# Caleb Miller (about me)

- BSc UNBC
- MSc Queen's, SNO+
  - Tellurium cosmogenic activation
  - Acrylic compatibility with scintillator cocktail
- PhD Candidate at UVic, BaBar and Belle II
  - Neutron detection to study beam backgrounds
  - MC generator validation and theory comparison
  - Development of new beam polarimetry technique

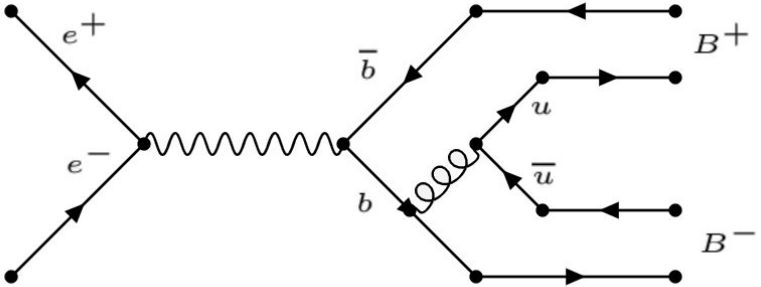
# Belle II

On the precision frontier

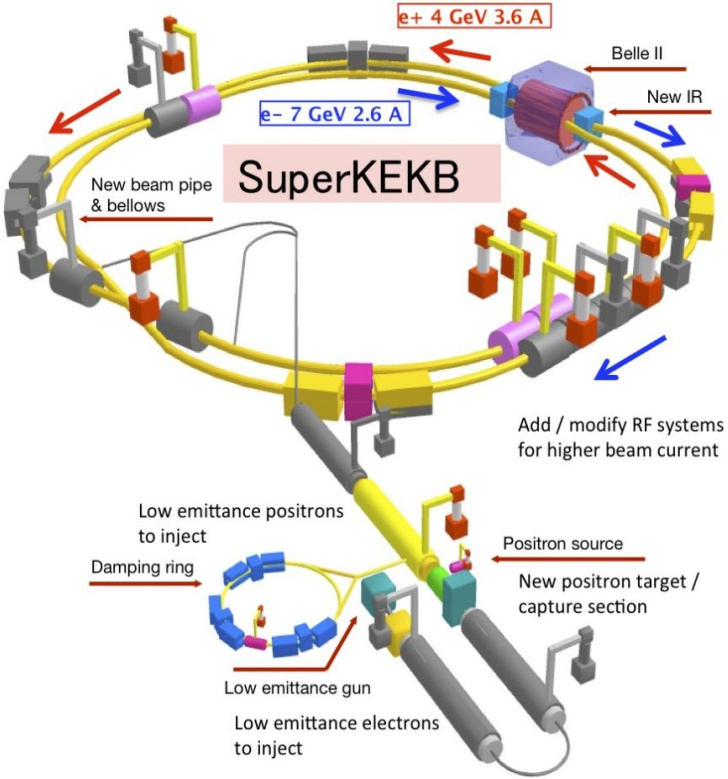

EIEIOO 2021

# SuperKEKB

- 3 km circumference $e^+e^-$ collider
- Located at KEK in Japan
- “B-factory”  10.577 GeV CM Energy (Y(4S))

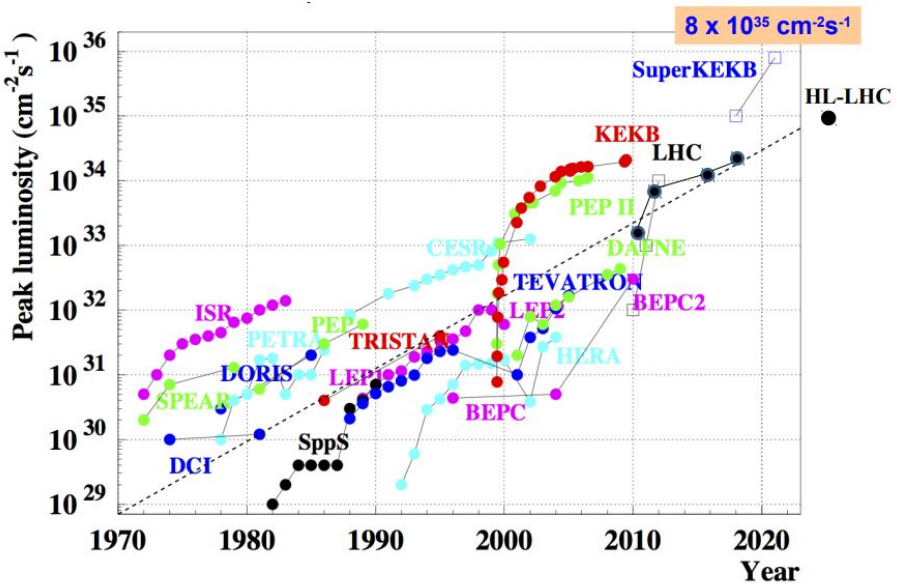






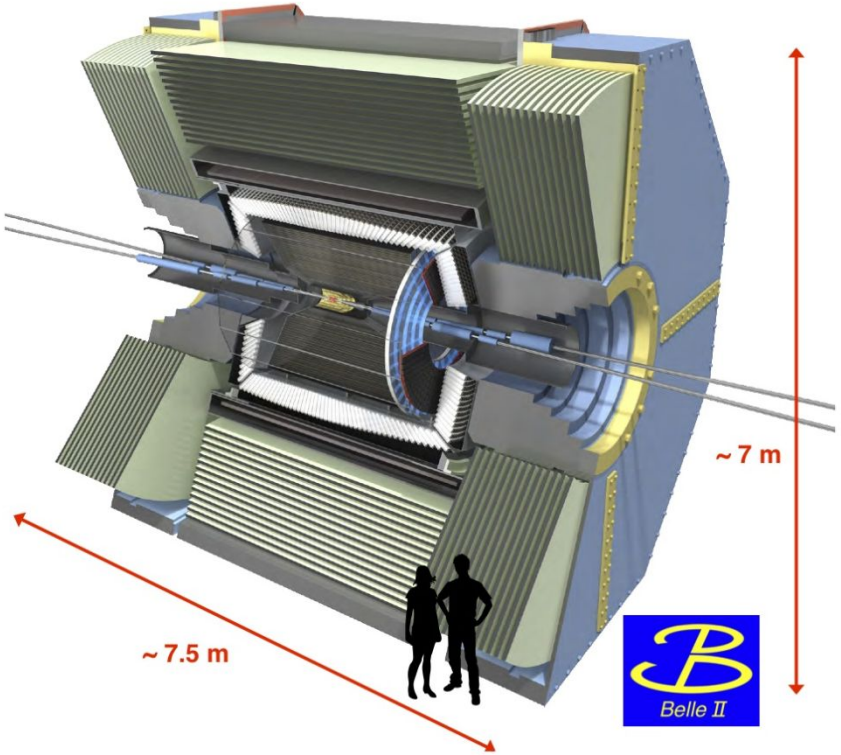
# Luminosity Goals

- SuperKEKB is designed to set a luminosity record at $8 \times 10^{35}\ cm^{-2}s^{-1}$
- Luminosity: particles per area per second
- Will allow us to collect a huge amount of data
- 50 $ab^{-1}$ over experiment lifetime
- 100x times more than BaBar or Belle collected
- Lets us measure properties of particles to sub-percent precision



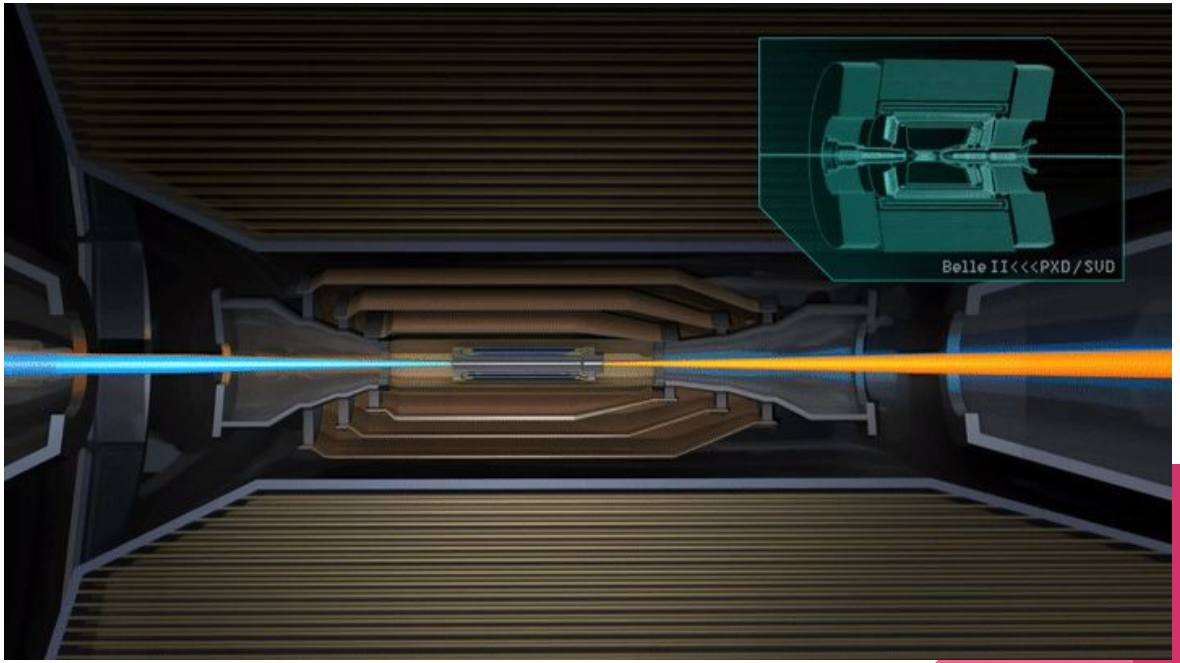
# Belle II

- Upgrade to the existing Belle detector
- Merged collaboration of the Belle and BaBar groups
- ~1000 active members
  - ~400 grad students+50 undergrads
- Layers of sub detectors
  1. PXD (VXDa)
  2. SVD (VXDb)
  3. CDC
  4. TOP + ARICH
  5. ECL
  6. KLM



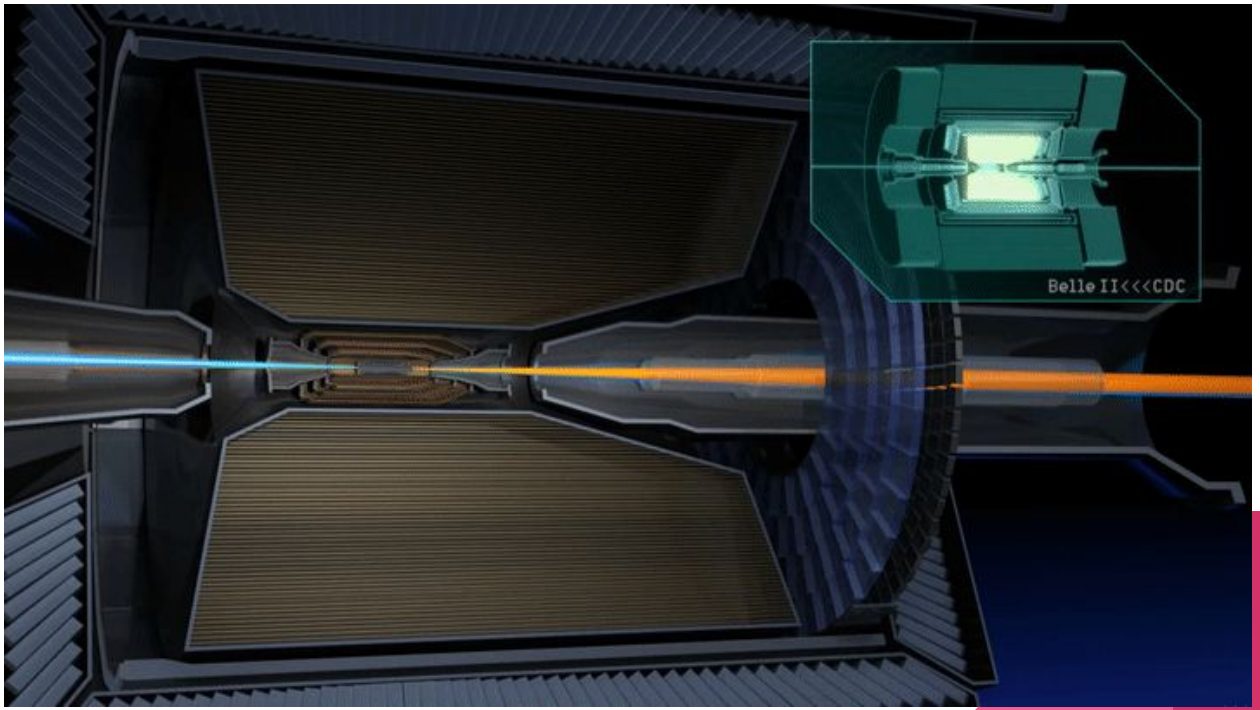
# VXD

- The **V**erte**x** **D**etector is made of 6 layers of silicon detectors
- The first 2 layers use square “pixels” ($50\mu m \times 50\mu m$) and are known as the PXD (silicon **Pix**el **D**etector)
- The next 4 use strips of silicon ($12cm \times 6cm$) and are known as the SVD (**S**ilicon **V**ertex **D**etector)



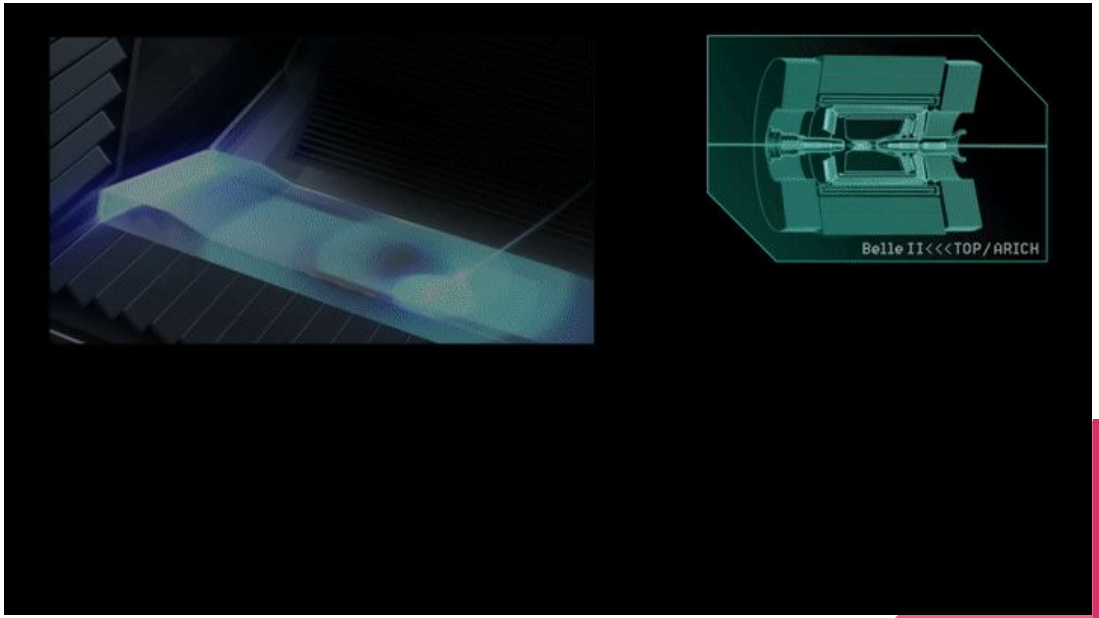
# CDC

- The **C**entral **D**rift **C**hamber does all the tracking of charged particles
- 1.13 m in radius with 14336 sense wires, all inside a 1.5 T magnetic field
- Tells us the charge, momentum (p), and dE/dx of each charged track



# TOP + ARICH

- The **T**ime **O**f **P**ropagation and **A**erogel **Ri**ng **Ch**erenkov detectors significantly improve particle identification
- Both use Cherenkov radiation to determine the speed of particles, $\cos\theta=(n\beta)^{-1}$
- Using the momentum from the CDC we can extract the rest mass, $p=\gamma m_0 v$



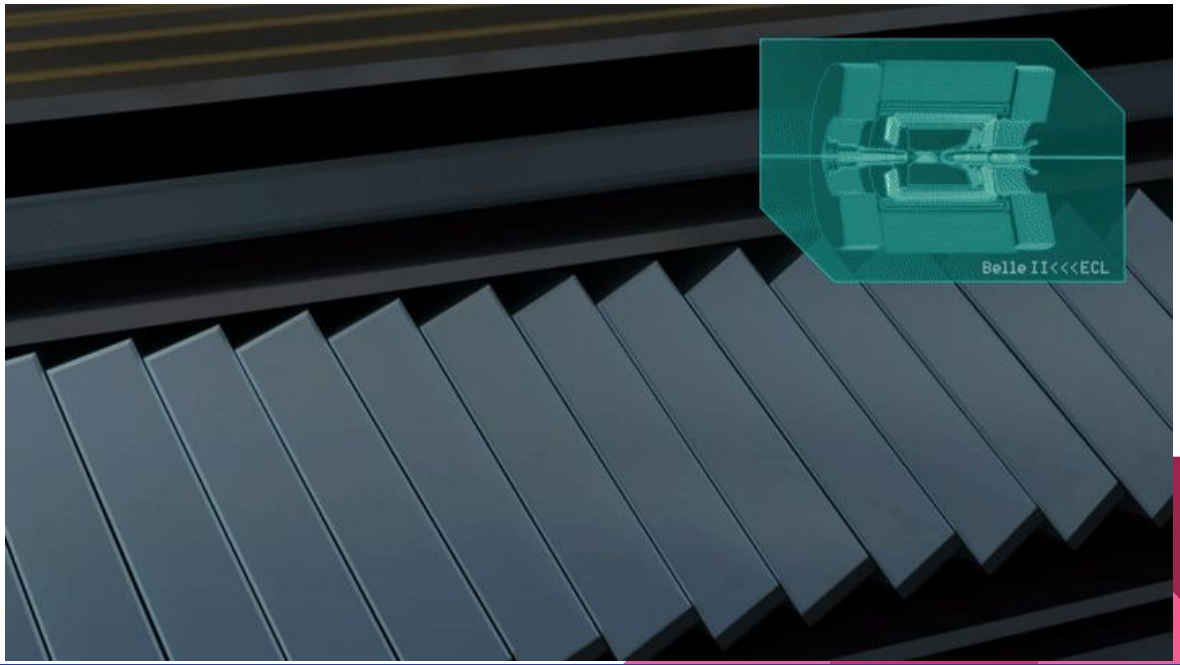
# ECL

- The **E**lectromagnetic **C**a**l**orimeter detects photons and stops most electrons and pions
- We can use E/p to identify electrons from pions with high efficiency
- Made of 8736 thallium-doped caesium iodide crystal (CsI(Tl)) covering 90% of the solid angle

- **Large Canadian contribution**

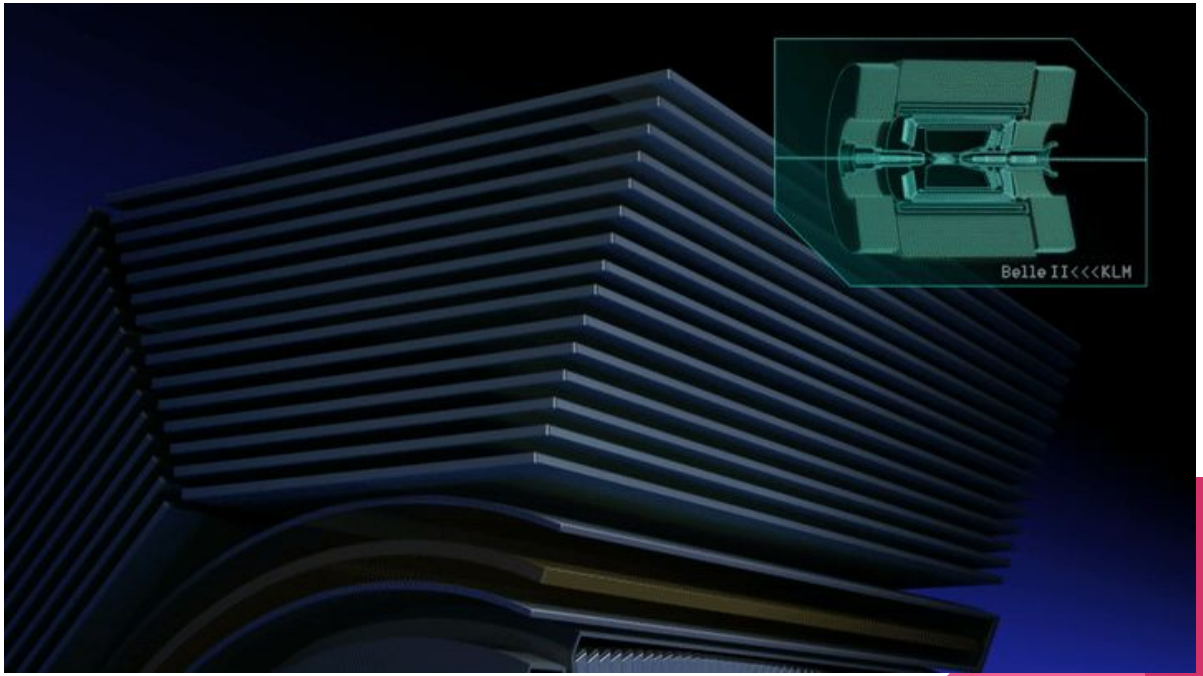
➔ Pulse Shape Discrimination developed at UVic

➔ UBC is responsible for timing calibrations



# KLM

- The **$K_L$** and **M**uon detector is the final layer of Belle II
- Consists of alternating sheets of iron and scintillator
- Stops the rest of the high energy hadrons, waves at the muons as they go by



# Belle II Physics

- CP violation in the quark sector (Do particles behave the same as antiparticles)
  - Currently in the SM there is not enough to explain why there's more matter in the universe
  - By making precise measurements of b→s and b→d quarks we could discover more CP violation
- **Multiple Higgs Bosons**
  - We don't have enough energy to produce Higgs' directly but we can still detect their effects
- Lepton Flavour Violation
  - We can look for and set limits on processes such as $\tau \rightarrow \mu\gamma$
- **Dark Sector**
  - Are there dark matter particles enhancing certain process, or carrying away energy?
- And much more

# Multiple Higgs Bosons

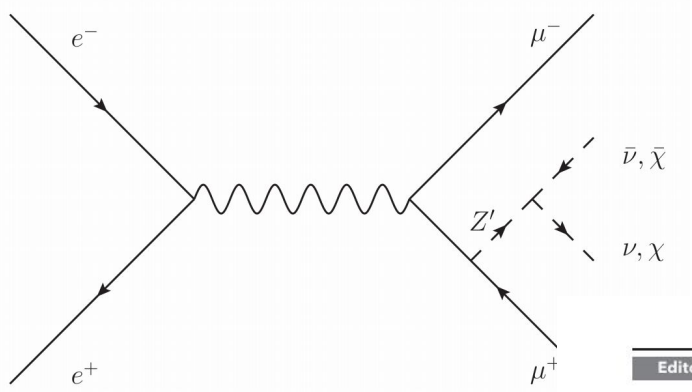
- The Higgs Boson couples to matter and gives it mass
- Therefore processes involving heavier particles should be more sensitive to them

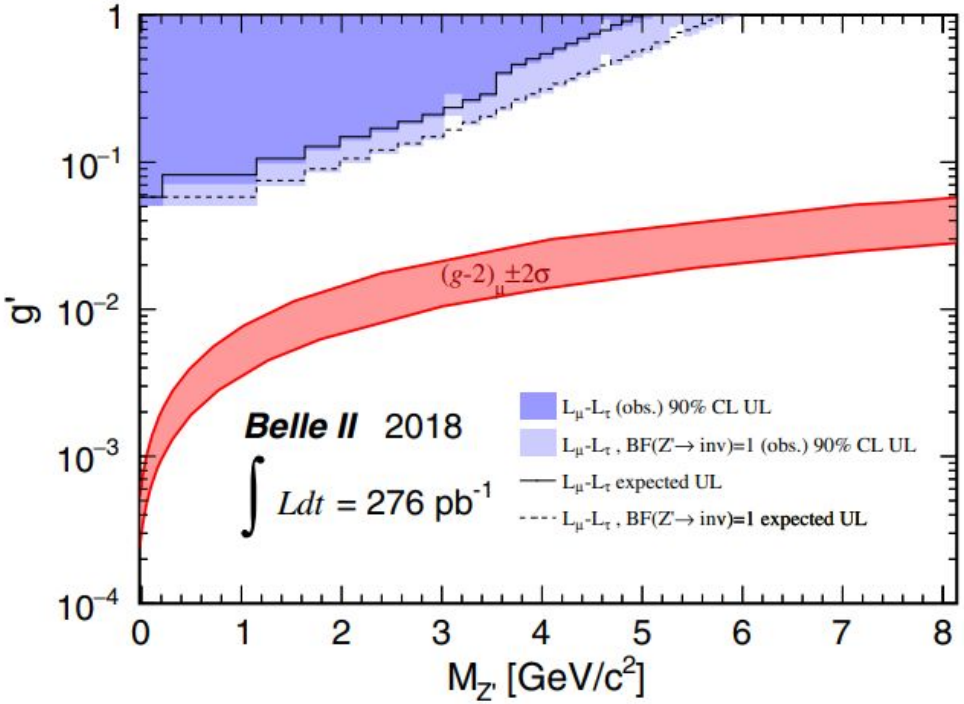
$$\Gamma_{\Upsilon\to\ell\ell} = 4\alpha^2 e_q^2 \frac{|\Psi(0)|^2}{M^2}(1+2m_\ell^2/M^2)\sqrt{1-4m_\ell^2/M^2}$$

$$R_{\tau\mu} = \frac{\Gamma_{\Upsilon\to\tau\tau}}{\Gamma_{\Upsilon\to\mu\mu}} = \frac{(1+2m_\tau^2/M^2)\sqrt{1-4m_\tau^2/M^2}}{(1+2m_\mu^2/M^2)\sqrt{1-4m_\mu^2/M^2}}$$

# Dark Matter

- Belle II has published a search for a Z' from 276 $pb^{-1}$ (0.005% of expected full data)




PHYSICAL REVIEW LETTERS **124,** 141801 (2020)

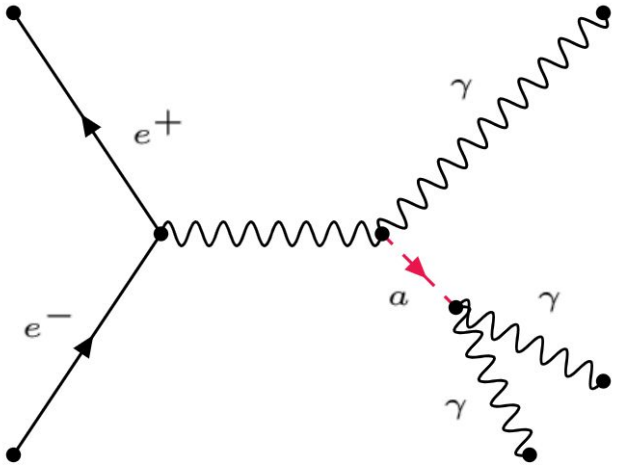
Editors' Suggestion | Featured in Physics

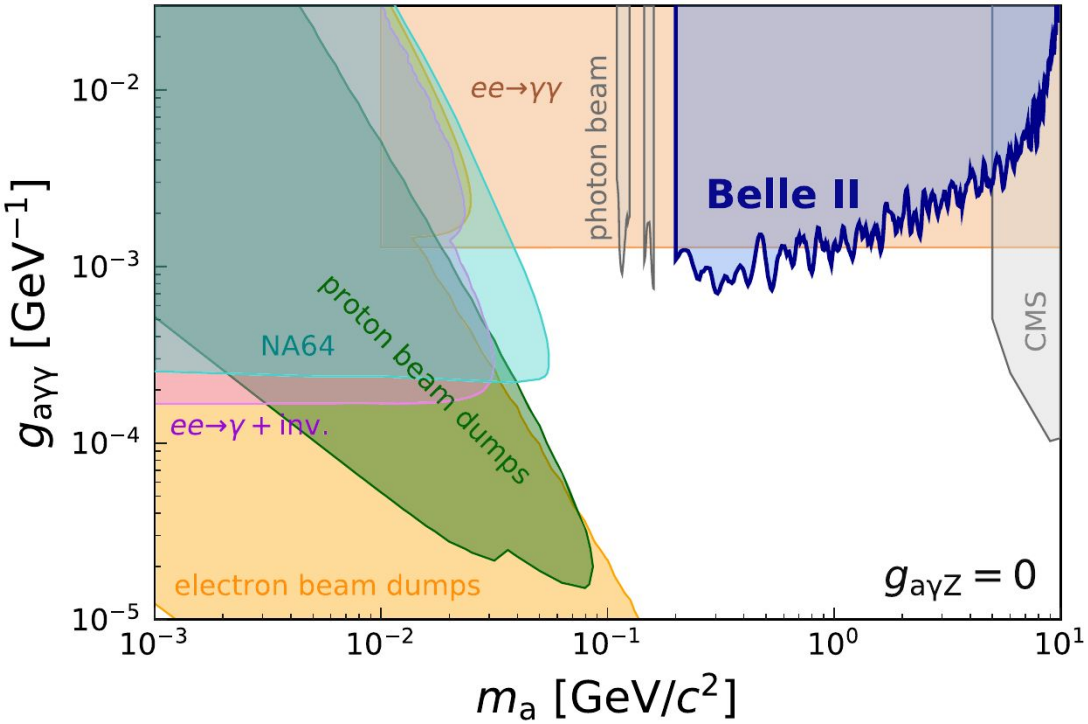
**Search for an Invisibly Decaying $Z'$ Boson at Belle II in $e^+e^- \to \mu^+\mu^-(e^\pm\mu^\mp)$ Plus Missing Energy Final States**

I. Adachi,[21,18] P. Ahlburg,[95] H. Aihara,[111] N. Akopov,[117] A. Aloisio,[86,33] N. Anh Ky,[30,12] D. M. Asner,[2] H. Atmacan,[97]

# Dark Matter

- Belle II has also published a search for axions from 445 $pb^{-1}$ (0.009% of expected full data)




PHYSICAL REVIEW LETTERS **125,** 161806 (2020)

**Search for Axionlike Particles Produced in $e^+e^-$ Collisions at Belle II**

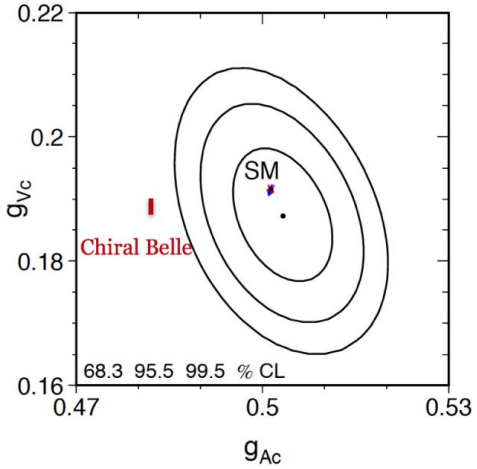
F. Abudinén,[42] I. Adachi,[21,18] H. Aihara,[115] N. Akopov,[121] A. Aloisio,[87,35] F. Ameli,[39] N. Anh Ky,[32,11] D. M. Asner,[2] T. Aushev,[23] V. Aushev,[77] V. Babu,[9] S. Baehr,[46] S. Bahinipati,[25] P. Bambade,[96] Sw. Banerjee,[105] S. Bansal,[68] J. Baudot,[97] J. Becker,[46] P. K. Behera,[27] J. V. Bennett,[109] E. Bernieri,[40] F. U. Bernlochner,[99] M. Bertemes,[29] M. Bessner,[102]

# “Chiral” Belle

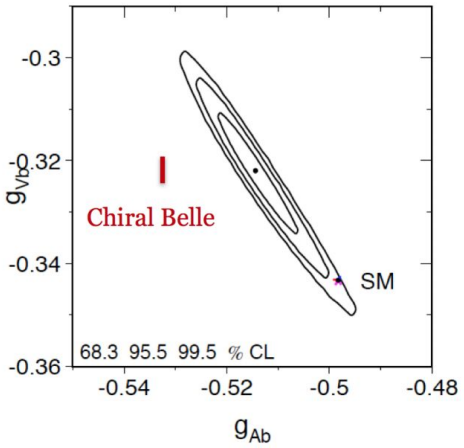
- Belle II just started data taking which means it’s time to think about upgrades
- One promising upgrade path is a polarized electron beam

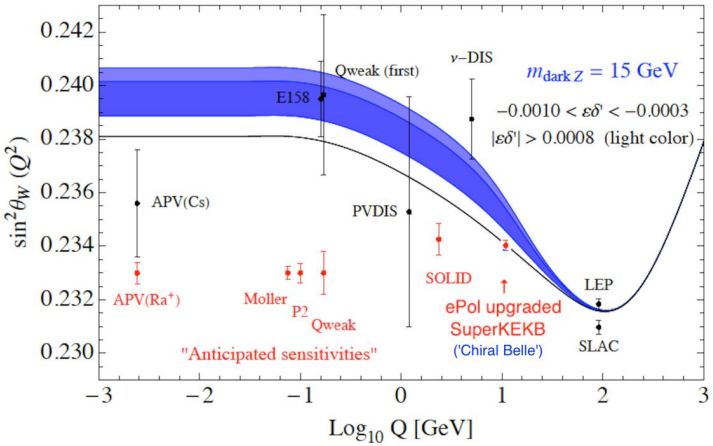
**c-quark:** **with 20 ab$^{-1}$** **b-quark:**

Chiral Belle ~7 times more precise



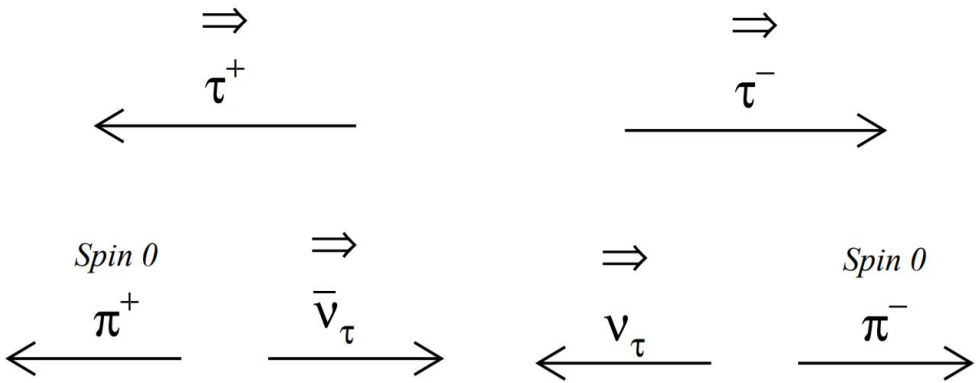

Chiral Belle ~4 times more precise



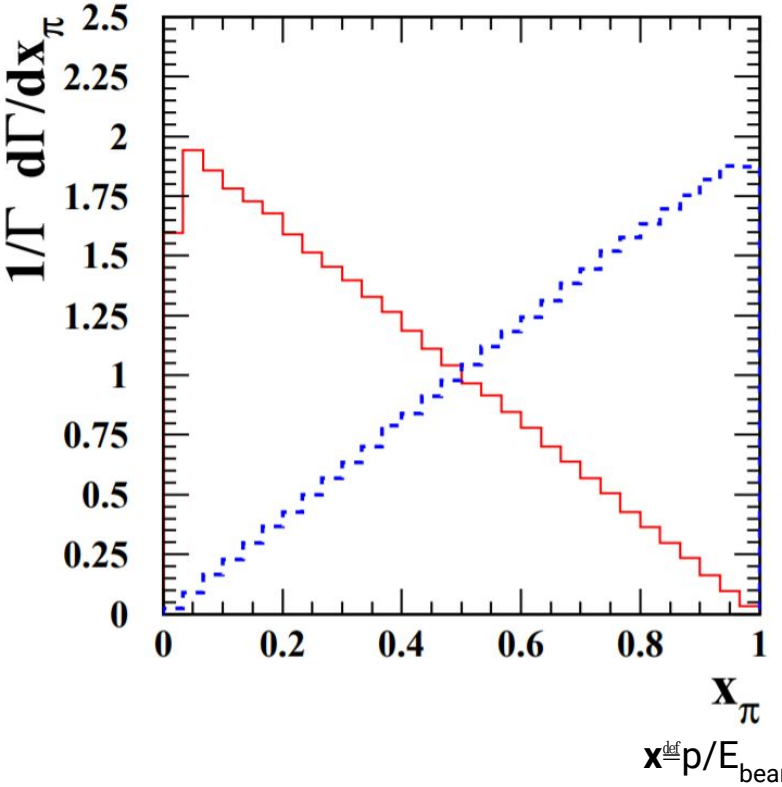



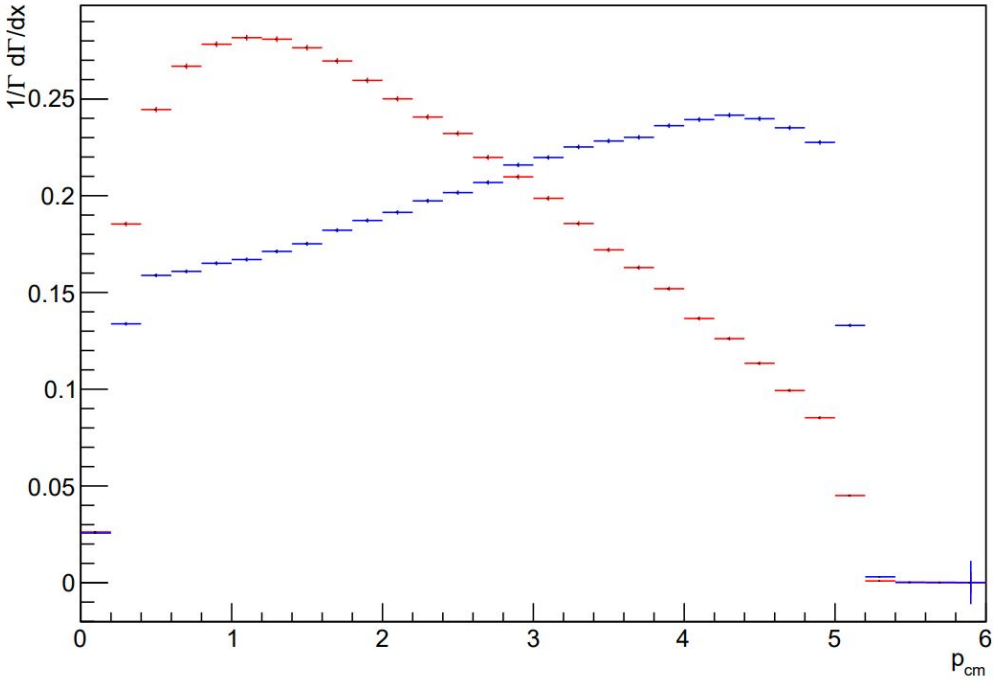
# Polarimetry

- Precision of the measurements is limited by the precision we can know the average beam polarization
- Tau Polarimetry!



# Polarimetry



# Polarimetry

- Using 30 $fb^{-1}$ of BaBar data we measured:

$$< P >= 0.0135 \pm 0.0106_{\text{stat}} \pm 0.0045_{\text{sys}}$$

- Working now on full dataset and getting a publication out
- Starting to reproduce the analysis on Belle II

# Summary

- Belle II is taking data and there's plenty of topics to work on
- Data Analysis, Software Development, Hardware, Theory
- In Japan!
  - Sushi, Ramen, Okonomiyaki

**Thank you all for listening**
Enjoy your summer!