Experimental Beam Physics
2013 USPAS at Duke University

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Duke University

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Schedule for Exp. Beam Phy.

1. Daily Schedule

Morning: 09:00 - 11:30
Lunch break: 11:30 - 13:00
Afternoon: 13:00 - 17:30

Bus: Route PR-1
http://parking.duke.edu/buses_vans/bus_sched/pr1.php
Bassett Drive: 8:29 8:58
Circuit Drive: 8:40 9:09

Circuit Drive: 5:23 5:47
Bassett Drive: 5:28 5:52

(Hotel meals:
Breakfast buffet: 7 to 11 am
Dinner: : 6 to 7 pm)

Schedule for Exp. Beam Phy.

2. Week 1 Schedule

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Mon (1/14)
 9:00 - 10:10: Tour of the DFELL/HIGS Accelerator Facility
10:10 - 10:20: Break
10:20 - 11:30: Overview of Beam lifetime and test

13:00 - 17:30: Exp: Beam current and lifetime measurement

Tue (1/15)
 9:00 - 11:30: Accelerator Physics Overview
13:00 - 17:30: Exp: Beam Orbit measurement

Wed (1/16)
 9:00 - 11:30: Accelerator Physics Overview
13:00 - 17:30: Exp: Beam Profile measurement

Thu (1/17)
 9:00 - 11:30: Accelerator Physics Overview
13:00 - 17:30: Exp: Tune measurement

Fri (1/18)
 9:00 - 11:30: Exp: Beam study
13:00 - 17:30: Exp: Beam study and makeup time

Schedule for Exp. Beam Phy.

3. Week 2 Schedule

Mon (1/21), MLK, * Bus; * Late Start
10:00 - 11:30: Exp: Beam injection
13:00 - 17:30: Exp: Beam tuning

Tue (1/22)
9:00 - 11:30: Exp: FEL/HIGS tuning
13:00 - 17:30: Exp: FEL study/measurement

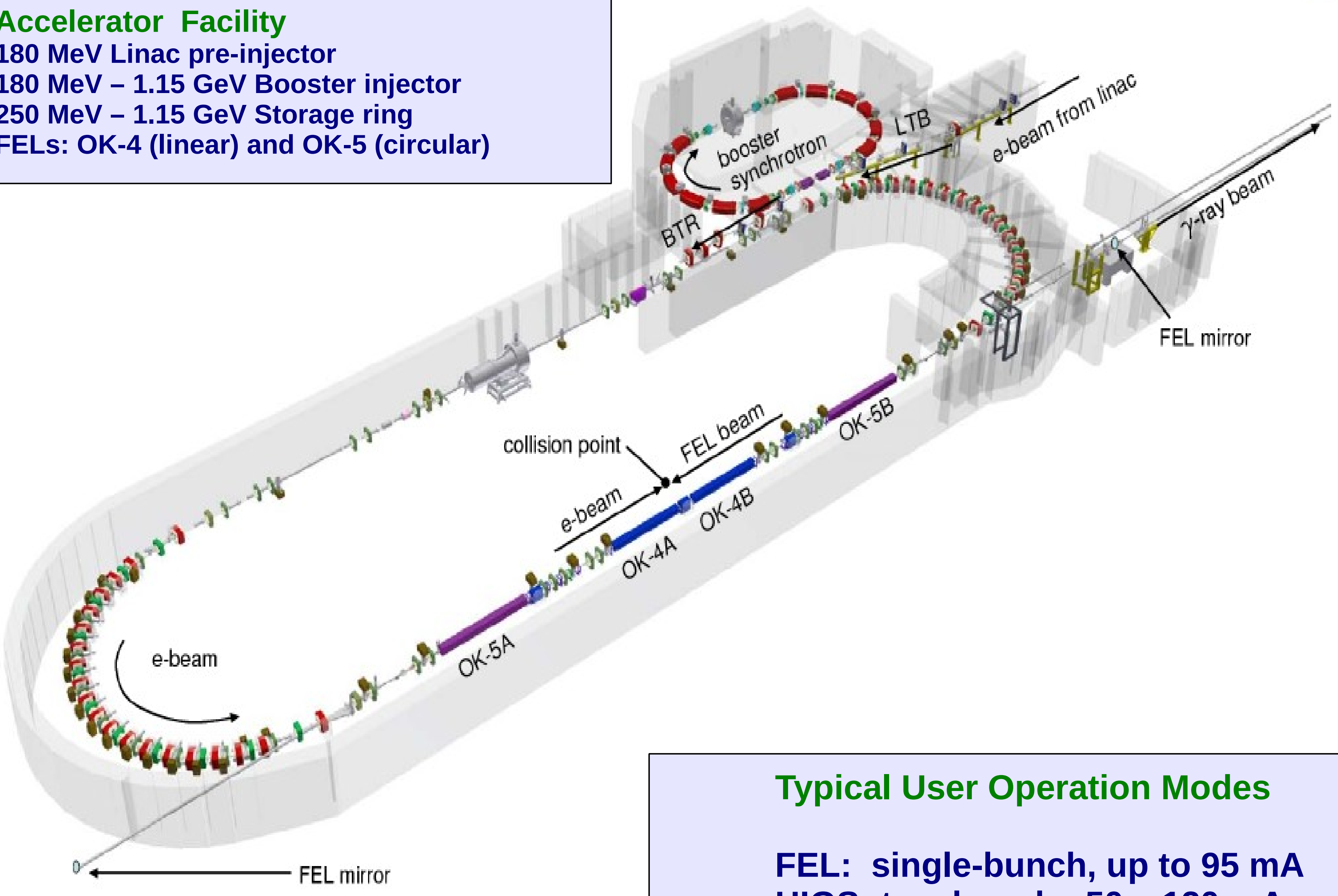
Wed (1/23)
9:00 - 11:30: Exp: Response matrix
13:00 - 17:30: Exp: Orbit correction

Thu (1/24)
9:00 - 11:30: Exp: Beam based quad center measurement
13:00 - 17:30: Exp: Continued

Fri (1/25)
9:00 - 11:30: Exp: Makeup time
13:00 - 17:30:

High Intensity Gamma-ray Source (HIGS) Accelerators

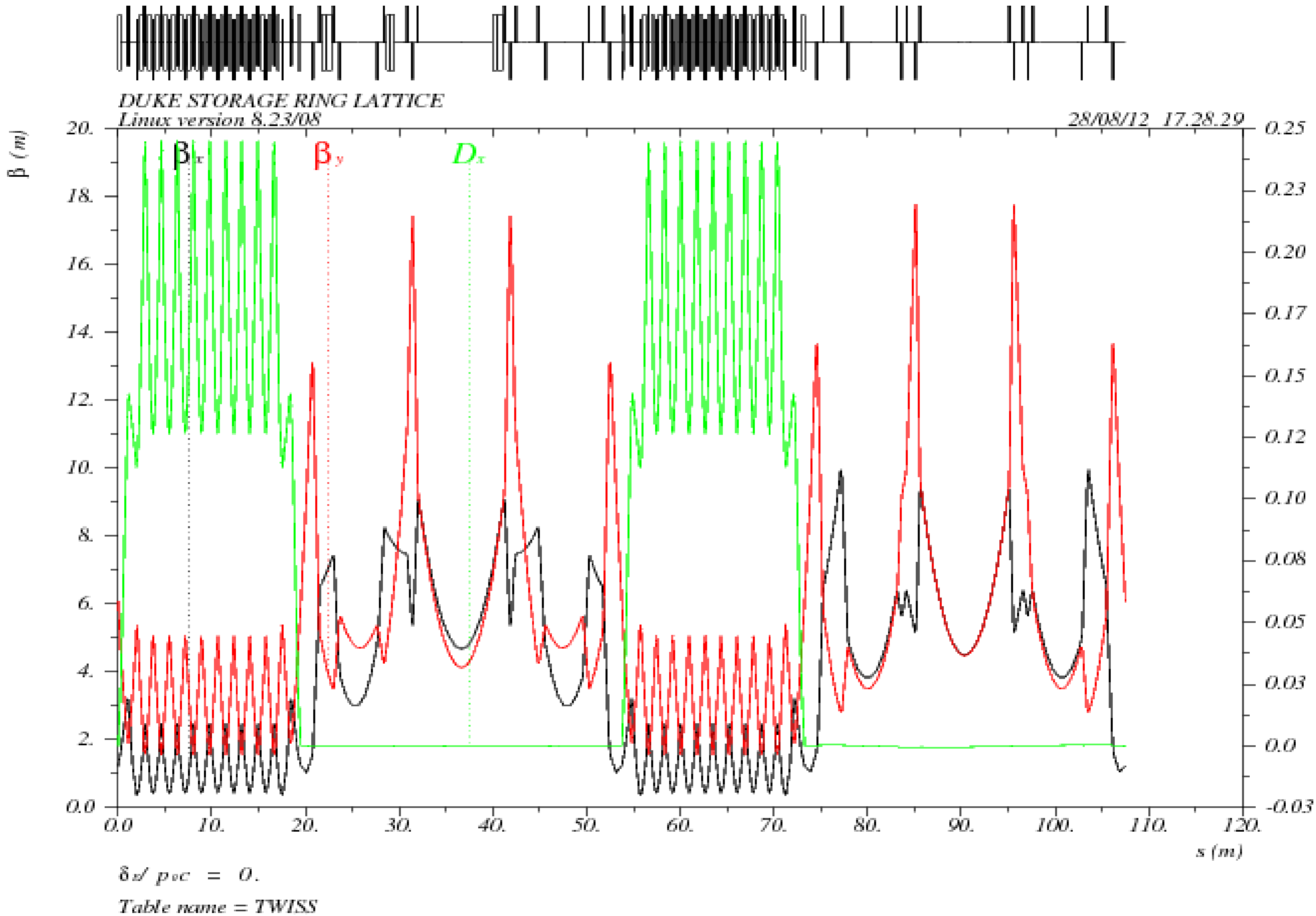
Accelerator Facility
180 MeV Linac pre-injector
180 MeV – 1.15 GeV Booster injector
250 MeV – 1.15 GeV Storage ring
FELs: OK-4 (linear) and OK-5 (circular)



Typical User Operation Modes

FEL: single-bunch, up to 95 mA
HIGS: two-bunch, 50 – 120 mA

Duke Storage Ring Beta-functions, Eta-function



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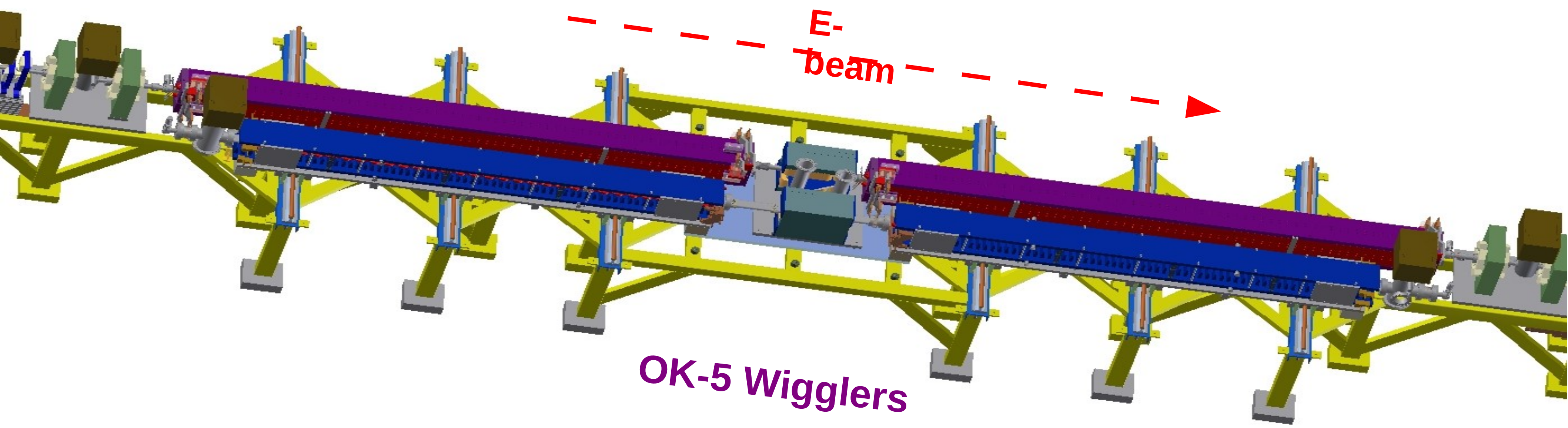
FEL Switchyard System for High Gain FEL Operation



Electron Beam Lifetime in the Storage Ring

Lifetime of Electron Beam In the Storage Ring

- **Beam Loss In the Storage Ring**
  - **Fast beam losses (examples)**
    - **Malfunction of hardware: power supplies, RF cavity, magnets, etc.**
    - **Injection loss**
    - **Beam loss when crossing (betatron) resonances**
    - **Beam loss due to instabilities**
    - **More ...**
  - **Slow beam loss => Lifetime effects**

- **Beam Lifetime Mechanisms**
  - **Quantum lifetime: due to quantum fluctuation as result of radiation**
  - **Residual gas lifetime: due to electron collisions with residual gas**
  - **Touschek lifetime: due to electron-electron collision/scattering inside the beam**

Defining Beam Lifetime

Particle loss rate

$$\alpha = \frac{1}{\tau} = -\frac{1}{N}\frac{dN}{dt}$$

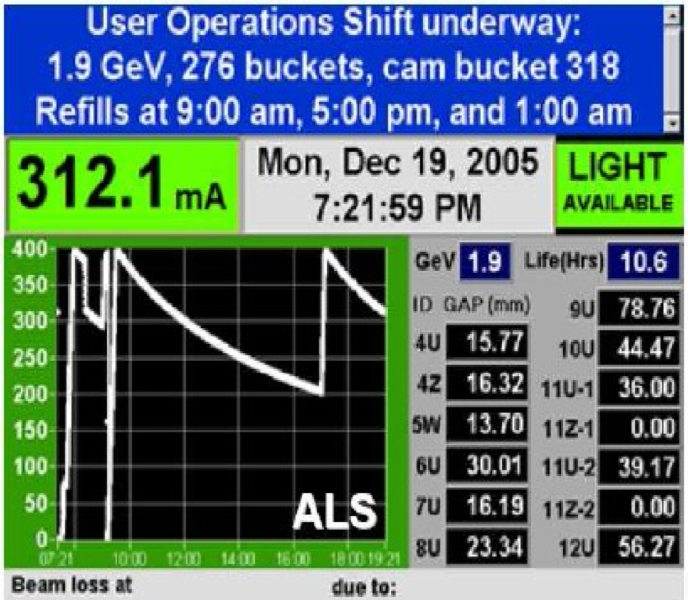
Slow dependency on N and t

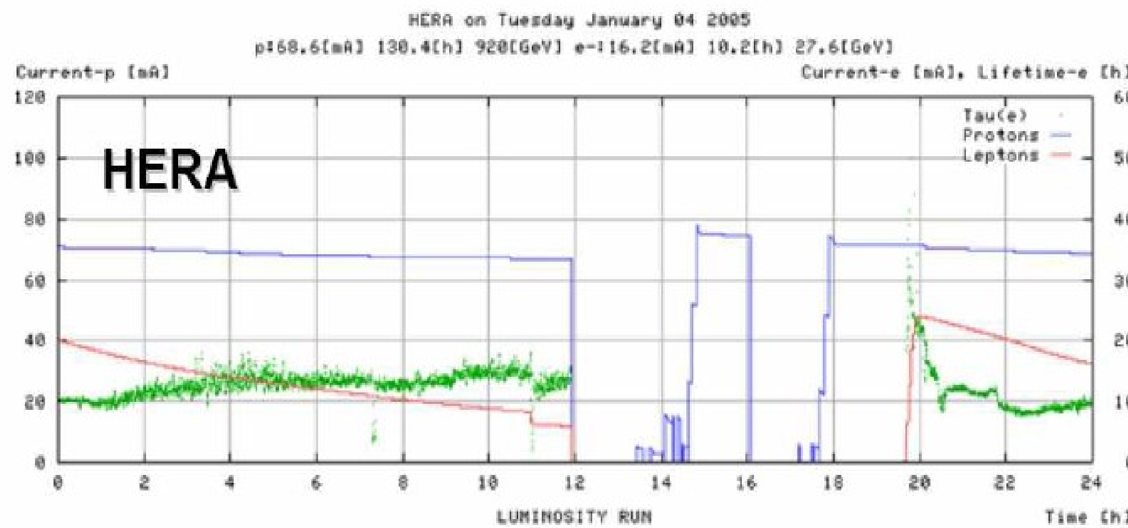
$$N(t \geq t_1) = N(t_1)\, e^{(t-t_1)/\tau}$$

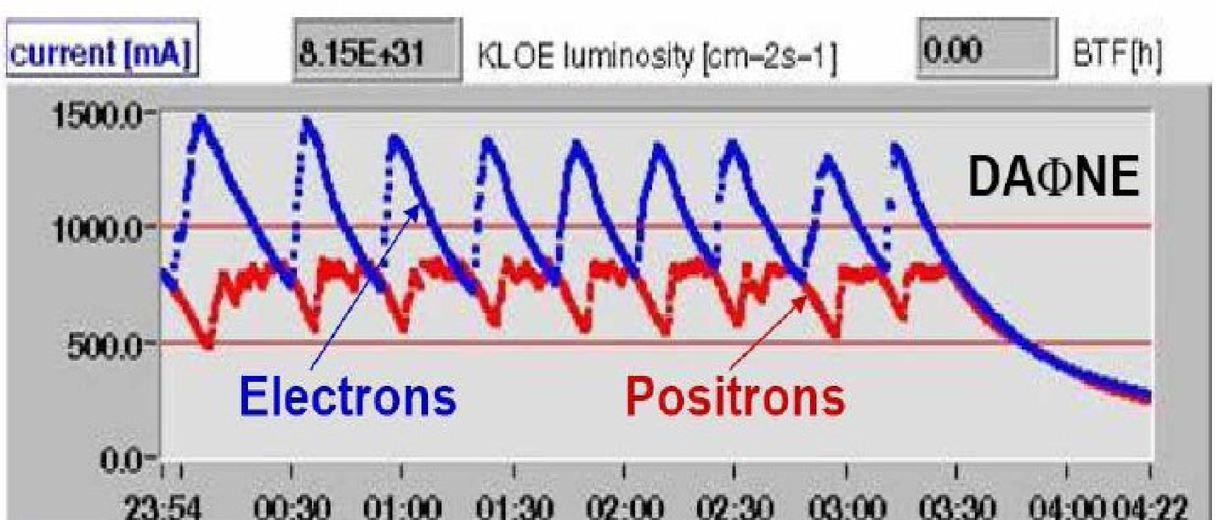
Beam lifetime can depend on time (slow), beam current, etc.

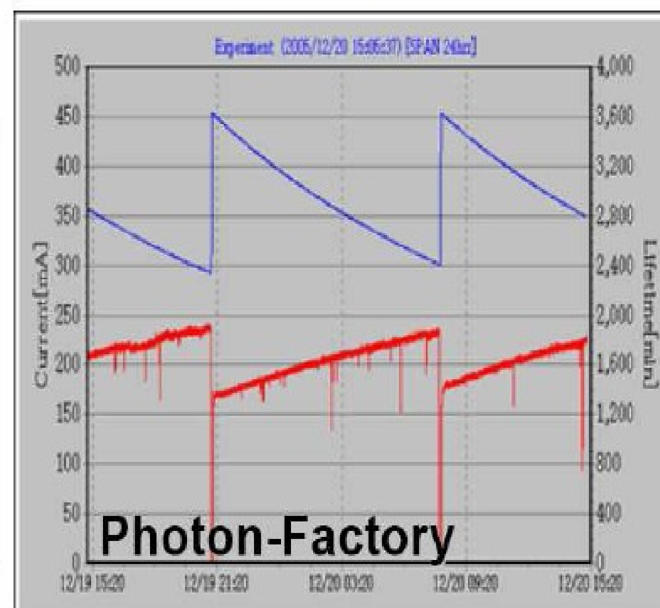
$$\tau(t, I_{beam}, \ldots)$$

Beam Lifetime in Real Accelerators







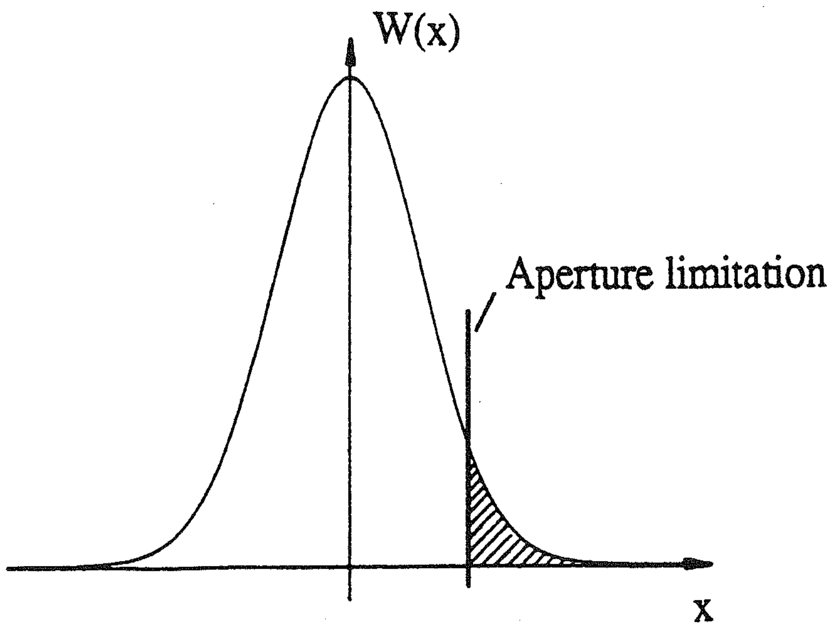


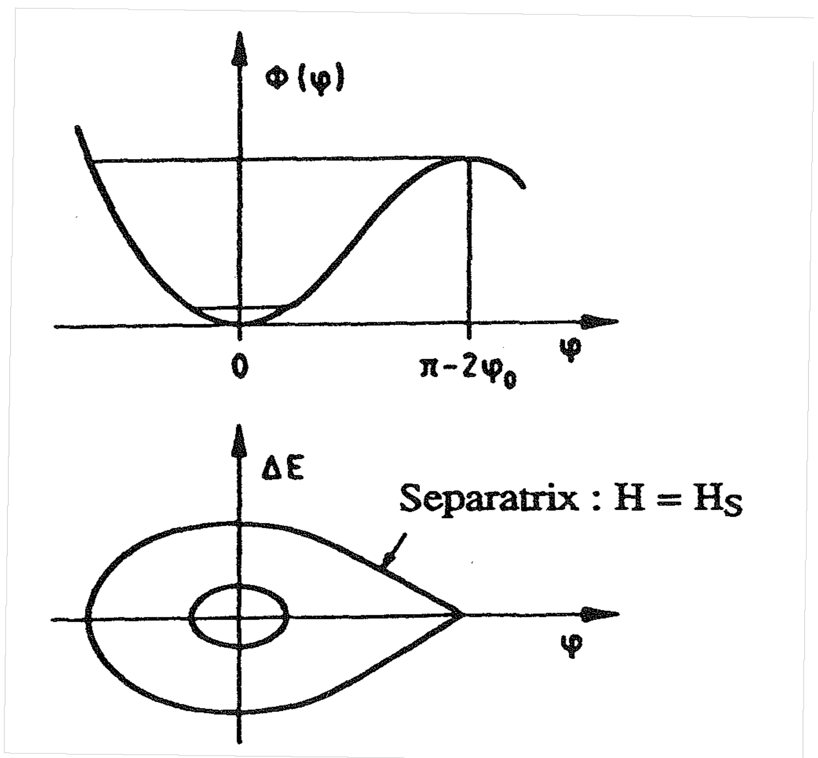
Courtesy of F. Sannibale

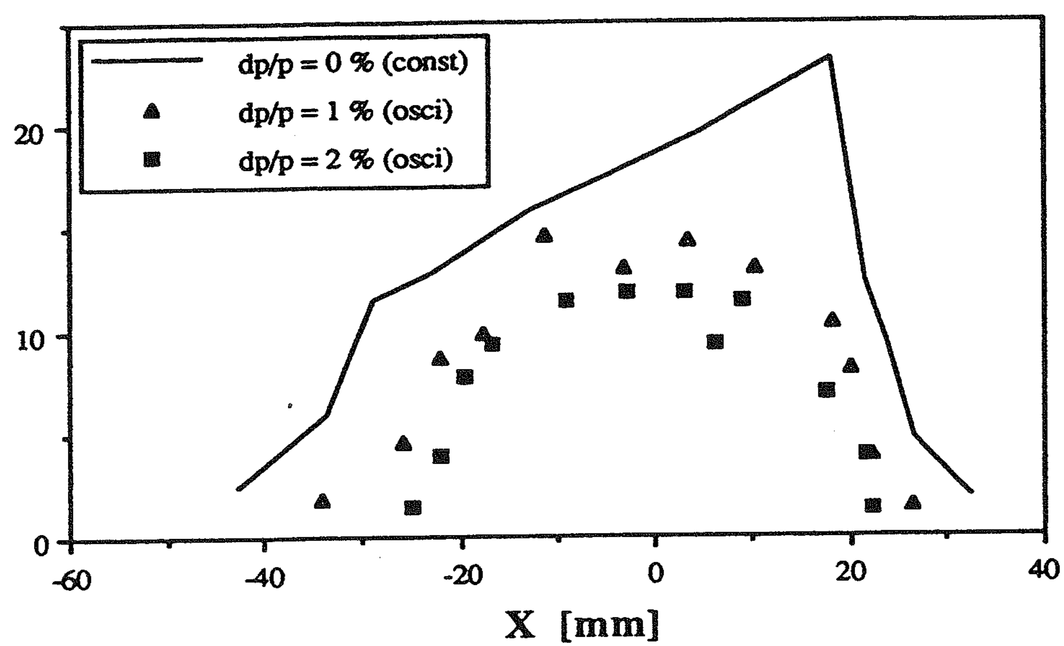
Beam Lifetime Issues

Quantum Lifetime

- Longitudinal (Energy/momentum)
  - RF (momentum/energy) acceptance
  - Off-momentum dynamic aperture
- Transverse
  - Dynamic aperture (transverse)
  - Physical aperture (scraper/knife-edge)







A. Wrulich, *"Single-beam lifetime", CERN 94-01, p. 409, v1, (1994).*

Beam Lifetime Issues

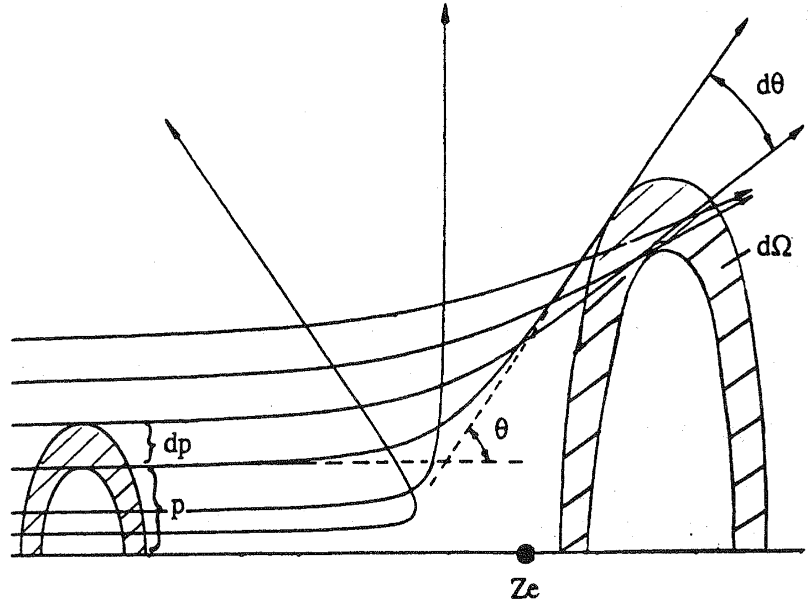
Gas Lifetime (limited by apertures)

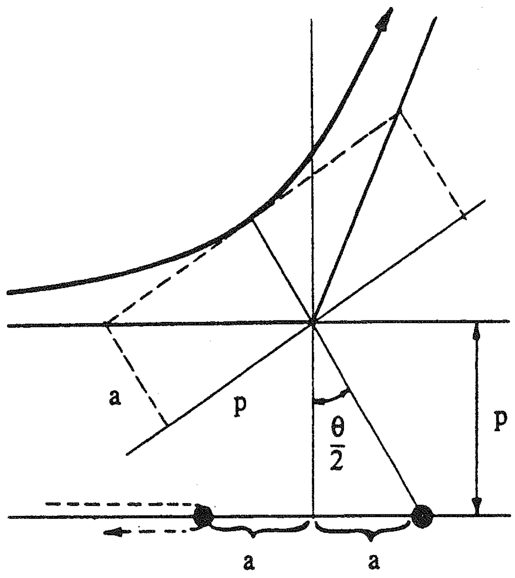
- **Elastic Scattering**

$$\frac{1}{\tau_{scat}} = \frac{4 r_e^2 Z^2 \pi \rho c}{2\gamma^2}\left\{\frac{\langle\beta_x\rangle\beta_{x,max}}{a^2} + \frac{\langle\beta_y\rangle\beta_{y,max}}{b^2}\right\}$$

- **Inelastic Scattering (Bremsstrahlung on nuclei)**

$$\frac{1}{\tau_{brem}} = \frac{16 r_e^2 Z^2 \rho c}{411}\ln\left(\frac{183}{Z^{1/3}}\right)\left\{-\ln\epsilon_{RF} - \frac{5}{8}\right\}$$





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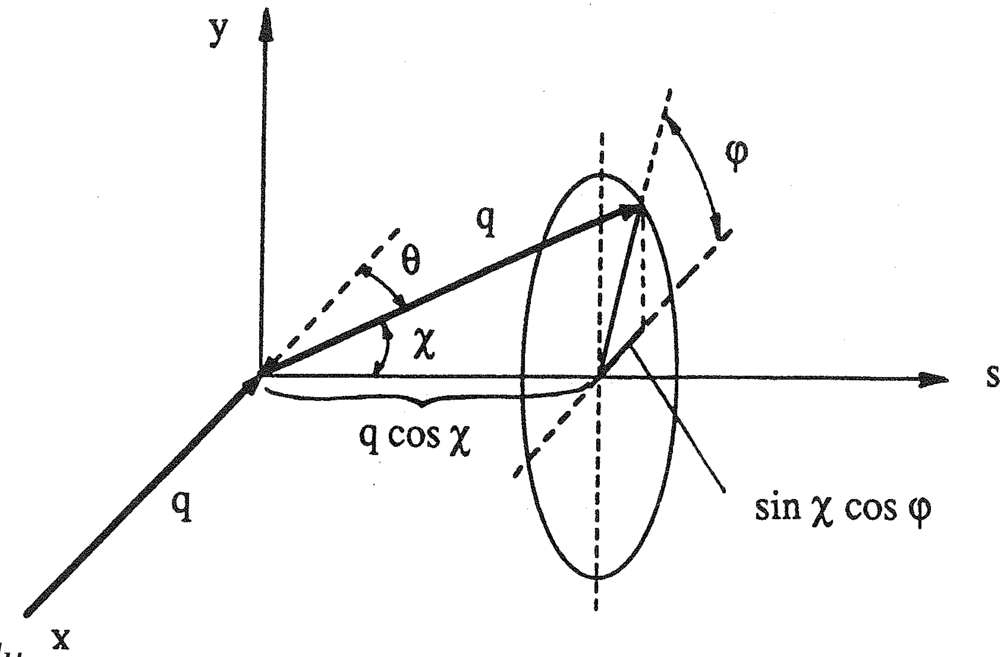
Beam Lifetime Issues

Touschek Lifetime

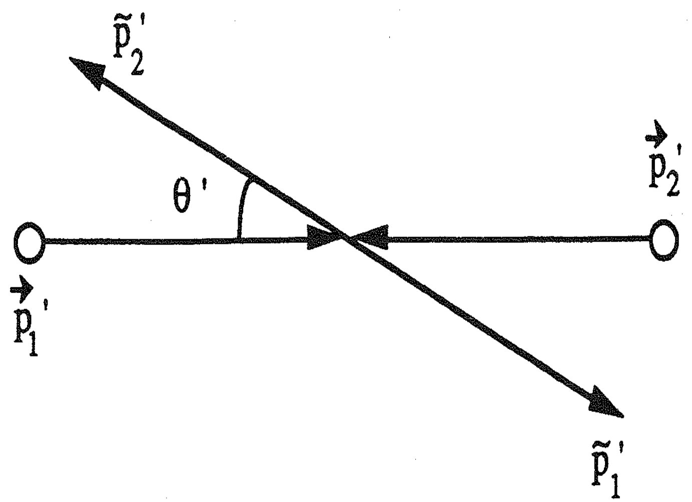
- **Elastic Scattering**
  - **Momentum transfer**



$$\frac{1}{\tau_{T1/2}} = \frac{\sqrt{\pi}\, r_e^2 c N C(\zeta)}{\sigma'_x \gamma^3 \epsilon_{acc}^2 V}$$

$$V = 8\pi^{3/2}\sigma_x\sigma_y\sigma_L \qquad \zeta = [\epsilon_{acc}/(\gamma\sigma'_x)]^2$$

$$C(\zeta) = -\frac{3}{2}e^{-\zeta} + \frac{\zeta}{2}\int_\zeta^\infty \frac{\ln u}{u}e^{-u}du + \frac{1}{2}(3\zeta - \zeta\ln\zeta + 2)\int_\zeta^\infty \frac{e^{-u}}{u}du$$



Total Lifetime

$$\frac{1}{\tau_{tot}} = \frac{1}{\tau_q} + \frac{1}{\tau_{scat}} + \frac{1}{\tau_{brem}} + \frac{1}{\tau_{Tous}}$$

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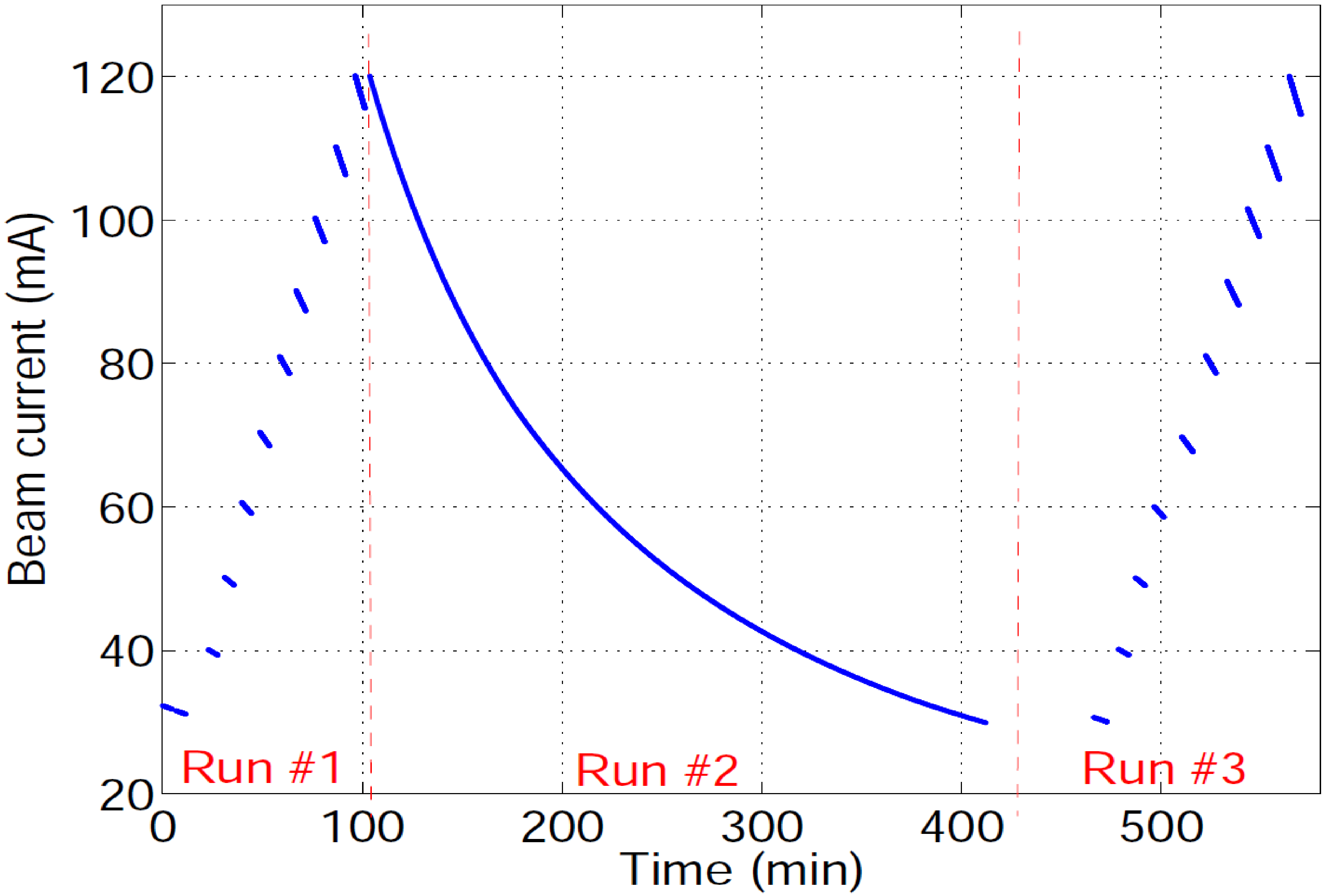
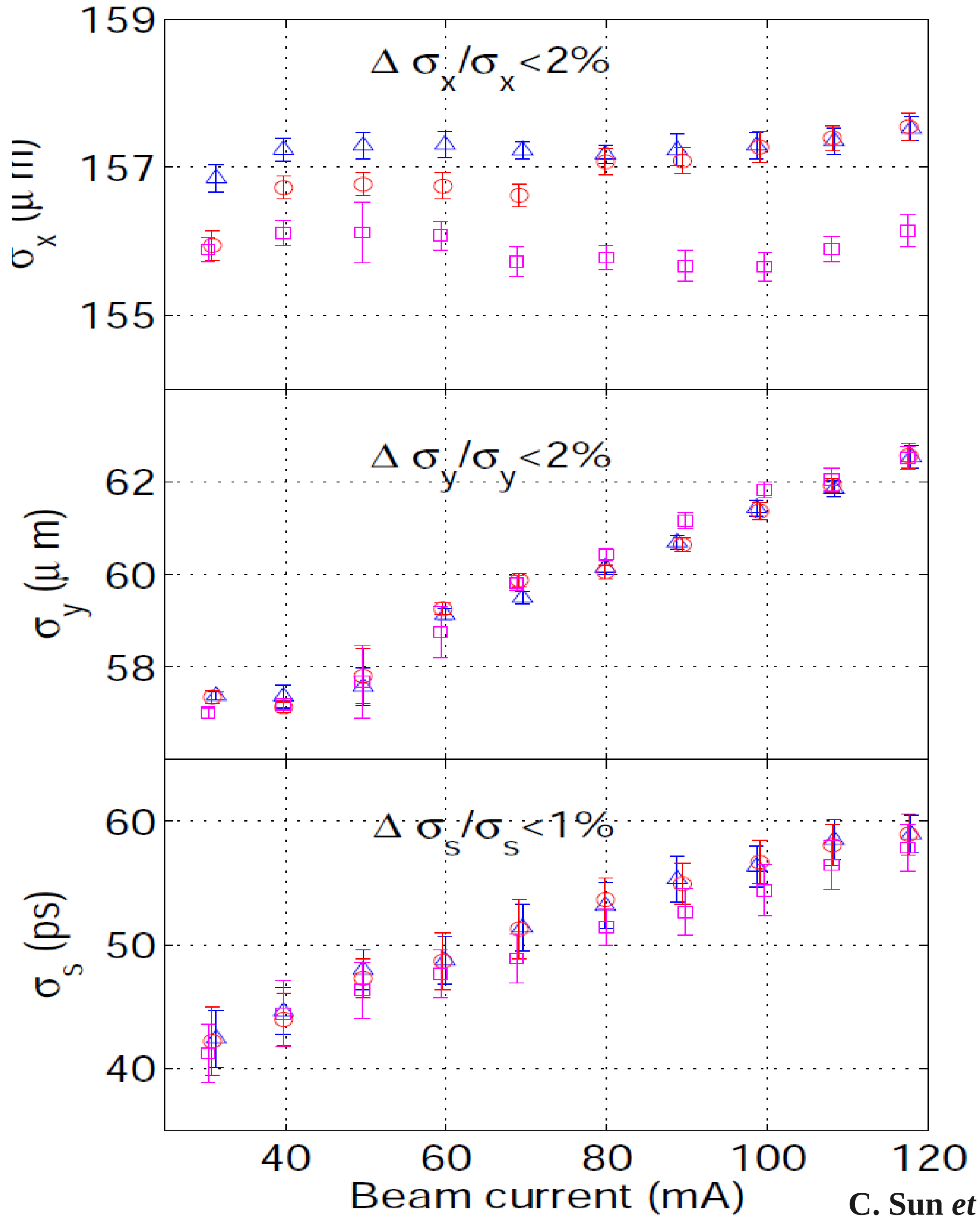
Duke Storage ring: E-beam Polarization Measurement Using Beam Lifetime



C. Sun *et al.*. NIMA614, p 339 (2010).

E-beam Polarization Measurement Using Beam Lifetime



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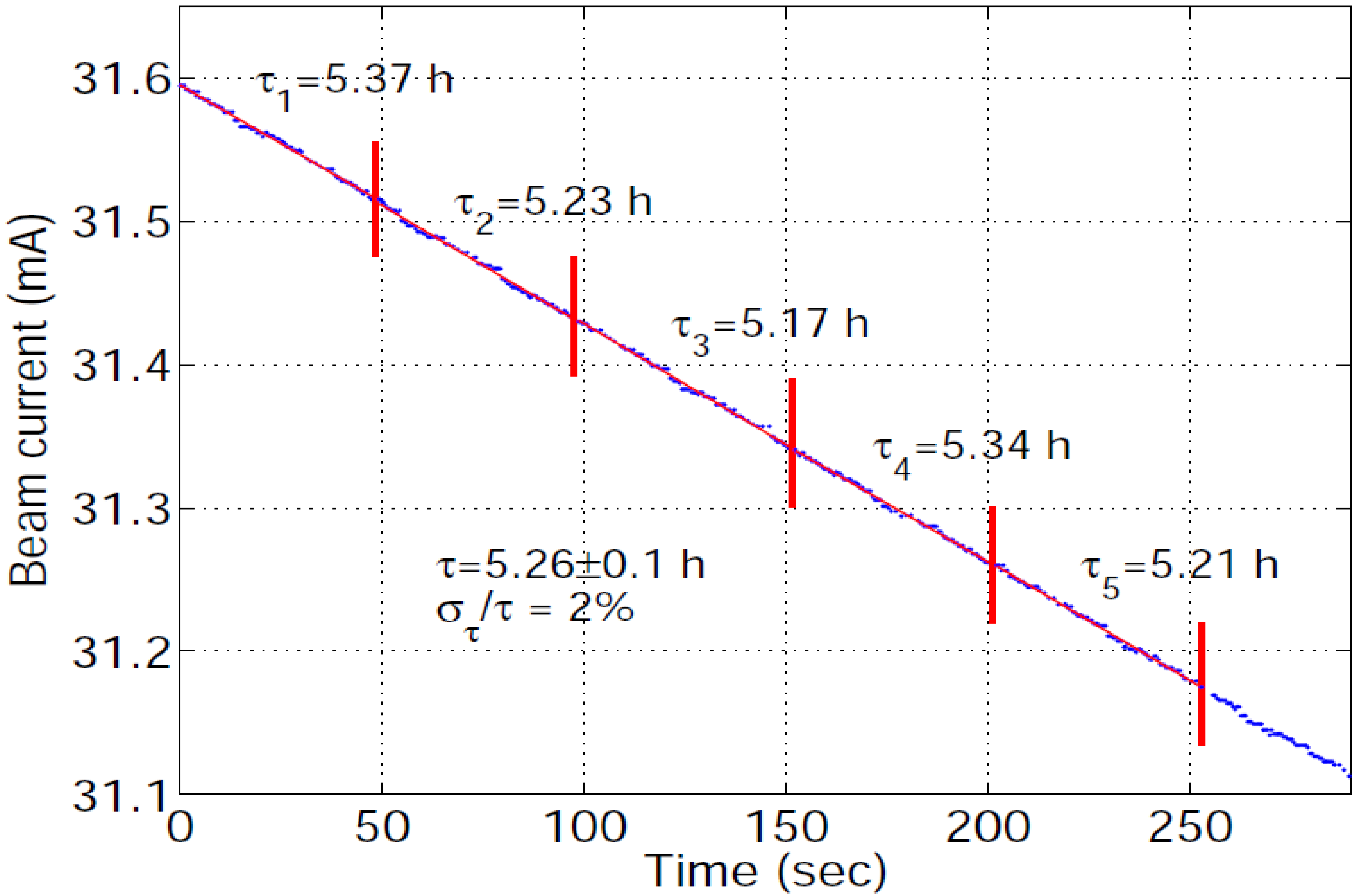

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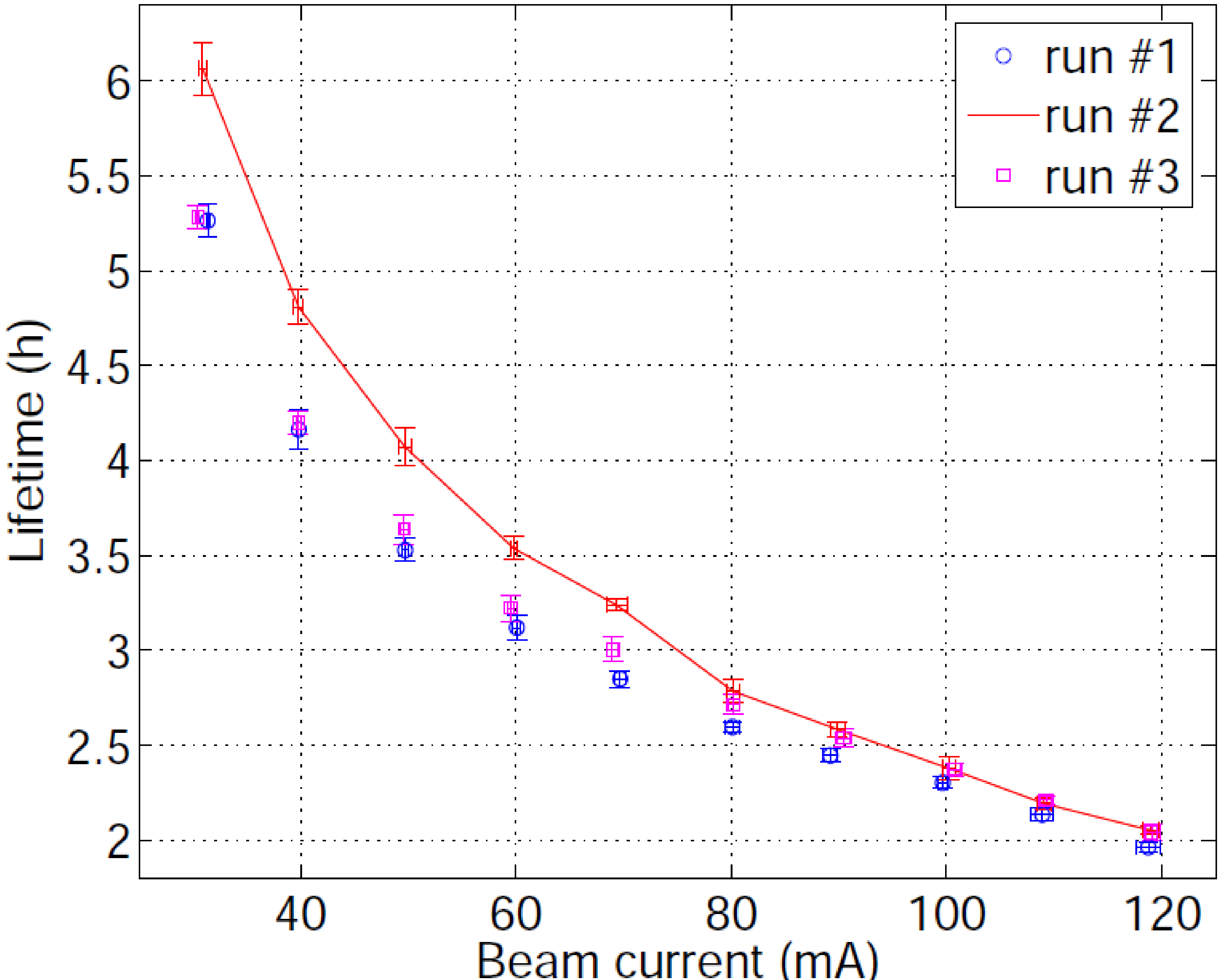

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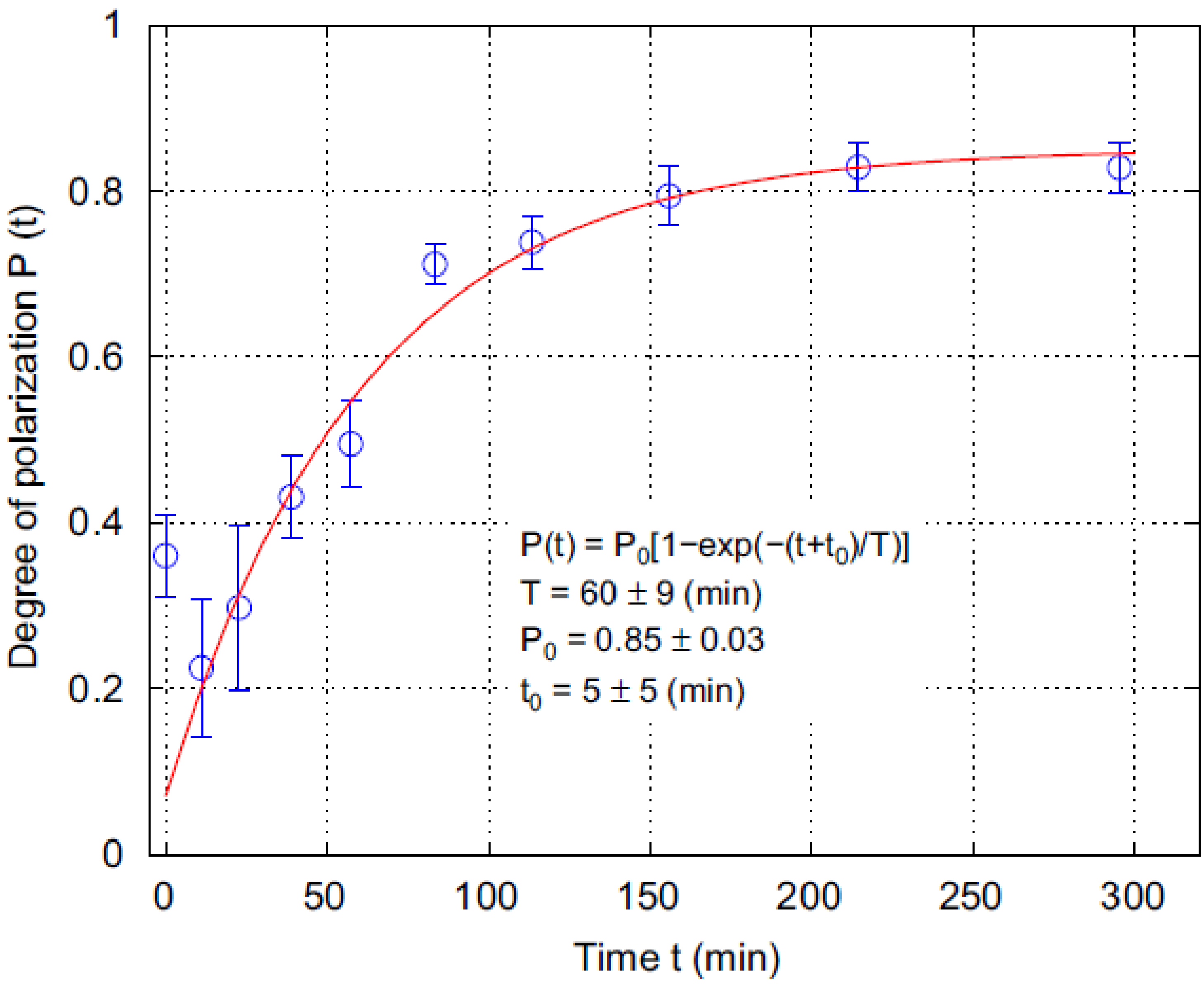

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