# Status and Upgrade of RHIC Beam Vacuum Systems

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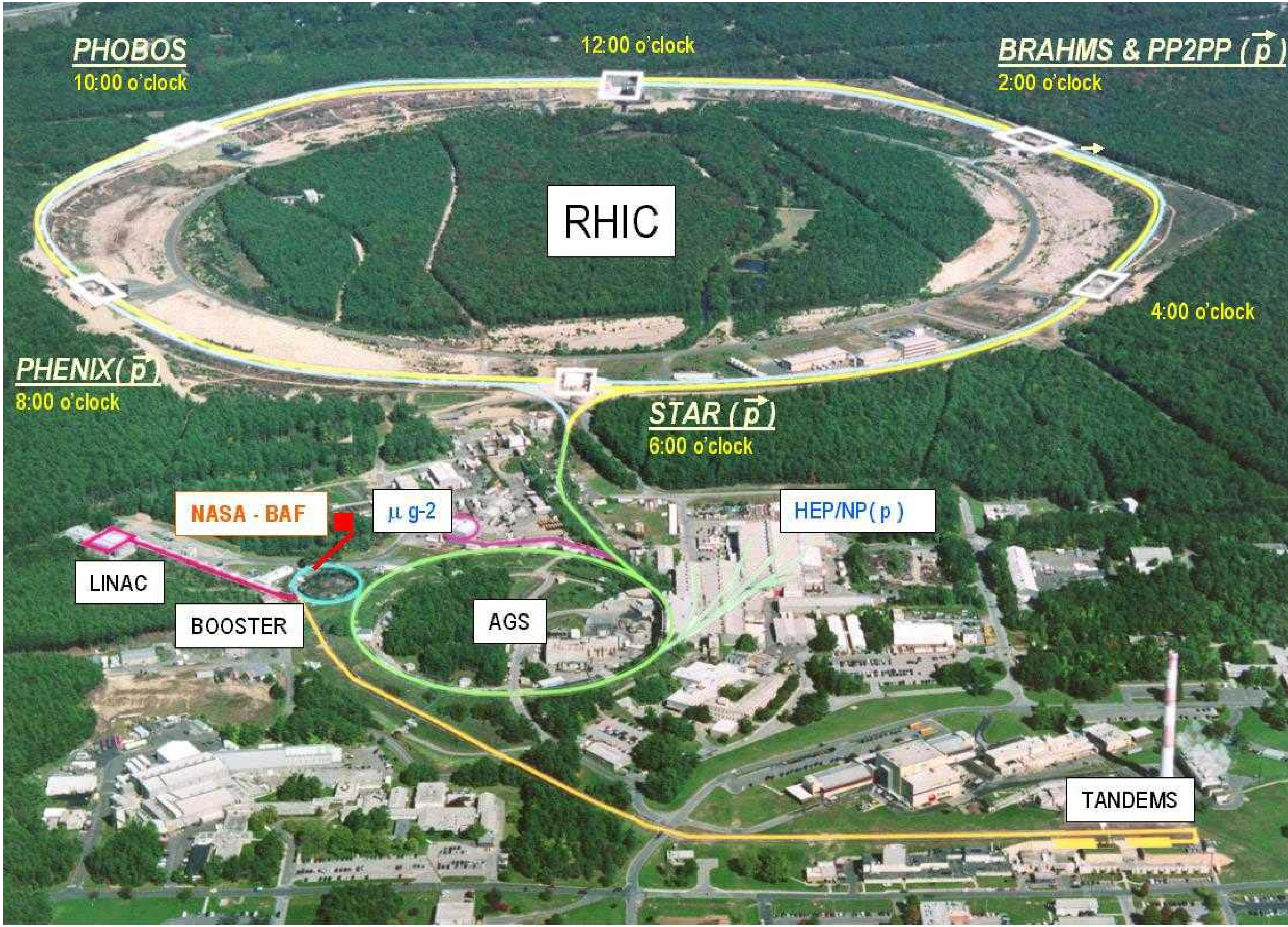
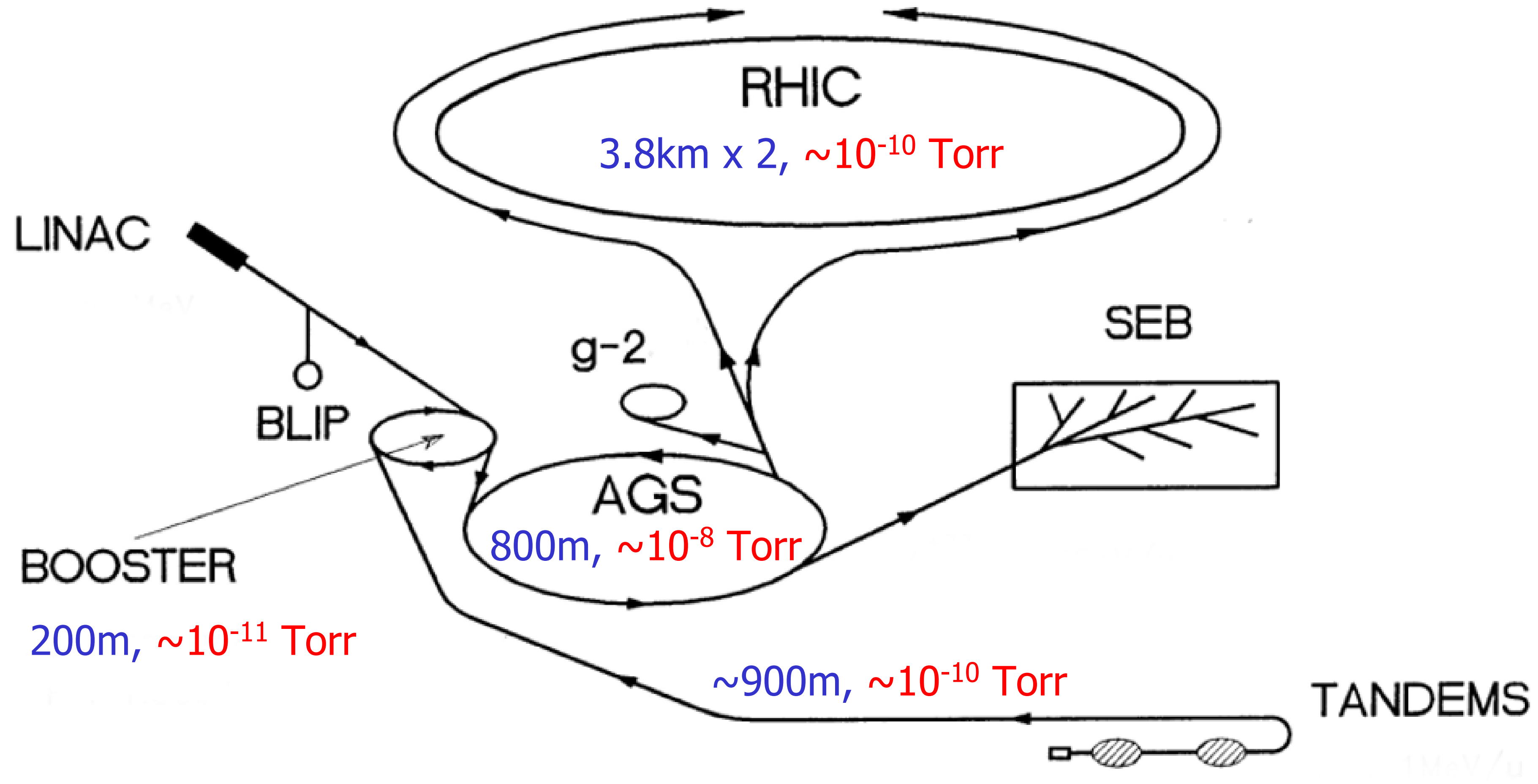
# Outline

- RHIC Vacuum Layout
- Beam Vacuum Systems
  - Vacuum Requirement
  - Cold Vacuum Sections
  - Warm Vacuum Sections
- Studies and Upgrade Plan
  - FY03 Run: Upgrade and Studies
  - FY04 Run and Beyond
- Summary


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NASA - BAF
μ g-2
HEP/NP( p )
LINAC
BOOSTER
AGS
TANDEMS

# C-AD Vacuum Systems



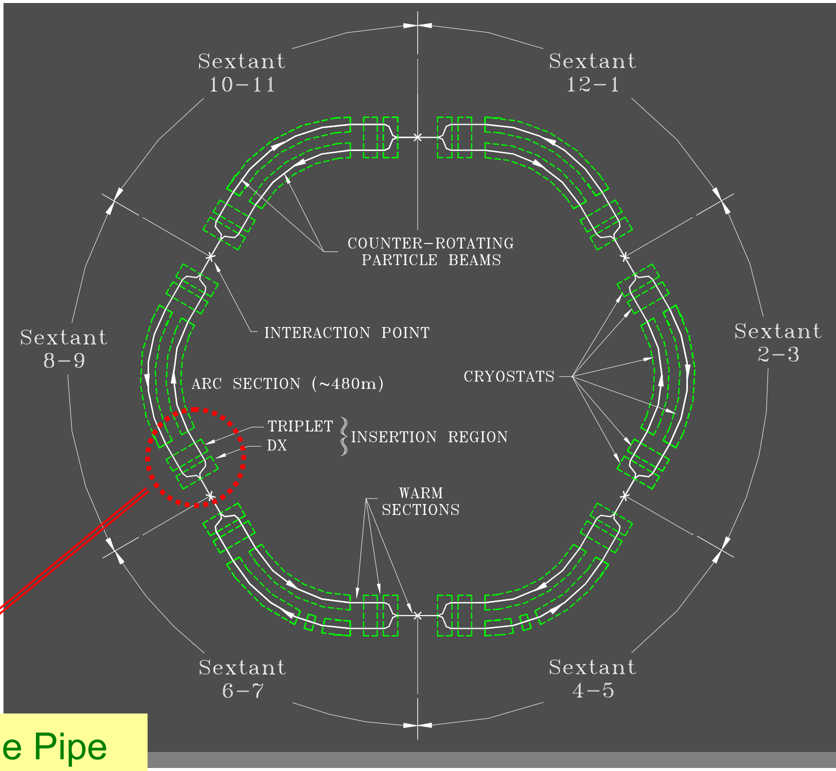
# RHIC Beam Vacuum Systems

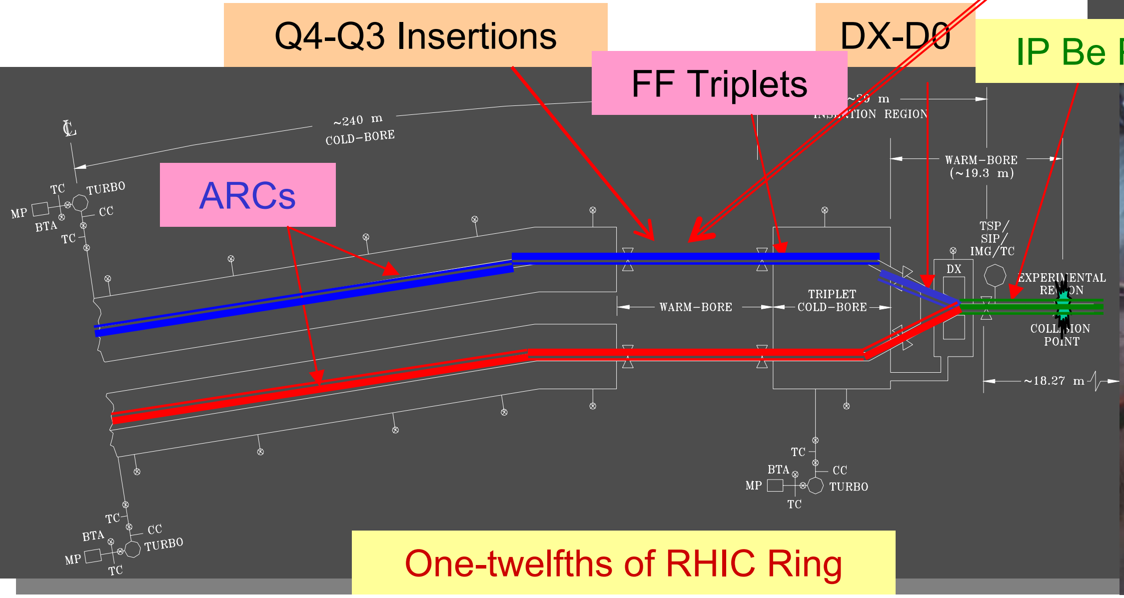
3.8 km x 2 (Blue + Yellow), 84% @4.5K

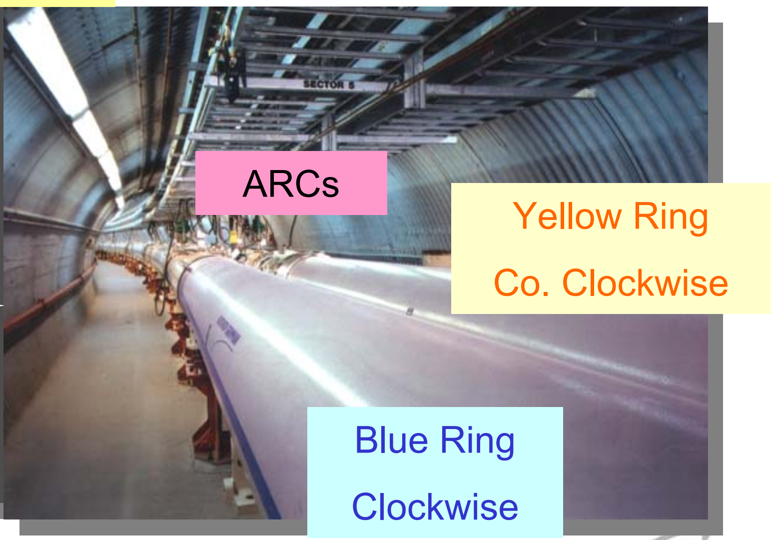
6 sextants: 12 Arcs (500m) and 24 triplets (19m ea.)

1.2 km warm beam sections

- 24 Q3-Q4 insertion regions (34m each)
- 4 Inj. kickers + Lambertson regions (~9m)
- 12 DX-D0 for merging B & Y beams (6m)
- 6 IP regions for experiments (17m)



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- Beam Vacuum Systems
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    - Experimental background
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# RHIC Vacuum Requirement

(BNL-47070, Rhoades-Brown & Harrison, Dec. 1991, D. Trbojevic, Feb. 1993)

$\rho = 2\text{x}10^{+7}$ molecules/cm$^3$

$\Rightarrow$ Warm < $5\text{x}10^{-10}$ Torr (~ 90% $H_2$ )

Cold < $1\text{x}10^{-11}$ Torr ($H_2$ and He)

Beam – gas interactions for $Au^{+79}$ at $\gamma = 30$ (lowest energy @ store)

Electron Capture ($\tau$)

| | | |
|---|---|---|
| $\sigma_{REC}$ | $= a\, Z_P^5\, Z_T / \gamma$ | ~ $5\text{x}10^{-25}$ cm$^2$ |
| $\sigma_{NREC}$ | $= b\, Z_P^5\, Z_T^5 / \gamma$ | ~ $4\text{x}10^{-32}$ cm$^2$ |
| $\sigma_{VAC}$ | $= d\, Z_P^5\, Z_T^2 \ln(\gamma/\gamma_o)$ | ~ $2\text{x}10^{-27}$ cm$^2$ |

Nuclear Scattering ($\tau$ + detector bkg)

$\sigma_N = \pi R_N^2 = \pi [1.25 (A_T^{1/3} + A_P^{1/3})]^2$ ~ $2.5\text{x}10^{-24}$ cm$^2$

$1 / \tau = c\, \beta\, \rho \sum \sigma$ $\tau_{b-g} > 200$ hr (» $\tau_{IBS}$ ~ 10 hr)

Rate (beam-gas, $l = \pm 40$m ) = $N_{Au} l\, \rho\, \sigma_N$

< $1\text{x}10^{-4}$/ bunch crossing @ Ł~$2\text{x}10^{26}$ cm$^{-2}$ s$^{-1}$ (S. White, Oct.,1991)

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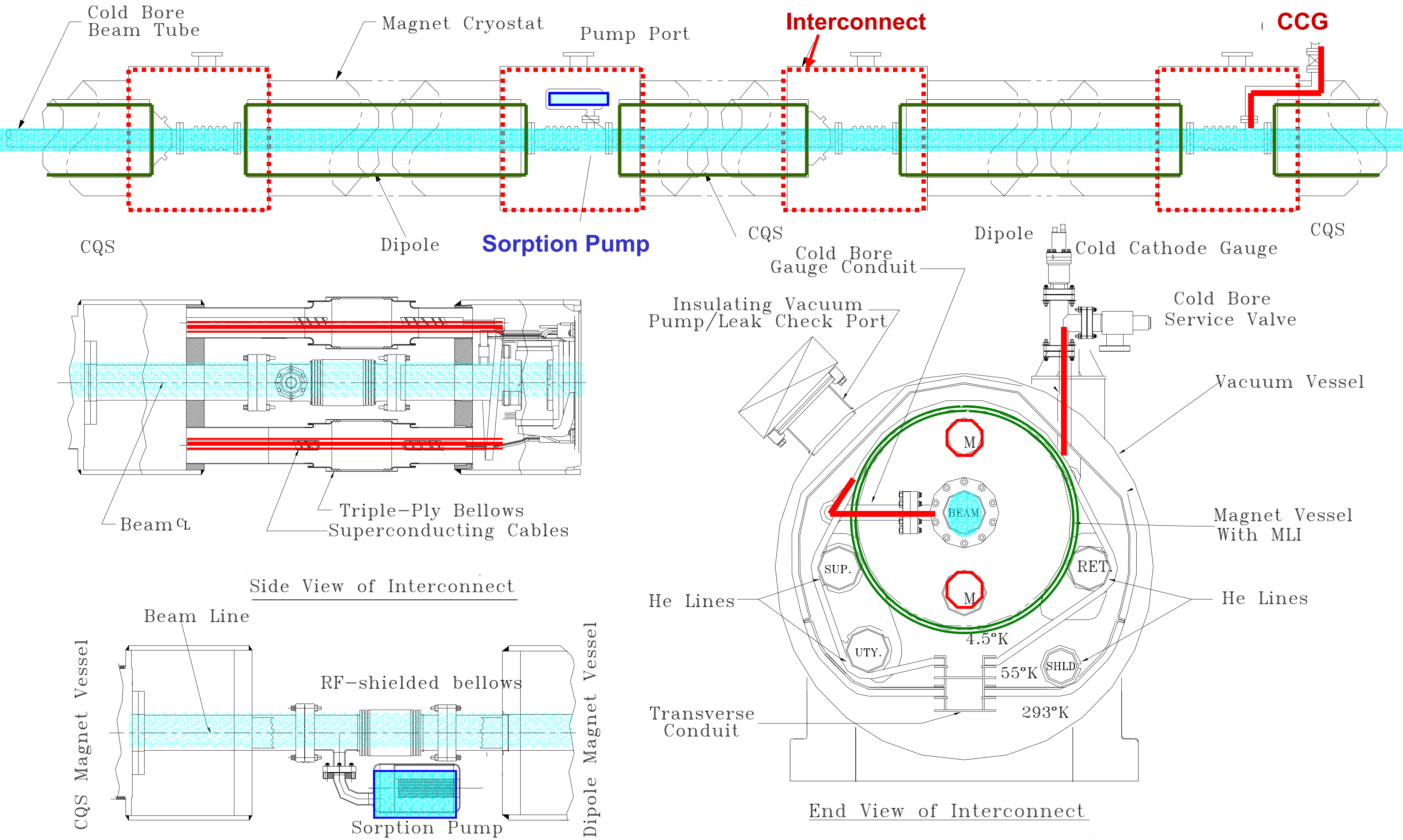
# Layout of RHIC Arc Cold Bore Vacuum

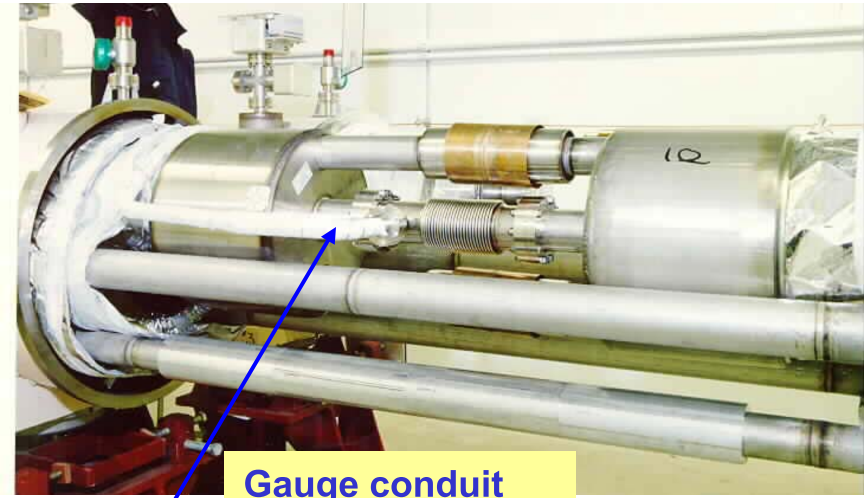


# Cold bore pumps and gauges

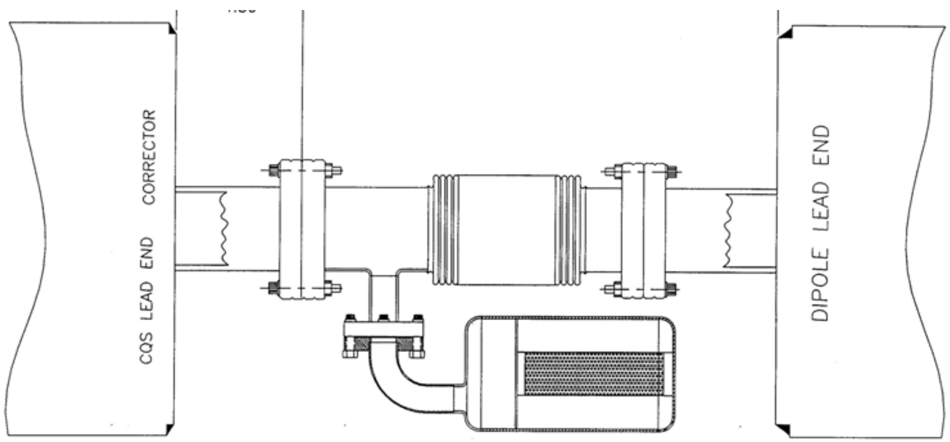
CCG and Sorption pump every other 15m

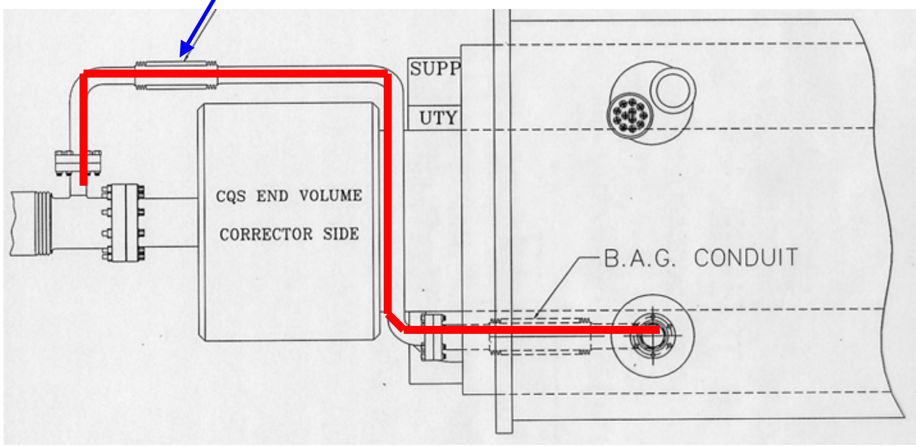
Pump down with TMP to e-3 Torr

Most CCGs read low e-9 to mid e-10 Torr



Gauge conduit




**Sorption Pumps with 300g charcoal**

**@ ~ 10K, S(He) ~ 2 l/s**

**P (He) e-10 Torr @ Q(He) > 30 *Torr.l***

**CCGs with a 1.5mx1” Φ conduit to cold bore**

**Q ~ $10^{-9}$ *Torr.l/s*, C < 1 l/s**

**⇒ P ~ $10^{-9}$ Torr**

# Measurement of He pressure and travel speed in cold bore during FST

With controlled leak of 4e-5 scc/s x 9 days in RHIC 500m arc @ 4.5K

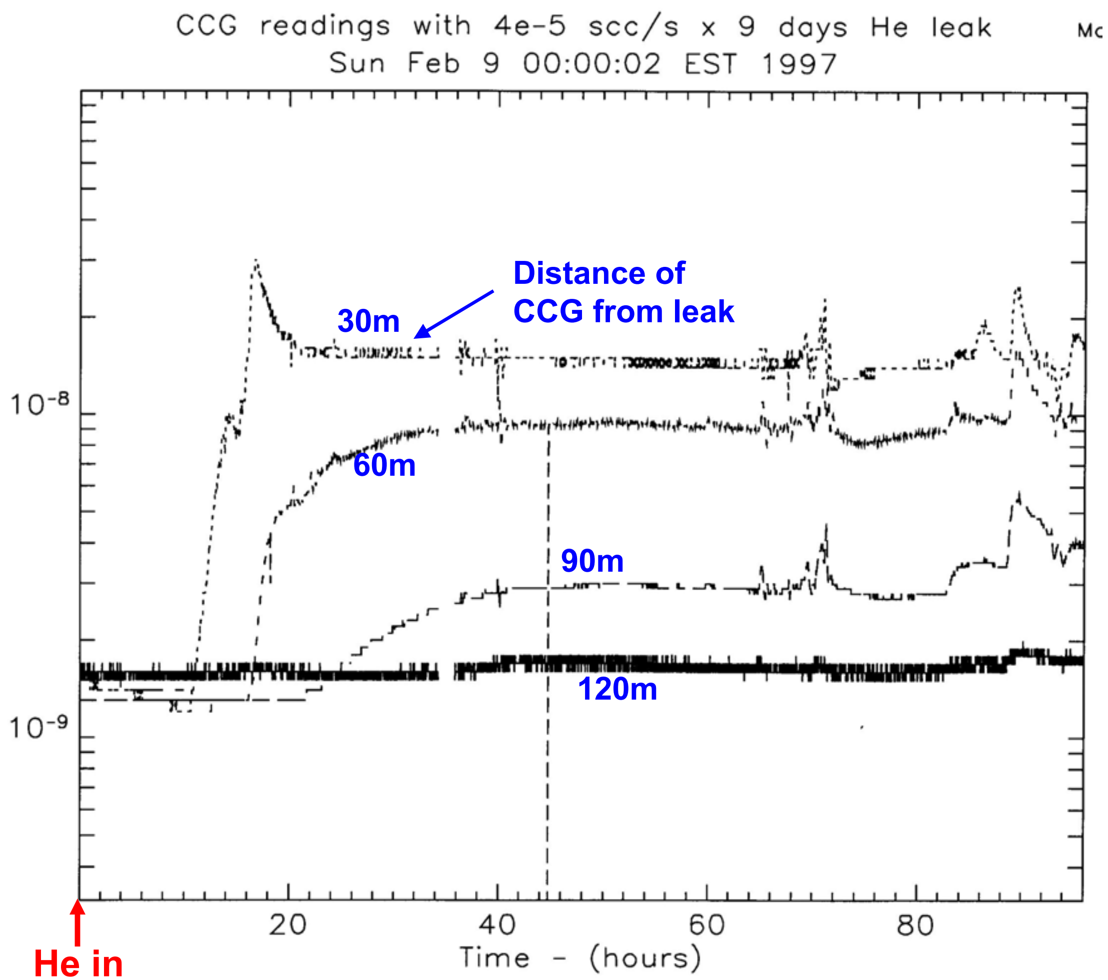
With sorption pumps and CCGs at 30m intervals

Result agrees well with physical adsorption model with steep adsorption front

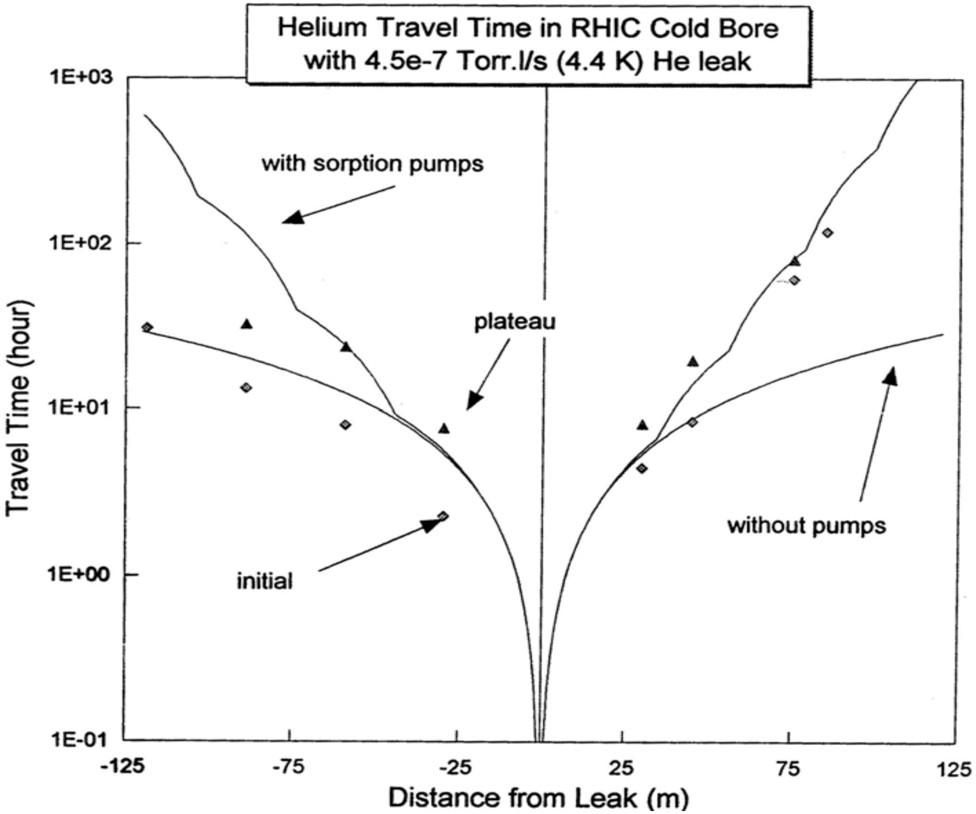
Verified the usefulness of sorption pumps in slowing down He travel

CCGs are sensitive to He $\Delta P$ to

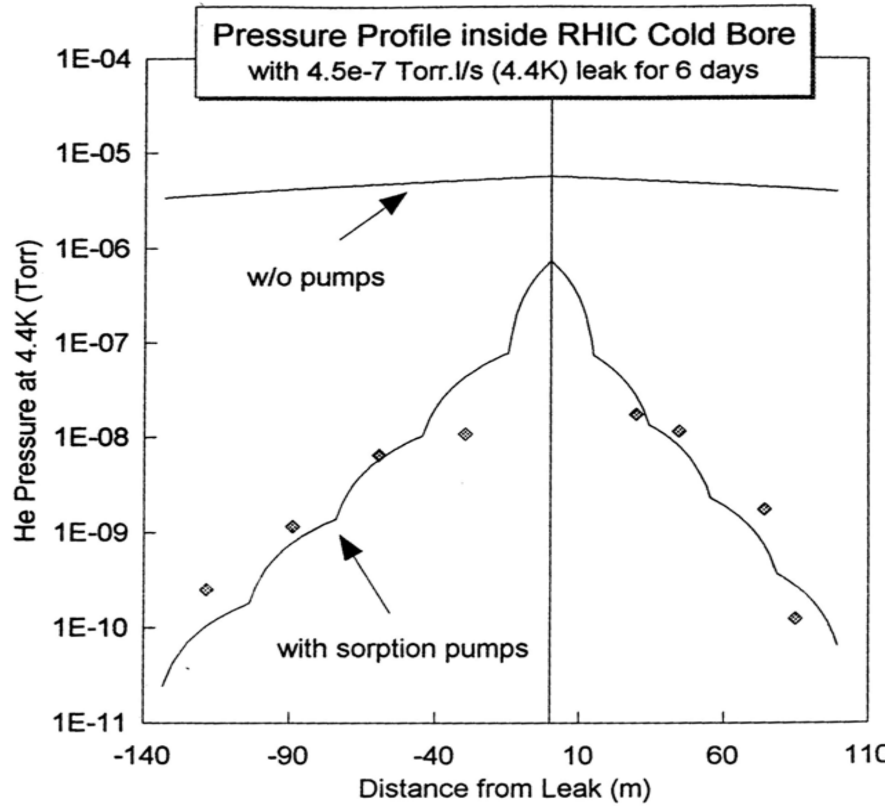
~ $10^{-10}$ Torr



Sorption pumps slowed down the He wave significantly




Sorption pumps reduced the He pressure profile by several decades




No detectable He leaks in cold bore over the last four years

CCGs are not sensitive to ΔP of other gas species due to large cryopumping

Was there or will there be ΔP in cold bore @ high intensity?

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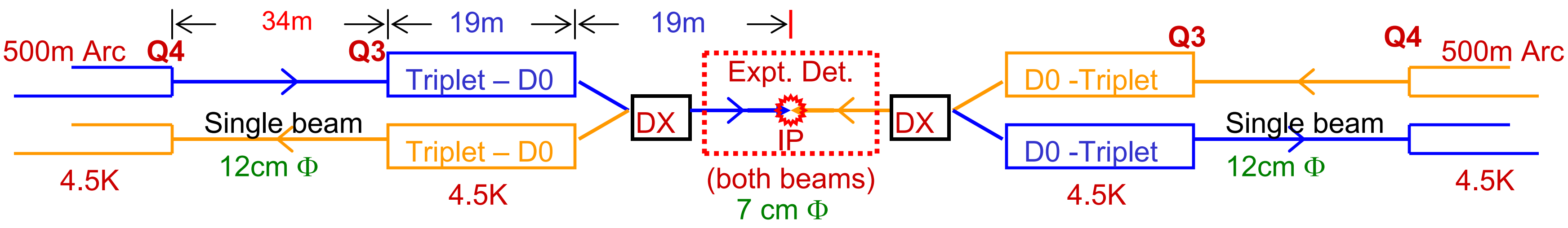
# Layout of Warm Vacuum Sections – Insertions + IR




Pumped with ion pumps and titanium sublimation pumps every 10 – 17 m

Small effective pumping speed of 8 - 24 *l*/s.m for $H_2$ ($\Phi$ = 7 – 12cm)

$P_{AVG}$ / $P_{Pump/CCG}$: 8 ($H_2$) – 28 (CO) for $\Phi$ = 7cm (IP region)

2.6 ($H_2$) – 7 (CO) for $\Phi$ = 12cm (Q3 – Q4)

In-situ baked to ≤ 250 C x ≥ 40 hours

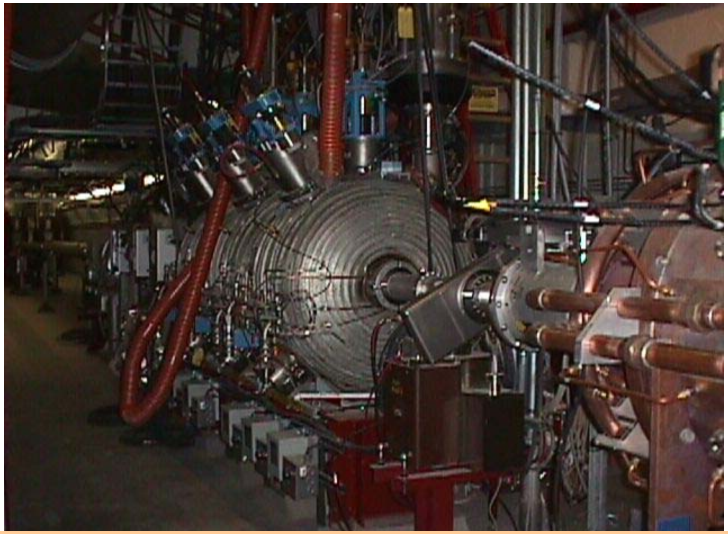
All the incoming sections to < $10^{-10}$ Torr

All the common (IP + DX-D0) sections to low $10^{-11}$ Torr

Some outgoing lines to low $10^{-10}$ Torr

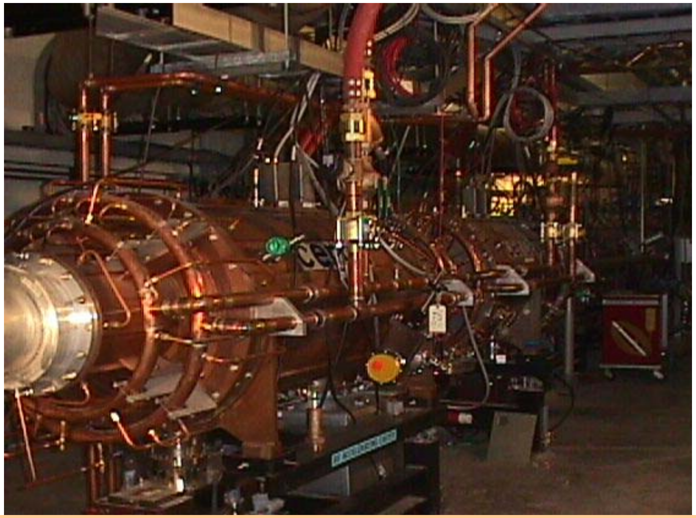
7 of 46 sections (mostly @ RF regions) were not baked – low $10^{-9}$ - $10^{-10}$ Torr

# RHIC warm vacuum sections



197 MHz  Storage Cavities, 1 MVx7 / turn

Standard warm pipes w/ IPs and TSPs
In-situ baked to 250ºC x 40 hrs



28 MHz  Accel. Cavities, 300kVx2 / turn


DX-D0 chamber for both beams
In-situ baked to 250ºC x 40 hrs

# Interaction Regions

Be beam pipes inside expt. detectors

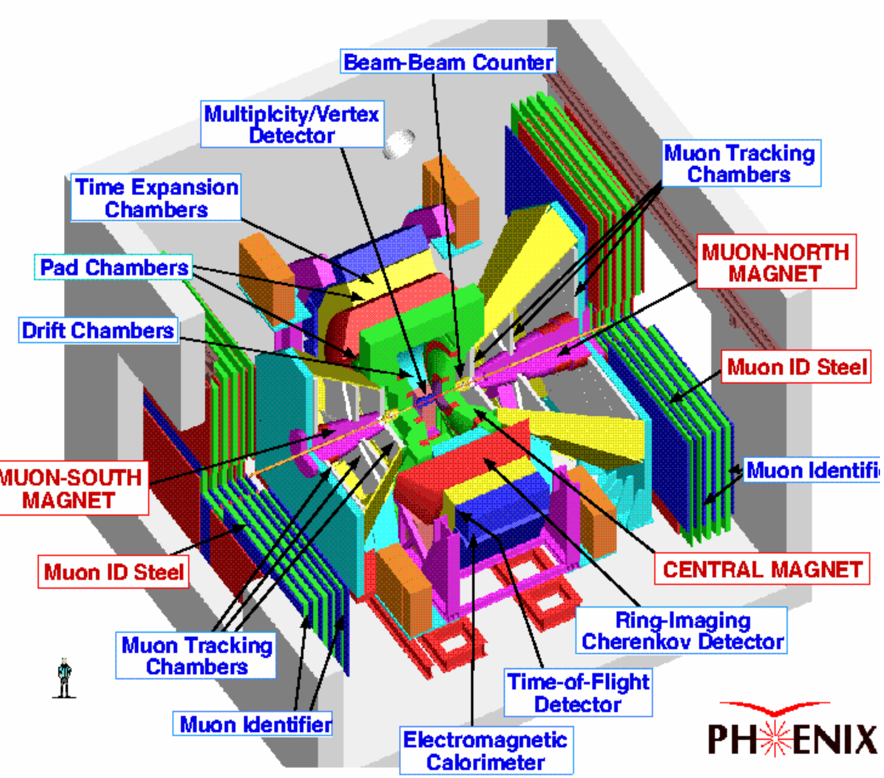
- Be brazed to SS or Al extensions
- 4 – 12m long, 7cm Φ, 1mm wall

IP+TSP ~17m apart

# Phenix Detector

**Phenix**

- **6m Be/SS beam tube of 7cm Φ**
- **In-situ baked @ 200 C to ~2x10$^{-11}$ Torr**
- **Heating jackets removed after bake**
  - **by moving >10$^{2}$ ton magnets around**
  - **with ~mm clearance**




# STAR Detector

**8m Be/Al pipe of 7cm Φ inside detector**

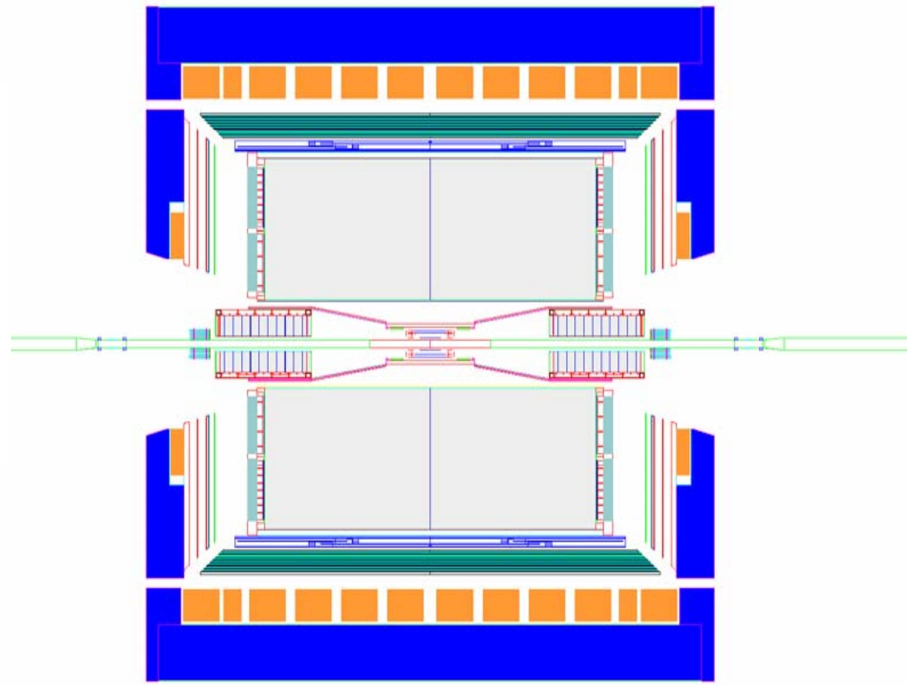
**No heating jackets allowed**

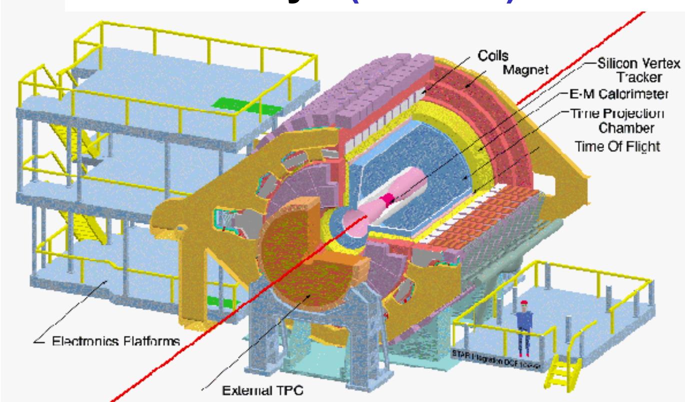
**No access before and after bakeout ⇒**

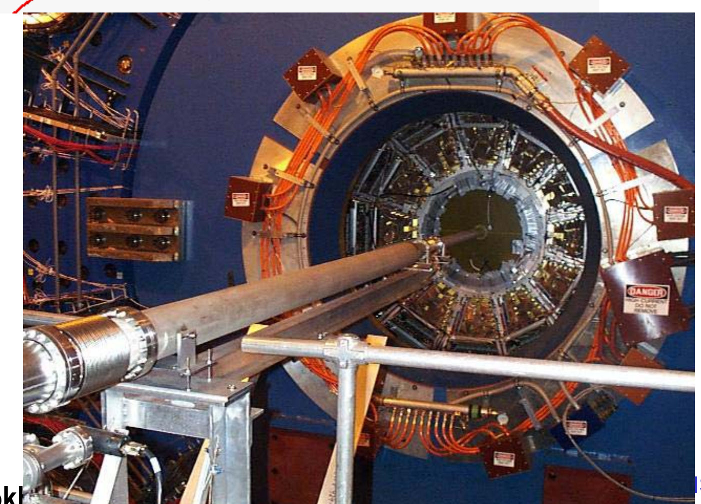
**0.025mm x 5 Kapton insulation**

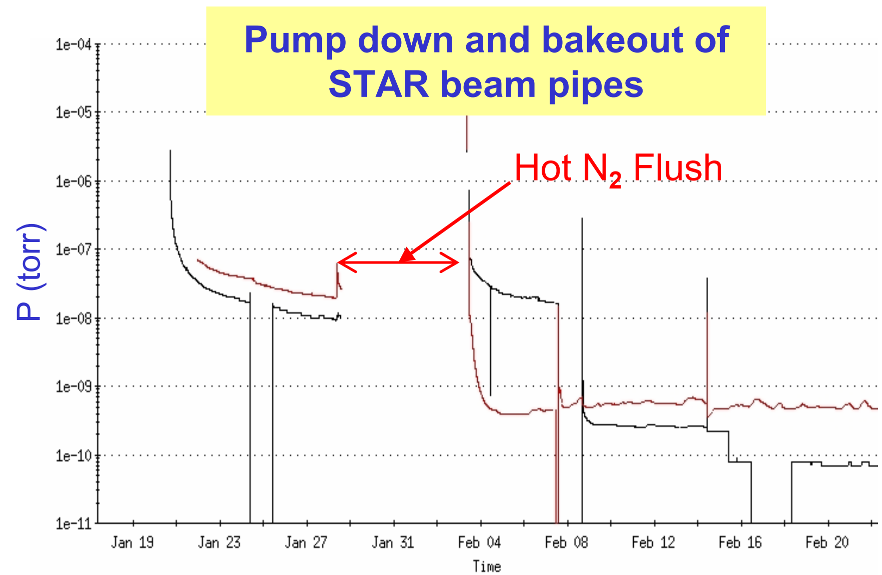
**Hot (~200°C) $N_2$ ($LN_2$ boil-off) flush**

**for 3 days (~100°C) ⇒ ~3x10$^{-11}$ Torr**







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- Beam Vacuum Systems
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    - Types of pressure rise
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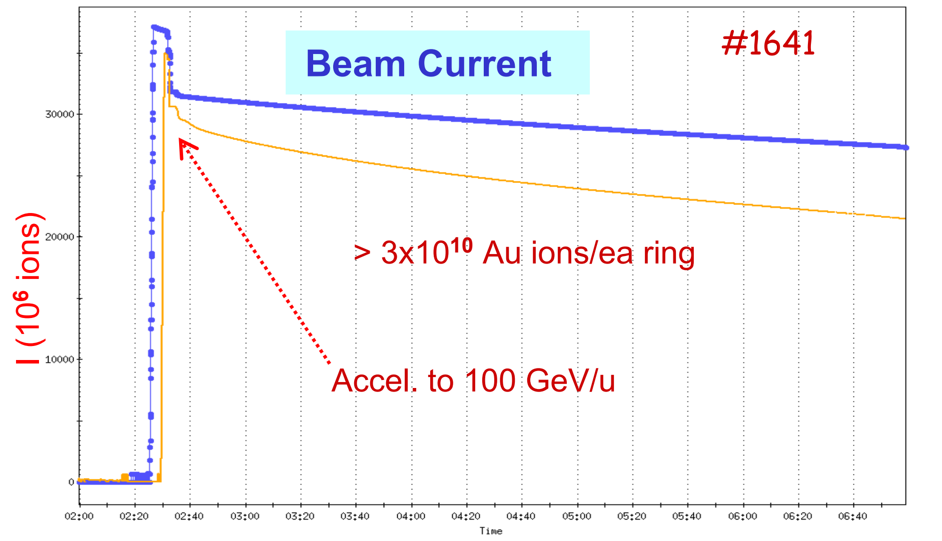
# Pressure Rise with Medium Intensity of $6x10^8$ Au/bh x 55 bunches

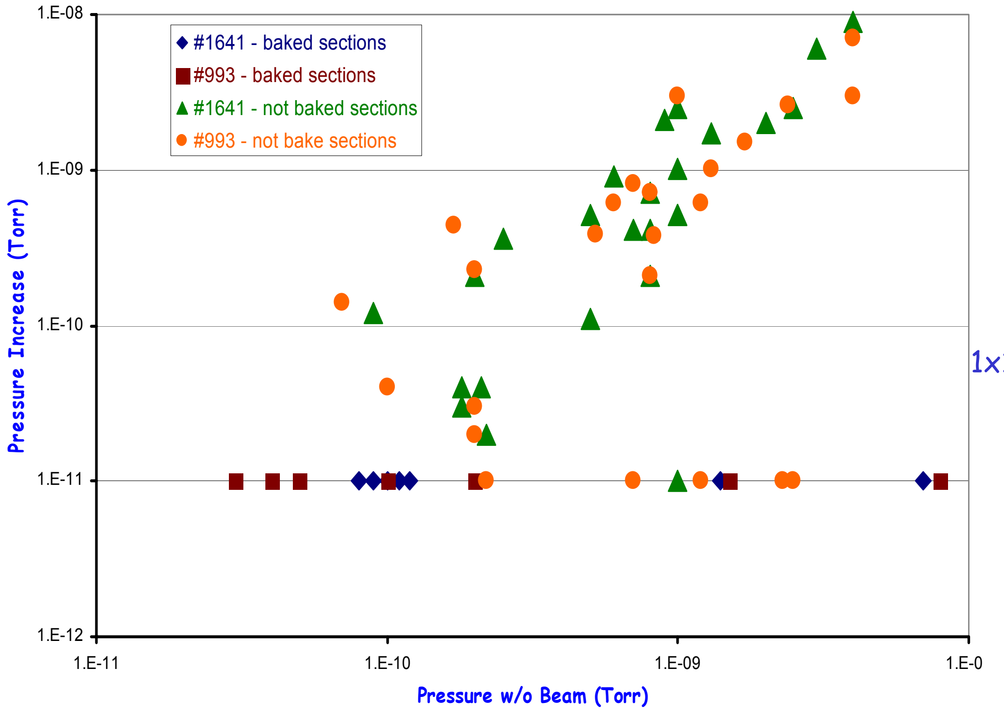
ΔP < 10X at not baked regions

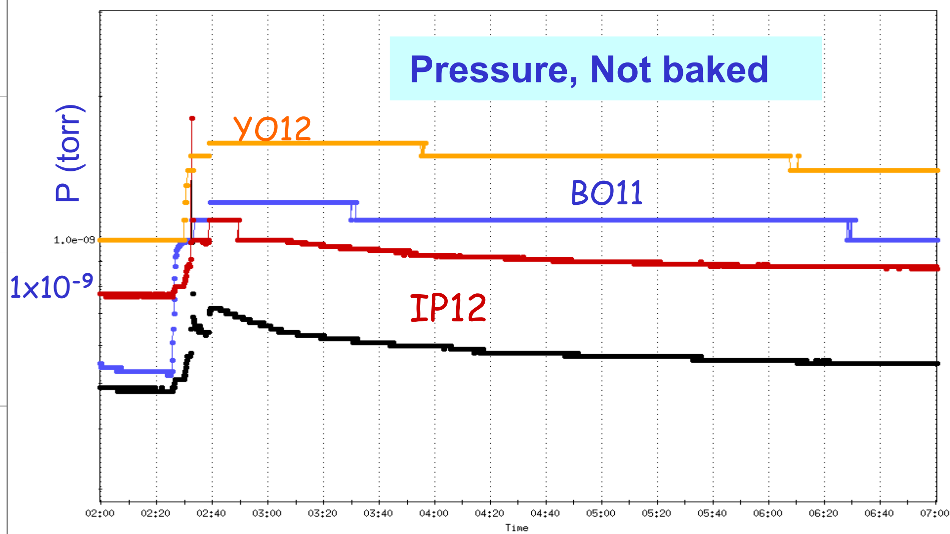
No ΔP at baked regions




5 hrs

Pressure Increase during Stable Stores



# Two types of ΔP @ high beam current

W. Fischer, Tuesday
SY Zhang, this afternoon
P. He, this afternoon

## @ Injection

Sensitive to bunch intensity and spacing

ΔP(110) > ΔP(55) even when I(110) < I(55)

**Slow** pressure rise at many sections

with known $I_{th}$ for ΔP

Studied w/ electron detectors and solenoids

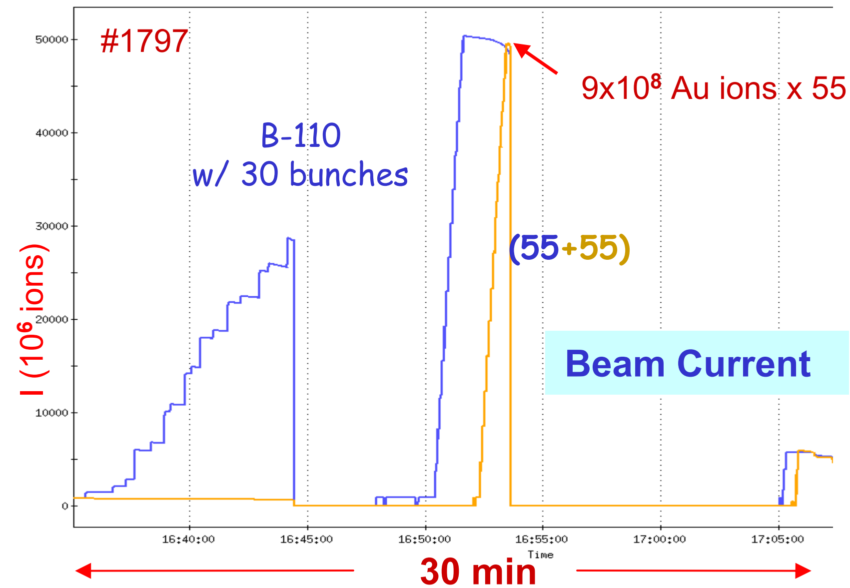
## @ Transition

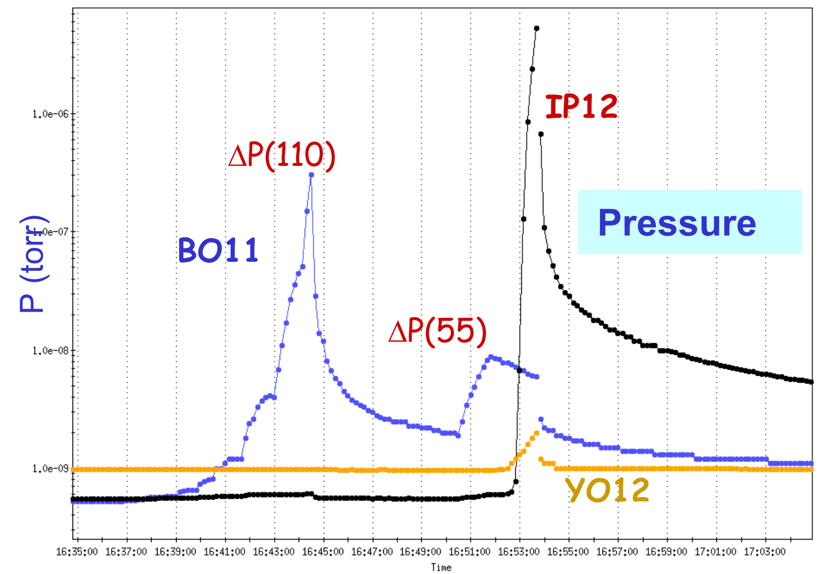
**Fast** pressure rise at one or two sections

∝ I, beam size and momentum spread

Caused by beam loss/halo scraping

Difficult to study and deal with

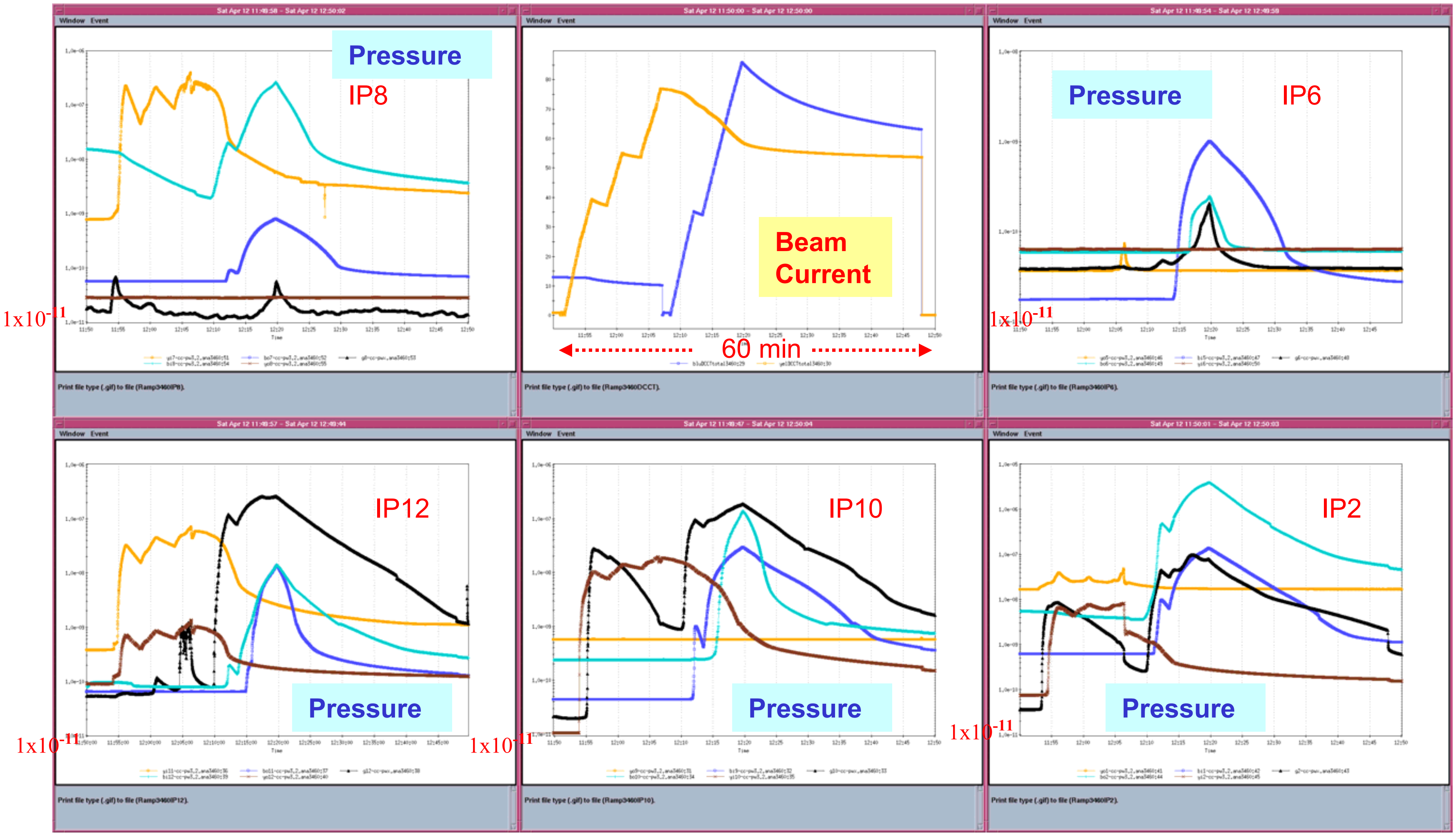


## High I - p^ x p^, 9x10$^{10}$ p^/bh x 110

# ΔP @ Injection

## ΔP over the whole rings up to 10$^{-6}$ Torr due to electron multi-pacting



# $I_{th}$ for p^, d & Au @ Injection

| | IP12 | BO11 or YO12 |
|---|---|---|
| $Au^{+79}$ - (55) | 7e+10 | 2e+10 |
| $Au^{+79}$ - (110) | 6e+10 | 1e+10 |
| p^ – (55) | 7e+12 | 4e+12 |
| p^ – (110) | 6e+12 | 2e+12 |
| ---------- after insitu bake ---------- | | |
| $Au^{+79}$ - (55) | >12e+10* | 4.5e+10 |
| $Au^{+79}$ - (110) | | 3.5e+10 |
| d - (55) | >12e+10* | > 7e+12 |
| d - (110) | | 7.0e+12 |
| p^ – (110) | 9e+12 | 3.5e+12 |

**$I_{th}$ (p^ & d) > 79 * $I_{th}$ (Au):**

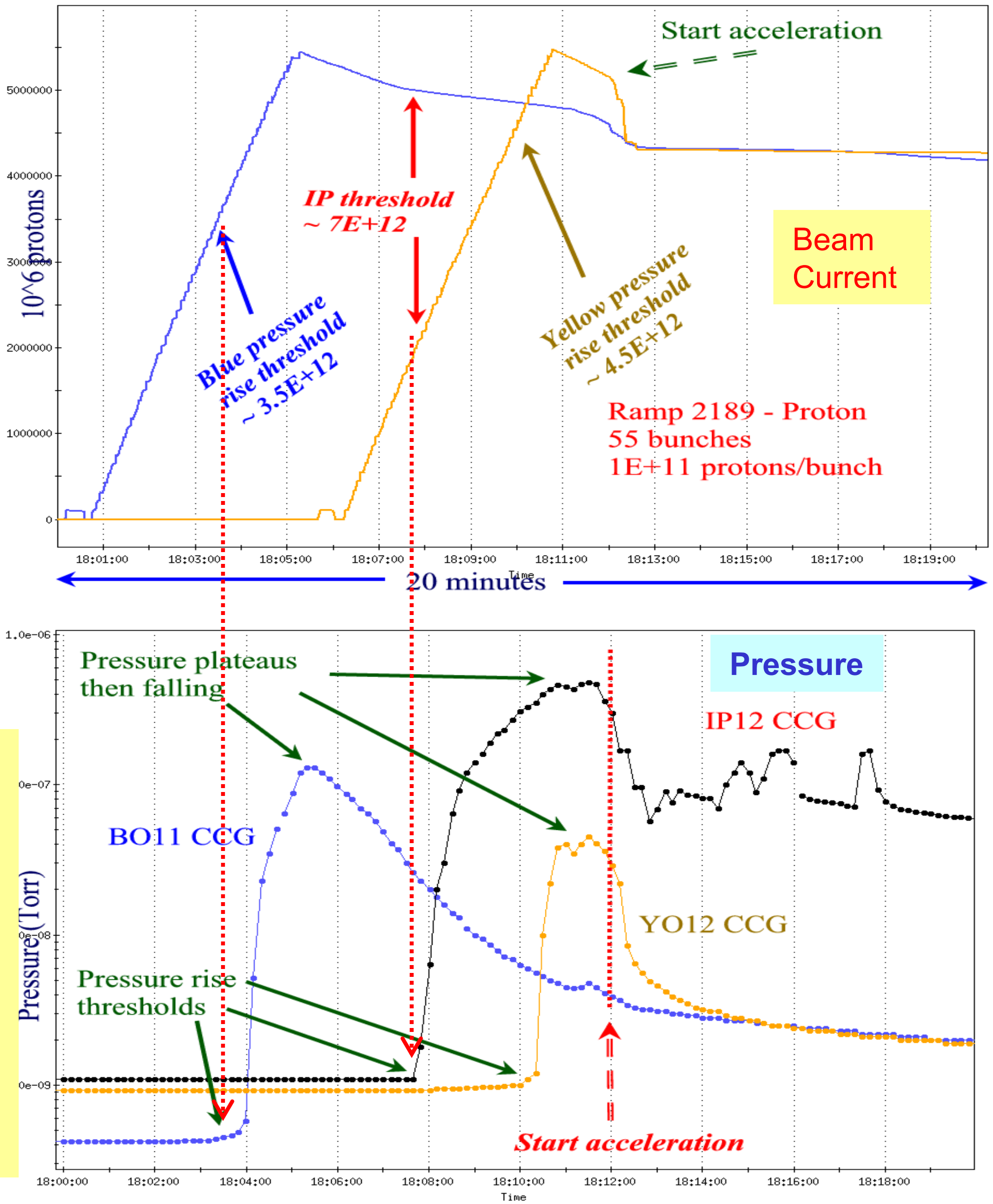
**σ (gas ionization) $\propto Z_p^2$**

**$I_{th}$ (baked) > $I_{th}$ (not-baked):**

**lower SEY, lower η for ESD & ID**

**$I_{th}$ (55) > $I_{th}$ (110):**

**electron survival in bunch gaps**



# ΔP @ Transition

## ΔP due to Beam Scraping/Loss

No ΔP during injections

During acceleration

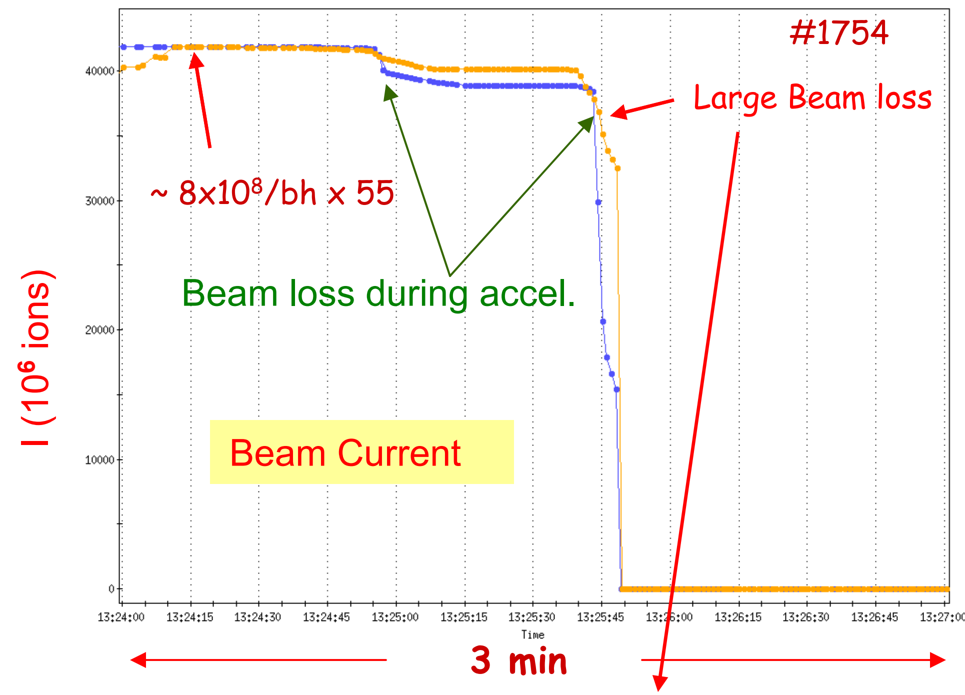
Rapid beam loss with ΔP of $10^5$

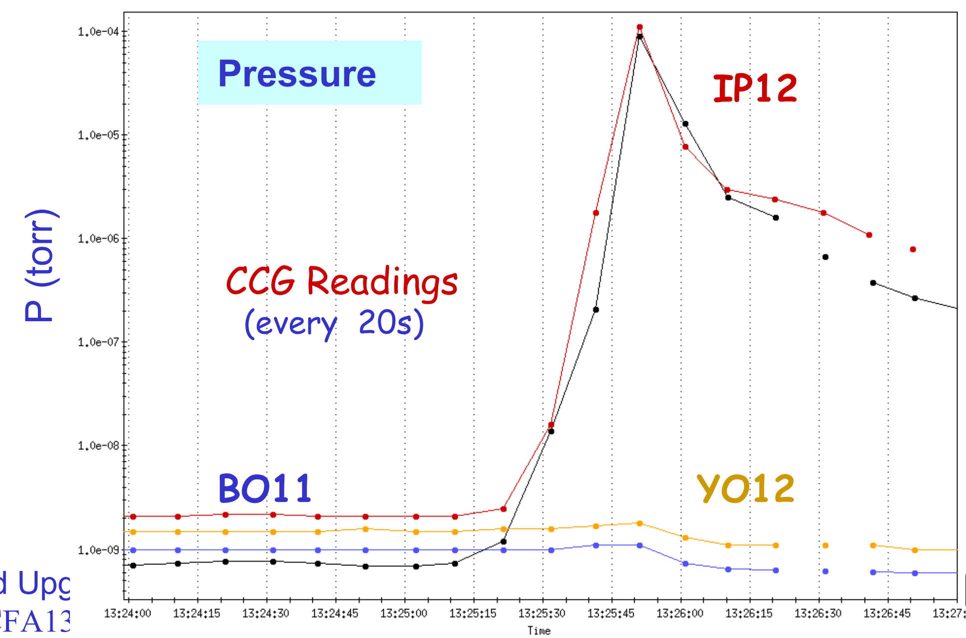
Difficult to measure localized beam loss of a few percent

From ΔP, V and S, the estimated desorption rate by beam scraping is

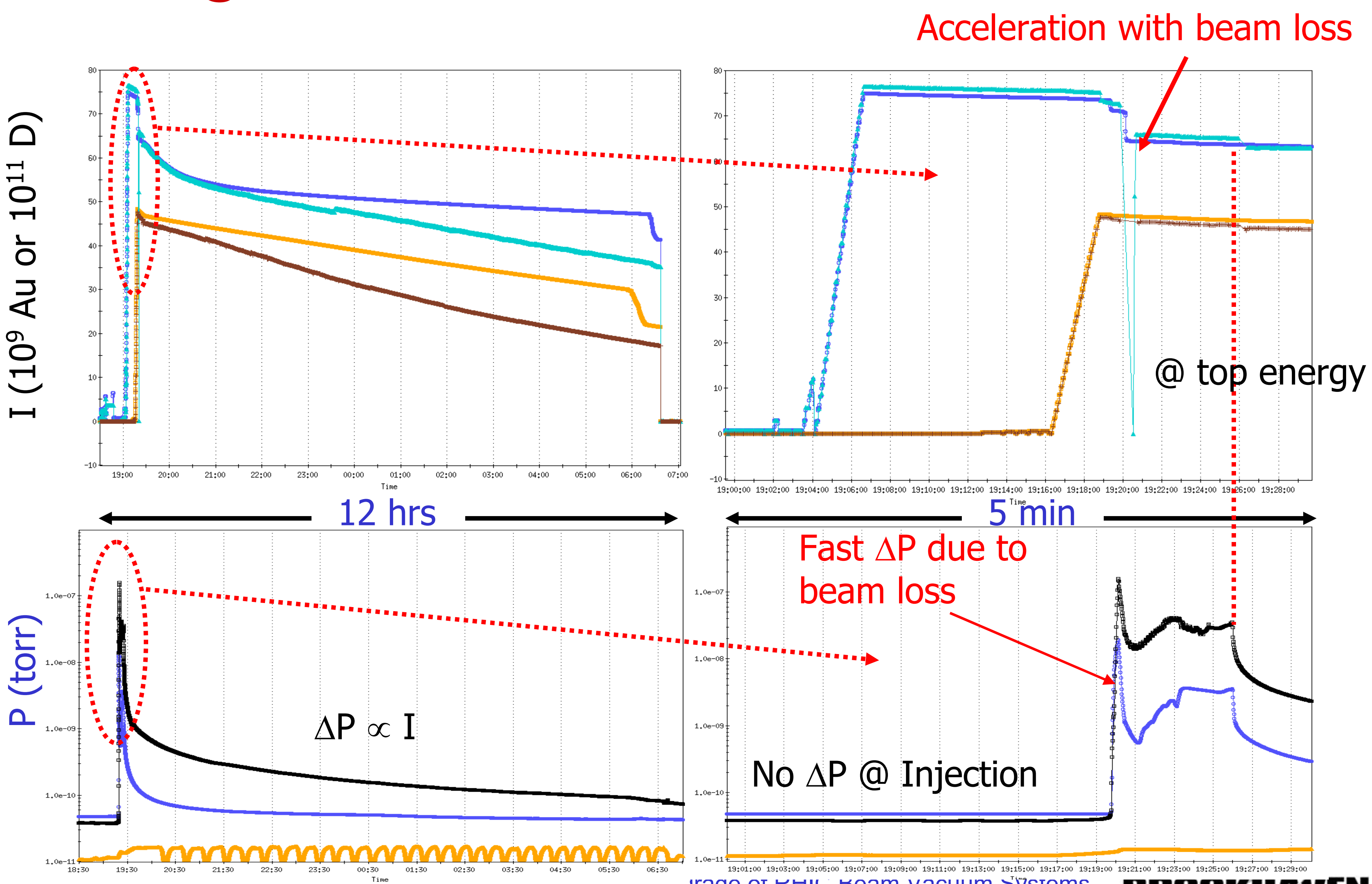
$\eta \sim 10^7$ molecules/lost Au ion

(assuming all beam lost in one section)



# ΔP @ Transition



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    - 12 BNL electron detectors + others
    - 4m x 16 solenoids
  - FY04 Run and Beyond
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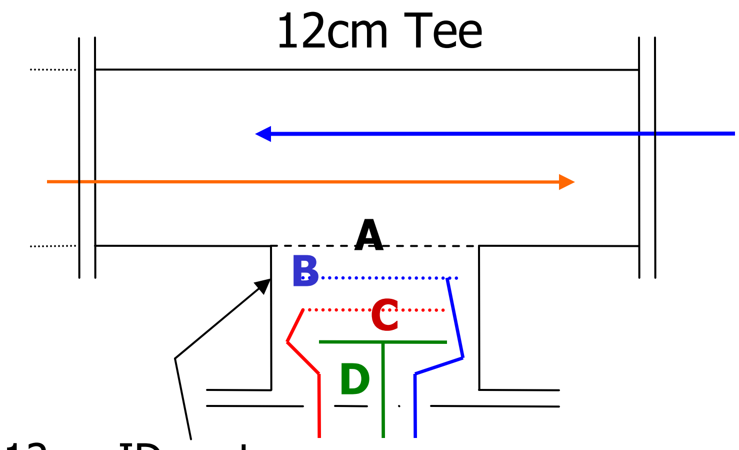
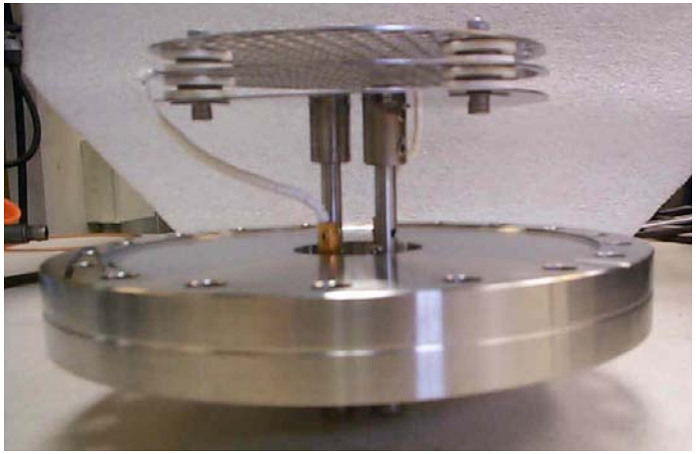
# BNL Custom Electron Detectors




A: RF shield (20% trans.)
B: grid 1 (-?V)
C: grid 2 ( -9 V)
D: collector (+45V)



- Simple and durable design
- Well shielded to minimize beam induced RF noise
- Large area (~150 $cm^2$) to increase signal
- 2 grids for individual biasing and selecting of electron energies
- Less than 10% transmission as calibrated w/ electron gun (P. He)
- May be modified to measure ion density and energy

# Solenoids to Reduce Multipacting

Loralie Smart

Wind coils on ambient beam pipes

~ 64 m for FY03

to confine the electrons to a spiral orbit with R ~1 cm

Secondary electron yield (SEY) peaked @ 300 eV

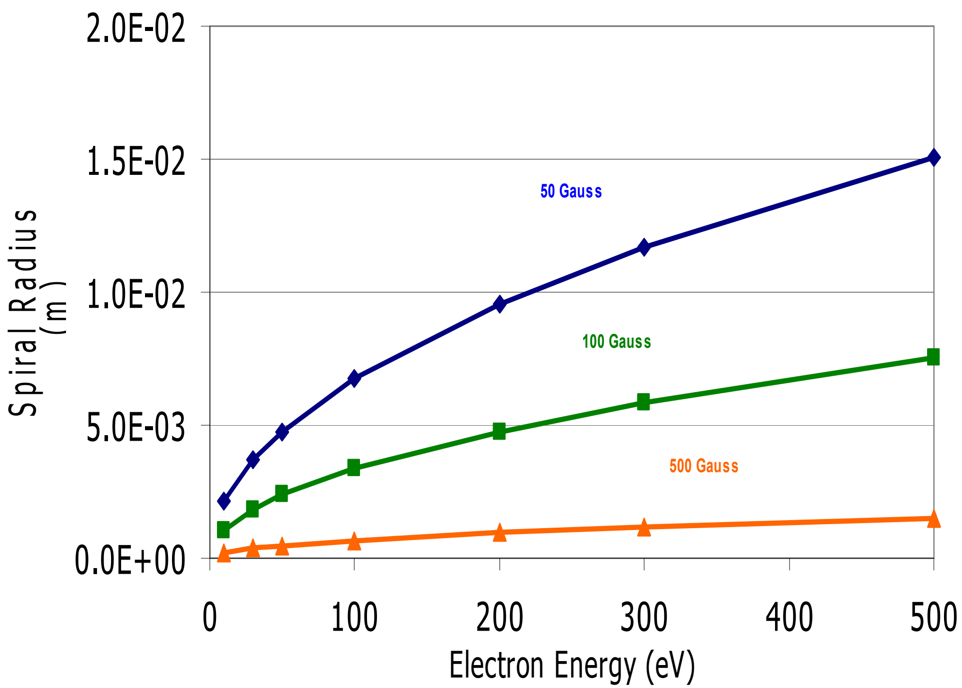
For $E_e$ ~ 300 eV, B = 50 Gauss ⇒

R = 1.2cm

~ 4,000 A-turns/m ⇒ ~ 50 Gauss

⇒ #10 wire of 20A x 200 turns

Spiral radii vs. electron energy and B



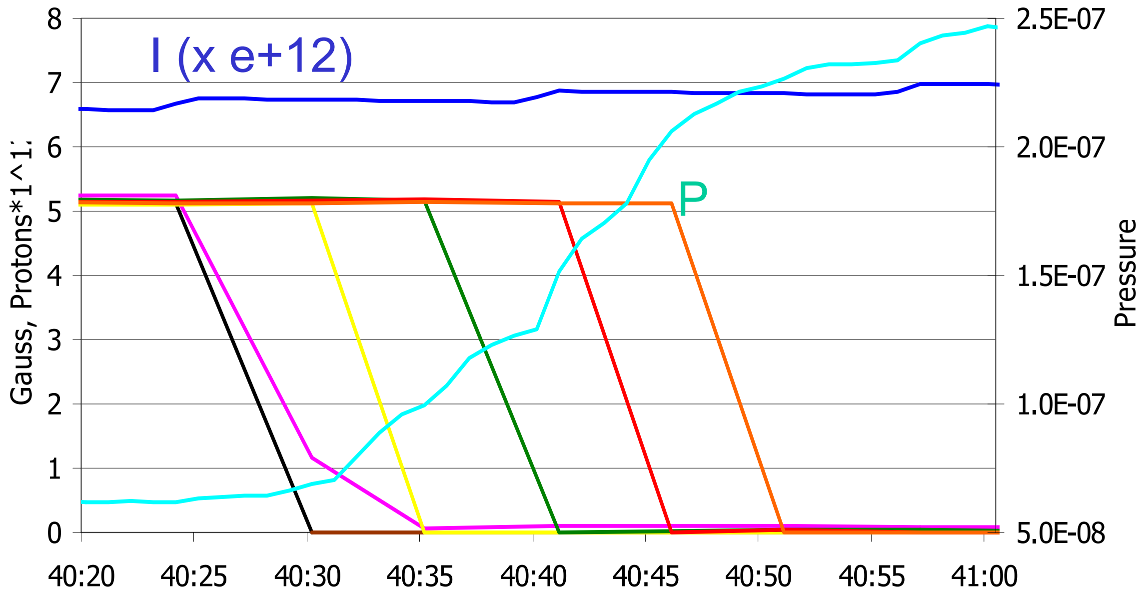
# Solenoid Construction (L. Smart)

- PVC insulated wire installed on 64 meters of pipe in FY02 shutdown
  - #10 AWG
  - N = 212 turns/m
  - 2.7 Gauss/Amp (< 60 gauss)
- Replaced with Kapton insulated wires (~30m) during FY03 shutdown
  - #8 AWG
  - N = 234 turns/m ( < 100 gauss)
  - Bakeable to 250ºC


Winding fixture

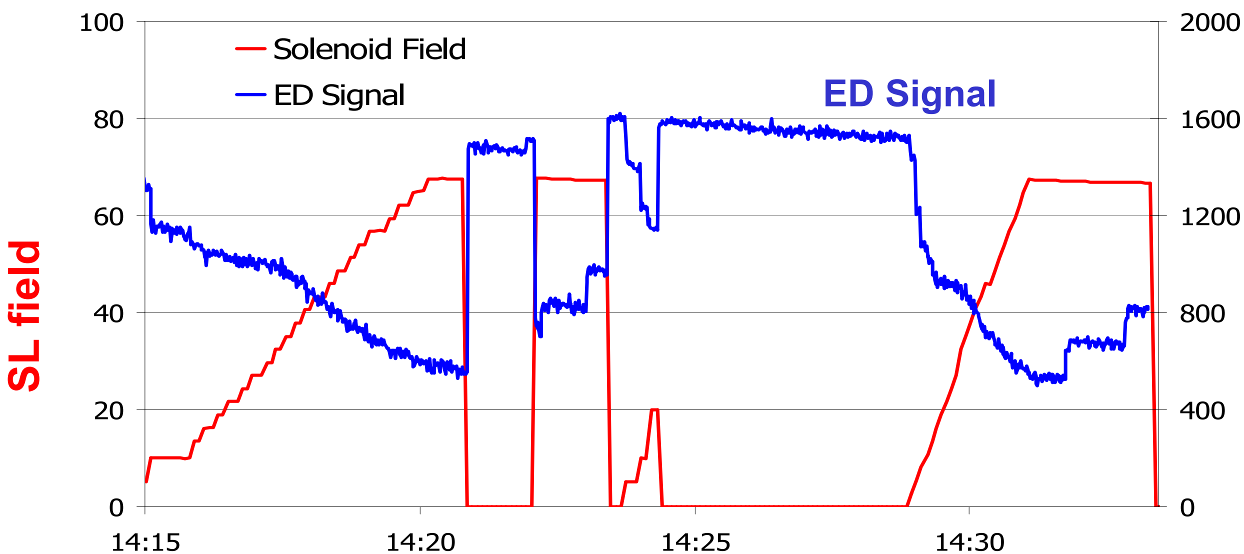
1 kW DC PS, < 35A x < 40V

# Effectiveness of Solenoid in Reducing ΔP and $e^-$




Ping He's talk

Pressure rise was reduced by x 4 with 5 gauss solenoid field




$e^-$ signal was reduced by x 2 with 65 gauss solenoid field

Not conclusive!

Need more studies

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    - NEG Coated Pipes
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# Upgrades and Studies for FY04 Runs

- Extensive bakeouts to 250ºC x > 40hrs during FY03 shutdown; ~85% baked
- Upgraded solenoids with #8 Kapton wire
- Upgraded electron detector amplifiers to x1600 gain
- More analog gauge signals to MADC for fast data monitoring and logging
- Additional RGAs (P. He's talk, this afternoon)
- Additional secondary collimators (3 in each ring) to reduce beam halo scraping
- Warm dipoles for scrubbing studies

  (H. Huang's talk, Friday)
- 11 x 5.2 m x 12cm Φ TiZrV NEG coated (SNEG) pipes


# NEG coated beam pipes for RHIC

Installed at 12cm Φ regions which had high ΔP during FY03 d-Au runs

Special bakeout/activation cycles

- So not to saturate the coating during in-situ bake
- No remote activation during the run

Measure desorption of SS and SNEG using 1 MeV/u Au (~$10^{+10}$ /s) @ Tandem

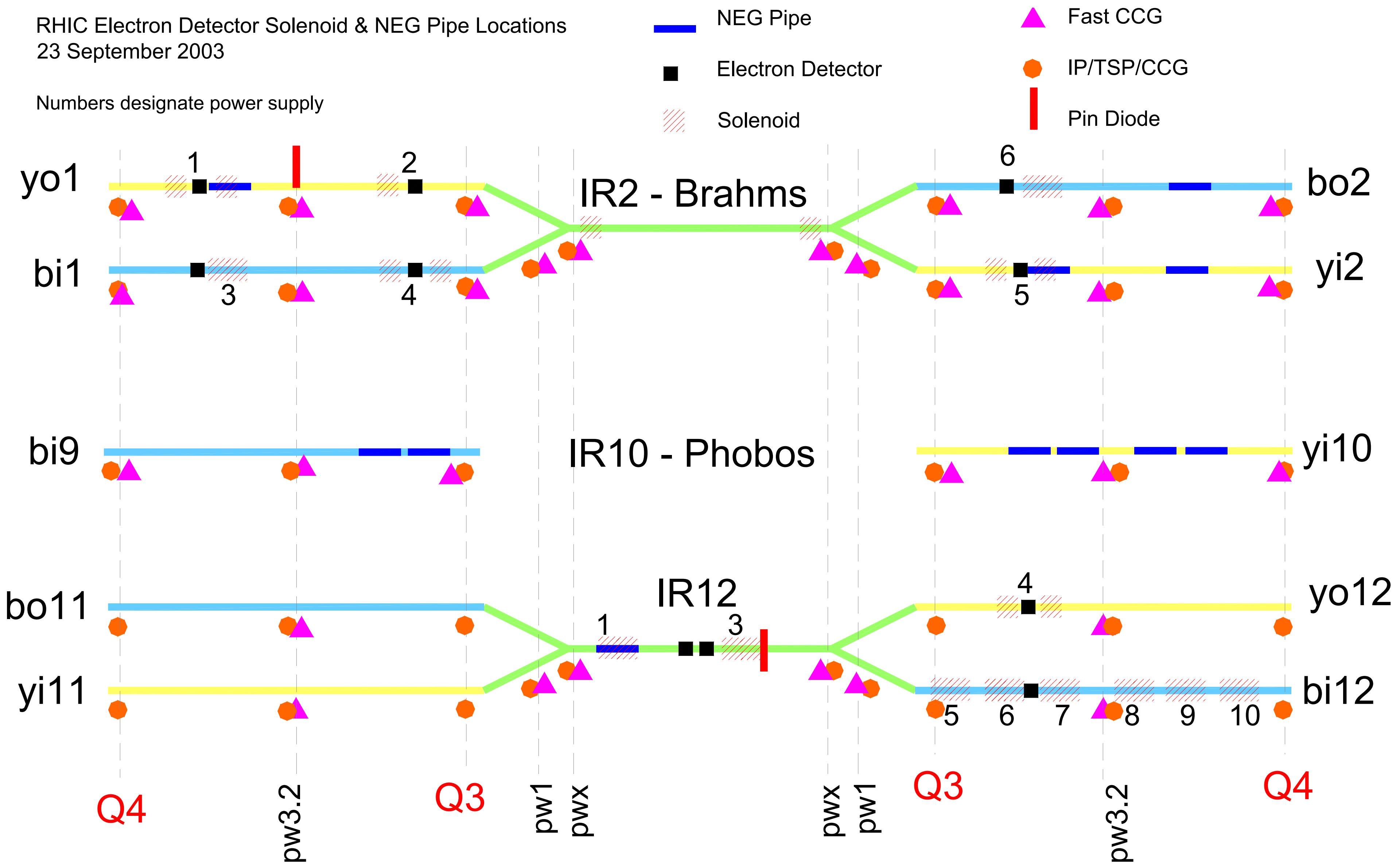
NEG strips (P. Thieberger) similar to those @TTB ~ 1 km in operation since 1985

If coated pipes are beneficial @ high intensity

- 500m SNEG coated pipes at Q3-Q4
- Develop in-house coating system for IR pipes
  - DX-D0 chambers for beam merging
  - Be beam pipes (SEY ~2.8)
- Develop remote activation system?

# Locations of Solenoids, ED, SNEG…

Loralie Smart



# SNEG Pipe Particulars

- Developed at CERN (Benvenuti et. al.)
- TiZrV tertiary alloy sputter-coated by SAES

  Cathode: three wires twisted together

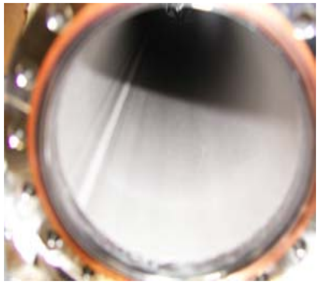
  DC Magnetron sputtering @ ~ 500 gauss

  Kr gas at $2x10^{-2}$ Torr, ~ 200V @ 100ºC

  Takes ~10 hours per position to coat ~1 μm
- Activate at as low as 180 C x 24 hrs

  Activated at 250 C x 2 hrs in RHIC
- Limited capacity, 1 μm thick ~5 air exposures
- Should provide low SEY, ESD & ID

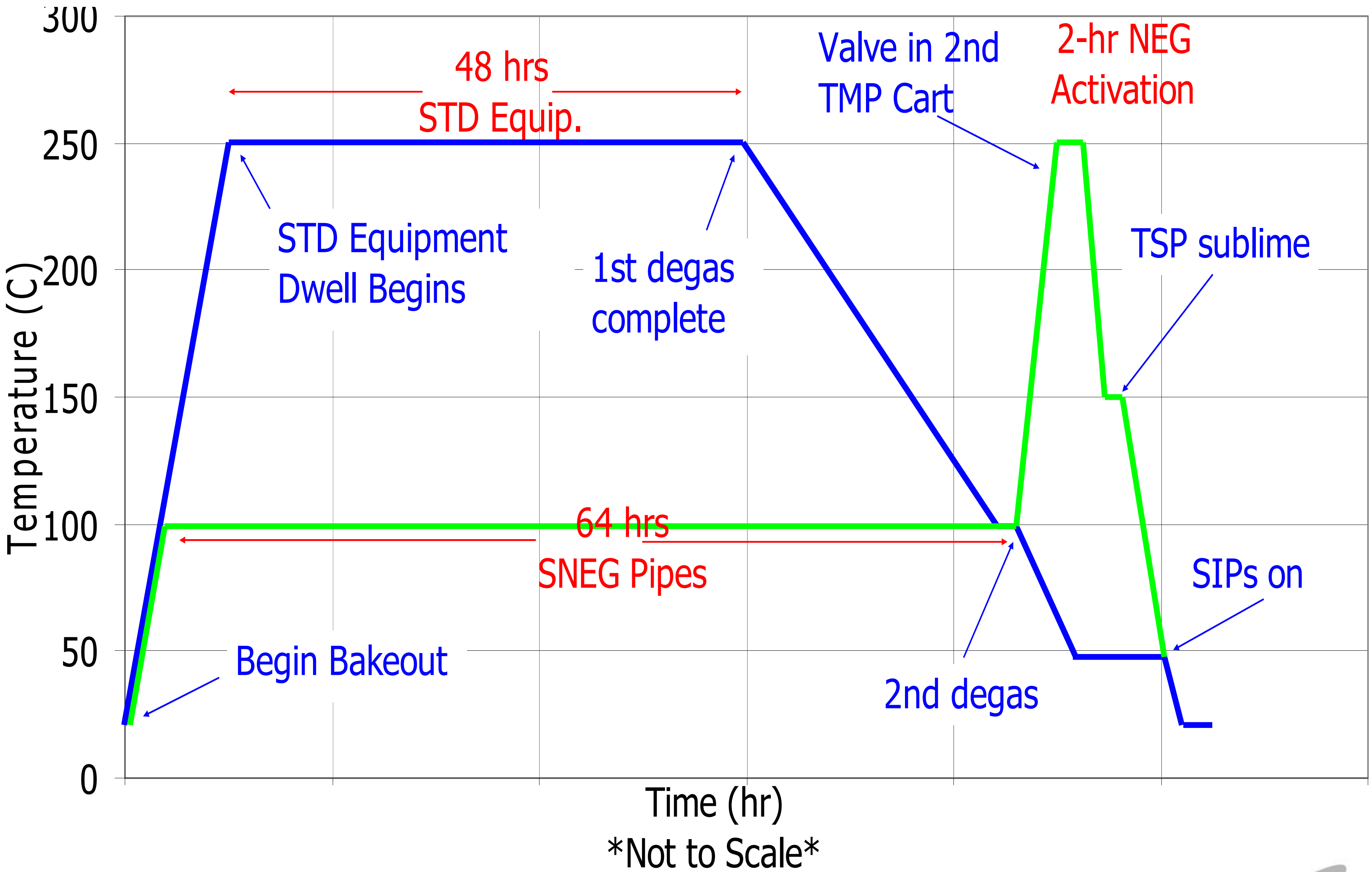
  and high pumping speed ( $>10^2$ l/s.m )



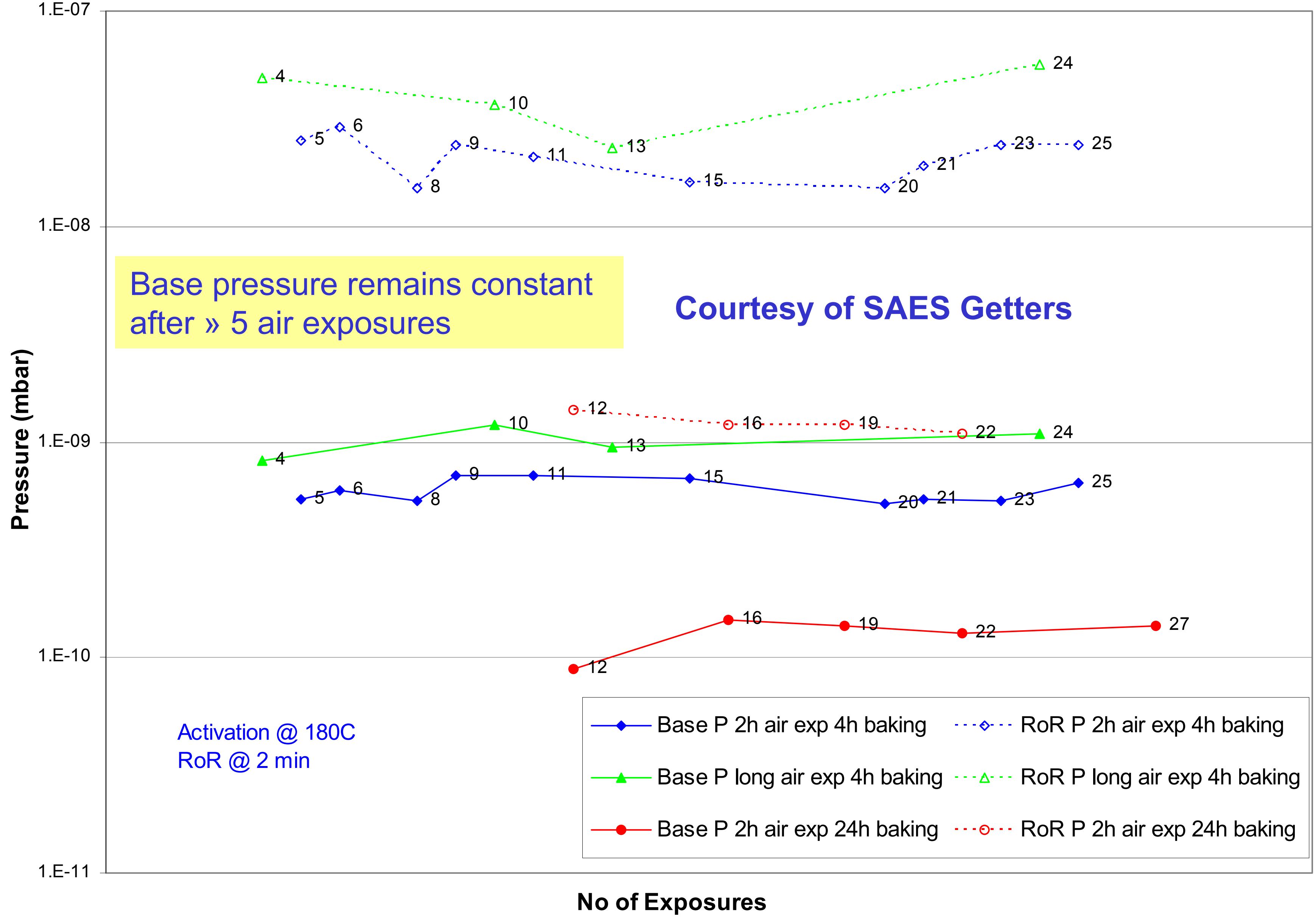
Coated RHIC Pipe

SAES Getters Coating Setup

# Typical RHIC SNEG Section Bakeout/Activation Cycles

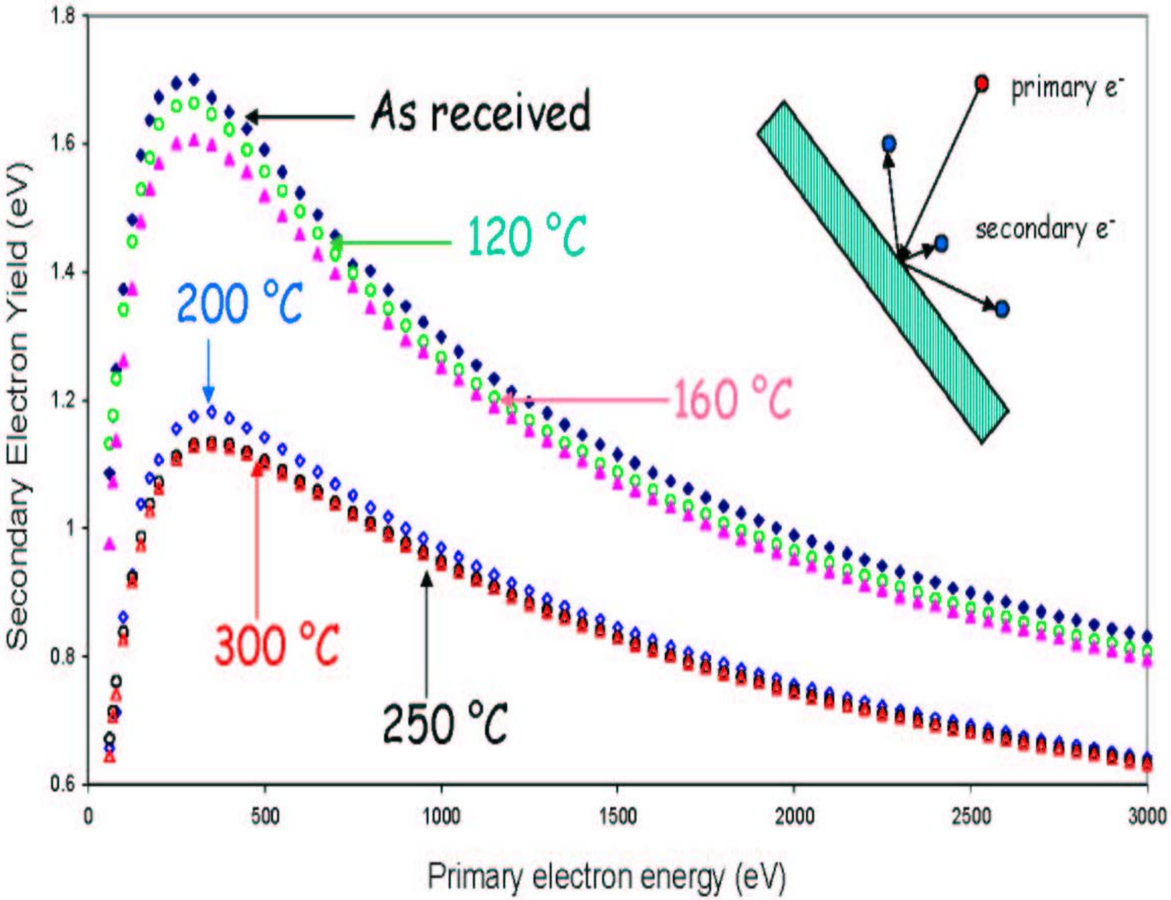


# Base pressure & RoR pressure



# SEY, ESD and ID of SNEG Surface

(CERN data, courtesy P. Chiggiato and others)




Secondary electron yield as a function of the primary electron energy for a Ti-Zr-V coating as received and after **2 hours** heating at 120, 160, 200, 250, and 300 °C

**SEY**

- SS > 2.0
- SNEG ~ 1.7 as received
- SNEG ≤ 1.2 after activation

**ESD**

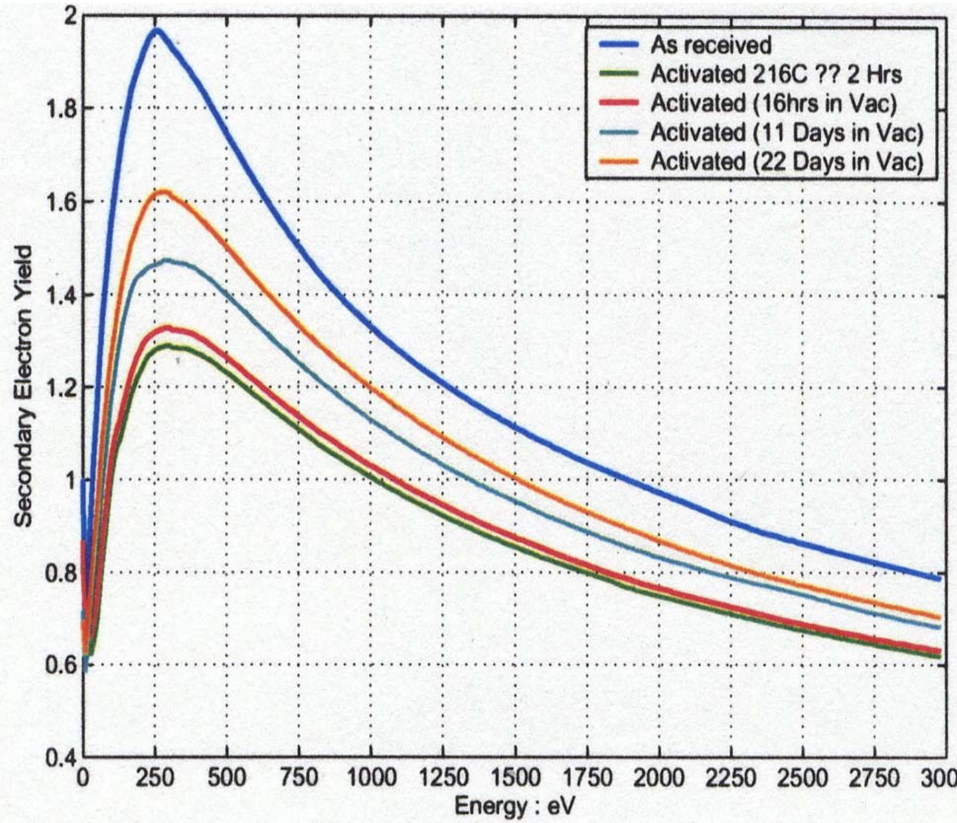
- $\sim 10^{-2}$ before activation
- $\sim 10^{-4}$ after activation

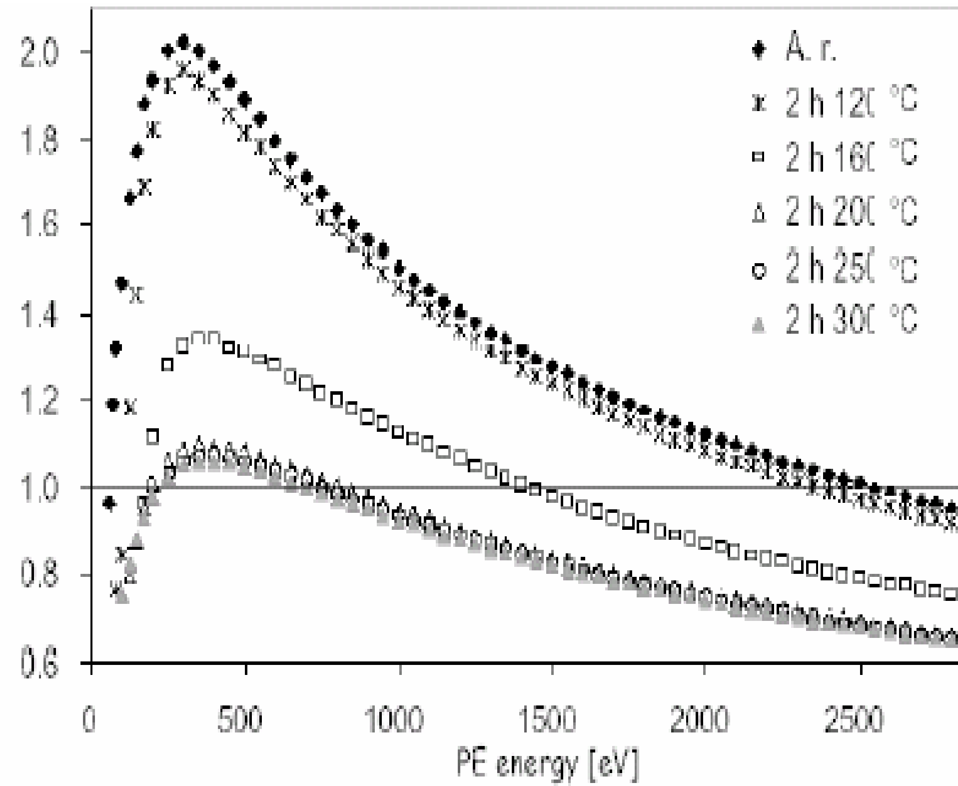
**Ion Desorption**

- reduction by >10X

# SEY of the TiZrV samples exposed to a residual gas pressure of ~3x10^-10 Torr for an extended period of time,

(R. Kirby, et.al, SLAC)



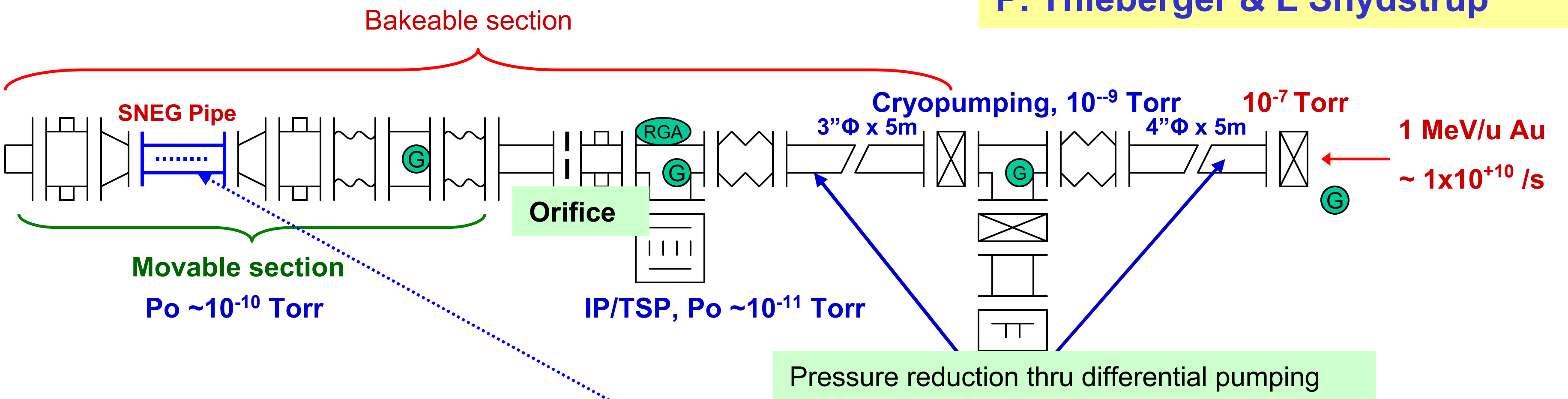

Vladimir Ruzinov of CERN

/orkshop on NEG coatings and NEG coated vacuum chambers for synchrotron radiation sources

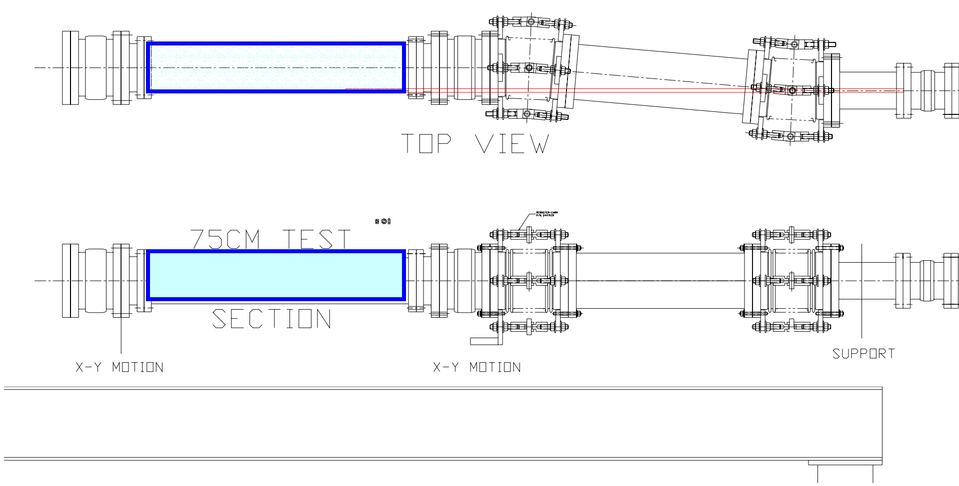
23rd and 24th September 2002

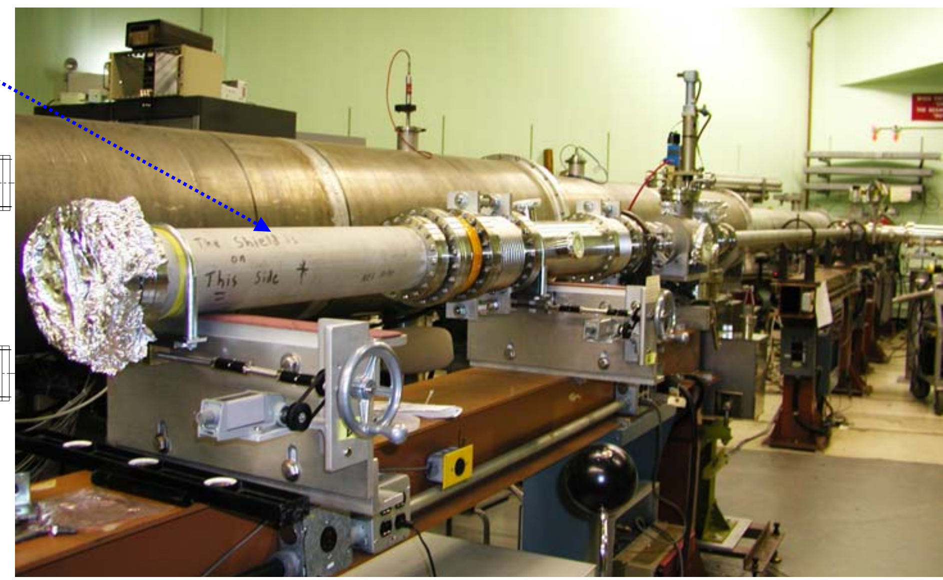
# Measure Desorption by 1 MeV/u Au from SS and SNEG Surface @ Tandem

**P. Thieberger & L Snydstrup**




**Movable section for grazing incidence beam**



# Summary

- RHIC pressure rise can prevent future machine improvement
- We have studied slow pressure rise events with
  - Solenoids and electron detectors
- Fast pressure rise from beam halo scraping is not well understood
- Vacuum improvements with
  - Bakeouts, solenoids, scrubbing, collimators, SNEG pipes, etc.
    - Will these measures be sufficient for higher intensity beams during FY04-08, RHIC II, eRHIC…
- Beam studies in FY04 run will steer the direction of future improvements

  more SNEG? more solenoids? Scrubbing, More IP+TSP...
- Cold bore pressure rise and heat load?