



Canadian Belle II upgrade activities

TRIUMF—KEK symposium,
Tom Blake, University of Victoria



**UNIVERSITY
OF ALBERTA**



**University of
British Columbia**



McGill



**University
of Manitoba**

Introduction

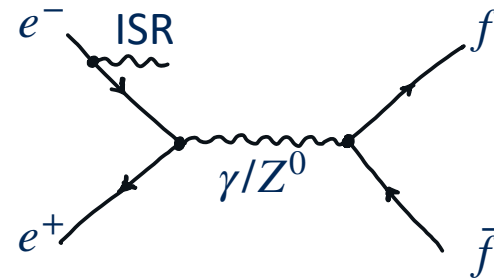
1. Chiral Belle
2. Belle II drift chamber replacement/upgrade

Why Chiral Belle?

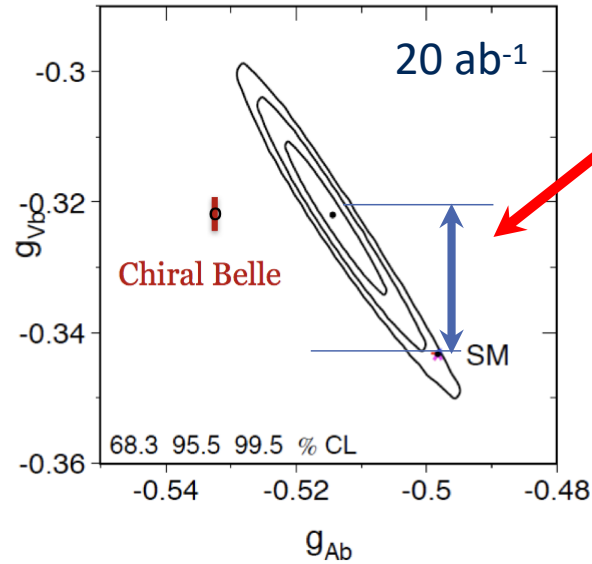
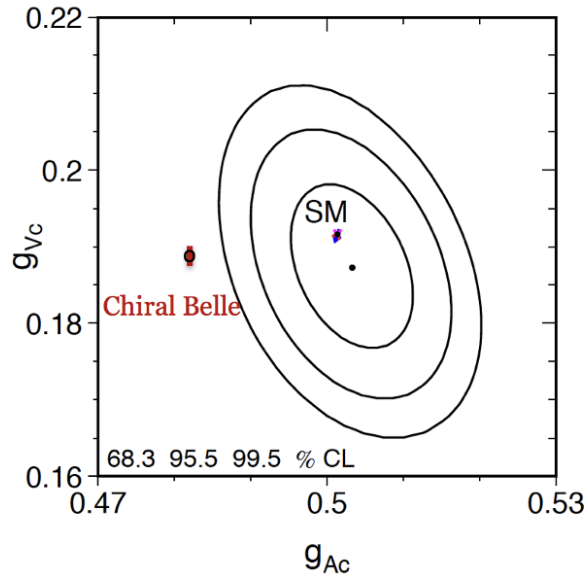
- Polarised e^- beam allows access to precision electroweak observables, e.g. to probe vector and axialvector interference in Standard Model.
- Can use left-right detection asymmetries to probe SM vector couplings for different fermion flavours (charm, beauty, tau):

$$A_{\text{LR}} = \frac{\sigma_{\text{L}} - \sigma_{\text{R}}}{\sigma_{\text{L}} + \sigma_{\text{R}}} = \frac{4}{\sqrt{2}} \left(\frac{G_{\text{FS}}}{4\pi\alpha Q_f} \right) g_A^e g_V^f \langle \text{polarisation} \rangle$$

where $g_V^f = T_3^f - 2Q_f \sin^2 \theta_{\text{W}}$



Expected precision on $g_V^{c,b}$



Tension in existing measurements of g_V^b , can be resolved by Chiral Belle.

Expect significant improvement over LEP+SLD

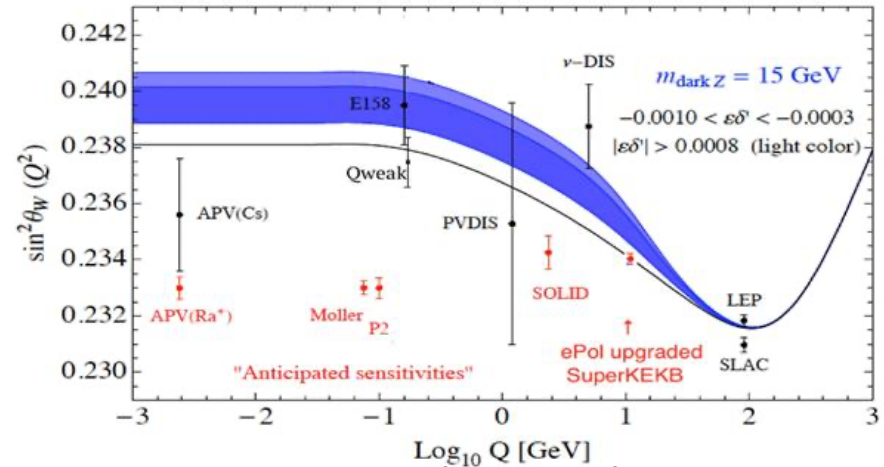
Measurement	Current average	Chiral Belle (20 ab^{-1})
g_V^b	± 0.0077	± 0.002
g_V^c	± 0.0070	± 0.001
g_V^τ	± 0.0010	± 0.001

Current best average from:
Physics Reports 427 (2006) 5—6

Sensitivity to $\sin^2 \theta_W$

- The weak mixing angle is energy dependent (due to the running of the gauge couplings).
- $\sin^2 \theta_W$ is measured precisely at the Z-pole by LEP and SLD.
- $\sin^2 \theta_W$ is known less precisely at low Q^2 .

Phys. Rev. D92 (2015) 035008

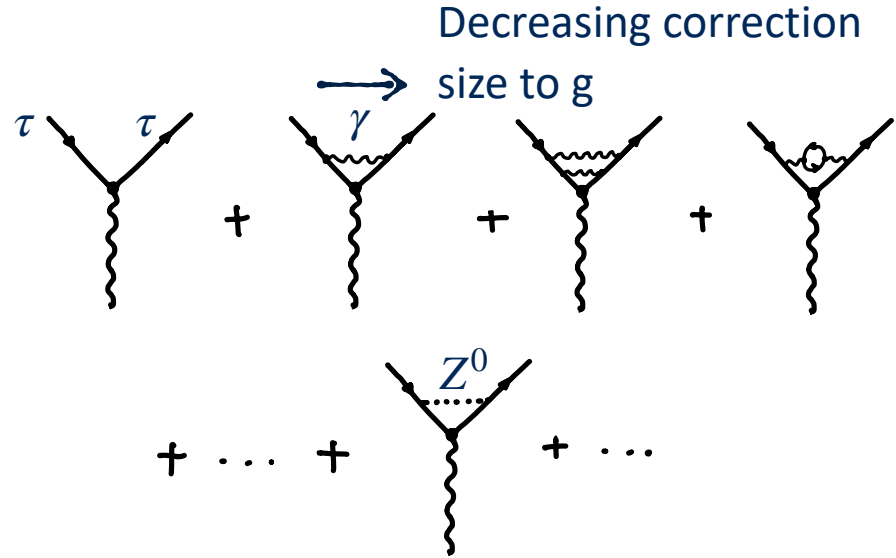


$\sin^2 \theta_W$ at low Q^2 can be a sensitive probe of dark sector extensions of SM with dark photons/dark Z bosons

Tau $g - 2$

- Tau anomalous magnetic moment can be highly sensitive to presence of new virtual particles.
- Expect BSM contributions to $a_\tau = (g - 2)_\tau / 2$ to be significantly enhanced

$$a_\tau \sim a_\mu \left(\frac{m_\tau}{m_\mu} \right)^2$$



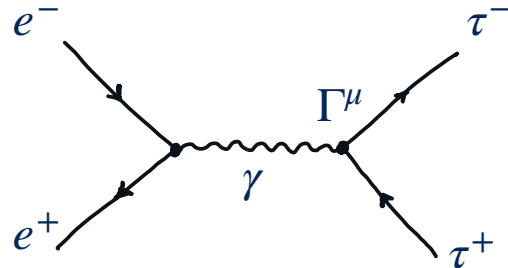
Tau $g - 2$

- Expect precision at the level of 10^{-5} with Chiral Belle (up-to 1000x more precise than existing measurements).
- Experimental uncertainties can be significantly reduced by measuring charge-dependent left/right asymmetries.

See e.g

[Phys. Rev. D106 (2022) 093007]

[JHEP 07 (2025) 172]



Vertex can be decomposed into terms with different Lorentz structures

$$\Gamma^\mu = F_1(Q^2)\gamma^\mu$$

$$+ \frac{1}{2m_\tau} F_2(Q^2) i\sigma^{\mu\nu} q_\nu$$

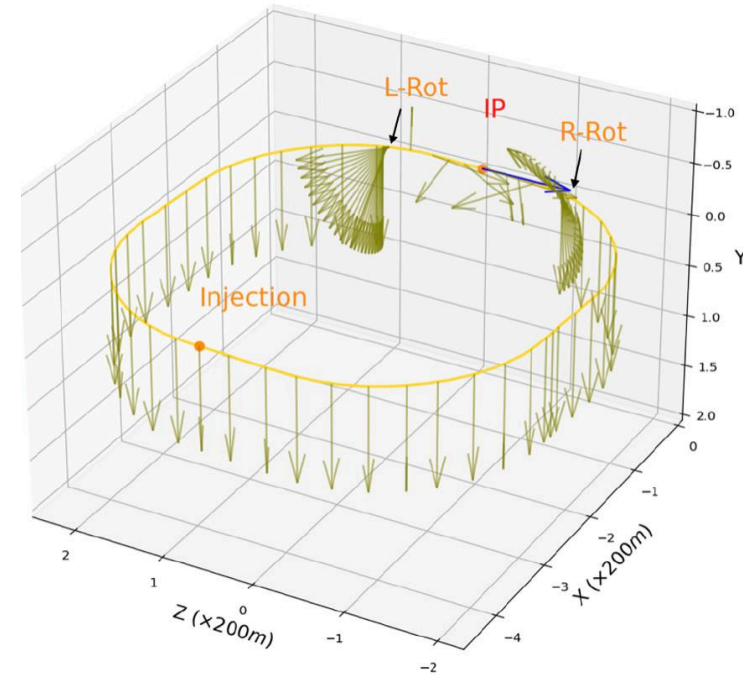
Magnetic dipole moment

$$+ \frac{1}{2m_\tau} F_3(Q^2) \gamma_5 \sigma^{\mu\nu} q_\nu \gamma_5$$

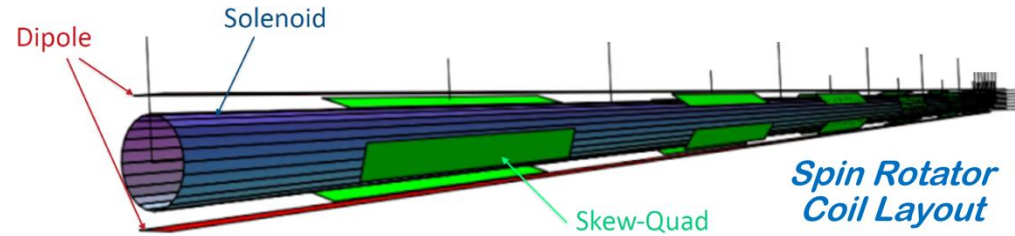
Electric dipole moment

Polarised beams

- Target 70% longitudinal polarisation of the electron beam at the IP.
- Generate transversely polarised beam with spins in the vertical direction.
- Rotate spins before/after IP using spin rotator magnets.
- Monitor polarisation using a Compton polarimetry system.



Spin rotators



- Replace existing ring dipoles by combination of a dipole and solenoid.
 - Enables running with same machine geometry with/without polarisation by enabling/disabling the solenoid field.
- Introduce skew-quadrupoles to compensate for x—y couplings from the solenoid.
- A prototype spin-rotator magnet will be produced by BNL (exploiting expertise with direct wind magnets).

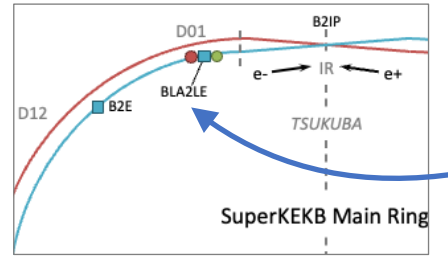
Designed by
U. Wienand
(Argonne National Lab)

Polarimetry

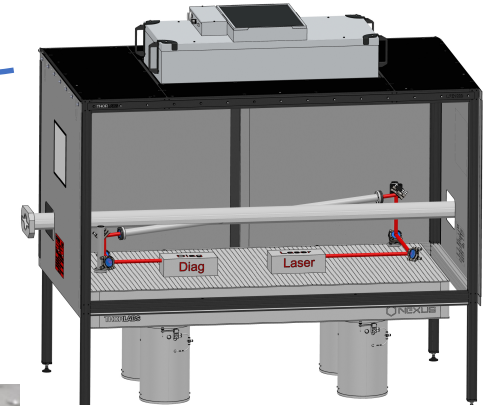
- Precise knowledge of polarisation is essential for the Chiral Belle programme.
 - Target 0.5% precision on $\langle \text{polarisation} \rangle$.
- Two methods will be used to monitor the polarisation:
 - Compton polarimetry
[JINST 18 (2023) P10014]
Target 1% precision in 5 minutes of running.
 - Data-driven tau pair reconstruction
[Phys. Rev. D108 (2023) 092001],
BaBar obtain 0.4% precision in 424fb^{-1} .

Compton polarimeter

- Plan to introduce a Compton electron detector system just before the IR.
- Scatter polarised electrons from circularly polarised laser source and measure the energy of the scattered photons/electrons.

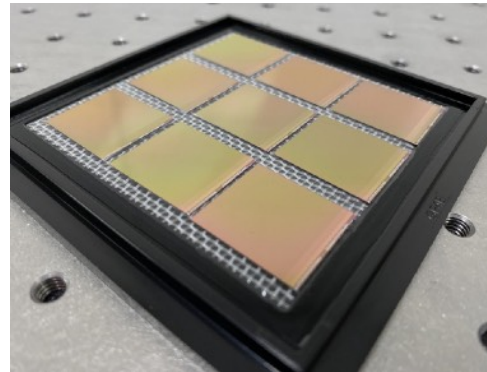


R&D at University
of Manitoba



HVMAP pixel
sensors electron
detection.

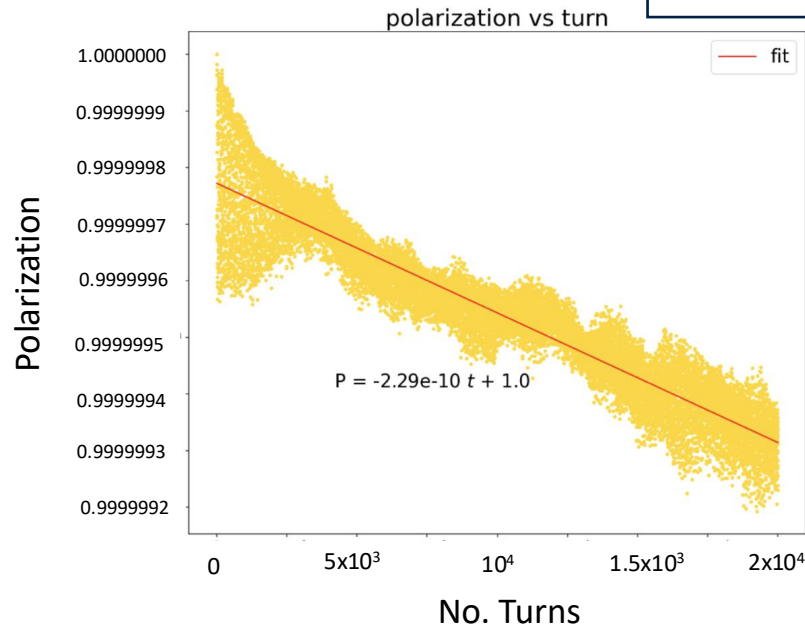
MuPIX11 sensors
at Manitoba.



Simulation of spin and beam lifetime

Y. Peng
UVic

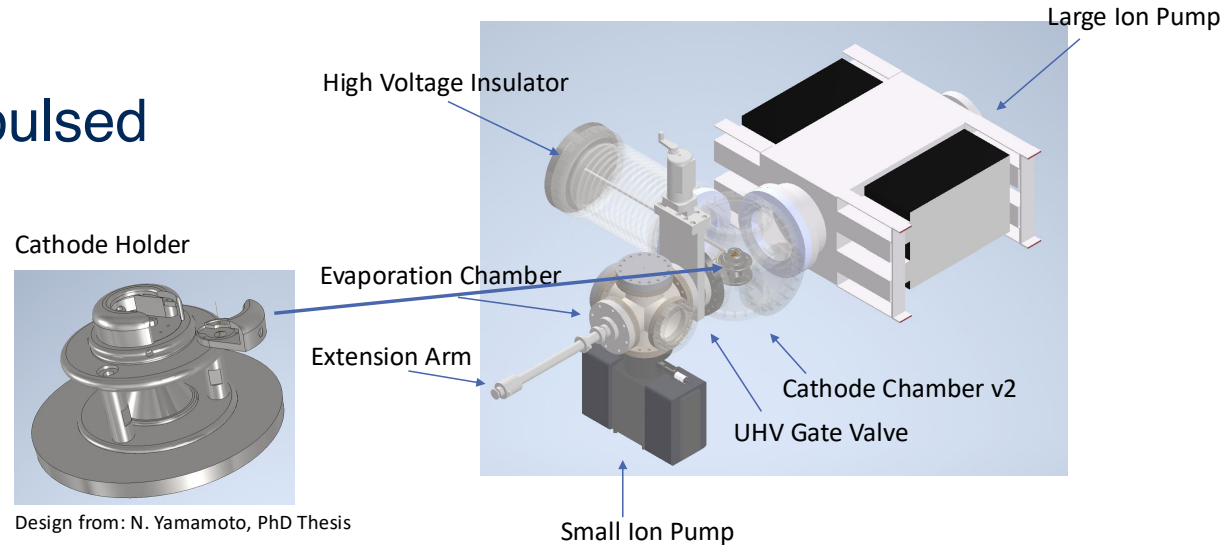
- Simulation of the Belle II HER ring carried out with BMAD.
[NIM A 558 (2006) 356—359]
- Particle tracking over 20k turns shows excellent preservation of the beam polarisation with long polarisation lifetimes.
 - Requires small change in HER energy ($\sim 0.7\%$).



Polarised source

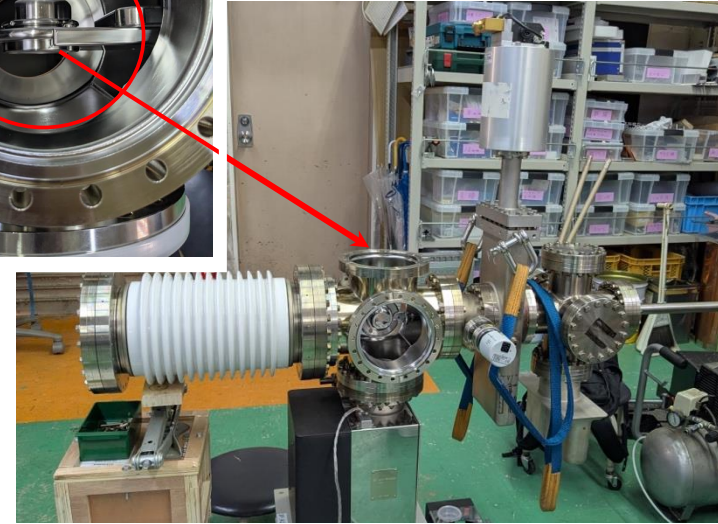
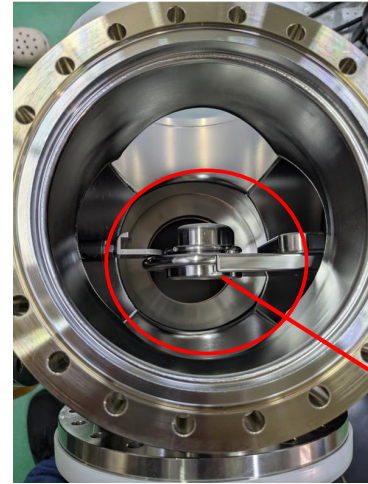
- Conceptual design developed for source for Touschek lifetime measurement to validate polarisation lifetime.
- Beam produced by pulsed laser incident on a photocathode.
- Cathode design optimised to minimise emittance.

A. Beaubien
(UVic, EPECR KEK-TRIUMF scholar)
M. Yoshida (KEK)



Polarised source

- Source assembled and prepared for testing at KEK.
- Plan to merge the source with the existing LINAC.
- Use Wien-filter spin rotator to obtain transversely polarised beams with spin in vertical direction.



Chiral Belle project staging

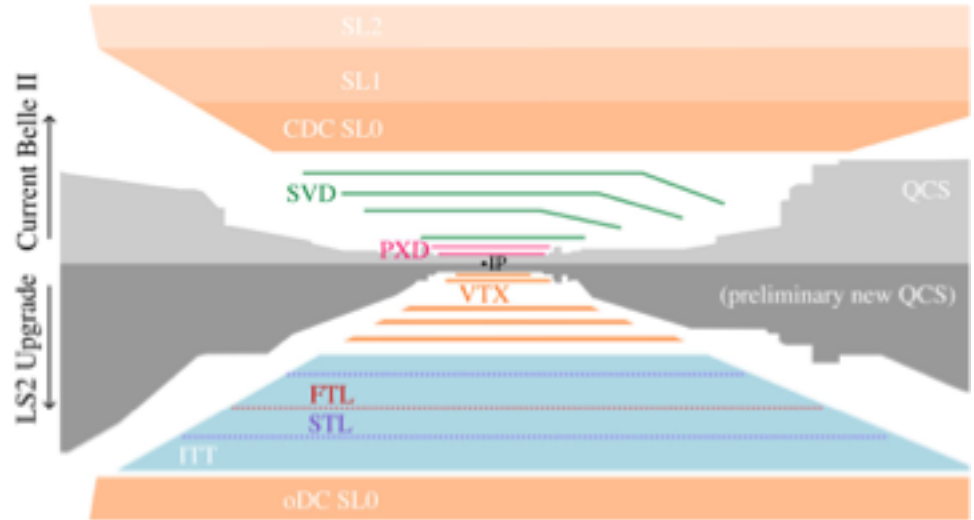
- Complete R&D on spin rotators, polarised source and Compton polarimeter.
 - Carry out validation of the beam lifetime studies using Touschek lifetime.
- Construction phase for final components aiming for installation in LS2 (2032—2033).
Initial running with specific polarisation runs.

Funded by CFI
at \$4.17M

Anticipate application for
CFI-IF in “2029” round

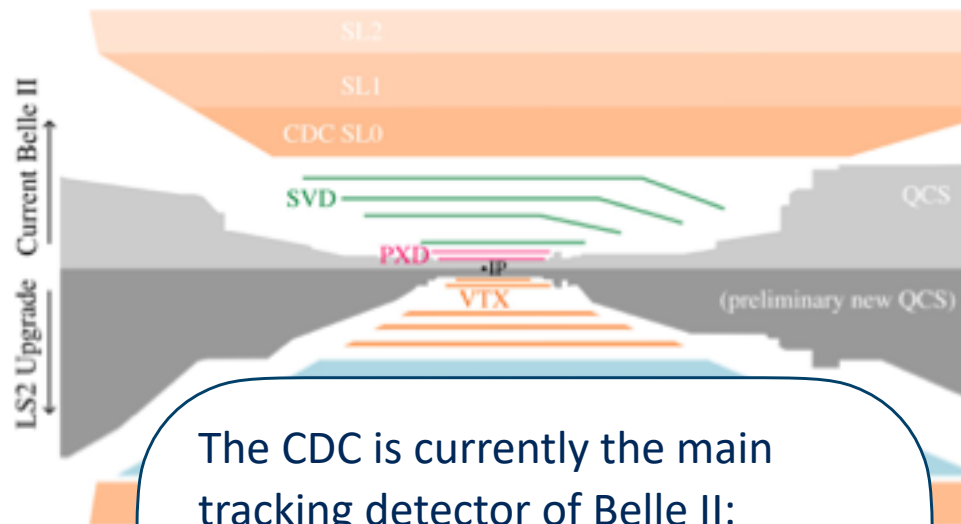
Belle II detector upgrade

- New IR design (QCS) to reach higher instantaneous luminosities.
- PXD/SVD replaced with new VTX detector.
- New fast-timing layer and transition layer detectors replace inner drift chamber volume.
- New outer drift chamber (oDC) replacing CDC.



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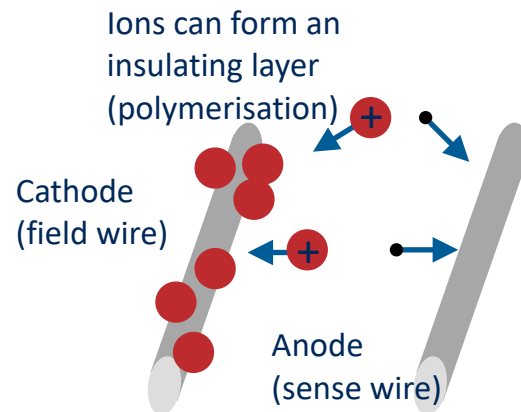
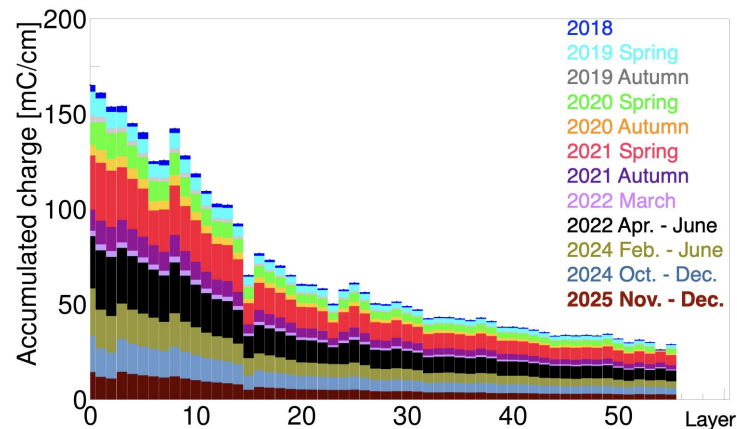


The CDC is currently the main tracking detector of Belle II:

- Provides a momentum measurement.
- Provides particle identification through dE/dx .

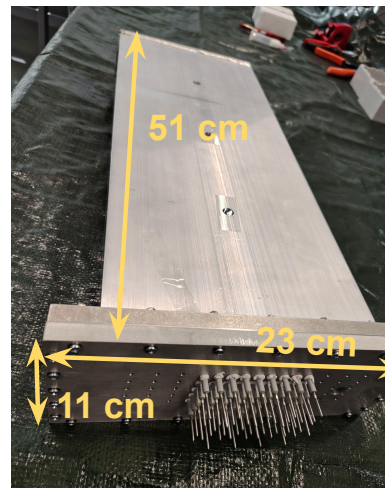
Why replace the CDC?

- Inner regions see large accumulated charges (from beam backgrounds):
 - High detector occupancies.
 - Gain drop due to polymerisation.
 - Induced sustained chamber currents in inner most regions.



Outer drift chamber

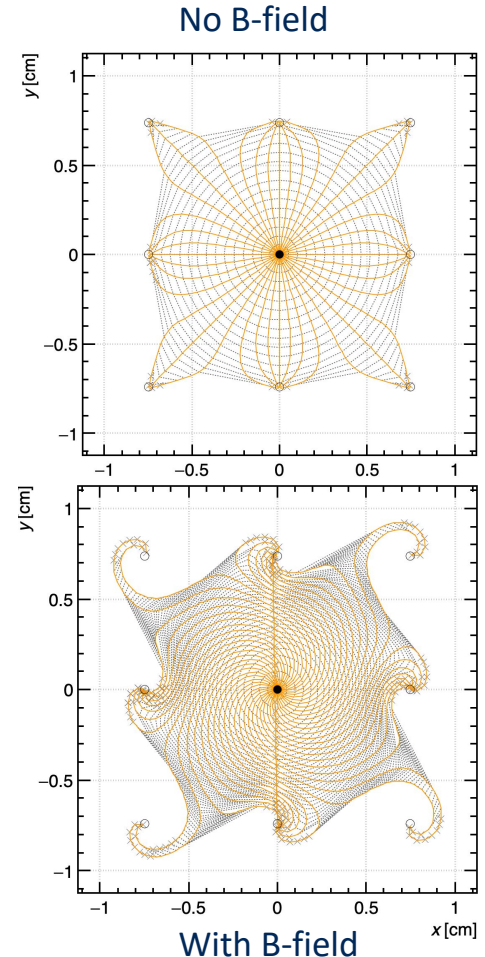
- Highest occupancy, inner region of the detector removed.
- New mechanical structure needed:
 - Support from NSERC—MRS requested for design effort.
- Replacement of readout electronics to improve radiation hardness and cross-talk.
- R&D on gas mixtures and field wire coating to improve Malter effect.



Small test chambers have been produced for irradiation test by Uppsala, Torino, Bonn and KEK

Drift chamber simulation

- Simulation studies performed in BASF2 + a standalone simulation with simplified setup using:
 - Garfield++ for simulation of drift cells.
 - Geant4 for detector simulation.
 - Genfit for track reconstruction.
- Aim to test different layer/cell configurations to optimise detector performance (smaller inner cells, all stereo layers etc).

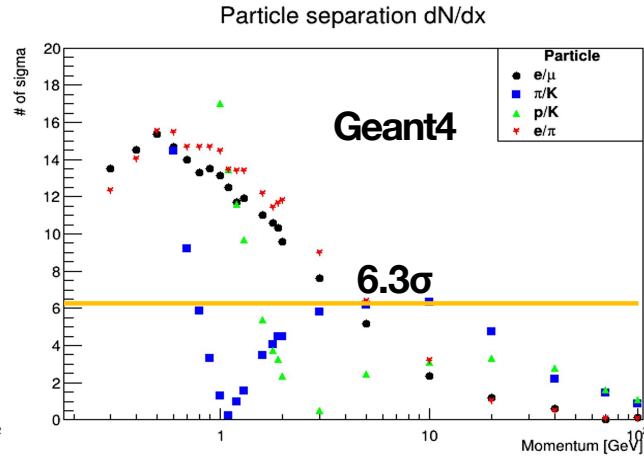
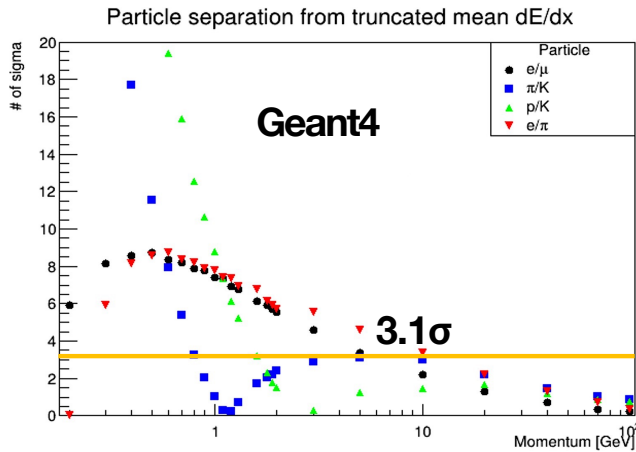


Cluster counting

- PID performance can be improved by counting ionisation events rather than just measuring dE/dx .
 - Remove influence from long Landau tail.
- Idea proposed for Super-B factory, FCC-ee (IDEA) and CEPC drift chamber concepts.
- For Belle II this would require:
 - Faster electronics.
 - Modified gas mixture (and gas system)
e.g. 90:10 He:iC₄H₁₀ rather than 50:50 He:C₂H₆.

Cluster counting

- Studies ongoing for Belle II.



For IDEA concept
[NIMA 1046 (2023) 167734],
demonstrated to give
significant
improvements in
separation power

- Can cluster count based either on derivatives of the pulse shape or use multivariate forecasting techniques (LSTM).

oDC staging

- New Canadian effort (Tom Blake, Steve Robertson, Andreas Warburton).
- Near term opportunities for engagement on mechanical design and gas system.
- Longer term opportunities for engagement on fast electronics and modified gas system for cluster counting.
- We are in contact with Fabrice Retiere and plan to submit an application for resources from the TRIUMF detector group soon.

Anticipate application for CFI-IF in “2029” round

