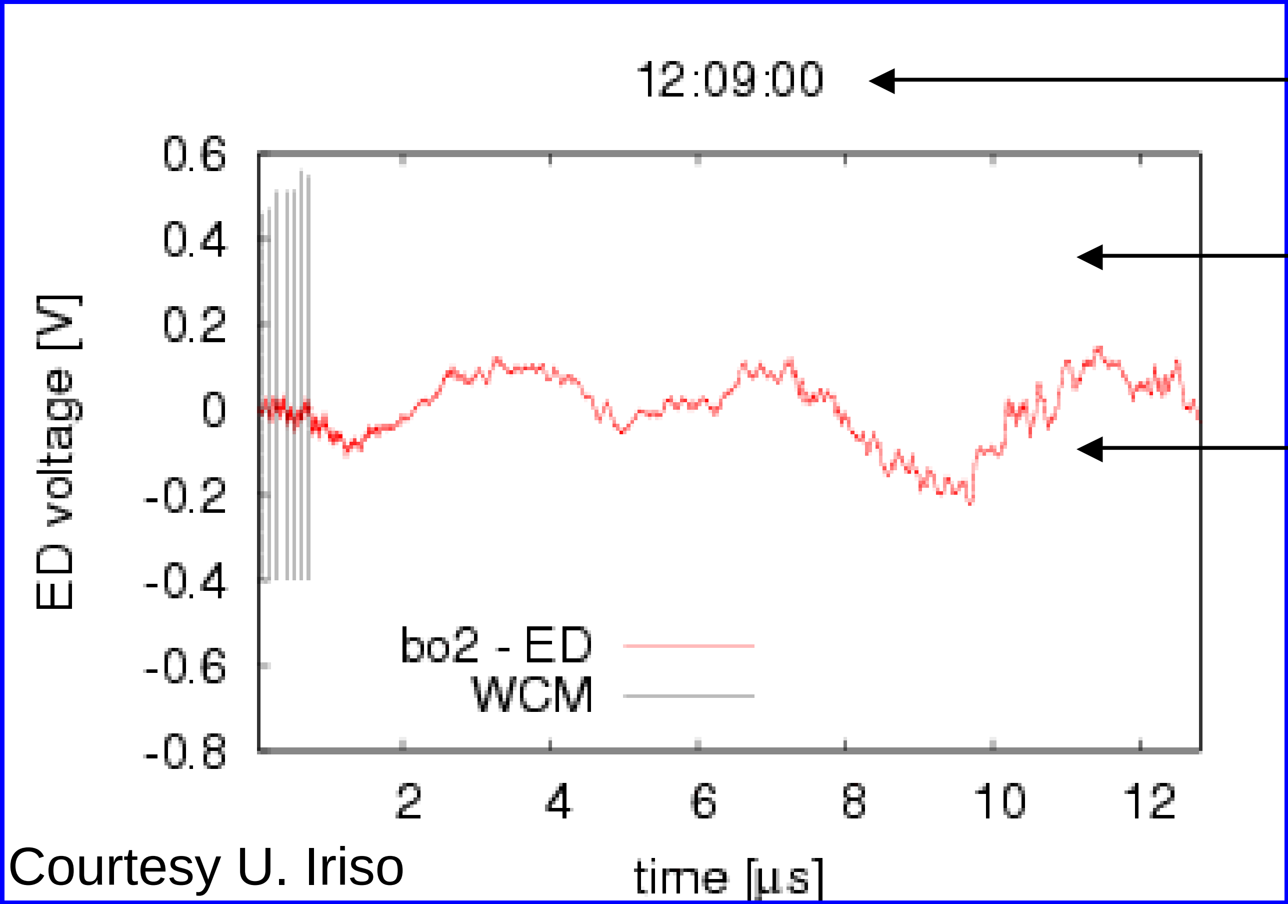


Courtesy
U. Iriso



Energy spectrum can be determined with Grid 1

E-cloud observation: formation at injection

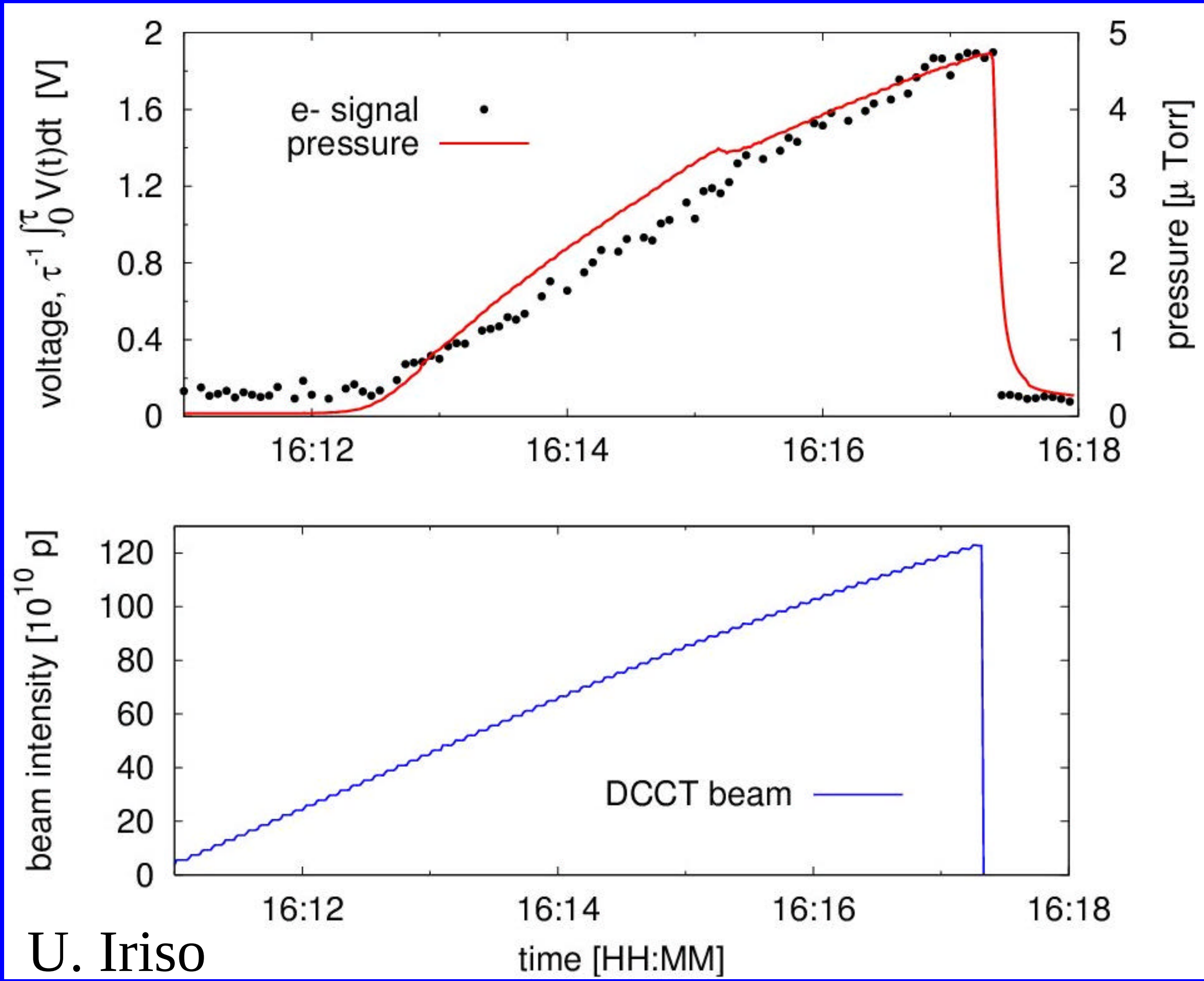


time

bunches being filled

electron cloud density (red line)

E-cloud observation: formation at injection

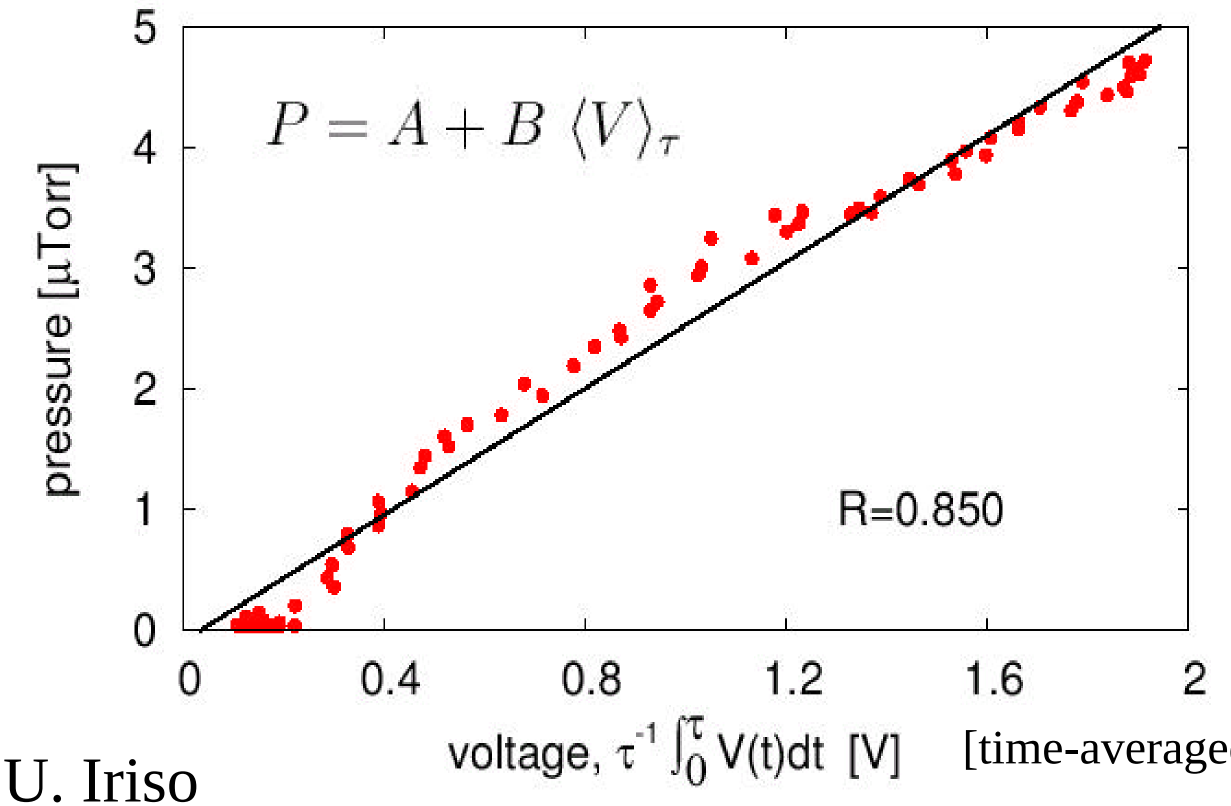


U. Iriso

Clear correlation between beam intensity, e-signal, and pressure.

E-cloud observation: pressure rise

Pressure increase is proportional to average e-cloud density

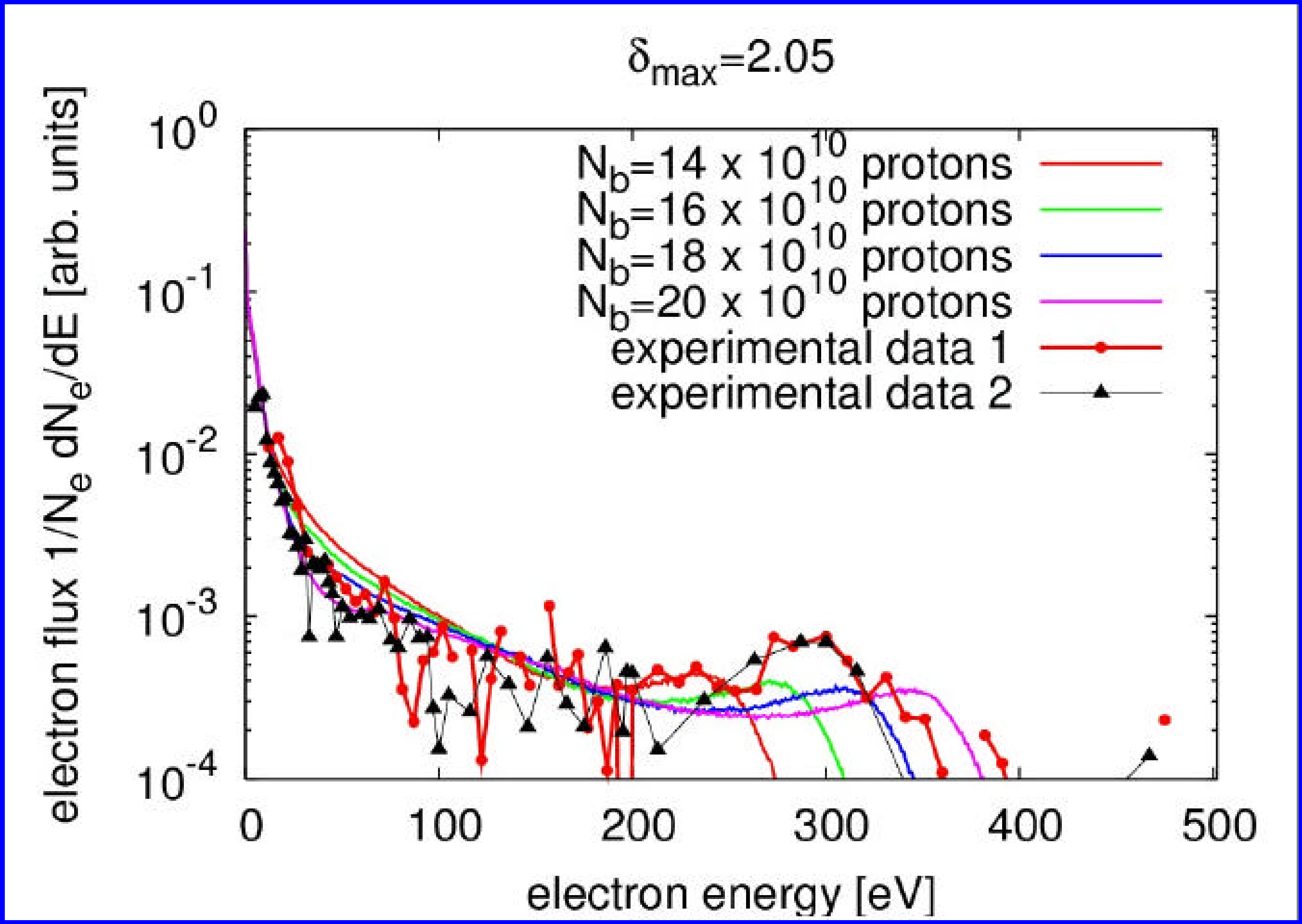


U. Iriso

[time-averaged e-detector signal]

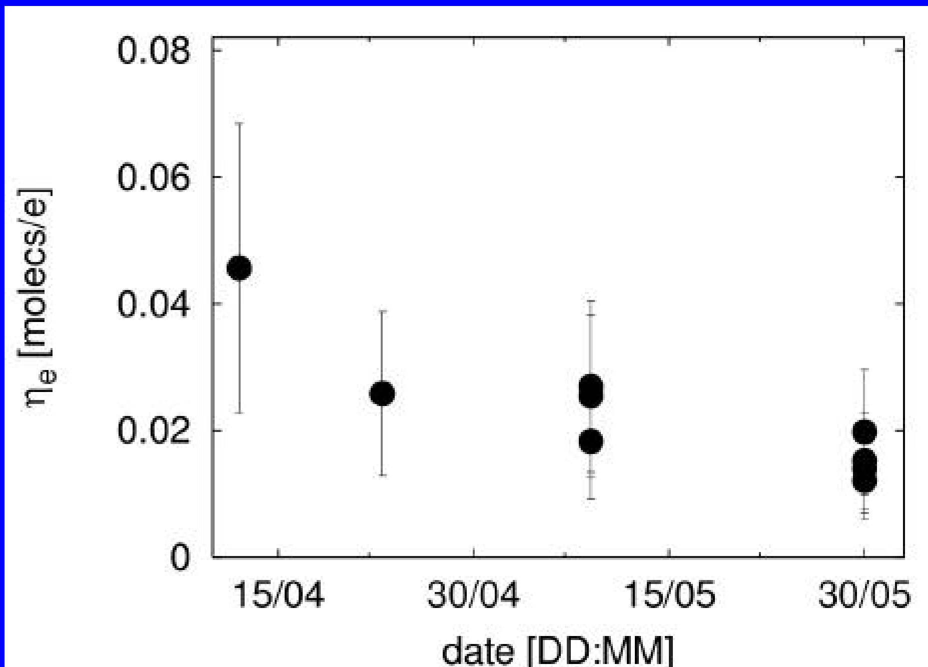
Concluded that all operationally relevant dynamic pressure increases can be explained by electron clouds.

Measured energy spectrum in e-cloud



Dominated by low energy electrons (peak at 10 eV, to »300 eV).
Spectrum can be reproduced in simulation
[U. Iriso and W. Fischer, PRST-AB 8, 113201 (2005)]

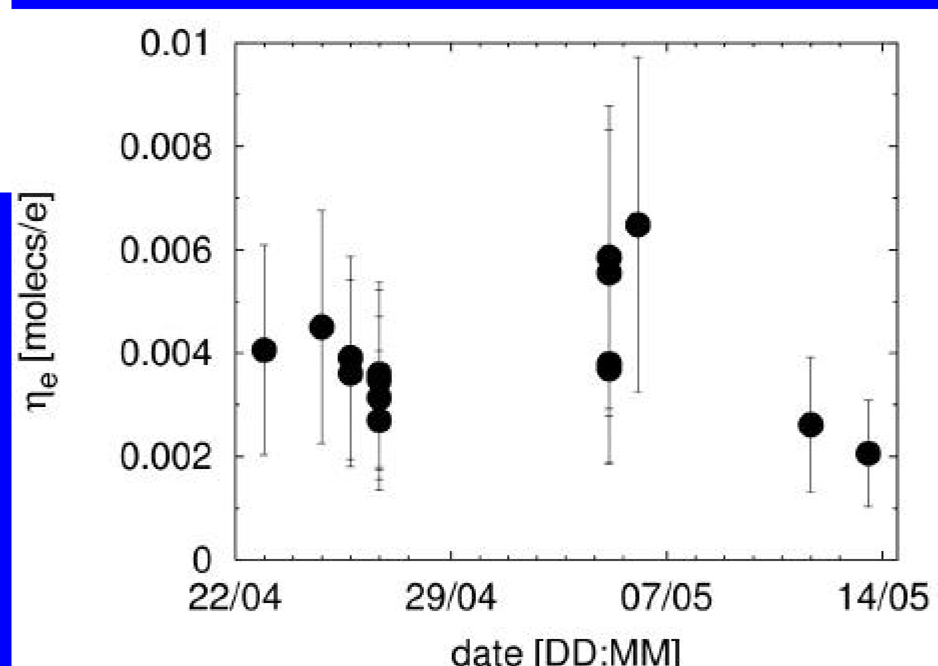
Measured electron-impact desorption coefficients η_e



Unbaked stainless steel:

h_e = 0.01 ± 0.005 (CO)

Scrubbing visible



Baked stainless steel:

h_e = 0.004 ± 0.001 (CO)

No scrubbing visible

[U. Iriso and W. Fischer, PRST-AB 8, 113201 (2005)]

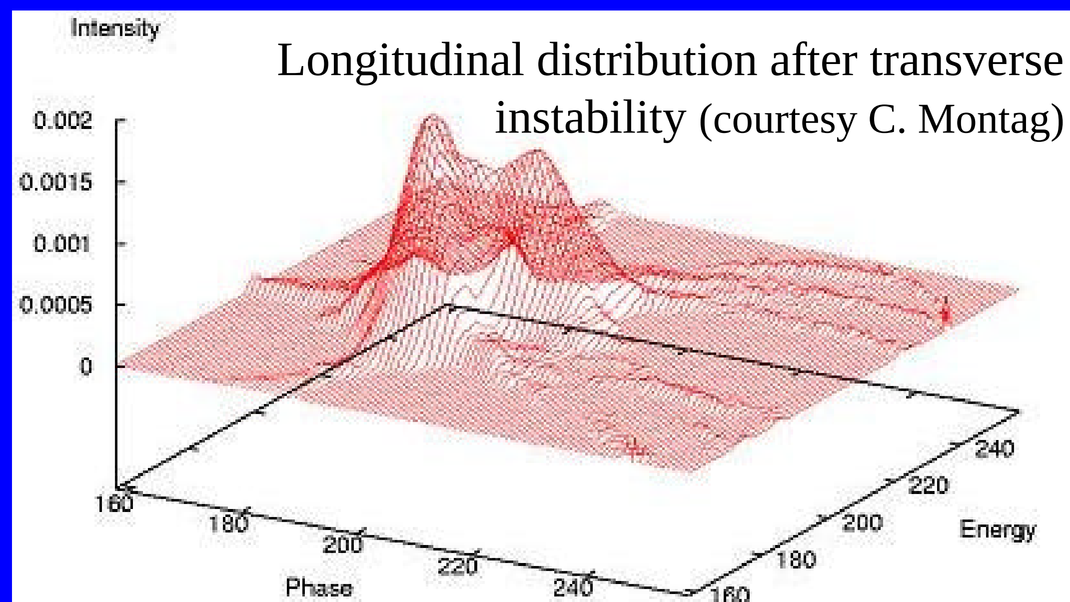
E-cloud observation: beam instability

Crossing transition with slowly ramping sc. magnets
(all ions except protons)

→ Instability limits bunch intensities for ions (~1.5×10^{11} e)

→ Instability is fast (τ =15 ms), transverse, single bunch

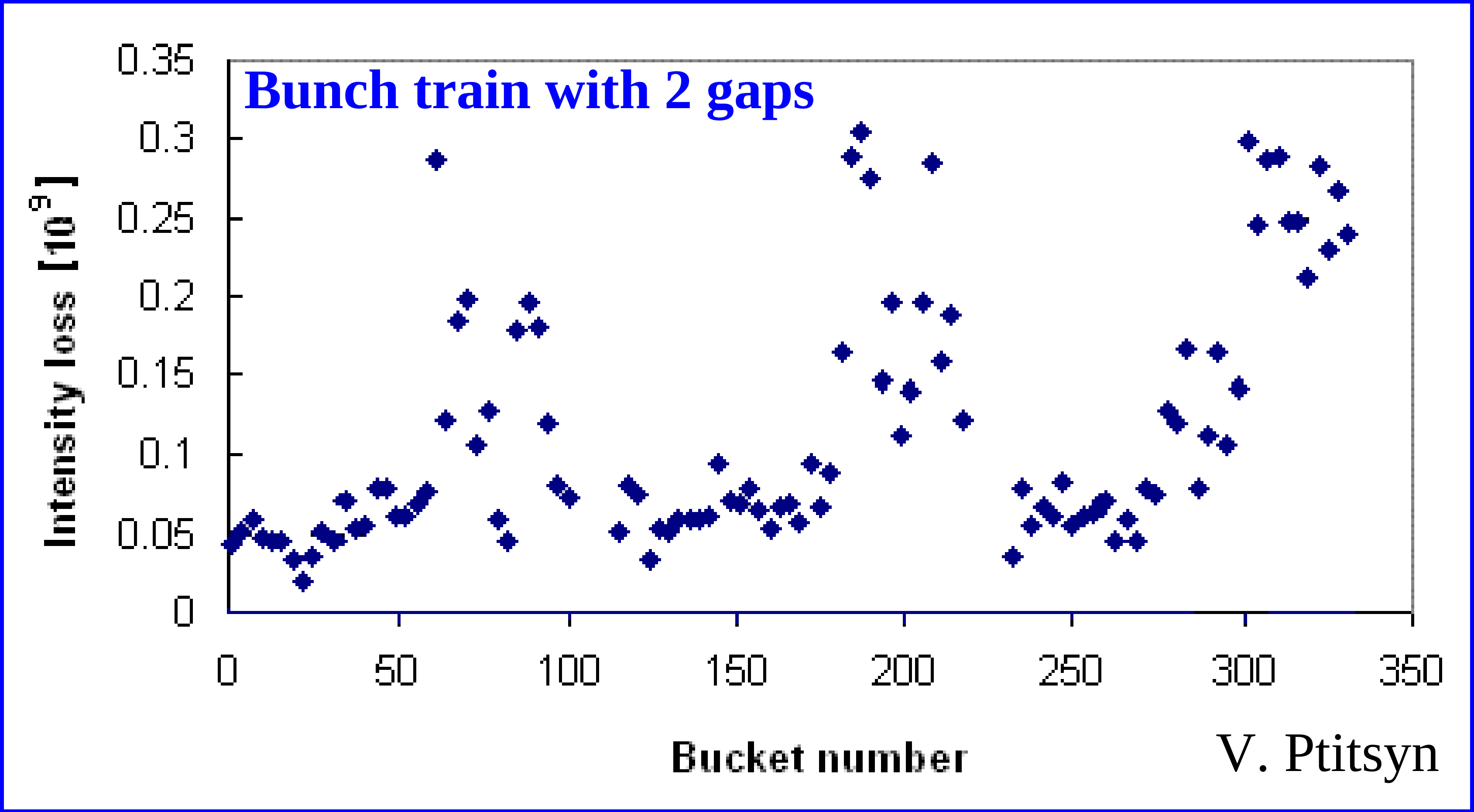
- γ_t-jump implemented
- Octupoles near transition
- Chromaticity control
  (need ξ-jump for higher bunch intensities)



Longitudinal distribution after transverse instability (courtesy C. Montag)

→ Electron clouds can lower stability threshold,
will gain more operational experience in current Au-Au run

Intensity loss during transition crossing (Au)

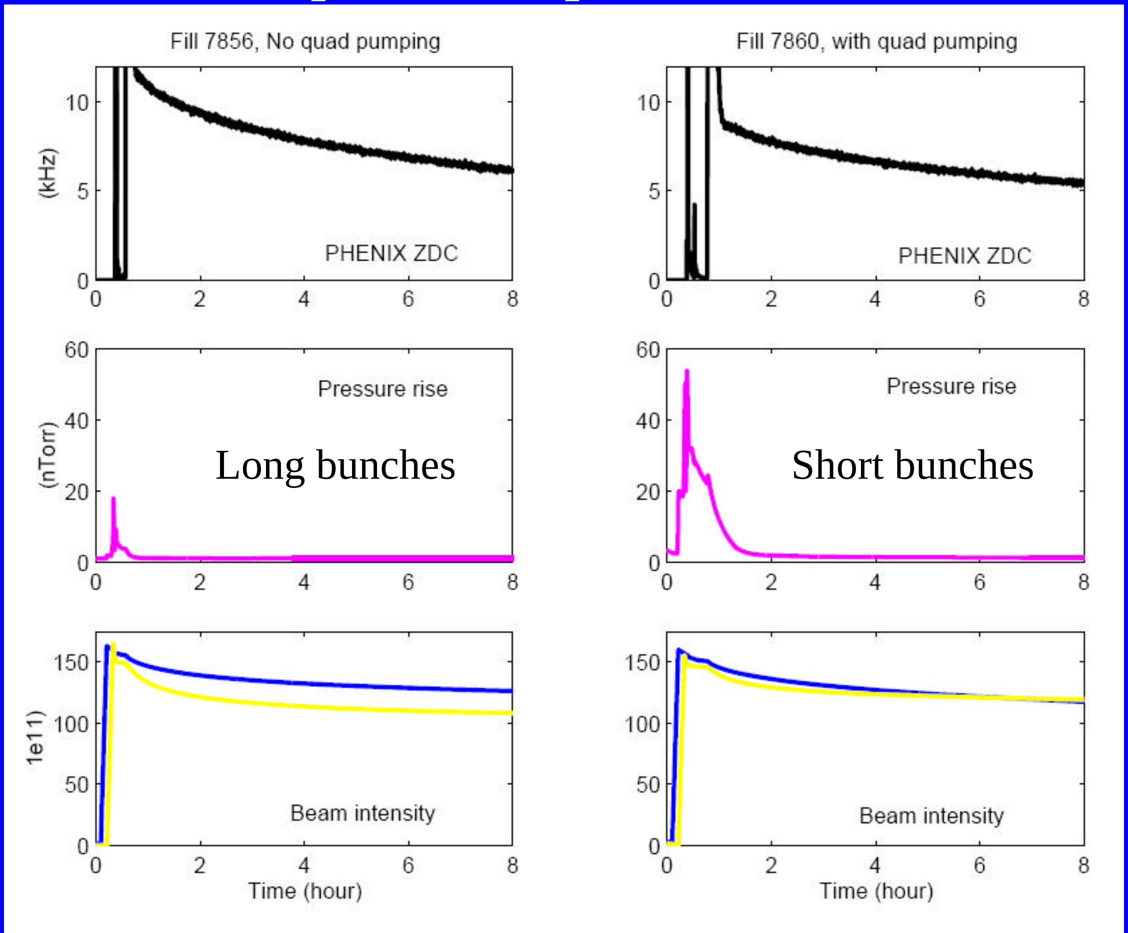


Losses increase along bunch train, are reset after gaps.

E-cloud observation: emittance growth

2 polarized proton stores

Courtesy S.Y. Zhang



Short bunches with same intensity lead to smaller luminosity.

[Single short-bunch store only for comparison. ε-growth from reasons other than e-cloud possible.]

[E. Benedetto et al., "Simulation study on electron …", PRST-AB 8, 124402 (2005); **E. Benedetto et al., "Incoherent effects of electron clouds in proton storage rings", PRL 97, 034801 (2006);** S.Y. Zhang and V. Ptitsyn, "Proton beam emittance growth in Run-5 and Run-6", BNL C-A/AP/257 (2006).]

E-cloud cures investigated in RHIC

1. **In-situ baking**
2. **NEG coating**
3. **Bunch patterns**
4. **Solenoids**
5. **Anti-grazing rings**
6. **Pre-pumping in cold regions**
7. **Scrubbing**

E-cloud cure: in-situ baking

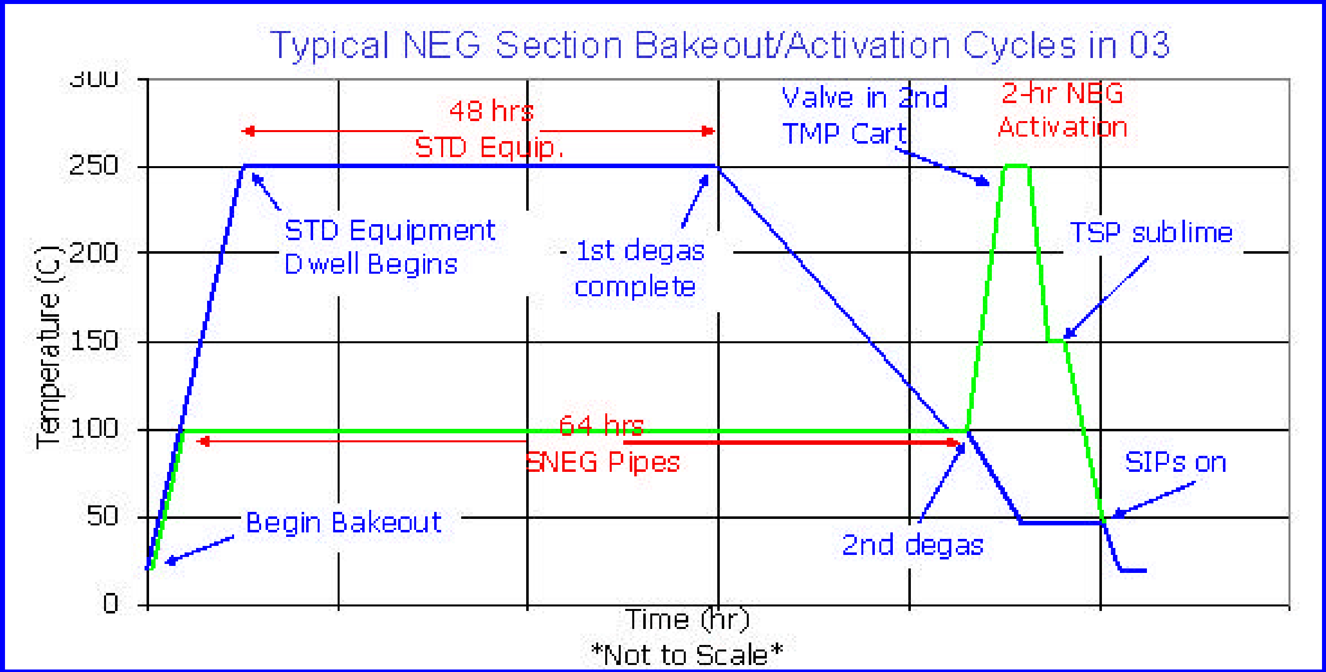
RHIC beam pipes preparation:

- 316LN, purchased from Mannesmann Handel AG, Düsseldorf
- Drawn tubes were detergent-cleaned, water rinsed, acid prickled (HF + HNO_3), water rinsed, annealed at 1050ºC for 10 min, quenched (all at manufacturer)
- At BNL, the pipes were cut to length, the end flanges welded, then baked under vacuum at 350ºC for 24 h (?), leak checked, and sealed before delivering to Grumman (magnet maker)

Warm regions not baked initially, started comprehensive in-situ baking after observation of dynamic pressure rise

E-cloud cure: NEG coating (1)

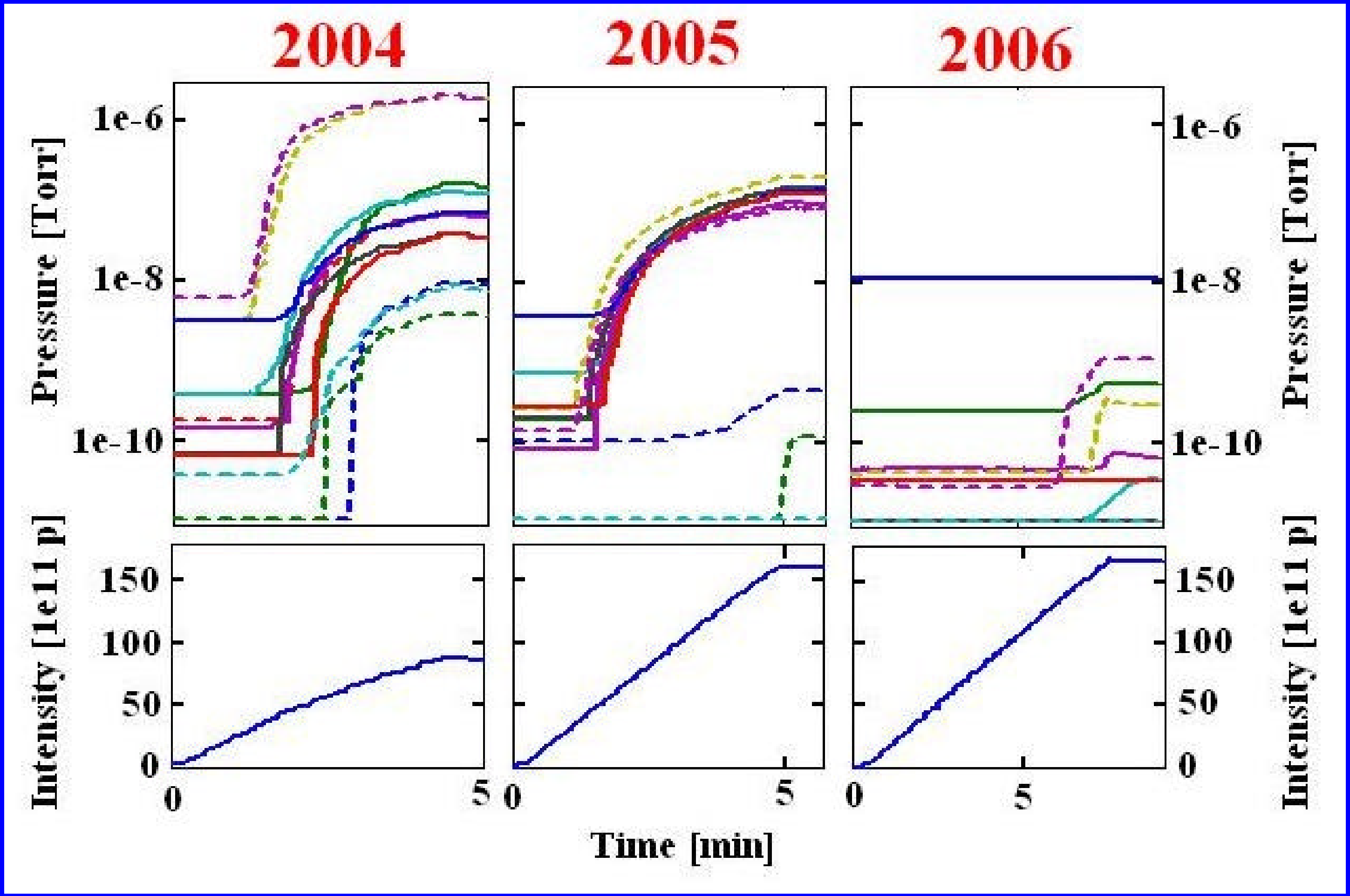
- Primary counter measure for warm sections
  - Total length of warm sections : 700 m
  - Sections that can be NEG coated: 520 m
- Coating done by SAES Getters, Milan
- Activation:
  >180ºC x 24 hrs, or 200ºC x 4 hrs, or 250ºC x 2 hrs



H.C. Hseuh

E-cloud cure: NEG coating (2)

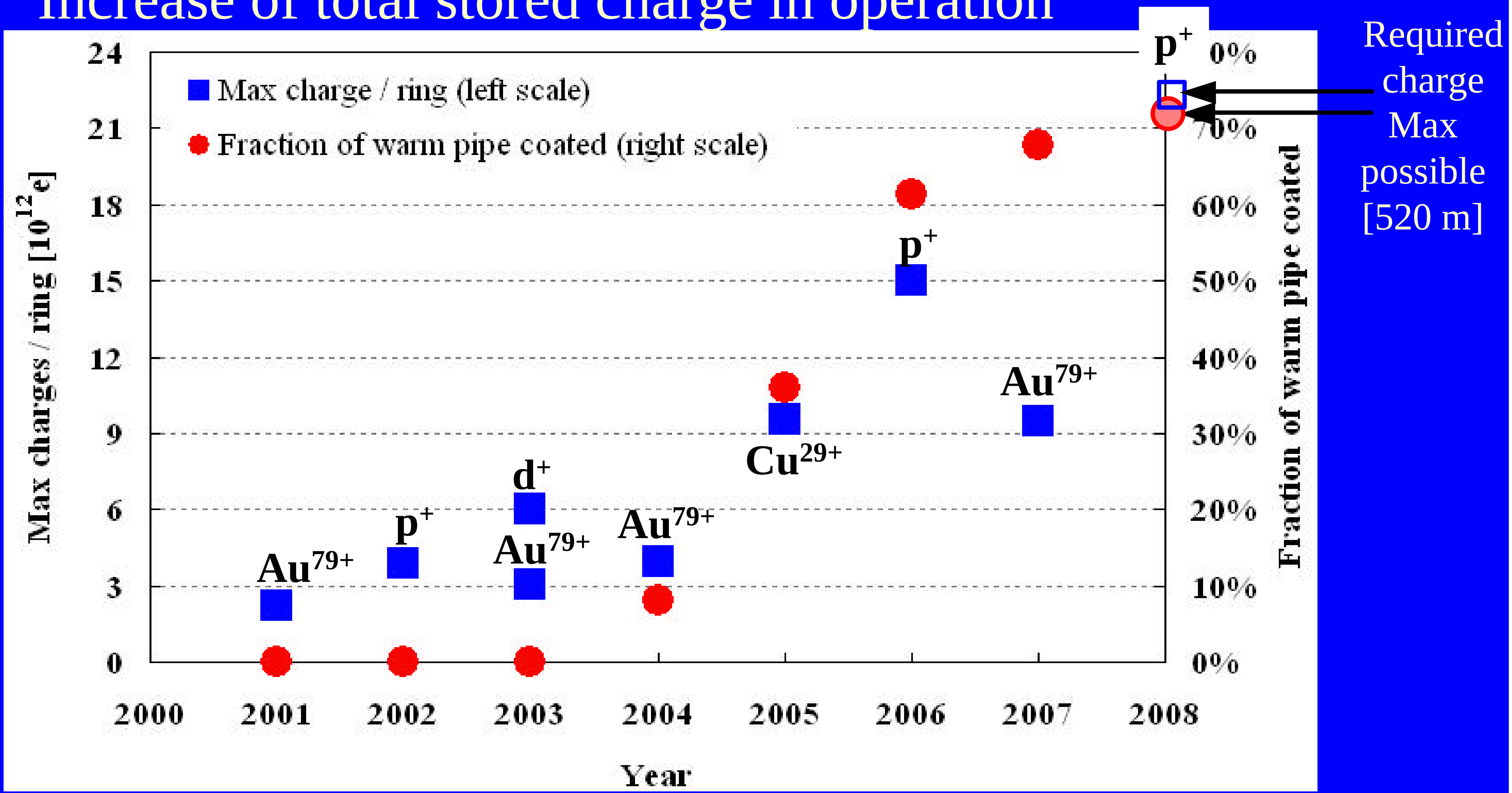
Pressure and proton intensity in 12 Blue warm strait sections (Q3-Q4).



[S.Y. Zhang et al., "Experience in reducing electron cloud and dynamic pressure rise …", EPAC06]

E-cloud cure: NEG coating (3)

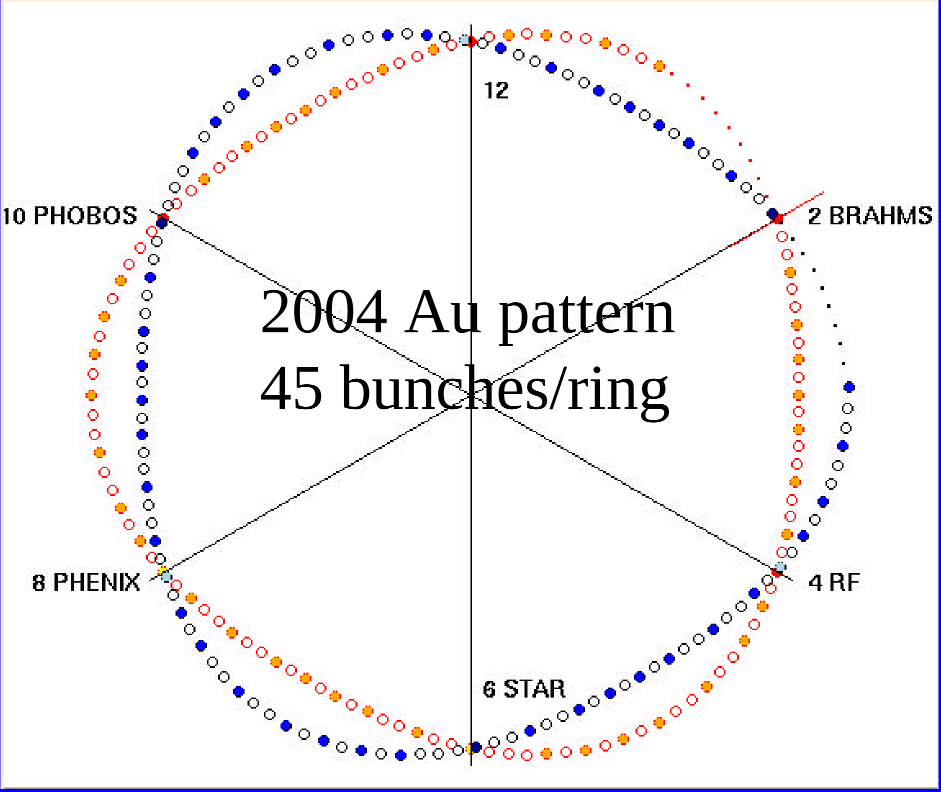
Increase of total stored charge in operation



Notes: charge also limited by effects other than total charge (injectors, transition), dynamic pressure can be limited by single location (experiment).

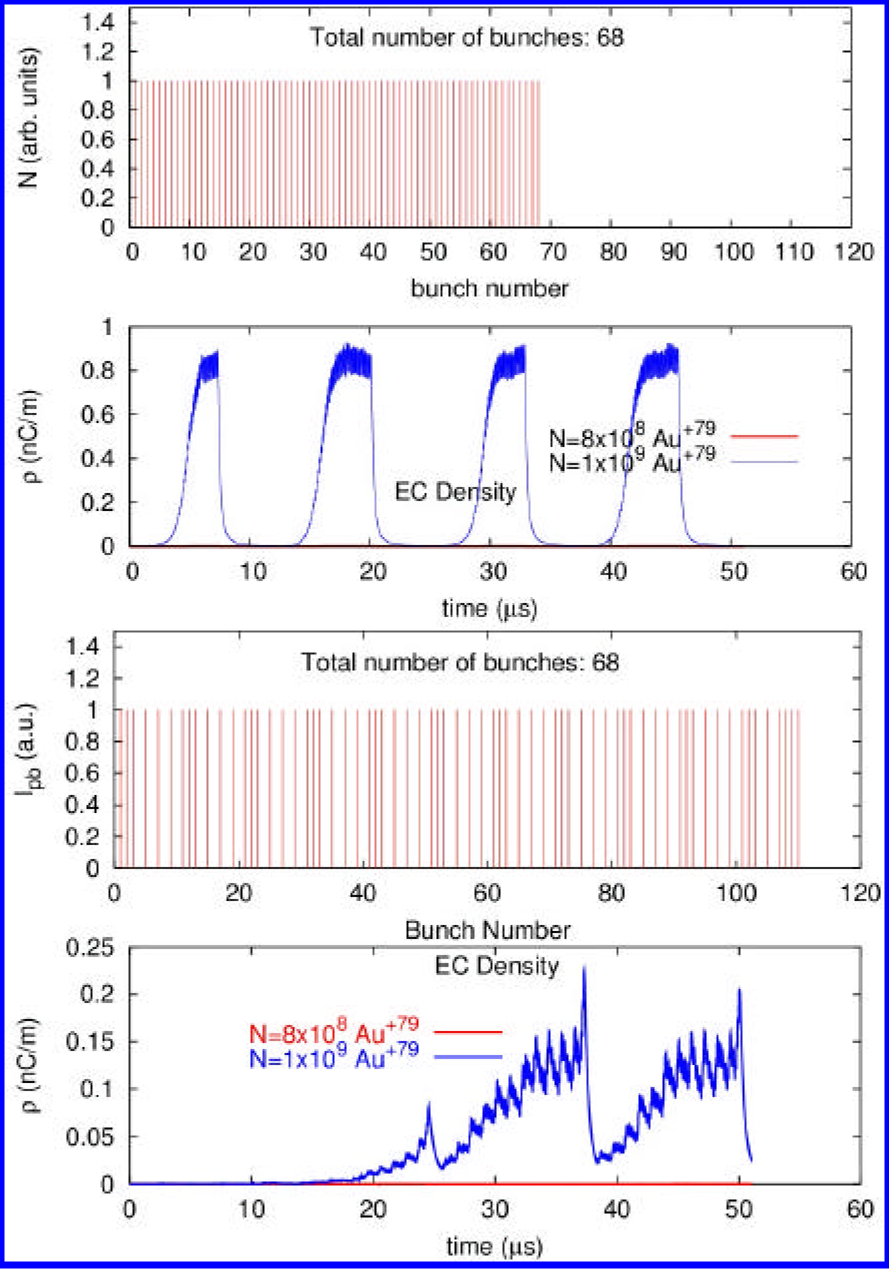
E-cloud cure: bunch patterns

- Useful for operation with less than max number of bunches
- **Patterns with <u>same intensity in fewer bunches</u> and <u>most uniform distributions along circumference</u> both maximize luminosity and minimize e-cloud**
  (problem lends itself for analysis with maps – U. Iriso)
- RHIC 2004 Au-Au limited by dynamic pressure in PHOBOS experiment
- Changed number of bunches from 61 to 56 to 45 as more bunch intensity became available, maximized luminosity at e-cloud limit in PHOBOS



[G. Rumolo and W. Fischer, "Observation on background …", BNL C-A/AP/146 (2004);
W. Fischer and U. Iriso, "Bunch patterns and pressure rise in RHIC", EPAC04; U. Iriso, PhD thesis]

68 bunches in different patterns (simulation)



Single gap of maximum length

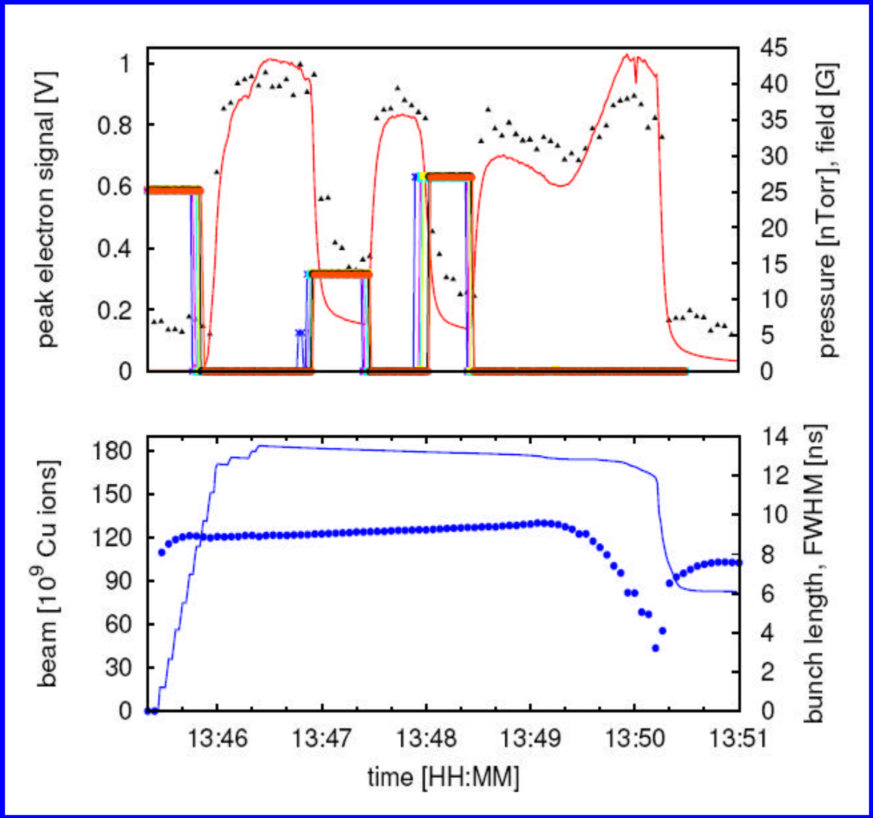
Approximately uniform distribution around circumference

® **Peak e-cloud density reduced by about factor 4 (average even more)**

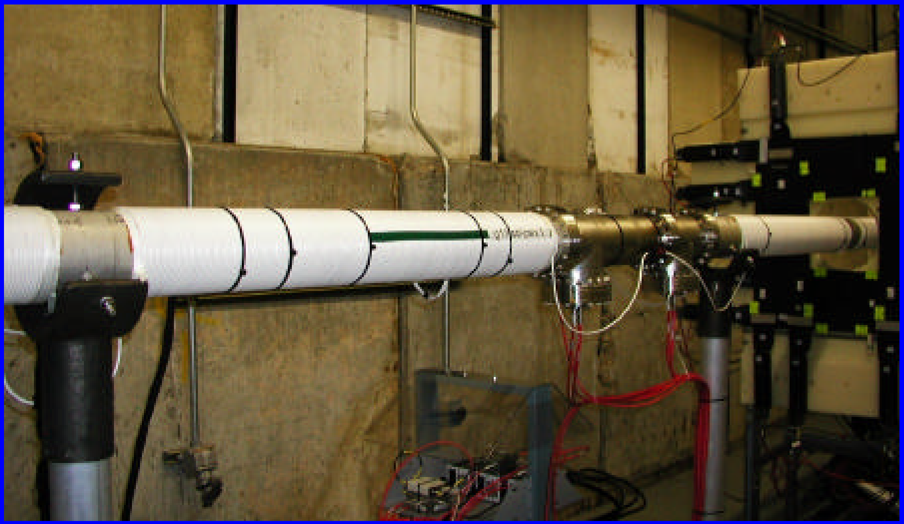
[W. Fischer and U. Iriso, EPAC'04]

E-cloud cure: solenoids

Had 64 m of solenoids installed, max field of 65 G.

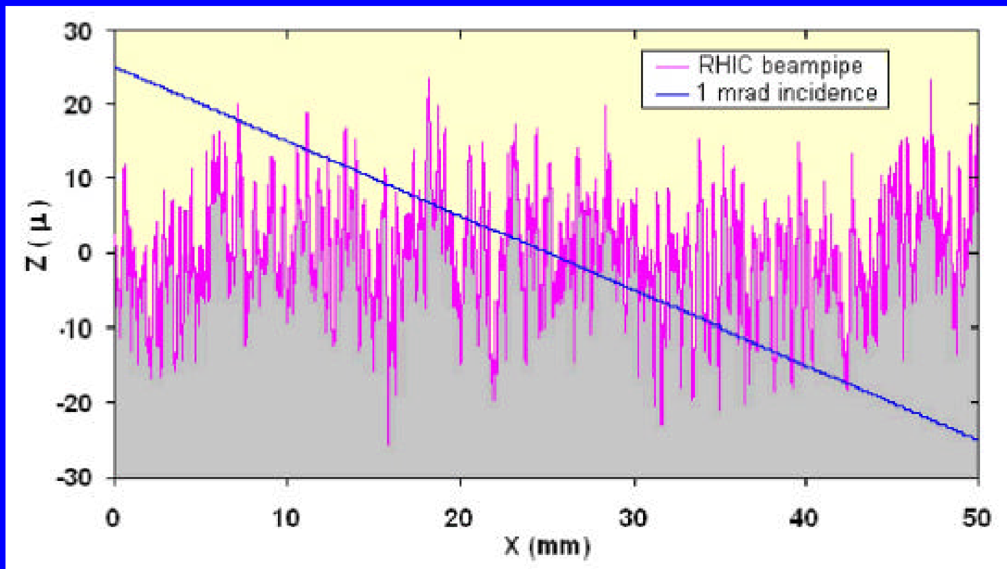


Courtesy U. Iriso

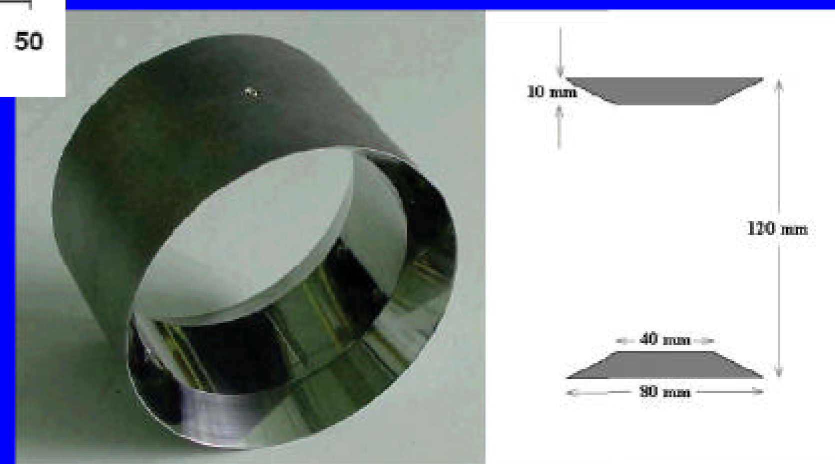


- Both pressure and e- signal decrease with weak solenoid fields, not suppressed completely
- No further reduction noticed with field increases from 12 to 27 G

E-cloud cure: anti-grazing rings (1)



Measured RHIC beam pipe surface and 1 mrad incidence trajectory



Idea of Peter Thieberger:

Macroscopic ridges will transform

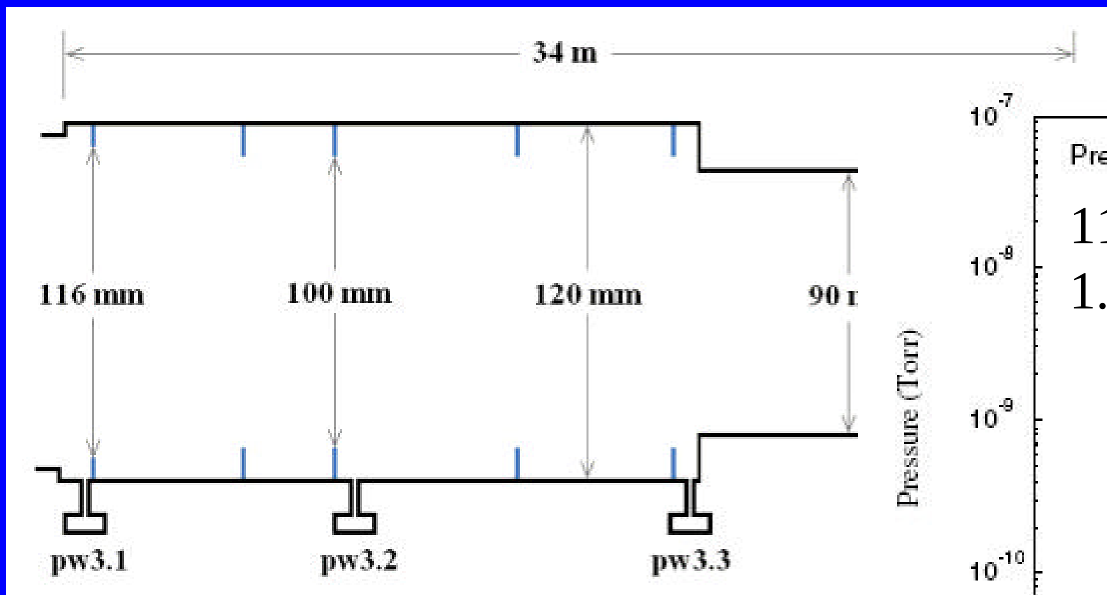
- beam loss with grazing incidence (= multiple perpendicular hits) into
- beam loss with single perpendicular hit
- reduce ion-impact desorption by factor ≈100 (both electrons and molecules)

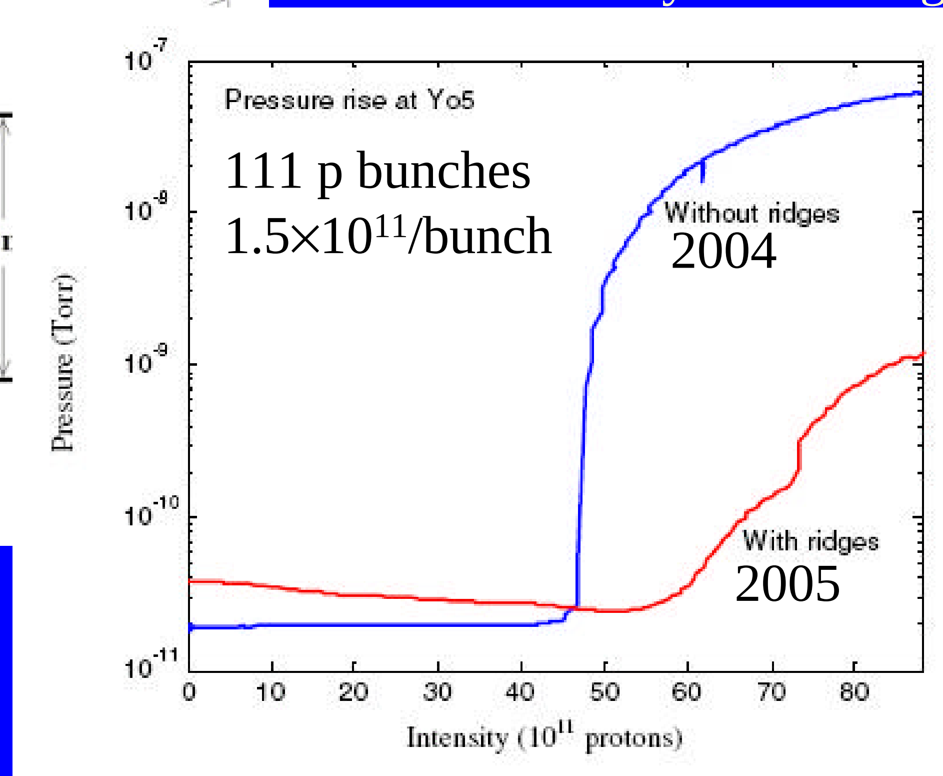
[P. Thieberger et al., “Estimates for secondary …”, Phys. Rev. ST Accel. Beams 7, 093201 (2004).]

E-cloud cure: anti-grazing rings (2)

Had 5 grazing rings installed in 2 long straight sections (bi5, yo5)

Courtesy S.Y. Zhang



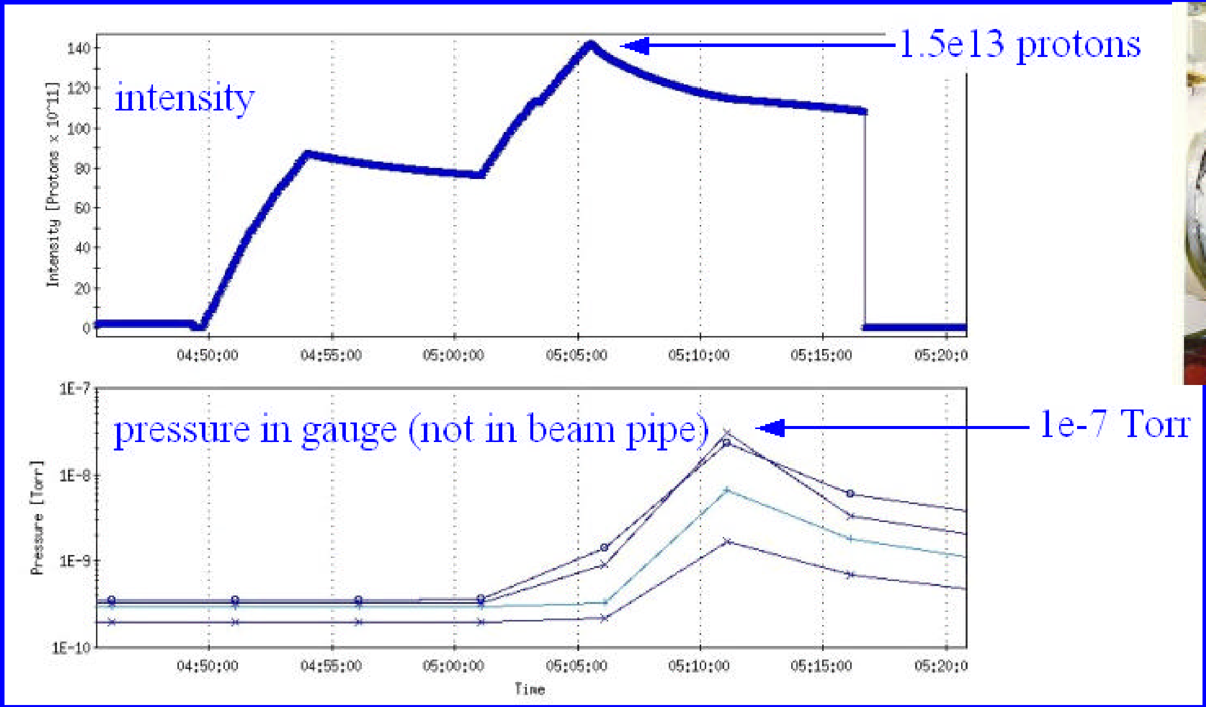


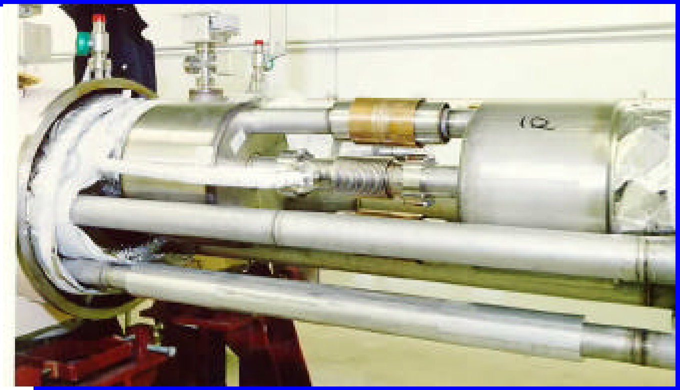
See improvement, but to be effective ridges must intercept beam, which can create additional background. Ridges currently not used in RHIC.

[S.Y. Zhang et al., "Effects of antigrazing ridges …", Phys. Rev. ST Accel. Beams 8, 123201 (2005).]

E-cloud cure: pre-pumping cold regions

- RHIC relied on cryo-pumping in arcs initially (up to 100 mono-layers on wall)
- Observed increase in gas density with high-intensity beam



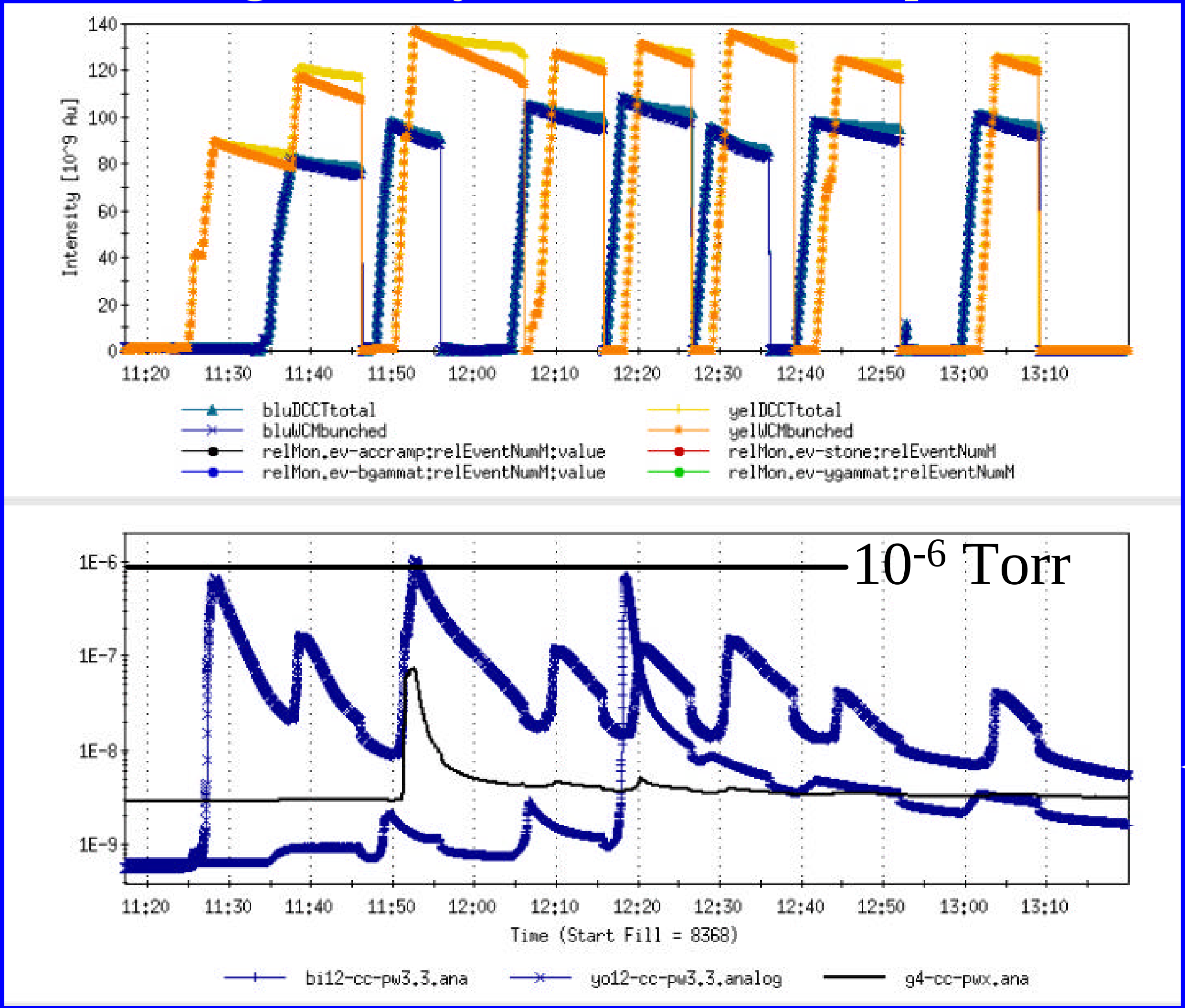


H.C. Hseuh

- Additional pumps lowered pressure to 10^{-6} to 10^{-7} Torr (corresponding to less than mono-layer) before cool-down

E-cloud cure: scrubbing

Scrubbing recently used in Au-Au operation:



← 7 high intensity fills in about 2 h

← Reduced dynamic pressure in worst location by more than 1 order of magnitude

Summary – E-cloud in RHIC

- **E-cloud effects observed at RHIC:**
  dynamic pressure rise, tune shift, electrons,
  instabilities (beam and pressure), emittance growth

- **Cures investigated at RHIC include:**
  in-situ baking, NEG coating, bunch patterns, solenoids,
  anti-grazing rings, pre-pumping in cold regions, scrubbing

- **Open problems:**
  instabilities during transition crossing,
  emittance growth (will learn more next year with polarized protons)