Precision electroweak measurements at SuperB with polarised beam

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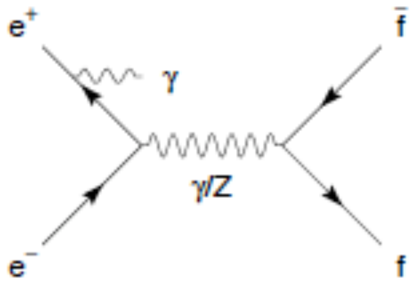
(on behalf of the SuperB Collaboration)

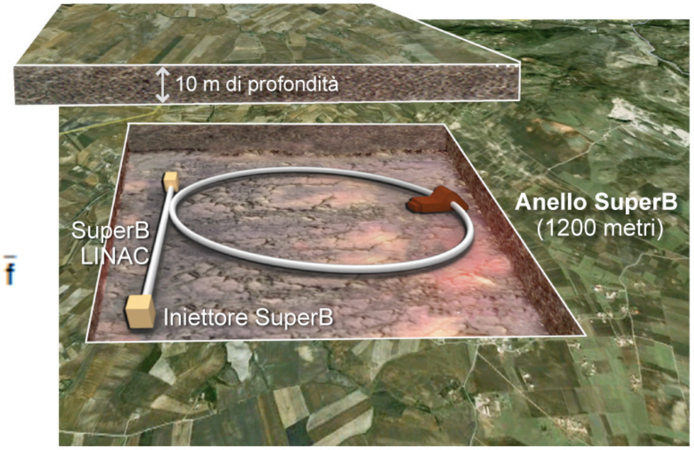
36th International Conference on
High Energy Physics
6 July 2012

ICHEP2012
Melbourne

SuperB:

$\mathcal{L}=10^{36}\text{cm}^{-2}\text{s}^{-1}$, $E_{cm}\sim 10$GeV, asymmetric e^+e^- collider flavour factory approved to be built by CabibboLab on the Univ. Roma-2 Tor Vergata campus





- SuperB is the only e^+e^- high-$\mathcal{L}$ B-factory with a polarised beam: has a unique, and rich, 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)
  - charm (U)
  - tau
  - muon
  - electron

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

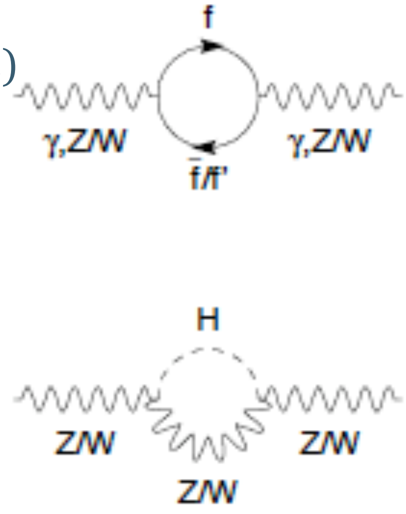
SuperB:

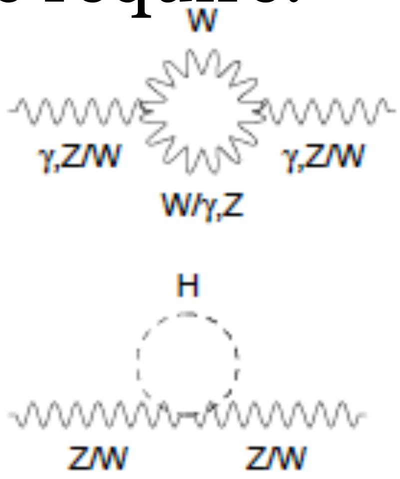
For each of the fermion flavours, SuperB provides:

1. Precise determination of the weak mixing angle, $\sin^2\theta_W$ precise (most precise available for b, c,τ,μ)
2. Most precise study of the running of $\sin^2\theta_W$: probes TeV scale
3. First-time precision parity violation measurements with e^+e^- E_{cm}~10GeV
   - unique probe of potential low energy “dark” (or “hidden”) sector new gauge bosons

At lowest order, the electroweak Standard Model is extensively descriptive with only three input parameters: G_{F}, M_{Z}, α

- Within SM can interpret as precision constraints on M_W and the weak mixing angle, $\sin^2\theta_W$
- Deviation from these constraints is a signal for new physics, but higher order corrections require:
  - $\Delta\alpha_h^{(5)}$ (had. vac. pol. corrections)
  - M_{TOP}
  - M_{HIGGS}





in particular for sin$^2\theta_W$

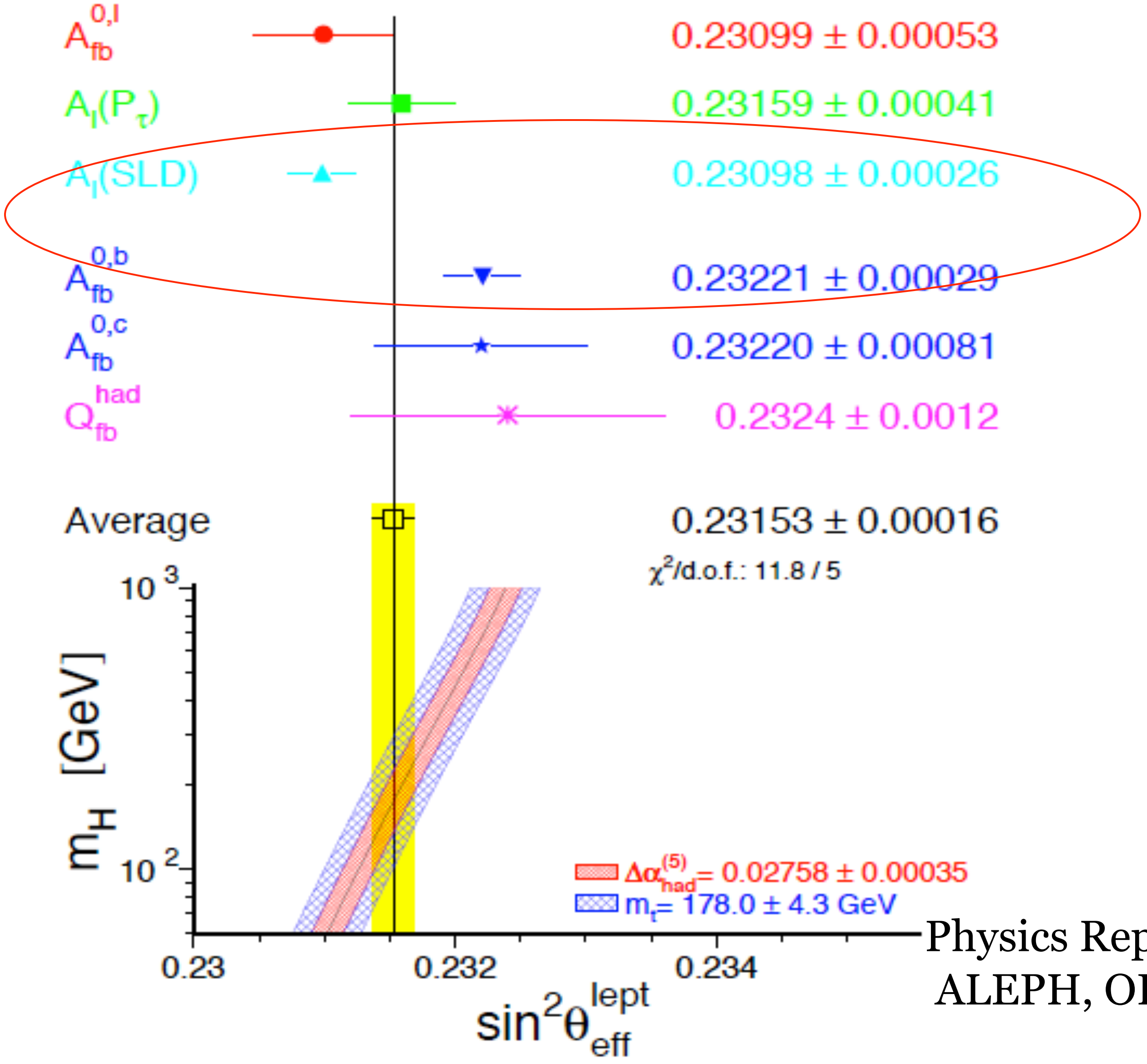
$$\sin^2\theta_{\overline{MS}}(M_Z) = 0.23101 + 0.00969\left(\frac{\Delta\alpha_h^{(5)}}{0.02767} - 1\right) - 0.00277\left[\left(\frac{m_t}{178\ \mathrm{GeV}}\right)^2 - 1\right]$$
$$+\ \ 0.0004908\ \ \log\left(\frac{m_H}{100\ \mathrm{GeV}}\right)\ +\ 0.0000343\ \left(\log\left(\frac{m_H}{100\ \mathrm{GeV}}\right)\right)^2$$

(using parameterization of hep-ph/0203224, hep-ph/0411179 for the MSbar renormalization scheme)

Note LEP/SLC use: $\sin^2\theta_{eff}^{lept}$

$$\sin^2\theta_{eff}^{lept}(M_Z) \sim \sin^2\theta_{\overline{\mathrm{MS}}}(M_Z) + 0.00028$$

Existing tension in data on the Z-Pole:



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

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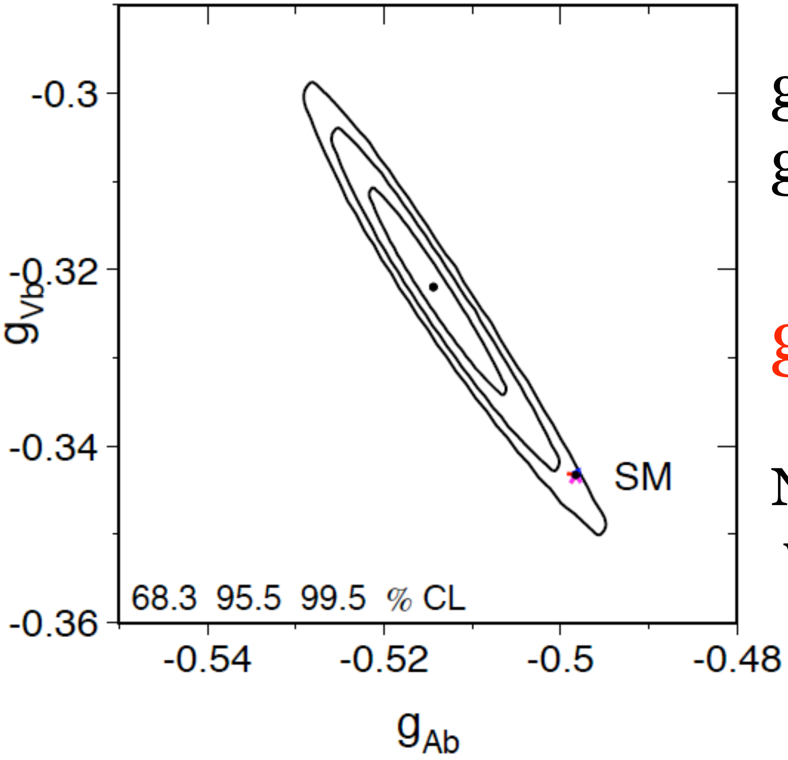
ALEPH, OPAL, L3, DELPHI, SLD

Existing tension in data on the Z-Pole:

For a 125GeV Higgs,



g_{Vb} 2.8σ from SM
g_{Ab} 3.1σ from SM

$g_{Rb} = (g_{Vb} - g_{Ab})/2$ is 3σ from SM

Note: $g_{Lb} = (g_{Vb} + g_{Ab})/2$ is consistent with SM - tightly constrained by $R_b \propto = (g_{Ab}{}^2 + g_{Vb}{}^2)$

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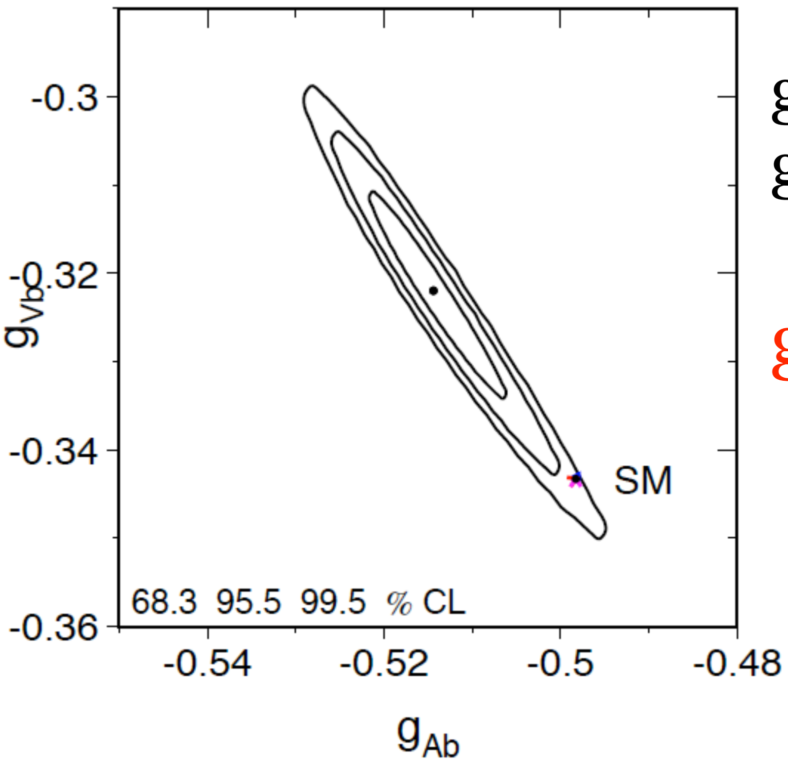

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$g_{Rb} = (g_{Vb} - g_{Ab})/2$ is 3σ from SM

SuperB is the only facility in foreseeable future that will be able to experimentally address this 3σ deviation

SuperB Left-Right Asymmetries

- Measure difference between cross-sections with left-handed beam electrons and right-handed beam electrons
- At ~10GeV, polarised 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:

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

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

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

SuperB Left-Right Asymmetries

•Same technique as A_{LR} measurement performed by SLD at the Z-pole used to get the single most precise measurement of $\sin^2\theta_{eff}^{lept} = 0.23098 \pm 0.00026$

•SuperB will have a $\sin^2\theta_{eff}^{lept}$ error of ± 0.00024 with 70% electron beam polarisation and 75 ab^{-1} of data with tau-pairs and mu-pairs assuming lepton universality and 0.5% uncertainty on <*Pol*>

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Polarisation in SuperB

- inject vertically polarised electrons into the Low Energy Ring (LER -> electron ring)
  - use polarised electron source similar to SLC source
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoids
  - solenoids scale in strength with energy, hence use LER for polarized beam
- Expect ~70% polarisation with 80% polarised source
- As polarisation is flipped in a random, but known, manner, detector systematic effects will cancel
- Use Compton polarimeter to measure longitudinal polarisation with <1% precision
- Can also measure beam polarisation to ~0.5% via tau polarisation forward-backward asymmetry

Tau Polarisation as Beam Polarimeter:

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

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

- Dominant term is the polarisation forward-backward asymmetry ($A^{\mathrm{pol}}_{\mathrm{FB}}$) whose coefficient is the beam polarization
- Measure tau polarization as a function of scattering angle, θ, for the separately tagged beam polarisation states
- Because it's a forward-backward asymmetry it doesn't use information we'd want to use for new physics studies & note EW contribution is small

Tau Polarisation as Beam Polarimeter:

- Advantages:
    - Measures beam polarization at the IP: biggest uncertainty in Compton polarimeter measurement is 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, it's effect is automatically included
- Experience from OPAL (at LEP) using only $\tau \to \pi\nu$ indicates a 0.2% on systematic error on the A^{pol}_{FB} is achievable, translates into 0.5% error on the beam polarisation
- Experience from BaBar indicates that the statistical error on A^{pol}_{FB} will be negligible

SuperB Left-Right Asymmetries

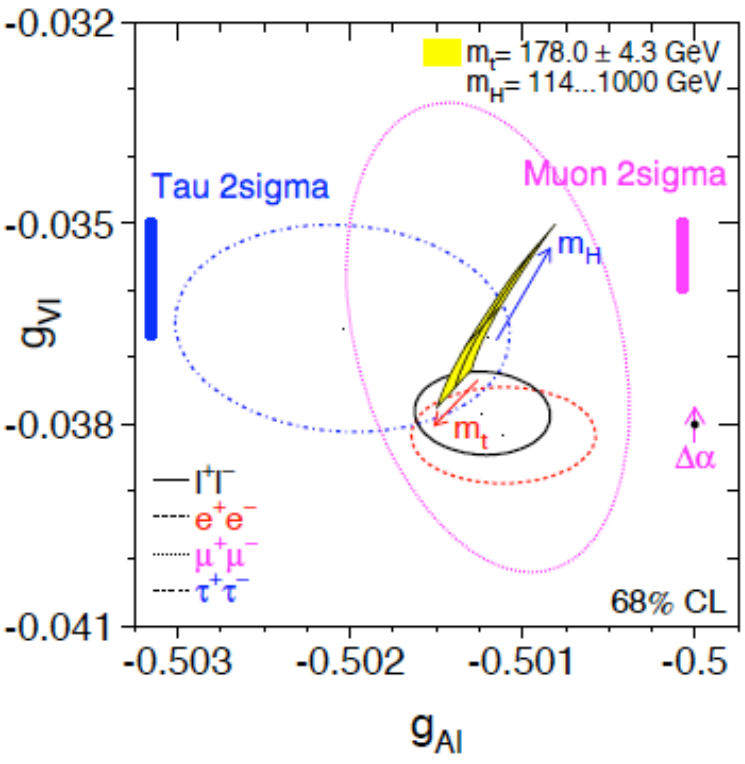
Fermion flavour	σ (nb) eff %	Number Selected events (billions)	SM g_V^f (M_z)	A_{LR} 70% Pol	g_V^f Total Error (%)	$\sin^2\theta_W(M_z)$ Total Error
beauty	1.1 (95%)	38	-0.3437 ± .0001	-0.013	0.5	0.0026
charm	1.3 (30%)	29	+0.1920 ±.0002	-0.003	0.5	0.00076
tau	0.92 (25%)	17	-0.0371 ±.0003	-3×10^{-4}	2.3	0.00043
muon	1.15 (54%)	46	-0.0371 ±.0003	-3×10^{-4}	1.5	0.00027

b-quark coupling at SuperB

- SuperB is in a unique position to experimentally address the existing 3σ discrepancy between the g_R of the b-quark and the SM prediction
- At SuperB no QCD corrections for the b-quark coupling -> smaller systematic errors
  - At LEP QCD corrections were required – hadronization effects, hard gluons, etc
  - An advantage at SuperB over a high energy machine, e.g. Z-factory, is that these corrections do not exist: we are coupling to pseudoscalars with no hadronization

Comparisons with present neutral current vector coupling uncertainties

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



tau:	±0.0010	cf SuperB ±0.0009
muon:	±0.0023	cf SuperB: ±0.0005

LEP/SLC:
Lepton g_V= -0.03753± 0.00037

SuperB error will be ± 0.00047 combining tau and muon
Using electrons at large angles will improve on this

Comparisons with present neutral current vector coupling uncertainties

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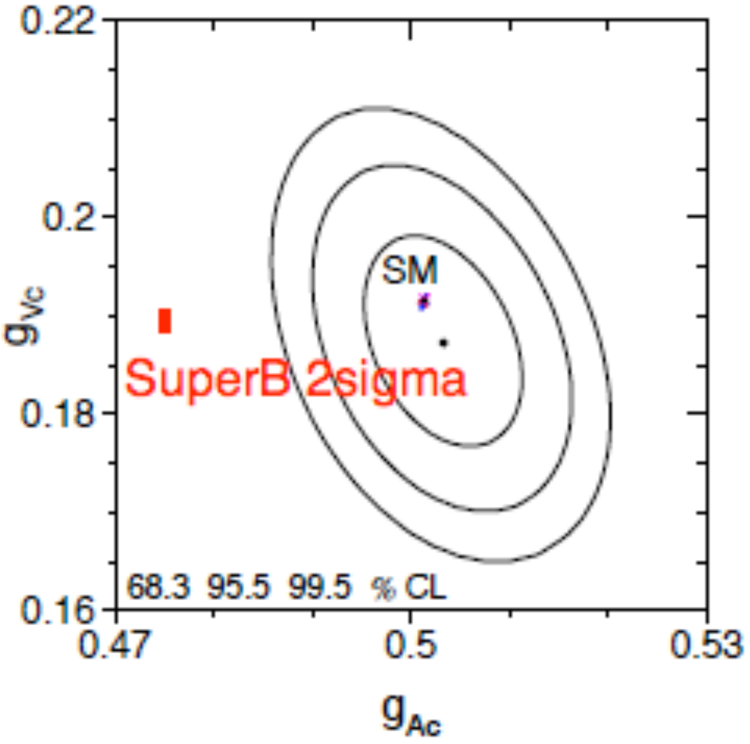
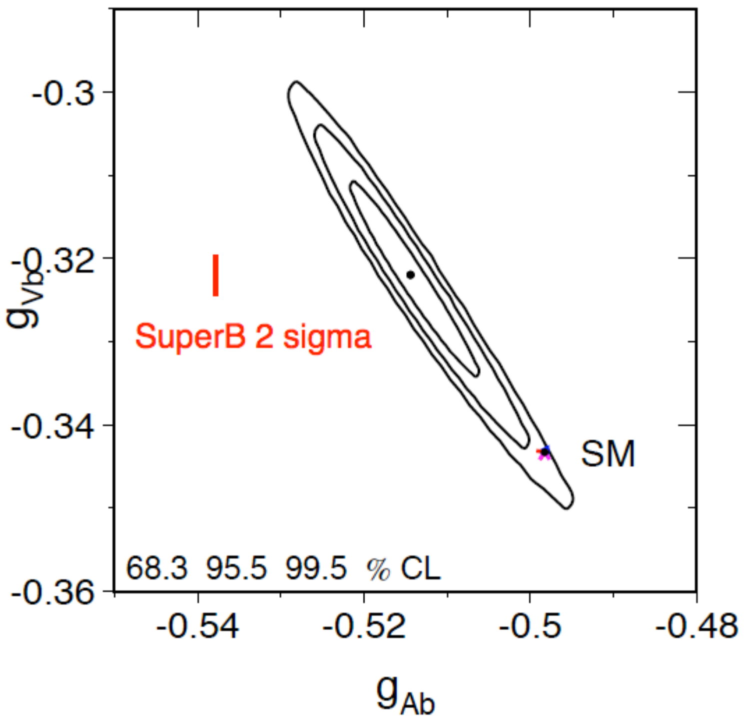
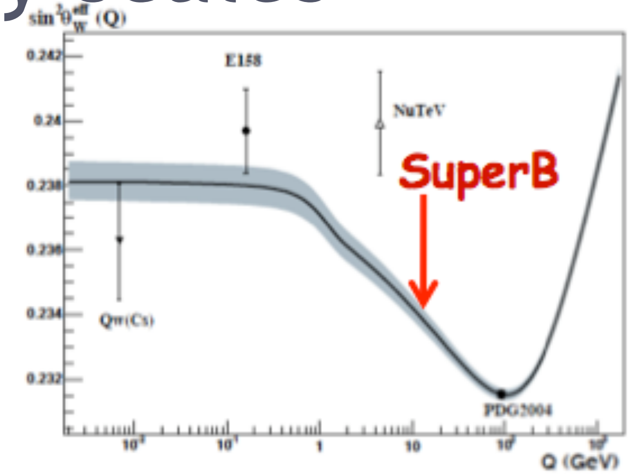
c-quark: SuperB ~7 times more precise



b-quark: SuperB ~5 times more precise

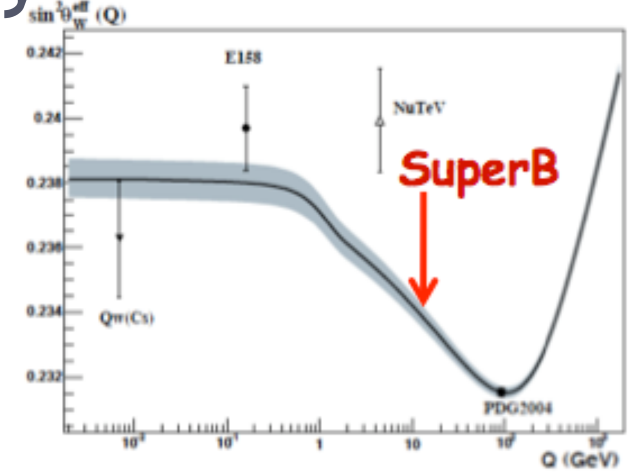


SuperB at 10GeV probes both high and low energy scales



- Measurements of $\sin^2\theta_{eff}^{lepton}$ of using lepton pairs of comparable precision to that obtained by LEP/SLD, except at 10.58GeV
    - sensitive to Z' > TeV scale; unique position to probe 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 (~2%)
- As it provides the most precise measurements for charm and beauty:
    - probes both heavy quark phenomenology and Up vs Down

SuperB at 10GeV probes both high and low energy scales



- Scenarios for new physics include the presence of a ‘hidden’ or ‘dark’ sector which is weakly coupled to the SM and which have its own gauge boson and Higgs sector but at lower energy.
- SuperB provides a means to search for Dark Sector neutral gauge bosons and is the only means available for masses between the M_B and $2xM_B$
- Note that using ISR from the un-polarised beam particles, can also probe parity violating processes in e^+e^- collisions at lower energies, but with lower precision

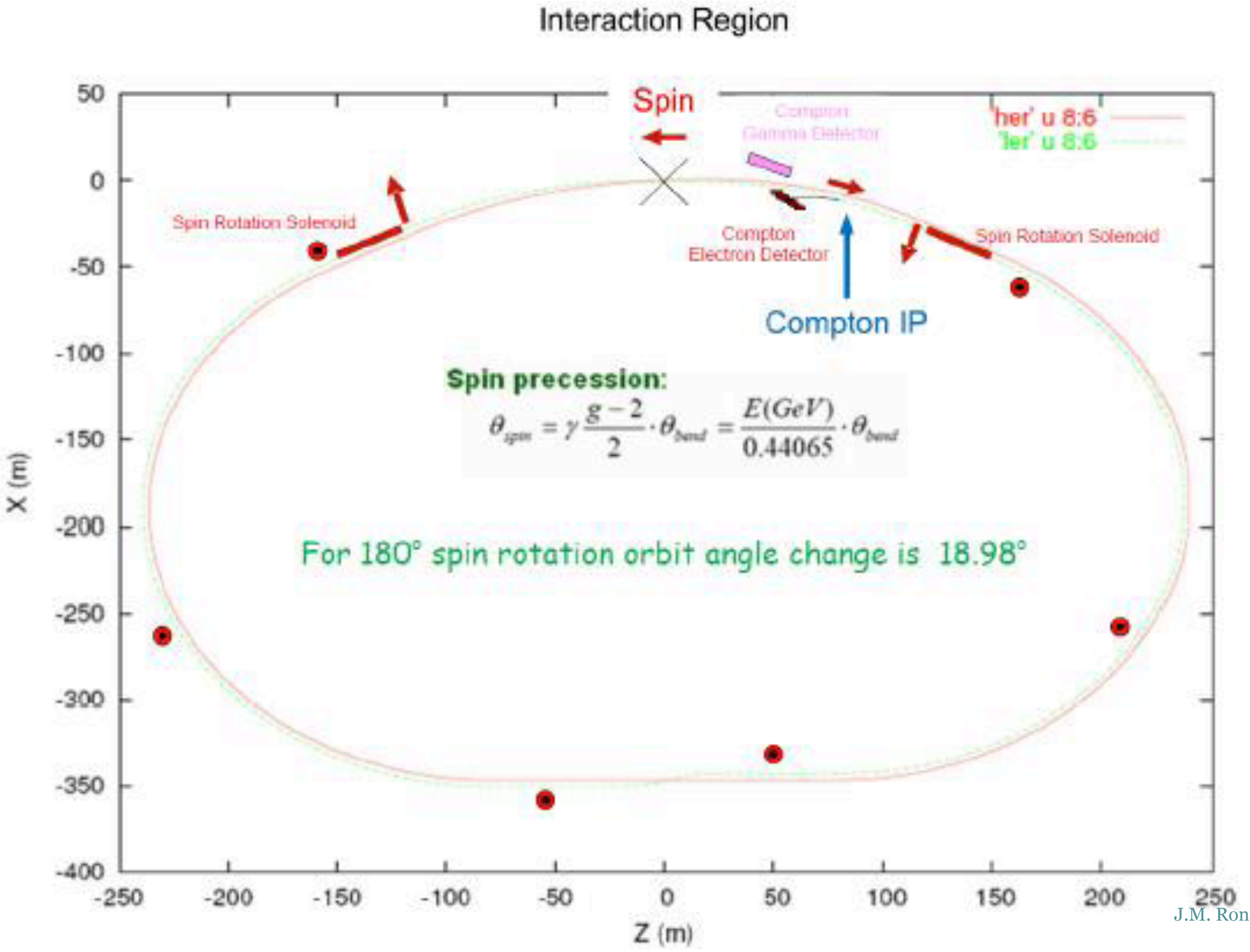
Summary

- The CabibboLab's SuperB project on the University of Rome-2 Tor Vergata campus is designed to have $\mathcal{L}=10^{36}cm^{-2}s^{-1}$ and electron beams with 70% polarisation
- This opens a unique window on precision electroweak physics
- SuperB will measure the b, charm, tau and muon weak neutral current vector couplings with the highest precision of any experiment
- Will yield $\sin^2\theta_W$ measurements with a precision comparable to those at the Z-pole
- As these precision measurements are made at 10.58GeV using interference with the γ, SuperB is sensitive to new physics at both TeV scales and in a lower energy 'dark sector'

Additional slides

Polarisation in SuperB

Spin Rotator location for Beam Polarization



Spin precession:

$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend}$$

For 180° spin rotation orbit angle change is 18.98°

Estimates of Polarisation Systematic errors from Compton Polarimeter… arXiv:1009.6178

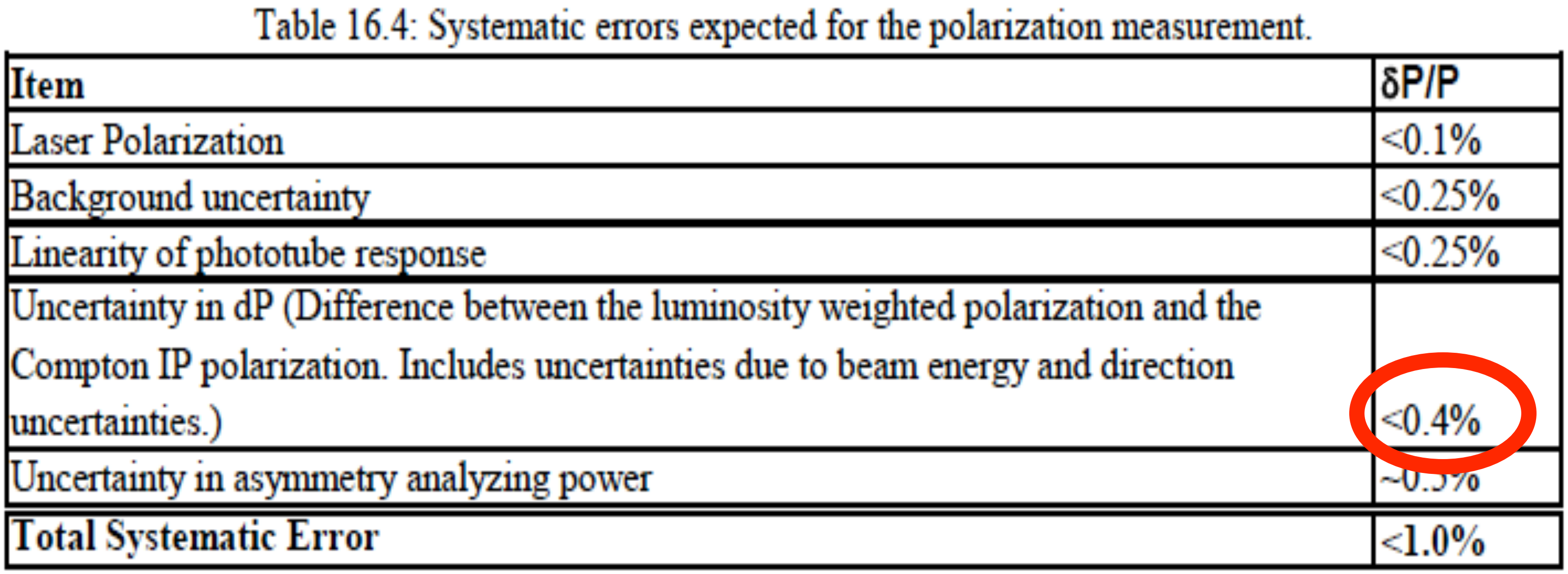


Table 16.4: Systematic errors expected for the polarization measurement.

Item	δP/P
Laser Polarization	<0.1%
Background uncertainty	<0.25%
Linearity of phototube response	<0.25%
Uncertainty in dP (Difference between the luminosity weighted polarization and the Compton IP polarization. Includes uncertainties due to beam energy and direction uncertainties.)	<0.4%
Uncertainty in asymmetry analyzing power	~0.5%
Total Systematic Error	<1.0%

SuperB Overview

- Use a broad set of measurements to observe physics beyond the Standard Model and to elucidate its nature
- Precision measurements
    - new physics enter in loops
    - interference ⇒ asymmetries
- Rare/Forbidden (in SM) decays
- Probe beyond the TeV scale with precision measurements
- Probe lower energy scale new physics with small couplings – such as the dark or hidden sectors

SuperB Overview

- Next generation e^+e^- collider Flavour factory:
  - Primarily will operate at the ϒ(4S) (→BB), but with ability to run on ϒ (1, 2, or 3S) and above the ϒ(4s) and for SuperB at charm threshold.
- Asymmetry e^+e^- collider with luminosity ~100× PEP-II/KEKB, $\mathcal{L}=10^{36}\text{cm}^{-2}\text{s}^{-1}$, but with comparable beam currents and power.
  - somewhat lower asymmetry, $\beta\gamma = 0.28$ vs 0.56
- For SuperB e- (low energy) beam will be longitudinally polarised ~70%
- Complements LHC program, both of ATLAS, CMS as well as LHCb

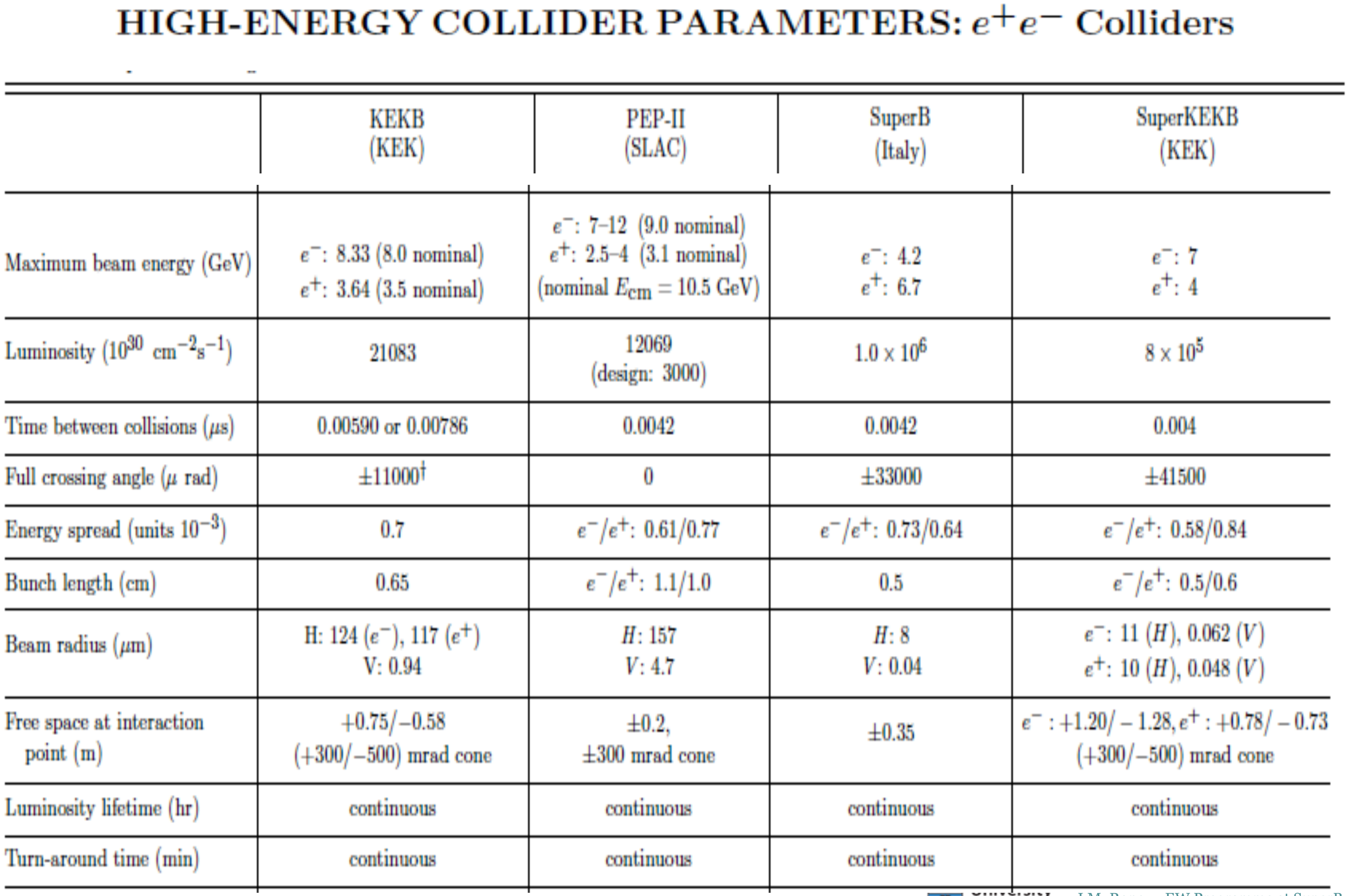
SuperB Overview

- Test CKM at 1% level
  - CPV in B decays from new physics (non-CKM)
- B-recoil technique for B->K(*)ll, B->τν, B->D*τν
- τ physics: lepton flavour violations, g-2, EDM, CPV
- With polarised beam: Precision EW physics
- Many other topics:
  - ϒ(5S) physics, CPV in Charm, ISR radiative return, spectroscopy…
- Physics programme complementary to LHC
  - If LHC finds NP, precision flavour input essential
  - If LHC finds no NP, high statistics B and τ decays are unique way of probing >TeV scale physics

Recent publications from proponents of e^+e^- Super Flavour Factories

- SuperB 2010 Progress Reports:
  - Physics arXiv:1008.1541
  - Detector arXiv:1007.4241
  - Accelerator arXiv:1009.6178
- Physics at Super B Factory (Belle-II + theorists)
  - arXiv:1002.5012

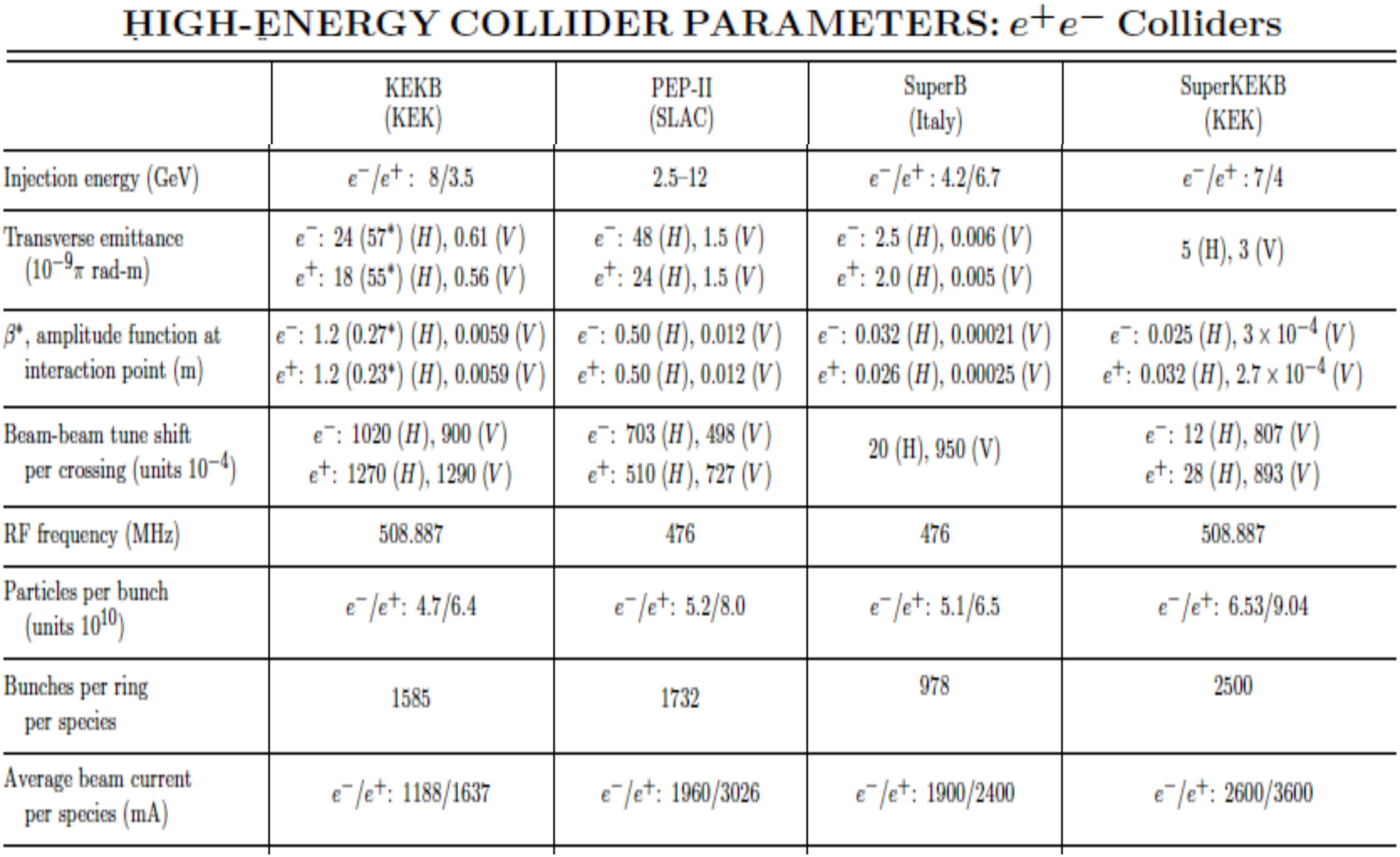
PDG 2010:



HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders

	KEKB (KEK)	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Maximum beam energy (GeV)	e^-: 8.33 (8.0 nominal) e^+: 3.64 (3.5 nominal)	e^-: 7–12 (9.0 nominal) e^+: 2.5–4 (3.1 nominal) (nominal $E_{\rm cm} = 10.5$ GeV)	e^-: 4.2 e^+: 6.7	e^-: 7 e^+: 4
Luminosity (10^{30} cm^{-2}s^{-1})	21083	12069 (design: 3000)	1.0 x 10^6	8 x 10^5
Time between collisions (μs)	0.00590 or 0.00786	0.0042	0.0042	0.004
Full crossing angle (μ rad)	±11000†	0	±33000	±41500
Energy spread (units 10^{-3})	0.7	e^-/e^+: 0.61/0.77	e^-/e^+: 0.73/0.64	e^-/e^+: 0.58/0.84
Bunch length (cm)	0.65	e^-/e^+: 1.1/1.0	0.5	e^-/e^+: 0.5/0.6
Beam radius (μm)	H: 124 (e^-), 117 (e^+) V: 0.94	H: 157 V: 4.7	H: 8 V: 0.04	e^-: 11 (H), 0.062 (V) e^+: 10 (H), 0.048 (V)
Free space at interaction point (m)	+0.75/−0.58 (+300/−500) mrad cone	±0.2, ±300 mrad cone	±0.35	e^- : +1.20/ − 1.28, e^+ : +0.78/ − 0.73 (+300/−500) mrad cone
Luminosity lifetime (hr)	continuous	continuous	continuous	continuous
Turn-around time (min)	continuous	continuous	continuous	continuous

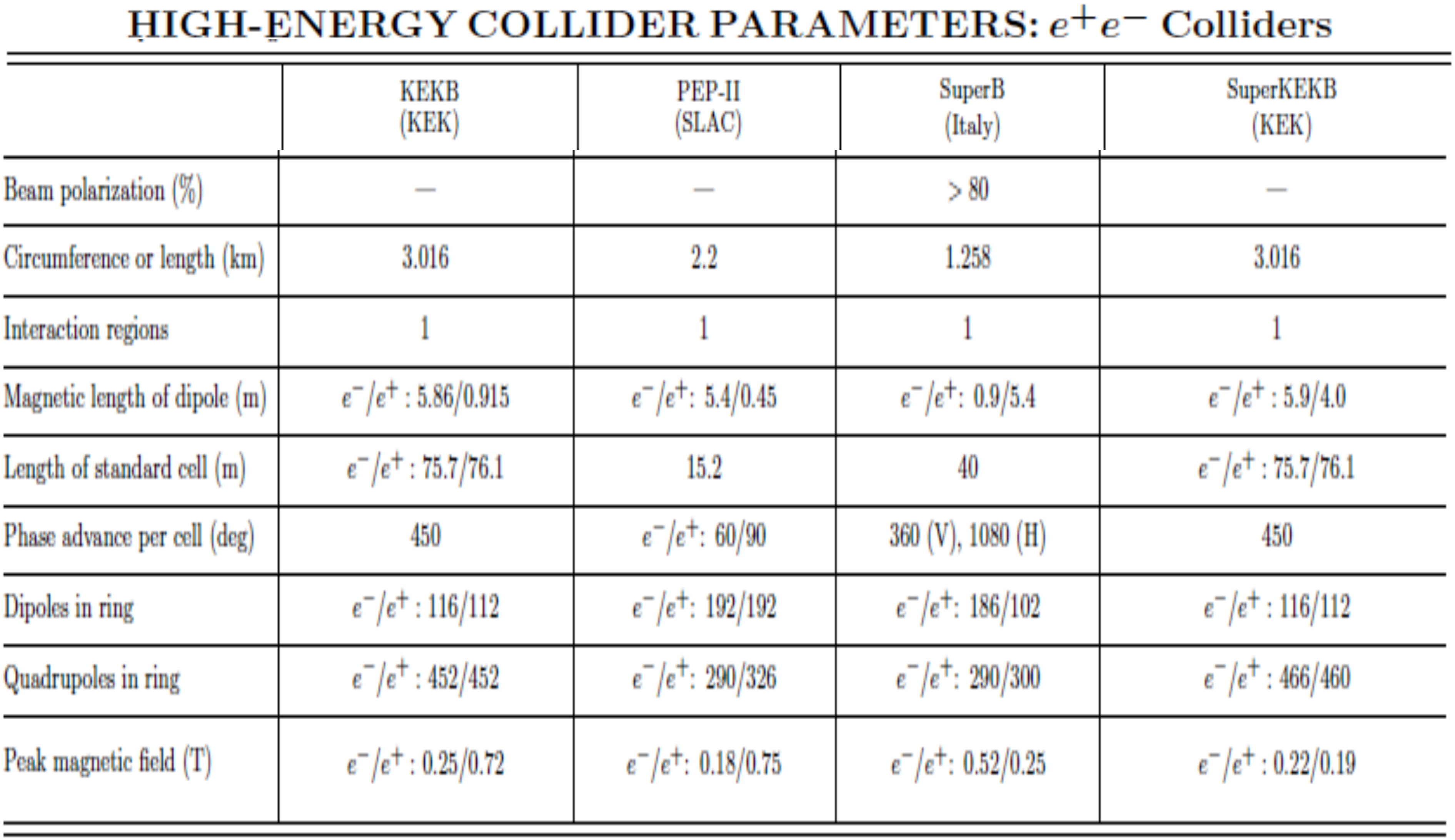
PDG 2010:



HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders

	KEKB (KEK)	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Injection energy (GeV)	e^-/e^+: 8/3.5	2.5–12	e^-/e^+ : 4.2/6.7	e^-/e^+ : 7/4
Transverse emittance ($10^{-9}\pi$ rad-m)	e^-: 24 (57*) (H), 0.61 (V) e^+: 18 (55*) (H), 0.56 (V)	e^-: 48 (H), 1.5 (V) e^+: 24 (H), 1.5 (V)	e^-: 2.5 (H), 0.006 (V) e^+: 2.0 (H), 0.005 (V)	5 (H), 3 (V)
β^*, amplitude function at interaction point (m)	e^-: 1.2 (0.27*) (H), 0.0059 (V) e^+: 1.2 (0.23*) (H), 0.0059 (V)	e^-: 0.50 (H), 0.012 (V) e^+: 0.50 (H), 0.012 (V)	e^-: 0.032 (H), 0.00021 (V) e^+: 0.026 (H), 0.00025 (V)	e^-: 0.025 (H), 3×10^{-4} (V) e^+: 0.032 (H), 2.7×10^{-4} (V)
Beam-beam tune shift per crossing (units 10^{-4})	e^-: 1020 (H), 900 (V) e^+: 1270 (H), 1290 (V)	e^-: 703 (H), 498 (V) e^+: 510 (H), 727 (V)	20 (H), 950 (V)	e^-: 12 (H), 807 (V) e^+: 28 (H), 893 (V)
RF frequency (MHz)	508.887	476	476	508.887
Particles per bunch (units 10^{10})	e^-/e^+: 4.7/6.4	e^-/e^+: 5.2/8.0	e^-/e^+: 5.1/6.5	e^-/e^+: 6.53/9.04
Bunches per ring per species	1585	1732	978	2500
Average beam current per species (mA)	e^-/e^+: 1188/1637	e^-/e^+: 1960/3026	e^-/e^+: 1900/2400	e^-/e^+: 2600/3600

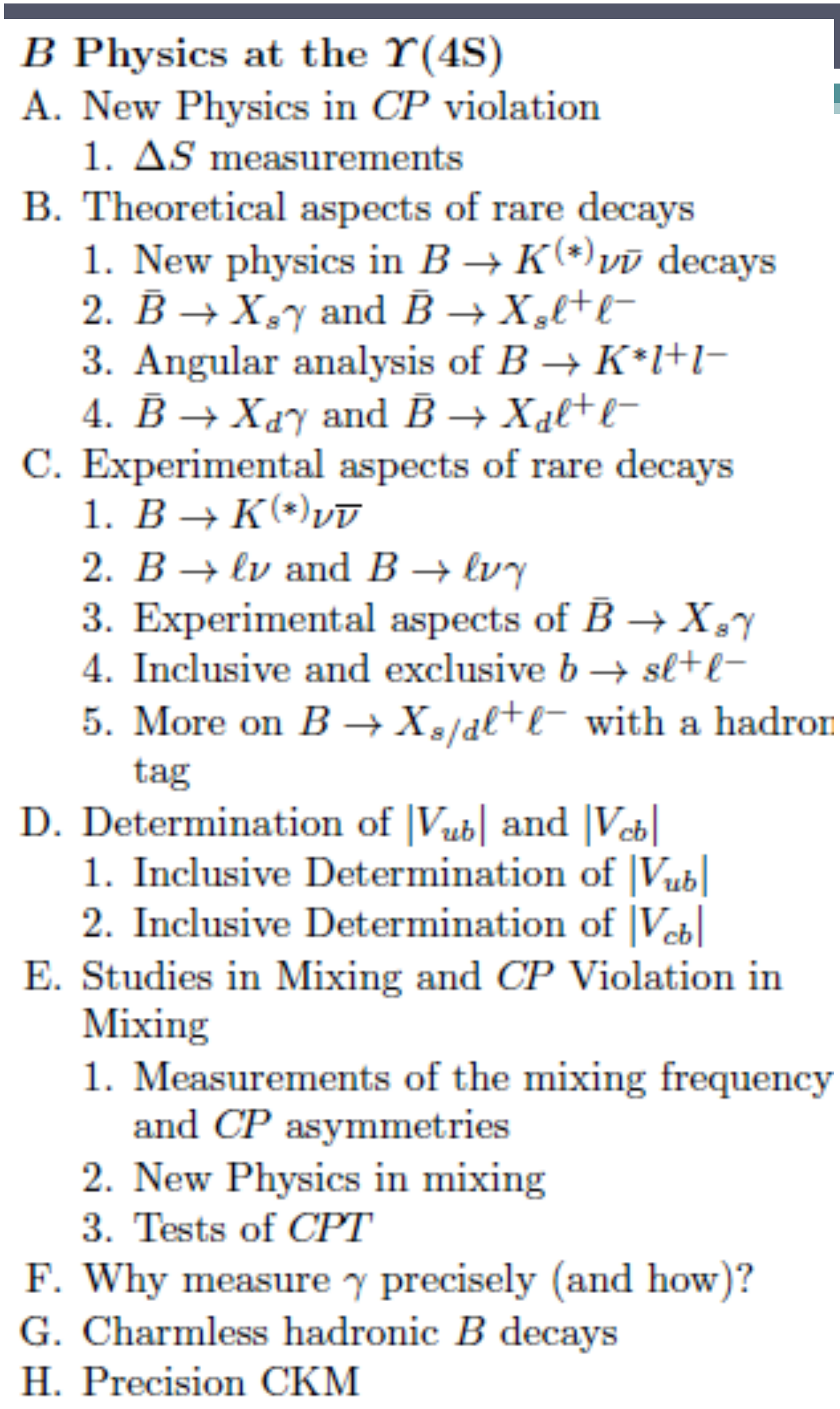
PDG 2010:



HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders

	KEKB (KEK)	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Beam polarization (%)	—	—	> 80	—
Circumference or length (km)	3.016	2.2	1.258	3.016
Interaction regions	1	1	1	1
Magnetic length of dipole (m)	e^-/e^+ : 5.86/0.915	e^-/e^+: 5.4/0.45	e^-/e^+: 0.9/5.4	e^-/e^+ : 5.9/4.0
Length of standard cell (m)	e^-/e^+ : 75.7/76.1	15.2	40	e^-/e^+ : 75.7/76.1
Phase advance per cell (deg)	450	e^-/e^+: 60/90	360 (V), 1080 (H)	450
Dipoles in ring	e^-/e^+ : 116/112	e^-/e^+: 192/192	e^-/e^+: 186/102	e^-/e^+ : 116/112
Quadrupoles in ring	e^-/e^+ : 452/452	e^-/e^+: 290/326	e^-/e^+: 290/300	e^-/e^+ : 466/460
Peak magnetic field (T)	e^-/e^+ : 0.25/0.72	e^-/e^+: 0.18/0.75	e^-/e^+: 0.52/0.25	e^-/e^+ : 0.22/0.19

Super Flavour Factory Physics Program Summary



B Physics at the $\Upsilon(4S)$

A. New Physics in CP violation
   1. ΔS measurements

B. Theoretical aspects of rare decays
   1. New physics in $B \to K^{(*)} \nu \bar{\nu}$ decays
   2. $\bar{B} \to X_s \gamma$ and $\bar{B} \to X_s \ell^+ \ell^-$
   3. Angular analysis of $B \to K^* l^+ l^-$
   4. $\bar{B} \to X_d \gamma$ and $\bar{B} \to X_d \ell^+ \ell^-$

C. Experimental aspects of rare decays
   1. $B \to K^{(*)} \nu \bar{\nu}$
   2. $B \to \ell \nu$ and $B \to \ell \nu \gamma$
   3. Experimental aspects of $\bar{B} \to X_s \gamma$
   4. Inclusive and exclusive $b \to s \ell^+ \ell^-$
   5. More on $B \to X_{s/d} \ell^+ \ell^-$ with a hadron tag

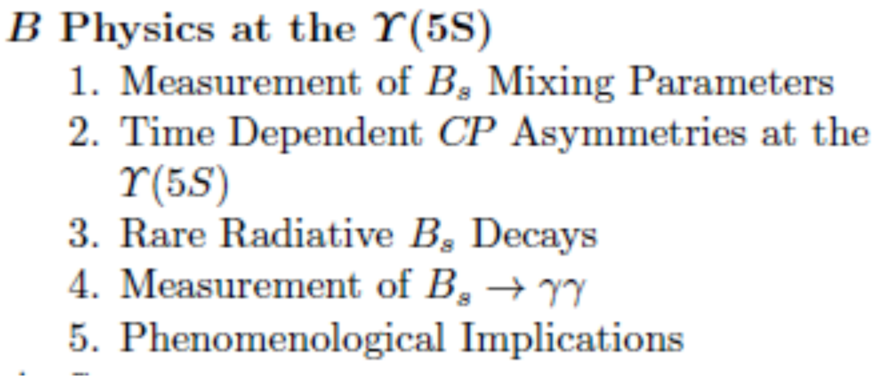
D. Determination of $|V_{ub}|$ and $|V_{cb}|$
   1. Inclusive Determination of $|V_{ub}|$
   2. Inclusive Determination of $|V_{cb}|$

E. Studies in Mixing and CP Violation in Mixing
   1. Measurements of the mixing frequency and CP asymmetries
   2. New Physics in mixing
   3. Tests of CPT

F. Why measure γ precisely (and how)?

G. Charmless hadronic B decays

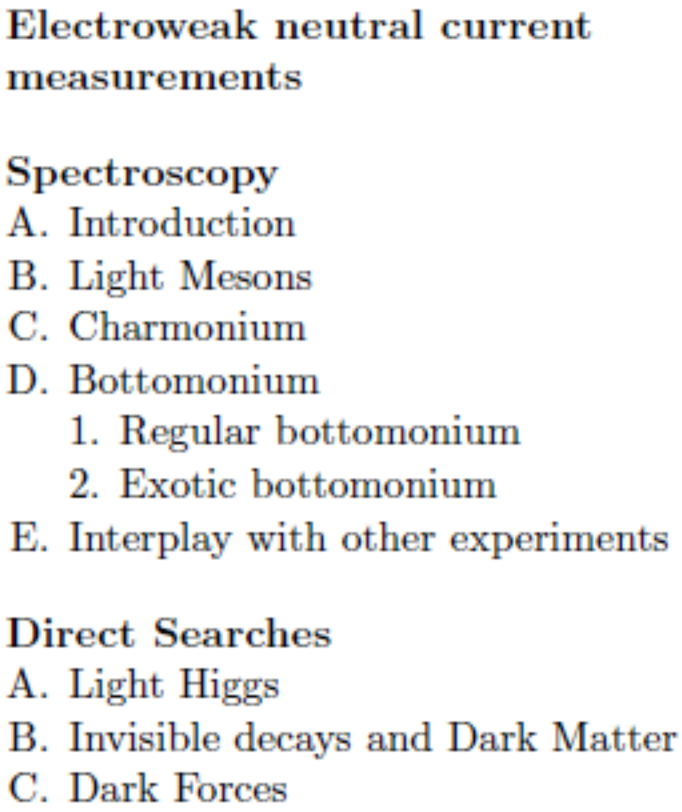
H. Precision CKM



B Physics at the $\Upsilon(5S)$

1. Measurement of B_s Mixing Parameters
2. Time Dependent CP Asymmetries at the $\Upsilon(5S)$
3. Rare Radiative B_s Decays
4. Measurement of $B_s \to \gamma\gamma$
5. Phenomenological Implications

Super Flavour Factory Physics Program Summary



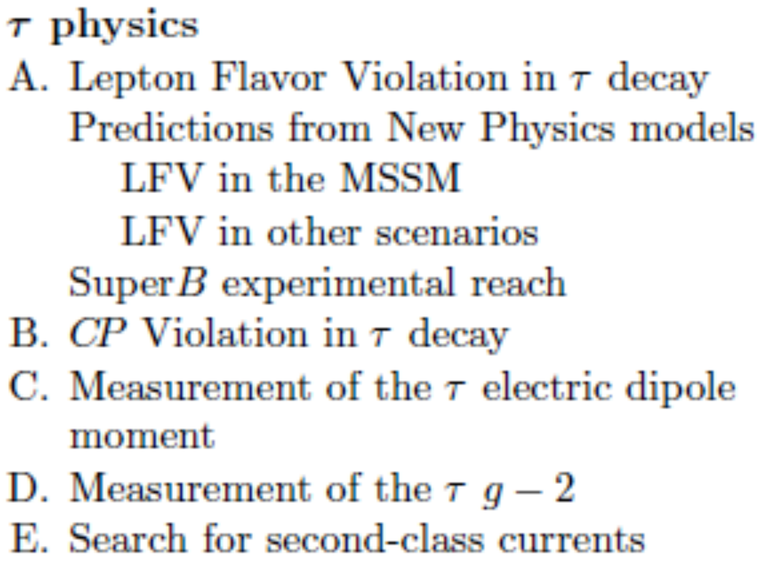
Electroweak neutral current measurements

Spectroscopy

A. Introduction
B. Light Mesons
C. Charmonium
D. Bottomonium
  1. Regular bottomonium
  2. Exotic bottomonium
E. Interplay with other experiments

Direct Searches

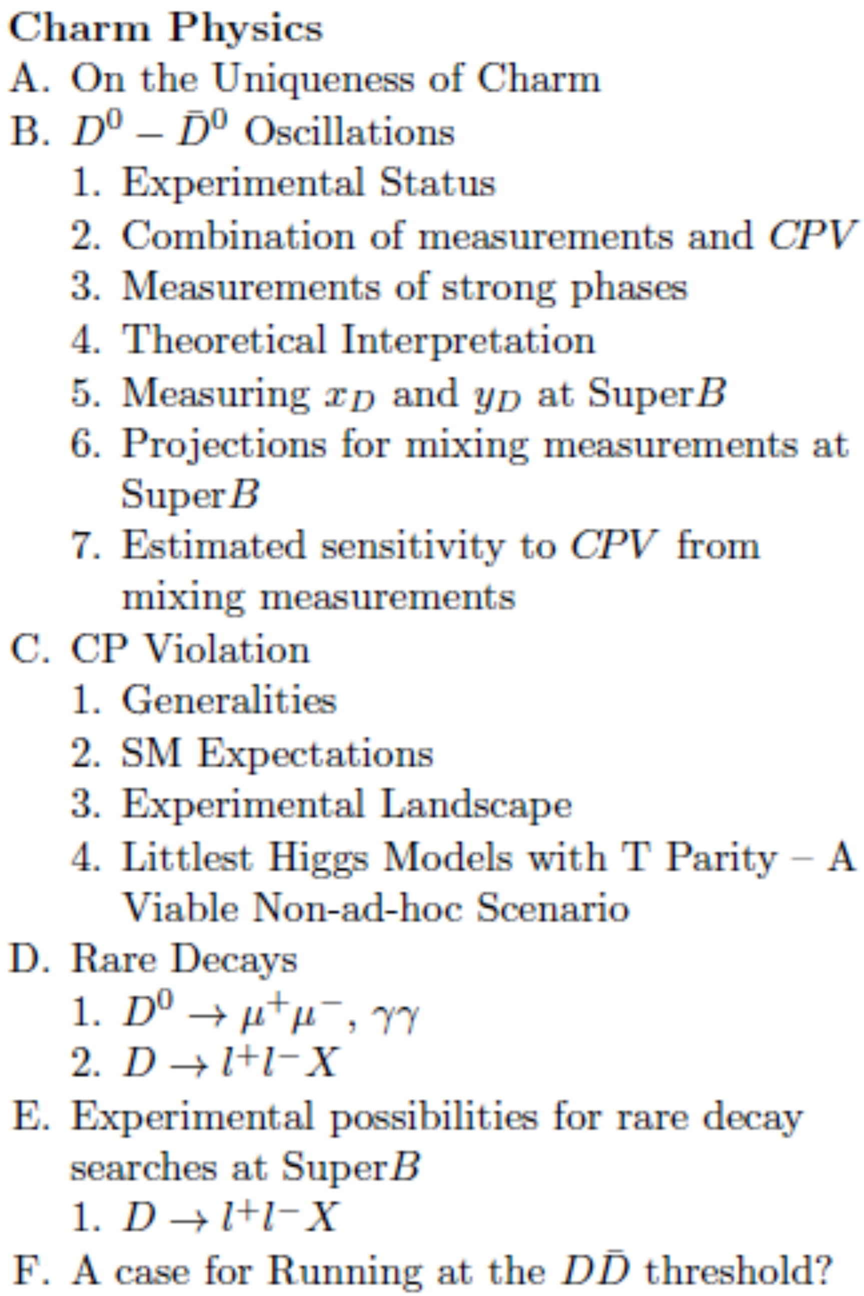
A. Light Higgs
B. Invisible decays and Dark Matter
C. Dark Forces



τ physics

A. Lepton Flavor Violation in τ decay
  Predictions from New Physics models
    LFV in the MSSM
    LFV in other scenarios
  Super$B$ experimental reach
B. *CP* Violation in τ decay
C. Measurement of the τ electric dipole moment
D. Measurement of the τ $g-2$
E. Search for second-class currents

Super Flavour Factory Physics Program Summary



Charm Physics

A. On the Uniqueness of Charm

B. $D^0 - \bar{D}^0$ Oscillations
   1. Experimental Status
   2. Combination of measurements and CPV
   3. Measurements of strong phases
   4. Theoretical Interpretation
   5. Measuring x_D and y_D at Super$B$
   6. Projections for mixing measurements at Super$B$
   7. Estimated sensitivity to CPV from mixing measurements

C. CP Violation
   1. Generalities
   2. SM Expectations
   3. Experimental Landscape
   4. Littlest Higgs Models with T Parity – A Viable Non-ad-hoc Scenario

D. Rare Decays
   1. $D^0 \to \mu^+\mu^-, \gamma\gamma$
   2. $D \to l^+l^-X$

E. Experimental possibilities for rare decay searches at Super$B$
   1. $D \to l^+l^-X$

F. A case for Running at the $D\bar{D}$ threshold?

Complementary with LHCb

	Belle or BaBar	SuperB or Belle II	LHCb
	$\sim 0.5\ ab^{-1}$	$50\ ab^{-1}$	$10\ fb^{-1}$
$\Delta S(\phi K_S)$	0.22	0.029	0.14
$\Delta S(\eta' K_S)$	0.11	0.020	---
β_s from $S(J/\psi\phi)$	---	---	0.01
$S(K^*\gamma)$	0.36	0.03	---
$S(\rho\gamma)$	0.68	0.08	---
$\Delta B/B(B \rightarrow \tau\nu)$	3.5σ	3%	---
$B_s \rightarrow \mu\mu$	•	•	5σ @ $6\ fb^{-1}$
$\tau \rightarrow \mu\gamma\ [\times 10^{-9}]$	<45	<8	---
$\tau \rightarrow \mu\mu\mu\ [\times 10^{-9}]$	<209	<1	---
α / ϕ_2	11^0	1^0	4.5^0
γ / ϕ_3	16^0	2^0	2.4^0

Advantage:

LHCb

- Modes where the final states are charged only.
- B_s
- B_c, Λ_b
- …..

B factories

- Modes with γ, π^0 .
- Modes with ν .
- τ decays.
- K_S vertex.