RECENT SURVEY RESULTS OF THE SUPERKEKB MAIN RING AND THE STUDY OF ATL APPLICATION

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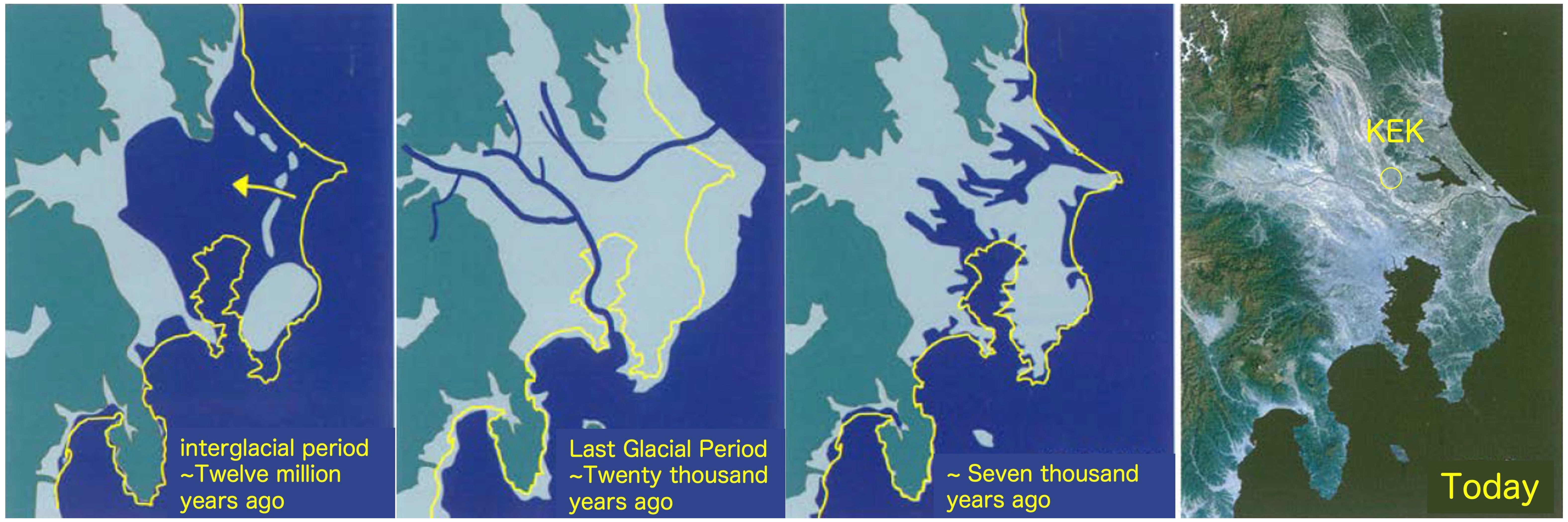
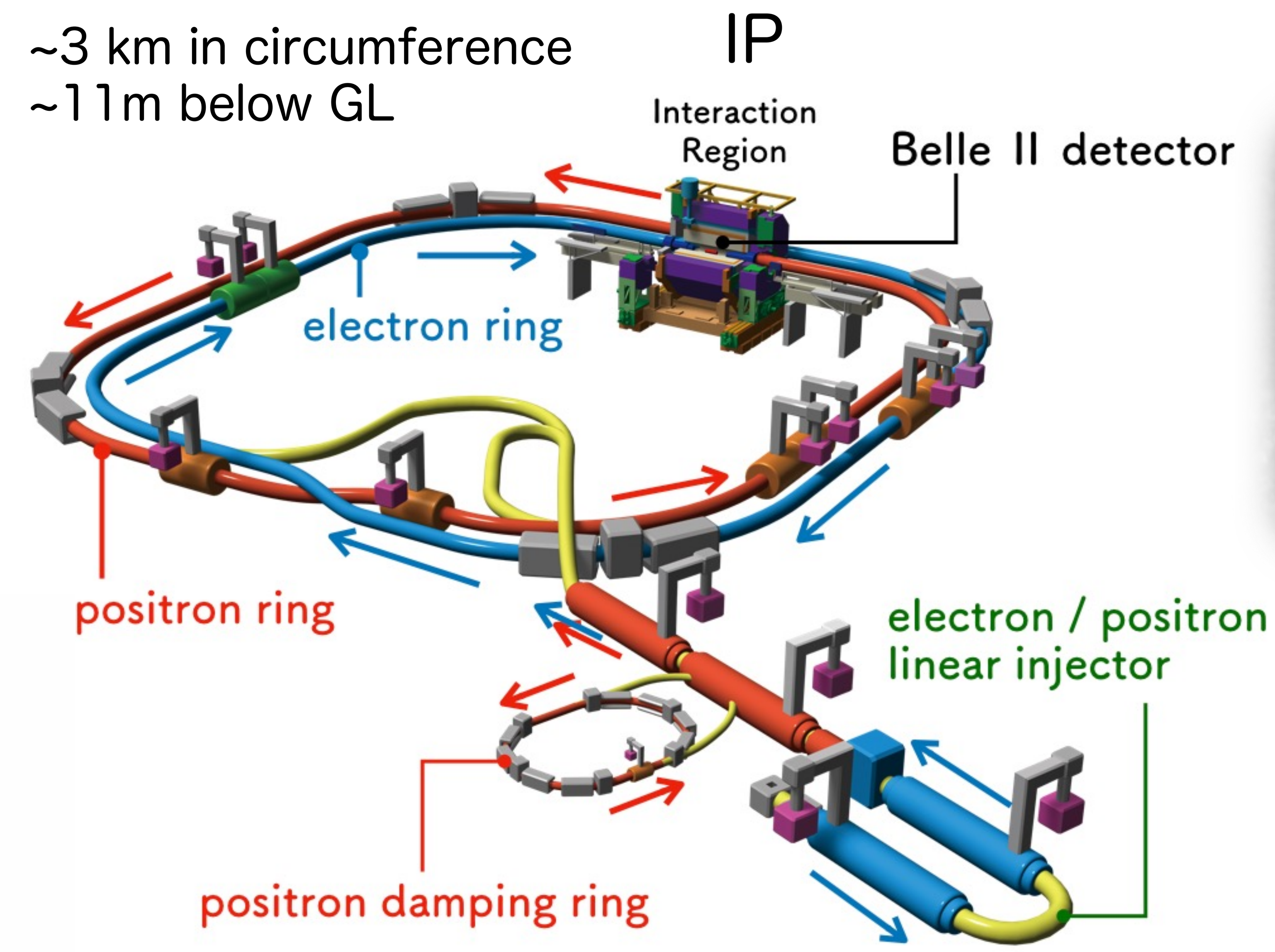
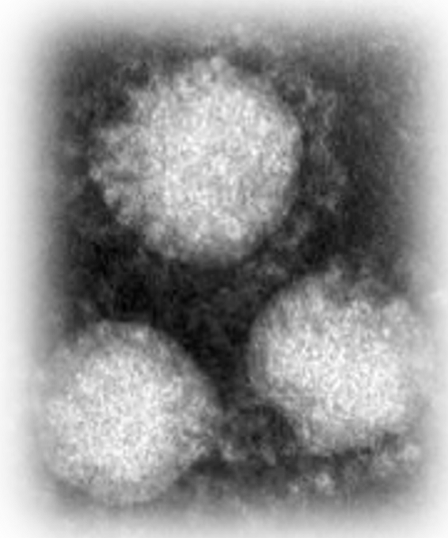
KEK is established on soft ground with an abundance of groundwater.



SuperKEKB employs a "nano-beam scheme," wherein two low-emittance beams collide at a crossing angle of 83 mrad at the interaction point (IP), aiming at several dozen times high peak luminosity than KEKB.

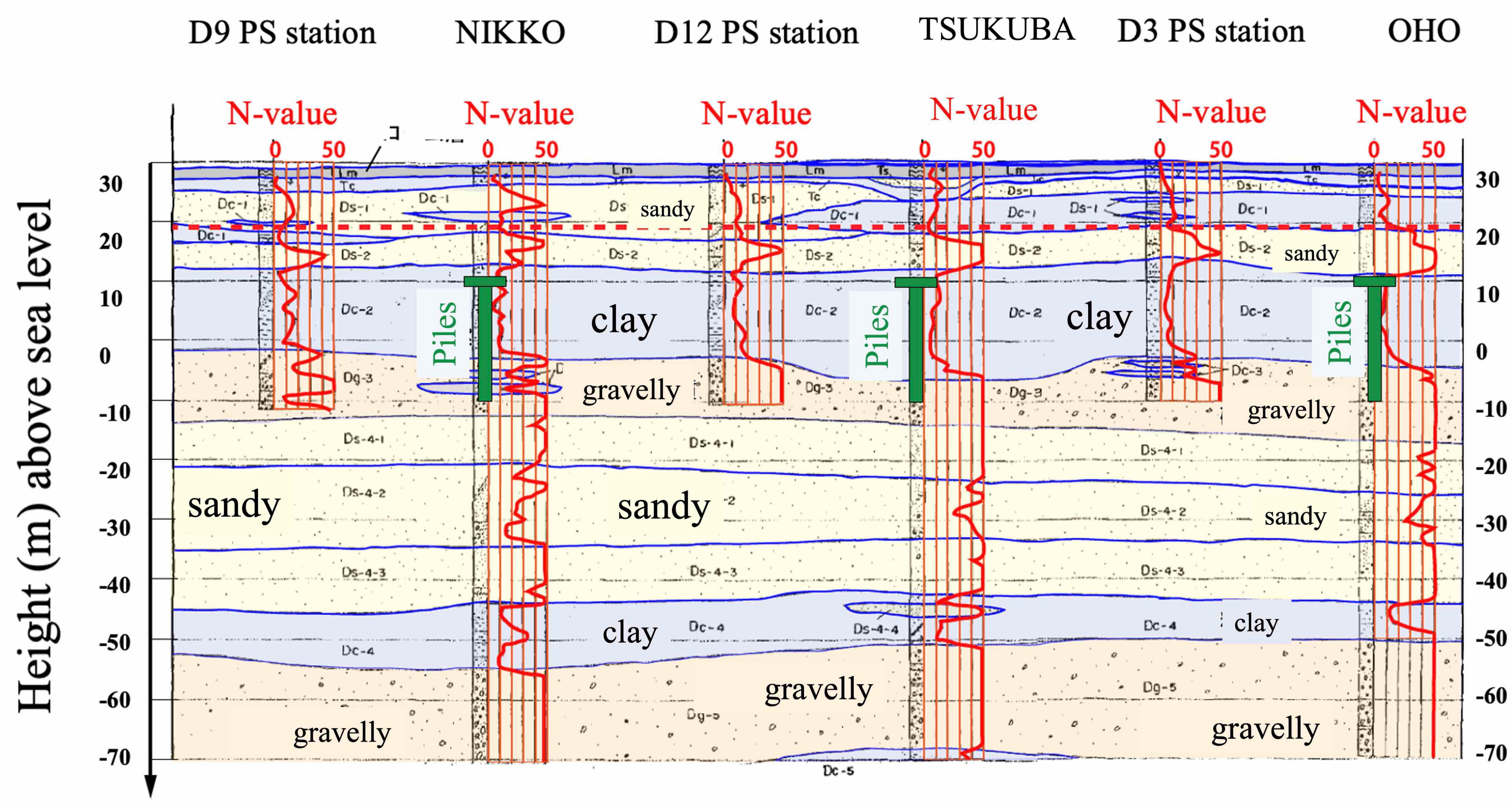
The design vertical beam size of the beam at the IP is ~60nm, which is about the same size as COVID-19.



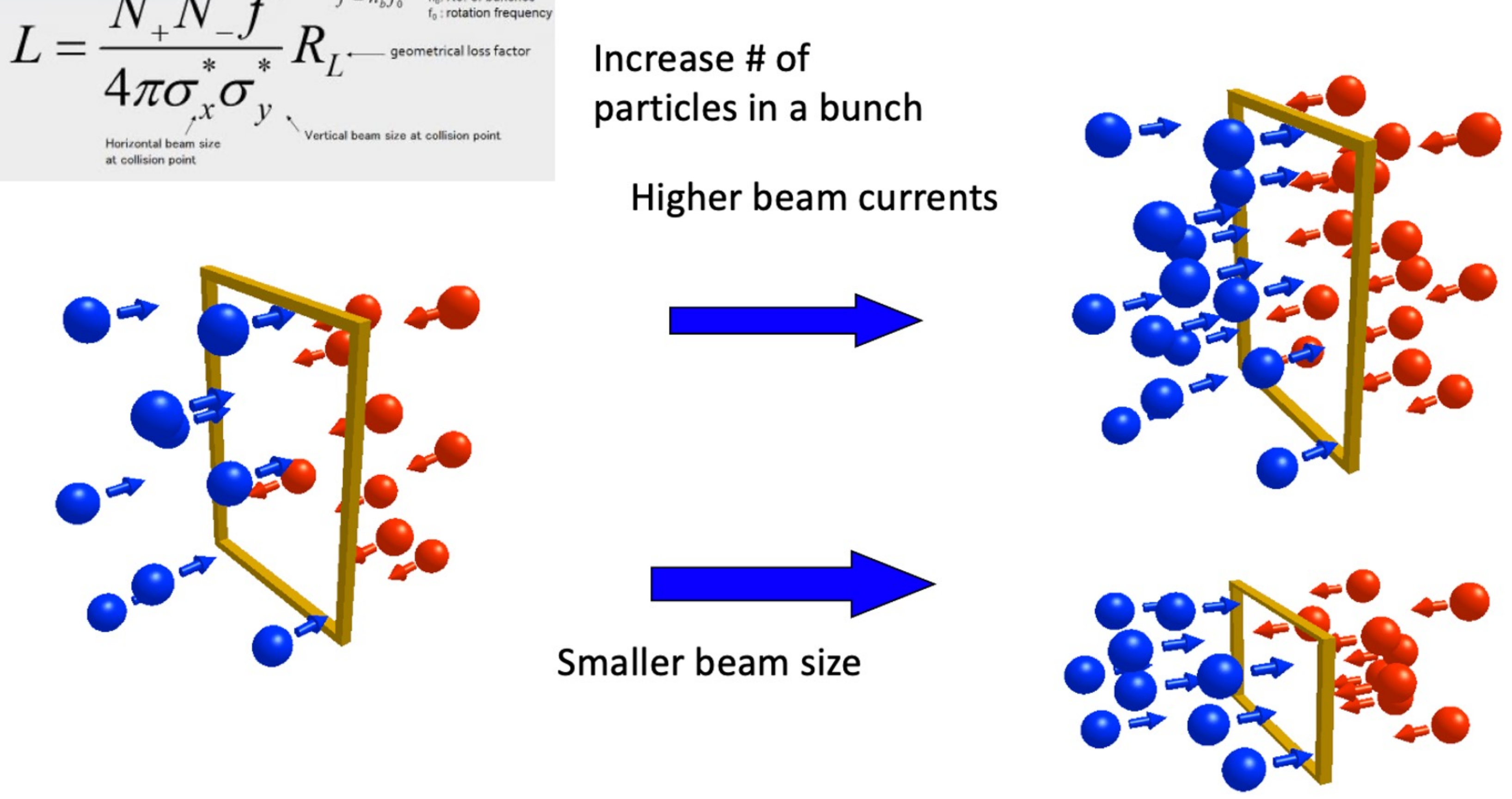


COVID-19

Geological columnar sections along the KEKB/SuperKEKB tunnel, obtained from a boring survey

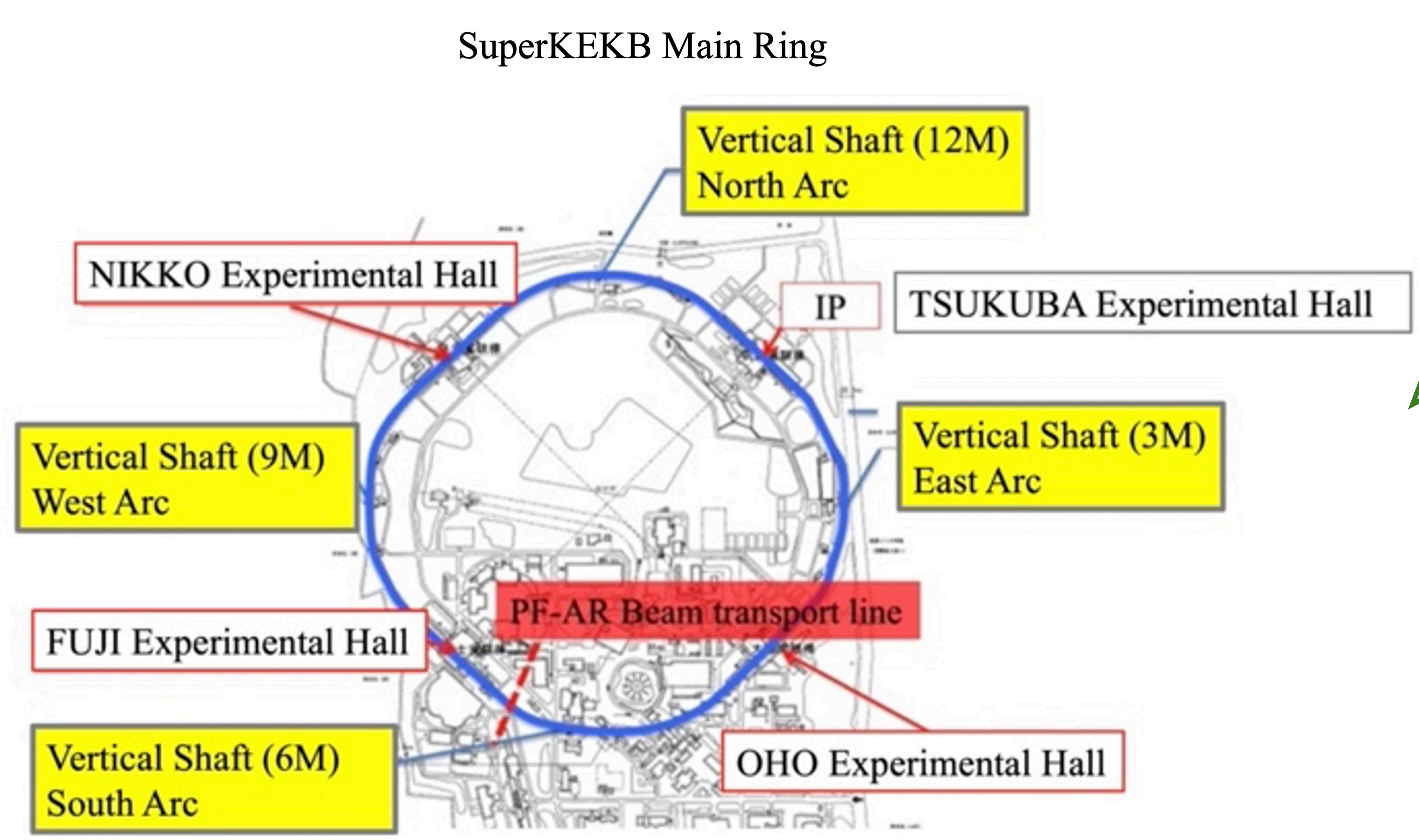


$$L = \frac{N_+ N_- f}{4\pi\sigma_x^*\sigma_y^*} R_L$$

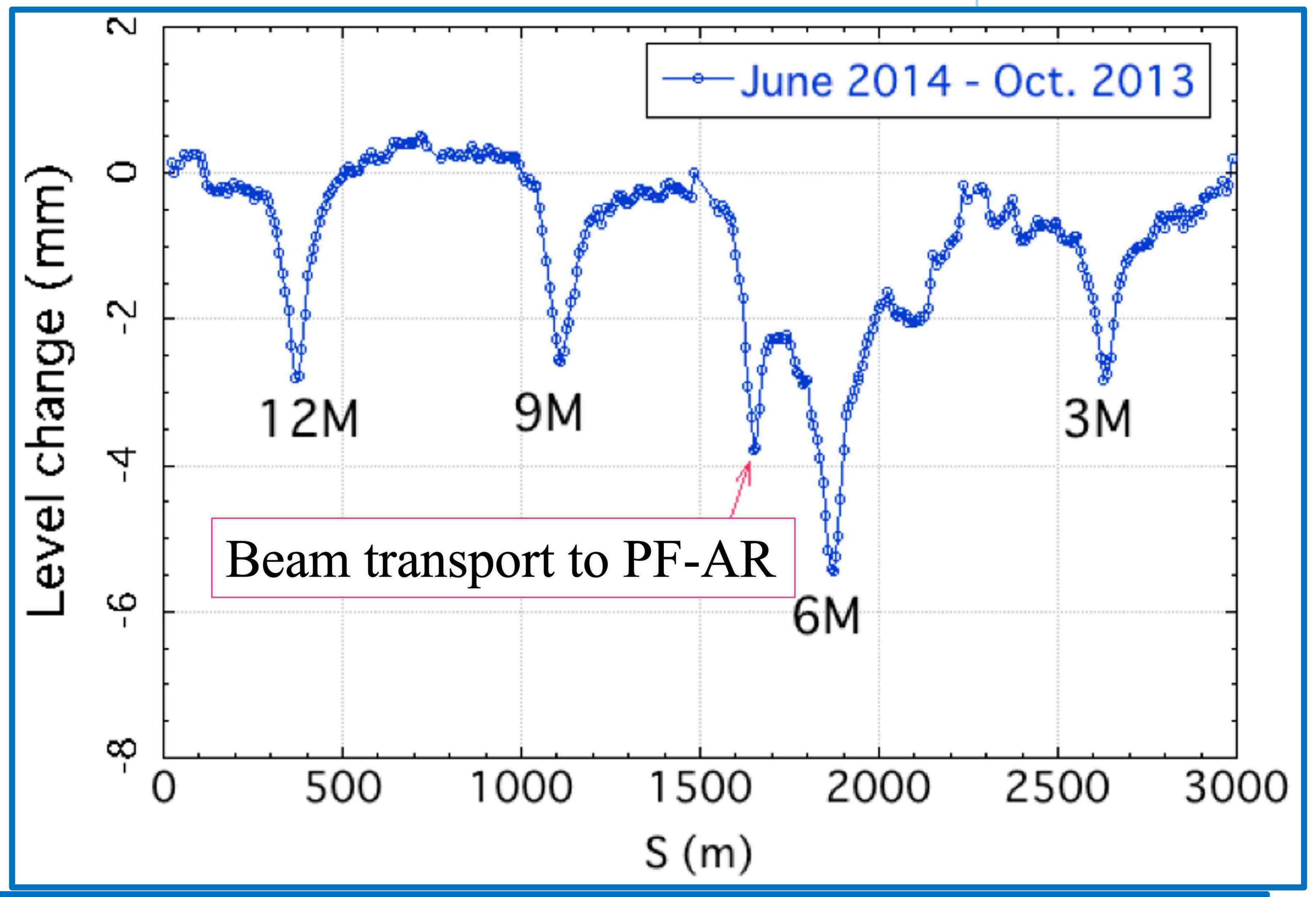


The construction of SuperKEKB started in 2010, and despite the Great East Japan Earthquake in 2011, beam commissioning began in February 2016.

Tunnel level change

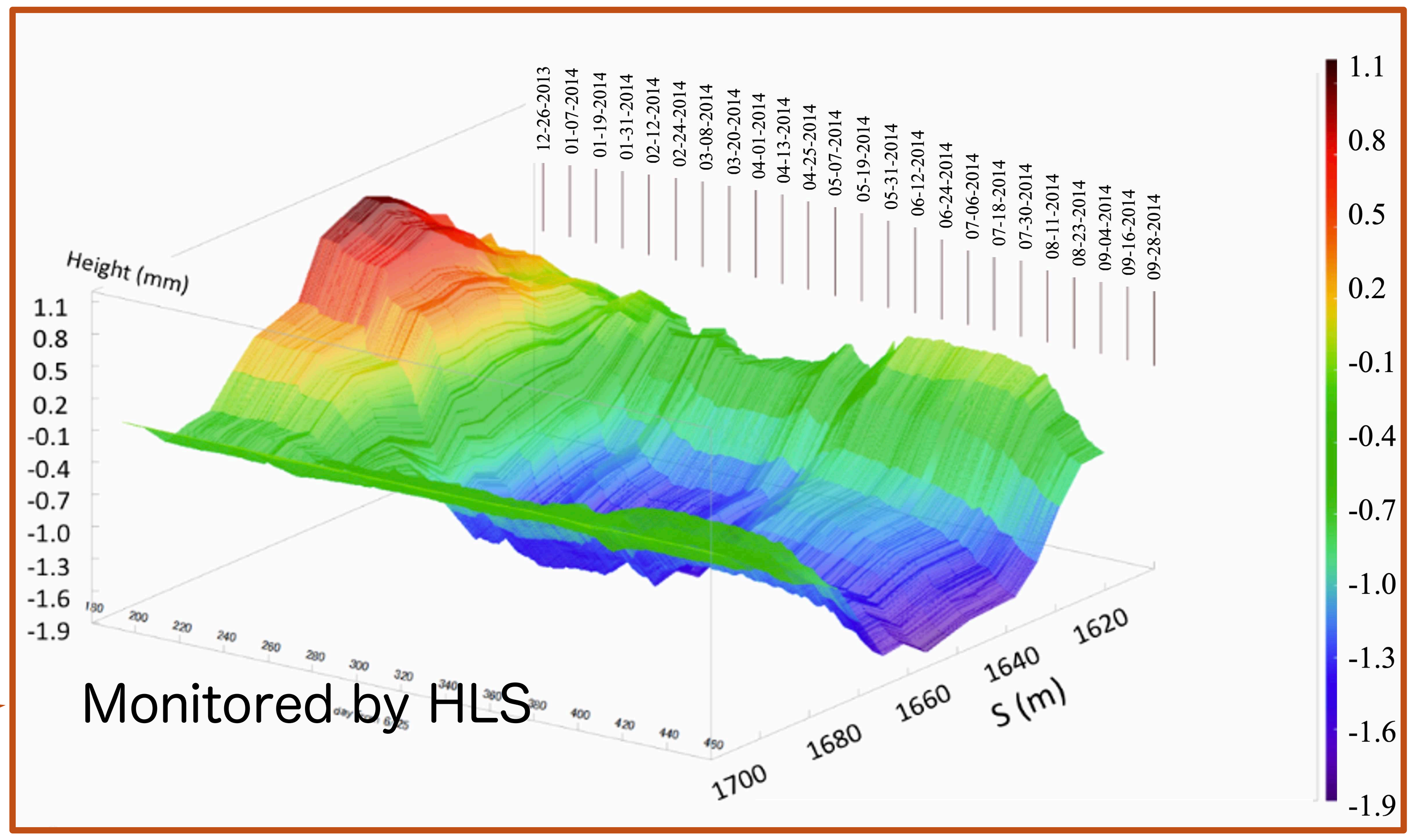


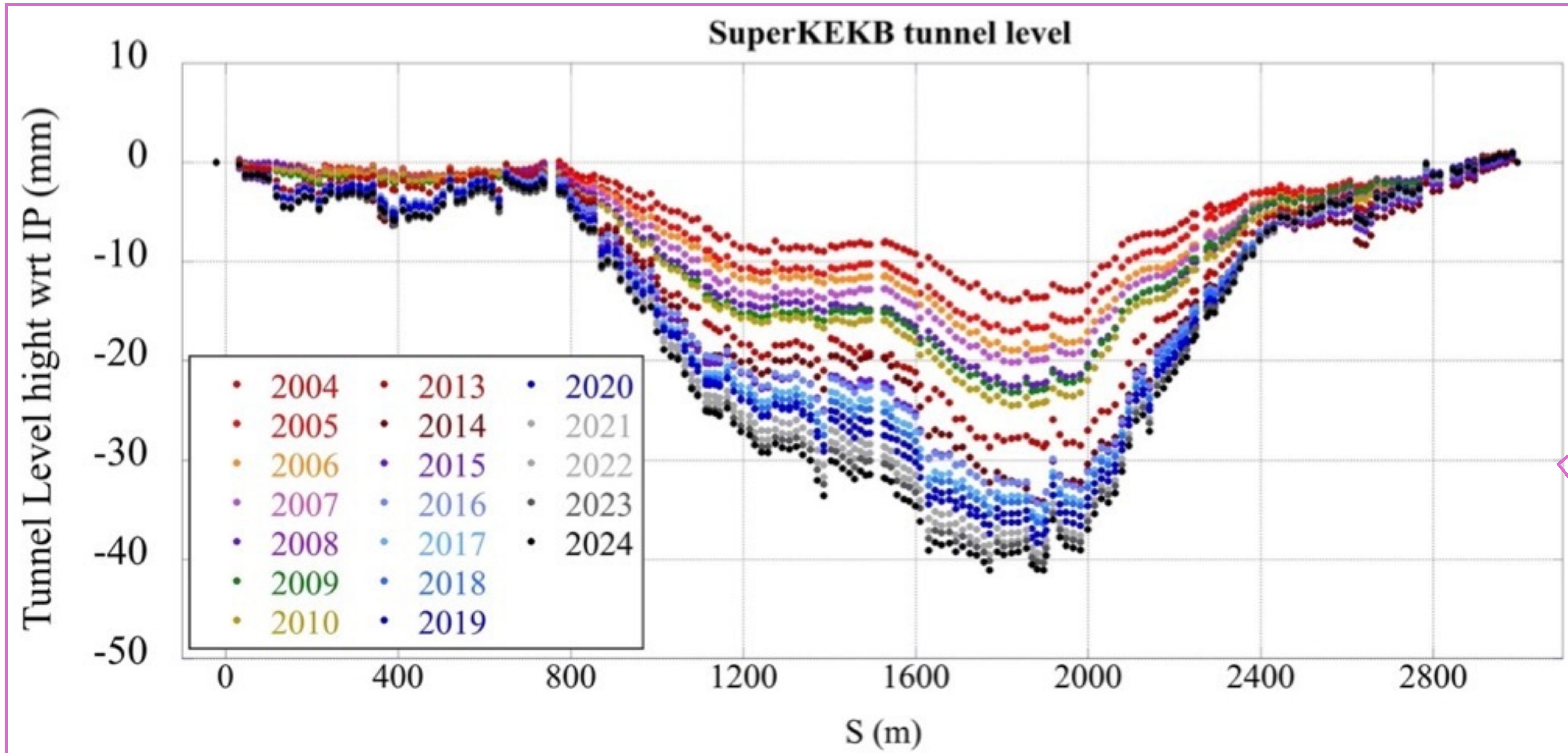
Due to the extremely tight construction schedule, the installation, surveying, and adjustment of the magnets for were carried out concurrently with the construction of the utility building for the new power supply and water supply systems (3M, 6M, 9M and 12M), located above ground near the tunnel.



Comparison of tunnel level changes before and after the utility construction. The labels 3M, 6M, 9M, and 12M correspond to the newly excavated vertical shafts.

Additionally, a few meters above the SuperKEKB tunnel, work was underway on a new beam transport line that would con-nect to another accelerator facility (PF-AR)





Tunnel level relative to the IP plotted against *s*, the distance from the IP measured counterclockwise.

The data presented were obtained from the level marker surveys conducted during the summer shutdown periods.

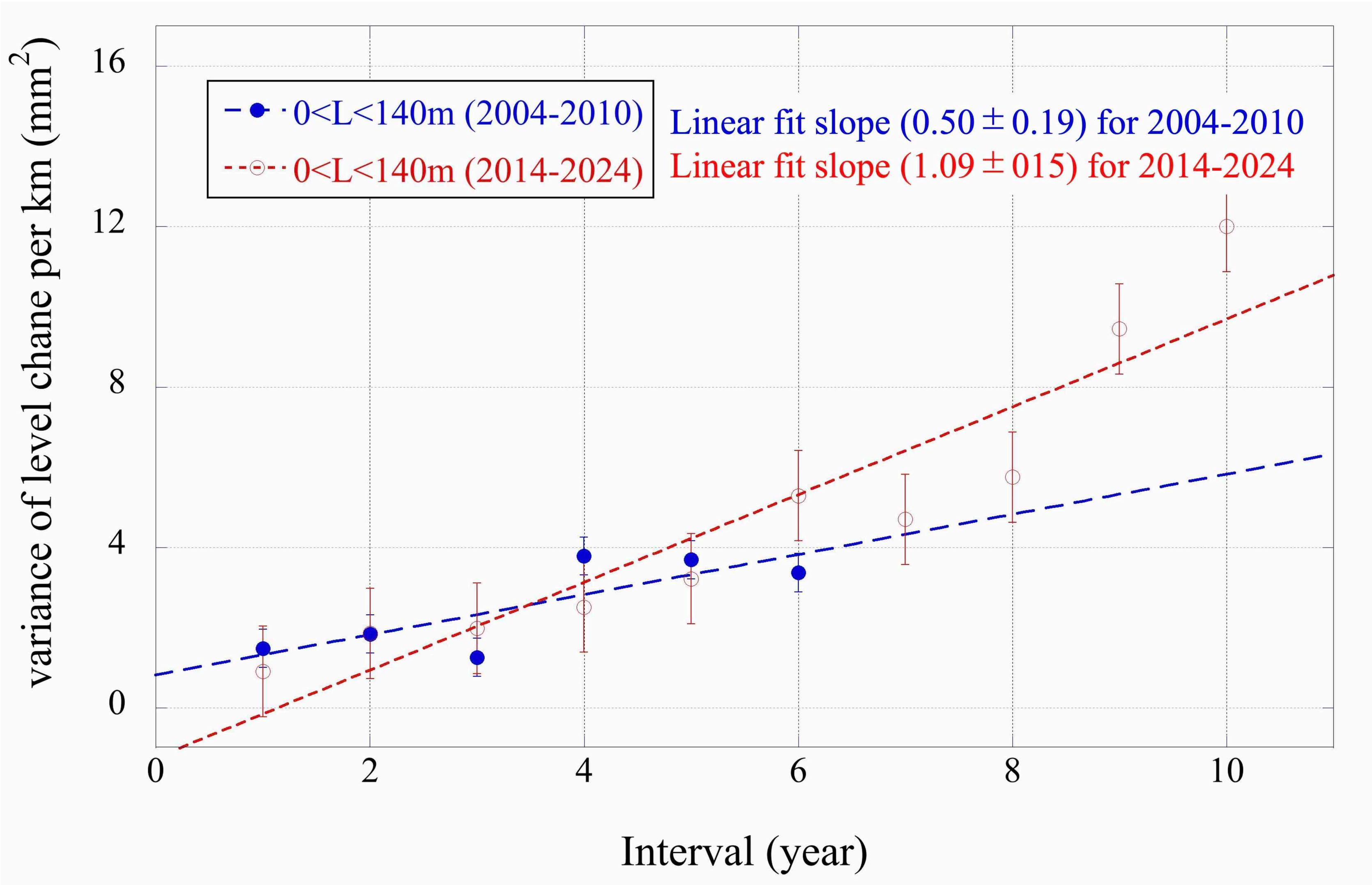
The data for 2011 and 2012 are excluded from this plot, as those surveys were conducted in February and March.

Application of ATL Law & Conclusion

The variance $\langle dz^2 \rangle$ of the height difference of the ground over a time interval T between two points separated by a distance L, with both exponents close to 1 $(\alpha \sim 1,\ \beta \sim 1)$ $\quad \langle dz^2 \rangle \approx AT^{\alpha}L^{\beta}$

The variance of the tunnel level changes was calculated using the equation, where M and N represent the number of combinations of pairs of time intervals T and tunnel level marker points, respectively, separated by L:

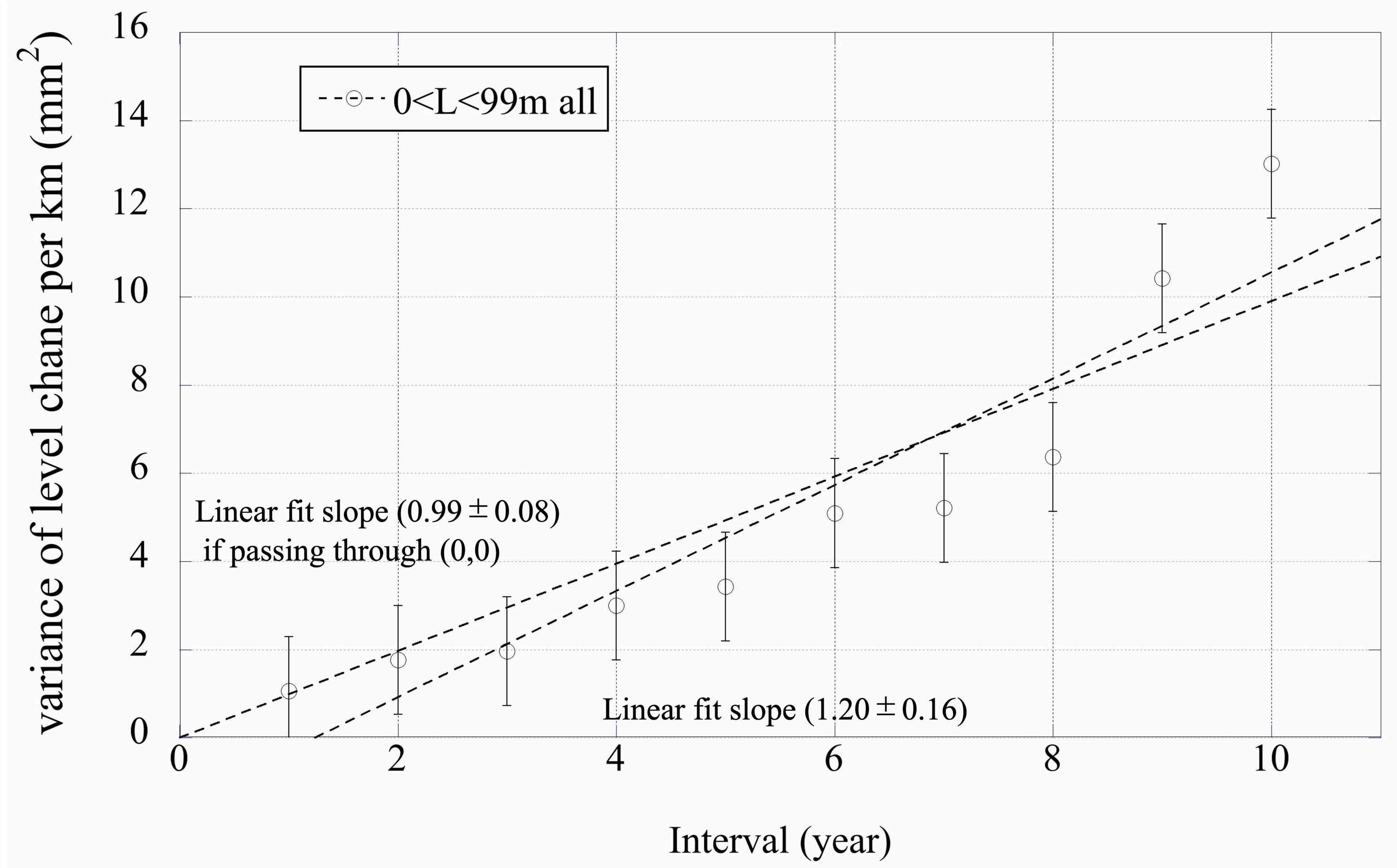
$$\langle dz^2(T,L) \rangle = \frac{1}{M}\sum_M \frac{1}{N}\sum_N \{dz(T,s+L) - dz(T,s)\}^2$$

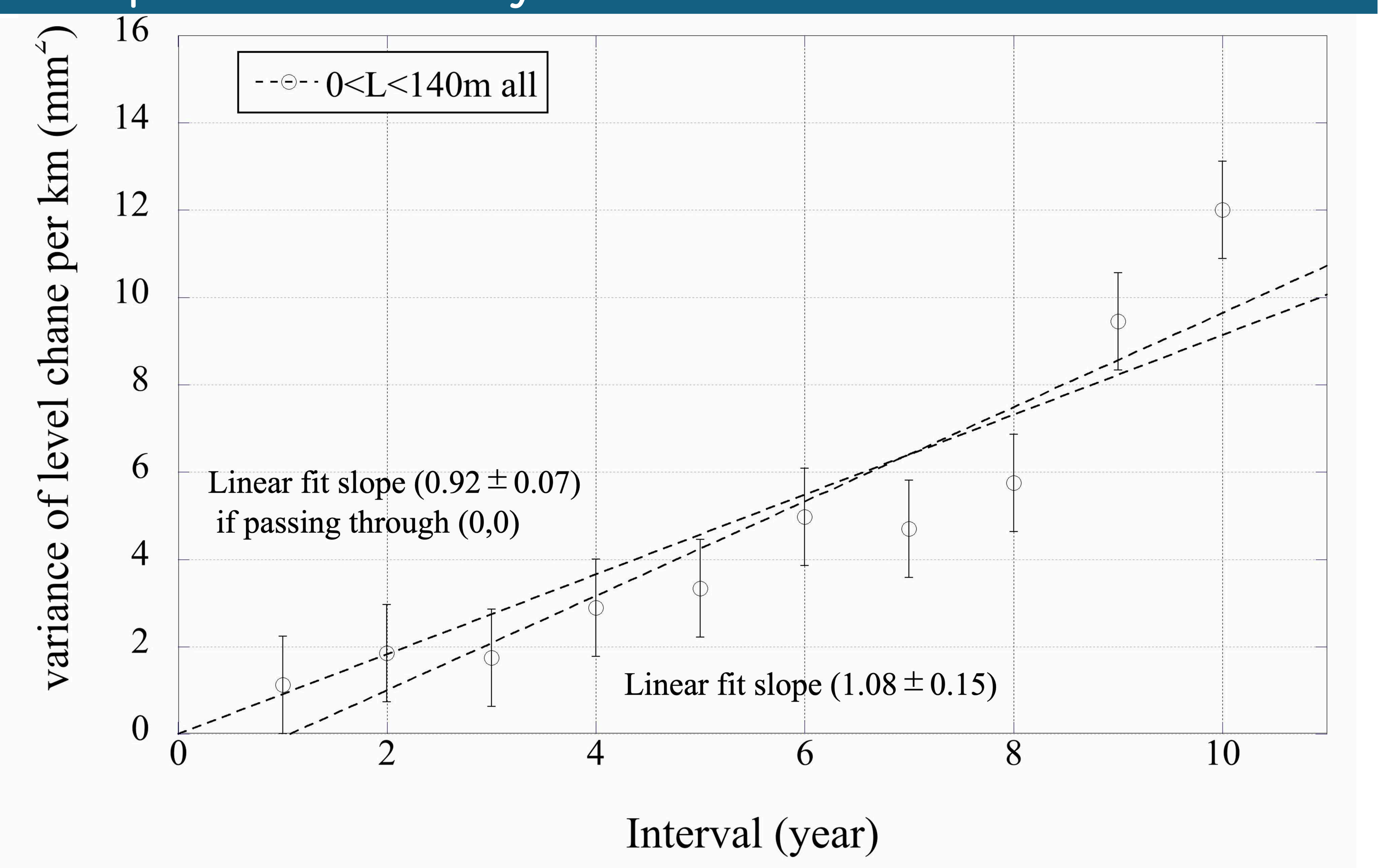


Variance of level change per unit distance (km) plotted against the survey interval. T

The data set is divided into two periods: 2004 to 2010, prior to the earthquake and large-scale construction, and 2014 to 2024, following these events.

If the analysis range o L, is extended further, the systematic movements of tunnel subsidence become more pronounced, exceeding the applicability of the empirical ATL analysis.





Left: Variance of level change per unit distance (km) plotted for $0 < L < 99\ (m)$. Right: Variance of level change per unit distance (km) plotted for $0 < L < 140\ (m)$ All data from 2004 to 2024 are combined.

Diffusion coefficient comparison

Larger *A* indicates softer ground

Site	*A* $10^{-6}\mu m^2/s/m$	Time	Comments
LEP	3 ± 0.6	6 yrs	ΔL = 39m
CERN SPS	14 ± 5	3-12 yrs	ΔL = 32m
TEVATRON	4.9 ± 0.1	1-6 yrs	ΔL = 30m
SPring-8	7.6 ± 1.4	20 yrs	ΔL ~ 400m
SuperKEKB	(29~34) ± ~5	~10 yrs	ΔL ~ 140m

- Tunnel-level survey data from 2004 to 2024 have been summarized and presented.
- The southern arc section of the SuperKEKB MR continues to sink, with the relative amount of subsidence with respect to the IP exceeding 40 mm. Currently, there are no indications that the tunnel subsidence has ceased; if this trend continues, the relative subsidence could reach 50 mm by 2030.
- This study marks the first attempt to apply the empirical ATL law to the tunnel deformation of the SuperKEKB MR.
- Several factors may have contributed to systematic ground deformation, including the use of different construction methods for the SuperKEKB tunnels, the occurrence of a major earthquake just before construction, and extensive excavation work around the MR after SuperKEKB's construction began.
- For this reason, we analyzed the data separately for the period before the earthquake and during the construction phase, while limiting the spatial scale to approximately 150 m.
- We obtained a diffusion coefficient that is several to ten times larger than those of other accelerators, which was somewhat anticipated given that the ground at the KEK site is softer than at other locations.
- The ATL law was applied in the vertical direction, specifically to the variation in tunnel-level marker changes. Future efforts will focus on applying the law in the horizontal direction, examining variations in the circumference.