Beamstrahlung monitor

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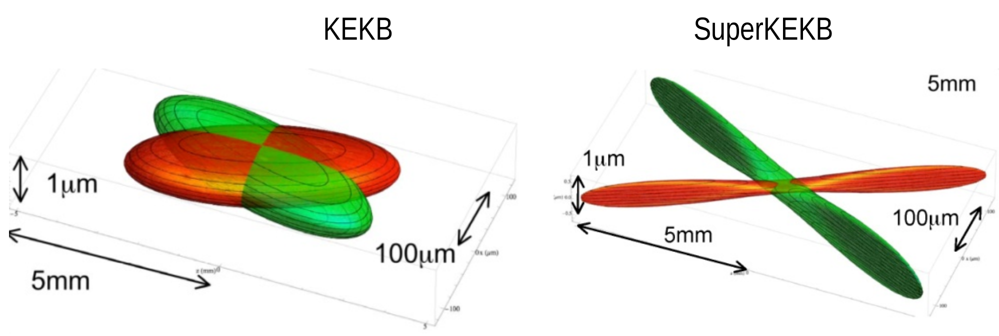
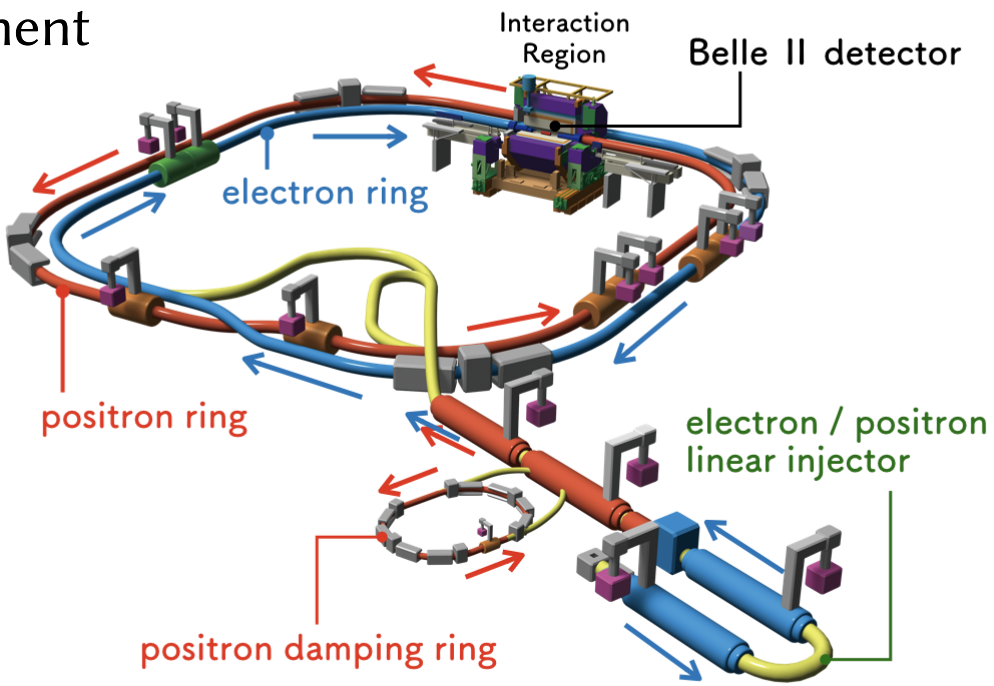
SuperKEKB

- e^+e^- asymmetric circular collider located at KEK in Tsukuba (Japan)
- Provides luminosity to Belle II experiment
- Goal is 40x instantaneous luminosity comparing to KEKB ("nano-beams")

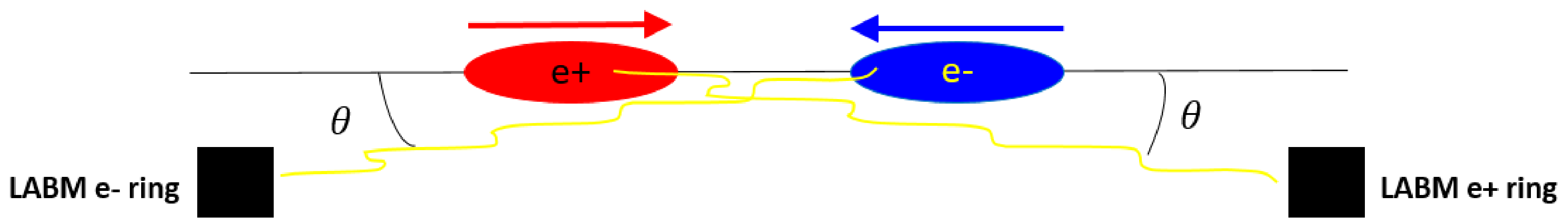




	E(GEV) HER/LER	β^*_y(mm) HER/LER	β^*_x(mm) HER/LER	2φ (mrad)	I(A) HER/LER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	1200/1200	22	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	32/25	83	3.6/2.6	80×10^{34}

Beamstrahlung

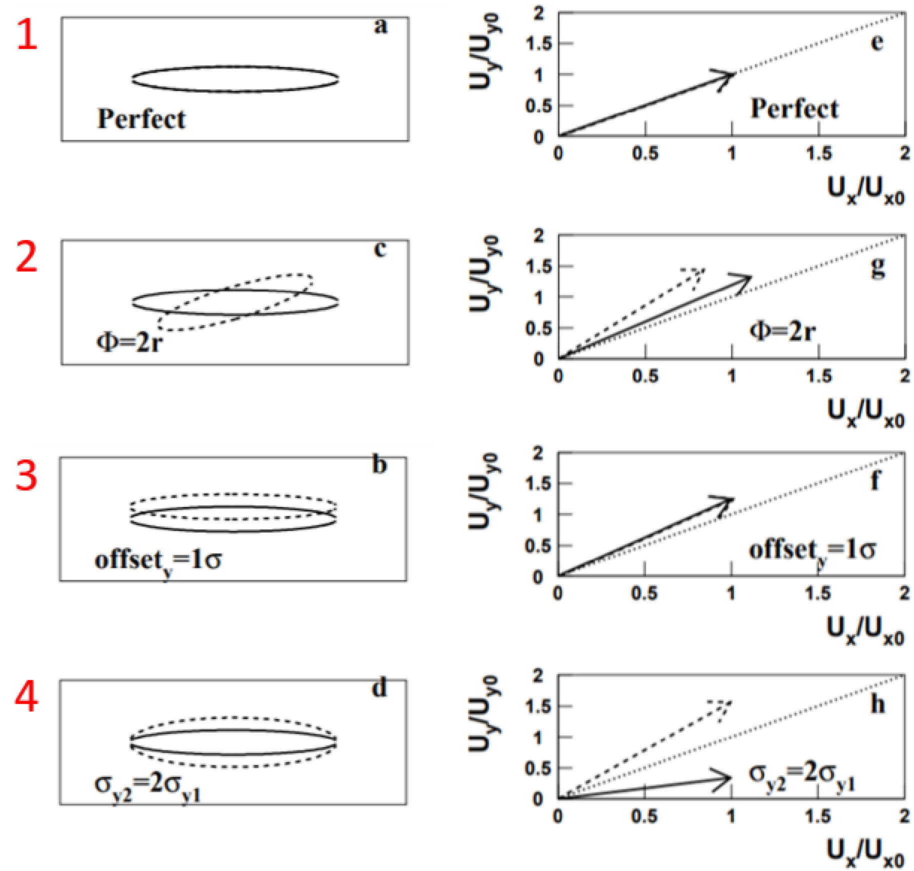
- Beamstrahlung: radiation emitted from one beam of charged particles during the e.m. interaction with another beam of charged particles
- At large angle ($\gamma\theta \gg 1$), beamstrahlung is strongly polarized and contamination from synchrotron radiation is small
- Visible light (350–650nm)
  - Easy to work with,
  - Fractions 10^{-11} (e^-) to 10^{-12} (e^+) of total beamstrahlung energy emitted but enough for LABM



Luminosity and beamstrahlung

- Highest luminosity is achieved for the best match (overlap) of the beams at the interaction point
- Typical pathologies are rotation, offset and bloating
- Ratios of x-y polarizations show characteristic pattern for each type of mismatch
- SuperKEKB limited by bloating (mismatch 4, different vertical beam sizes at IP)

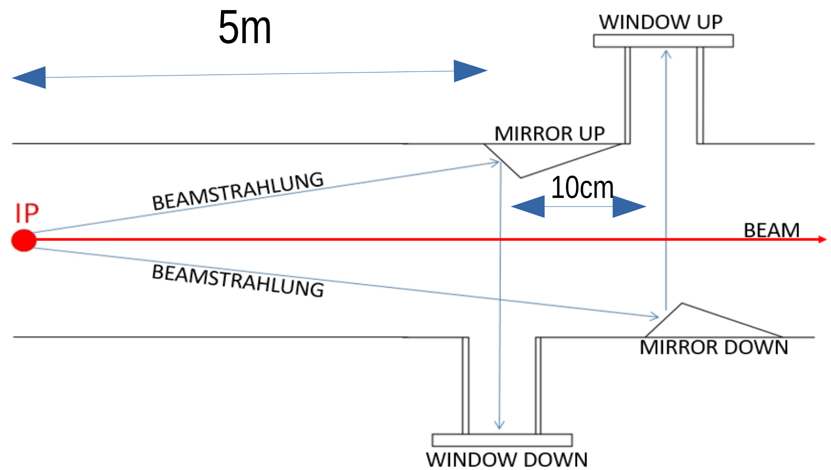
HEAD ON EXAMPLE
DOTTED/SOLID LINE IN/OUT OF THE PAGE



Simulation results
U_0 is expected value

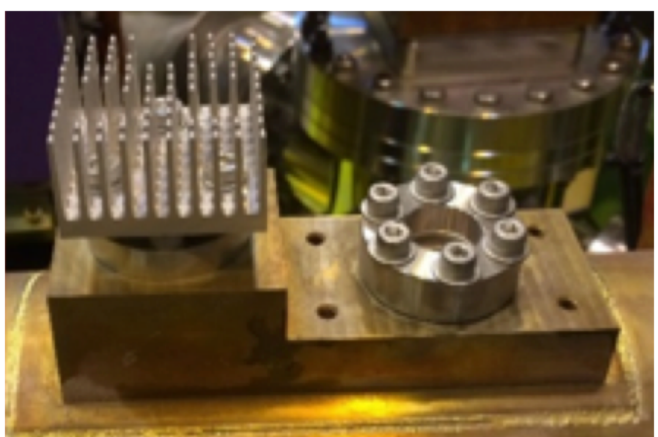
Light extraction

- Beamstrahlung from IP intercepted through vacuum mirror and extracted through a special window
- Optical channel (~10m) brings the light out of the radiation region
- Two optical channels (up/down) for each ring (e^+/e^-)

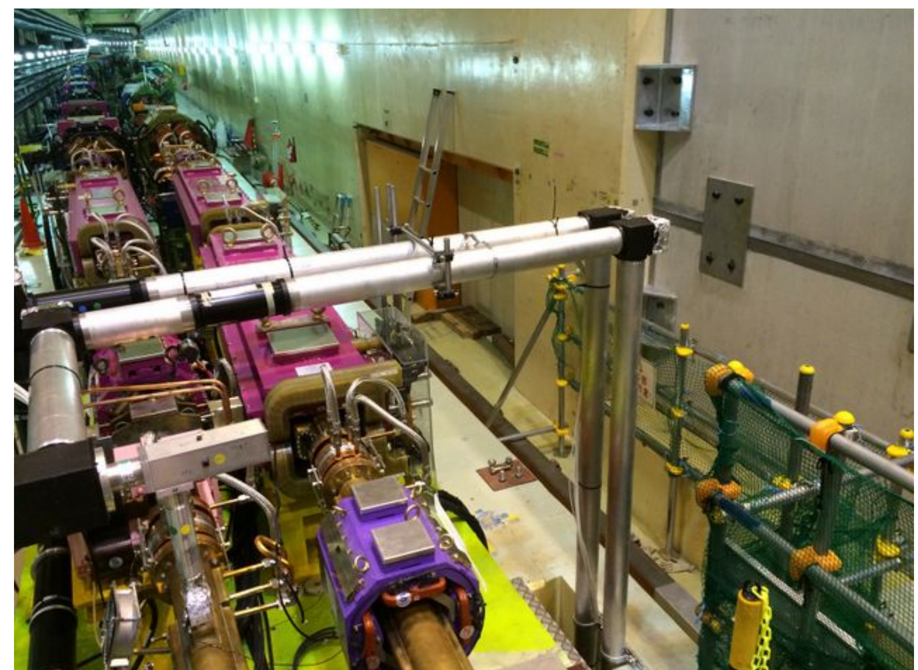


Vacuum Be mirror

Special window

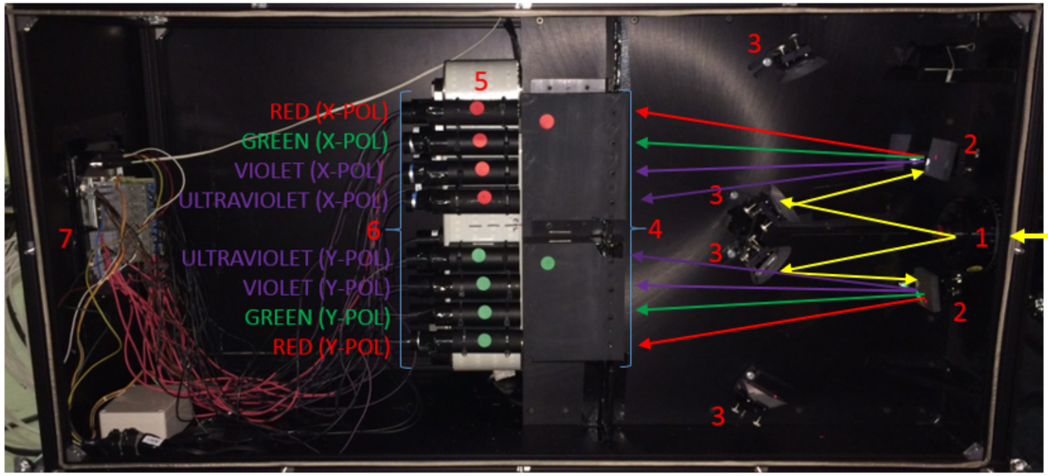


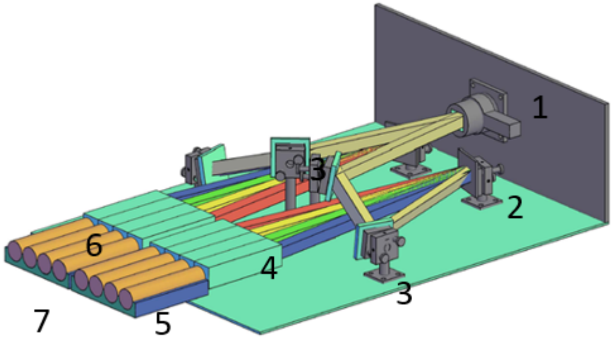
Optic channel



Light detection

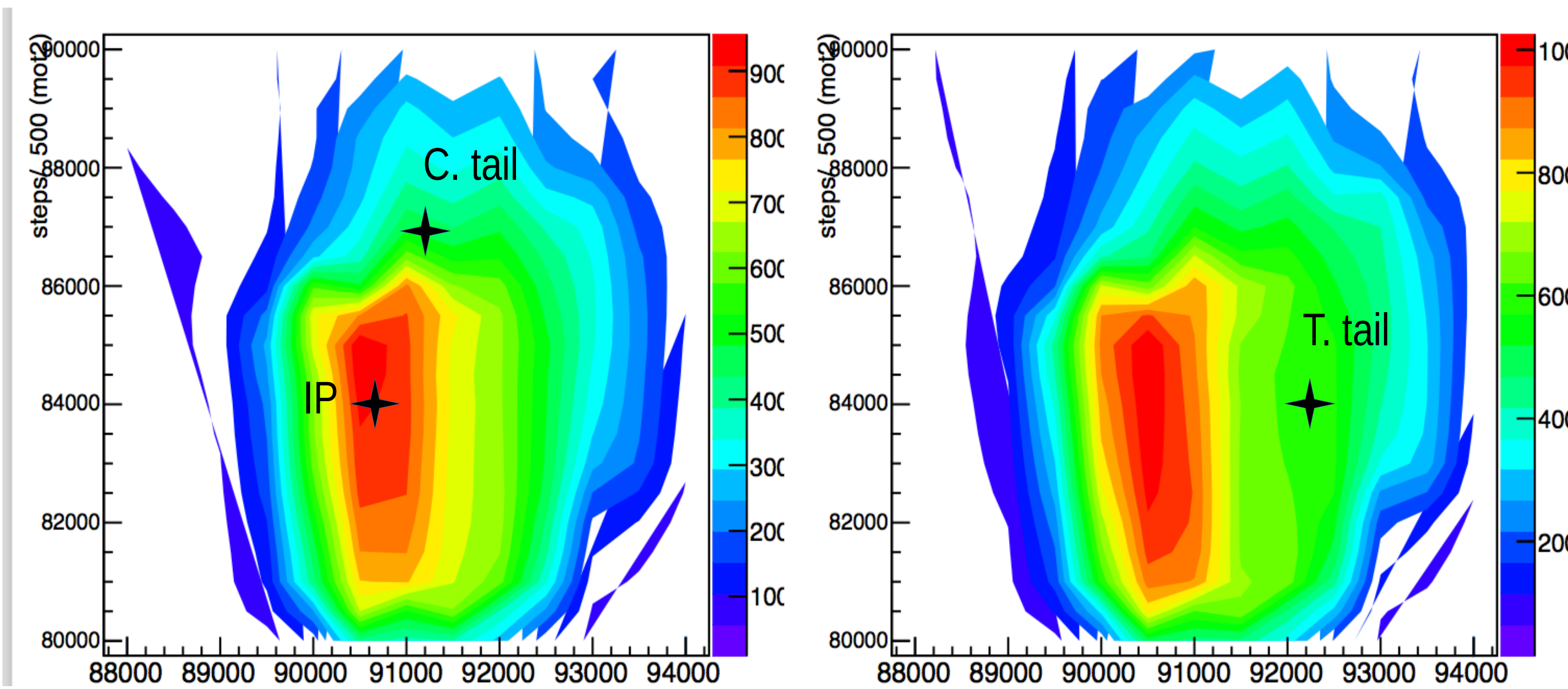
- Optic box setup 2015 – 2023
  - 1) Wollaston prism
  - 2) Gratings
  - 3) Mirrors
  - 4) Focusing lenses
  - 5) Conveyor belt
  - 6) Photo-multipliers
  - 7) Electronics
- PMT provide point measurement
- 2D scans done by moving primary mirrors, took days and months





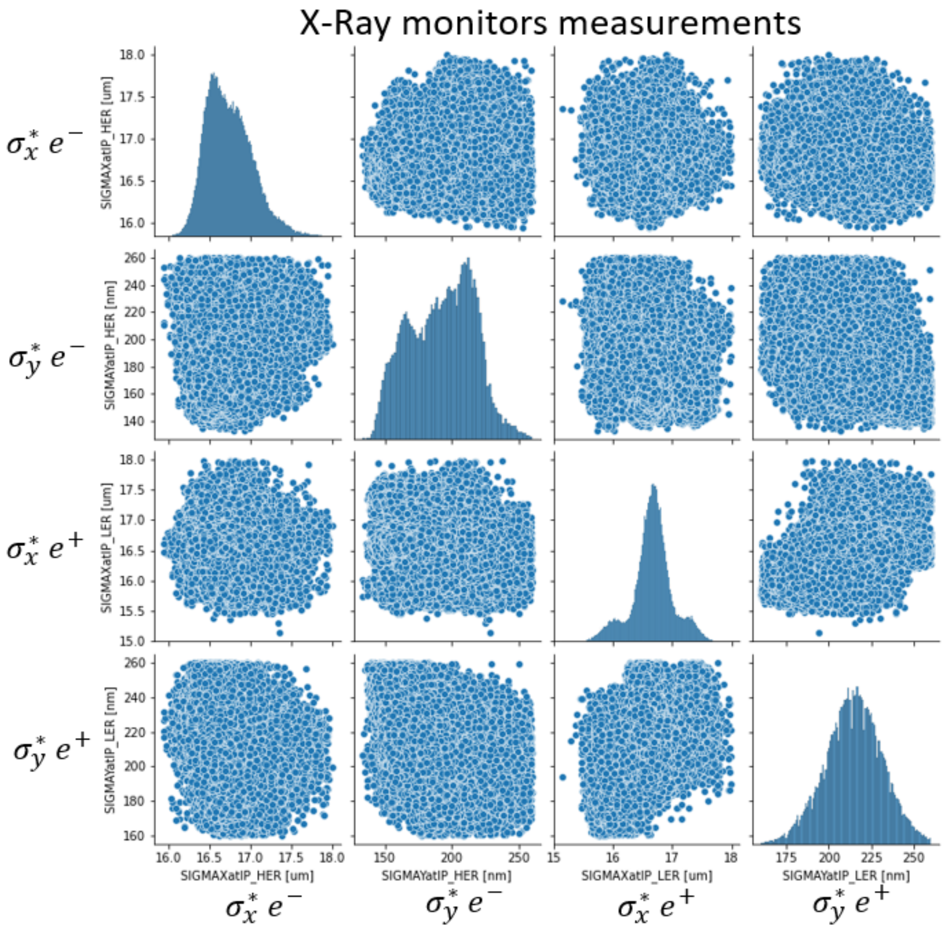
Fine 2D scan

- Fine 2D scan shows a square feature corresponding to 2×2mm² mirror.
- Surrounding light is from beam tails in the quads and reflected light in the background. Due to nature of Coulomb and Touschek tails they occupy slightly different halo regions. This redundancy is welcome and can provide extra information (C. ~luminosity, T. ~1/area).



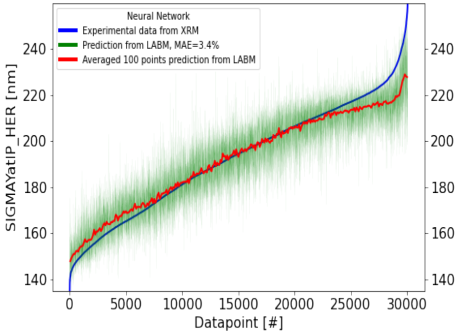
Data selection

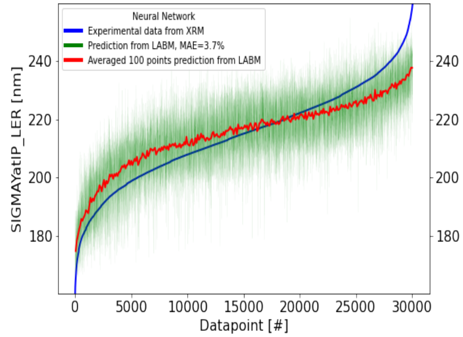
- For further analysis we used external measurements (XRM)
- Weak correlation between any pair of parameters, good parameter space coverage
- Stable physics runs, I>100mA
- A lot of variability even for stable runs

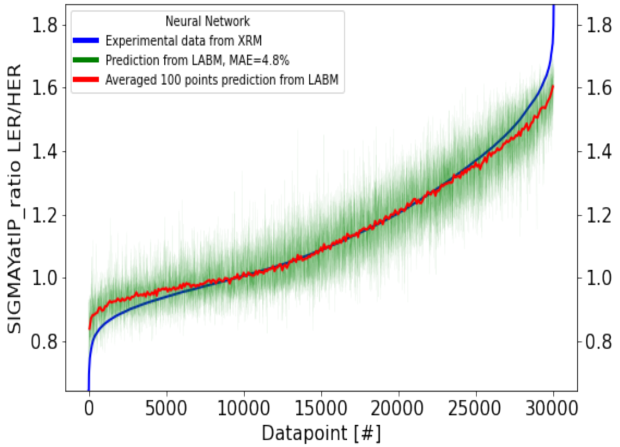


Neural network results

- Results may be obtained analytically, but difficult (rapidly varying beam conditions vs lengthy scans, theory well developed for collinear beams but not for large crossing angle like SuperKEKB)
- Neural network may take everything into account, but needs training
- Measurements from 16 PMTs (one side) to offsets, transverse sizes, aspect ratios, bunch lengths, vertical angle
- NN reproduced SuperKEKB vertical beam sizes at IP at a few percent!



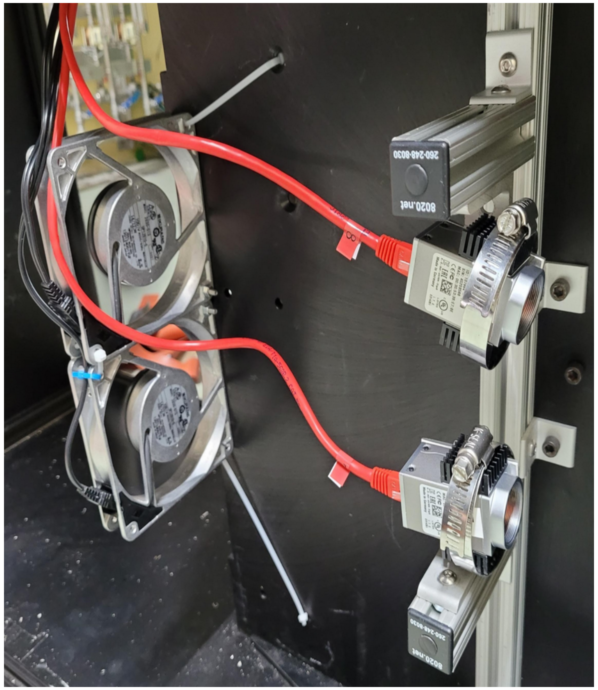




Optic box upgrade 2023

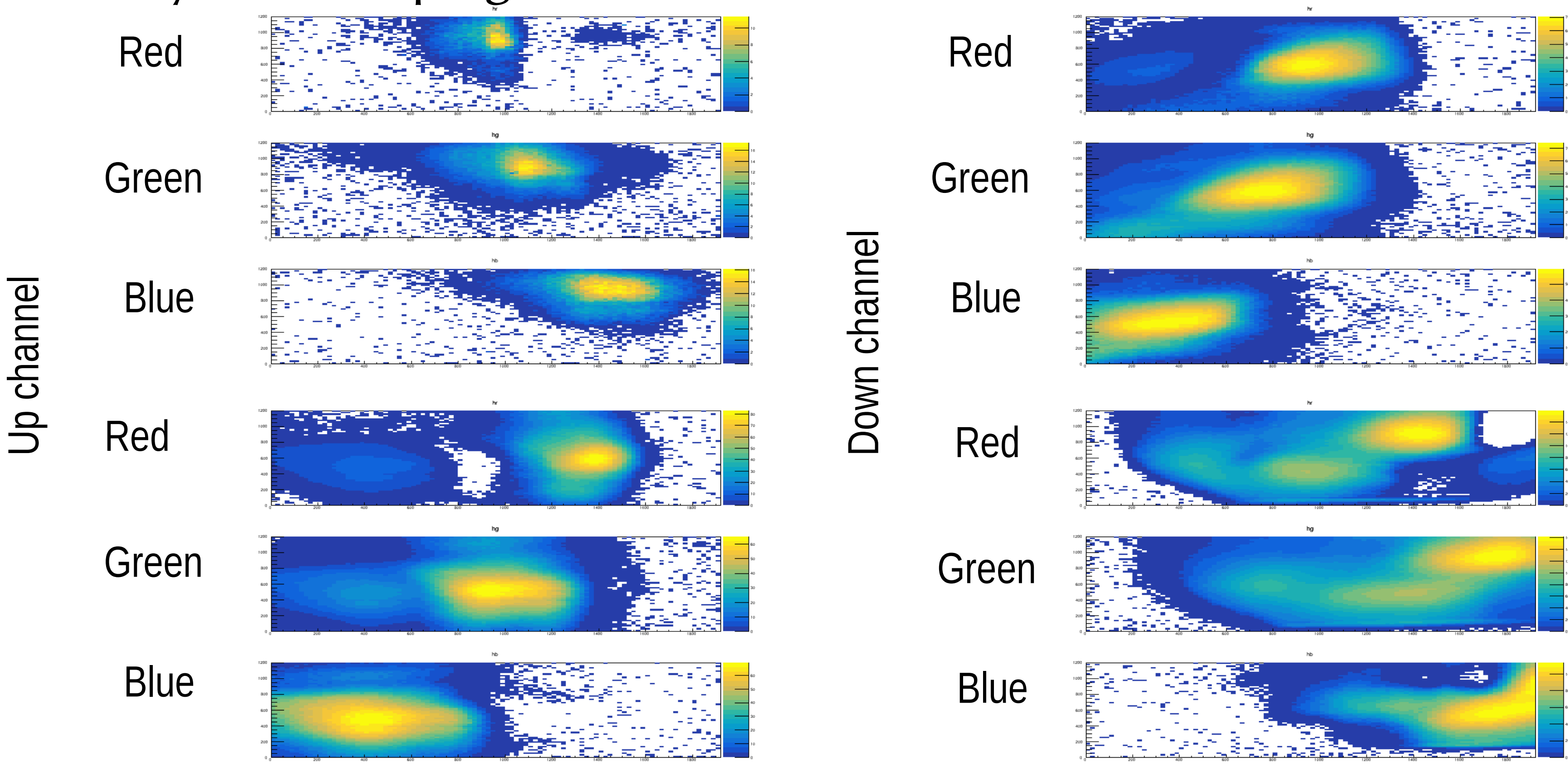
- In 2023 PMTs replaced with Basler CMOS cameras
- Get rid of most filling in optic boxes
- Only one initial scan needed to find the spot
  - Accurate positioning of cameras needed (sensor size 6.68×4.20mm)

Focusing lens goes here



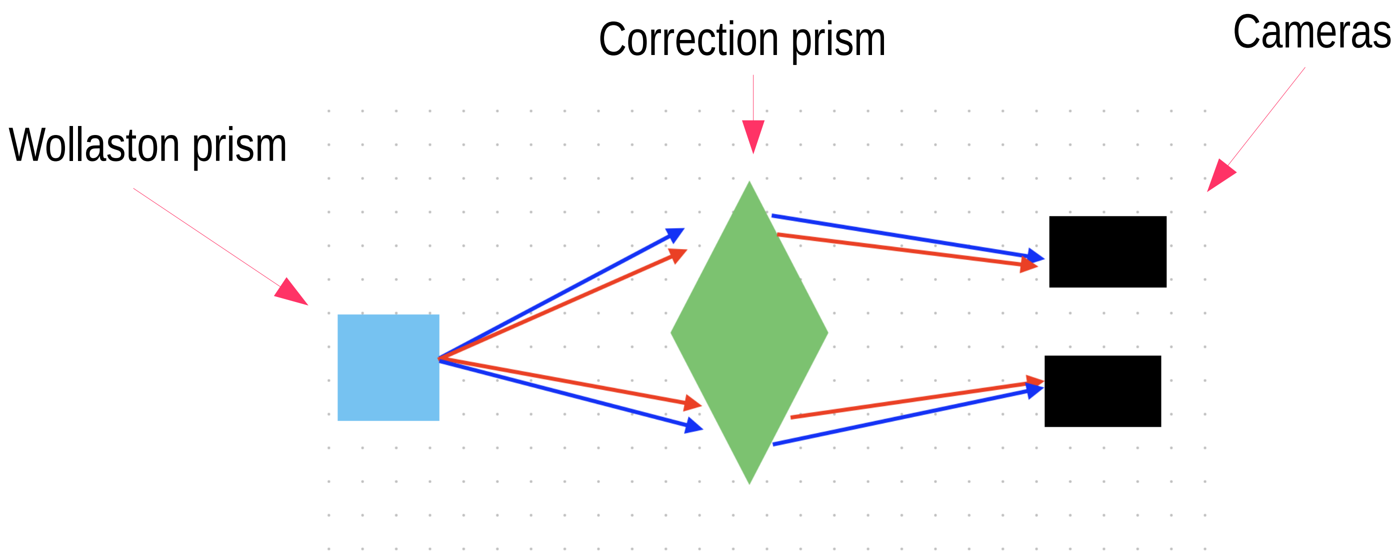
Photos of the IP (LER)

- Positron beam (LER) optic channels, both polarizations (4 cameras)
- Different positions of RGB spots due to chromaticity of Wollaston prism
- Analysis still in progress



Future upgrades

- Long optic channels make tuning lengthy, unreliable and frustrating
- Without bulky optic box it is possible to move cameras next to primary mirrors
  - Radiation damage to cameras is a concern
  - Will measure backgrounds next winter
- Take care to focus image on the cameras' sensors



Summary

- Beamstrahlung detection makes possible monitoring beams parameters and beams relative position/orientation.
- Implementation of LABM at SuperKEKB went a long way;
  many improvements were made since original design, more to come.
  - Analysis of most recent data still in progress.
- One sided option allows to determine sizes of both beams.
- Neural network made possible to extract beams parameters with very good precision.
- LABM may be installed at EIC, which will start taking data in 2031. Three invited seminars given at BNL.
  - Only one beam is electrons;
  - For protons radiation suppressed by $(r_p/r_e)^3$ but enhanced by $(\gamma_e/\gamma_p)^2$, may still be doable; also may see radiation from interaction with magnets.

Backup

Useful links

- Theoretical foundation
  - G. Bonvicini, D. Cinabro, E. Luckwald, "Measurement of colliding beam-beam parameters with wide-angle beamstrahlung", Phys.Rev. E59 (1999) 4584-4593, arXiv:physics/9 812 020
  - G. Bonvicini, J. Welch, "Large angle Beamstrahlung as a beam-beam monitoring tool", NIM A418 (1998) 223-232, arXiv:physics/9 812 023
- Intermediate results
  - R. Ayad *et al*, "Phase I results with the Large Angle Beamstrahlung Monitor (LABM) with SuperKEKB beams", arXiv:1709.01608
- Neural network results
  - S. Di Carlo *et al*, "A Neural Network approach to reconstructing SuperKEKB beam parameters from beamstrahlung", NIM A1042 (2022) 167 453, arXiv:2206.11709

Large angle beamstrahlung power

- Energy for collinear collision by beam 1 is:

$$P_0 = \frac{0.11\gamma^2 r_e^3 mc^2 N_1 N_2^2}{\sigma_x^2 \sigma_z}$$

- Wider angular distribution (compared to quadrupole SR) provides main background separation
- CESR regime: exponent is about −4.5
- SuperKEKB: exponent is −0.13 to −1.2

$$\frac{d^2 I}{d\Omega d\sigma} = \frac{3\sigma_z}{4c\pi\sqrt{\pi}} P_0 \frac{1}{\gamma^4\theta^4} \exp\left(-\frac{\omega^2\theta^4\sigma_z^2}{16c^2}\right)$$

Photos of the IP (HER)

- Electron beam (HER) images don't look so well, long optic channels make it hard to find a spot. NN may still be able to determine beam parameters.