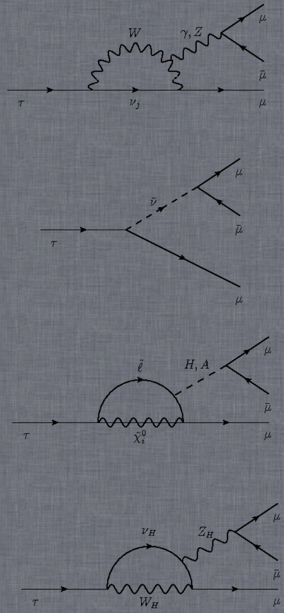
The SuperB factory

physics prospects and project status

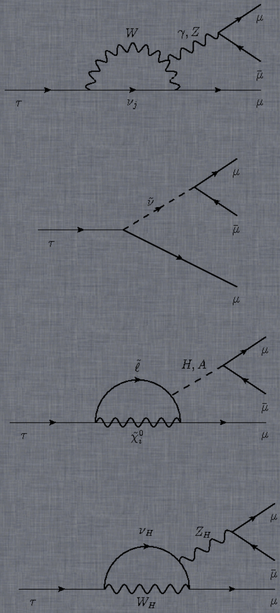
Marcin Chrząszcz

Institute of Nuclear Physics,
Polish Academy of Science,
on behalf of the SuperB collaboration

21st September 2012



- Introduction
- SuperB Infrastructure
- B Physics
  - Precision Measurements
  - TDCP
  - $B \to X_s\gamma$
  - $\mathrm{B_s}$ Decays
  - Charm Physics
- τ Physics
  - LFV
  - τ $g-2$
  - EDM at SuperB
  - EDM at SuperB
  - CP Violation



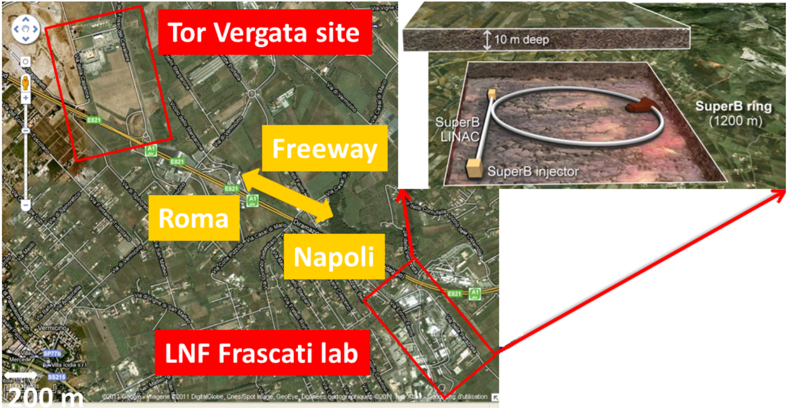
B factories

B factories have contributed to many important physics discoveries over the last decade. They will be succeeded 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

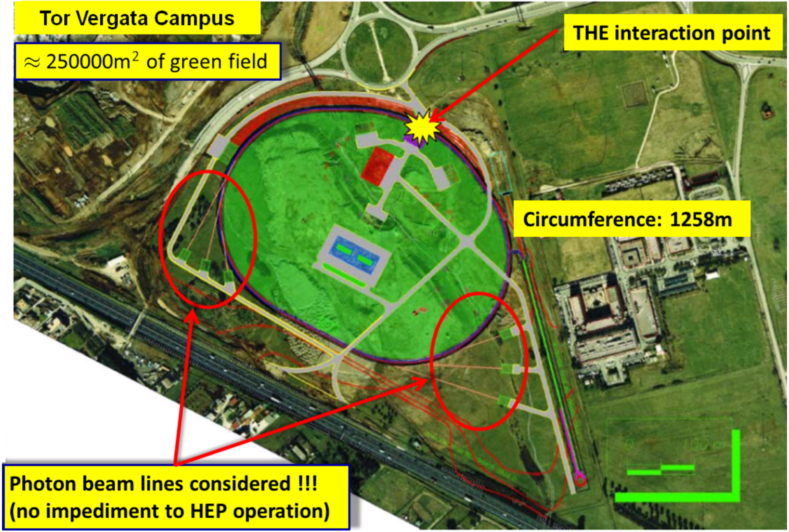
Tor Vergata Site



Important dates:

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

Tor Vergata Site



Tor Vergata Campus

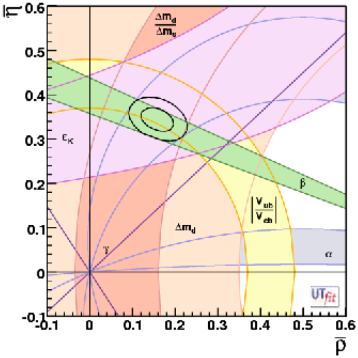
≈ 250000m^2 of green field

THE interaction point

Circumference: 1258m

Photon beam lines considered !!!
(no impediment to HEP operation)

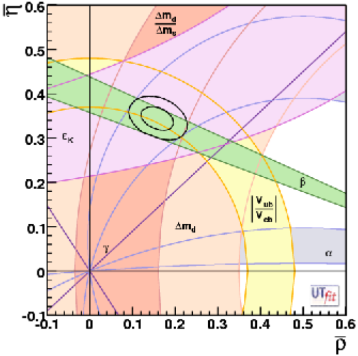
CKM Matrix

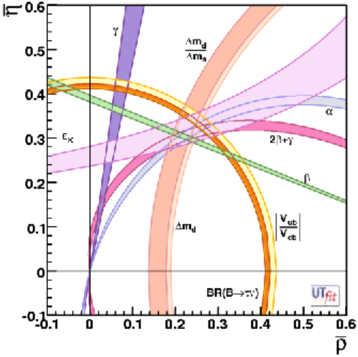


$$\Delta\bar{\eta} = 0.016$$

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

CKM Matrix





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

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

$\Delta\overline{\eta} = 0.0024$
$\Delta|V_{cb}|_{incl} = 0.5\%$ $\Delta|V_{cb}|_{excl} = 1.0\%$
$\Delta\overline{\rho} = 0.0028$
$\Delta|V_{ub}|_{incl} = 1.0\%$ $\Delta|V_{ub}|_{excl} = 3.0\%$

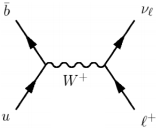
$B \to \tau\nu$

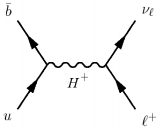
Precise SM prediction:

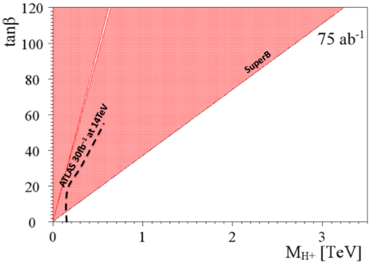
$$Br(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2}) f_B^2 |V_{ub}|^2 \tau_B$$

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:

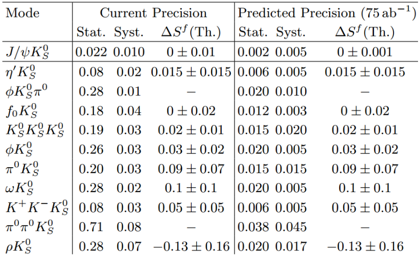
$b \to s\bar{s}c$, $b \to s$

Current experimental results show Δ(SM - Observed):

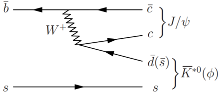
$\Delta sin(2\beta) = 2.7\sigma$, penguin

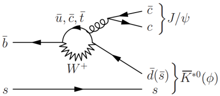
$\Delta sin(2\beta) = 2.1\sigma$, tree

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.	ΔS^f (Th.)	Stat.	Syst.	ΔS^f (Th.)
$J/\psi K^0_S$	0.022	0.010	0 ± 0.01	0.002	0.005	0 ± 0.001
$\eta' K^0_S$	0.08	0.02	0.015 ± 0.015	0.006	0.005	0.015 ± 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 ± 0.02	0.012	0.003	0 ± 0.02
$K^0_S K^0_S K^0_S$	0.19	0.03	0.02 ± 0.01	0.015	0.020	0.02 ± 0.01
ϕK^0_S	0.26	0.03	0.03 ± 0.02	0.020	0.005	0.03 ± 0.02
$\pi^0 K^0_S$	0.20	0.03	0.09 ± 0.07	0.015	0.015	0.09 ± 0.07
ωK^0_S	0.28	0.02	0.1 ± 0.1	0.020	0.005	0.1 ± 0.1
$K^+ K^- K^0_S$	0.08	0.03	0.05 ± 0.05	0.006	0.005	0.05 ± 0.05
$\pi^0 \pi^0 K^0_S$	0.71	0.08	–	0.038	0.045	–
ρK^0_S	0.28	0.07	-0.13 ± 0.16	0.020	0.017	-0.13 ± 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 done 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.

$\mathrm{B_s}$ Decays

$\mathrm{B_s}$ is clearly LHCb domain

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

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

Potentials in SuperB:

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

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

Charm Physics

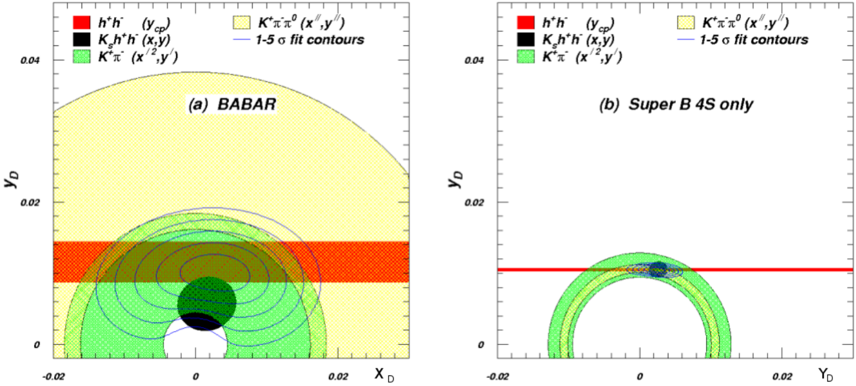
1. Plan for running at $\psi(3770)$ threshold
2. Scenario: Collect $500\mathrm{fb}^{-1}$
3. D tag possible; other meson can be studied with very small background

Potential improvement from SuperB:

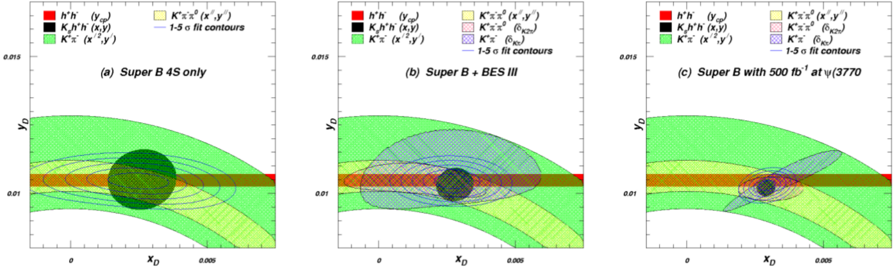
- Improved measurement of the mixing parameters x_D and y_D
- CP violation in $\overline{\mathrm{D}} - \overline{\mathrm{D}}$: $A_{SL} = \dfrac{N_1 - N_2}{N_1 + N_2}$

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

Charm Physics



Charm Physics


(a) Super B 4S only

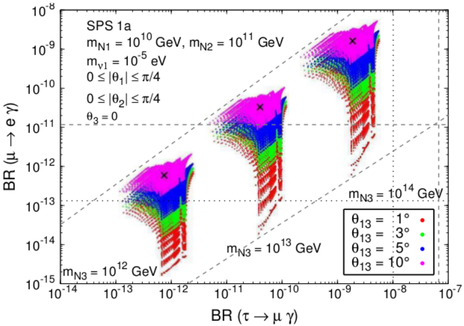
(b) Super B + BES III

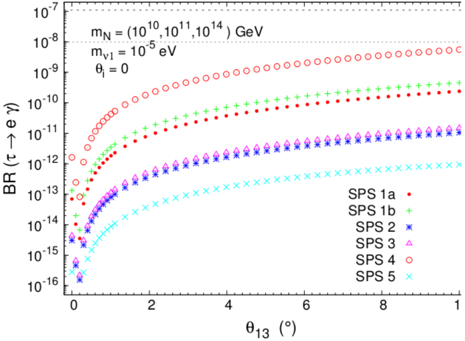
(c) Super B with 500 fb^{-1} at ψ(3770

τ Physics

1. Lepton Flavaur Violation
   - Some SUSY model can occure in SuperB sensitive.
   - 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. τ $g - 2$
   - MSSM can explain 3×10^{-9} discrepancy.
   - SuperB sensitivety is in range of doing this.
3. τ EDM and CPV
   - In SuperB sensitivity!
   - τ EDM constrained by electron EDM upper limit to a range inaccessible by SuperB

CMSSM Model



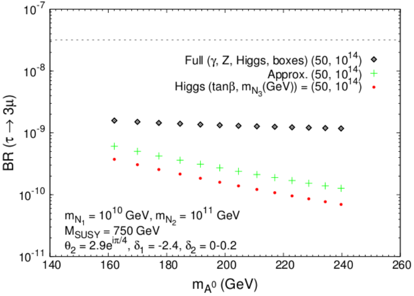


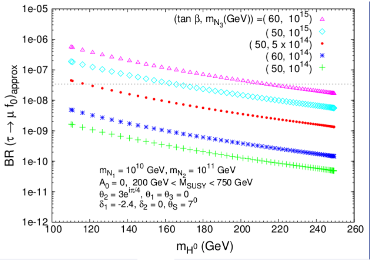
- N_i - right handed neutrinos
- ν_i - left handed neutrinos
- ϕ_i - complex mixing angle
- ϕ_{13} - PNMS matrix.

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

JHEP11(2006)090

NUHM Model





- δ_1, δ_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 $\tau \to \mu\gamma$

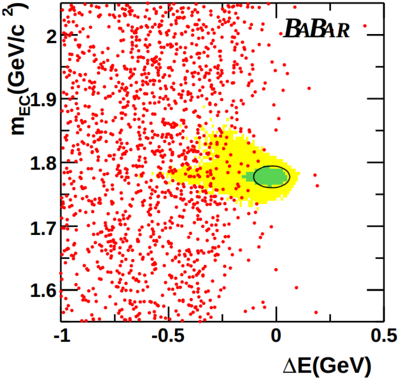
JHEP11(2006)090

SuperB sensitivity

1. Taking 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. Sensitivety 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

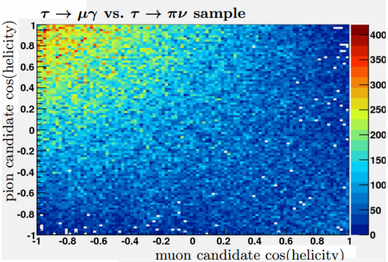
- Better tracking resolution, reduced $\Delta m - \Delta E$ box by 65%
- Higher photon efficiency
- Increase of geometry acceptance
- Thicker signal peak
- Approximate frequentistic upper limits, only Poissonian BKG uncertainty.
- Smaller boost improves the performance of the fit.

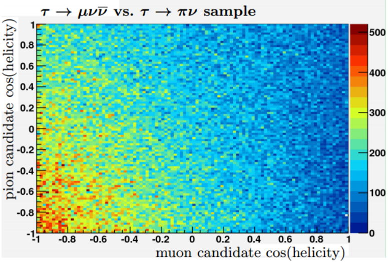


SuperB limits:

Process	Error on 90% upper limit	3σ observation
$\tau \to \mu\gamma$	2.4×10^{-9}	5.4×10^{-9}
$\tau \to e\gamma$	3.0×10^{-9}	6.8×10^{-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: $\sqrt{\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}} \approx 12$

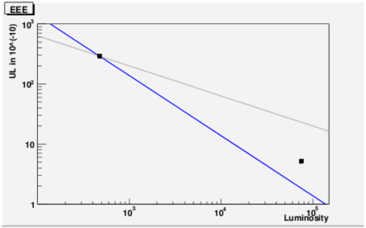
② Signal is rising linearly: $\mathcal{L}_{SuperB}/\mathcal{L}_{BaBar}$

③ No detector resolution assumed.

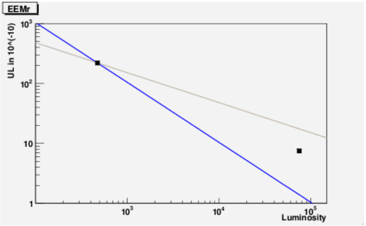
④ Approximate frequentistic upper limits, only Poissonian BKG uncertainty

⑤ Babar papers used to extrapolate:
  - Phys.Rev.Lett.104:021802,2010, arXiv:0908.2381v2
  - PhysRevD.81.111101(2010), arXiv:1002.4550v1

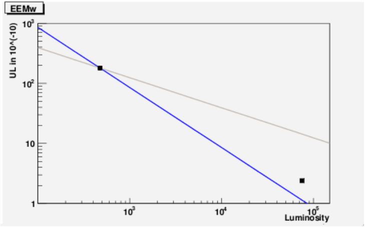
$\tau \to 3\ell$



$\tau \to eee$

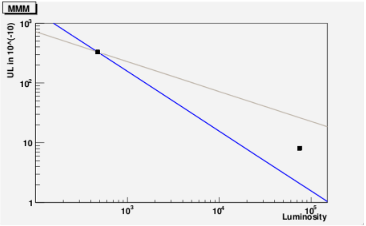


$\tau \to e^- e^+ \mu$

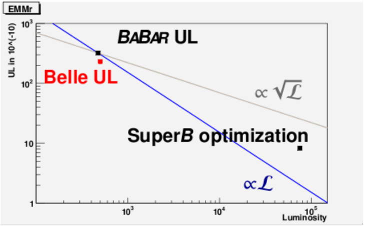


$\tau \to e^- e^- \mu$

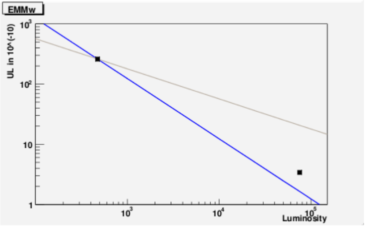
$\tau \to 3\ell$



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



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



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

LFV Summary

Current analysis:

- SuperB will be the cutting age factory for LFV in τ decays.
- Beam polarization will improve the the analysis and make distinguishng among NP models possible.

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

τ $g-2$

- 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
- Luckly 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 $|d_e|(q^2)$.
- Luckly 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. 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!

Other aproach: arXiv:0707.1658v1

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

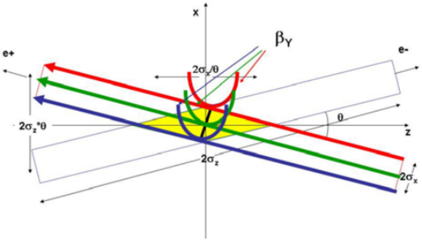
CP Violation

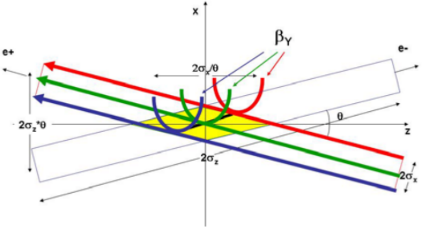
- CP violation has never been observed in τ sector
- SM prediction is negligibly small $O(10^{-12})l$ in $\tau^{\pm} \to K^{pm}\pi^{0}\nu$.
- Any observation is clear indication of NP
- Very few NP models can explain this:
  1. RPV SUSY
  2. Multi Higgs models
- SuperB can improve sensitivity 75 times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

Backup

Backup

Quest for Luminosity



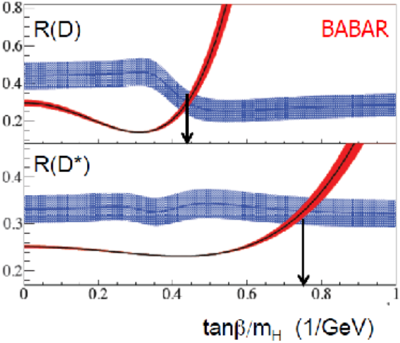


$$L \propto \frac{1}{\sqrt{\beta_y}}, \Phi \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$$

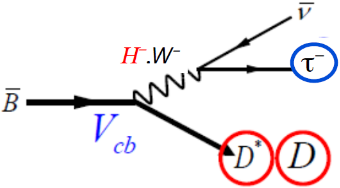
B Rare Decays

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

Babar ref. arXiv:1205.5442



Hot decay for SuperB!



Observables:

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

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