Belle II

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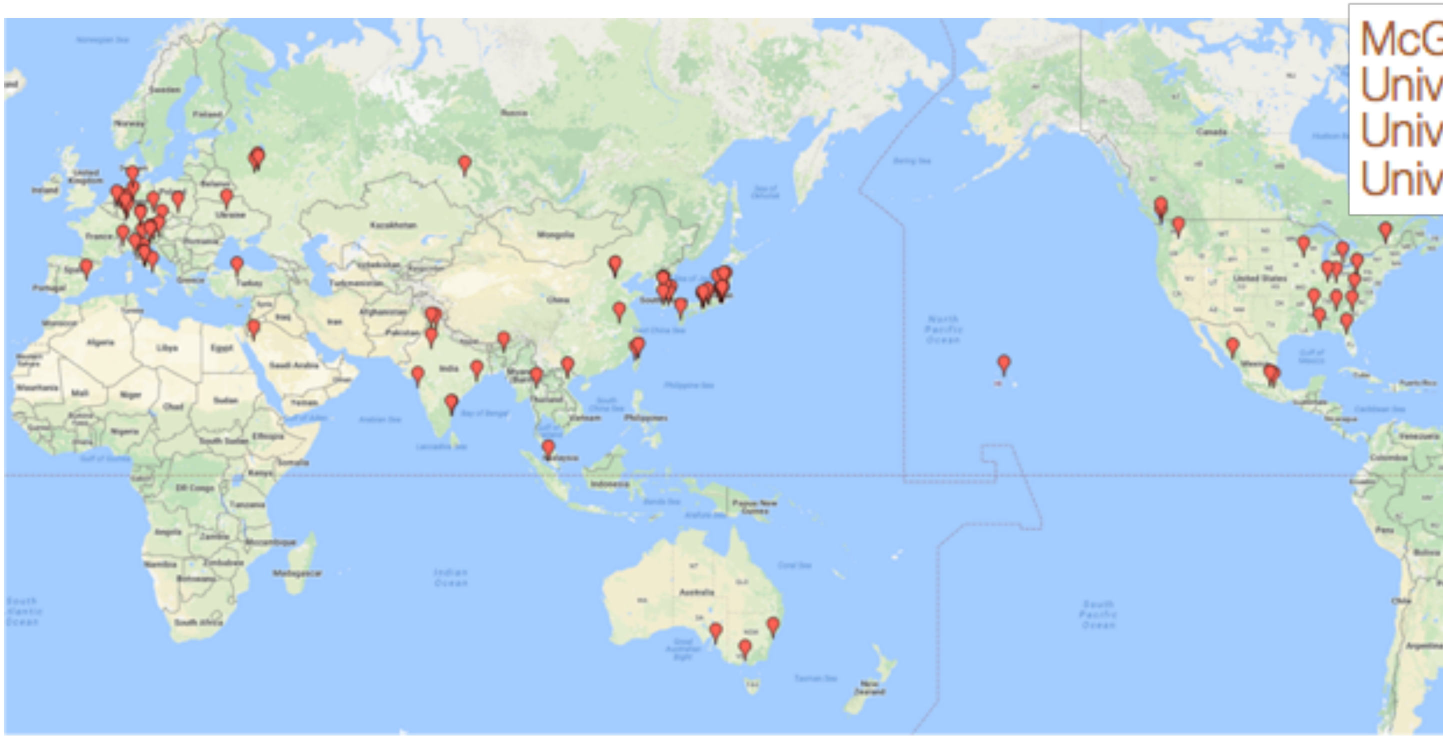
Belle II

- Located at the SuperKEKB e^+e^- collider
- Collisions at E_{cm} = 10.58 GeV
- Primary physics: search for evidence of physics beyond the SM through a wide range of measurements sensitive to heavy virtual particles.
- Luminosity goal: 50 ab^{-1}, 30x combined BaBar+Belle.

Some of the fundamental questions to be addressed with the 50ab^{-1} e^+e^- dataset of Belle II:

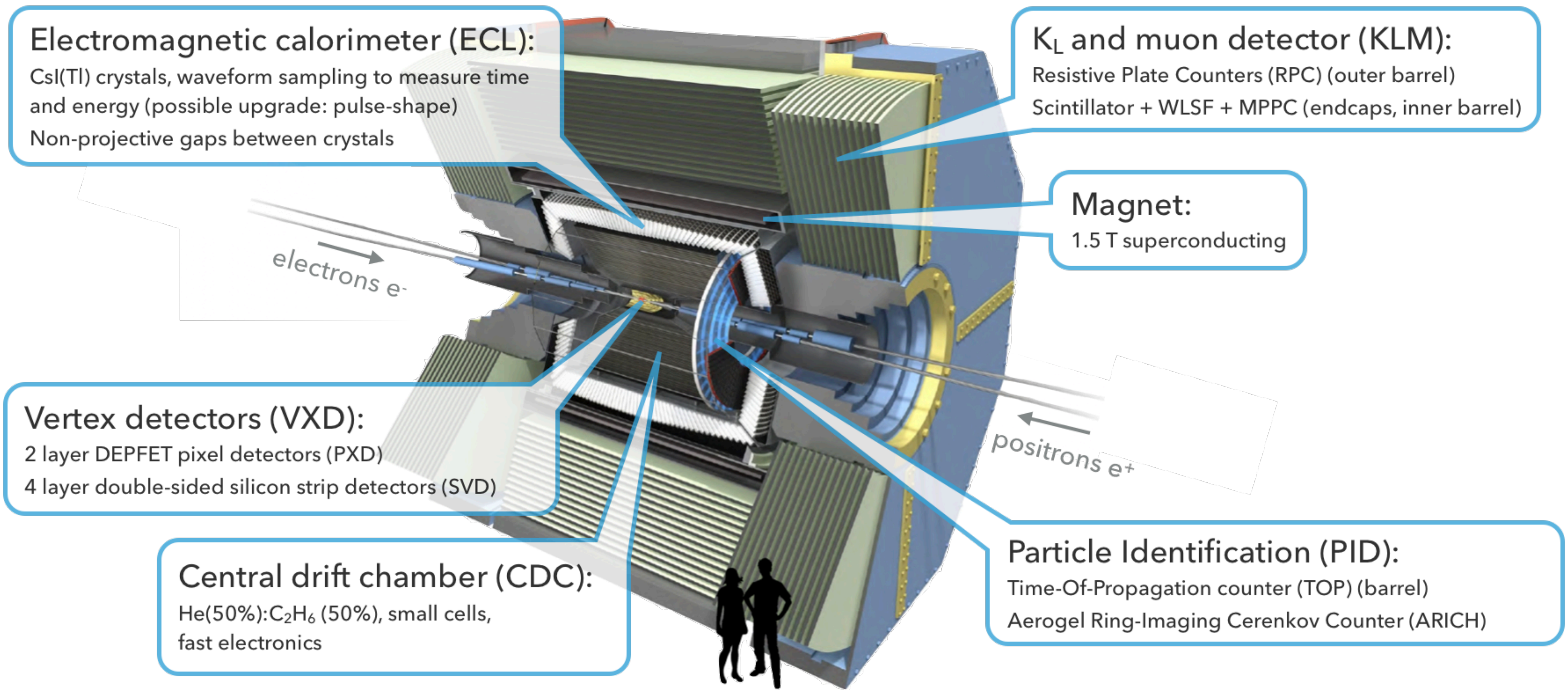
- Are there new CP violating phases?
- Are there sources of lepton flavour violation beyond the Standard Model?
- Are there new operators involving quarks enhanced by New Physics?
- Do Higgs bosons multiplets exist with a low-mass Higgs?
- Is there a hidden dark sector that explains dark matter?

- 23 countries, 100 institutions, 750 collaborators, including 380 PhD physicists & 260 graduate students.

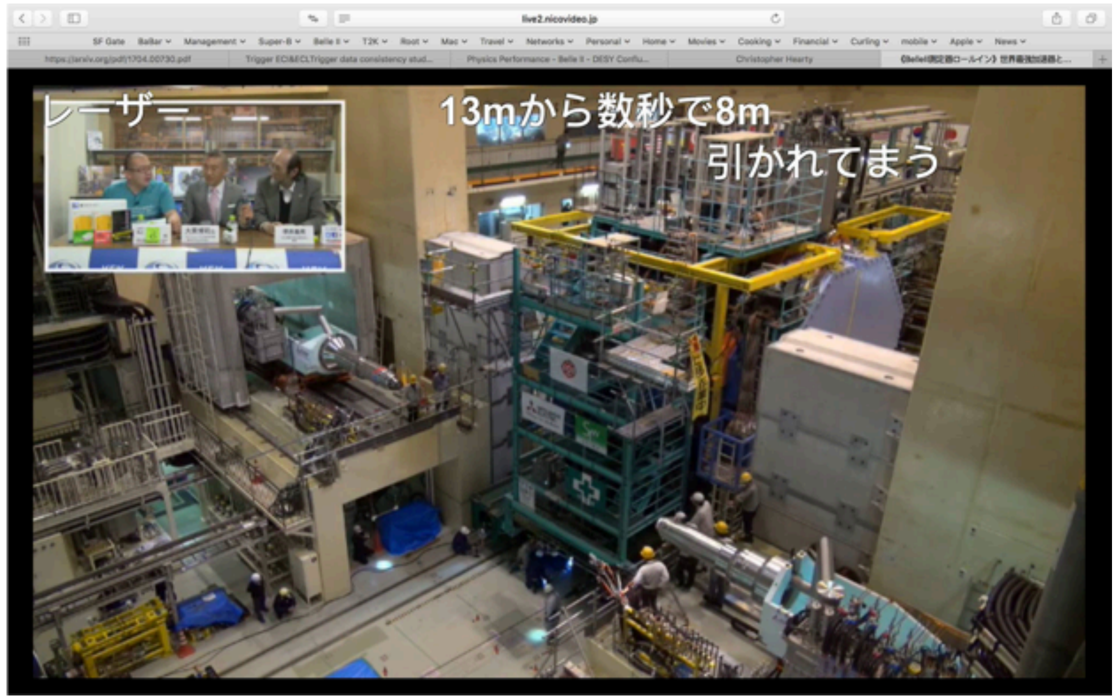


McGill Univ.
Univ. of Montreal
Univ. of British Columbia
Univ. of Victoria

- Detector is an upgrade of Belle. New vertex, tracking, and particle ID detectors; upgrades to muon and calorimeter.



- Detector moved onto the beam line in April 2017, following single-beam commissioning in Spring 2016.



- Forward calorimeter endcap and ARICH installed this fall.
- Vertex detectors will be installed after first colliding beam run.

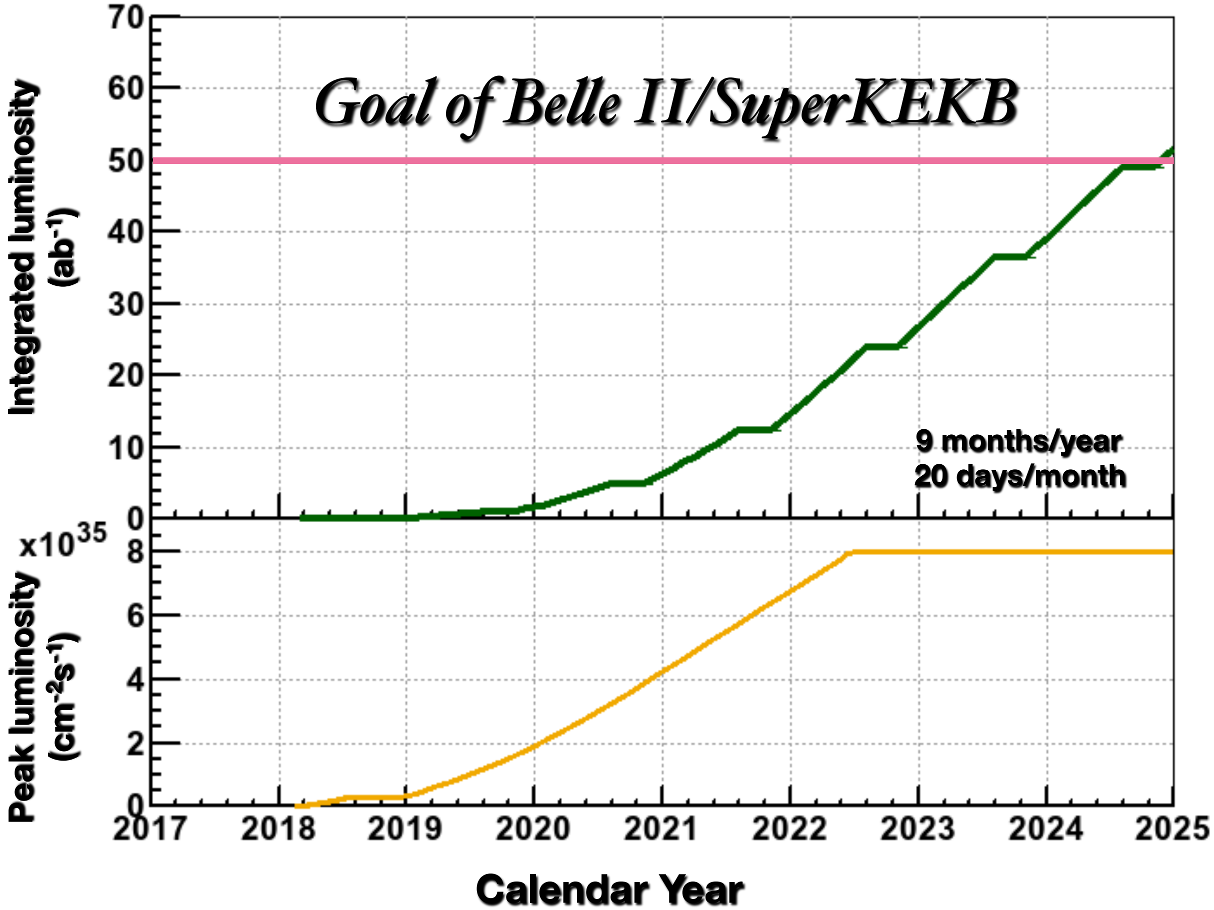
Status / outlook

- Global cosmic run February 2018
- HER & LER single beam operations Feb / Mar
- Colliding beam commissioning (Phase 2)

  Apr – July. Goal is 1–2x KEKB peakluminosity.

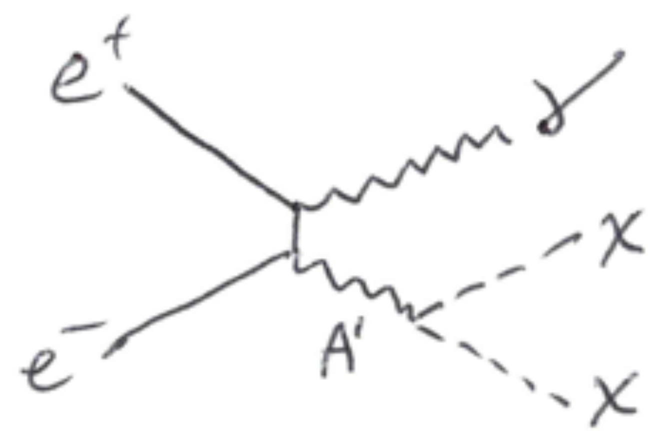
  - Hope to accumulate ~20 fb^{-1} of physics data.

- First physics run with full detector late 2018 / early 2019.



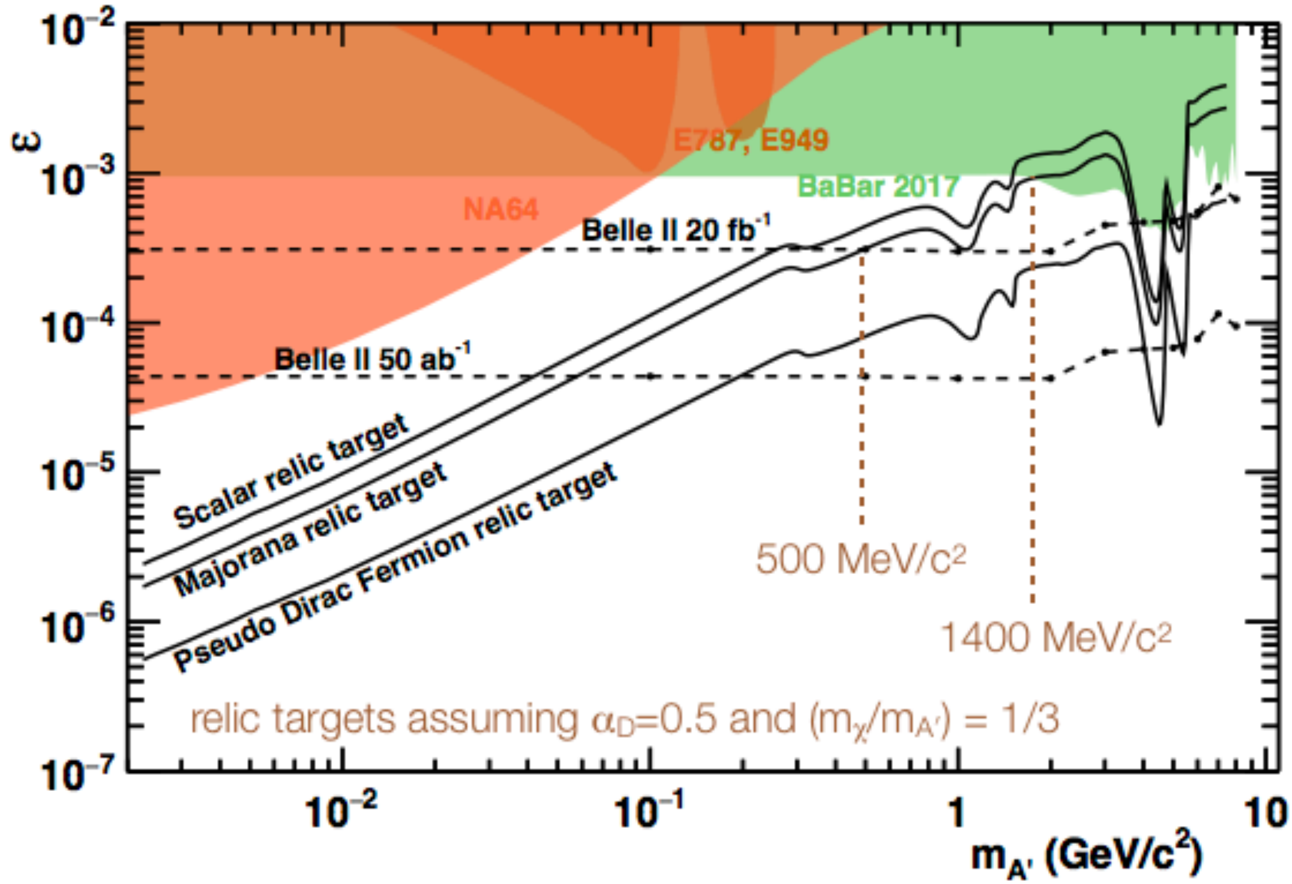
Phase 2 physics: Search for light dark matter using $e^+e^- \rightarrow \gamma$ + invisible

- Dark Sector models include light dark matter χ accessible through decay of a dark photon A' that mixes with γ with strength ε. Belle II will have unique capabilities, even with the initial small dataset.
  - Belle did not have a trigger; BaBar had limited data and a less hermetic calorimeter.



Projected Belle II sensitivity

BaBar PRL 119, 131804 (2017); NA64 1710.00971 Renat Dusaev; g-2 & πνν Rouven Essig; relic densities adapted from E. Izaguirre, G. Krnjaic, P. Schuster, N. Toro, PRL 115, 251301 (2015); Belle II C. Hearty /Torben Ferber;



Summarizing the Phases…

Phase 1: 2016 - Machine commissioning: no collisions or Belle II detector

Phase 2: Starting April 2018 - Belle II and SuperKEKB take first physics (no vertex detector in Belle II)

Phase 3: Starting within ~year of Phase 2 – Full Belle II detector: begin searching for new physics at heavy flavour precision frontier

Chiral Belle:
Potential Upgrade Opening a New Path for Discovery with Belle II and SuperKEKB

- Upgrading SuperKEKB with polarized electron beams yields a rich and unique high precision electroweak program

- Left-Right Asymmetries (A_{LR}) yield measurements of unprecedented precision of the neutral current vector couplings (g_V) to each of five fermion flavours, f :
  - beauty (D-type)
  - charm (U-type)
  - tau
  - muon
  - electron

$$\text{Recall}: \ g_V^f \text{ gives } \theta_W \text{ in SM} \begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$$

T_3 = -0.5 for charged leptons and D-type quarks
+05 for neutrinos and U-type quarks

Chiral Belle Left-Right Asymmetries

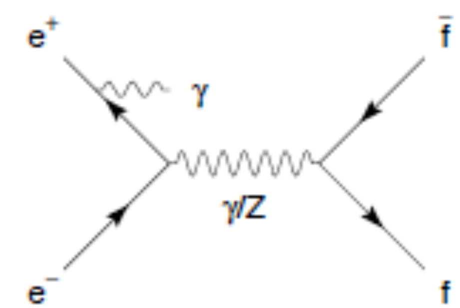
- Measure difference between cross-sections with left-handed beam electrons and right-handed beam electrons
- Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

  $\sin^2\theta_{eff}^{lepton} = 0.23098 \pm 0.00026$

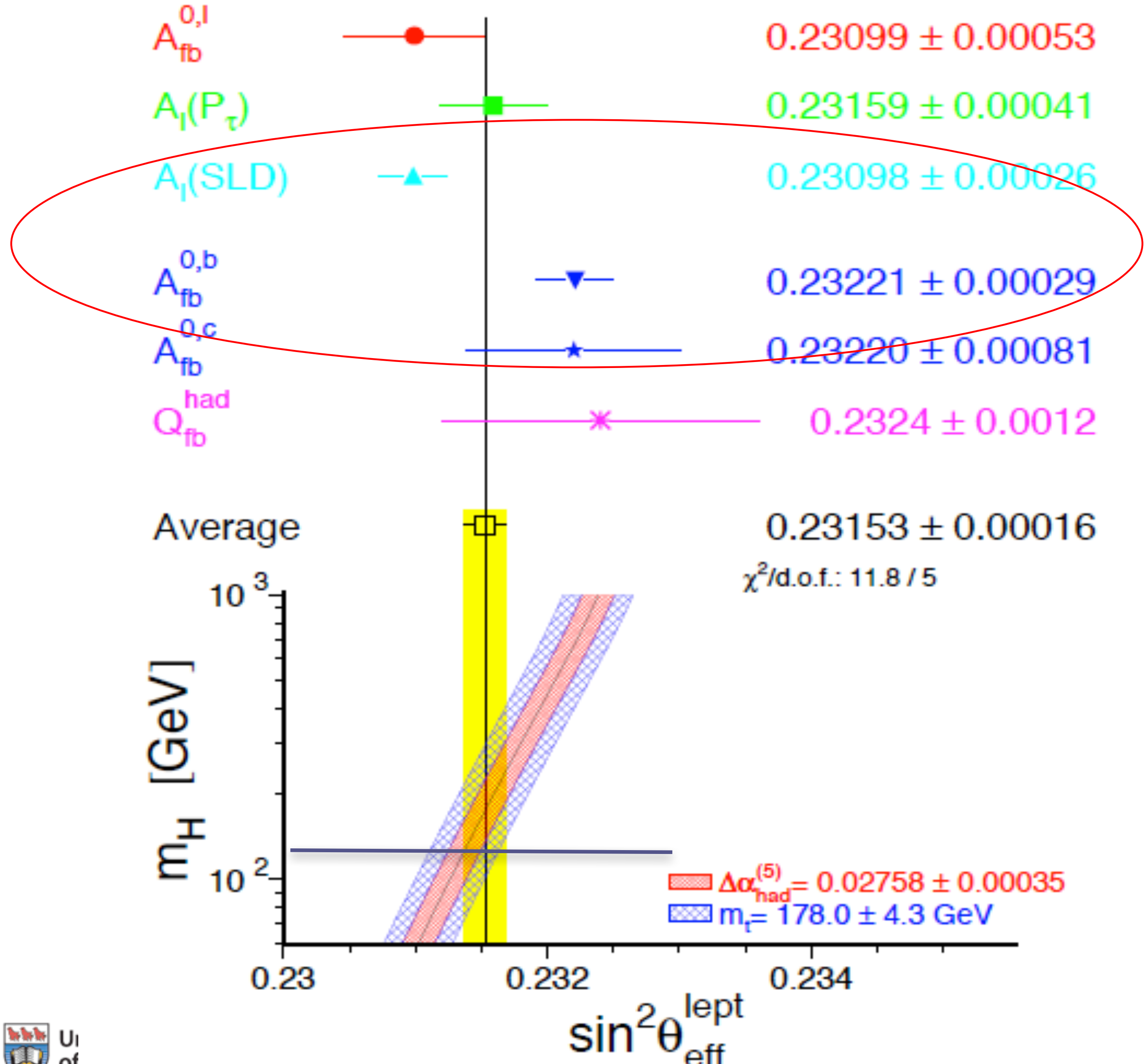
- At 10.58 GeV, polarized e- beam yields product of the neutral axial-vector coupling of the electron and vector coupling of the final-state fermion via Z-γ interference:

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$



Existing tension in data on the Z-Pole:



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

3.2σ comparing only A_{LR} (SLC) and $A^{0,b}_{fb}$(LEP)

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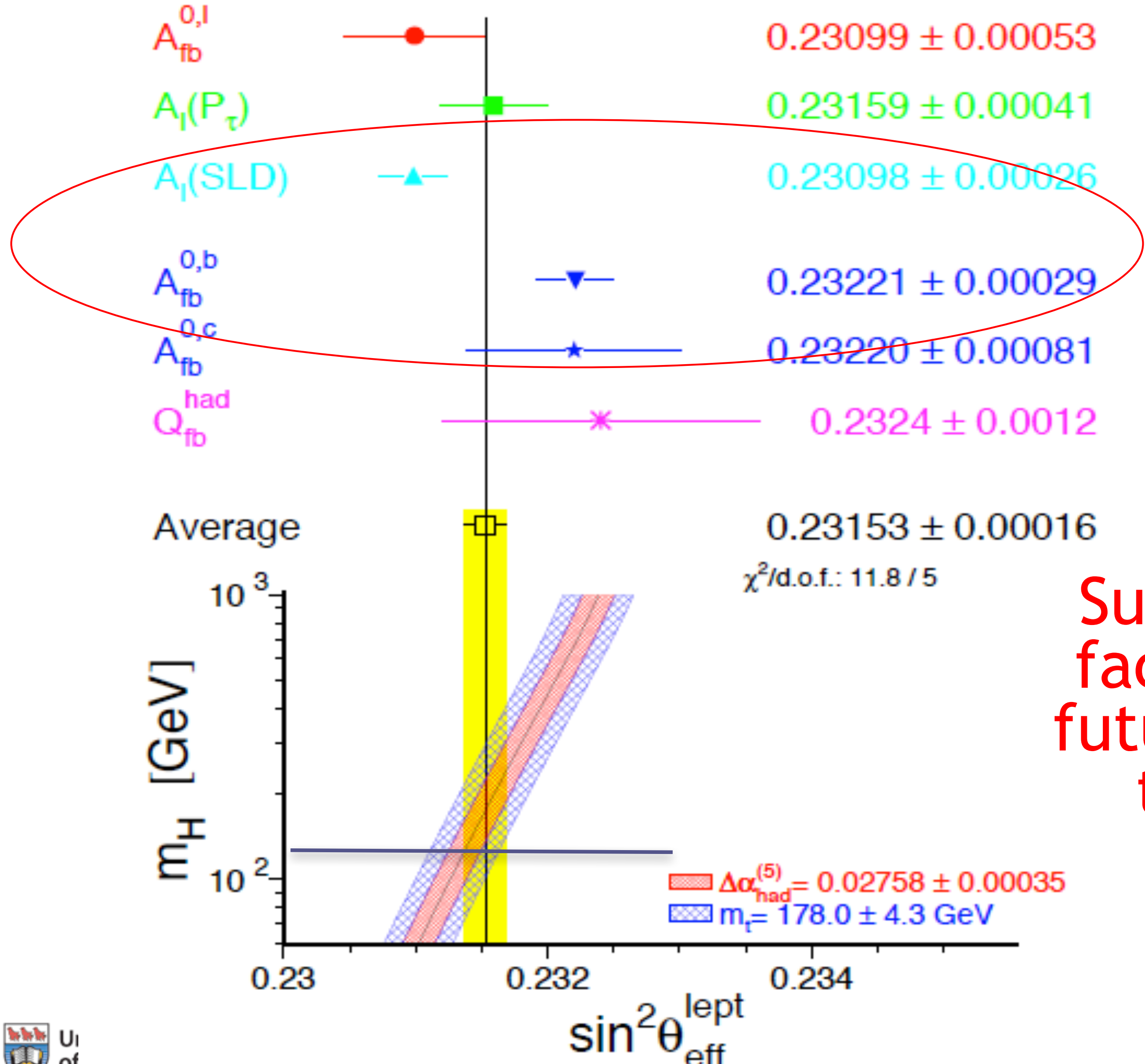

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3.2σ comparing only A_{LR} (SLC) and $A^{0,b}_{fb}$(LEP)

Chiral Belle at SuperKEKB is the only facility in foreseeable future that will be able to experimentally address this 3σ deviation

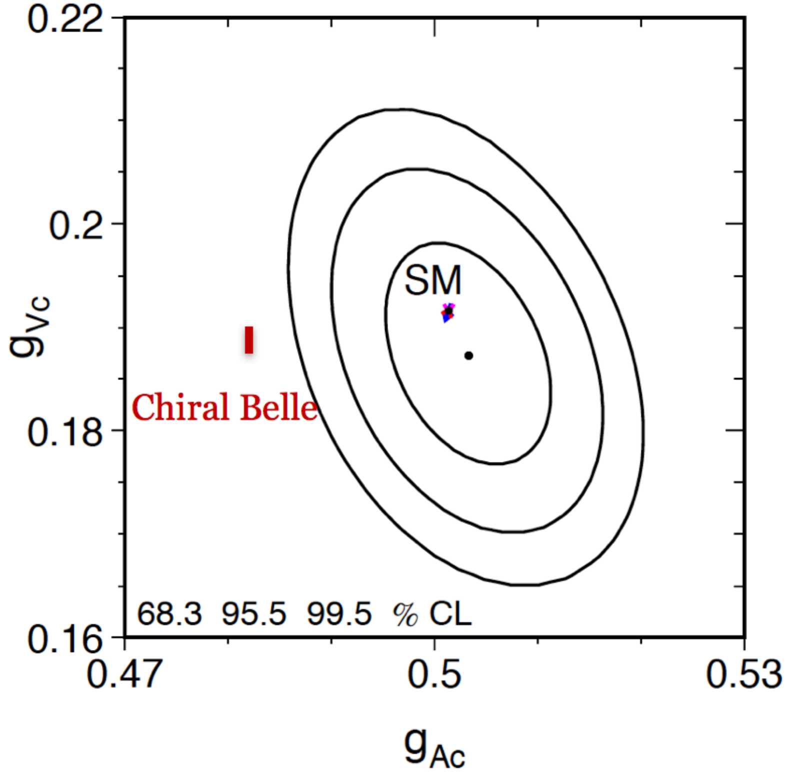
Comparisons with present neutral current vector coupling uncertainties

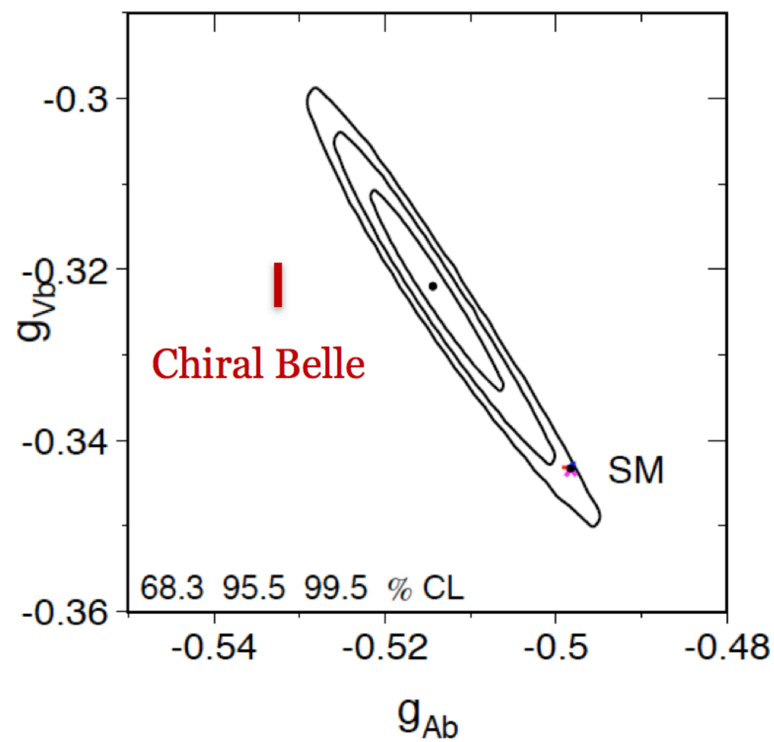
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

c-quark:
Chiral Belle ~7 times more precise

b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}





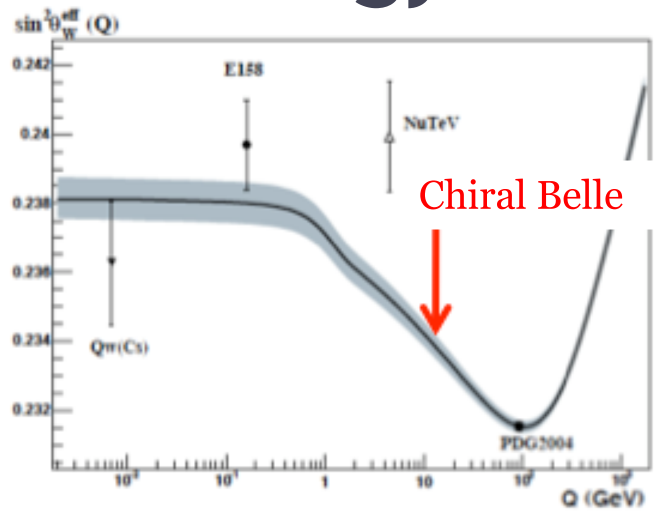
With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

Final State Fermion	SM g_V^f (M_Z)	World Average[1] g_V^f	Chiral Belle σ 20 ab^{-1}	Chiral Belle σ 40 ab^{-1}	Chiral Belle σ $\sin^2\Theta_W$ 40 ab^{-1}
b-quark (selection effic.=0.3)	-0.3437 ± .0001	-0.3220 ±0.0077 (high by 2.8σ)	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920 ±.0002	+0.1873 ±0.0070	0.001 Improve x7	0.001	0.0008
Tau (eff. = 0.25)	-0.0371 ±.0003	-0.0366 ±0.0010	0.001 (similar)	0.0007	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667 ±0.0023	0.0007 Improve x3	0.0005	0.0003
Electron (eff. = 0.015)	-0.0371 ±.0003	-0.03816 ±0.00047	0.0007	0.0005	0.0003 *(all leptons will give ~current* WA error)

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

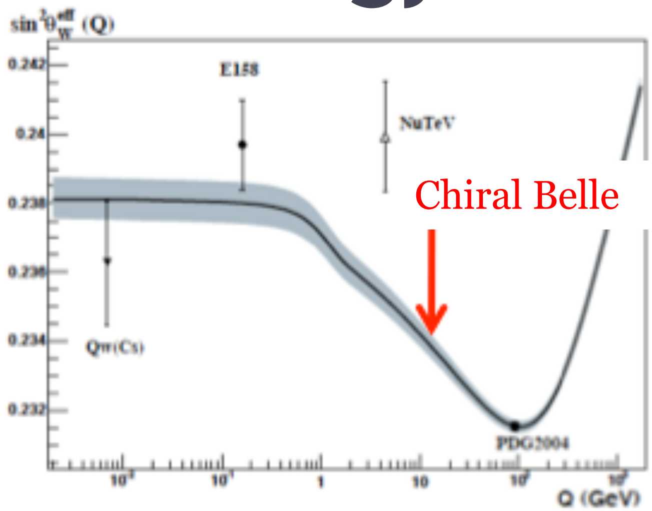
$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

Chiral Belle, at 10GeV, probes both high and low energy scales



- Measurements of $\sin^2\theta_{eff}^{lepton}$ of using lepton pairs with 40ab^{-1} competitive precision to that obtained by LEP/SLD, except at 10.58GeV
  - sensitive to Z' > TeV scale; can probe purely Z' that only couple to leptons: complementary to direct Z' searches at LHC which couple to both quarks and leptons
- highest precision test neutral current vector coupling universality
- Most precise measurements for charm and beauty
  - probes both heavy quark phenomenology and Up-type vs Down-type

Chiral Belle, at 10GeV, probes both high and low energy scales



- Unique sensitivity to Dark Sector light neutral gauge bosons between the M_B and $2xM_B$ that cause deviations from SM by violating universality
  - Because couplings are small, this sector would have been hidden
- Using ISR from the un-polarized e+ beam particles, can also probe parity violating processes in e^+e^- collisions at lower energies, but with significantly lower precision.

Polarization in SuperKEKB

- Aim for ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Inject vertically polarized electrons into the High Energy Ring (HER -> electron ring)
  - use polarized electron source similar to SLC source
  - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields
- Use Compton polarimeter to monitor longitudinal polarization with ~1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry

Tau Polarization as Beam Polarimeter

$$P_{z'}^{(\tau-)}(\theta,P_e) = -\frac{8G_F s}{4\sqrt{2}\pi\alpha}\mathrm{Re}\left\{\frac{g_V^l - Q_b g_V^b \Upsilon_{1S,2S,3S}(s)}{1+Q_b^2\Upsilon_{1S,2S,3S}(s)}\right\}\left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e \frac{\cos\theta}{1+\cos^2\theta}\right)$$

$$+ P_e \frac{\cos\theta}{1+\cos^2\theta}$$

- Dominant term is the polarization forward-backward asymmetry (A^{pol}_{FB}) whose coefficient is the beam polarization
- Measure tau polarization as a function of θ for the separately tagged beam polarization states
- Gives ~0.5% absolute precision of the polarization at the interaction point – includes transport effects, lumi-weighting, stray e+ polarization

Time to start considering a SuperKEKB polarization upgrade → Chiral Belle

- Grow international team
- Bring new resources from international partners to KEK
  - Japanese effort needs to stay focused on achieving highest luminosity – upgrades to RF
- Opportunity to build on international partnerships with KEK for a unique discovery machine
- Aim for polarization physics in 2023

Summary

- Belle II and SuperKEKB on the way for physics in 2018

- Beyond Phase 3: Chiral Belle potential upgrade at SuperKEKB would open a unique discovery window with precision electroweak physics
  - Measure the b, charm, tau, muon vector couplings with the highest precision and competitive electron coupling measurement
  - Unique probe of universality at unprecedented precision
- Would provide weak mixing angle measurements competitive with those at the Z-pole but at 10.58 GeV centre-of-mass:
  - test running of couplings
  - probe new physics at TeV scale complementary to LHC
  - probe 'Dark Sector'
- Build on international partnerships with KEK to create a unique discovery machine with physics in 2023

Additional Information

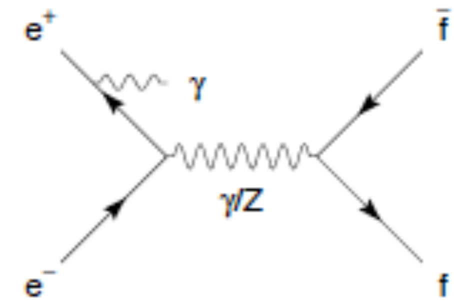
Chiral Belle Left-Right Asymmetries

As at SLC, the electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

$$\langle Pol \rangle = 0.5\left\{\left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_R - \left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_L\right\}$$



Source generates mainly right-handed electrons

Source generates mainly left-handed electrons

Tau Polarization as Beam Polarimeter

- Advantages:
  - Measures beam polarization at the IP: biggest uncertainty in Compton polarimeter measurement is likely the uncertainty in the transport of the polarization from the polarimeter to the IP.
  - It automatically incorporates a luminosity-weighted polarization measurement
  - If positron beam has stray polarization, its effect is automatically included
- Experience from OPAL (at LEP) indicates a 0.2% on systematic error on the A^{pol}_{FB} is achievable, translates into 0.5% error on the beam polarization
- Experience from BaBar indicates that the statistical error on A^{pol}_{FB} will be negligible

- These electroweak measurements require highest luminosity possible
- Polarized source not expected to reduce luminosity
- Spin rotators might affect luminosity if not carefully designed to minimize couplings between vertical and horizontal planes
  - Higher order and chromatic effects have to be considered in the design to ensure luminosity is not degraded