Some problems in suppression of beam-beam interactions in $\mu\mu$ colliders

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A basic idea: if $n_p \gg n_b$ plasma compensates the beam field (by induced charges and return current). Sessler, Whittum ....

Problems:

1) Photo-nuclear background

$\sigma_{\gamma Li} \sim 0.3 \cdot 10^{-27}\,cm^2$, $N_\gamma \sim \int \frac{\alpha}{\pi}\frac{d\omega}{\omega}\ln\vartheta^2 \sim 0.4\,N_\mu$ – virtual photons.

$\sigma_{eff.} \sim 10^{-28}\,cm$.

If. $N_\mu = 10^{12}$, $\Delta z = 1\,cm$, $n_{Li} \sim 5 \cdot 10^{22}\,cm^{-3}$

$N_{react./cross} \sim 10^7$, $\Delta E \sim 10^{+3} - 10^4\,TeV$!

Each react. gives ~1 particle at large angle ($\gtrsim 30°$), π with $p_\perp \sim 300\,MeV$ (+ recoil Li nucl. which can be stopped in vac. pipe.)

Too much!

2) $\mu Li \to \mu Li e^+e^-$ $\sigma \sim 10^{-26} Z^2 \sim 10^{-25}\,cm$.

The prob. to collide on 10^3 turns for μ

$P \sim n\sigma\Delta z \cdot 1000 \sim 5 \cdot 10^{22} \cdot 10^{-25} \cdot 1 \cdot 10^3 \sim 5$

$\Rightarrow$ fast decrease of $L_{\mu\mu}$

(needs more accurate calculation)

3) In the dense plasma (Li) one should take into account <u>collisions</u>

For $n_p/n_b = 10 \Rightarrow v/c \sim \frac{n_b}{n_p} \sim 0.1$ (Suppr. ~5 Lotov Skrinsky)

$\Rightarrow T_e$(in „return" current) ~ 2.5 keV

The electron with such energy have the range in Li $R \sim 10^{-4}$ cm, but it will not stop because $I_{ret} = I_{beam}$, so $v_{\parallel} \approx$ const.

However <u>the electron scatters on ions</u>

The scattering length λ can be found from

$$\theta_{sc} \sim \frac{15\ \text{MeV}}{(\text{Q.T.})}\sqrt{\frac{\lambda}{L_R}} \sim \pi \qquad L_R(\text{Li}) \sim 155\ \text{cm}$$

$$\Rightarrow \lambda \sim 10^{-4}\ \text{cm}$$

This means that Δx (transverse displ.) $\sim \lambda$ on $\Delta z \sim \lambda$

The total Δx on $\Delta z = \sigma_z$(beam) is

$$\underline{\Delta x_{tot}} \approx \Delta x_1 \sqrt{\frac{\sigma_z}{\lambda}} \sim \sqrt{\lambda \sigma_z} \sim \sqrt{10^{-4} \cdot 0.5}$$

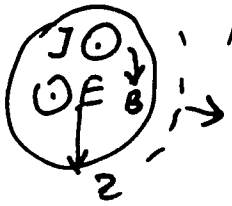
$$\sim \underline{7 \cdot 10^{-3}\ \text{cm}}$$

Plasma suppression works when $\Delta x_{tot} \ll \sigma_x$(bea

but we have obtained $\Delta x_{tot} > 100\,\sigma_x$(be

(for $\sigma_x \sim 0.5\mu$

Other way of "return" current.



$B=0$
$E=0$

$$\int E\,dl = \frac{1}{c}\frac{\partial \Phi}{\partial t} \Rightarrow E = \frac{v B}{c} \quad (1)$$

$$j = \sigma E \quad (2) \qquad B = \frac{2J}{cz} = \frac{2\pi\sigma E z}{c} \quad (3)$$

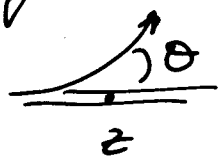
$$\Rightarrow v = \frac{c^2}{2\pi\sigma z}$$

$$v \sim \frac{d\sigma_x}{dt} \Rightarrow \frac{d}{dt}(\sigma_{x,ret}^2) \sim \frac{c^2}{4\pi\sigma}$$

$$t \sim \frac{\sigma_z}{c} \Rightarrow \sigma_x^2 \sim \frac{c\sigma_z}{4\pi\sigma}$$

σ – conductivity of plasma.

Let's calculate σ from scattering of electrons on ions. small angle approximation



$$\Delta p_{\parallel} = p\frac{\theta^2}{2} = p\frac{E_s^2}{(2T)^2}\frac{dz}{L_R} = eE\,dt$$

$$j = env = \sigma E \qquad T = \frac{mv^2}{2}, \quad E_s = 14\,M$$

$$\Rightarrow \sigma = \frac{4e^2 n T^2 L_R}{p E_s^2}$$

$$\boxed{\sigma_{x,ret}^2 = \frac{pc\,\sigma_z E_s^2}{16\pi r_e n_p T^2 L_R m c^2}}$$

$$\sigma_{x,ret} \propto \sqrt{\frac{\sigma_z}{n_p}}\left(\frac{n_p}{n_b}\right)^{3/2}$$

For $v = \frac{1}{10}c$ $\quad n_p = 5\cdot 10^{22}\,(Li)$, $T = 2.5\,keV$, $L_R = 150\,cm$

$$\Rightarrow \sigma_{x,ret} \sim 2\cdot 10^{-4}\,cm$$

(while $\sigma_{x,beam}$ at IP $\lesssim 0.5\,\mu m$)

Problems! (Comp. works when $\sigma_{x,ret} \ll \sigma_x(beam)$).

Conclusion

- Collision in plasma limit seriously the possibilities of the beam-beam compensation scheme.
- More accurate calc. are necessary
- Backgrounds are huge, may be too huge