# The SuperB factory

## physics prospects and project status

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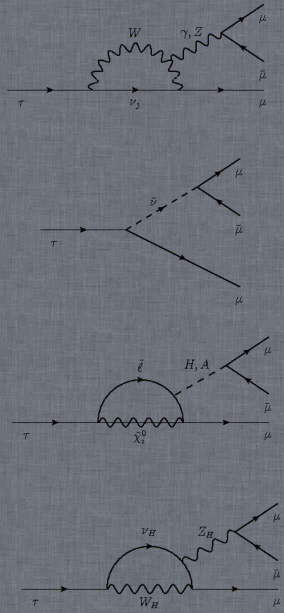
on behalf of the SuperB collaboration

$21^{st}$ September 2012



Introduction

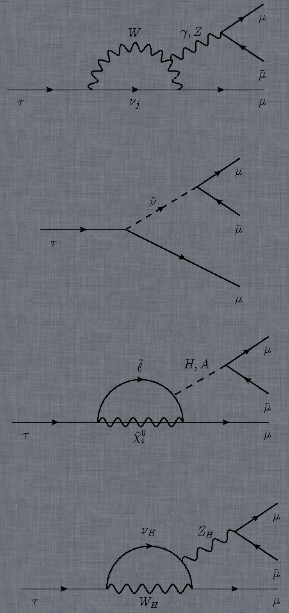
SuperB Infrastructure

B Physics

- Precision Measurements
- TDCP
- $B \to X_s \gamma$
- $\mathrm{B_s}$ Decays
- Charm Physics

$\tau$ Physics

- LFV
- $\tau$ $g - 2$
- EDM at SuperB
- CP Violation



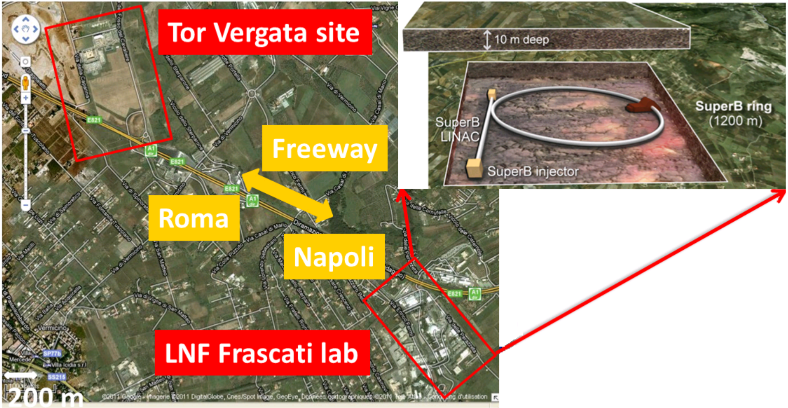
# B factories

B factories have contributed to many important physics discoveries over the last decade. They will be succeeded by the Super Flavor Factories:

## Super Flavor Factories

1. Data $75ab^{-1}$
2. Luminosity $10^{36}cm^{-2}s^{-1}$
3. Flexibility to run on charm threshold with luminosity $10^{35}cm^{-2}s^{-1}$
4. Longitudinal polarization of electron beam 80%
5. Upgraded BaBar detector
6. Start of data taking: 2018
7. $10ab^{-1}$ per year

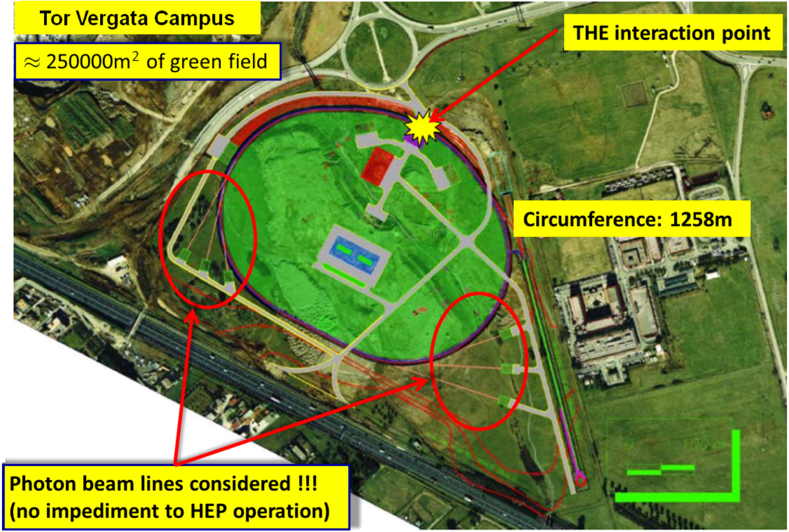
# Tor Vergata Site



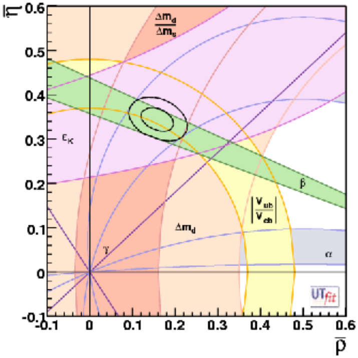

Important dates:

1. TDR: Autumn this year.
2. Colliding beams: June 2018.

# Tor Vergata Site



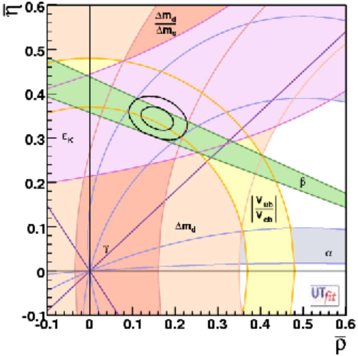
# CKM Matrix

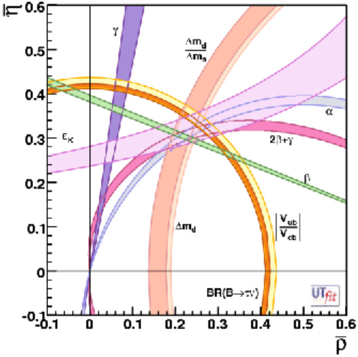



$$\Delta\bar{\eta} = 0.016$$

$$\Delta\bar{\rho} = 0.028$$

# CKM Matrix




$\Delta\overline{\eta} = 0.016$

$\Delta\overline{\rho} = 0.028$

$\Delta\overline{\eta} = 0.0024$

$\Delta|V_{cb}|_{incl} = 0.5\%$ $\Delta|V_{cb}|_{excl} = 1.0\%$

$\Delta\overline{\rho} = 0.0028$

$\Delta|V_{ub}|_{incl} = 1.0\%$ $\Delta|V_{ub}|_{excl} = 3.0\%$

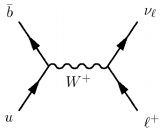
# $B \to \tau\nu$

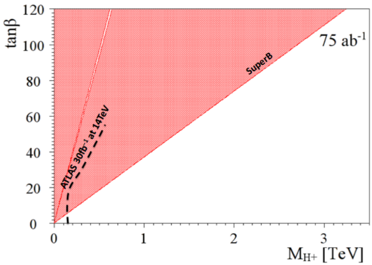
Precise SM prediction:

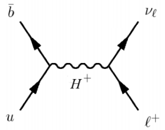
$$Br(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2}) f_B^2 |V_{ub}|^2 \tau_B$$

In SUSY:

$$Br(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2}) f_B^2 |V_{ub}|^2 \tau_B (1 - \frac{tan^2\beta}{1 + \bar{\epsilon} tan\beta} \frac{m_B^2}{m_H^2})$$



# Time-Dependent CP (TDCP)

Time-dependent CP analysis can show signs of new physics. One has to study a set of modes:

$b \to s\bar{s}c$, $b \to s$

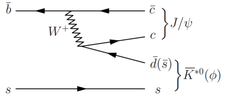
Current experimental results show $\Delta$(SM - Observed):

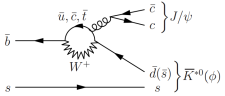
$\Delta sin(2\beta) = 2.7\sigma$, penguin

$\Delta sin(2\beta) = 2.1\sigma$, tree

Golden modes in SuperB: $B \to J/\psi K^0$, $B \to \eta' K^0$, $B \to f_0 K^0_s$

| Mode | Current Precision | | | Predicted Precision ($75\,\mathrm{ab}^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Stat. | Syst. | $\Delta S^f$ (Th.) | Stat. | Syst. | $\Delta S^f$ (Th.) |
| $J/\psi K^0_S$ | 0.022 | 0.010 | $0 \pm 0.01$ | 0.002 | 0.005 | $0 \pm 0.001$ |
| $\eta' K^0_S$ | 0.08 | 0.02 | $0.015 \pm 0.015$ | 0.006 | 0.005 | $0.015 \pm 0.015$ |
| $\phi K^0_S \pi^0$ | 0.28 | 0.01 | – | 0.020 | 0.010 | – |
| $f_0 K^0_S$ | 0.18 | 0.04 | $0 \pm 0.02$ | 0.012 | 0.003 | $0 \pm 0.02$ |
| $K^0_S K^0_S K^0_S$ | 0.19 | 0.03 | $0.02 \pm 0.01$ | 0.015 | 0.020 | $0.02 \pm 0.01$ |
| $\phi K^0_S$ | 0.26 | 0.03 | $0.03 \pm 0.02$ | 0.020 | 0.005 | $0.03 \pm 0.02$ |
| $\pi^0 K^0_S$ | 0.20 | 0.03 | $0.09 \pm 0.07$ | 0.015 | 0.015 | $0.09 \pm 0.07$ |
| $\omega K^0_S$ | 0.28 | 0.02 | $0.1 \pm 0.1$ | 0.020 | 0.005 | $0.1 \pm 0.1$ |
| $K^+ K^- K^0_S$ | 0.08 | 0.03 | $0.05 \pm 0.05$ | 0.006 | 0.005 | $0.05 \pm 0.05$ |
| $\pi^0 \pi^0 K^0_S$ | 0.71 | 0.08 | – | 0.038 | 0.045 | – |
| $\rho K^0_S$ | 0.28 | 0.07 | $-0.13 \pm 0.16$ | 0.020 | 0.017 | $-0.13 \pm 0.16$ |



# $B \to X_s\gamma$

Very important probe for new physics! Current experimental average:
$Br(B \to X_s\gamma) = (3.52 \pm 0.23 \pm 0.09)10^{-4}$
Theoretical prediction from NNLO:
$Br(B \to X_s\gamma) = (3.15 \pm 0.23)10^{-4}$
There are two ways to study this decay:

1. Exclusive:
   - The earliest results were obtained using a large number of exclusive decays, which were fully reconstructed
   - Errors arising from unseen modes
   - Obsolete for SuperB
2. Inclusive:
   - Use tagging to tag the other B
   - No requirements on $X_s$
   - Disadvantage: Cut on photon energy
   - Effort to keep the cut as small as possible

Experimentally challenging to measure inclusive decays.

# $B_s$ Decays

$B_s$ is clearly LHCb domain

Short runs at CLEO and Belle showed that $e^+ e^-$ can also contribute in $B_s$ studies

| Observable | Error on $1fb^{-1}$ | Error on $30fb^{-1}$ |
|---|---|---|
| $\Delta\Gamma[ps^{-1}]$ | 0.16 | 0.03 |
| $\beta_s$ from $B_s \to J/\psi\phi[deg]$ | 16 | 6 |
| $\beta_s$ from $B_s \to K\overline{K}^0[deg]$ | 24 | 11 |
| $\left\lvert\frac{V_{td}}{V_{ts}}\right\rvert$ | 0.08 | 0.017 |

Potentials in SuperB:

1. Decays with neutral particle $B_s \to J/\psi\eta$ , $B_s \to K_S^0\pi$, $B_s \to D^*K_S^0$, $B_s \to \Phi\eta'$
2. Measurements of $\mathcal{B}(B \to \gamma\gamma)$. SM prediction $\mathcal{B}(B \to \gamma\gamma) = (2-4) \times 10^{-7}$. NP (SUSY) $\mathcal{B}(B \to \gamma\gamma) = 5 \times 10^{-6}$.
3. Measurements of semi-leptonic asymmetry. $A_{SL}^s = \dfrac{1-\left\lvert\frac{q}{p}\right\rvert^4}{1+\left\lvert\frac{q}{p}\right\rvert^4} = \dfrac{N_1 - N_2}{N_1 + N_2}$

$N_1 = B_s \to \overline{B}_s \to D_s^{*-}\ell^+\nu$ $N_2 = B_s \to \overline{B}_s \to \overline{D}_s^*\ell^-\nu$

# Charm Physics

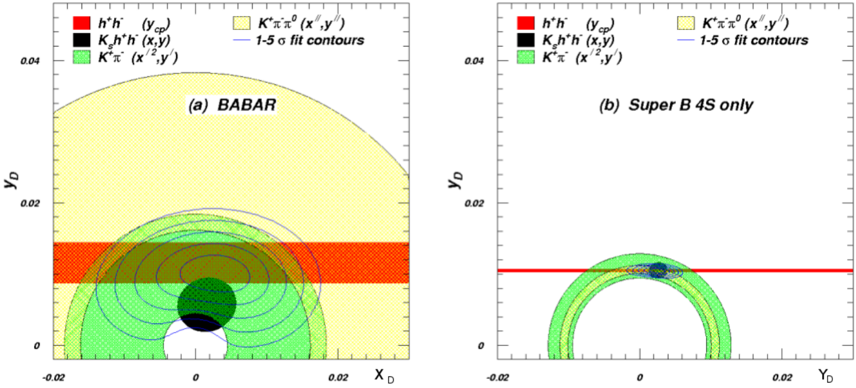
1. Plan for running at $\psi(3770)$ threshold
2. Scenario: Collect 500fb$^{-1}$
3. D tag possible; other meson can be studied with very small background

Potential improvement from SuperB:

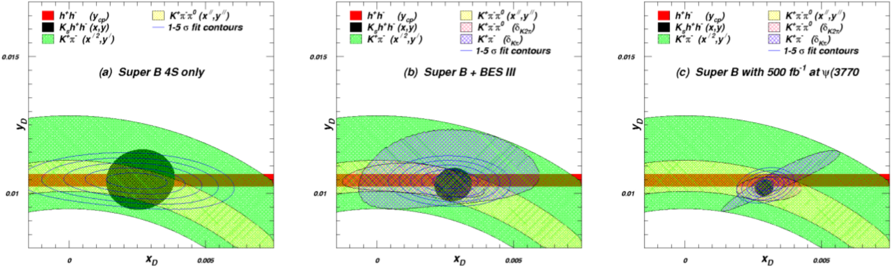
- Improved measurement of the mixing parameters $x_D$ and $y_D$
- CP violation in $\overline{\mathrm{D}} - \overline{\mathrm{D}}$: $A_{SL} = \dfrac{N_1 - N_2}{N_1 + N_2}$

  $N_1 = \Gamma(\mathrm{D}^0 \to \ell^- \nu \mathrm{K}^+)$,
  $N_2 = \Gamma(\overline{\mathrm{D}^0} \to \ell^+ \nu \mathrm{K}^-)$
- Search for $\mathrm{D}^0 \to \mu\mu$
- Quantum correlations allow one to measure relatively strong phase

# Charm Physics



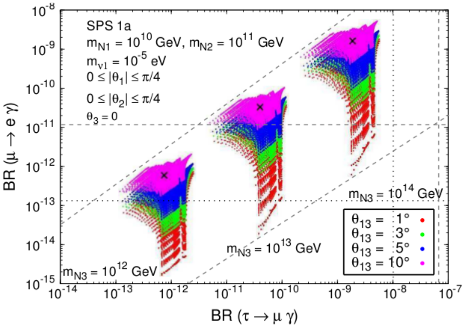
# Charm Physics

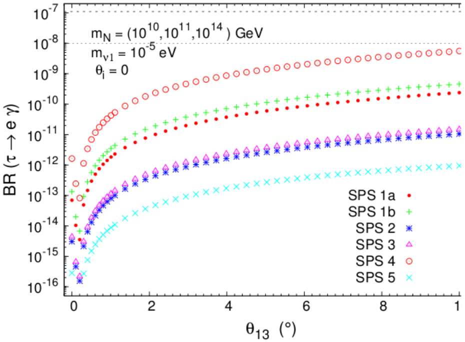


# $\tau$ Physics

1. Lepton Flavour Violation
   - SuperB sensitive to some SUSY models
   - Complementary to searches in LHC and MEG
   - Golden channels: $\tau \to 3\ell$, $\tau \to \ell\gamma$, $\tau \to \rho\ell$, $\tau \to \ell\eta$
2. $\tau$ $g - 2$
   - MSSM can explain $3 \times 10^{-9}$ discrepancy
   - Within SuperB sensitivity
3. $\tau$ EDM and CPV
   - Witin SuperB sensitivity!
   - $\tau$ EDM constrained by electron EDM upper limit to a range inaccessible for SuperB

# CMSSM Model



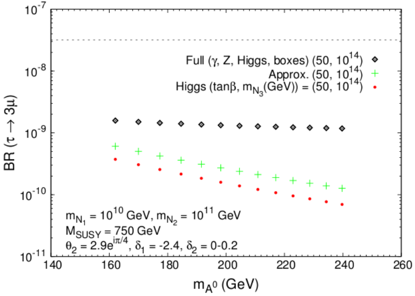



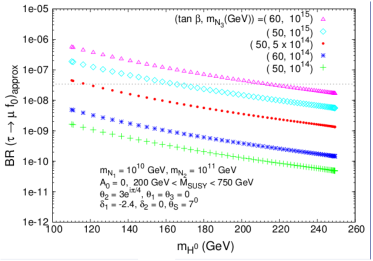

- $N_i$ - right handed neutrinos
- $\nu_i$ - left handed neutrinos
- $\phi_i$ - complex mixing angle
- $\phi_{13}$ - PNMS matrix.

- LFV up to present limit
- $\tau \to \mu\gamma$ complementary to $\mu \to e\gamma$

JHEP11(2006)090

# NUHM Model




- $\delta_1$, $\delta_2$ parametrizes the non-universal Higgs masses.

arXiv:0812.2692v1

- Increase sensitivity for $\tau \to f_0(980)\mu$, $\tau \to \eta\mu$, than to $\tau \to \mu\gamma$

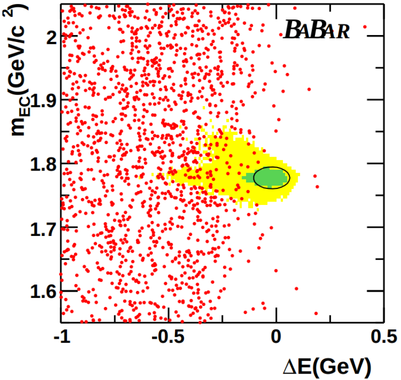
JHEP11(2006)090

# SuperB Sensitivity

1. Taking BaBar results and improving: $\sqrt{\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}} \approx 12$
2. Signal rises linearly: $\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}$
3. Sensitivity increases with detector resolution
4. Babar papers used to extrapolate:
    - Phys.Rev.Lett.104:021802,2010, arXiv:0908.2381v2
    - PhysRevD.81.111101(2010), arXiv:1002.4550v1

# $\tau \to \ell\gamma$ Sensitivity

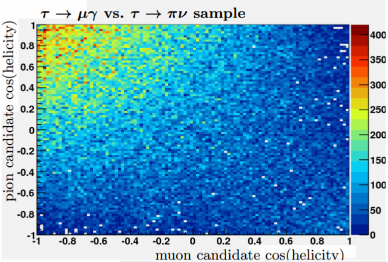
- Better tracking resolution, reduced $\Delta m - \Delta E$ box by 65%
- Higher photon efficiency
- Increase of geometry acceptance
- Thicker signal peak
- Approximate frequentist upper limits, only Poissonian BKG uncertainty
- Smaller boost improves the performance of the fit

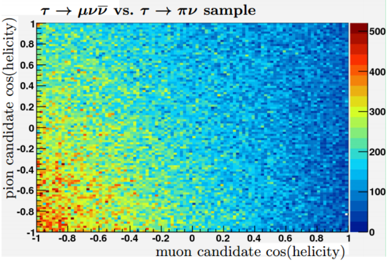



SuperB limits:

| Process | Error on 90% upper limit | $3\sigma$ observation |
|---|---|---|
| $\tau \to \mu\gamma$ | $2.4 \times 10^{-9}$ | $5.4 \times 10^{-9}$ |
| $\tau \to e\gamma$ | $3.0 \times 10^{-9}$ | $6.8 \times 10^{-9}$ |

# Polarization



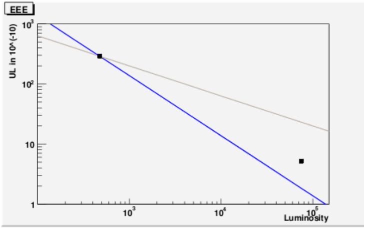




1. SuperB will have polarized electron beam (80%)
2. One can use this information in NP searches
3. TAUOLA SUSY decay model
4. Discriminating between NP models!

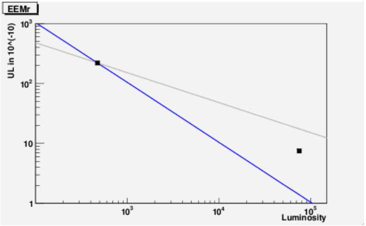
# SuperB sensitivity for $\tau \to 3\ell$

1. Taking the BaBar analysis results and improving: $\sqrt{\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}} \approx 12$
2. Signal is rising linearly: $\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}$
3. No detector resolution assumed.
4. Approximate frequentist upper limits, only Poissonian BKG uncertainty
5. Babar papers used to extrapolate:
   - Phys.Rev.Lett.104:021802,2010, arXiv:0908.2381v2
   - PhysRevD.81.111101(2010), arXiv:1002.4550v1

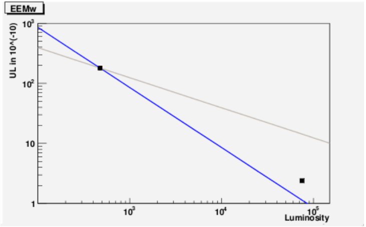
# $\tau \to 3\ell$




$\tau \to eee$

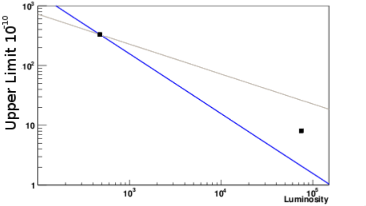



$\tau \to e^- e^+ \mu$

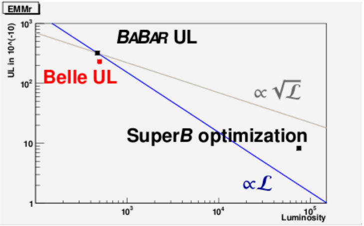



$\tau \to e^- e^- \mu$

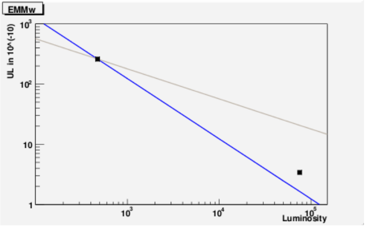
# $\tau \to 3\ell$




$\tau \to \mu\mu\mu$




$\tau \to \mu^-\mu^+e$




$\tau \to \mu^-\mu^-e$

# LFV Summary

Current analysis:

- SuperB will be the cutting edge factory for LFV in $\tau$ decays
- Beam polarization will improve the the analysis and make distinguishment among NP models possible

| Process | Error on 90% upper limit | $3\sigma$ observation |
|---|---|---|
| $\tau \to \mu\gamma$ | $2.4 \times 10^{-9}$ | $5.4 \times 10^{-9}$ |
| $\tau \to e\gamma$ | $3.0 \times 10^{-9}$ | $6.8 \times 10^{-9}$ |

# $\tau$ $g-2$

- MSSM would shift muon $g-2$ by about the presently observed discrepancy $\Delta a_\mu \approx 3 \times 10^{-9}$
- SuperB sensitivity estimates: $\sigma(a_\tau) = 2.6 \times 10^{-6}$ JHEP098P1108
- SuperB measures $a_\tau(q^2)$ from final state distributions of $e^+e^- \to \tau^+\tau^-$ See M.Passera talk
- Luckily NP contributions are constant for small $q^2$

# EDM at SuperB

- Experimental status: $|d_e| < 1.6 \times 10^{-}27$
  PhysRevLett.88.071805
- NP expect: $|d_\tau| \propto (m_\tau / m_e)|d_e|$
- SuperB upper limit $|d_e| \approx 10^{-22}$
  SuperB 2010 Physic Report
- Again we measure $|d_e|(q^2)$
- Luckily NP contributions are constant for small $q^2$

# EDM at SuperB

Belle result:

1. $29.5fb^{-1}$ data sample
2. Resolution: $0.9 - 1.7 \times 10^{-19} ecm$
3. $\boxed{\text{J. Bernabeu hep-ex/0210066}}$
4. Extrapolation for SuperB ($75ab^{-1}$): $\sigma(d_\tau) = 17 - 34 \times 10^{-17} ecm$
5. No beam polarization assumed!

Another approach: $\boxed{\text{arXiv:0707.1658v1}}$

- Assume beam polarity: $(80 \ \pm 1)$
- 80% geometry acceptance
- Track reconstruction 97.5%
- $\sigma(d_\tau) \approx 10 \times 10^{-17} ecm$

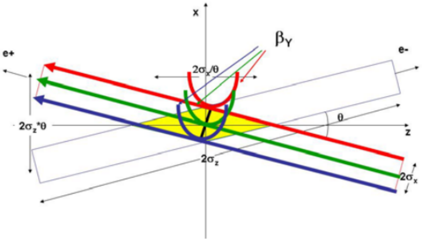
# CP Violation

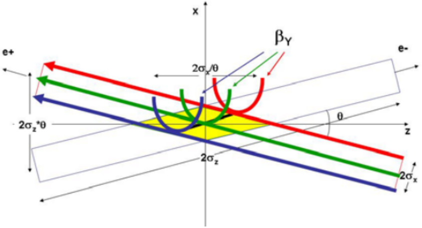
- CP violation has never been observed in $\tau$ sector
- SM prediction is negligibly small $O(10^{-12})l$ in $\tau^{\pm} \rightarrow K^{pm}\pi^0\nu$.
- Any observation is clear indication of NP
- Very few NP models can explain this:
  1. RPV SUSY
  2. Multi Higgs models
- SuperB can improve sensitivity 75 times compared to CLEO ($\xi(\tau \rightarrow K_s\pi\nu) = -2.0 \times 10^{-3}$)

Thank you for your attention.

# Backup

# Quest for Luminosity



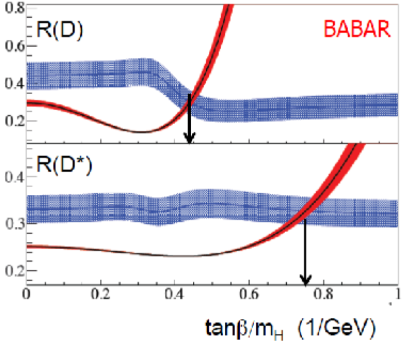




$$L \propto \frac{1}{\sqrt{\beta_y}}, \Phi \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$$

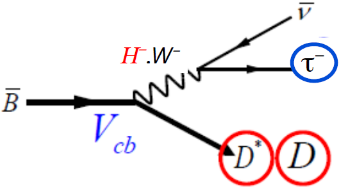
# B Rare Decays

$B^{\pm} \to D^{(*)}\tau^{\pm}\nu$

Babar ref. arXiv:1205.5442




Hot decay for SuperB!




Observables:

- $R(\mathrm{D}) = \dfrac{\mathrm{B} \to \mathrm{D}\tau\nu}{\mathrm{B} \to \mathrm{D}\ell\nu}$
- $R(\mathrm{D}^*) = \dfrac{\mathrm{B} \to \mathrm{D}^*\tau\nu}{\mathrm{B} \to \mathrm{D}^*\ell\nu}$

| | $R(\mathrm{D})$ | $R(\mathrm{D}^*)$ |
|---|---|---|
| BaBar | $0.440 \pm 0.071$ | $0.332 \pm 0.029$ |
| SM | $0.297 \pm 0.017$ | $0.252 \pm 0.003$ |
| Difference | $2.0\sigma$ | $2.7\sigma$ |