STATUS OF LUMIBELLE2 LUMINOSITY MONITOR

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Task 2.4: Luminosity Monitor [CNRS, KEK]

LumiBelle2
Luminosity Monitoring for Belle II

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Luminosity monitoring:
two complementary techniques

LumiBelle2
Luminosity Monitoring for Belle II

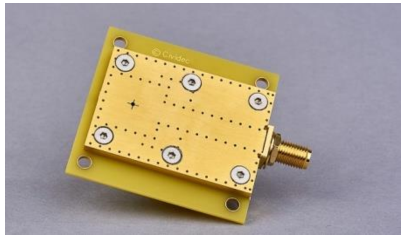
LumiBelle2 | **ZDLM (Zero Degree Luminosity Monitor)**

Both measure photons, recoiling electrons or positrons from the extremely forward-angle radiative Bhabha scattering, which has a large cross section ($\sigma \approx 200\ mbarn$).

LumiBelle2

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

LER



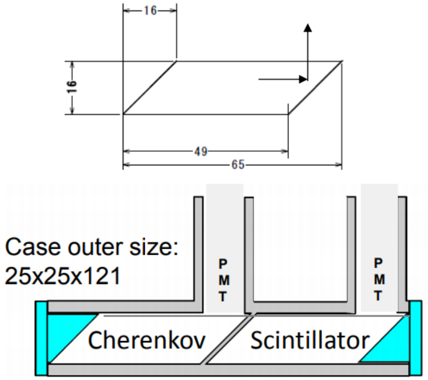
GOALS:

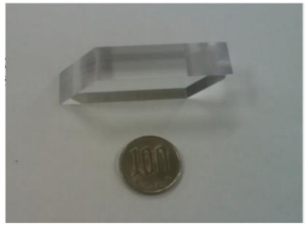
- TIL (Train Integrated Luminosity): 1% relative precision at 1kHz;
- BIL (Bunch Integrated Luminosity): monitoring with 1 % precision at 1 Hz;
- Large dynamic range with high SNR :

$L = 10^{32} - 10^{36} cm^{-2} s^{-1}$

ZDLM (Zero Degree Luminosity Monitor)

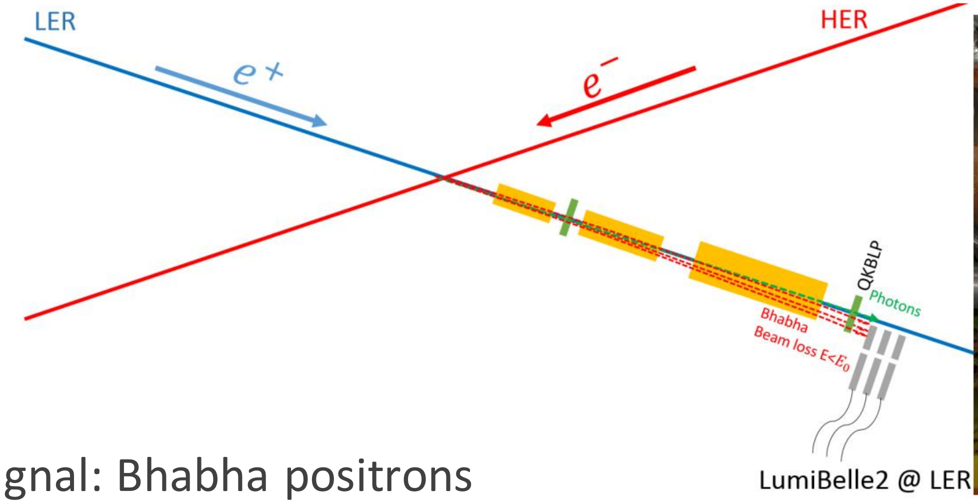
- Cherenkov and scintillator detectors;
- $15 \times 15 \times 64\ mm^3$ ES-crystal (quartz) and LGSO non-organic scintillator ;
- Photomultipliers;
- Analog electronics;

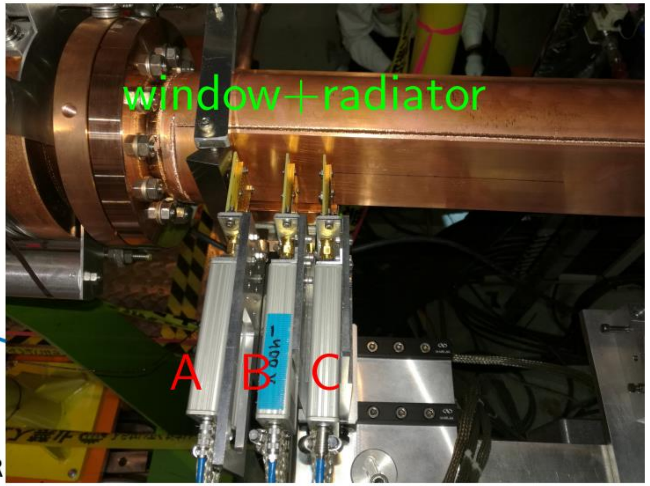


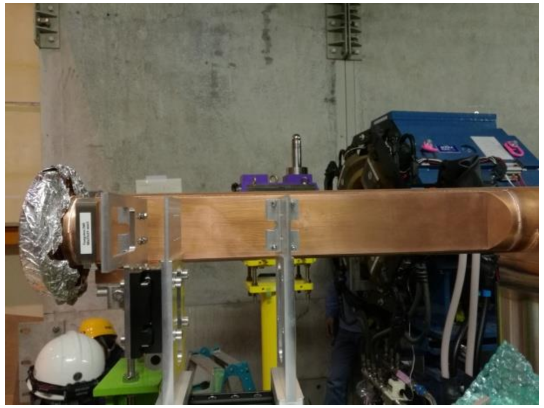


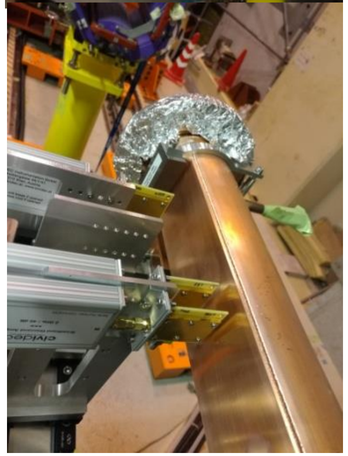
LER (positron) side experimental setup

LumiBelle2
Luminosity Monitoring for Belle II







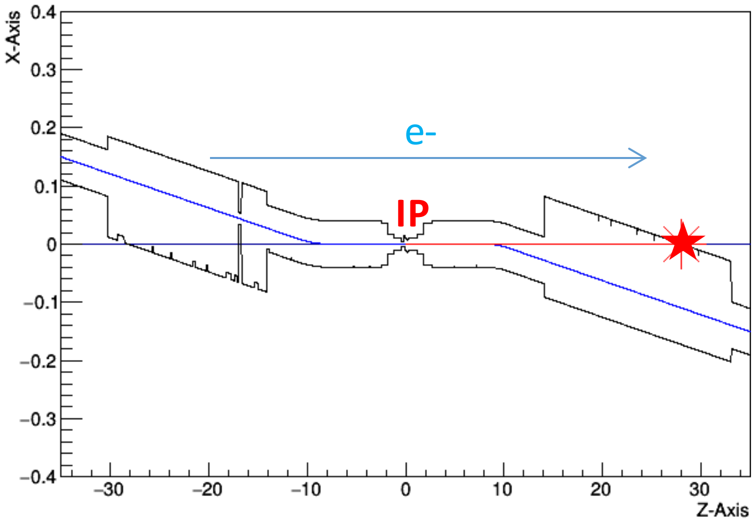


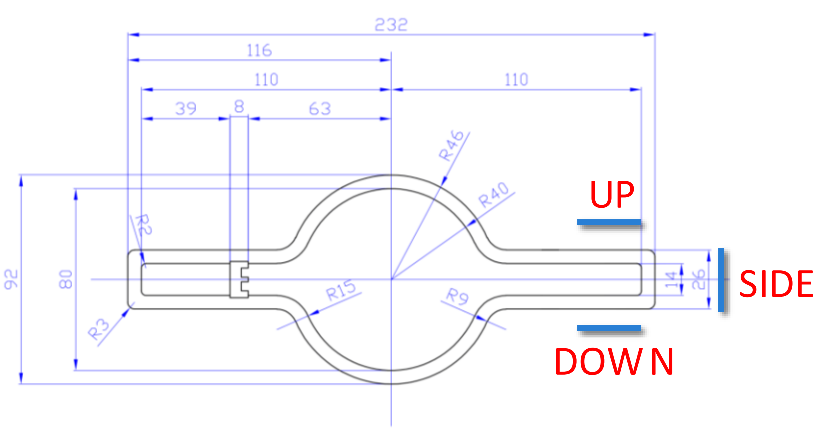
- Signal: Bhabha positrons
- Background: Bremsstrahlung positrons, Touschek positrons
- Platform: 11 m downstream of IP
- 3 sensors aligned
- Special beam pipe with window + radiator

HER (electron) side experimental setup

LumiBelle2 – Luminosity Monitoring for Belle II

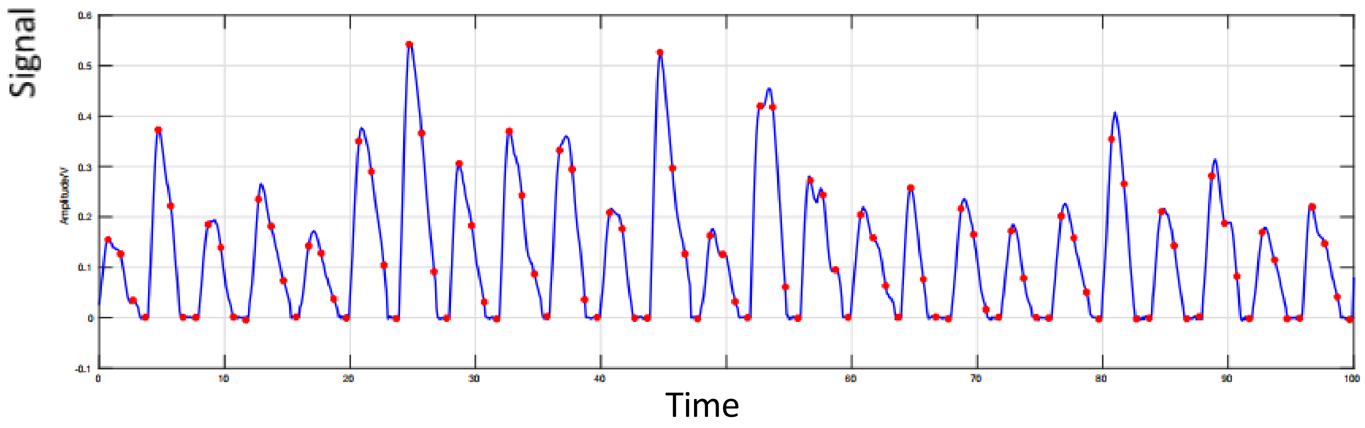
- Signal: Bhabha photons
- Background: Bremsstrahlung photons, Touschek electrons
- Platform: 30.5-30.8 m downstream of IP
- 3 sensors: up, down, side

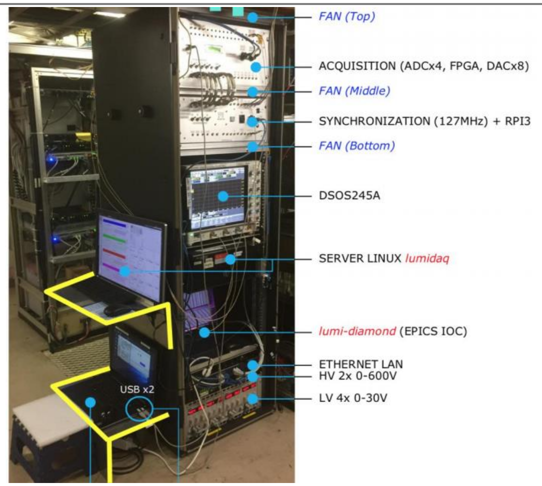




Signal processing algorithms

Sampling on the signal sequences at 1GHz:





- TIL:

if $S[(i-1)\times 2+1] - S[(i-1)\times 2+4] > threshold$:

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

- RAWSUM:

if $S(j) > threshold$:

  Rawsum $\mathrel{+}= S(j)$

- TIL and RAWSUM represent different ways to calculate the luminosity from the measured signal .
- No trigger + Synchronization -----> Continuous monitoring, averaging at 1 kHz.
- EPICS PV with measured luminosity are continuously provided to the SuperKEKB control room.

Background study

SIMULATION FEATURES:

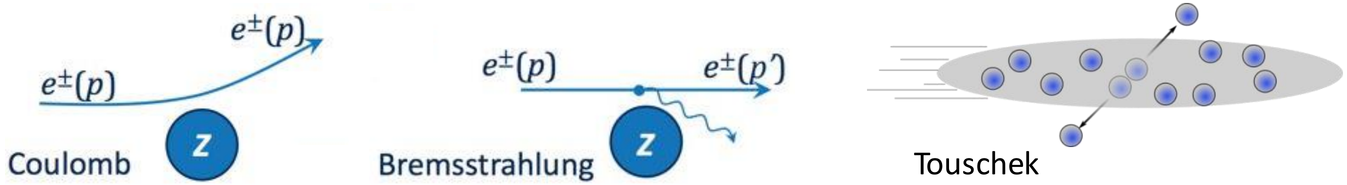
- Bremsstrahlung, Coulomb, and Touschek scattering;
- Detailed simulation of pressure profile and chemical composition of vacuum gas ($Z_{eff} \approx 4.2 - 4.5$). J. Carter (ANL) and M. Ady (CERN);

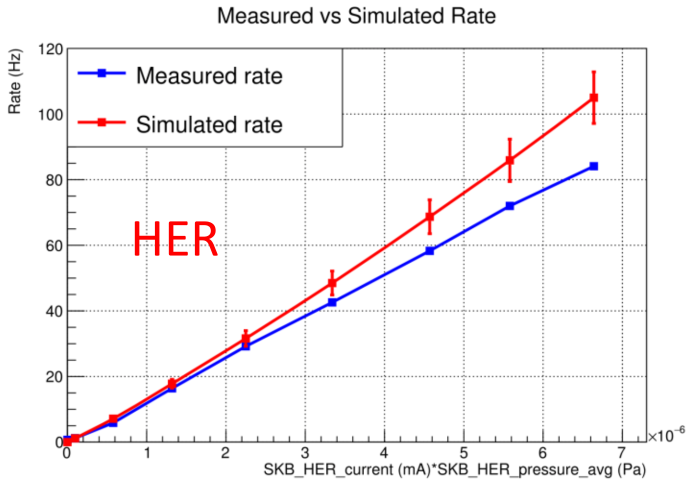
HER:

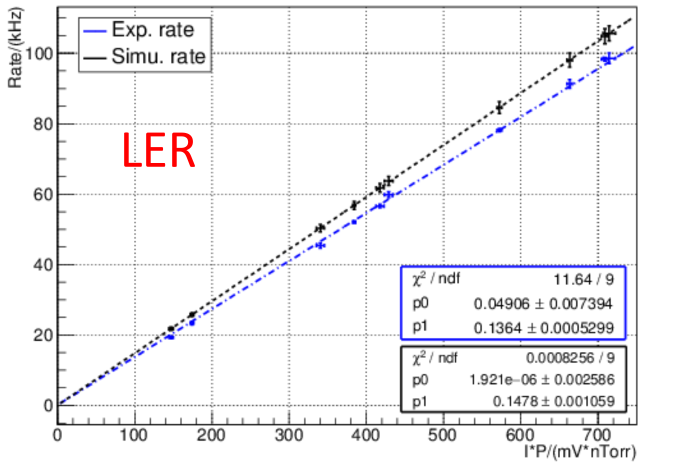
- The only significant rate comes from Bremsstrahlung photons;
- Electron rates from Bremsstrahlung, Coulomb, and Touschek are negligible($\ll 1Hz$);

LER:

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

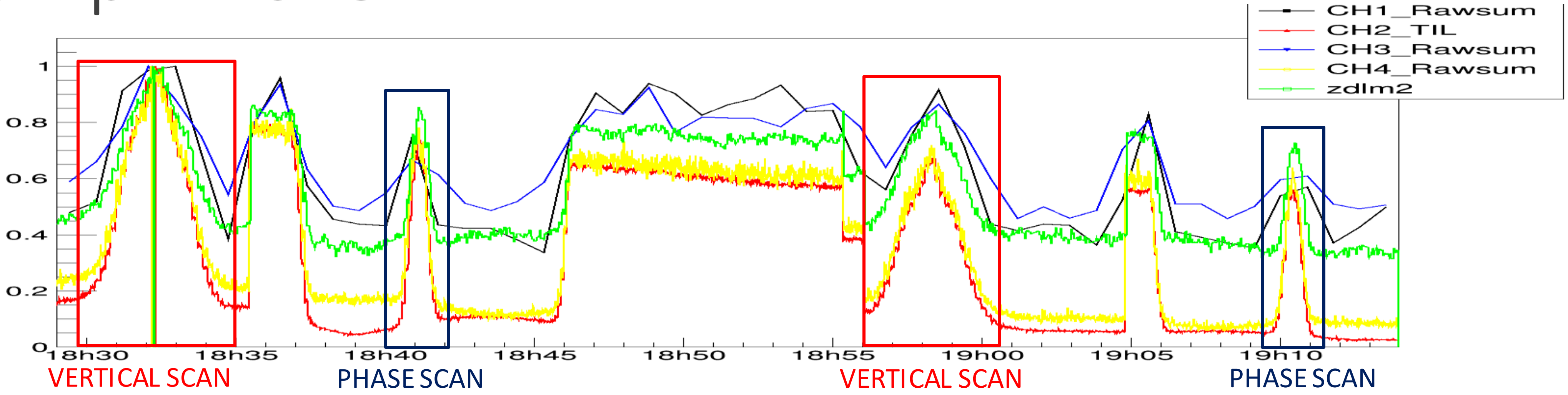






First luminosity measurements 25 April 2018

LumiBelle2
Luminosity Monitoring for Belle II



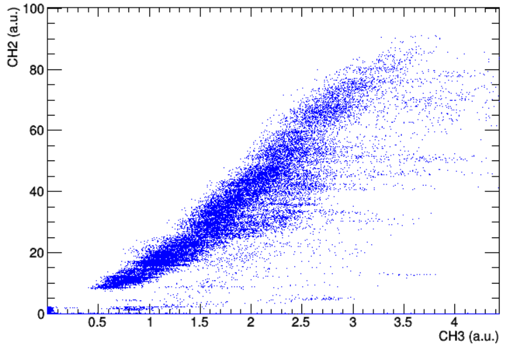
- First Bhabha events measured on April 25, 2018;
- Vertical and phase (longitudinal) scans were performed to find the optimal position of the beams;
- The 4 detectors LumiBelle2 and the ZDLM work well and are in agreement;
- We successfully measured and provided the luminosity from the first collision to the end of Phase 2 (July 18, 2018).

Correlation with other monitors: ZDLM and ECL

LumiBelle2
Luminosity Monitoring for Belle II

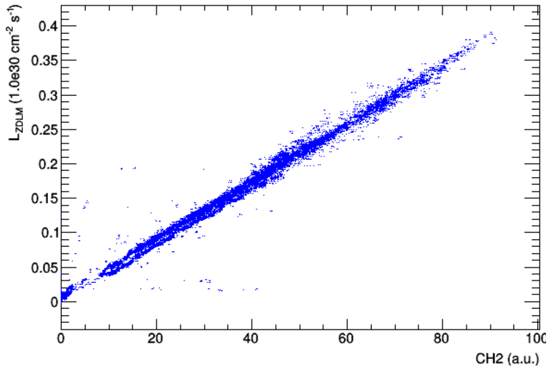
- We observe good correlation between our channels and with other luminosity monitoring devices on a day-by-day basis or shorter time scale;
- Long term variations in SNR and relative sensitivities are seen and can be explained by changes in beam conditions and changes in our setups in terms gains, position of the sensors, thresholds, etc.

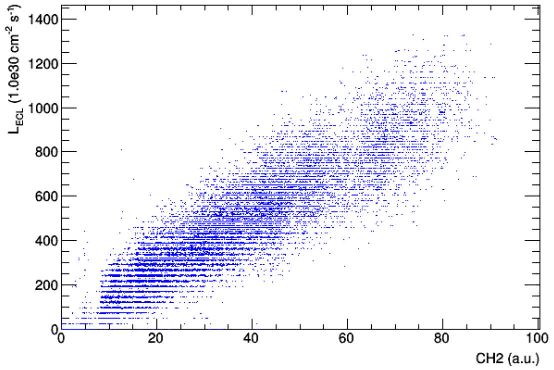
LB2: LER vs HER



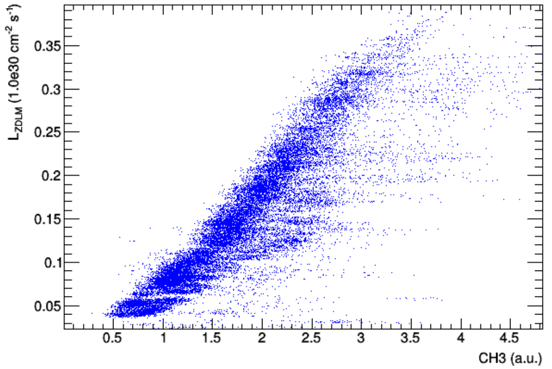
ZDLM | **ECL**

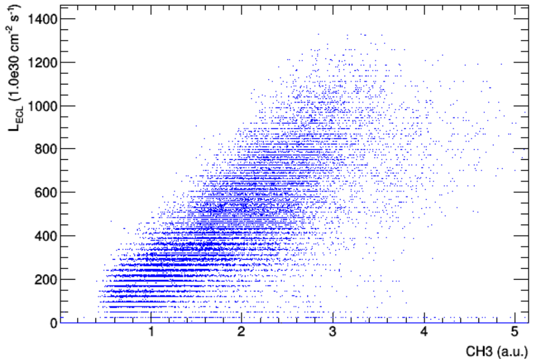
LB2 LER





LB2 HER



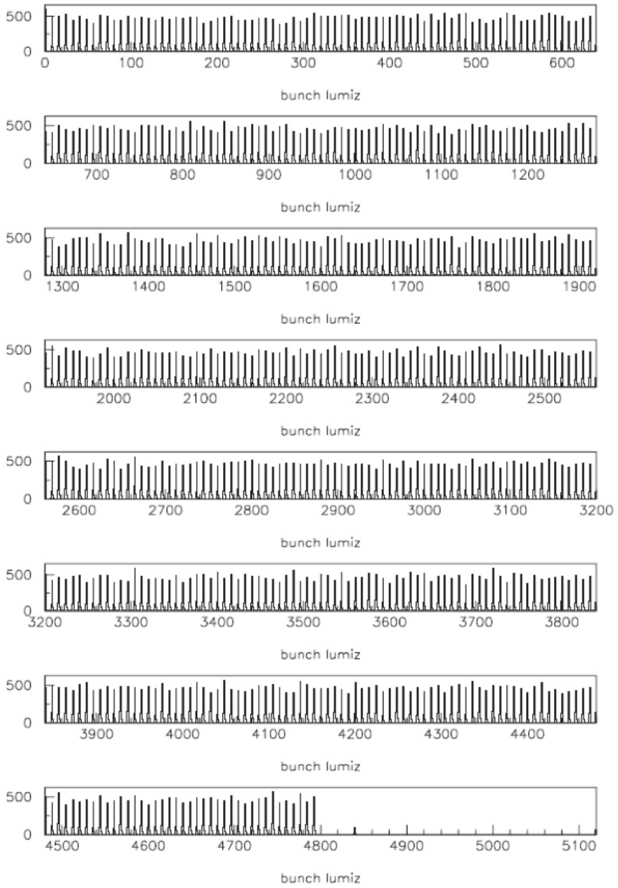


LumiBelle2

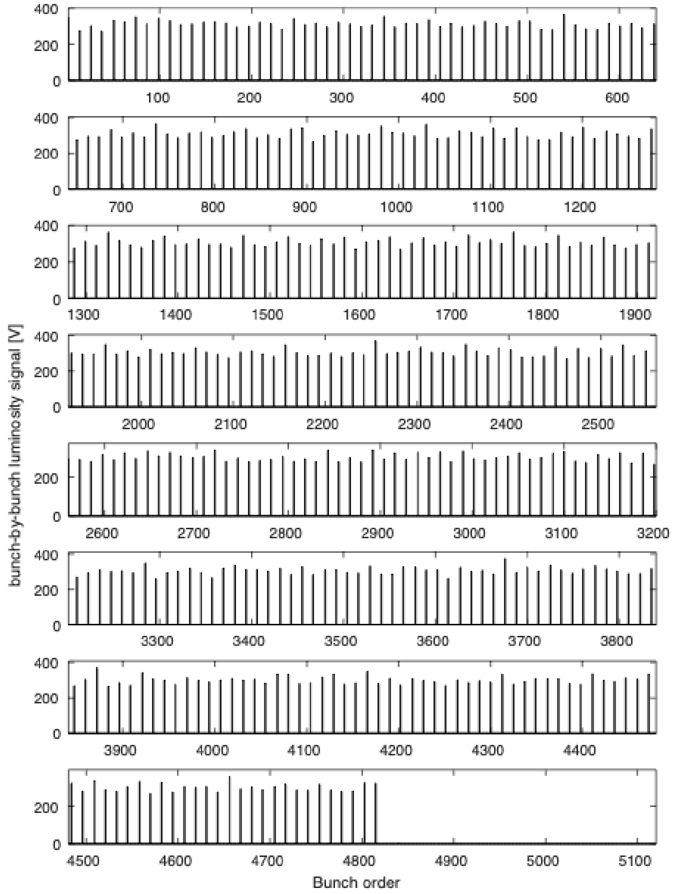
Luminosity Monitoring for Belle II

Bunch-by-bunch luminosity

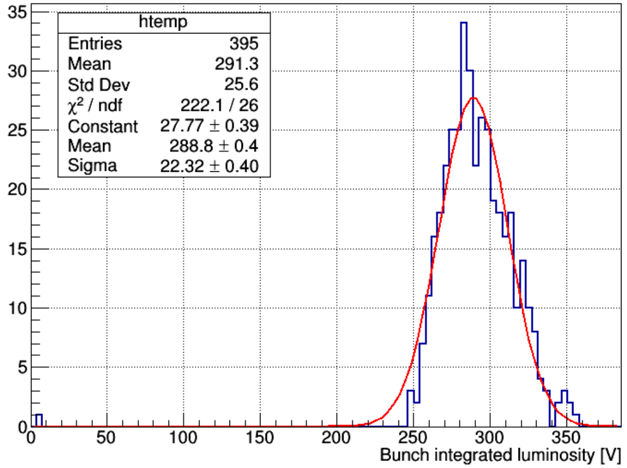
ZDLM



LumiBelle2



8% spread in bunch luminosities



- Bunch-by-bunch luminosity signals @1Hz are available through EPICS PV;
- Bunch luminosity precision: 1-2%;
- 8% spread mainly depends on bunch current differences;
- Online display in SKB control room.

Beam size estimation through vertical scans

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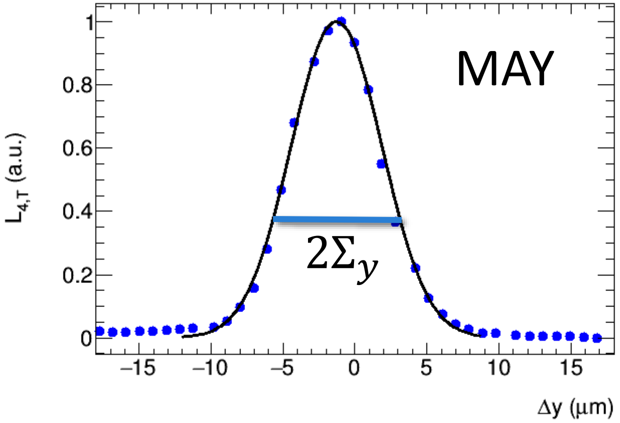
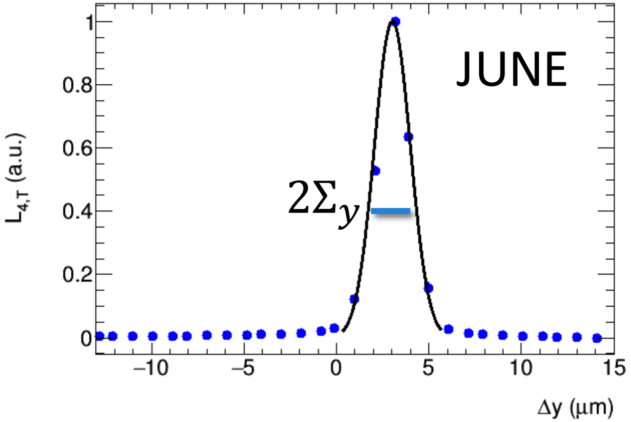
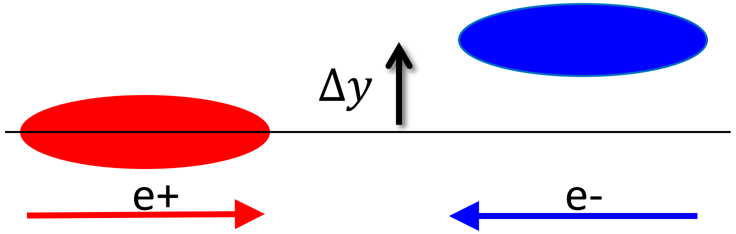
Luminosity Monitoring for Belle II







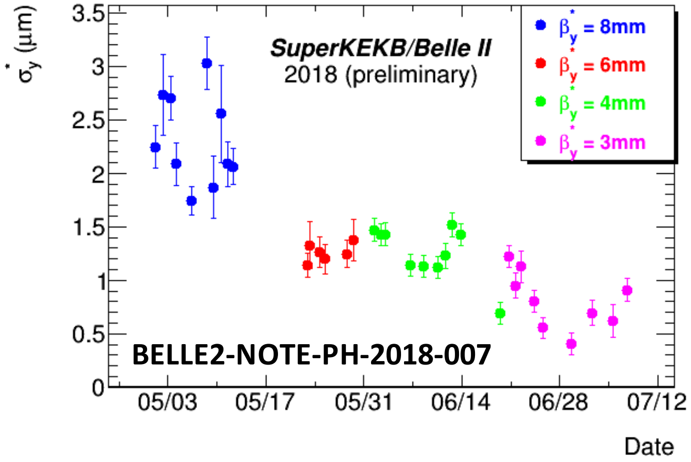
Simple geometrical result obtained integrating Gaussian distributions with vertical offset

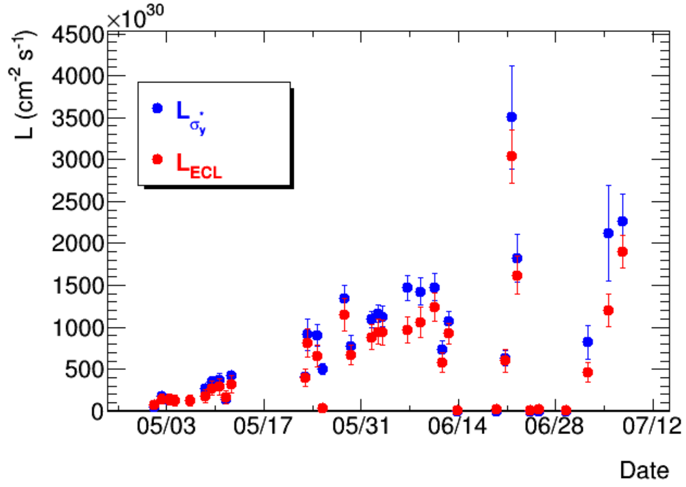
$$\frac{L}{L_0} = exp\left(-\frac{\Delta y^2}{2\Sigma_y^2}\right)$$

$$\Sigma_y^2 = \sigma_{1,y}^2 + \sigma_{2,y}^2 \approx 2\sigma_y^2$$

$$L_0 = \frac{fN_+N_-}{4\pi\sigma_{x,eff}^*\sigma_y^*} \xrightarrow{\quad L_{\sigma_y^*}\quad}$$

$$\sigma_{x,eff}^* \approx \sigma_z\theta_{cross} = 224\mu m$$



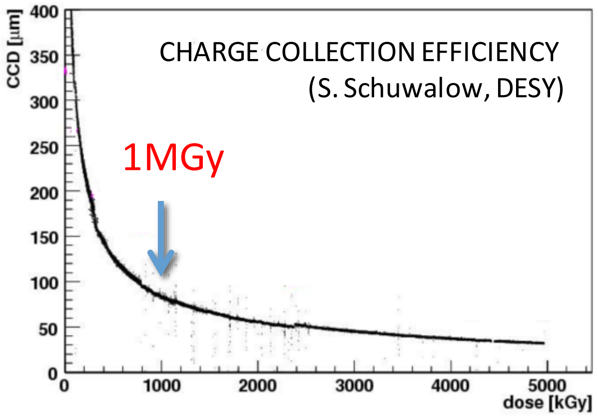


LumiBelle2 precision/dose and luminosity

LumiBelle2 Luminosity Monitoring for Belle II

HER:
- Initially low precision;
- Position change in Phase 3.
- Low dose expected in Phase 3;

LER:
- High precision;
- Noise issue in Phase 2;
- Potential high dose issue in Phase 3.



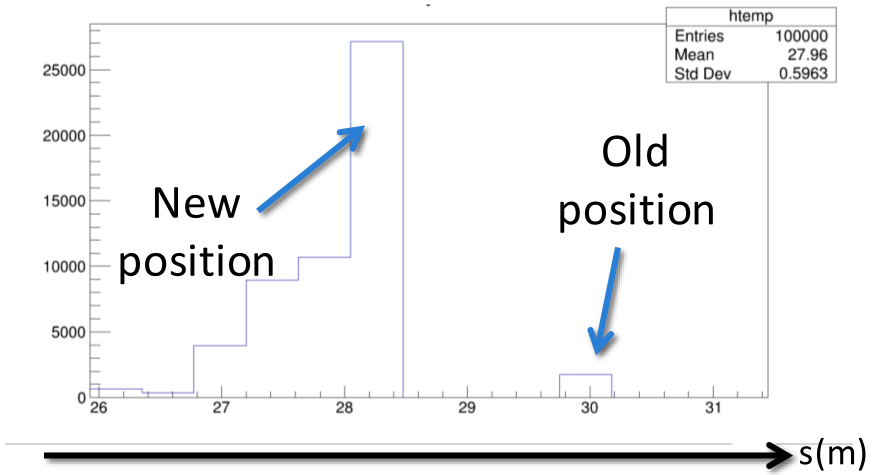
- We need both HER and LER to cover the whole range of SKB luminosities (10^{32} => 10^{36}) and cope with the accumulated dose and any unexpected issues (noise,…);
- HER precision will be improved by changing the position of the diamond sensors;
- LER diamond is motorized and can be moved to receive a lower dose;
- Simulation study shows that 1% level precision is enough for horizontal IP orbit feedback with dithering technique;
- Fraction of cross section intercepted is 1%/0.001% for LER/HER.

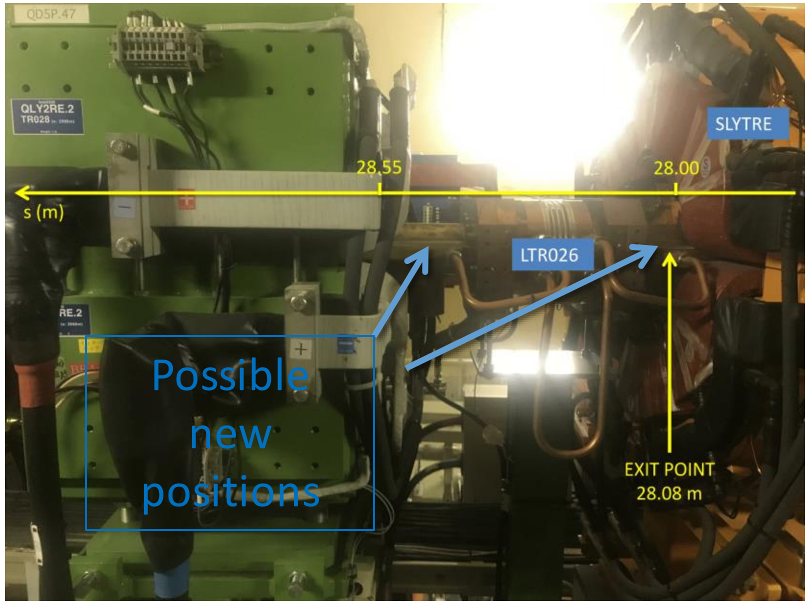
	Phase	Luminosity	ΔL/L % 1ms HER/LER	Dose (Mgy/h) HER/LER
Experimental	Phase 2	$2 \times 10^{33} cm^{-2} s^{-1}$	60/2	4e-7/4e-4
Prediction	Phase 3	$1 \times 10^{34} cm^{-2} s^{-1}$	30/1	2e-6/2e-3
Prediction	Phase 3	$8 \times 10^{35} cm^{-2} s^{-1}$	3/0.1	1e-4/0.1

HER Phase 3 update

LumiBelle2
Luminosity Monitoring for Belle II

- A potentially better position was found by detailed tracking simulation of photons inside HER beam pipe;
- The new position is expected to have a rate ~10 times higher;
- To place the sensors in the new position, new special holders were designed at LAL (Y. Peinaud);
- Fraction of cross section intercepted is now 1%/0.01% for LER/HER;
- 1% precision for HER is expected at design luminosity.





Phase	Luminosity	ΔL/L % 1ms HER/LER	Dose (Mgy/h) HER/LER
Phase 3	$1 \times 10^{34} cm^{-2} s^{-1}$	10/1	2e-5/2e-3
Phase 3	$8 \times 10^{35} cm^{-2} s^{-1}$	1/0.1	1e-3/0.1

Conclusions and plans

Conclusions

- Reasonable agreement with simulation for single beam backgrounds;
- Provides useful online luminosity information for SKB machine tuning (e.g. IP beam size tuning);
- Good correlation with other luminosity monitors;
- Provides bunch-by-bunch luminosities.
- Application: evaluate mean σ_y^* of beams at IP by vertical offset scans;
- Provided our measurements as input to horizontal IP orbit dithering feedback: 1st test was successful;

Plans

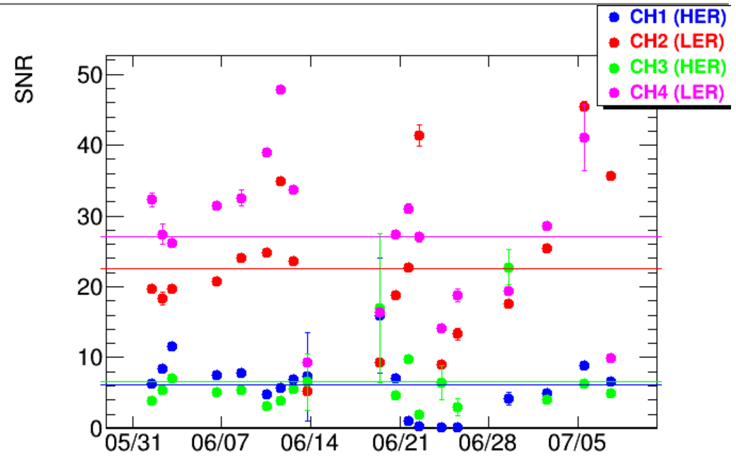
- Increase HER signal rates, we have identified and will use better location for Phase 3;
- Faster charge amplifiers & lower noise current amplifiers;
- Long term DAQ solution, possibly with a few more channels;
- Shielding / protection to mitigate activation on LER side under study;
- Ability to easily vary signal acceptance to keep few % precision @ 1 kHz over $10^{32} - 10^{36}\ cm^{-2}s^{-1}$;
- It will be important to limit accumulated radiation dose;
- In Phase 3 and over the life of the Belle II/SKB project there will be more remote operations, with less human resources and less presence at KEK. LAL is committed to that, now as part of its participation in Belle II.

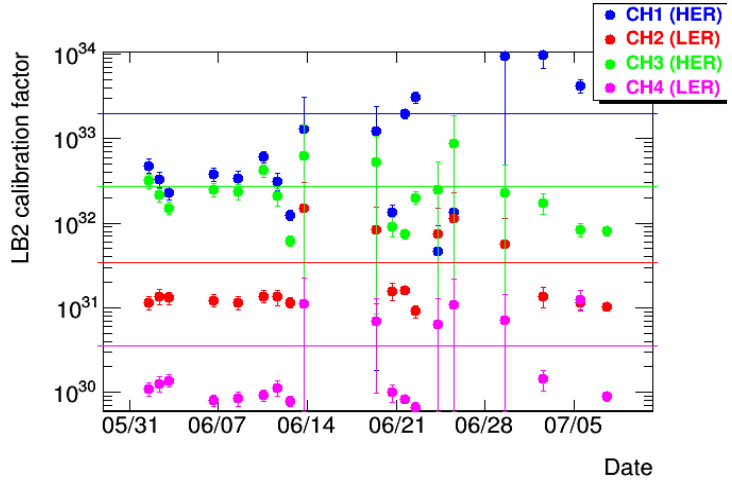
BACKUP

SNR and absolute calibration stability during Phase 2

- The SNR is large for LER, while small for HER. The LER was the most performing side during Phase 2;
- The fluctuations in SNR are due to changes in pressure, which result in changes of beam-gas background rates;
- The LumiBelle2 is designed to measure relative luminosity but it can be calibrated;
- The calibration has to be performed frequently, since it depends on beam conditions and changes in our setups in terms gains, position of the sensors, thresholds, etc.

LumiBelle2 CH#	SNR	Calibration factor
CH1 (HER)	6 ± 4	$2 \pm 3 \times 10^{33}$
CH2 (LER)	23 ± 10	$3 \pm 4 \times 10^{31}$
CH3 (HER)	7 ± 5	$3 \pm 2 \times 10^{32}$
CH4 (LER)	27 ± 10	$4 \pm 4 \times 10^{30}$





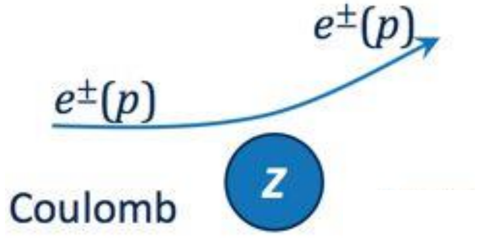
LumiBelle2

Luminosity Monitoring for Belle II

Background sources

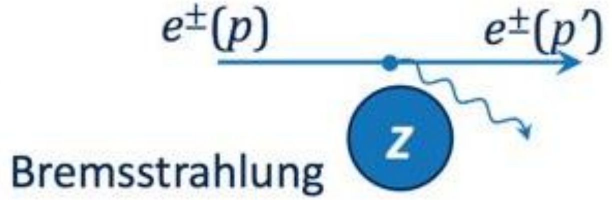
Coulomb scattering:

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



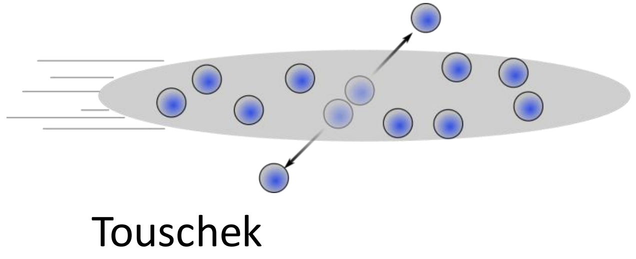
Bremsstrahlung scattering:

- 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)

LumiBelle2
Luminosity Monitoring for Belle II

A-B (current-rate vs time):

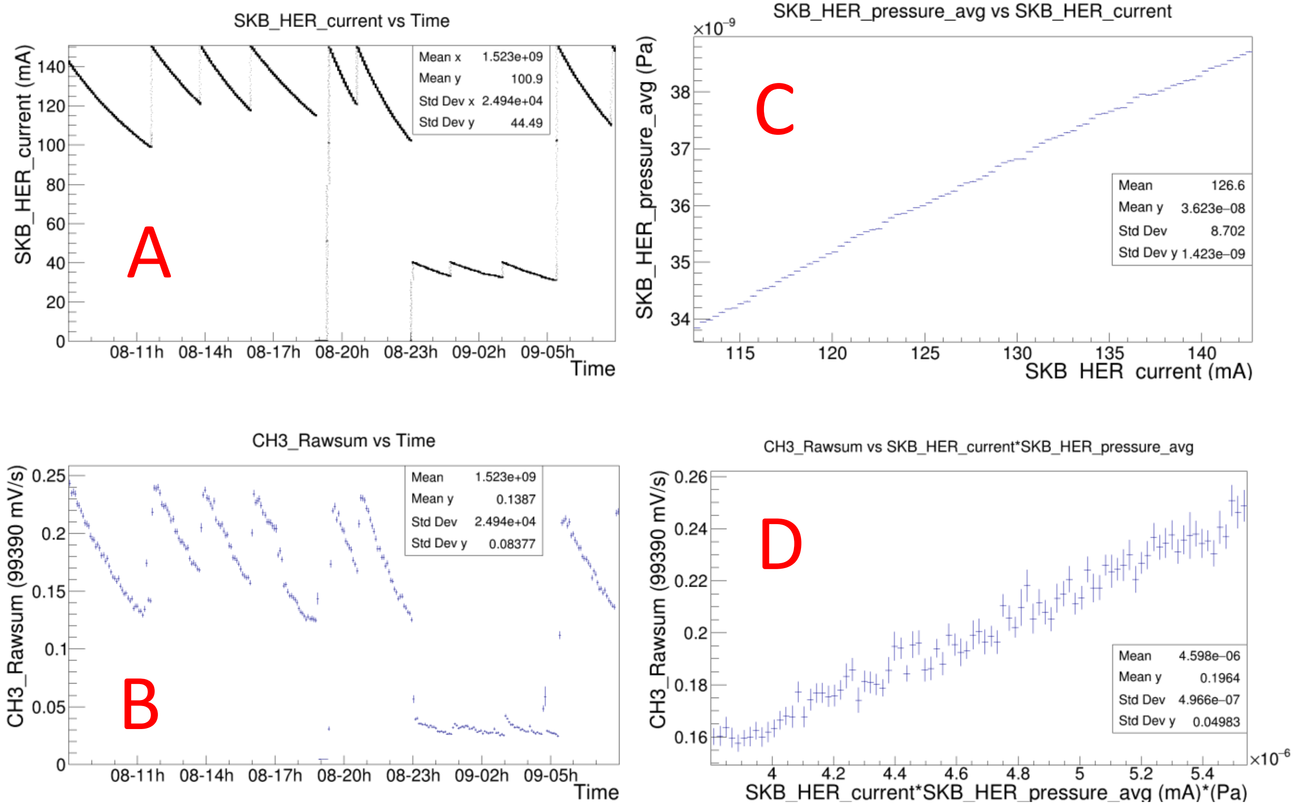
- Rate (B) well correlated with SKB current (A);
- Rate is due to beam background.

C (pressure vs current):

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

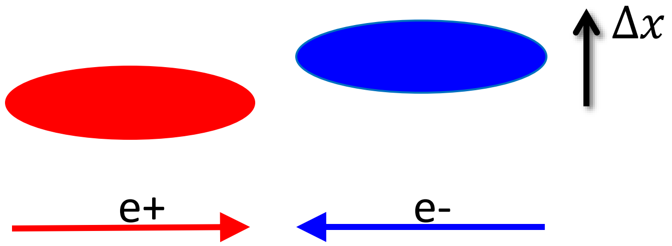
D (rate vs pressure X current):

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

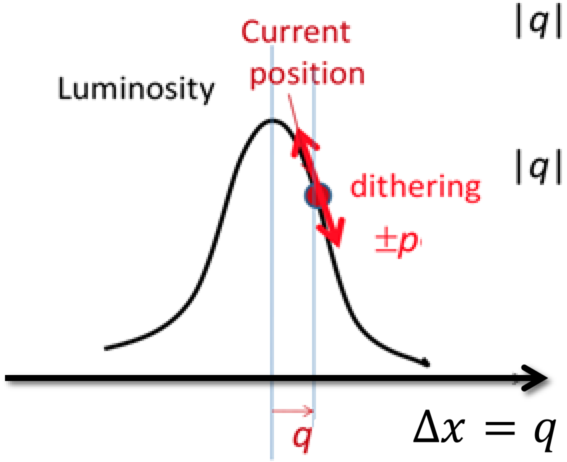


Dithering feedback system

- The dithering system makes one beam to oscillate around its orbit as Δx_{dith}= p sin(2πft) with frequency f =77Hz ;
- 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;



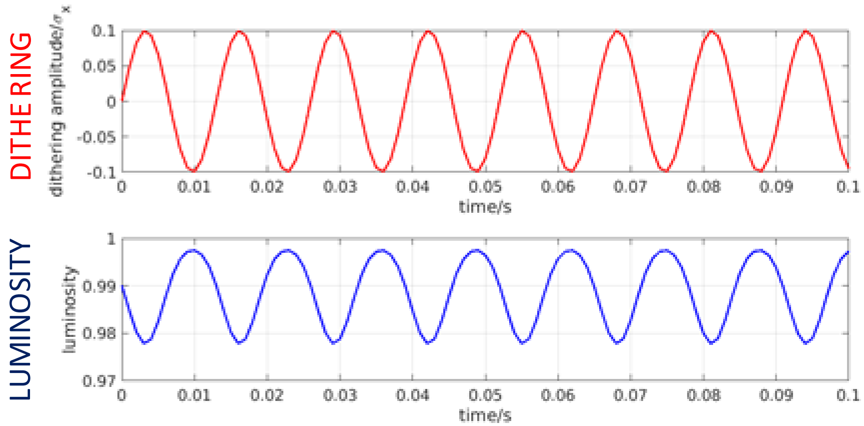
$$L(t) = \frac{f_{rev} N_1 N_2}{4\pi\sigma_x\sigma_y} e^{-\left(\frac{[q + psin(2\pi ft)]^2}{4}\right)}$$



$|q|>p$ goes up and down on a side

$|q|<p$ goes over across the peak

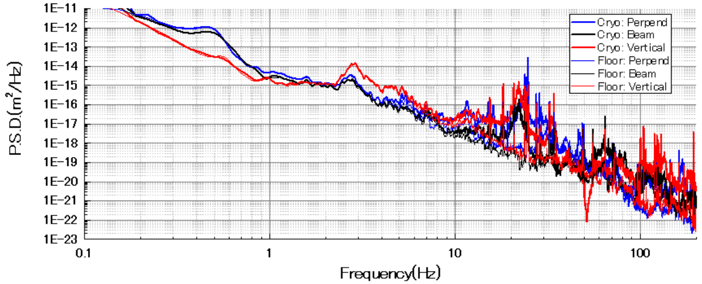
$\Delta x = q + $ p sin(2πft)



Fast luminosity monitoring at SuperKEKB

LumiBelle2
Luminosity Monitoring for Belle II

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

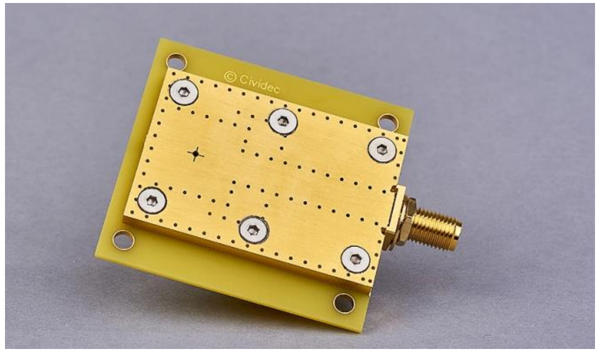


- A dithering feedback system is used to monitor and control the horizontal position of the beams;

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

$$dN/dt = \sigma L$$

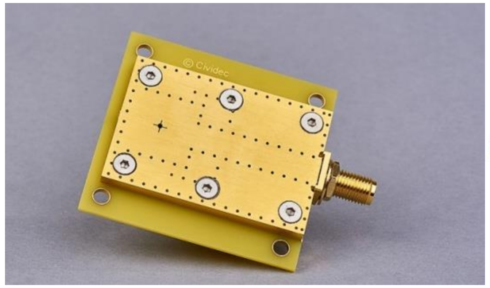
- LumiBelle2 is a fast luminosity monitor that measures Bhabha events using diamond sensors.



Diamonds sensors and amplifiers

LumiBelle2
Luminosity Monitoring for Belle II

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

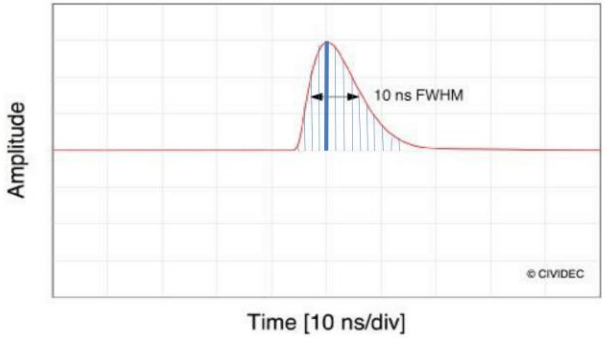


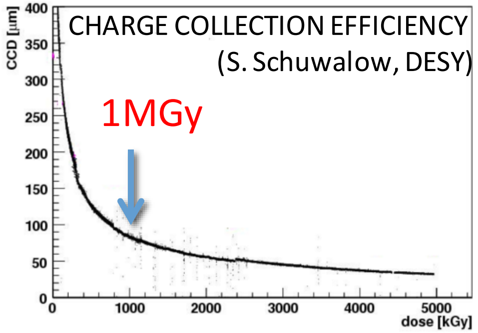
	CVD Diamond	Potential device application benefit
Bandgap (eV)	5.47	High temperature
Breakdown field ($MVcm^{-1}$)	10	High voltage
Electron saturation velocity ($x10^7$ cm s^{-1})	2	High frequency
Hole saturation velocity ($x10^7$ cm s^{-1})	0.8	
Electron mobility (cm^2 V^{-1} s^{-1})	4500	
Hole mobility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

SUPERKEKB COLLISION PERIOD = 4ns

140/500 μm diamond + CURRENT/CHARGE AMPLIFIER:

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





Beam H-V offset and luminosity degradation

HORIZONTAL OFFSET FEEDBACK

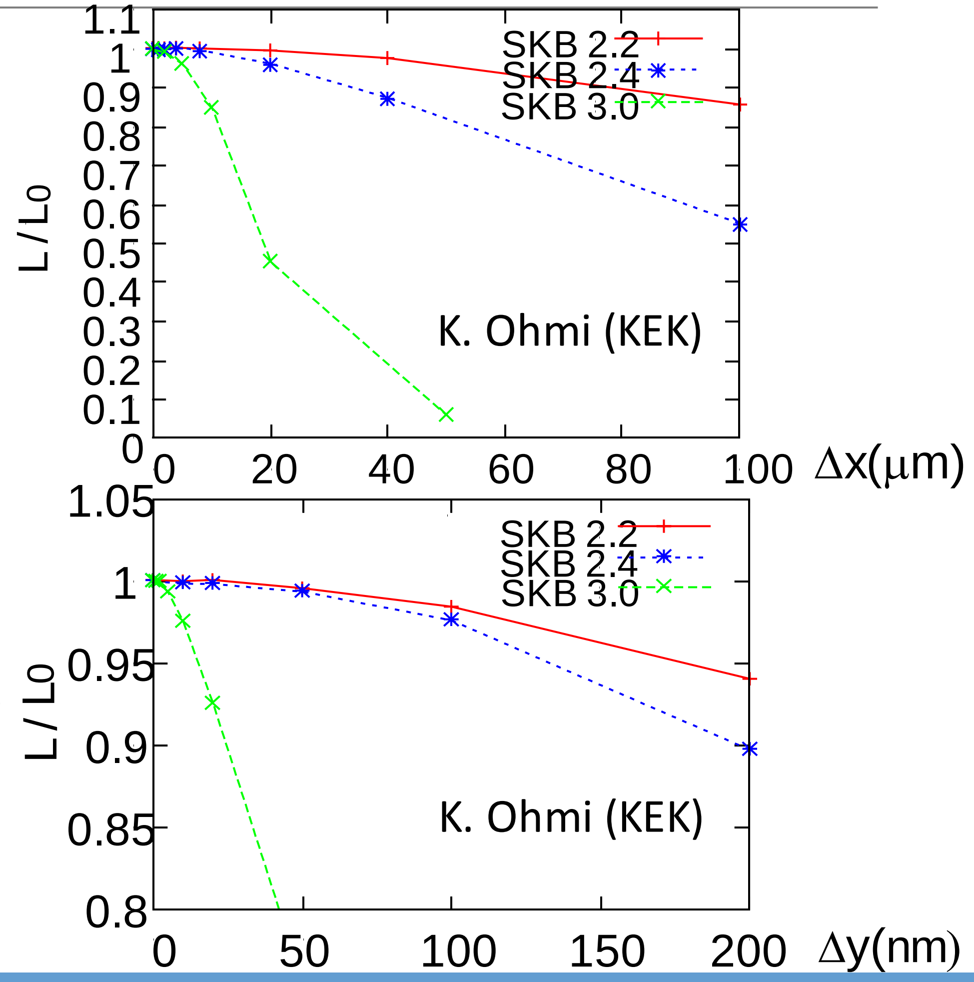
- Dithering system inherited from PEP-II;
- 8 sets of coils (H/V) on LER, dithering at f=77 Hz, max horizontal bump $5\sigma_x^*$;
- Fast luminosity monitors (LumiBelle2, ZDLM), 1 kHz;
- Lock-in amplifier to extract luminosity components at f, 2f;

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 → $\Delta y = 18.6nm\ (rms)$ → luminosity drop 4.6%;

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

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



LumiBelle2

Luminosity Monitoring for Belle II

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:

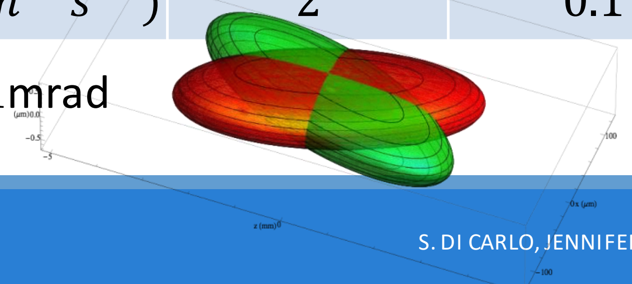
- $E_{e^+} = 4\ GeV$
- $E_{e^-} = 7\ GeV$
- $L = 8 \times 10^{35} cm^{-2} s^{-1}$

UPGRADES:

- Nano-beam scheme
- Doubled currents

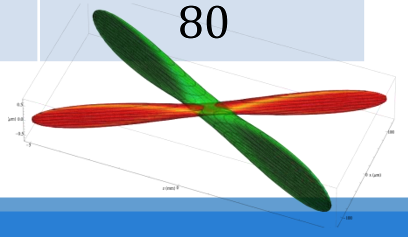
$LER(e^+)$ $HER(e^-)$	KEKB		SuperKEKB Phase 2.1		SuperKEKB Phase 2.2		SuperKEKB Phase 2.3		SuperKEKB Phase 2.4		SuperKEKB Phase 3.0	
	LER	HER	LER	HER	LER	HER	LER	HER	LER	HER	LER	HER
$\sigma_x^*\ (\mu m)$	103	116	20	30	23.2	30.3	16.4	21.4	16.4	21.4	10.1	10.7
$\sigma_y^*\ (nm)$	1900	1900	1300	1920	476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

$\phi_{cross} = 11$mrad



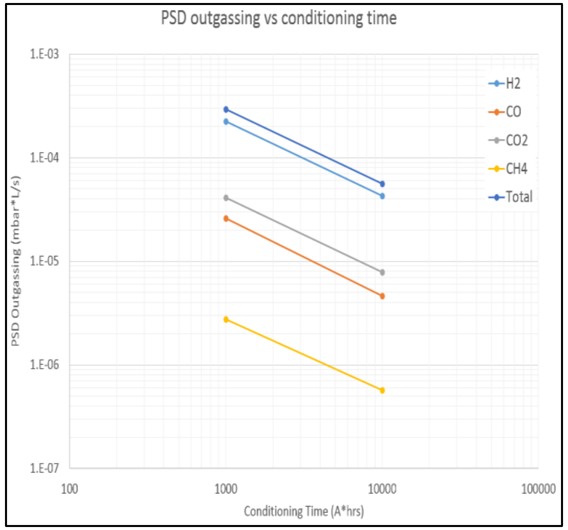
CURRENT PHASE

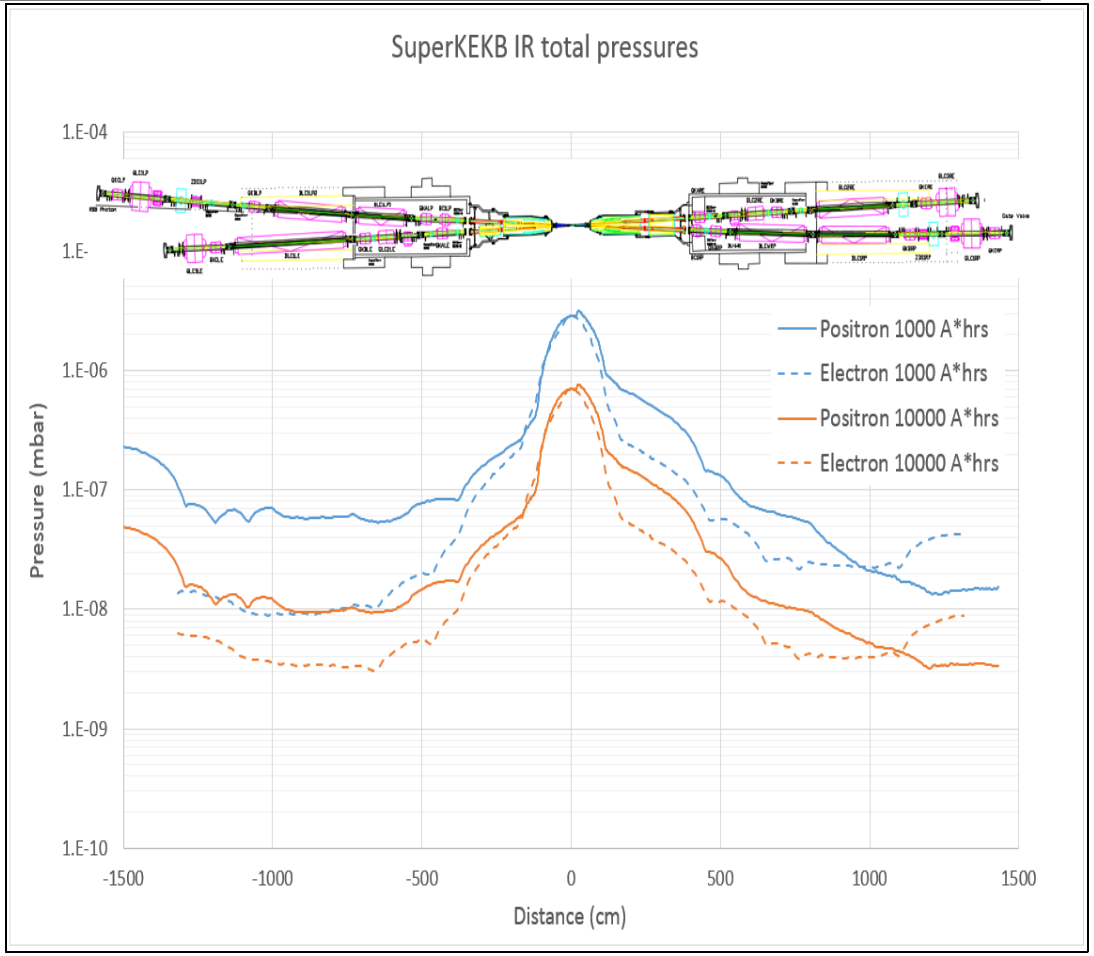
$\phi_{cross} = 41.5$ mrad



Pressure profile around the IP

- Total indicates sum of H_2, CO, CO_2, and CH_4 partial pressures
- Asymmetric because of synchrotron radiation
- Total pressures at 1000, 10000 A*hrs, I = 3.6 A

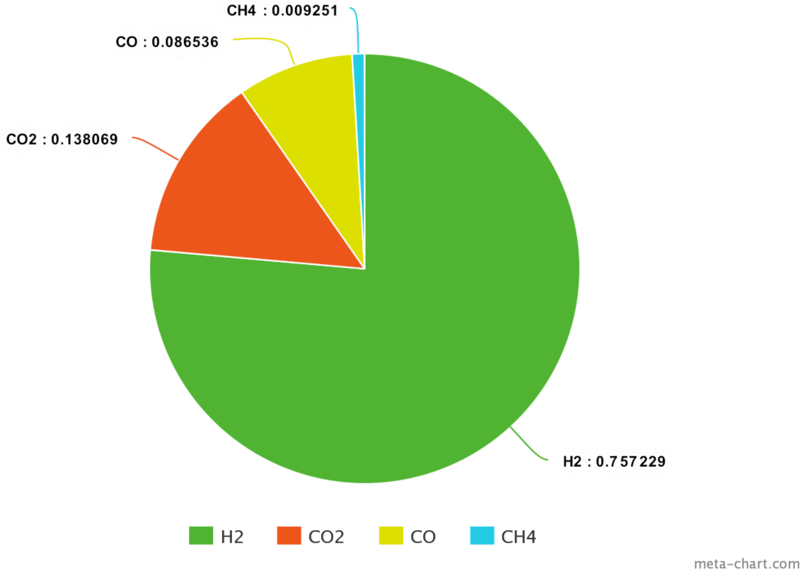




Jason CARTER – Argonne National Laboratory
Marton ADY - CERN

LumiBelle2
Luminosity Monitoring for Belle II

Gas composition



Molecule	Partial pressure: $p_i = P_i/P_{tot}$
H2	0.757229
CO2	0.138069
CO	0.086536
CH4	0.009251

$$Z_{eff}^2 * \ln\left(\frac{1}{Z_{eff}^{\frac{1}{3}}}\right) = \frac{\sum_j b_j Z_j^2 * \ln\left(\frac{1}{Z_j^{\frac{1}{3}}}\right)}{\sum_j b_j} \quad ; \quad b_j = Z_j \sum_i p_i N_i \quad ; \quad Z_{effBREMS} \approx 4.5 \quad ; \quad Z_{effCOUL} \approx 4.2$$

Index i runs over molecules, index j runs over atoms. Z_j is the atomic number of an atom in the molecule and N_i is the number of atoms in the molecules.