

Touschek Polarization Lifetime Experiment Planning

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Experiment Planning

0.5% lifetime measurement will be sufficient to measure the transverse beam polarization and to detect the $\gamma G = 16$ depolarizing resonance, the presence of which would indicate that polarization is preserved and the resonance reduces it.

Because of this connection to the beam energy (the resonance is at a beam energy of 7049.86 MeV) the resonance can be used to precisely calibrate the beam energy by performing an energy scan.

Goals of Experiment:

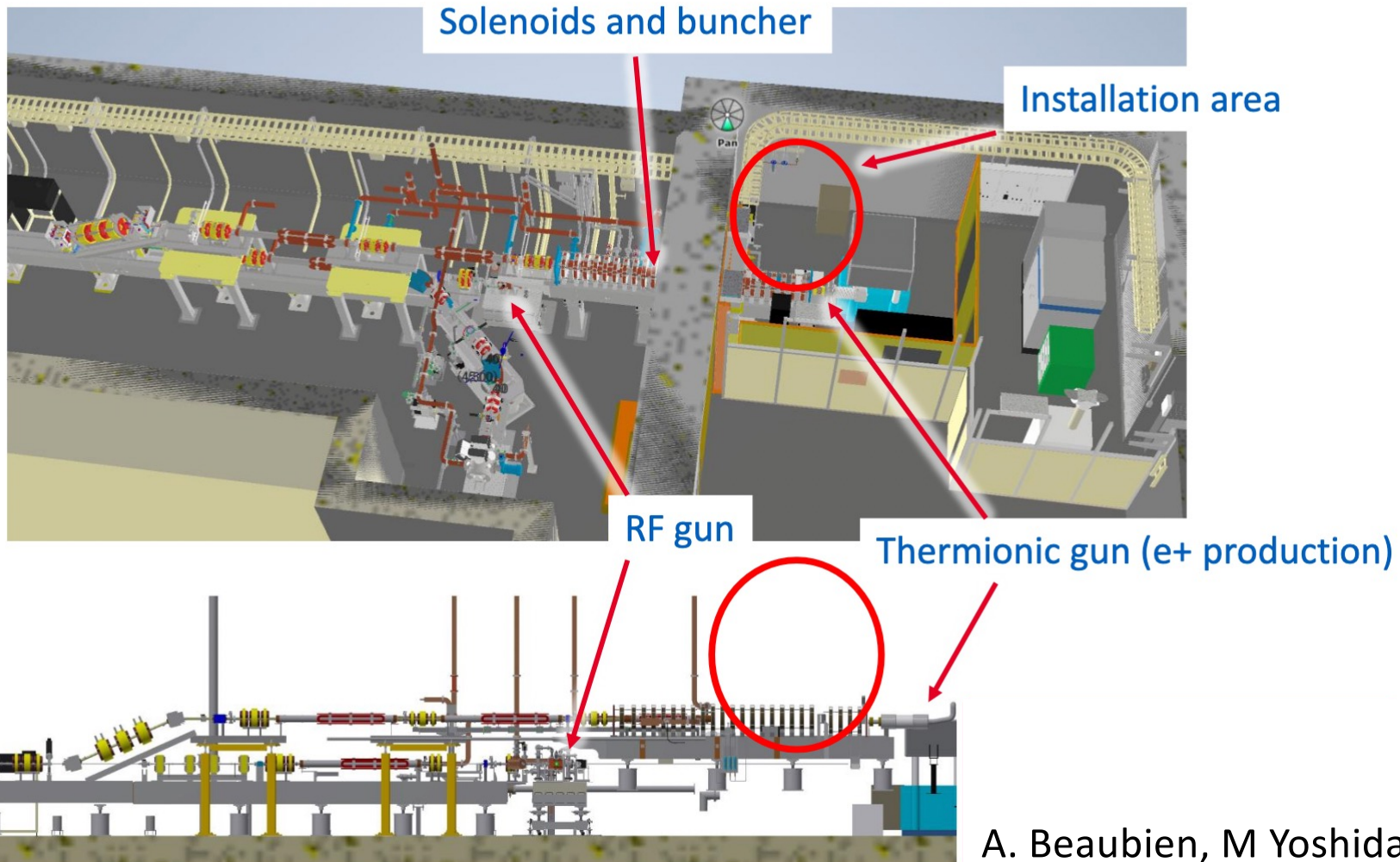
- Verify spin-transport through the injector chain is understood and preserves the polarization magnitude and direction.
- Verify polarization is preserved upon storage of the electron bunches in the HER, determine the polarization lifetime and map out the topology around the $\gamma G = 16$ spin resonance.
- If possible, to detect and quantify the effect of the beam-beam interaction on the polarization lifetime and develop mitigation strategies.
- If beam-beam effects are detectable, quantify the effect on polarization in terms of the beam-beam parameter
- Starting to investigate how the polarization probe of beam-beam parameter compares with other methods of measuring it

R&D Work

- Develop the temporary polarized source (M. Yoshida, A. Beaubien, Z. Liptak)
 - Design
 - Construction
 - Installation and testing in lab with Mott polarimeter
- Polarized Source line development
 - Source
 - Wein filter
 - Merger
- Integration into source room
 - Address solenoid fields in bunchers

Source for Touschek Polarization Experiment

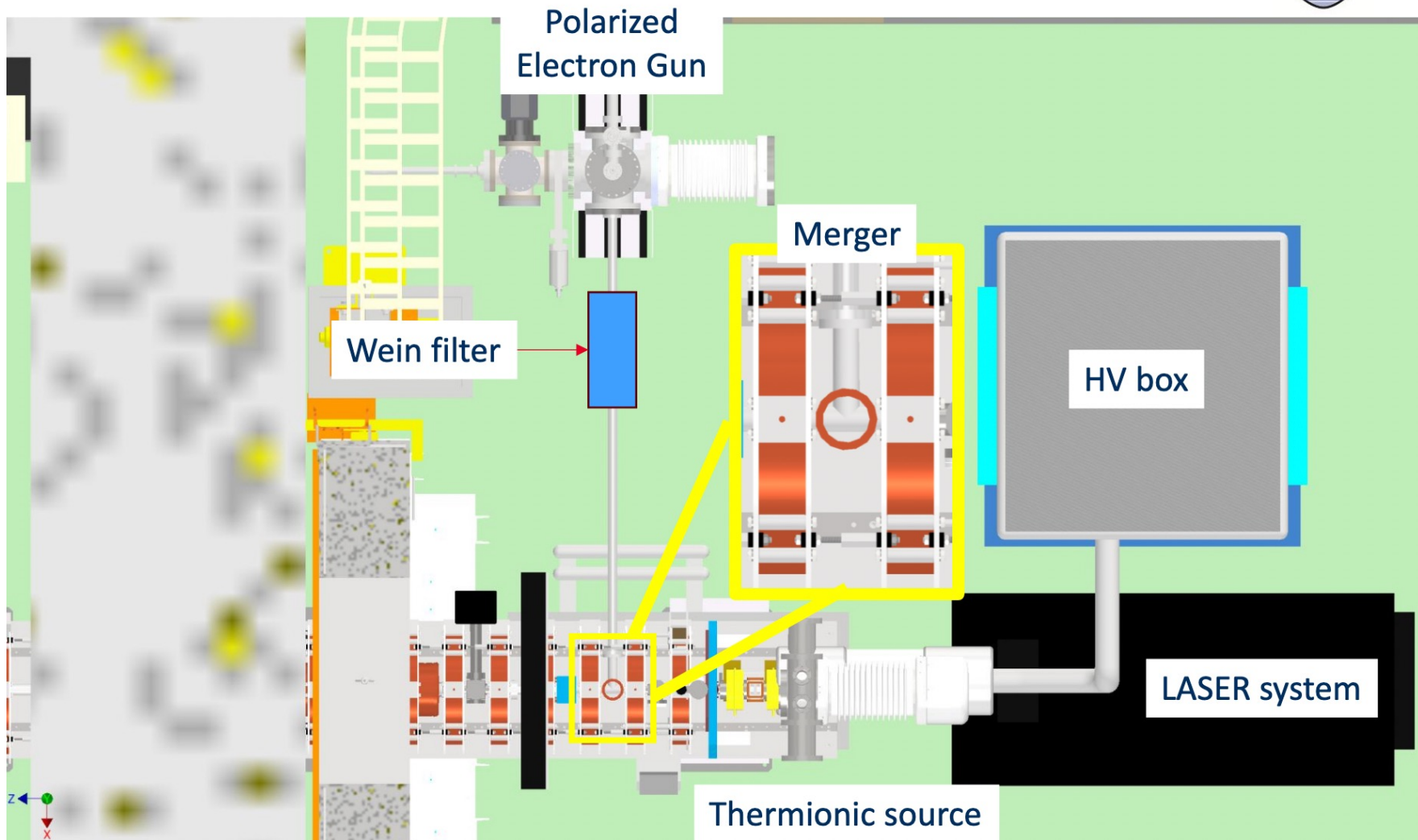
Source Room Available Area



A. Beaubien, M Yoshida

Source for Touschek Polarization Experiment

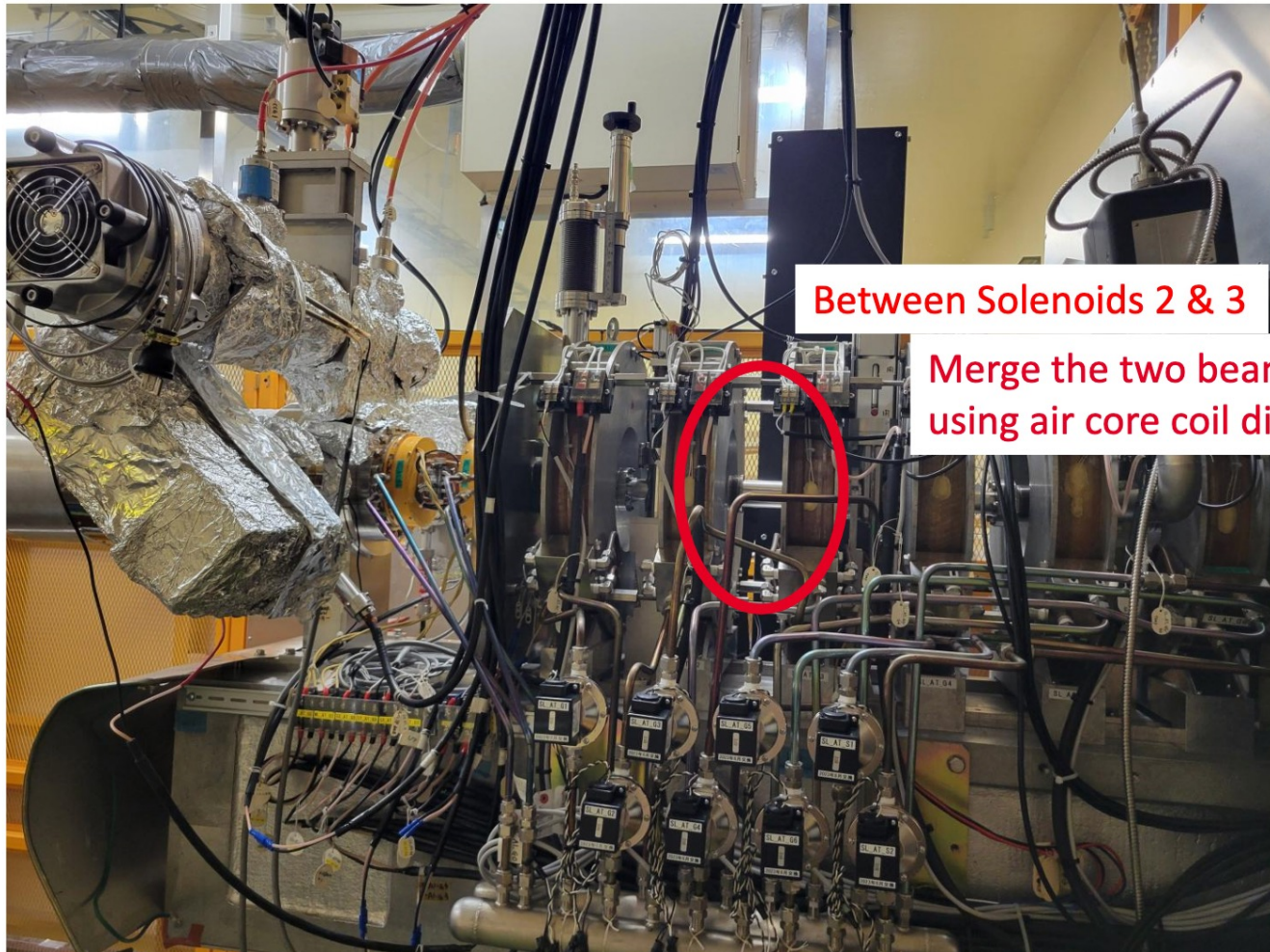
Conceptual Design



A. Beaubien, M. Yoshida

Merge Line

Merge Location



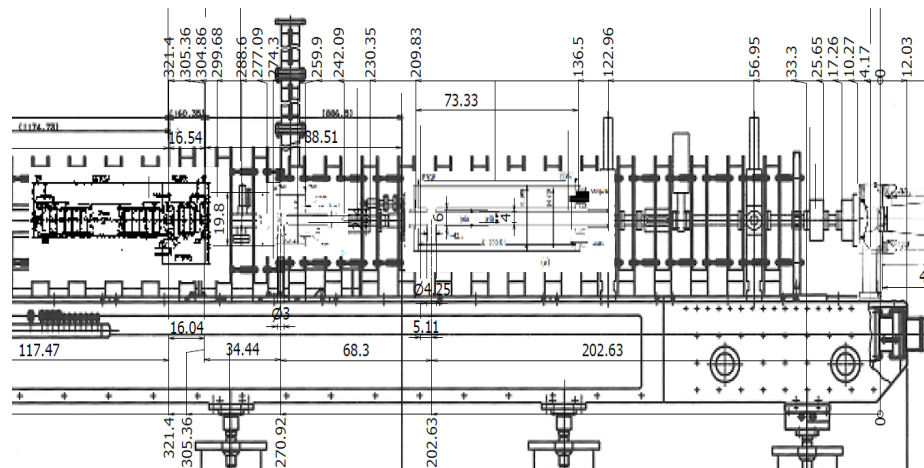
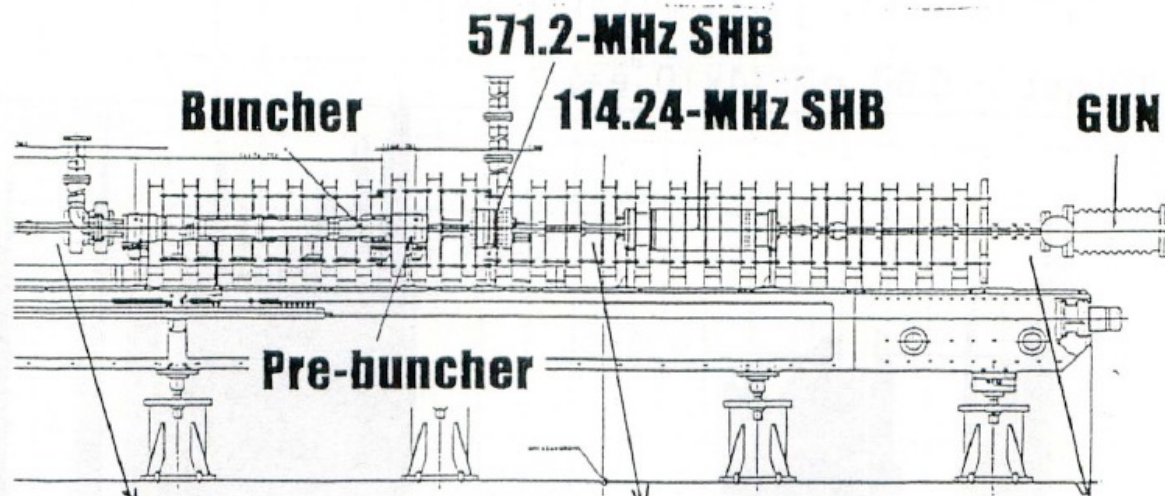
Between Solenoids 2 & 3

Merge the two beams
using air core coil dipole

Alex Beaubien, M. Yoshida

Merge Line

Pre-injector



M. Yoshida

High-level Run Plan

Anticipate 3 days to match the beam from the new source to the injection linac, verifying the beam transport and capture into the linac and acceleration, and that the measured beam parameters are as expected.

Once the beam is stored in the HER, the beam-lifetime measurement (bunch-by-bunch or in groups) will be verified and lifetime data taken under specific conditions to allow separating Touschek lifetime from beam-gas lifetime, and the time needed to get a better-than 0.5% lifetime measurement will be re-established.

Four days for the resonance scan—from 7000 MeV to 7100 MeV in 10-MeV steps—incl. refinement steps in energy to detect synchrotron satellites and increase accuracy of the resonance energy. The ability and efficiency of ramping the energy of the HER will set the duration needed for each energy point.

Nominally the resonance is expected at 7049.86 MeV. Assuming run proceeds reasonably smoothly to this point, plan to inject positron beam into LER and study the effect of the beam-beam interaction on polarization.

Step	Duration (d)	Task	Outcome
1	1	Turn on source and magnet	Beam in transport line
2	1	Accelerate electrons	Beam at 7 GeV
3	1	HER injection	Beam stored
4	1	Initial Measurements	Separate Touschek and b-g lifetime
5	1	Set ring to lowest energy (7 GeV)	Initial point on ramp
6	4	Ramp ring in steps to 7.1 GeV	Production measurements
7	5	Beam-beam effect measurements	Parametrize change in resonance behaviour vs beam-beam

Preparation Planning

The experiment will be prepared in detail using modeling of the beam transport and spin-tracking in the HER to precisely locate the resonance in beam energy, taking into account the beam orbit and possible uncompensated solenoidal field components from the detector.

(use Bmad and other tools capable of modeling spin dynamics)

This will feed back into the planning of the experimental details.

The depolarizing-resonance spectrum will be modeled in sufficient detail to be able to predict polarization lifetime using the DKM formula.

If the synchrotron satellites are detectable, measuring their offset in energy will help cross-check the measurement since the synchrotron tune is known.

Anticipated Results:

- Measurement of polarization lifetime achievable in the HER
- Measurement of the Sokolov-Ternov (de-)polarization time constant
- Energy calibration of the HER to an accuracy of 1 MeV or better
- Potential assessment of the beam-beam parameter by measuring the effect of beam-beam on polarization lifetime

Experiment Run Plan Proposal

SuperKEKB Polarization experiment			
Initial State	Source installed and all under vacuum. Laser tested and ready. Well characterized cathode installed. Well characterized e^- beam properties.		
Resonance:	$\gamma G=16$: 7050 MeV (nominal) Sync. Satellites: ± 12.34 MeV		
Expt. Plan	Initial coarse scan 7000 $\rightarrow$ 7100 MeV in 10 MeV steps Refine with 5 MeV interleaving steps to identify synchrotron satellites. 2 data-taking coasts for $<0.5\%$ lifetime accuracy each. Optional: add LER beam, observe resonance shift with LER intensity		

Experiment Run Plan Proposal

Step	Duration	Task	Expected Outcome		
	(d)				
1	1	Turn on Source and switching magnet • Turn on HV and laser and verify source produces e^- • Turn on switching magnet to correct polarity & STDZ. • Verify beam makes it through the switching magnet. • Steer beam on axis and towards linac entrance. Parameters are source HV and vertical steering. • Characterize beam sizes and charge. • Tune up if needed. • Verify polarization switch w/o beam property changes	Beam in transport line		
2	1	Accelerate electrons • Inject into Linac. Verify acceptance. • Measure and center timing curve. • Steer beam through linac as needed. • Once beam is through linac assess beam loss. • Tune up beam as required. • Ideally, only the launch conditions need tuning.	Beam at 7 GeV		
3	1	HER injection	Beam passes into HER and stores		
4a	0.5	• Standard injection tuning. - Prepare beam for measurements	Stored beam with desired intensity and bunch pattern		
4b	0.5	Initial beam lifetime measurement • Constant bunch current, vary total current • Constant total current, vary bunch current	verify time needed for $\leq 0.5\%$ lifetime data.		
			These are to separate Touschek from beam-gas scattering.		
		• I would want to take data for at least twice the minimum length			
		• Run half the ring with spin-up, half with spin-down and see if S-T time constant can be extracted.			
5	1	Ramp ring to lowest energy point (7000 MeV) • Procedure depends on how KEK does this.	Stored beam and lifetime after STDZ.		
6	4	Ramp ring in suitable steps • 10 steps in 10-MeV increments 10 to 7100 MeV to find resonance • 4 additional steps to id. synchrotron satellites.	measure lifetime at each step.		
7	5	Try assessing beam-beam effect on spin			
		Resonance scan with LER in collision	Look for movement of resonance		
		Resonance scan with LER without collisions	Look for absence of movement of resonance		
		Same with different LER bunch charge	Does any effect scale with LER intensity?		

Additional Slides

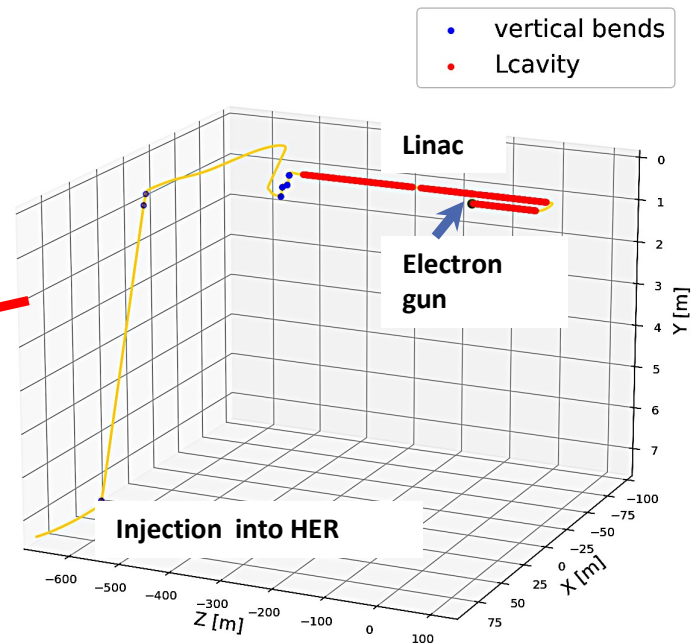
Touschek Polarization Lifetime Experiment

Proposing to put LTT studies to the test with data in a dedicated experiment with TRANSVERSE polarized beam to validate polarization lifetime

Inject transversely polarized beam at the HER injection point



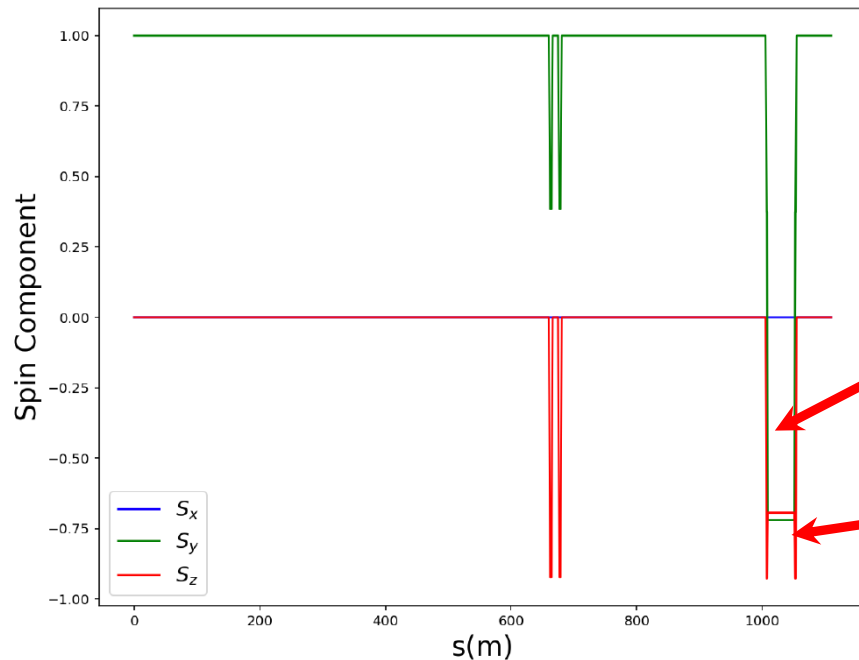
KEK Linac



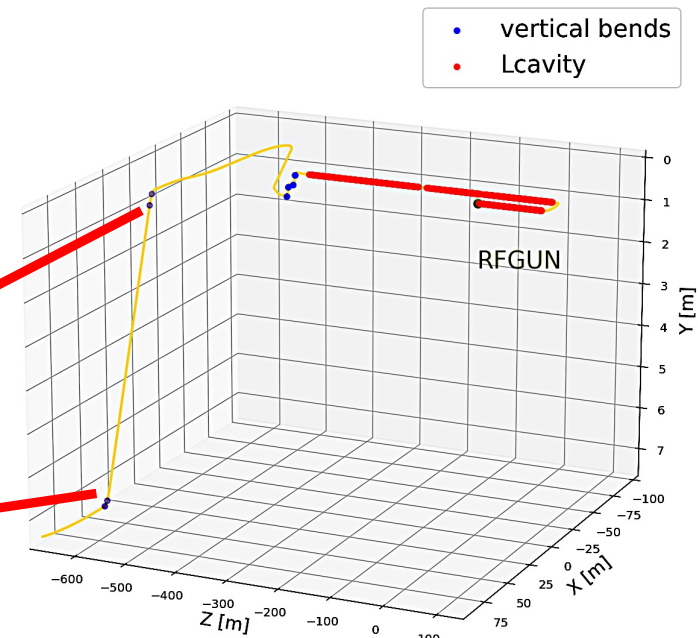
KEK Injection Linac polarization Bmad studies

Spin motion in the KEK Injection Linac

Y. Peng (UVic)



KEK Linac

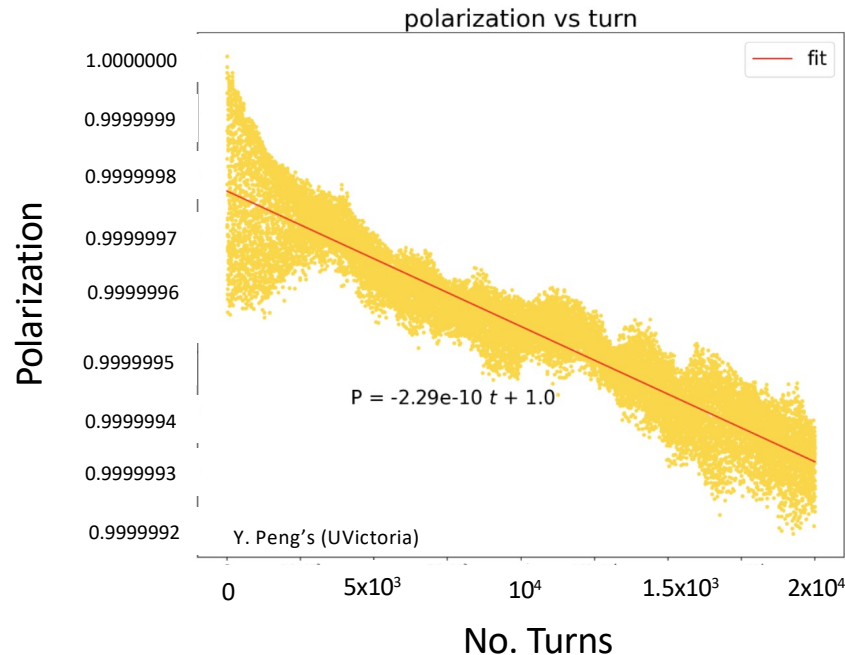


These spin tracking using BMAD show if the electron starts with vertical spin (0,1,0) at the source, after all the vertical beam motion, it will end up with a vertical spin at the injection point, as desired.

KEK Injection Linac polarization Bmad studies

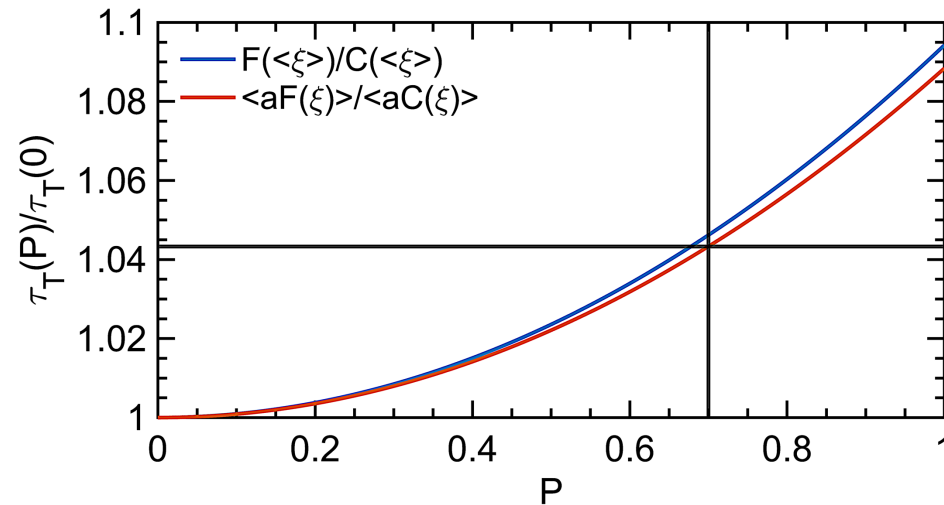
Inject transversely polarized beam at the HER injection point

Transverse polarization survival rate in HER



- Tracking 100 particles for 20000 turns in the HER with BMAD
- This study estimates polarization lifetime > 10 hours

Touschek Lifetime Dependence on e- polarization



For 70% polarization this is a ~4% effect assuming (overall) momentum acceptance of 0.6%

Touschek lifetime measurements already performed in HER with required precision

Touschek Lifetime Studies

from Andrii Natochii (BNL)

Belle II Background Group

Beam current as a function of beam lifetime

$$I = I_0 \times e^{-\frac{t}{\tau}}$$

lifetime →

Heuristic fit formula for beam losses

$$\frac{I}{\tau} = -\frac{dI}{dt} = B \times I \bar{P}_{\text{eff.}} + T \times \frac{I^2}{n_b \sigma_x \sigma_y \sigma_z}$$

ring average effective residual gas pressure seen by the beam → B

→ I *# of bunches in the ring*

→ $\sigma_x \sigma_y \sigma_z$ *bunch volume*

Heuristic fit formula

Bunch length

[H.Ikeda, KEK, private communication (2021)]

$$\left\{ \begin{array}{l} \sigma_z^{\text{LER}} [\text{mm}] = 5.4466 + 1.7642 \times \frac{I^{\text{LER}} [\text{mA}]}{n_b^{\text{LER}}} \\ \sigma_z^{\text{HER}} [\text{mm}] = 6.0211 + 1.3711 \times \frac{I^{\text{HER}} [\text{mA}]}{n_b^{\text{HER}}} \end{array} \right.$$

More information in <https://arxiv.org/pdf/2302.01566>

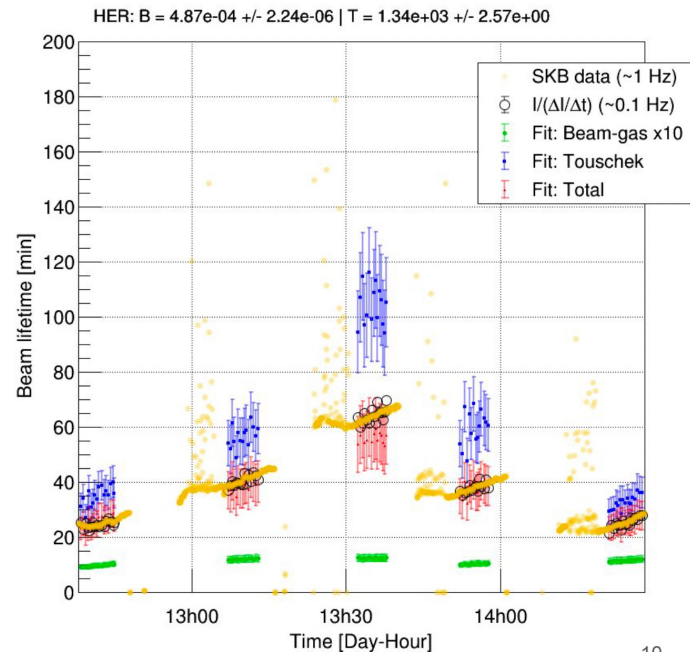
See also: Qingyuan Liu presentation at eeFACT2025 : “SuperKEKB/Belle II background studies update”

Touschek Lifetime Studies

from Andrii Natochii (BNL)

Example of data and results of
heuristic fit for HER

Beam lifetime estimation for June 2020



Period	Experimental HER Touschek Lifetime (minutes) at a current of 1.0 A	Ratio of Experimental to SAD Simulation lifetimes
May 2020	37.929 ± 0.057 (0.15%)	0.642 ± 0.002
June 2020	33.656 ± 0.064 (0.19%)	0.746 ± 0.005
June 2021	27.93 ± 0.10 (0.36%)	0.601 ± 0.003
December 2021	24.107 ± 0.079 (0.33%)	0.519 ± 0.002

The Touschek Lifetime in the HER has been measured at the few per-mil level (statistical) – sufficient for seeing changes in lifetime from polarization effects, which are at the 4% level