

PHASE 2 RESULTS OF LUMIBELLE2 FOR THE SUPERKEKB ELECTRON RING



LumiBelle²

Luminosity Monitoring for Belle II

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SuperKEKB

SuperKEKB is an asymmetric-energy and double-ring electron-positron collider.

It is the upgrade of KEKB with a luminosity 40 times larger than its predecessor.

FIGURES OF MERIT:

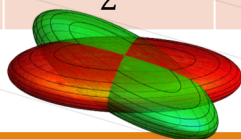
- $E_{e^+} = 4 \text{ GeV}$
- $E_{e^-} = 7 \text{ GeV}$
- $L = 8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

UPGRADES:

- Nano-beam scheme
- Doubled currents

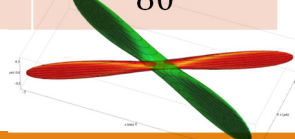
<i>LER(e⁺)</i> <i>HER(e⁻)</i>	KEKB		SuperKEKB Phase 2.1		SuperKEKB Phase 2.2		SuperKEKB Phase 2.3		SuperKEKB Phase 2.4		SuperKEKB Phase 3.0	
	<i>LER</i>	<i>HER</i>	<i>LER</i>	<i>HER</i>	<i>LER</i>	<i>HER</i>	<i>LER</i>	<i>HER</i>	<i>LER</i>	<i>HER</i>	<i>LER</i>	<i>HER</i>
$\sigma_x^* (\mu\text{m})$	103	116	20	30	23.2	30.3	16.4	21.4	16.4	21.4	10.1	10.7
$\sigma_y^* (\text{nm})$	1900	1900	1300	1920	476	743	252	393	126	197	48	62
$I (\text{mA})$	1637	1188	250	220	1000	800	1000	800	1000	800	3600	2600
$L (10^{34} \text{ cm}^{-2} \text{ s}^{-1})$	2		0.1		1		2		4		80	

$$\phi_{\text{cross}} = 11 \text{ mrad}$$



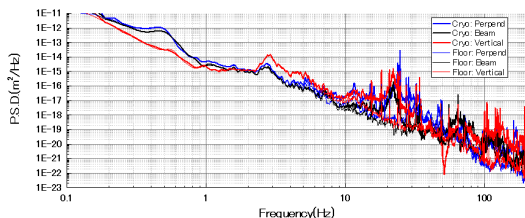
CURRENT
PHASE

$$\phi_{\text{cross}} = 41.5 \text{ mrad}$$



Fast luminosity monitoring at SuperKEKB

- Horizontal drifts and vibrations of the beams can cause a significant luminosity degradation;



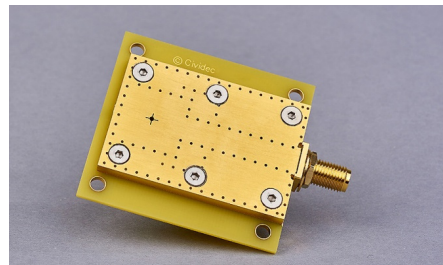
- A dithering feedback system is used to monitor and control the horizontal position of the beams;



- Fast luminosity monitoring is required for the dithering feedback system;
- Forward radiative Bhabha events have a very large cross section ($\sigma \approx 150 \text{ mbarn}$);
- The rate of Bhabha events is proportional to the luminosity;

$$dN/dt = \sigma L$$

- LumiBelle2 is a fast luminosity monitor that measures Bhabha events using diamond sensors.**



Beam H-V offset and luminosity degradation

HORIZONTAL OFFSET FEEDBACK

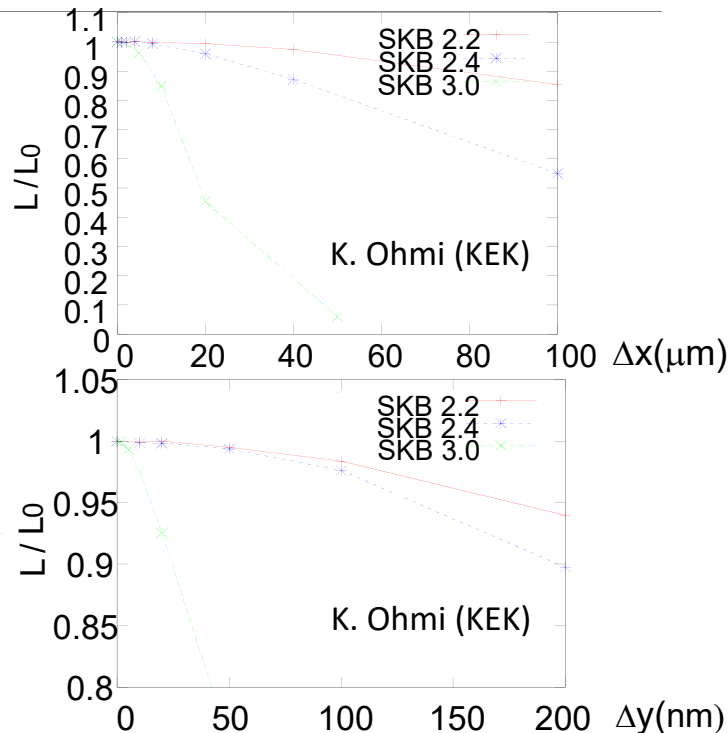
- Dithering system inherited from PEP-II;
- 8 sets of coils (H/V) on LER, dithering at $f=77$ Hz, max horizontal bump $5\sigma_x^*$;
- Fast luminosity monitors (LumiBelle2, ZDLM), 1 kHz;
- Lock-in amplifier to extract luminosity components at f , $2f$;

VERTICAL OFFSET FEEDBACK

- 4 beam position monitors (BPMs) at 51 cm from the IP in HER/LER, 32 kHz;
- 4 electrodes for each BPM at 10.5 mm from orbit;
- 25 Hz vibration $\rightarrow \Delta y = 18.6\text{nm}$ (rms) $\rightarrow$ luminosity drop 4.6%;

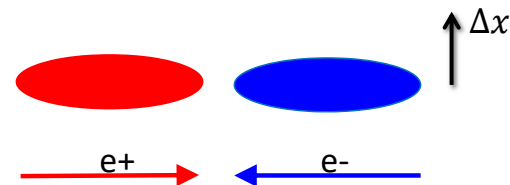
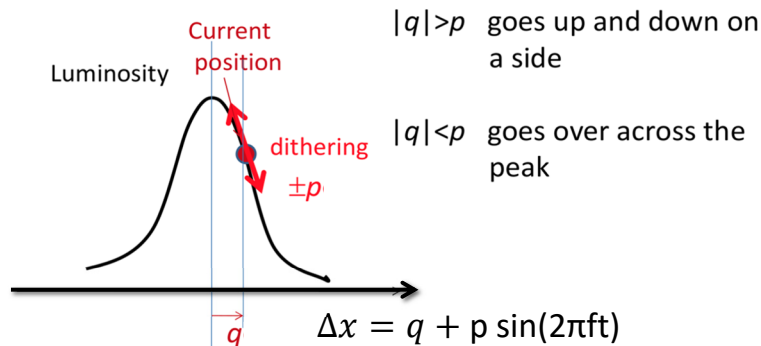
OFFSET CORRECTION (H: 1 Hz; V: 100 Hz)

- 12 corrector magnets (8V, 4H) on HER with max kick $50\text{ }\mu\text{rad}$;
- Ultimate goal: suppression of luminosity loss to below 1% in both H and V.

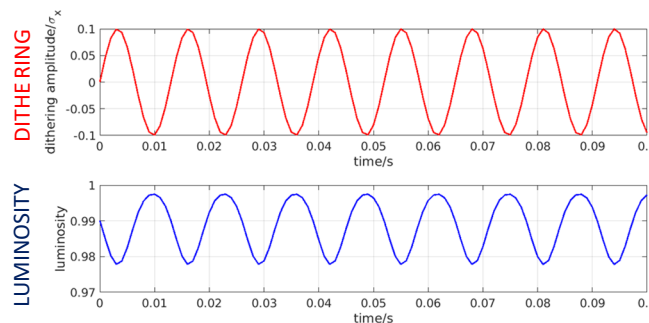


Dithering feedback system

- The dithering system makes one beam to oscillate around its orbit as $\Delta x_{dith} = p \sin(2\pi ft)$ with frequency $f = 77\text{Hz}$;
- Luminosity oscillates and Fourier components give information about the relative position of the beams;
- If $|q| > p$ FT peaks at $2f$, if $|q| < p$ FT peaks at f ;
- Relative phase dithering-luminosity gives sign of Δx ;



$$L(t) = \frac{f_{rev} N_1 N_2}{4\pi\sigma_x\sigma_y} e^{-\left(\frac{[q + p\sin(2\pi ft)]^2}{4}\right)}$$



Luminosity monitoring: two complementary techniques

LumiBelle2

Both measure photons, recoiling electrons or positrons from the extremely forward-angle radiative Bhabha scattering, which has a very large cross section ($\sigma \approx 150 \text{ mbarn}$).

- Single crystal CVD diamond sensors;
- $4 \times 4 \times 0.5/0.14 \text{ mm}^3$;
- Fast charge/current amplifiers;
- Digital electronics.



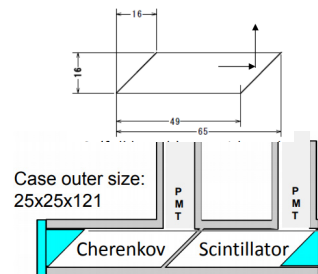
HER



LER

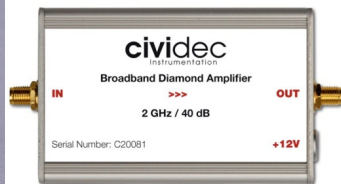
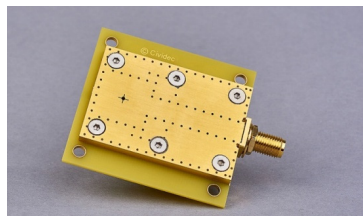
ZDLM (Zero Degree Luminosity Monitor)

- Cherenkov and scintillator detectors;
- Photomultipliers;
- $15 \times 15 \times 64 \text{ mm}^3$ LGSO non-organic scintillator and ES-crystal (quartz);
- Analog electronics;



Diamonds sensors and amplifiers

- Wide band-gap (5.5 eV) semiconductor devices;
- Strong atomic bond (radiation resistant);
- Radiation damage above $\approx 1\text{MGy}$;
- High drift velocity (fast detector).

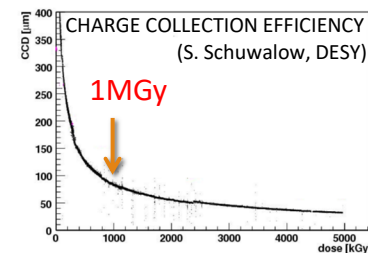
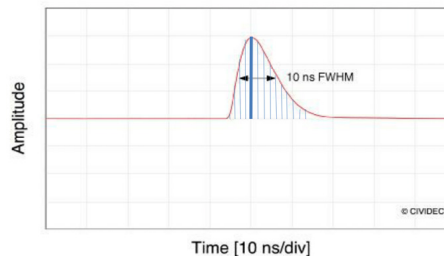


SUPERKEKB COLLISION PERIOD = 4ns

140/500 μm diamond + CURRENT/CHARGE AMPLIFIER:

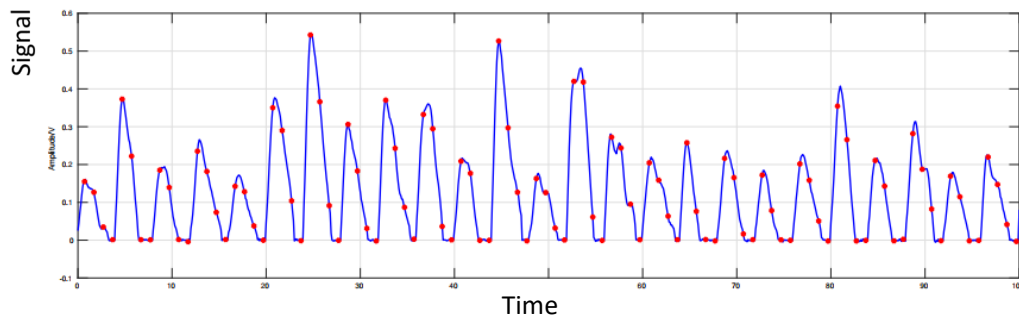
- Shaping time: 4/10 ns
- Threshold: 10/5 mV

	CVD Diamond	Potential device application benefit
Bandgap (eV)	5.47	High temperature
Breakdown field (MVcm ⁻¹)	10	High voltage
Electron saturation velocity (x10 ⁷ cm s ⁻¹)	2	High frequency
Hole saturation velocity (x10 ⁷ cm s ⁻¹)	0.8	
Electron mobility (cm ² V ⁻¹ s ⁻¹)	4500	
Hole mobility (cm ² V ⁻¹ s ⁻¹)	3800	
Thermal conductivity (Wcm ⁻¹ K ⁻¹)	24	High power



Signal processing algorithms

Sampling on the signal sequences at 1GHz:



• **TIL:**

if $S[(i-1) \times 2 + 1] - S[(i-1) \times 2 + 3] > threshold$:

TIL += $S[(i-1) \times 2 + 1] - S[(i-1) \times 2 + 4]$

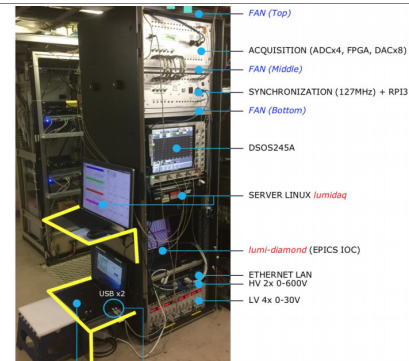
• **Rawsum:**

if $S(j) > threshold$:

Rawsum += $S(j)$

No trigger + Synchronization -----> Continuous monitoring, averaging at 1 kHz

TIL and **Rawsum** represent different ways to calculate the luminosity from the measured signal .

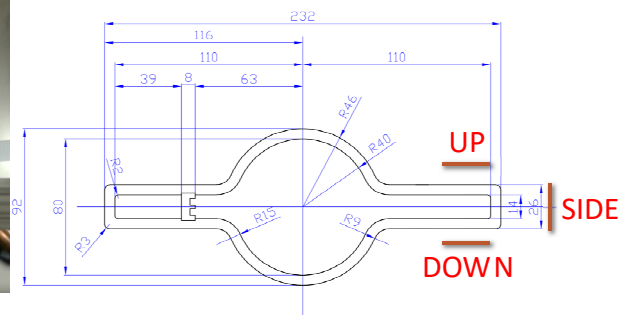
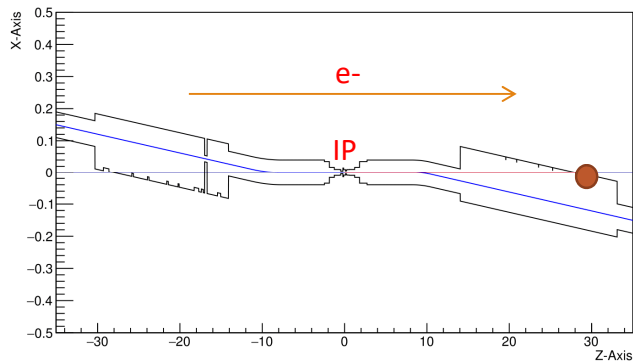


HER (electron) side experimental setup

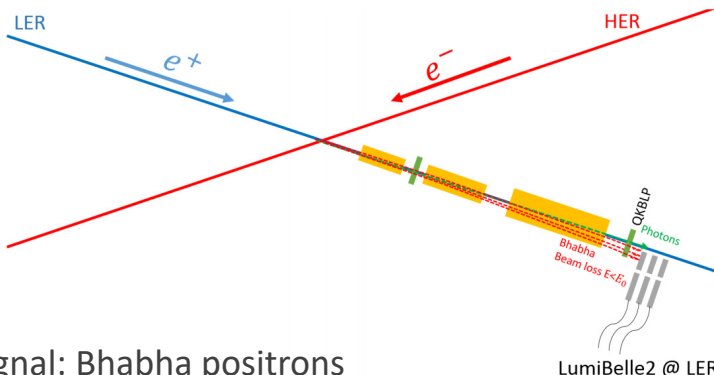
- Signal: Bhabha photons
- Background: Bremsstrahlung photons, Touschek electrons
- Platform: 30.5-30.8 m downstream of IP
- 3 sensors: up, down, side



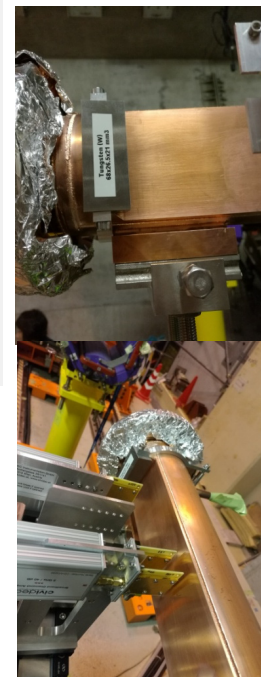
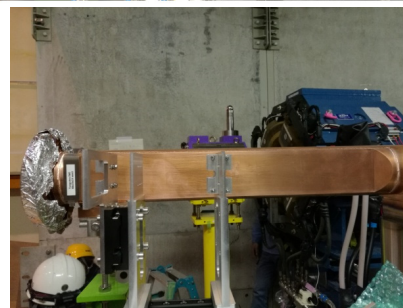
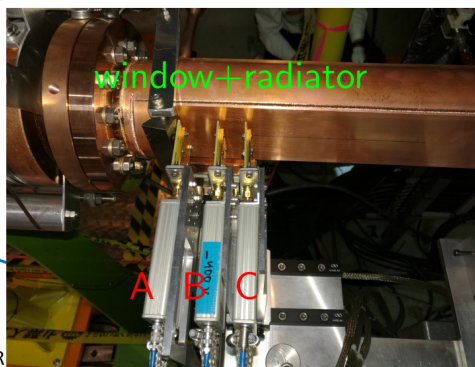
HER beam pipe



LER (positron) side experimental setup



- Signal: Bhabha positrons
- Background: Bremsstrahlung positrons, Touschek positrons
- Platform: 11 m downstream of IP
- 3 sensors aligned
- Special beam pipe with window + radiator



Background sources

Coulomb scattering:

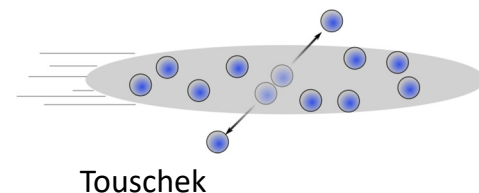
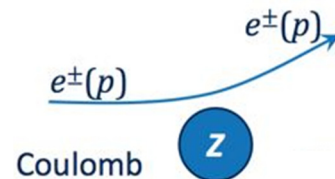
- Proportional to vacuum pressure and beam current;
- Important globally but negligible rate at LumiBelle2;

Bremsstrahlung scattering:

- Proportional to vacuum pressure and beam current;
- Largest source of background for LumiBelle2 in phase 2;
- Photons measured on HER (e-) side;
- Positrons measured on LER (e+) side;

Touschek scattering:

- Proportional to square of beam current;
- Inversely proportional to beam size;
- Sizable rate in LER LumiBelle2 for Phase 2.



Background measurements (HER)

A-B (current-rate vs time):

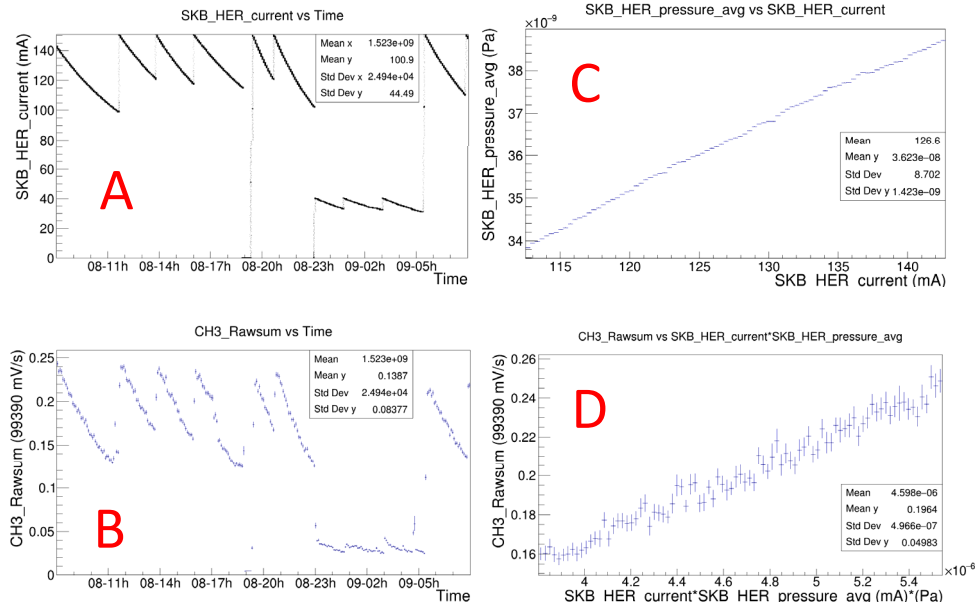
- Rate (B) well correlated with SKB current (A);
- Rate is due to beam background.

C (pressure vs current):

- Pressure proportional to current;
- Gas desorption due to SR.

D (rate vs pressure X current):

- Rate proportional to $I \times P$;
- Background from beam-gas scattering.



Comparison with simulation

SIMULATION FEATURES:

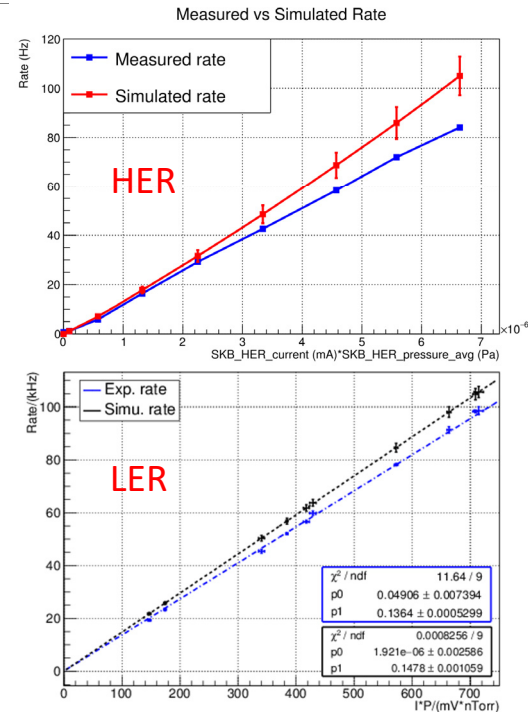
- Bremsstrahlung, Coulomb, and Touschek scattering;
- Detailed simulation of pressure profile and chemical composition of vacuum gas ($Z_{eff} \approx 4.2 - 4.5$).
J. Carter (ANL) and M. Ady (CERN);

HER:

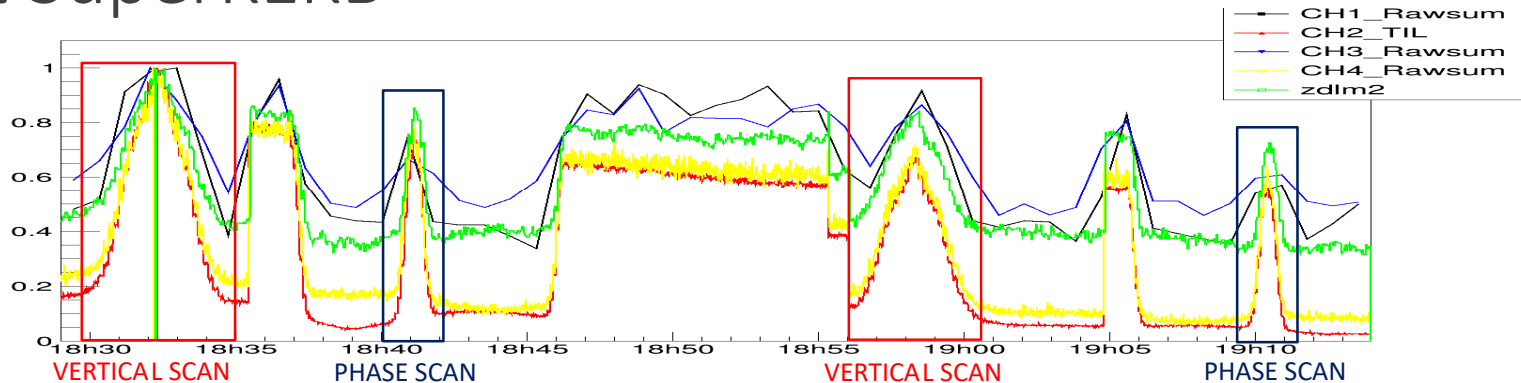
- The only significant rate comes from Bremsstrahlung photons;
- Electron rates from Bremsstrahlung, Coulomb, and Touschek are negligible ($\ll 1\text{Hz}$);

LER:

- The most significant rate comes from Bremsstrahlung positrons;
- 10% of the rate from Touschek effect;
- Positron rate from Coulomb scattering is negligible;



First luminosity measurements at SuperKEKB



- First Bhabha events measured on April 25, 2018;
- Vertical and phase (longitudinal) scans were performed to find the optimal position of the beams;
- Estimations of luminosity: $L_{HER} \approx 8 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$; $L_{LER} \approx 9 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$;
 $L_{ZDLM} \approx 7 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$ -----> $L \approx (8 \pm 2) \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$;
- The plot and the estimated luminosities show that our 4 detectors and the ZDLM work well and are in agreement.

LumiBelle2 precision/dose and luminosity

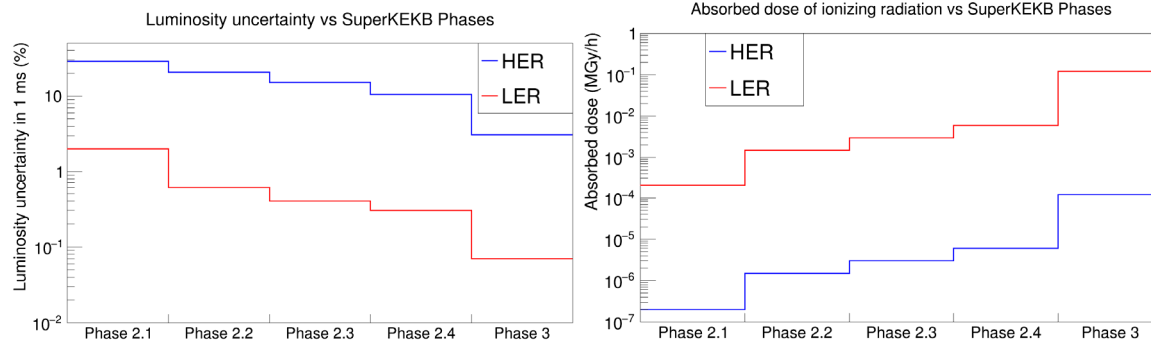
HER:

- Initially low precision
- Low dose

LER:

- High precision
- High dose in Phase 3

- We need both HER and LER to cover the whole range of SKB luminosities;
- Expected Signal/Background ratio 2-100 depending on L;
- HER precision can be improved by using larger diamonds;
- LER can be moved to receive a lower dose;
- Recent study shows 1% level precision enough for horizontal IP orbit feedback with dithering technique.



Phase	Luminosity	$\Delta L/L$ HER/LER (%)	Dose HER/LER (Mgy/h)
Phase 2.1	$1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$	29/2	2e-7/2e-4
Phase 2.2	$1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	21/0.6	1.5e-6/1.5e-3
Phase 2.3	$2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	15/0.4	3e-6/3e-3
Phase 2.4	$4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	11/0.3	6e-6/6e-3
Phase 3	$8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$	3/0.07	1.2e-4/0.12

Conclusion

- Presented project goals, experimental setup, measurements, simulation, for the fast luminosity monitor LumiBelle2 at SuperKEKB;
- Reported on the first operations of LumiBelle2 during the early stages of Phase 2 commissioning;
- LumiBelle2 monitor works as expected. We have shown measurements of single beam background and luminosity;
- Simulation shows reasonable agreement with the measurements. Background is produced by Bremsstrahlung, while other sources of background are smaller/negligible. Validated predictions for precision and S/N;
- The first collisions show that all of our 4 detectors and the ZDLM can measure the luminosity and are in agreement with each other.

Thank you

PLEASE CHECK OUT OUR OTHER CONTRIBUTIONS

- “Luminosity monitoring for IP orbit feedback system at superkekb”. C.Pang, P. Bambade, S. Di Carlo, D. Jehanno, V. Kubytskyi, Y. Peinaud, C. Rimbault (LAL, orsay), Y. Funakoshi, S. Uehara (KEK, ibaraki) **WEPAL038**
- “Simulation study on luminosity feedback for horizontal beam stabilization at superkekb”. C. Pang, P. Bambade (LAL, orsay), Y. Funakoshi, S. Uehara (KEK, ibaraki) **WEPAL037**