A Compact Superconducting Spin Rotator for SuperKEKB†

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†Part of the ***R&D for a New Belle II Era of Polarization Physics at SuperKEKB*** US/Japan Collaboration Proposal

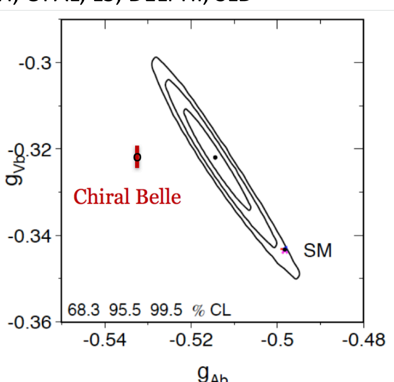
Physics Motivation for a Polarized Beam

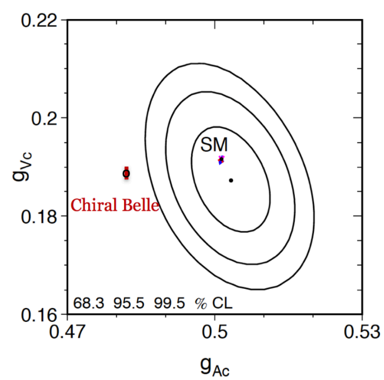
Polarization asymmetry $A^f_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{sG_F}{\sqrt{2}\pi\alpha Q_f} T_3^f g_V^f \langle POL \rangle$ Provides a direct measurement of $\sin^2\theta_W$ $g_V^f = T_3^f - 2Q_f \sin^2\theta_w$

Small tension currently exists between the SM and experiment.

With a 20/ab polarized data set, this tension could be resolved conclusively.

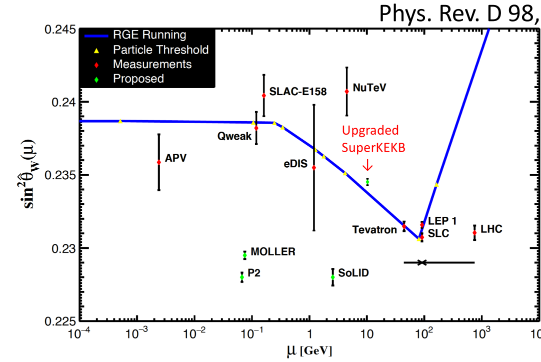
Physics Report Vol. 427
Nos. 5-6 (2006)
ALEPH, OPAL, L3, DELPHI, SLD



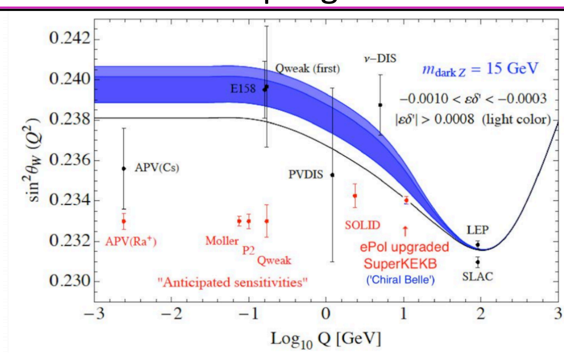


Predicted measurement capability for b, c quark coupling constants

J. Erler and A. Freitas
Phys. Rev. D 98, 030001 (2018)



Possibility for searches in a currently unexplored energy region (O(10GeV))



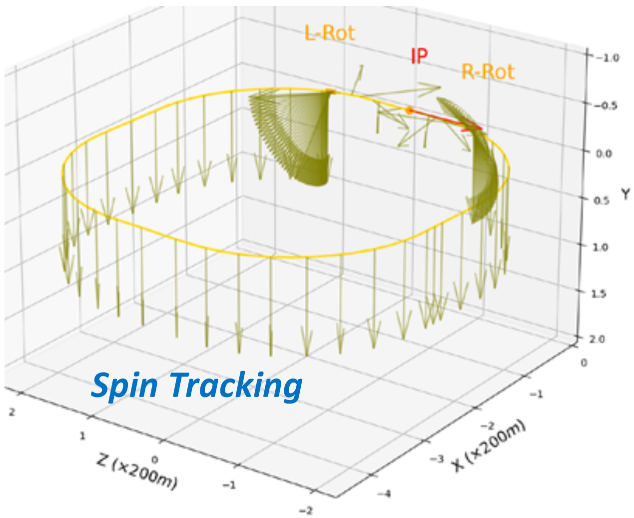
Further opportunities for new physics:

- Dark Z
- 'Heavy' Z' (TeV scale)

Changes manifest as distortions to the $\sin^2\theta_W$ spectrum

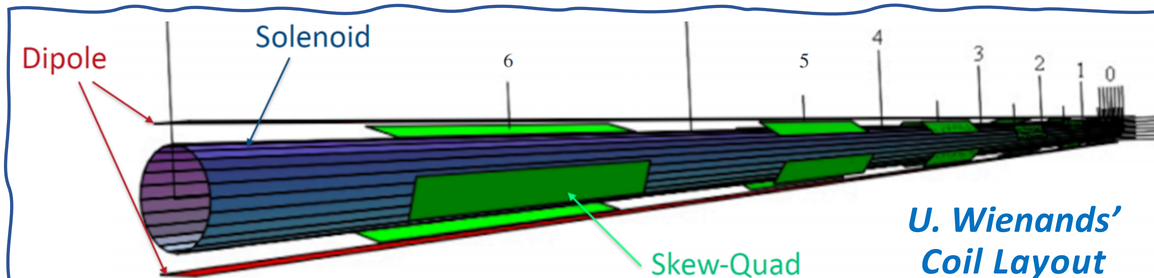
H. Davoudiasl, H.S. Lee and W.J. Marciano
Phys. Rev. D 92, no. 5, 055005 (2015)

SuperKEKB Compact Spin Rotator - Concept



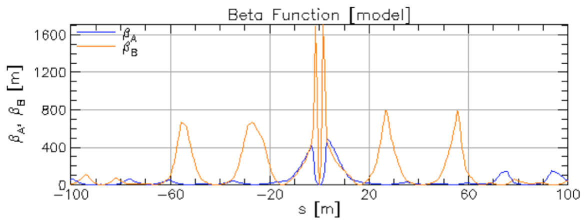
- **Need spin rotators upstream/downstream of Belle II to bring spin longitudinal and then return back to stable orientation in the arcs.**
- **We note that for a standard spin rotator solution we would need to find lattice space for strong solenoids and modify ring geometry, so the solenoids are at special angles with respect to IP.**
- **We propose to use multifunction spin rotator modules combining solenoid, dipole and skew-quadrupole fields to make drop-in units to replace four existing HER ring warm dipoles.**

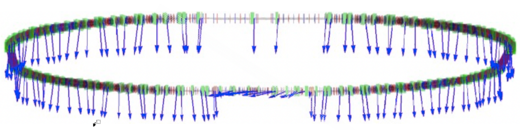
Compact Spin Rotator: Replace two dipoles on both sides of IP with superconducting magnets providing the same bending. Then a combination of solenoid and skew-quad coils rotate the spin direction and correct for locally induced coupling. Nearby quad strengths are adjusted to match existing ring optics and make the spin rotator "invisible" to the rest of the ring without changing the HER footprint in the tunnel.

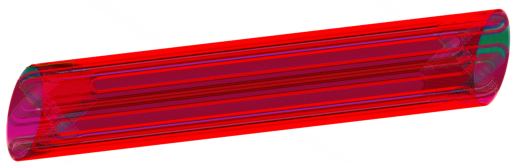


- Dipole coil matches the HER ring dipole bending,
- Along with solenoid to change the spin direction,
- Skew-quads make optics and coupling corrections.

SuperKEKB Compact Spin Rotator – R&D Topics†





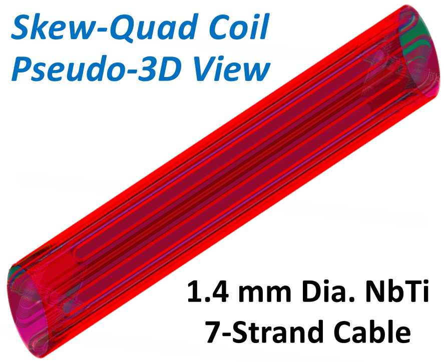


- Optics matching to make spin rotator invisible to rest of the HER: optimization.
- HER spin: tracking / design optimization.
- IP polarization: measurement / monitoring.
- Superconducting coil: design / optimization.
- Standalone, low heat-leak cryostat system with cryocoolers: design / optimization.

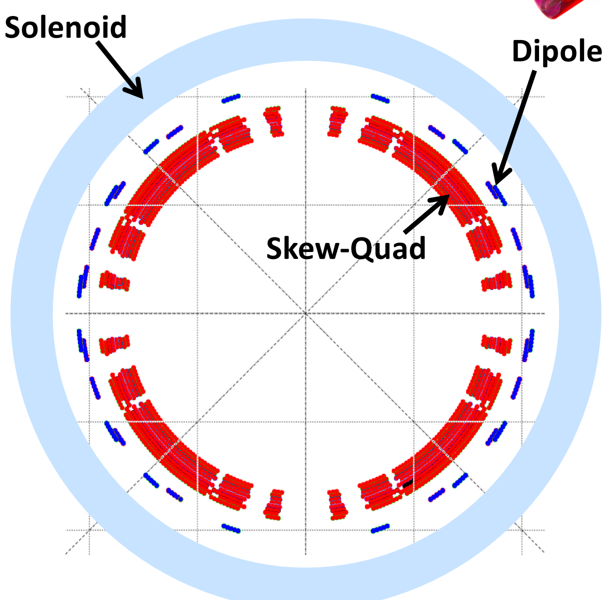
†All these topics are closely coupled and must be jointly iterated.

Compact Spin Rotator – Coil Feasibility

Skew-Quad Coil
Pseudo-3D View



1.4 mm Dia. NbTi
7-Strand Cable



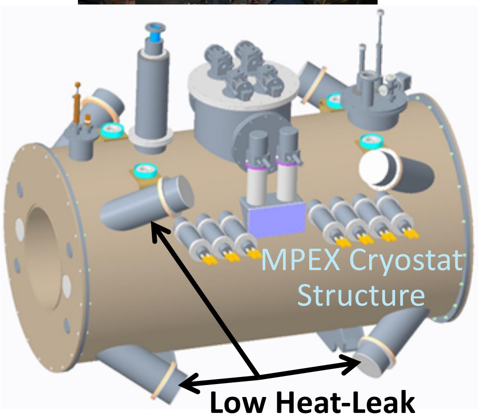
Solenoid Field 4.85 T
Skew Gradient 24 T/m
Dipole Field 0.2 T

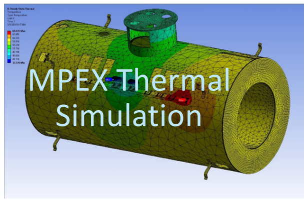
Combined Field @
Skew-Quad is 6.15 T
I_{op} = 729 A
I_q = 1050 A
for 69% Short Sample

Coil Cross Section at Skew-Quad Center

- **We plan to use BNL Direct Wind coil production technique to fabricate the nested coil structure.**
- **Results from first pass NbTi coil structure shown here yield desired operating margin at 4.22 K.**
- **Final coil layout requires careful optimization balancing warm-bore, intermediate heat shield, support structure and current lead designs to allow standalone cryocooler operation in tunnel.**
- **Resources needed to carry out this optimization are requested from US/Japan collaboration funding (also includes polarized source R&D).**
- **Our R&D results will then be used as a basis for a formal request to appropriate funding agency(ies) for the spin rotator component of a future Belle II based Spin Physics upgrade of SuperKEKB.**

Compact Spin Rotator – Cryostat System Feasibility





BNL Design Work: Snake magnet in AGS tunnel and conceptual Oak Ridge MPEX cryostat showing warm bore, low heat-leak support structure, current leads and integrated cooling via cryocoolers.

- Basic consideration: enough warm bore to accommodate HER beam pipe with water cooling and vacuum features.
- Also need some radial space for inner cryostat heat shield.
- But skew-quad inner radius should be as small as possible in order to limit peak field (we want to use NbTi cable!).
- We are far from any cryogenic supply; so, use cryocoolers.
- Cryocooler capacity depends upon heat leak: e.g., the heat shield, support structure and current lead requirements.
- For redundancy/rapid maintenance use closed "wet system."
- We need a self-consistent pre-conceptual design to find out basic info' such as helium structure (cryogenic safety input).
- Feedback from mechanical design used to adjust coil design and ultimately validate magnetic strengths for HER optics.