A quick review on the Touschek lifetime simulation

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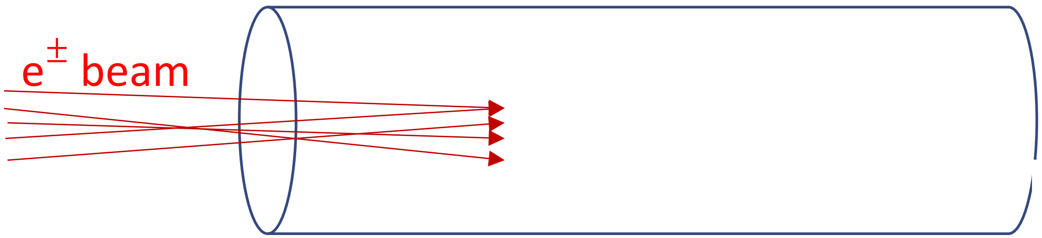
Introduction

Touschek is one of the main contributors to lifetime

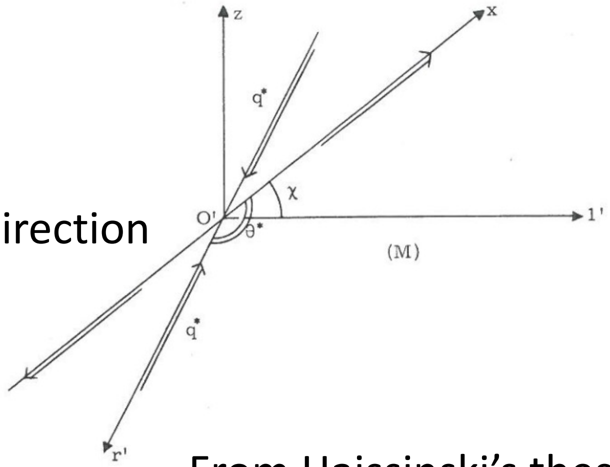
- There are some known MC/data discrepancies for HER/LER
- Simulation is not 'that' simple (computer extensive if made from first principles)

Purpose of today's presentation:

- A quick review of what is currently implemented
- Few suggestions for improvements



Some transverse momentum is transfered to longitudinal direction
→ To be compared with momentum acceptance



From Haissinski's thesis

Current situation

Currently

- Simulation is not 'that' simple (computer extensive if made from first principles); so approximation must be employed → Monte Carlo approach to compute a single integral
- The beam is assumed to be flat (no vertical dimension)
- The kinematics of the particles is assumed non-relativistic

Touschek/Haissinski/LeDuff/Bruck/…

$$\frac{1}{\tau} = \frac{2}{\sqrt{\pi}\,\delta q} \int_{\varepsilon_{RF}/\gamma c}^{\infty} f(q^*)\, e^{-\frac{q^{*2}}{(\delta q)^2}}\, dq^*$$

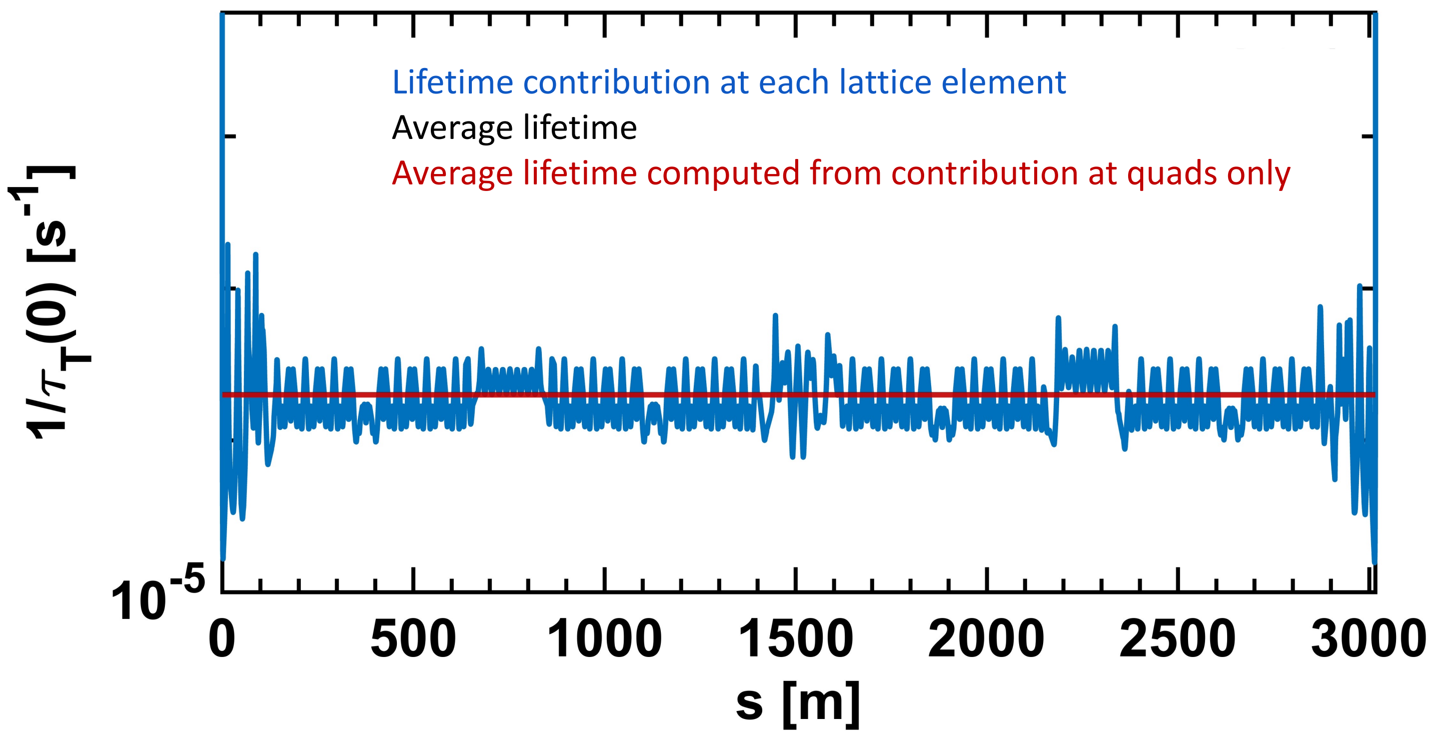
Lower limit removed in MonteCarlo implementation

The lifetime reduces to an integral over the the center of mass difference momentum of initial particles weighted by a gaussian distribution and a kinematic factor proportionnal to the cross-section.
→ Assumes momentum acceptance is known

Currently implemented in SAD tracking simulations as a weighted Monte-Carlo (sampling over the cross-section and momentum difference of particles).
This computation must be ideally done at any s-coordinate in the ring. It is done for convenience at the location of quadrupoles

Losses may be locally underestimated

Estimation of Touschek losses (previous integral) assuming constant momentum aperture all over the ring with (quite) old SAD lattice file, just for illustration.



In average, computation as quads only seems very appropriate but close to IP losses may be significanlty underestimated (1-2 orders of mag.)→ impact on Belle II background estimates ?

Kinematics is relativistic

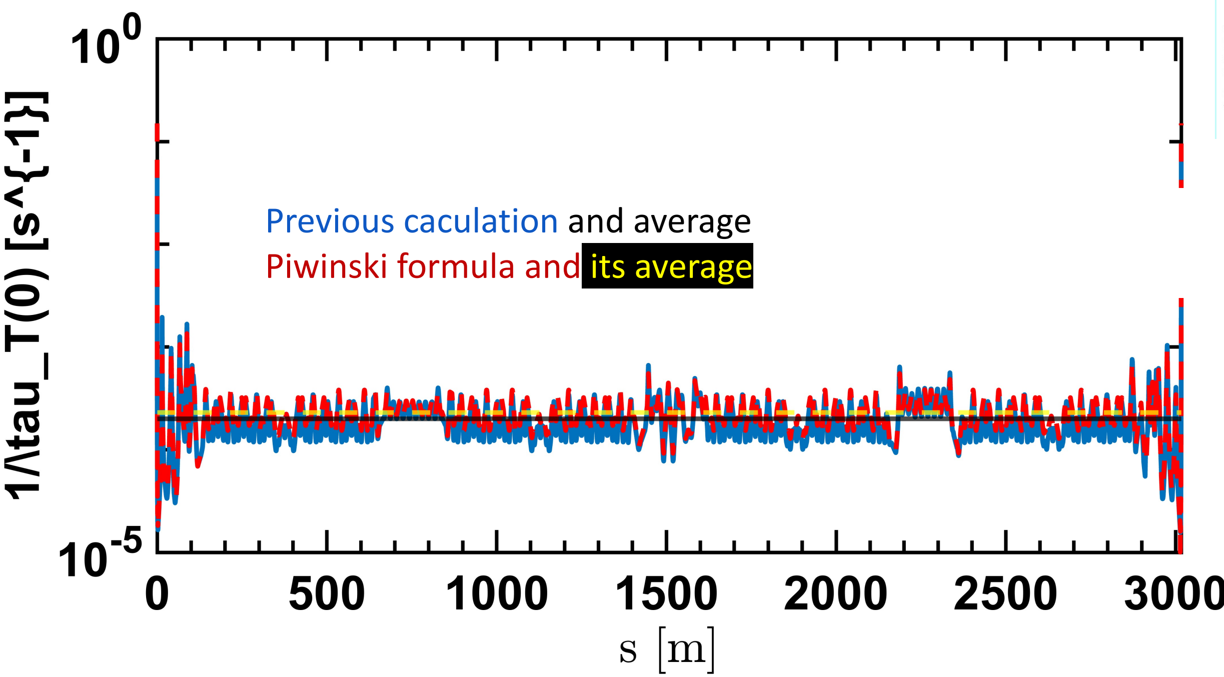
The typical max momentum difference is $3\sigma_{x',y'}p$ where p is the beam momentum and $\sigma_{x',y'}$ is related to the betatron function and emittance in horizontal and vertical planes

It can reach 5 MeV in horizontal plane maybe about 1MeV in the vertical plane.

→ Non relativistic approximation is likely incorrect

→ Vertical plane scattering may contribute too

→ Piwinski solved that problem already



→ 15% reduction of lifetime in average

DESY 98-179
November 1998

ISSN 0418-9833

c-ph] 22 Mar 1999

THE TOUSCHEK EFFECT
IN STRONG FOCUSING STORAGE RINGS

A. Piwinski

Some recent work where similar effect is observed on another ring (BEPC2, HEPS):

PHYSICAL REVIEW ACCELERATORS AND BEAMS **27,** 124401 (2024)

New analytical formula on the Touschek lifetime of the polarized electron beam in electron storage rings

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(Received 8 June 2024; accepted 28 October 2024; published 2 December 2024)

Proposal of new implementation

Implementation of the Piwinski formula seem feasible
→ Reduces also to an integral over a kinematic quantity
→ More complicated formula involving Bessel function (but can be numerically evaluated)

$$\bar{\sigma} = \frac{\pi r_p^2}{2\bar{\gamma}^2} \int_0^{\bar{\psi}_m} \left(\left(1 + \frac{1}{\bar{\beta}^2}\right)^2 \left(\frac{2(1+\cos^2\bar{\psi})}{\cos^3\bar{\psi}} - \frac{3}{\cos\bar{\psi}}\right) + \frac{4}{\cos\bar{\psi}} + 1 \right) \sin\bar{\psi}\, d\bar{\psi}$$

$$\begin{aligned} R &= \frac{c\beta\beta_x\beta_z\sigma_h N_p^2}{32\pi^{5/2}\sigma_{x\beta}^2\sigma_{z\beta}^2\sigma_s\sigma_p} \int_{4\chi_m^2}^{\infty} \int_0^{2\pi} \chi\sigma(\chi) \exp\{-\rho A_1 - \rho A_2 \cos(2\nu - \phi_o)\}\, d\nu\, d\rho \\ &= \frac{c\beta\beta_x\beta_z\sigma_h N_p^2}{16\pi^{3/2}\sigma_{x\beta}^2\sigma_{z\beta}^2\sigma_s\sigma_p} \int_{4\chi_m^2}^{\infty} \chi\sigma(\chi) \exp\{-\rho A_1\}\, I_o(\rho A_2)\, d\rho \qquad \text{(A2.5)} \end{aligned}$$

$$\begin{aligned} p'_{1,2} - p_{1,2} &\approx p'_{j1,2} - p_{j1,2} \\ &\approx \pm p\,\gamma_t \chi \cos\bar{\psi} \end{aligned} \qquad 4\chi^2 = (p_{x1} - p_{x2})^2/p^2 + (p_{z1} - p_{z2})^2/p^2 \qquad (\chi = \sqrt{\rho}/2)$$

Sampling the phase space in (Psi,chi) might prove more efficient (than sampling momentum variables directly) ?
Similar approach to the one currently used (Monte Carlo) to sample the integral
To be carefully tested before implementation

Preliminary conclusion

1. More points for sampling the lattice around IP to better describe large losses around Belle II ?
   - Use the existing simulation simply increasing granularity close to IP
   - Relatively « easy » to test
2. More involved implementation of Touschek scattering using Piwinski formula
   - Some significant work
   - Possible increase in computing time

NB: Implementation timeline is vague (spare time work) at this stage, may be easier if this work could be considered as qualifying task for a student (may have one joining in October, TBC)

Compton scattering on thermal photons

Introduction

Among the background sources, at least one, Compton scattering on thermal photons, has not been studied quantitatively, though

- It is a known source of potential background, cf Compton polarimeter study
- Already spotted a long time ago

Purpose of today's presentation:

- First, naïve, estimate of event rates (integrated over the ring)
- Work plan for discussion

304 Nuclear Instruments and Methods in Physics Research A260 (1987) 304–308
North-Holland, Amsterdam

SCATTERING OF ELECTRONS ON THERMAL RADIATION PHOTONS IN ELECTRON–POSITRON STORAGE RINGS

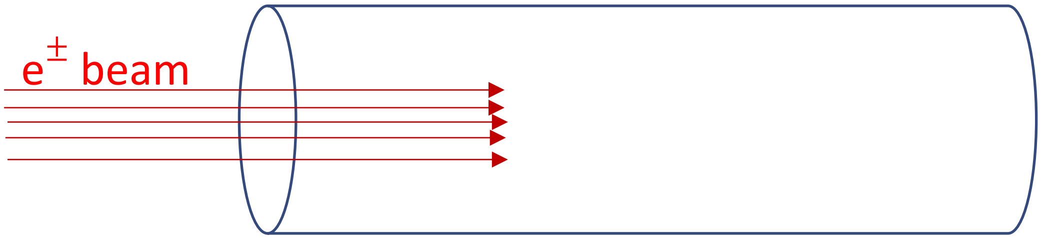
V.I. TELNOV

Institute of Nuclear Physics, 630090, Novosibirsk 90, USSR

Received 26 January 1987

It is shown that Compton scattering on thermal radiation photons restricts the lifetime of high energy electron beams in storage rings to a level of 30 h. At a vacuum pressure of 10^{-10} Torr the probability that an electron is knocked out from the beam due to scattering on thermal photons exceeds the probability of bremsstrahlung on residual gas ($\Delta E/E > 1\%$) by one order of magnitude, i.e. this effect can cause a considerable background in detectors.

Thermal bath of photons



The density and energy distribution of the thermal photons is given by the Plank formula

$$\mathrm{d}n_{\mathrm{P}} = \frac{\omega_0^2 \, \mathrm{d}\omega_0}{\pi^2 c^3 \hbar^3 (\mathrm{e}^{\omega_0/kT} - 1)}. \qquad (6)$$

The total number of photons per cm^3 is

$$n_{\mathrm{P}} = \frac{2.4(kT)^3}{\pi^2 c^3 \hbar^3} = 20.2 T^3 \text{ cm}^{-3}. \qquad (7)$$

The average photon energy

$$\bar{\omega}_0 = 2.7kT. \qquad (8)$$

Compton scattering

$$x = \frac{4E\omega_0}{m_e^2 c^4}\cos^2\frac{\alpha_0}{2},$$

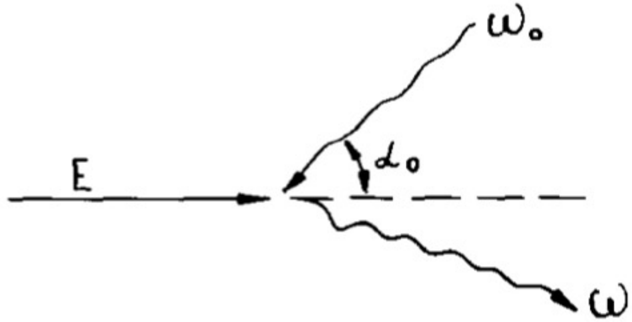


Fig. 1. Kinematics of Compton scattering.

The energy spectrum of the scattered photons is defined by the cross section

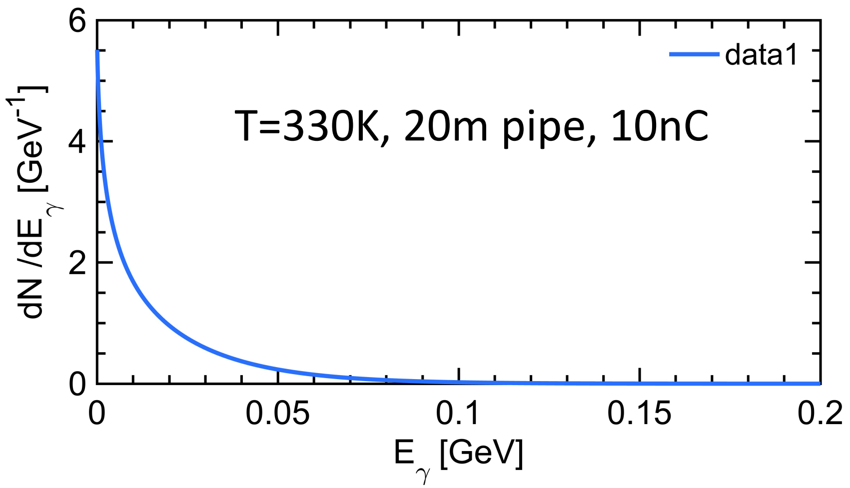
$$\frac{\mathrm{d}\sigma_C}{\mathrm{d}y} = \frac{2\pi r_e^2}{x}\left[\frac{1}{1-y} + 1 - y - \frac{4y}{x(1-y)} + \frac{4y^2}{x^2(1-y)^2}\right],$$

where $y = \omega/E$.

Combining both aspects, randomly choosing the crossing angle, provides an estimate for the number of scattered photons and their spectrum

First crude estimate

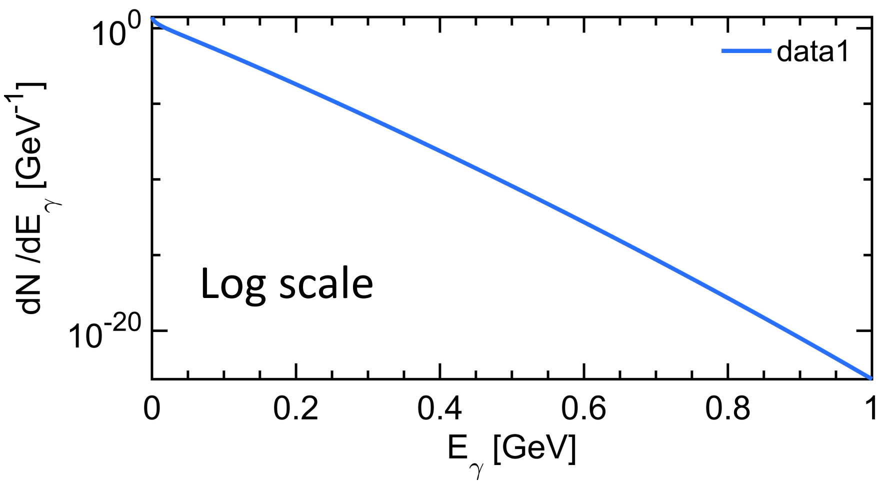
Crude model:
- assume pipe temperature is homogenous along the ring
- Assume that scatter with photon energy > momentum acceptance ~10 energy spread of electron beam ($6x10^{-4}$) are lost



Increasing by 30K the temperature of the beam pipe → x1.6 in photons with energy above threshold !
→ Knowledge of pipe temperature ?

Estimated lifetime ~150h (after scaling to 3km)

An effect independent of pressure (so most important for HER) and proportional to Intensity (not squared)
→ Different scaling law wrt to other bkgs



Model limitations

Temperature is not homogenous along the pipe, we know it can be realtively high in the IR

Momentum acceptance is a s-dependant quantity, the crude model may be an underestimation, but still the lifetime seems very long

Probably a small correction, maybe worth checking magnitude ?

Strategy, as suggested by Andrii:

- Implement in SAD with some assumption on the temperature profile
- Do we have some data on this aspect ?
- If not, may use SR to estimate pipe temperature (more difficult, less reliable ?)