The Pros and Cons of a Beer Can Electron Distribution in eRHIC

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Outline

- Advantages

- Disadvantages

  1. TEVATRON electron lens experience with beer can distribution

  2. Experience with mismatched beam sizes at HERA and SPS (a closely related problem)

  3. Simulation results

- Summary

Advantages

- A beer can electron distribution results in a linear beam-beam force on the protons. There is only a beam-beam tune shift, but no tune spread.
  $\longrightarrow$ No beam-beam limit!

- The beam-beam interaction does not cause long, populated transverse tails that need to be captured and decelerated.

Disadvantages

TEVATRON electron lens

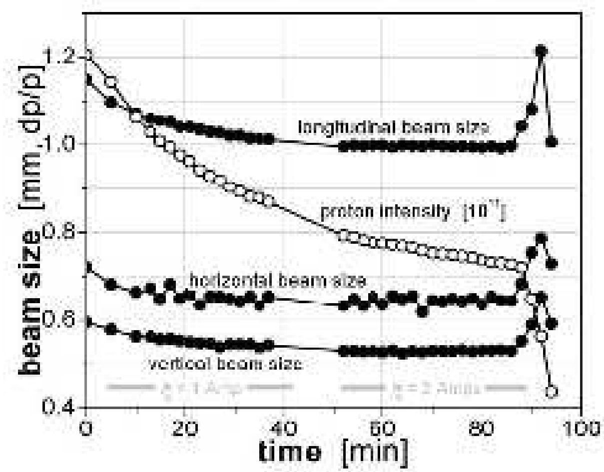


Fig.5: TEL as a "soft collimator"

Eventually, we realized that edges of the electron beam act as a "soft collimator". For example, Figure 5 shows the size of a particular bunch while it was collimated in this manner. One amp of electron-beam current was applied initially. Many particles were quickly lost, decreasing the beam size; however, the loss rate began to level off because the remaining core bunch was stable.

This unfortunate effect spurred the design of a new gun with a very smooth, almost Gaussian-shaped profile. The

V. Shiltsev et al., HALO '03

Mismatched beams in HERA

$\sigma^p{}_x$ [μm]	$\sigma^p{}_y$ [μm]	$\sigma^e{}_x$ [μm]	$\sigma^e{}_y$ [μm]	τ_p [hrs]
410	120	130	33	0.5
410	120	290	70	10
330	100	290	70	50
210	50	290	53	100
190	50	200	53	

Table 2: Tabulated IP electron and proton cross sections corresponding to Fig. 3 from reference [2]. The last row corresponds to the 1998/1999 data taking period where the measured lifetime was typically 300 hours.

M. Bieler et al., Beam-beam Workshop 1999

Mismatched beams in SPS

In some of the runs, where the machine went into coast with substantial smaller pbar emittances, the protons had a very bad lifetime and gave a lot of proton background, and this in spite of the fact that the pbar intensity was ten times less than the proton intensity. This phenomenon could be artificially reproduced by scraping one of the beams with a collimator at a place where they are separated and observing the background and/or the lifetime of the other beam. In fig 4 a

Experience with the SPS proton anti-proton collider showed that it is very important to have the same beam sizes for both beams in order to obtain good lifetimes and backgrounds.

K. Cornelis, Beam-beam Workshop 1999

Simulations

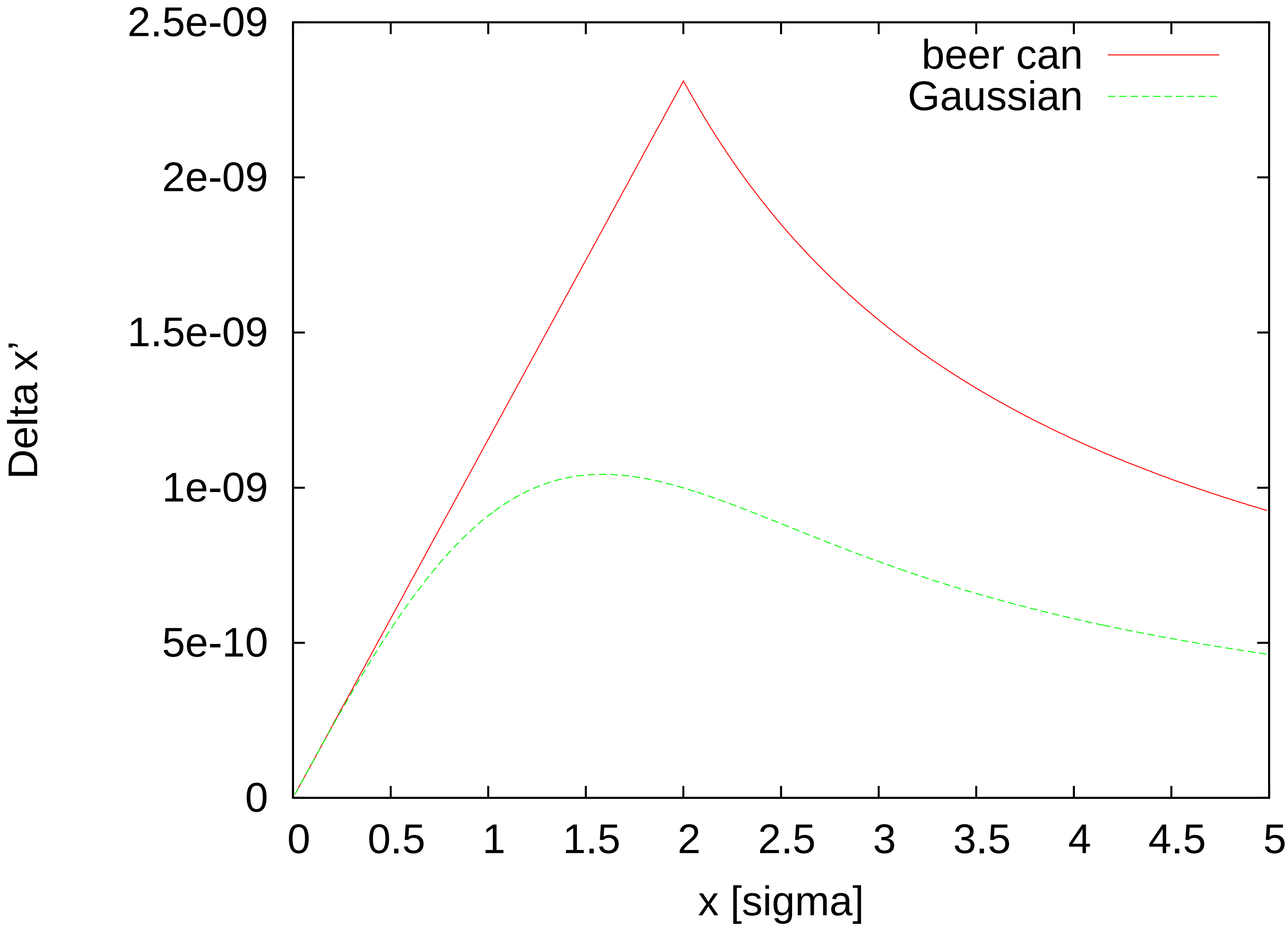
- beer can edge at $2\sigma_p$

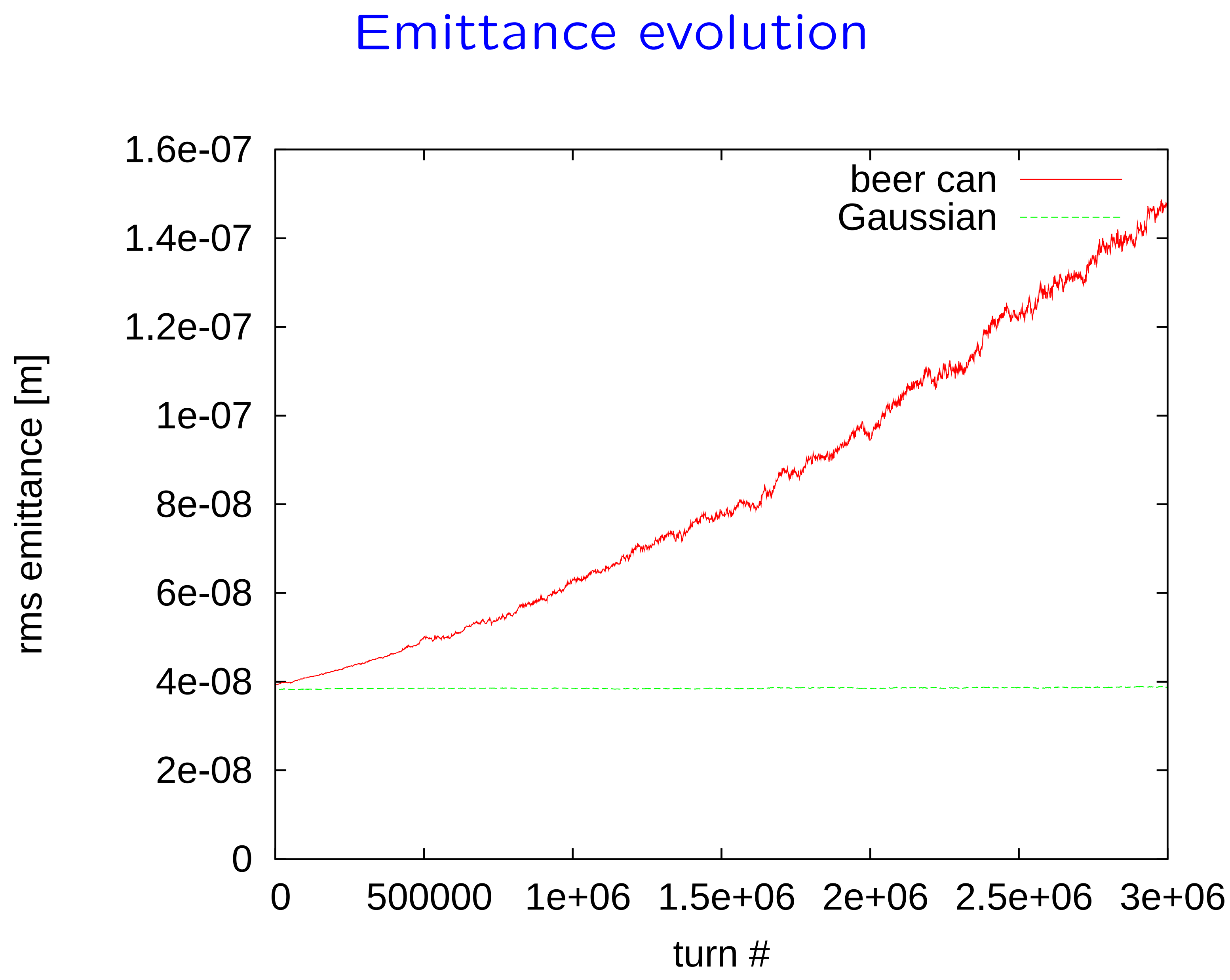
- $\Delta x' \propto \begin{cases} r, & r < 2\sigma_p \\ 1/r, & r > 2\sigma_p \end{cases}$

- $\xi = 0.01$ (for Gaussian and beer can)

- 1000 particles, $3 \cdot 10^6$ turns

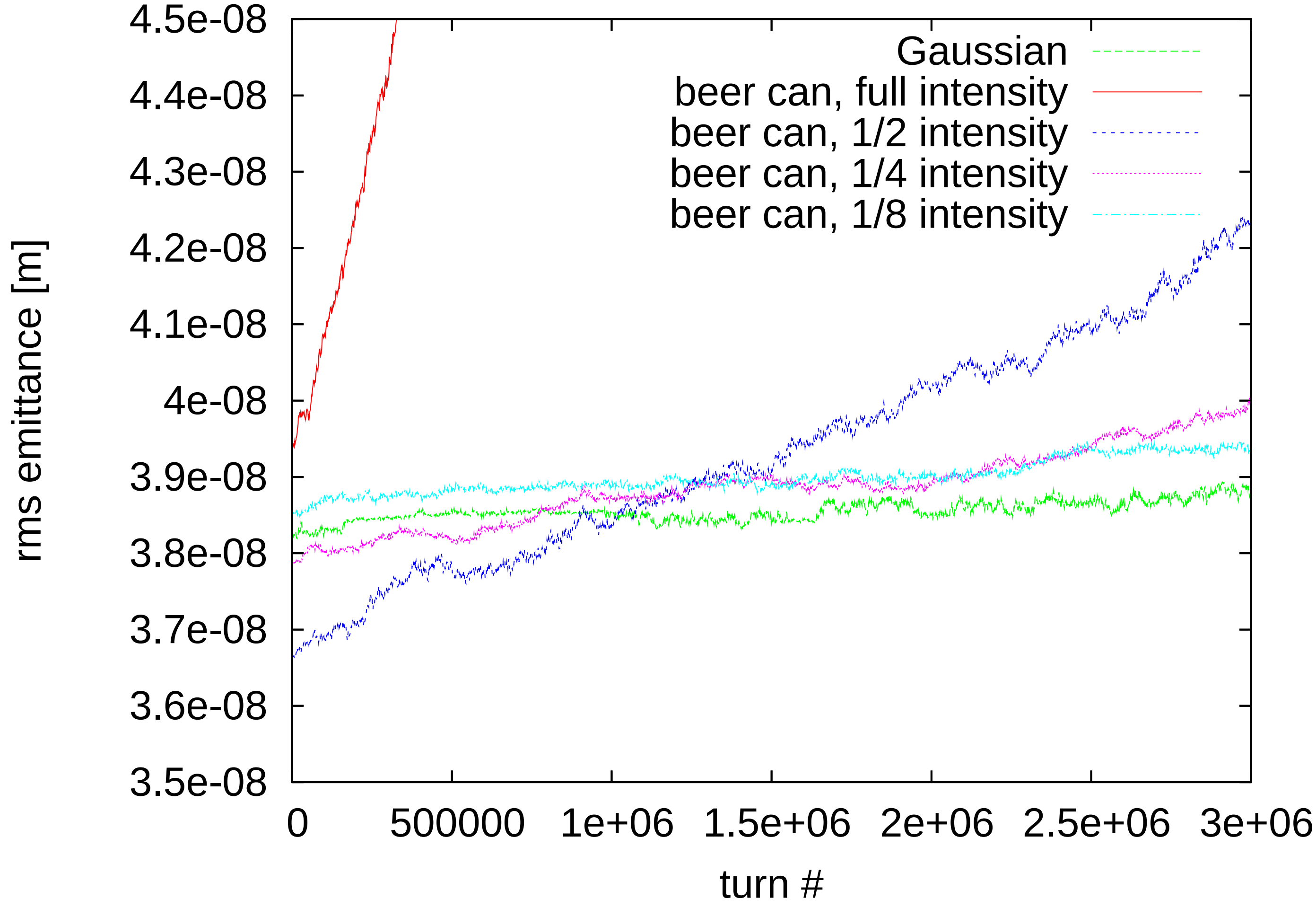
Beam-beam kick for Gaussian and beer can




Emittance evolution
rms emitance [m]
turn #
beer can
Gaussian
1.6e-07
1.4e-07
1.2e-07
1e-07
8e-08
6e-08
4e-08
2e-08
0
0
500000
1e+06
1.5e+06
2e+06
2.5e+06
3e+06

Emittance evolution

Reduced beer can intensity ($\rightarrow$ tune shift)



A simple explanation
– may be totally wrong

Gaussian kick:

$$\begin{aligned}\Delta r' &\propto \frac{1}{r}\cdot\left[1-\exp\left(-\frac{r^2}{2\sigma_r^2}\right)\right] \\ &= \sum_{k=1}^{\infty}\frac{\left(-\frac{r^2}{2\sigma_r^2}\right)^k}{k!} \\ &= \text{quadrupole} + \text{octupole} + \ldots\end{aligned}$$

Higher order multipoles vanish quickly

Beer can kick:
Approximating the sharp edge of the beer can kick requires strong multipoles of high order, which drive closely spaced high-order nonlinear resonances

Summary

- Beer can has overwhelming advantages due to its purely linear force on the proton beam.

- However, the edges of such a distribution act as a "collimator".

- To avoid detrimental effects, edges have to be far away from the proton beam core (beyond 3-4 σ_p).

- This requires a much larger electron beam intensity that does not result in increased luminosity (most electrons interact with low-density proton beam tails).