Beam-Gas and Beam-Beam Interaction Rates in STAR during the Commissioning and Year One Runs

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6th May 1997

Introduction

The type of physics programs that STAR can implement during the Commissioning and Year One Runs at RHIC will depend on the beam luminosity and the background rates at that time. The luminosity will depend on the number of bunches circulating, the bunch sizes and how that varies over time. The number of ions per bunch, and the number of bunches, is expected to rise during the first year of operation. However, normal RHIC operation involves storing each bunch for 10 hours, and during this time the more intense bunches expand and loose ions, leading to a drop in instantaneous luminosity. The background rates will depend on the pressure inside the beampipe. It is possible that at the beginning of the Commissioning Run STAR will be using a temporary beampipe instead of the permanent one currently being designed. In this case the beampipe will not be baked, so the gas pressure will be relatively high and the beam-gas background rates will also be high.

Here I will consider three possible situations:

- Early in the Commissioning Run - using a temporary beampipe and with low intensity beams
- Early in the Year One Run - using the permanent beampipe but still with low intensity beams
- End of the Year One Run - using the permanent beampipe and with high intensity beams

Commissioning Run - High Pressure, Low Intensity

Accelerator Parameters

Quantity	Symbol	Gold Start	Gold End
Beampipe Pressure (torr) [1]	P	5×10^{-9}	5×10^{-9}
Gas Composition in Beampipe [1]		50% H_20 + 50% H_2	50% H_20 + 50% H_2
Bunch revolution frequency (kHz) [2]	f	78.196	78.196
Number of ions per bunch [2]	N	2×10^8	2×10^8

Table 1: Accelerator Parameters as expected at the start and end of a 10 hour gold store for the Commissioning Run (relatively high vacuum pressure and low intensity). Note that at these intensities intra-beam scattering is unimportant, so N and ε remain constant during the store.

Quantity	Symbol	Gold Start	Gold End
Number of bunches circulating [2]	N_b	3	3
Lorentz gamma [2]	γ	108.4	108.4
Emittance ($\pi\mu$m) [2]	ε	10.0	10.0
Collision beta function (m) [2]	β	2.0	2.0

Table 1: Accelerator Parameters as expected at the start and end of a 10 hour gold store for the Commissioning Run (relatively high vacuum pressure and low intensity). Note that at these intensities intra-beam scattering is unimportant, so N and ε remain constant during the store.

Beam-Gas Interaction Rates

Molar volume at STP (760 torr) [3] = 22.414×10^{-3} m^3/mol= 22414 cm^3/mol

Molar volume at 5×10^{-9} torr = $\frac{760 \times 22414}{5 \times 10^{-9}}$

$= 3.4 \times 10^{15}$ cm^3/mol

Particle density = $\frac{Avogadros \text{ Number}}{MolarVolume} = 1.77 \times 10^{8}$ particles/cm^3

(compare to ~2 x 10^8 quoted in [1])

Since the gas is actually 50% H_2O and 50% H_2:

Oxygen density, $t_O = 0.88 \times 10^{8}$ particles/cm^3

Hydrogen density, $t_p = 3.54 \times 10^{8}$ particles/cm^3

A beam-gas interaction involves either a gold-oxygen, or gold-proton inelastic interaction. The cross-sections for these interactions were calculated using [4]:

$$\sigma_{int} = \pi r_0^{\,2}(A_1^{\,1/3} + A_2^{1/3} - \delta)^2 \;\; ; \;\; \delta = \frac{4.45}{A_1^{1/3} + A_2^{1/3}} \;\; ; \;\; r_0 = 1.31 \text{ fm} \qquad 1$$

This relation gives:

$\sigma_{O+Au} = 3300$ mb

$\sigma_{p+Au} = 2050$ mb

Number of Beam-Gas Interactions/cm due to one bunch is n_{bg}, where:

$$n_{bg} = \sum_i (\sigma_{(i+Au)} \times t_i \times N) \qquad 2$$

where the sum is over all the gas nuclei:

$$n_{bg} = 2.0 \times 10^{-7} \text{ cm}^{-1}$$

Number of Beam-Gas Interactions ($cm^{-1}s^{-1}$) in one ring is N_{bg}, where:

$$N_{bg} = N_b \times f \times n_{bg} \qquad 3$$

$N_{bg} = 0.05\ cm^{-1}s^{-1}$

At an interaction point, i.e. anywhere between the DX magnets in STAR, the bunches from both rings will be able to interact with the gas, so:

$$N_{STAR} = 2 \times N_{bg}\ \mathrm{cm}^{-1}\mathrm{s}^{-1} \qquad 4$$

$N_{STAR} = 0.1\ cm^{-1}s^{-1}$

Beam-Beam Interaction Rates

The instantaneous luminosity at RHIC, L, can be written as [2]:

$$L = \frac{3f}{2} \times \frac{N_b \times N^2 \times \gamma}{\varepsilon \times \beta'}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \qquad 5$$

Under the conditions of high pressure and low intensity shown in Table 1:

$L = 2.4 \times 10^{24}\ cm^{-2}s^{-1}$

The rate for any reaction, R, is given by:

$$R(A_1 + A_2) = \sigma_{(A_1 + A_2)} \times L \qquad 6$$

Using equation 1 for gold ions:

$\sigma_{(Au+Au)} = 6850$ mb

So, in these conditions, the rate of Au-Au inelastic interactions is:

$R_{(Au+Au)} = 16$ Hz

Early into Year One Run - Low Pressure, Low Intensity

Accelerator Parameters

Quantity	Symbol	Gold Start	Gold End
Beampipe Pressure (torr)	P	5×10^{-10}	5×10^{-10}
Gas Composition in Beampipe		10% C0 + 90% H_2	10% C0 + 90% H_2
Bunch revolution frequency (kHz)	f	78.196	78.196
Number of ions per bunch	N	2×10^8	2×10^8
Number of bunches circulating	N_b	3	3
Lorentz gamma	γ	108.4	108.4
Emittance ($\pi\mu$m)	ε	10.0	10.0
Collision beta function (m)	β	2.0	2.0

Table 2: Accelerator Parameters as expected at the start and end of a 10 hour gold store early in the Year One Run (relatively low vacuum pressure and low intensity)

Beam-Gas Interaction Rates

Recalculating the particle densities, using the new vacuum pressure and gas composition leads to:

Oxygen density, $t_O = 0.177 \times 10^7$ particles/cm^3
Carbon density, $t_C = 0.177 \times 10^7$ particles/cm^3
Hydrogen density, $t_p = 3.19 \times 10^7$ particles/cm^3

Using equation 1 the cross-sections for inelastic interactions of these species with gold ions is:

$\sigma_{O+Au} = 3300$ mb
$\sigma_{C+Au} = 3100$ mb
$\sigma_{p+Au} = 2050$ mb

Substituting these values into equation 2 gives:

$$n_{bg} = 1.5 \times 10^{-8} \text{ cm}^{-1}$$

Substituting n_{bg} into equation 3 gives:

$N_{bg} = 0.0035$ cm^{-1}s^{-1}

Substituting N_{bg} into equation 4:

$N_{STAR} = 0.007\ cm^{-1}s^{-1}$

Beam-Beam Interaction Rates

The luminosity calculation is the same as for the Commissioning Run:

$R_{(Au+Au)} = 16$ Hz

End of Year One Run - Low Pressure, High Intensity

Accelerator Parameters

Quantity	Symbol	Gold Start	Gold End
Beampipe Pressure (torr)	P	5×10^{-10}	5×10^{-10}
Gas Composition in Beampipe		10% C0 + 90% H_2	10% C0 + 90% H_2
Bunch revolution frequency (kHz)	f	78.196	78.196
Number of ions per bunch	N	1×10^9	0.6×10^9
Number of bunches circulating	N_b	60	60
Lorentz gamma	γ	108.4	108.4
Emittance ($\pi\mu$m)	ε	15.0	40.0
Collision beta function (m)	β	2.0	2.0

Table 3: Accelerator Parameters as expected at the start and end of a 10 hour gold store at the end of the Year One Run (relatively low vacuum pressure and high intensity)

Beam-Gas Interaction Rates

Repeating the beam-gas calculation rate as for early in Year One, but using N given in Table 3 gives new values for beam-gas interaction rate. With the higher intensity bunches, and bunch density, IBS become important and therefore N and ε vary during a 10 hour store:

$$n_{bg}(start) = 7.6 \times 10^{-8}\ cm^{-1}$$

$$n_{bg}(end) = 4.6 \times 10^{-8}\ cm^{-1}$$

Substituting n_{bg} into equation 3 gives:

$N_{bg}(start) = 0.36\ cm^{-1}s^{-1}$

$N_{bg}(end) = 0.22\ cm^{-1}s^{-1}$

$N_{bg}(start)$ can be compared to the value of 0.3 interactions $cm^{-1}s^{-1}$ obtained by Bill Christie in a previous calulation [5] using 54 bunches instead of 60, and assuming all the gas was hydrogen. Note that the original value obtained in [5] was 0.6 $cm^{-1}s^{-1}$, which was subsequently revised down due to an algebraic error [6].

$N_{STAR}(start) = 0.72\ cm^{-1}s^{-1}$

$N_{STAR}(end) = 0.44\ cm^{-1}s^{-1}$

Beam-Beam Interaction Rates

Recalculating the luminosity, using the parameters in Table 3:

$L(start) = 8.0 \times 10^{26}\ cm^{-2}s^{-1}$

$L(end) = 1.0 \times 10^{26}\ cm^{-2}s^{-1}$

So, in these conditions, the rate of Au-Au inelastic interactions is:

R(start) = 5.5 kHz

R(end) = 0.7 kHz

Summary and Conclusions

In order to compare the rate of beam-gas interactions in the TPC to beam-beam interactions it is necessary to estimate what fraction of beam-gas interactions will produce tracks in the TPC. It will be assumed that only beam-gas interactions occuring in the 18m between the DX magnets have any probability of producing such a track.

The angular distribution of particles produced in beam gas interactions is very small. The bulk of particles produced in a p+Au interaction have angles smaller than 0.4 degrees [5]. Particles produced in O+Au and C+Au interactions will have slightly larger angles. Interactions that originate within the TPC therefore have a very small chance of producing particles that enter the TPC. I will therefore count only those interactions that occur within 6m of the first DX magnet for each beam. Table 5 summarizes all the resulting rates:

		Beam-Gas (Hz)	Beam-Beam (Hz)	(Beam-Gas) / (Beam-Beam)
Commissioning Run:	Start of gold store	60	16	3.75
	End	60	16	3.75
Early Year One:	Start	4.2	16	0.26
	End	4.2	16	0.26
End Year One:	Start	430	5500	0.08
	End	265	700	0.4

Table 4: Summary of Beam-Gas and Beam-Beam Interaction rates in the first year of STAR running, assuming the beams are gold and counting all beam-gas interactions within 600 cm of the first DX magnet for each beam.

I understand (see STARSAS mailing list archives) that Jay says that we will never run in the first situation, i.e. with low intensity beams and a relatively high pressure. Dick Hseuh did not guarantee that the temporary beampipe would have been replaced with the permanent one by the beginning of the Commissioning Run. For both these statements to be true that could imply that STAR turn-on would be delayed beyond the beginning of the Commissioning Run if the temporary beampipe is still in use.

References

[1] Private communication from Dick Hseuh (head of the RHIC vacuum group):
"If no insitu bake: the pressure will be in the mid 10^-9 torr (~2 x 10^8 particles/cm^3) with 50% water equivalent and 50% H2.
If insitu baked: the pressure will be in the mid 10^-10 Torr with 90% H2 and 10% CO equivalent.
We will bake the DX and DX-D0 chambers on day 1 but will not bake the DX-DX pipe if it is a temporary pipe."

[2] RHIC Accelerator Commissioning and the Year One Run, Steve Peggs, 1996, RHIC/AP/115

[3] Review of Particle Properties, Phys. Rev. D

[4] T. Hoang et al, Zeitschrift fur Physik C29, 611 (1985)

[5] 1st Pass Estimate of Detector Backgrounds at RHIC
W. B. Christie, 2nd Workshop on Machine Backgrounds at RHIC, BNL, June 19 1996

[6] Private communication from Bill Christie:
"... in my calculation of the number of H targets per cm**3 I should have used (1 mole/2g) as opposed to the (1 mole/g) that I used..."