The SuperB factory
physics potential and project status

Jarosław Wiechczyński
Institute of Nuclear Physics PAS

4.06.2012 MESON2012

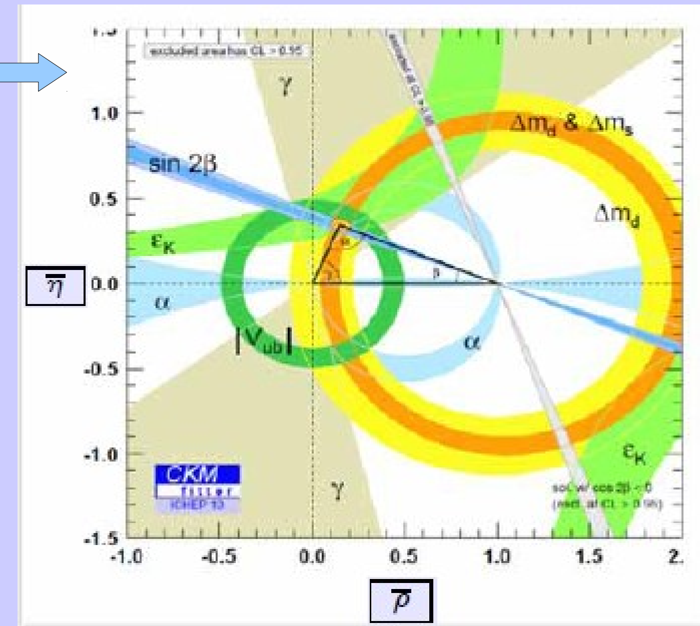
OUTLINE

1. Project motivation
2. Physics program
3. Accelerator & Detector
4. Project Status

Project motivation

Successful output of the last decade B factories
-> KEKB (Belle) and PEPII (BaBar)

- Qualitative progress in the measurements of angles and sides of the CKM matrix
- Observation of DIRECT CP violation in B decays
- b→s transition as a powerful tool to search for NP
- Observation of many rare B decay modes ($B \to D\tau\nu$, $B \to \tau\nu$ ...)
- Observation of charm-meson mixing
- Spectroscopy: evidence for several new states
- Qualitative progress in studies of τ rare decays



We need more precision to search for the evidence of the New Physics

Should work 50-100 times faster

MORE DATA !

SuperB in the Nutshell

Data sample of 75 ab^{-1} (@ϒ(4S))

Luminosity at least of **10^{36} $cm^{-2}s^{-1}$**

Squeeze the beams (ILC-like)

Same wall plug power as B factories

Re-usage of PEP-II components

Flexibility of the collider: runs at the **charm** (and **ϒ(5S)** ...) thresholds with the luminosity of **10^{35} $cm^{-2}s^{-1}$** (charm: 0.5 ab^{-1}, ϒ(5S): 1 ab^{-1})

Longitudinal **polarization** of the **electron beam** (80%)

Tau physics

Clean EW measurements

Moderate **improvements of the detector**

Site: Tor Vergata (Rome)

(almost) brand-new accelerator

Start of **data-taking: 2016- 2017**

Plans for at least 10 ab^{-1}/year

Main Physical goals

1. Υ(4S) physics: improvement by an order of magnitude in the precision (to compare with B factories)
2. Tests of the CKM paradigm at the 1% level
3. Potential spectroscopy discoveries

High luminosity needed

4. b physics at Upsilon resonances other than Υ(4S)
5. CPV in charm, also with time dependent asymmetries

Scan in CM energy

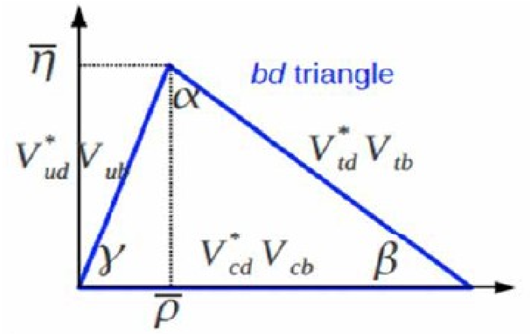
6. Electroweak measurements
7. Tau physics
   - Lepton Flavor Violation (LFV) sensitivity -> improvement by 1-2 orders of magnitude
   - CP and T-violation
   - Electro-magnetic structure of the tau

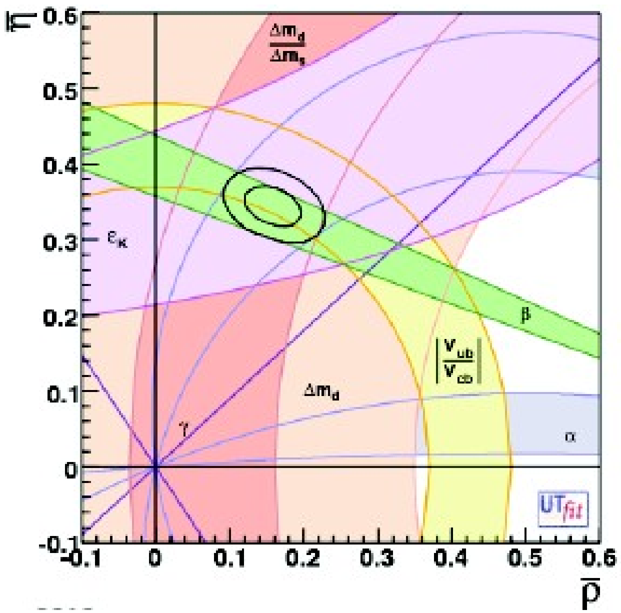
Longitudinal polarization of the electron beam

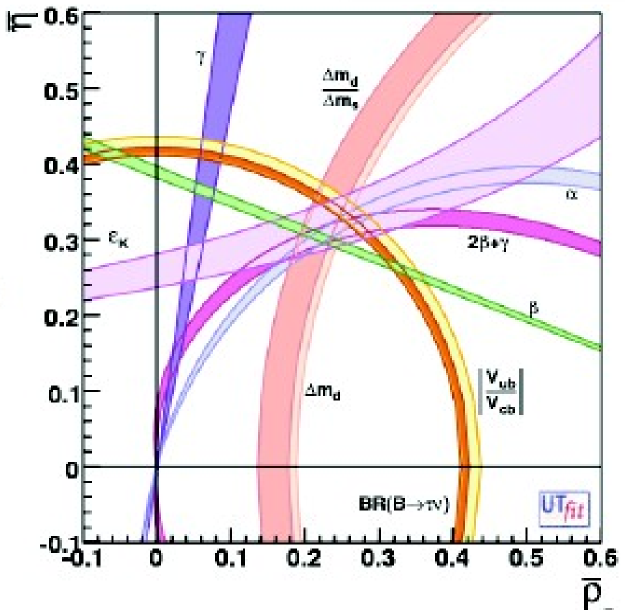
The complementarity with the LHC physics program

CKM precision

SuperB can determine the parameters of the Unitary Triangle with the precision of an order of magnitude better than measured by the previous B Factories.







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

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

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

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

B_s at Υ(5S)

Studies on B_s decays mainly performed at LHC experiments

However... high potencial for such studies for e^+e^- colliders – already shown by studies on Υ(5S) data collected by Belle and BaBar.

Potencial highlights from SuperB:

1. B_s decays with neutral particles: $B_s \to J/\psi\eta^{(\prime)}$ $B_s \to K_S^0\pi^0$ $B_s \to D^{(*)}K_S^0$ $B_s \to \phi\eta'$

2. Measurement of $\mathcal{B}(B_s \to \gamma\gamma)$ SM: Br » (2-8) x 10^{-7}, NP (e.g. SUSY) 5x 10^{-6}

   SuperB precision (30 ab^{-1}) **7%** (stat), **5%** (syst) (assuming the Br of the SM)

3. Measurement of the semileptonic asymmetry of the B_s:

$$A_{SL}^s = \frac{1-\left|\frac{q}{p}\right|^4}{1+\left|\frac{q}{p}\right|^4} = \frac{N_1-N_2}{N_1+N_2}$$

   SuperB precision (30 ab^{-1}): **0.004**

$$N_1 = \mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-}l^+\nu_l)$$

$$N_2 = \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+}l^-\nu_l)$$

Lepton Flavour Violation (LFV) at tau decays

- LFV as an unambiguos probe of NP, with negligible theoretical uncertainties
- The tau is the most suitable lepton to search for LFV effects
  (the heaviest charged lepton with many possible LFV decay modes)
- LFV for charged lepton is negligibly small in the SM
  (even after taking into account neutrino oscillations)

$\mathcal{B}(\tau \to l\gamma) < 10^{-54}$ $\mathcal{B}(\tau \to lll) < 10^{-14}$

The most promising decay channels:

$\tau \to \mu\gamma$

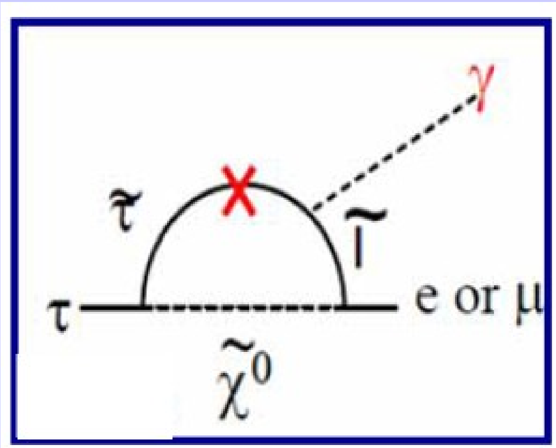
$\tau \to \mu\mu\mu$

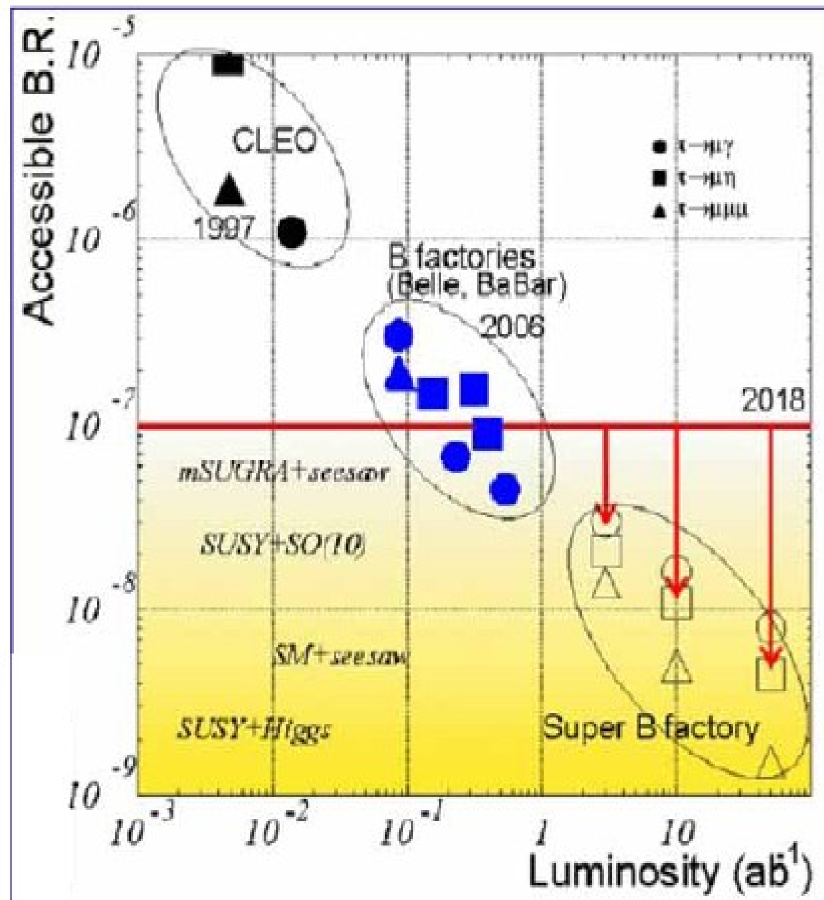
$\tau \to \mu\rho$ $\tau \to \mu\eta$

Sensitivity (90% U.L.)

$\mathcal{B}(\tau \to \mu\gamma) \sim 2.4 \times 10^{-9}$

$\mathcal{B}(\tau \to \mu\mu\mu) \sim 2.3 \times 10^{-10}$

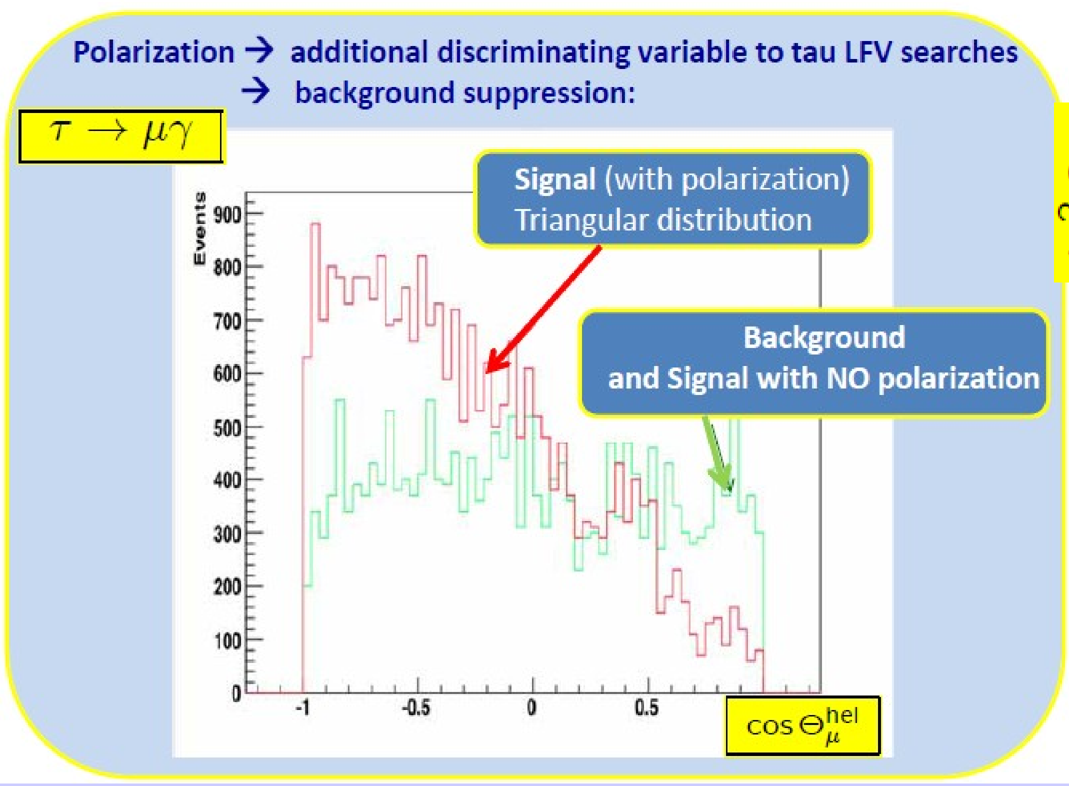


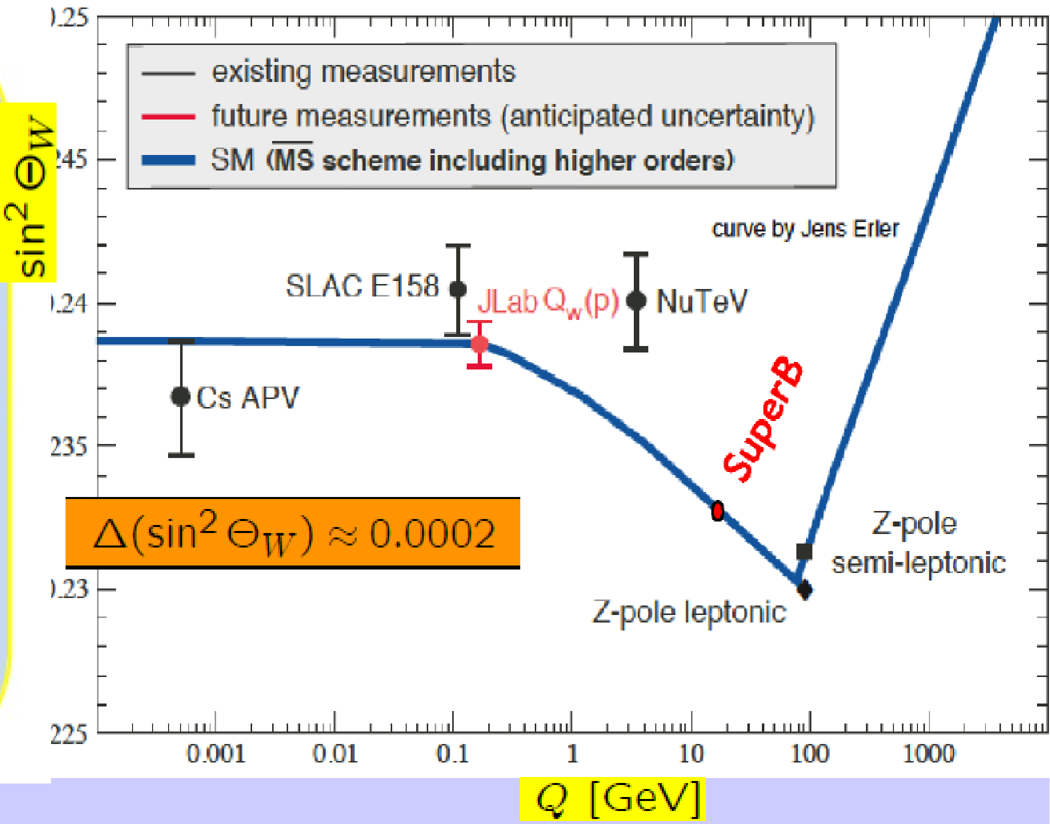


Polarization & Electroweak measurements

80% longitudinal polarization for electrons → unique feature for the SuperB experiment

- Useful for electric dipole moment (EDM) and anomalous magnetic moment g-2 measurements
- Additional discriminating variable to τ LFV searches
  → Improved background rejection
- $\sin^2\theta_W$ at 10.58 GeV (precision similar to LEP)





g-2 factor & EDM

- Long standing discrepancy for the muon g-2: $\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} \approx (3 \pm 1) \times 10^{-9}$
- The natural scaling: $\frac{\Delta a_\mu}{\Delta a_\tau} \sim \frac{m_\tau^2}{m_\mu^2}$
- interpreting the Δa_μ as a signal of NP → $\Delta a_\tau \approx 10^{-6}$
- The tau g-2 (and the tau EDM as well) influences both the angular distributions and the polarization of the tau produced in e^+e^- annihilation
- SuperB (**75 ab^{-1}**): can measure the g-2 form factor with the resolution of $(0.75 - 1.5) \times 10^{-6}$
- Proposed measurements :

Crucial role of beam polarization

1. Fit to the polar angle distribution of the SINGLE tau lepton
2. **Measurement of the transverse and longitudinal polarization of the tau from the angular distribution of its decay products**

Similar considerations and measurements for the electric dipole moment (EDM) of the tau

Charm physics

- SuperB: plans for **running at D-Dbar threshold**
- Possible scenario: **500 fb^{-1} at the Ψ(3770)** – few months of running (10^{35} cm^{-2} s^{-1})
- **D-Dbar pair is entagled**: tagging events in which one D meson is identified
  → the other D can be studied with very small background contamination
- **Potential highlights from the SuperB:**
  - → Improved (x10) precision in mixing parameters x_D and y_D
  - → CP violation in D-Dbar oscilations: $A_{SL}(D^0) = \frac{|q_D|^4 - |p_D|^4}{|q_D|^4 + |p_D|^4} = \frac{N_1 - N_2}{N_1 + N_2}$

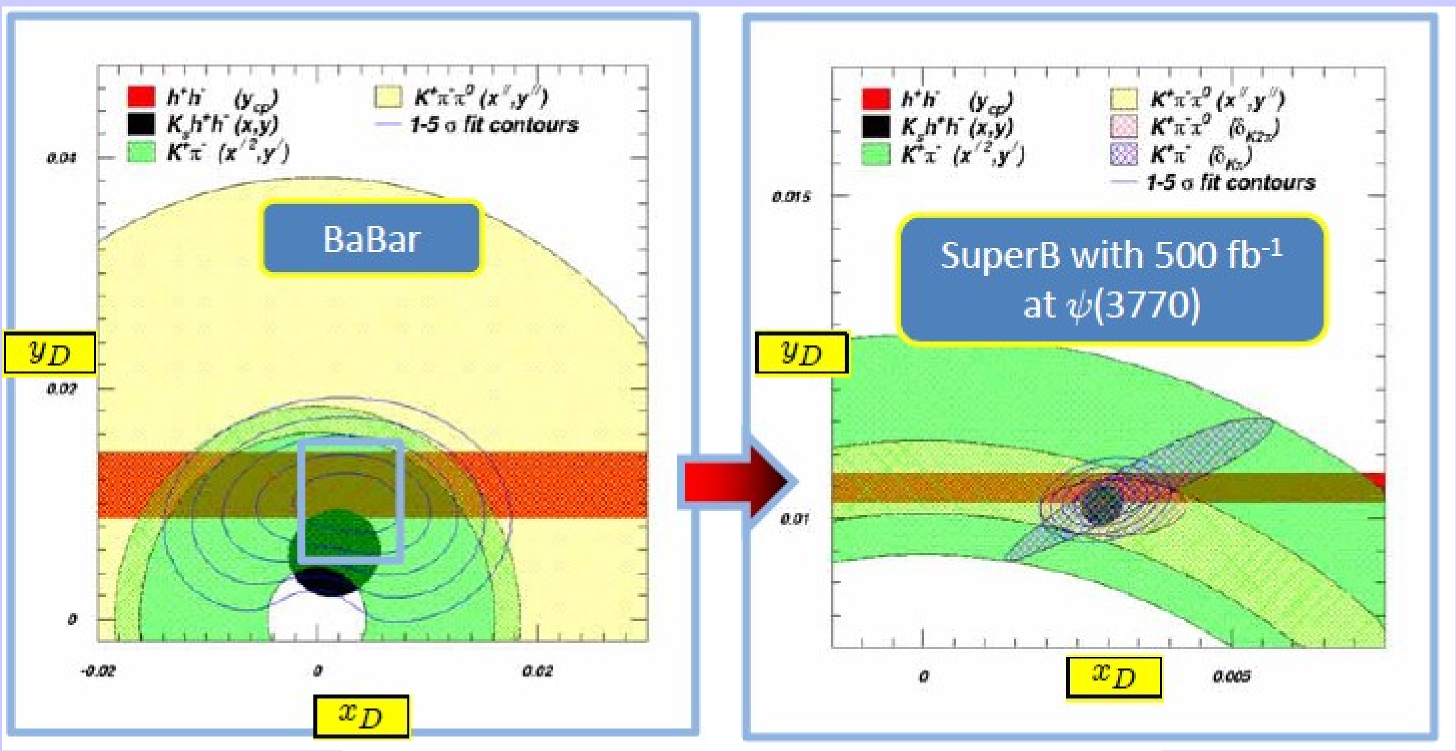
    $N_1 = \Gamma(D^0(t) \to l^- \overline{\nu} K^+)$

    $N_2 = \Gamma(\overline{D}^0(t) \to l^+ \nu K^-)$
  - → Search for $D^0 \to \mu^+ \mu^-$
  - → Quantum correlations in decays od D-Dbar can allow for measurement of their relative strong phases

D0 mixing

→ The availability of quantum-correlated D decays allows independent measurement of strong phases like δKπ , δKππ

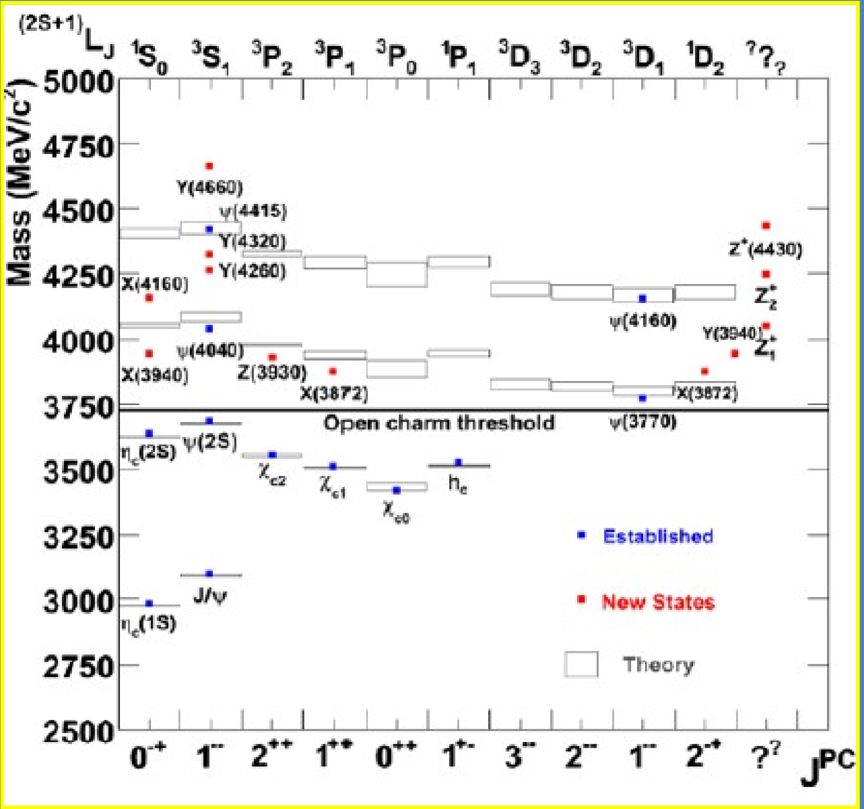
→ Substantial improvement of the precision in mixing parameters x_D and y_D to the level of the order of 10^{-4} is expected.



Observable	B Factories ($2ab^{-1}$)	SuperB ($75\ ab^{-1}$)
x_D	$2-3\times10^{-3}$	5×10^{-4}
y_D	$1-2\times10^{-3}$	3×10^{-4}

Spectroscopy

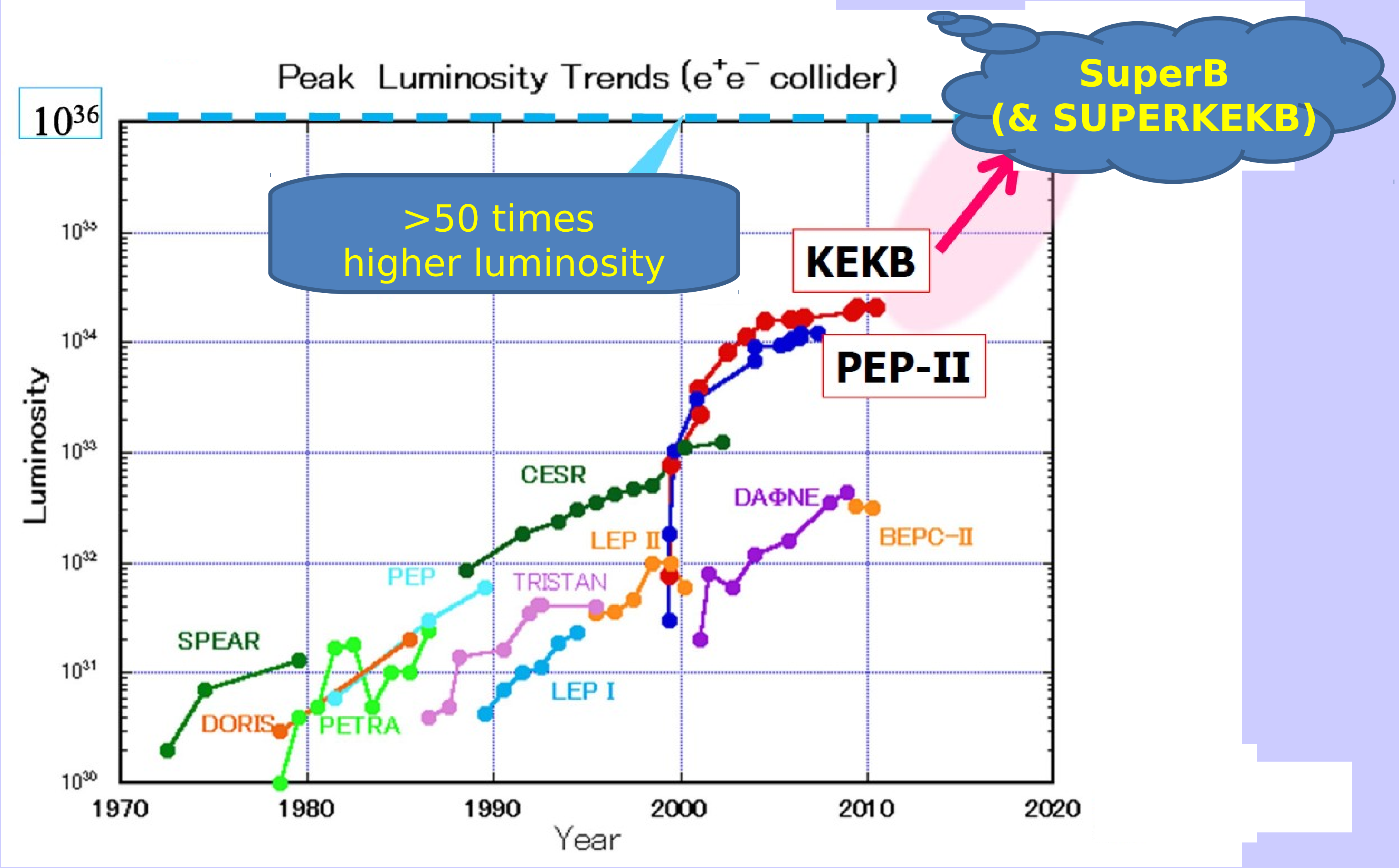
- **B factories: a plethora of new states**
- Most of them do not fit into conventional mesons and baryons ➔ hybrid mesons, molecules, tetraquarks …
- All the new c-cbar states (apart from the X(3872)) have been observed in only a single decay channel, each with a significance barely above 5σ



- **SuperB: x100 more events**
  → much more detailed studies of these states, also in several other modes
- **Natural expectations of new discoveries at the SuperB**
- Bottomonium: SuperB can look for not yet observed singlet states (parabottomonia)

ACCELERATOR
&
DETECTOR

Luminocity


Peak Luminosity Trends (e+e− collider)
SuperB
(& SUPERKEKB)
10^36
>50 times
higher luminosity
KEKB
PEP-II
CESR
DAΦNE
LEP II
BEPC-II
PEP
TRISTAN
SPEAR
DORIS
PETRA
LEP I
Luminosity
10^30
10^31
10^32
10^33
10^34
10^35
1970
1980
1990
2000
2010
2020
Year

Luminocity

Beam current
1.7/1.4 A e+e- KEKB
1.9/2.5 A SuperB

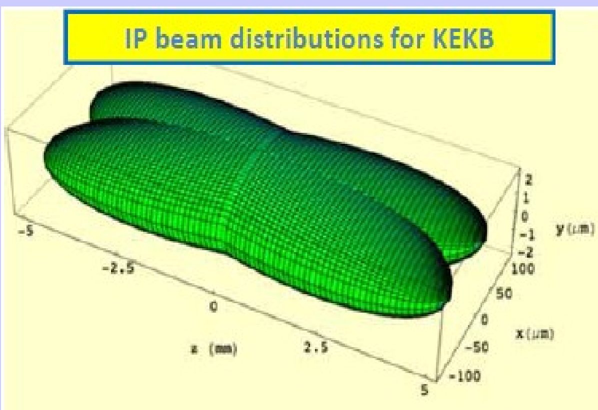
$$L \propto \frac{I_{\pm}\xi_{y\pm}}{\beta^*_{y\pm}}$$

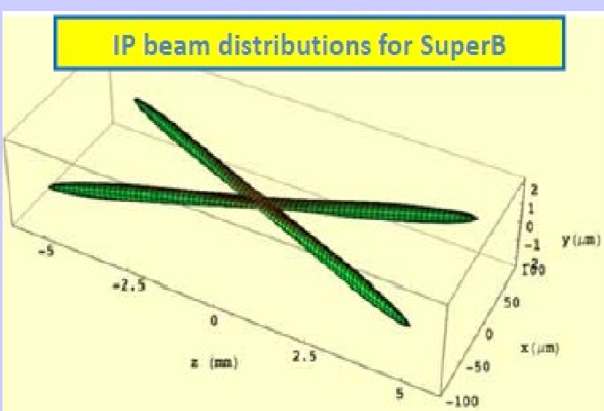
Beam-beam parameter
0.09 KEKB
0.125 SuperB

beta-function
(trajectories envelope) at IP
6 mm KEKB
0.3 mm SuperB

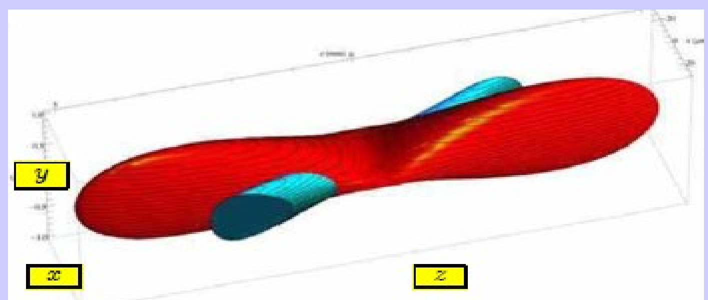
	KEKB	SuperB
I (A)	1.9	1.9/2.4
β_y^* (mm)	6	0.3
β_x^* (mm)	300	23
σ_y^* (µm)	3	0.035
σ_x^* (µm)	80	8
σ_z (mm)	6	5
L ($cm^{-2}s^{-1}$)	1.7×10^{34}	1×10^{36}

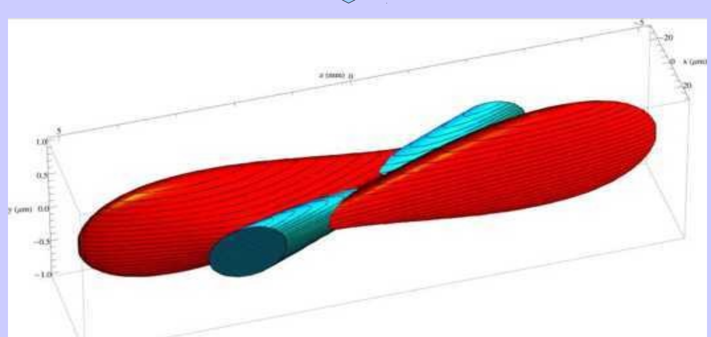
Here is Luminosity gain

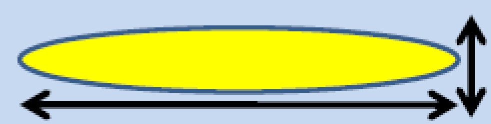




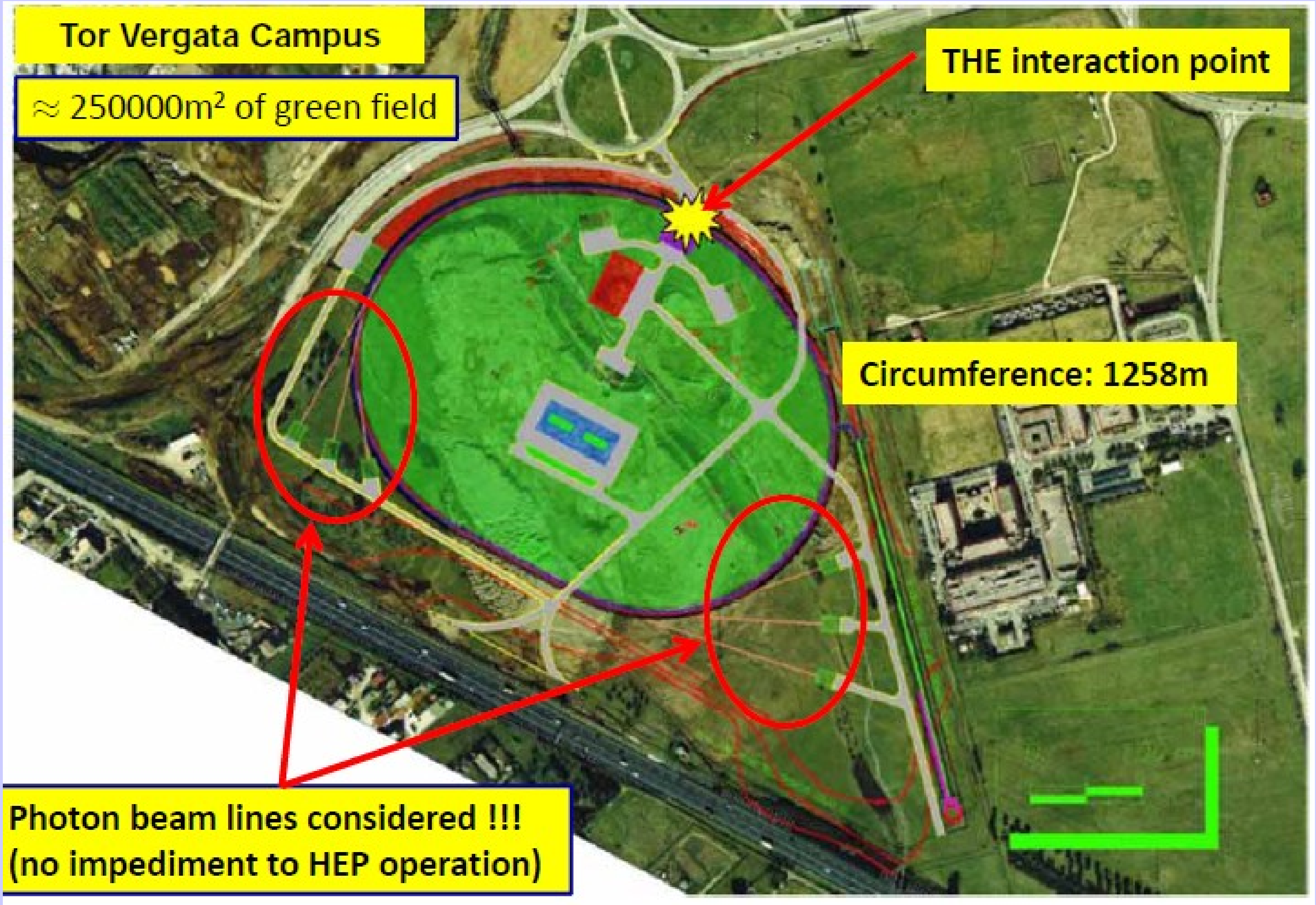
The Crab Waist



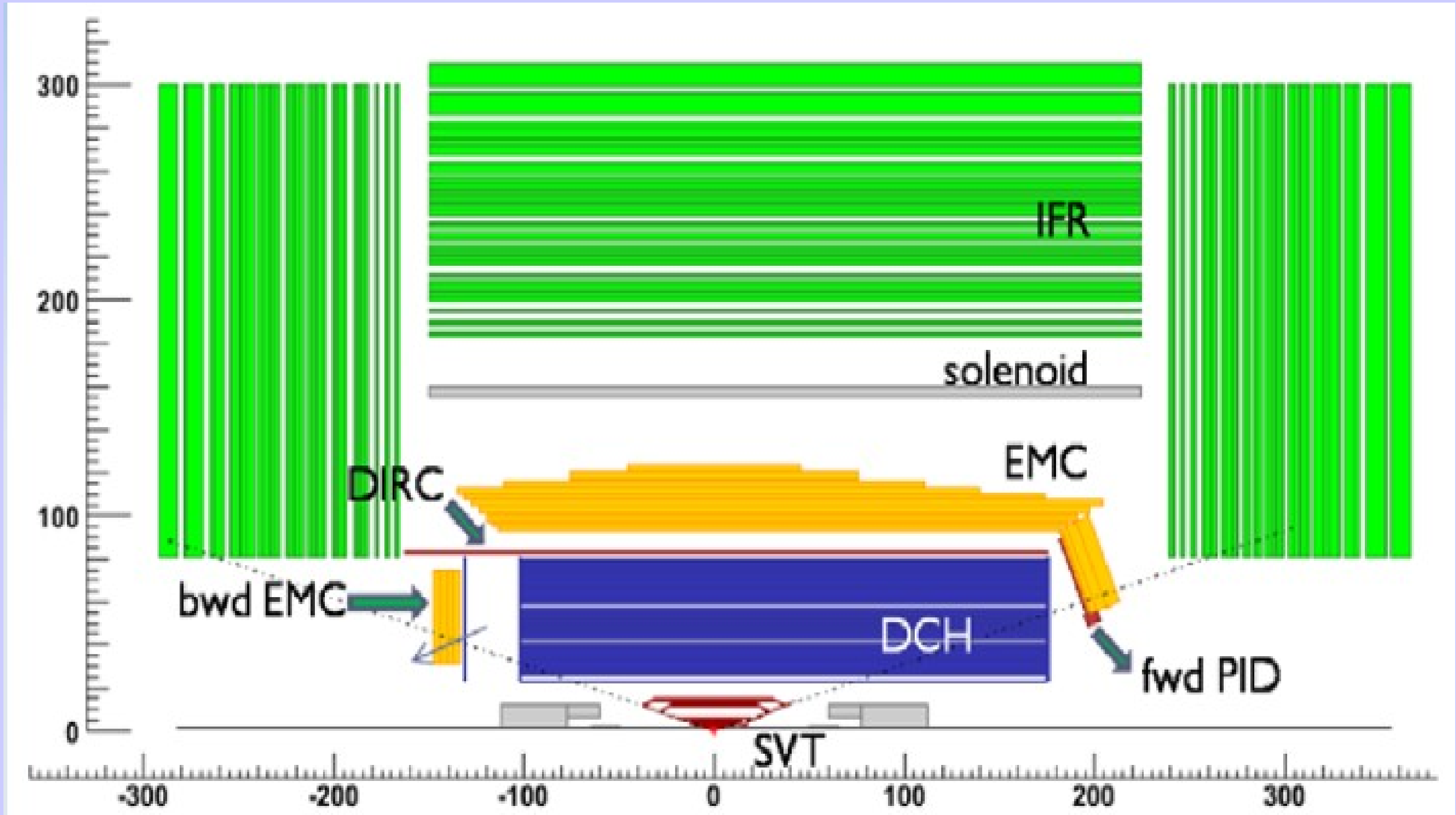




The N.Cabibbo Lab (Tor Vergata)



SuperB detector



- Silicon Vertex Tracker (SVT)
- Drift CHamber (DCH)
- Particle IDentification (PID)
- ElectroMagnetic Calorimeter (EMC)
- Instrumented Flux Return (IFR)

Status of the SuperB project

December 2010 - approval of the Project by the Italian Gov.

- funding 250 M EUR

May/June 2011 - Kick-off Meeting (Biodola, Isola Elba)

- decision about the site –Tor Vergata
- the Cabibbo Lab is announced

June 2011 – formation of the Consortium INFN –Univ. Tor Vergata

7 Oct. 2011 - the official startup of the Lab. N. Cabibbo

April 2012 – definition of the management team for the construction of the accelerator

September 2012 – TDRs for the accelerator and detector

waiting for the beginning of civil engineering works

Cracow activities

Polish „SuperB Consortium":

- **ACCELERATOR**
  - participation in the R&D, design, tests and CONSTRUCTION
- **IFR detector**
  - participation in the R & D, design, tests, construction...
  - mechanical engineering, electronic and DAQ aspects
- **LUMI MONITOR:**
  - preliminary studies related to the lumi cal. construction
- **COMPUTING:**
  - participation in the design and construction of the overall SuperB computing (& GRID, cloud etc.)
- **PHYSICS:** tau and B exclusive decays

Summary

New era: B-factories → Super Flavour Factories

The Super Flavour Factory SuperB aims to be a precise tool to elucidate New Physics in a way competitive to the LHC

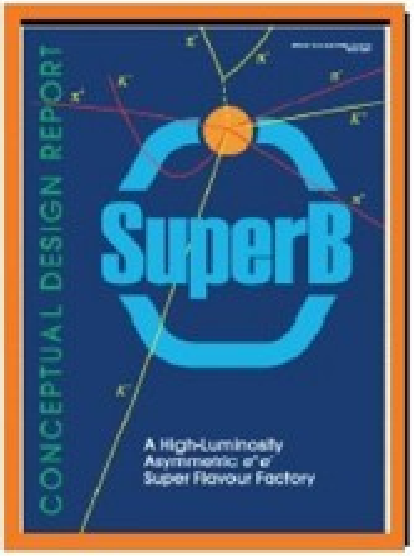
To achieve this goal, the reach of luminosity 10^{36} $cm^{-2}s^{-1}$ and the total sample of 75 ab^{-1} is expected

The SuperB offers <u>the highest luminosity</u>
AND <u>two unique features:</u>

1. polarization of e^- beam (vital for tau physics)
2. possibility of scan in CM energy with high luminosity (vital for charm physics)

SuperB References

A Conceptual Design Report (CDR),
signed by 85 Institutions:
arXiv:0709.0451 [hep-ph]



Progress reports (white papers):

- ✓ detector: arXiv:1007.4241 [hep-ph]
- ✓ accelerator: arXiv:1009.6178 [hep-ph]
- ✓ physics: arXiv 1008.1541 [hep-ph]

Other physics papers:

- ✓ „The Discovery Potential of a Super B factory", hep-ph/0503261 (2005)
- ✓ Valencia workshop proceedings arXiv:0810.1312 [hep-ex]

Homepages: SuperB: http://superb.infn.it/home/
Cabibbo Lab: http://www.cabibbolab.it/

BACKUP

CP violation in tau decays

- CP violation in charged lepton decays – not observed yet
- The SM: CP violating asymmetries are expected to be vanishingly small e.g.

$$A_{CP} = \frac{\Gamma(\tau^+ \to K^+\pi^0\bar{\nu}_\tau) - \Gamma(\tau^- \to K^-\pi^0\nu_\tau)}{\Gamma(\tau^+ \to K^+\pi^0\bar{\nu}_\tau) + \Gamma(\tau^- \to K^-\pi^0\nu_\tau)} \sim o(10^{-12})$$

- The CPV asymmetries in angular distributions can be enhanced even up to **o(10^{-1})**; in some NP frameworks (RPV SUSY, non-SUSY multi-Higgs models)
- Sizeable NP effects for $\tau \to K\pi\nu_\tau,\ \tau \to K\eta^{(\prime)}\nu_\tau,\ \tau \to K\pi\pi\nu_\tau$
- CLEO : study of tau charge-dependent asymmetry of the angular distribution

of the hadronic system produced in $\tau \to K_s^0\pi\nu_\tau$

CLEO estimate **(13.3 fb^{-1}):** $\xi(\tau \to K_s^0\pi\nu_\tau) = (-2.0 \pm 1.8) \times 10^{-3}$

the mean of the optimal asymmetry observable

SuperB sensitivity **(75 ab^{-1}):** $\xi(\tau \to K_s^0\pi\nu_\tau) \sim 2.4 \times 10^{-5}$

$$V_{ud}^{*}V_{ub}+V_{cd}^{*}V_{cb}+V_{td}^{*}V_{tb}=0$$

$e^{+}e^{-} \to \mu^{+}\mu^{-}$ | $e^{+}e^{-} \to \tau^{+}\tau^{-}$ | $e^{+}e^{-} \to c\bar{c}$

$$A_{LRFB} = \frac{(\sigma_F-\sigma_B)_L-(\sigma_F-\sigma_B)_R}{(\sigma_F+\sigma_B)_L+(\sigma_F+\sigma_B)_R}\frac{1}{<|P_e|>} \Rightarrow \sin^2\Theta_W$$