Fourth Workshop on Theory, Phenomenology and Experiments in Flavour Physics

The SuperB Project

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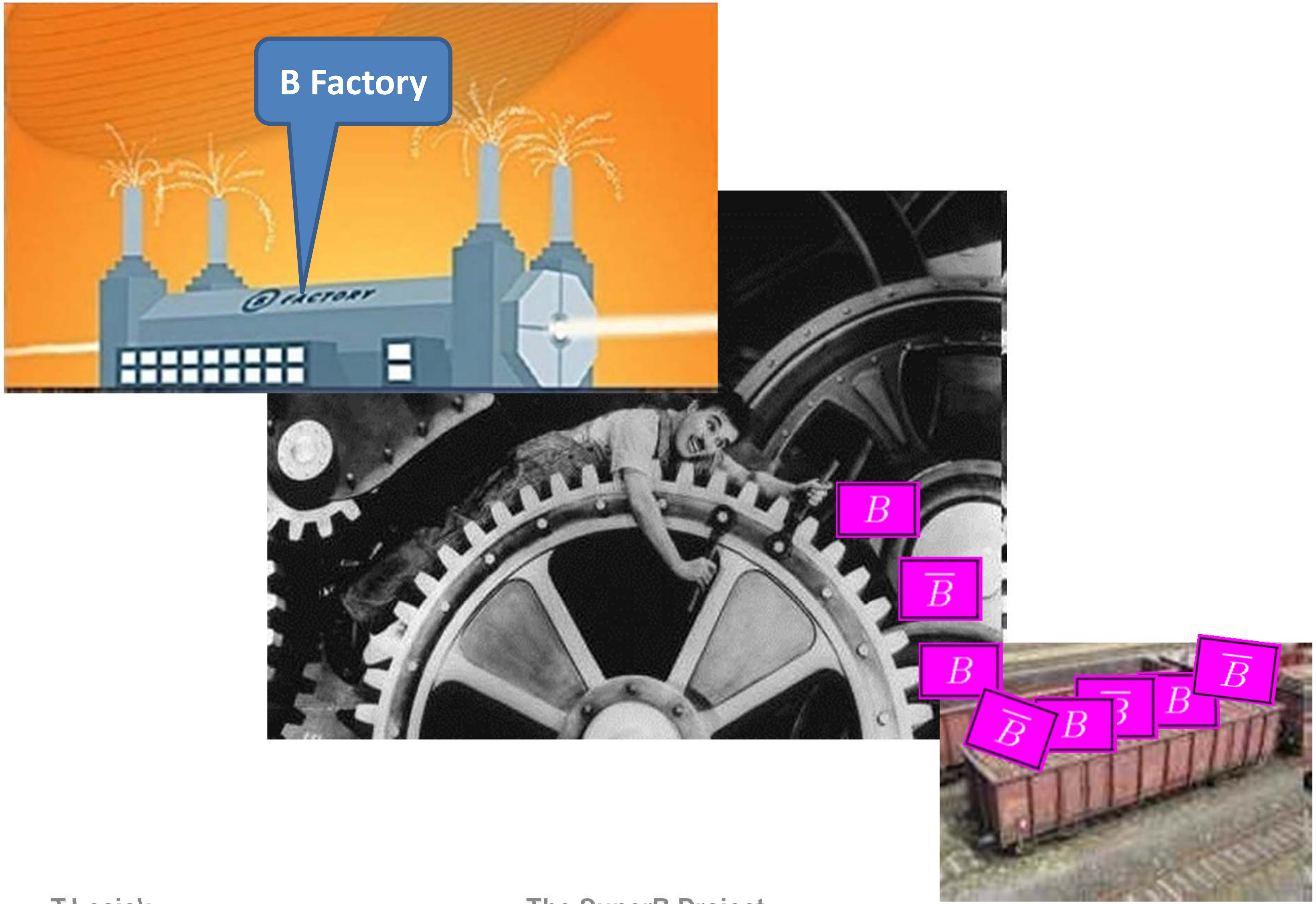
representing the SuperB Collaboration

Outline

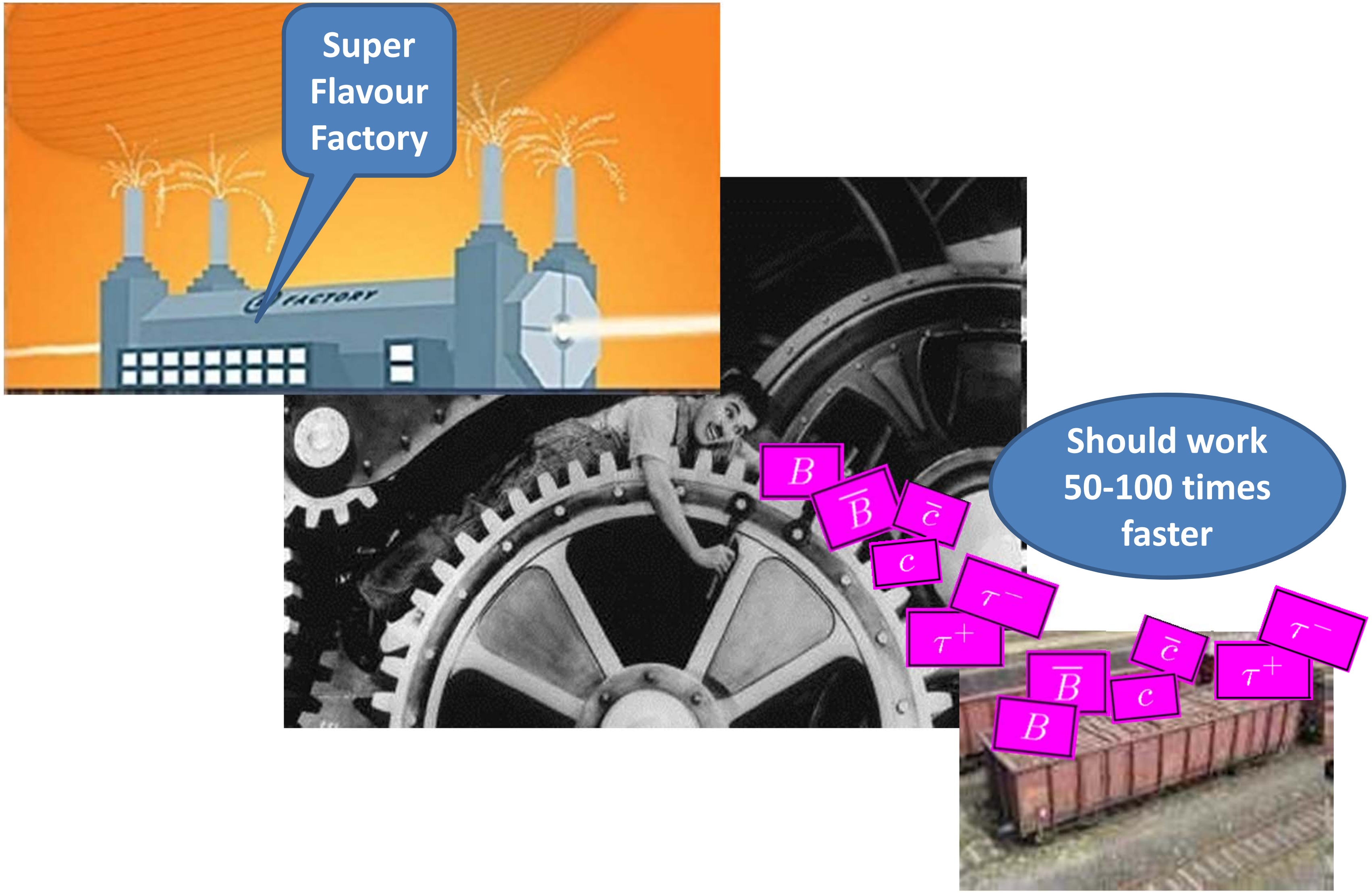
1. Project Motivation
2. Physics Program
3. Infrastructure (Accelerator and Detector)
4. Project Status

1. Project Motivation

B Factories: a Great Success



B Factories → Super Flavour Factories



Super Flavour Factory

Should work 50-100 times faster

SuperB in a 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

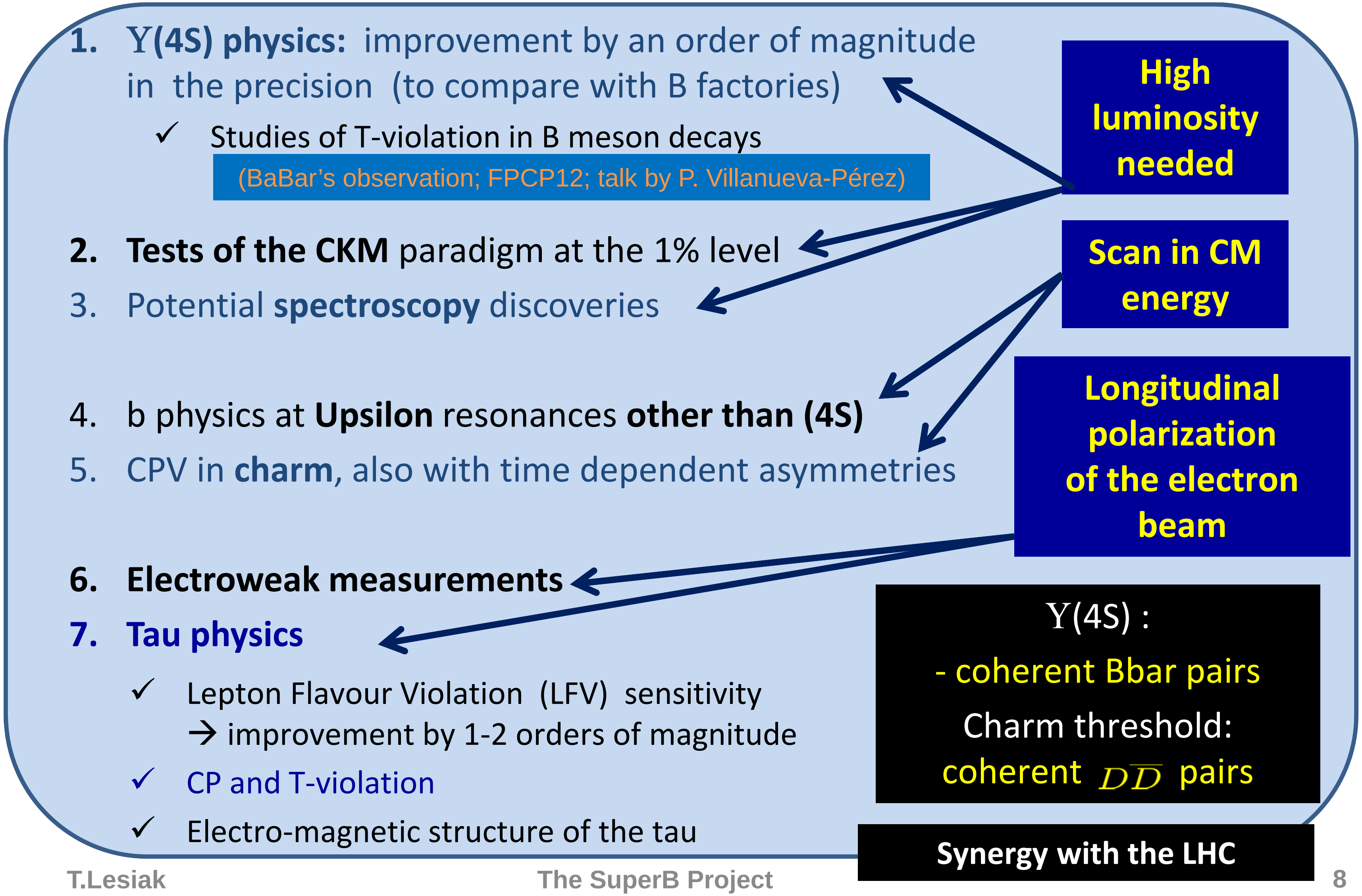
Start of **data-taking: 2017- 2018**

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

2. Physics Program

SuperB: Main Physics Goals

(moreless) in descending order of masses of heavy flavour particles:



1. **Υ(4S) physics:** improvement by an order of magnitude in the precision (to compare with B factories)
   - ✓ Studies of T-violation in B meson decays
     (BaBar's observation; FPCP12; talk by P. Villanueva-Pérez)
2. **Tests of the CKM** paradigm at the 1% level
3. Potential **spectroscopy** discoveries
4. b physics at **Upsilon** resonances **other than (4S)**
5. CPV in **charm**, also with time dependent asymmetries
6. **Electroweak measurements**
7. **Tau physics**
   - ✓ Lepton Flavour Violation (LFV) sensitivity → improvement by 1-2 orders of magnitude
   - ✓ CP and T-violation
   - ✓ Electro-magnetic structure of the tau

High luminosity needed

Scan in CM energy

Longitudinal polarization of the electron beam

Υ(4S) :

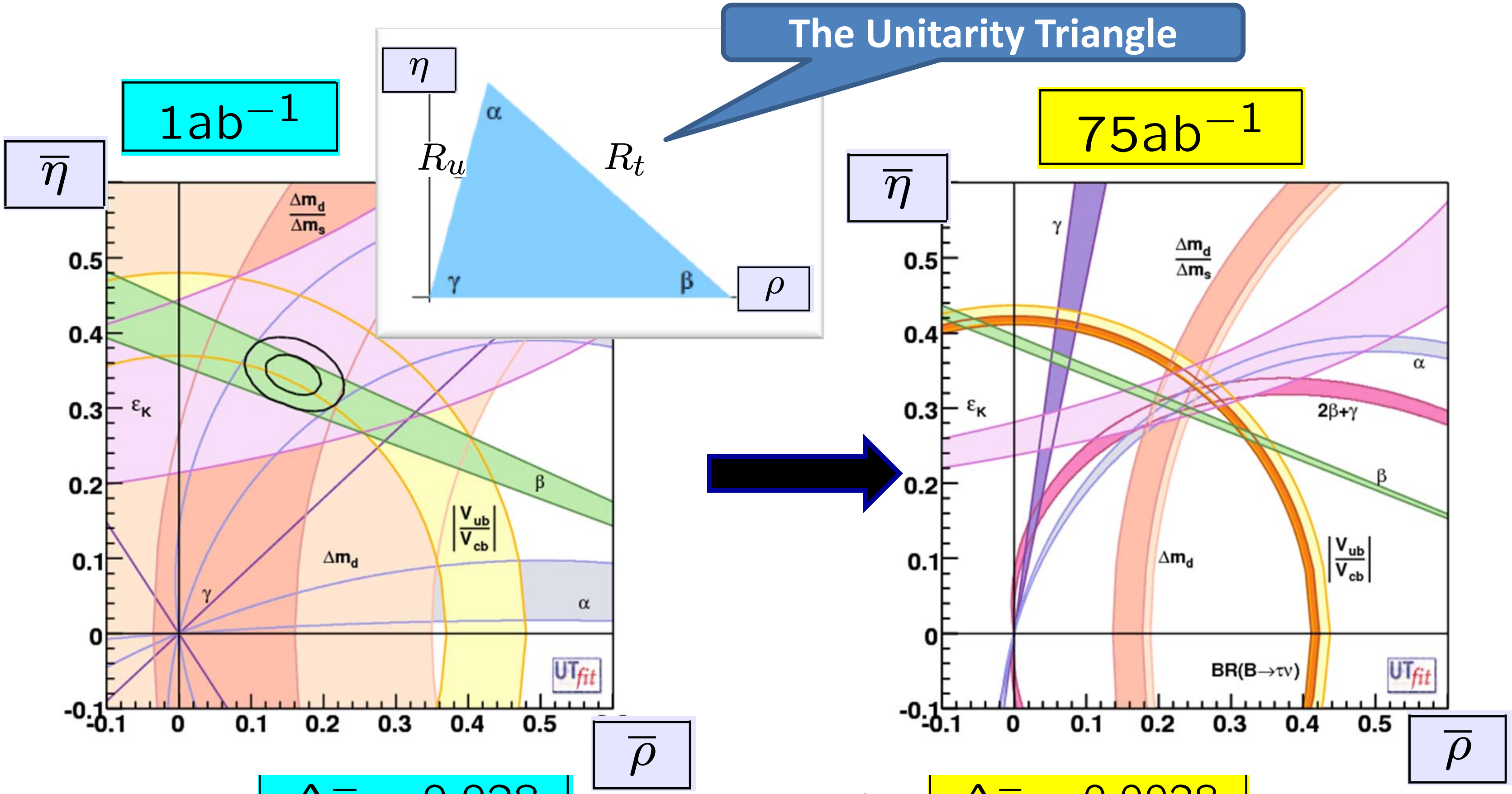
- coherent Bbar pairs

Charm threshold:

coherent $D\bar{D}$ pairs

Synergy with the LHC

CKM Precision Measurements



The Unitarity Triangle

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

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

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

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

$\Delta|V_{cb}|\text{incl} = 0.5\%$

$\Delta|V_{ub}|\text{incl} = 2\%$

$\Delta|V_{cb}|\text{excl} = 1\%$

$\Delta|V_{ub}|\text{excl} = 3\%$

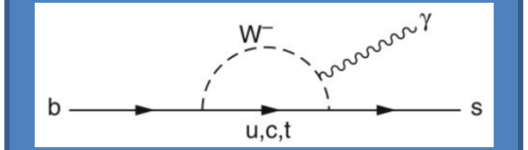
$\Delta\alpha = (1-2)^0$

$\Delta\beta = 0.1^0$

$\Delta\gamma = (1-2)^0$

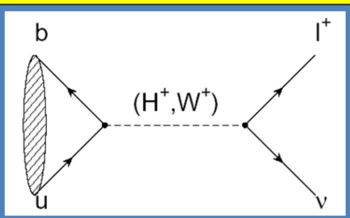
$B_{u,d}$ rare decays

$B \to X_s\gamma$



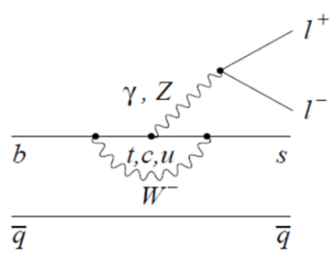
BR sensitive to the m(H^+)

$B^\pm \to l^\pm \nu_l,\ l = \mu, \tau$

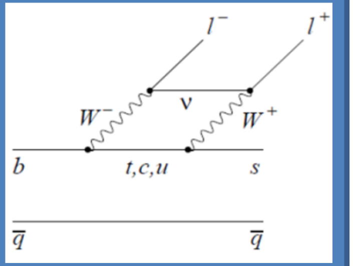


Rate modified by the presence of H^+

$B \to X_s l^+ l^-$



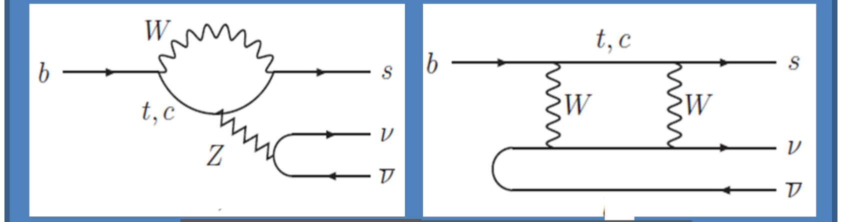
$B \to K^{(*)} l^+ l^-$



High sensitivity to New Physics

Many observables

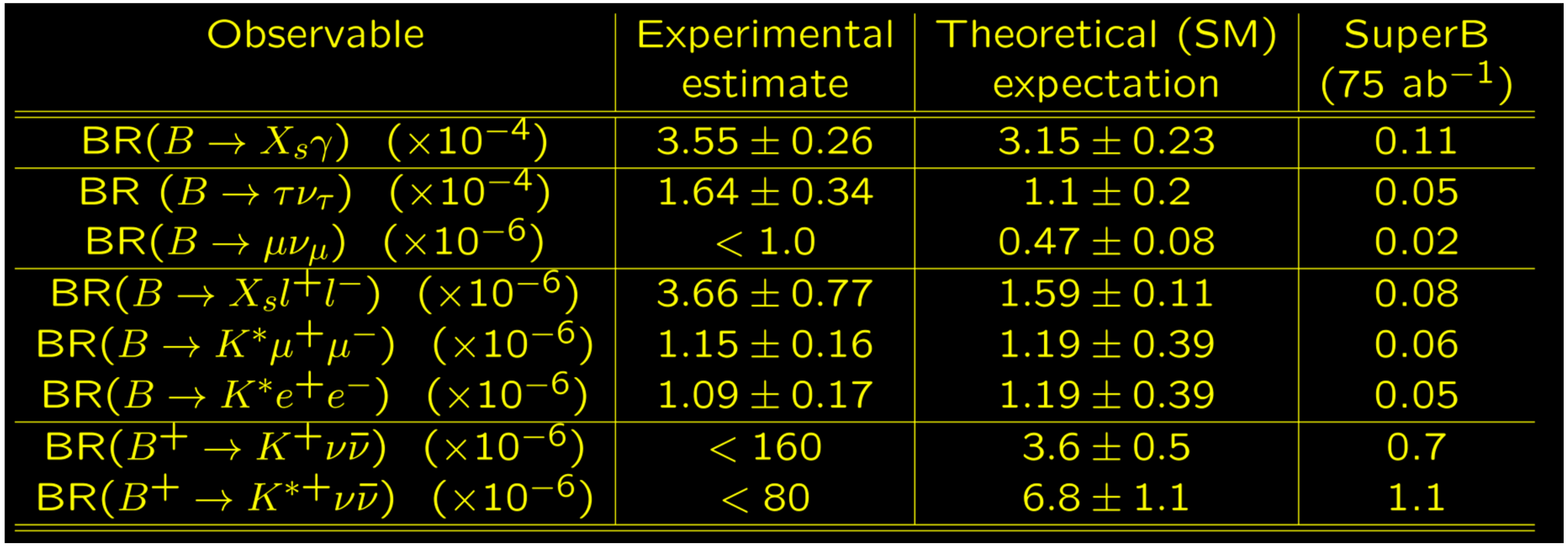
$B \to K^{(*)} \nu\bar{\nu}$



Existing limits are weak

Can be measured only at SFFs

$B_{u,d}$ rare decays



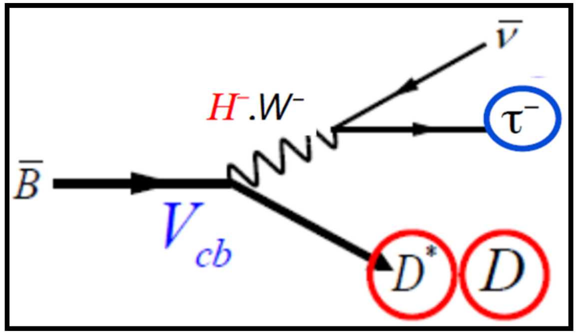
Observable	Experimental estimate	Theoretical (SM) expectation	SuperB ($75\ ab^{-1}$)
$BR(B \to X_s\gamma)\ \ (\times 10^{-4})$	3.55 ± 0.26	3.15 ± 0.23	0.11
$BR\ (B \to \tau\nu_\tau)\ \ (\times 10^{-4})$	1.64 ± 0.34	1.1 ± 0.2	0.05
$BR(B \to \mu\nu_\mu)\ \ (\times 10^{-6})$	< 1.0	0.47 ± 0.08	0.02
$BR(B \to X_s l^+ l^-)\ \ (\times 10^{-6})$	3.66 ± 0.77	1.59 ± 0.11	0.08
$BR(B \to K^* \mu^+ \mu^-)\ \ (\times 10^{-6})$	1.15 ± 0.16	1.19 ± 0.39	0.06
$BR(B \to K^* e^+ e^-)\ \ (\times 10^{-6})$	1.09 ± 0.17	1.19 ± 0.39	0.05
$BR(B^+ \to K^+ \nu\bar{\nu})\ \ (\times 10^{-6})$	< 160	3.6 ± 0.5	0.7
$BR(B^+ \to K^{*+} \nu\bar{\nu})\ \ (\times 10^{-6})$	< 80	6.8 ± 1.1	1.1

„The impact of SuperB on flavour physics” **arXiv:1109.5028 [hep-ph]**

$B_{u,d}$ rare decays

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

BaBar expt: arXiv:1205.5442 [hep-ph]
Vera Luth's talk at the FPCP12
F.Ferrarotto's talk at this Workshop



Observables:

$$R(D) = \frac{\Gamma(\overline{B} \to D\tau\nu)}{\Gamma(\overline{B} \to Dl\nu)}$$

$$R(D^{*}) = \frac{\Gamma(\overline{B} \to D^{*}\tau\nu)}{\Gamma(\overline{B} \to D^{*}l\nu)}$$

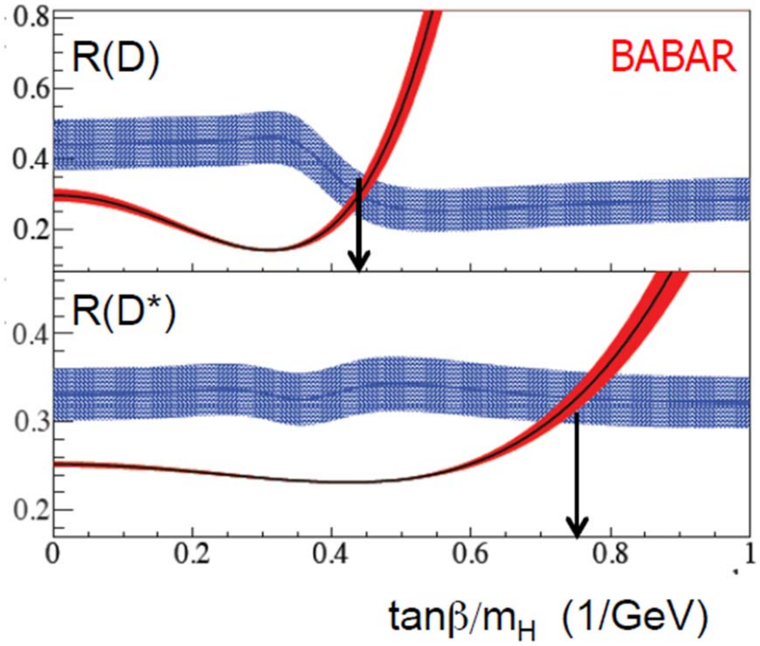
	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	2.0 σ	2.7 σ

The SM prediction is excluded at 3.4 sigmas

Sensitivity to the $\tan\beta/m_H$ in the 2HDM II model

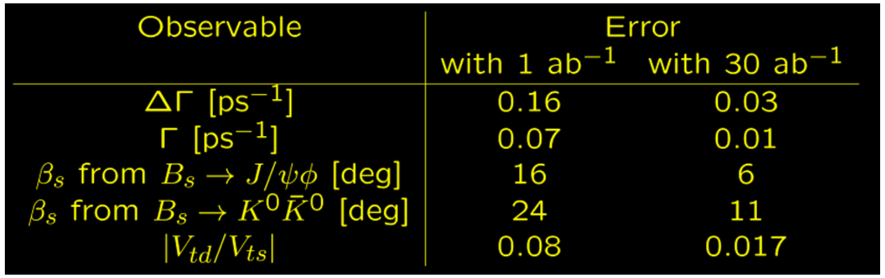
BUT… combination of $R(D)$ and $R(D^{*})$ inconsistent and excludes the 2HDM II (>99.8%)

„Hot" decay channel also for the SuperB



B$_s$ at Υ(5S)

- B$_s$-related measurements – domain of the LHCb (and ATLAS and CMS)
- BUT: short runs at the Υ(5S) (CLEO, Belle) indicated the potential for e$^+$e$^-$ machines to contribute in this area



Observable	Error with 1 ab^{-1}	 with 30 ab^{-1}
$\Delta\Gamma$ [ps^{-1}]	0.16	0.03
Γ [ps^{-1}]	0.07	0.01
β_s from $B_s \to J/\psi\phi$ [deg]	16	6
β_s from $B_s \to K^0\bar{K}^0$ [deg]	24	11
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017

- **Potential highlights from the SuperB:**

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

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$_s$:

$$A^s_{\mathrm{SL}} = \frac{1-\left|\frac{q}{p}\right|^4}{1+\left|\frac{q}{p}\right|^4} = \frac{N_1-N_2}{N_1+N_2}$$

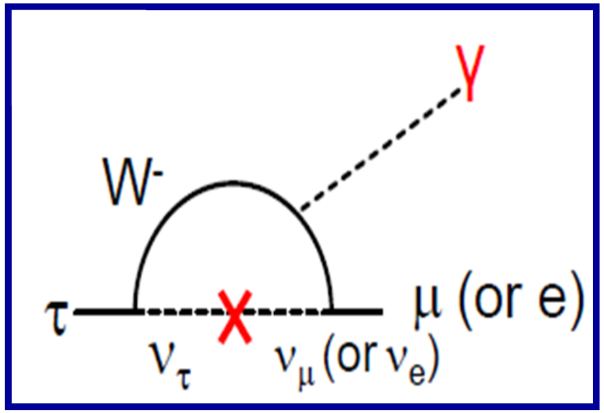
SuperB precision (30 ab^{-1}): **0.004**

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

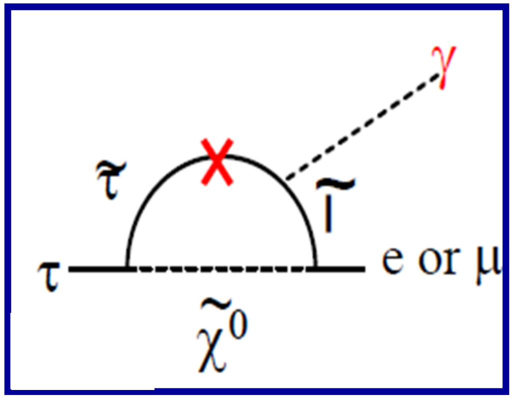
$$N_2 = \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+}l^-\nu_l)$$

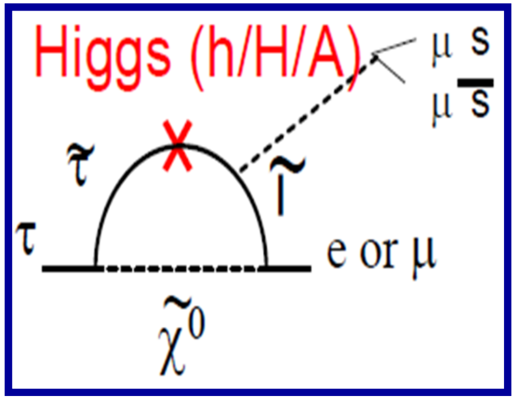
Lepton Flavour Violation (LFV) in tau decays

- 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)



- LFV decays occur in many extensions of the SM
  (SUSY in particular)





The branching fractions of many tau LFV decays are within SuperB sensitivity

Lepton Flavour Violation (LFV) in tau decays

The most promising decay channels:

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

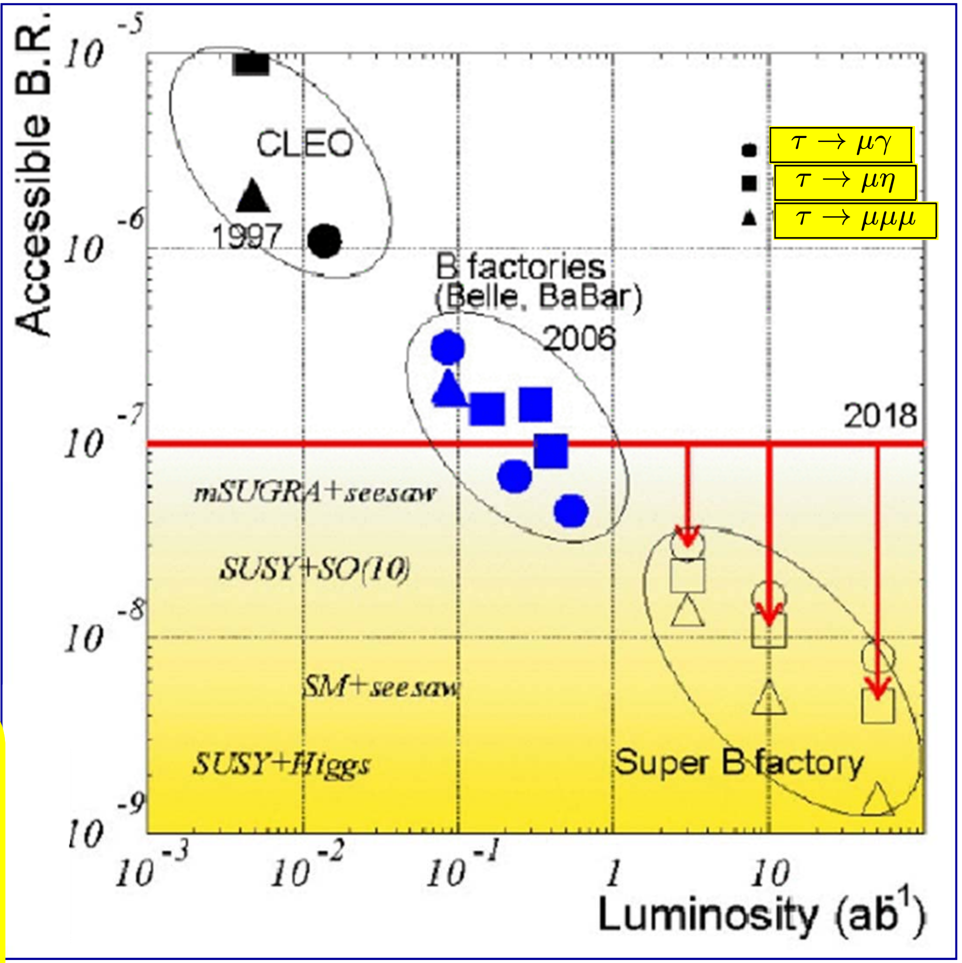
$\tau \to \mu\gamma$

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

Sensitivity (90% U.L.)

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

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



Complementarity

MEG (COMET, Mu2e) $\mu \to e\gamma$

&

SuperB $\tau \to \mu\gamma$

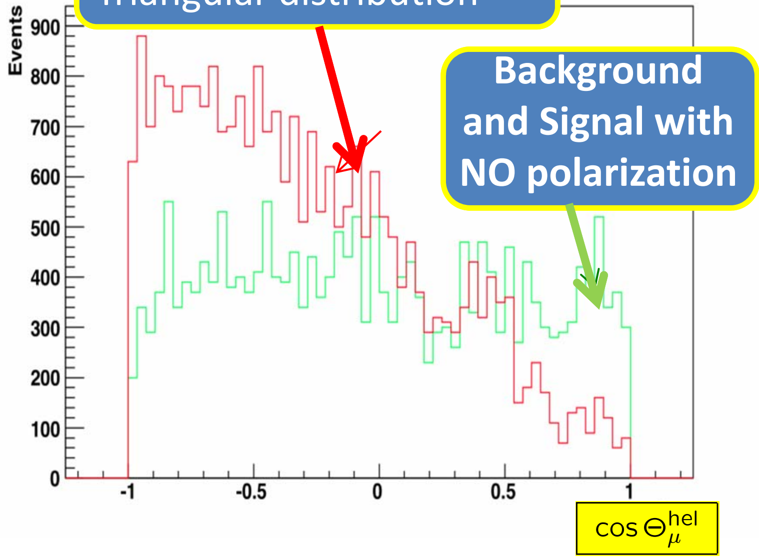
Tau LFV studies with Beam Polarization

Polarization (80%, electron beam):

→ **additional discriminating variable to be used in tau LFV searches**

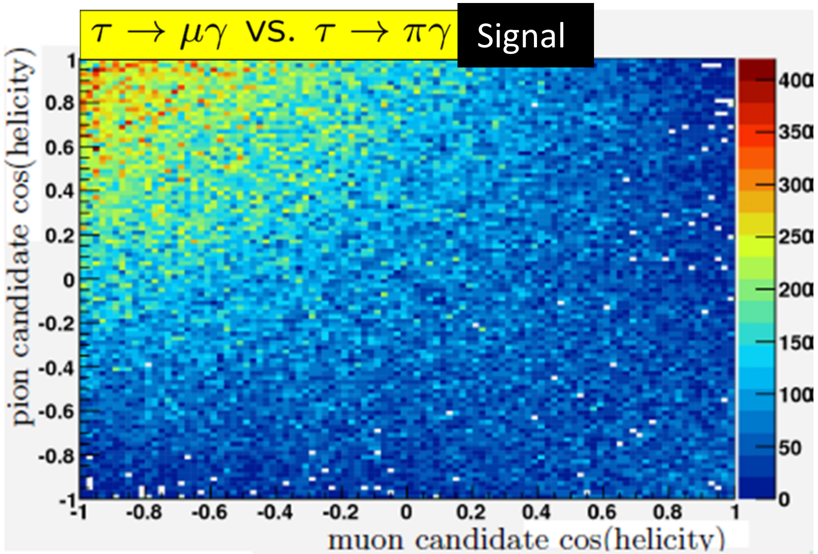
→ **background suppression:**

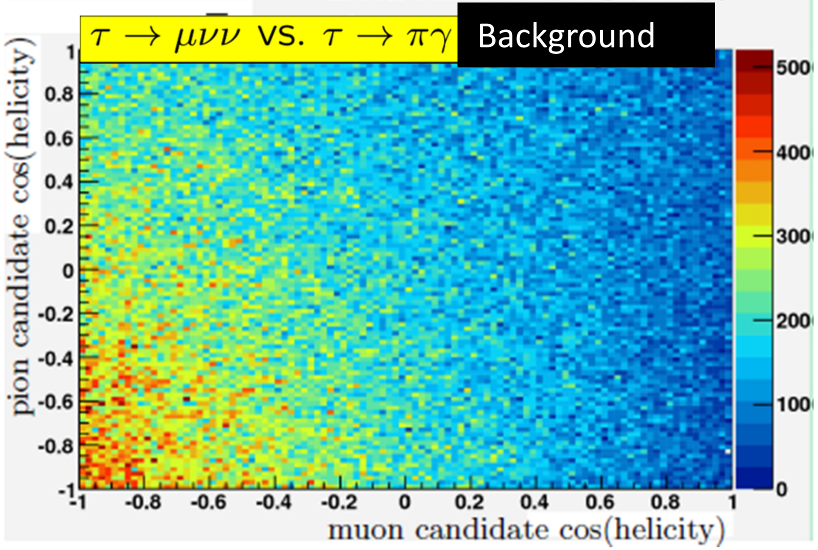
$\tau \to \mu\gamma$



Signal (with polarization)
Triangular distribution

Background and Signal with NO polarization





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

Tau g-2 Factor

- Long standing discrepancy for the muon g-2: $\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \approx (3 \pm 1) \times 10^{-9}$
- 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 $(0.75 - 2.4) \times 10^{-6}$
- Proposed measurements :

Crucial role of beam polarization

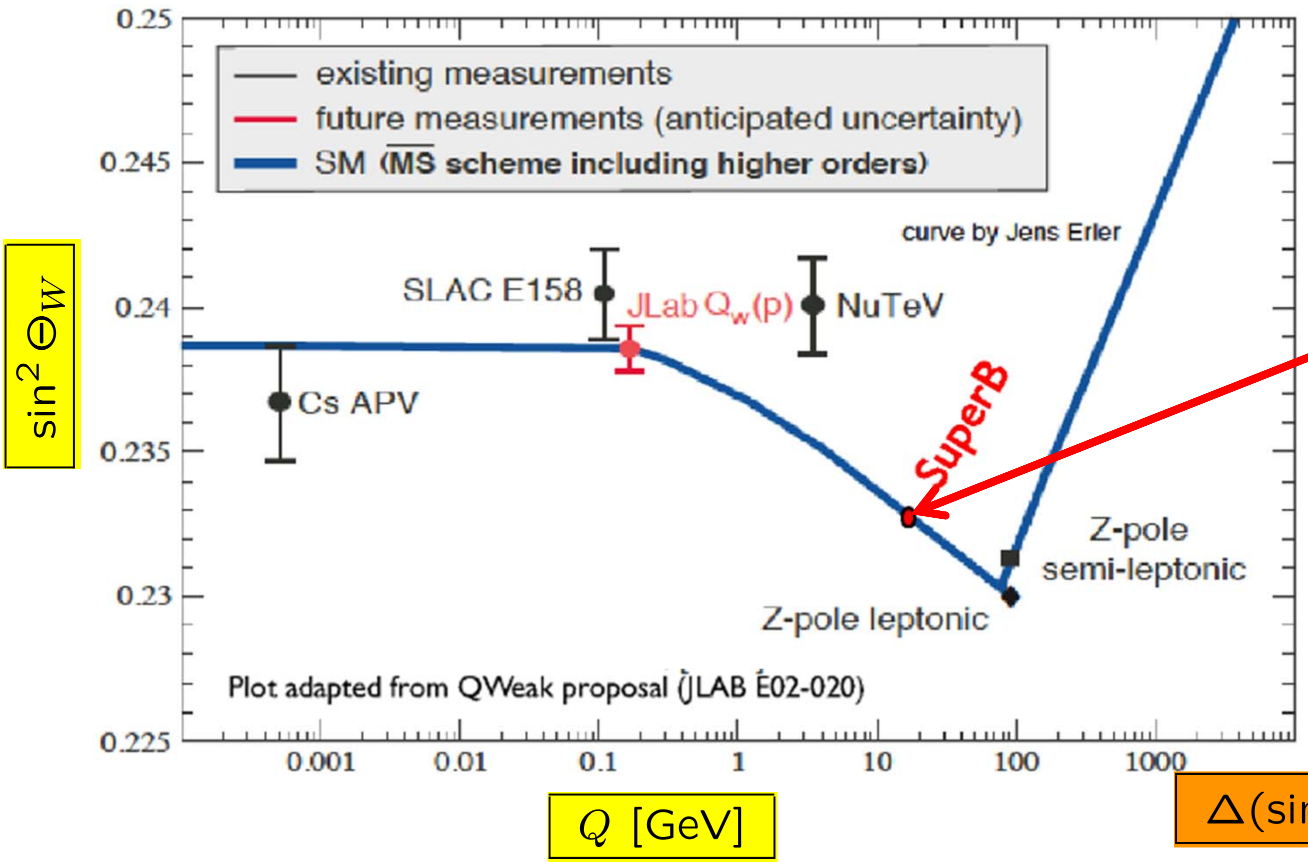
1. Fit to the polar angle distribution of the SINGLE tau lepton
2. **Measurement of the transverse and longitudinal polarization of the tau from the angular distribution of its decay products**

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

Polarization & Electroweak Measurements

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

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



$\Upsilon(4S)$

Precision on the $\sin^2\theta_W$ similar to LEP/SLC

$\Delta(\sin^2\Theta_W) \approx 0.0002$

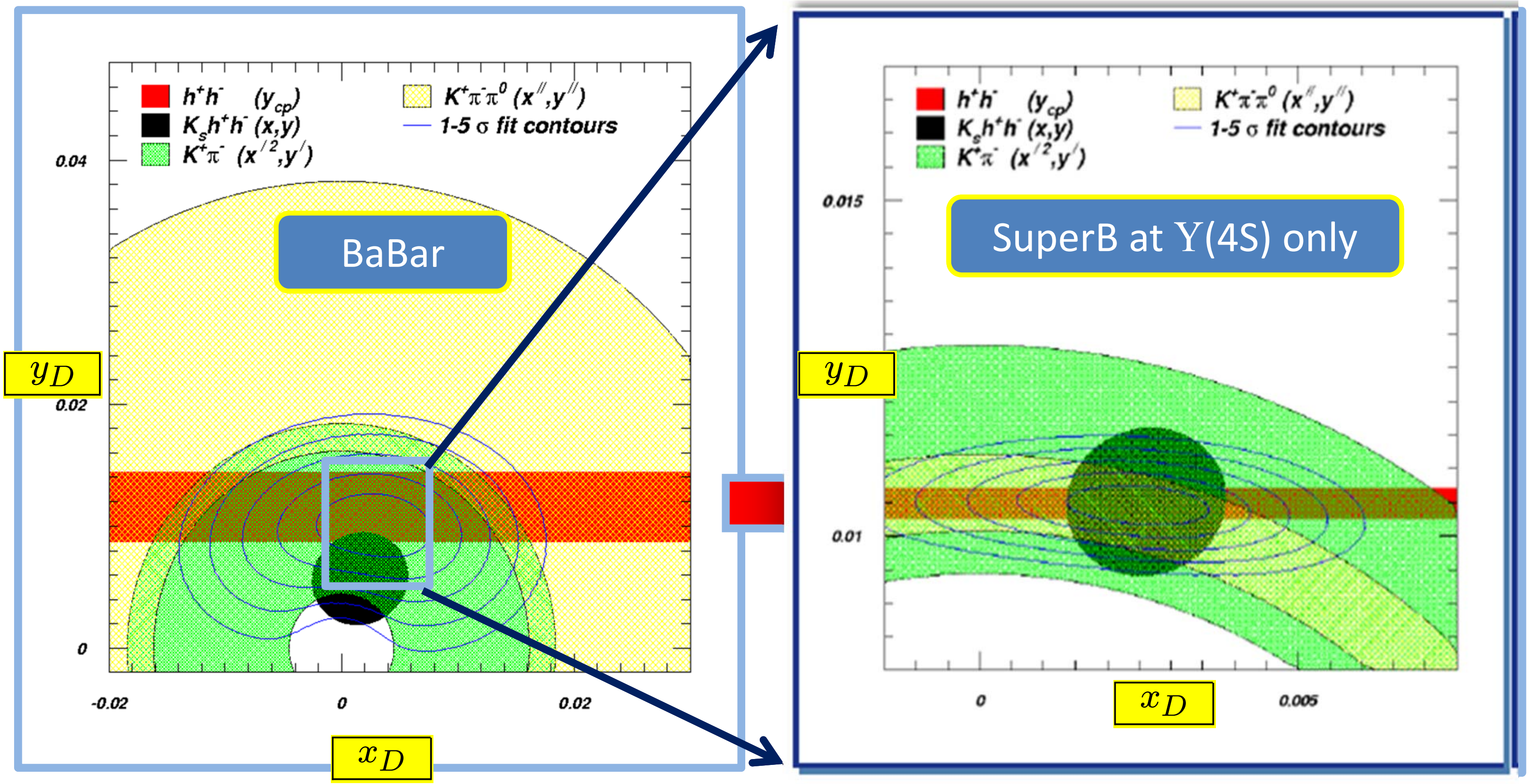
Charm Physics

- 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:**

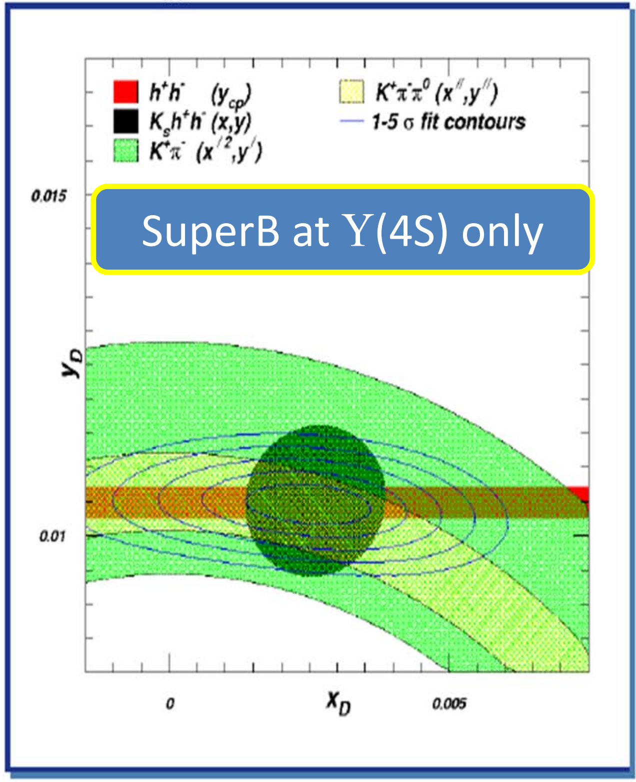
1. Improved (x10) precision in mixing parameters **x_D** and **y_D**
2. CP violation in D-Dbar oscillations: $$A_{SL}(D^0) = \frac{|q_D|^4 - |p_D|^4}{|q_D|^4 + |p_D|^4} = \frac{N_1 - N_2}{N_1 + N_2}$$
   $$N_1 = \Gamma(D^0(t) \to l^- \overline{\nu} K^+)$$
   $$N_2 = \Gamma(\overline{D}^0(t) \to l^+ \nu K^-)$$
3. Search for $D^0 \to \mu^+ \mu^-$
4. Quantum correlations in decays od D-Dbar can allow for measurement of their relative strong phases

BaBar:
F.Ferrarotto's talk
at this Workshop

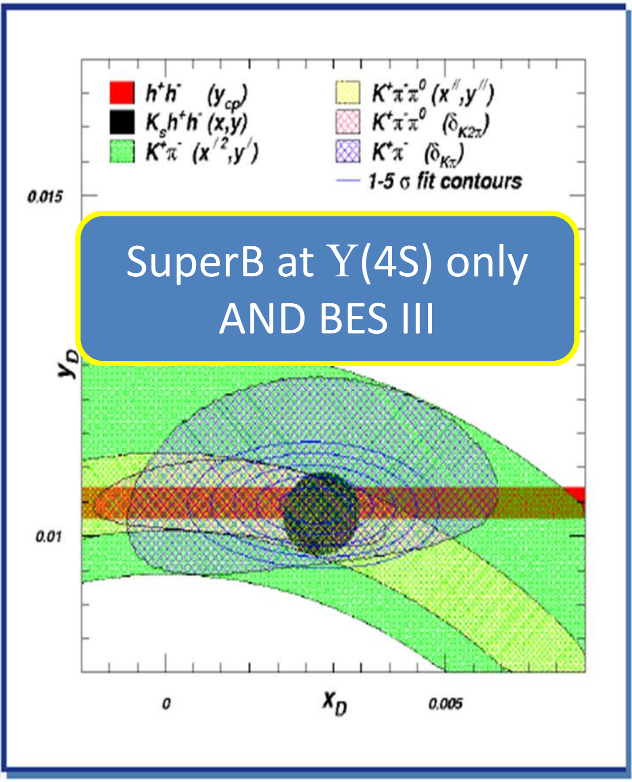
D^0 Mixing


BaBar
h^+h^- (y_{cp})
$K_sh^+h^-$ (x,y)
$K^+\pi^-$ (x'^2,y')
$K^+\pi^-\pi^0$ (x'',y'')
1-5 σ fit contours
0.04
0.02
0
-0.02
0
0.02
y_D
x_D
SuperB at Υ(4S) only
h^+h^- (y_{cp})
$K_sh^+h^-$ (x,y)
$K^+\pi^-$ (x'^2,y')
$K^+\pi^-\pi^0$ (x'',y'')
1-5 σ fit contours
0.015
0.01
0
0.005
y_D
x_D

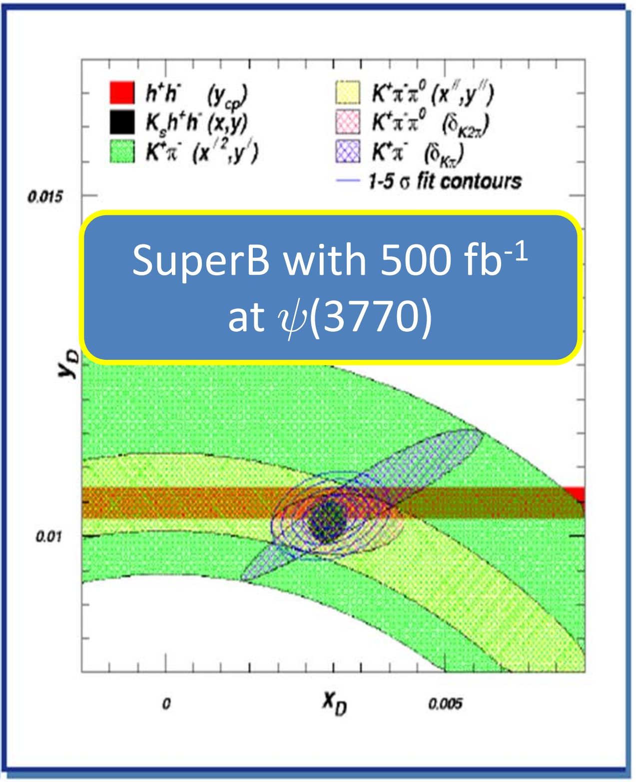
D^0 Mixing



SuperB at Υ(4S) only



SuperB at Υ(4S) only AND BES III



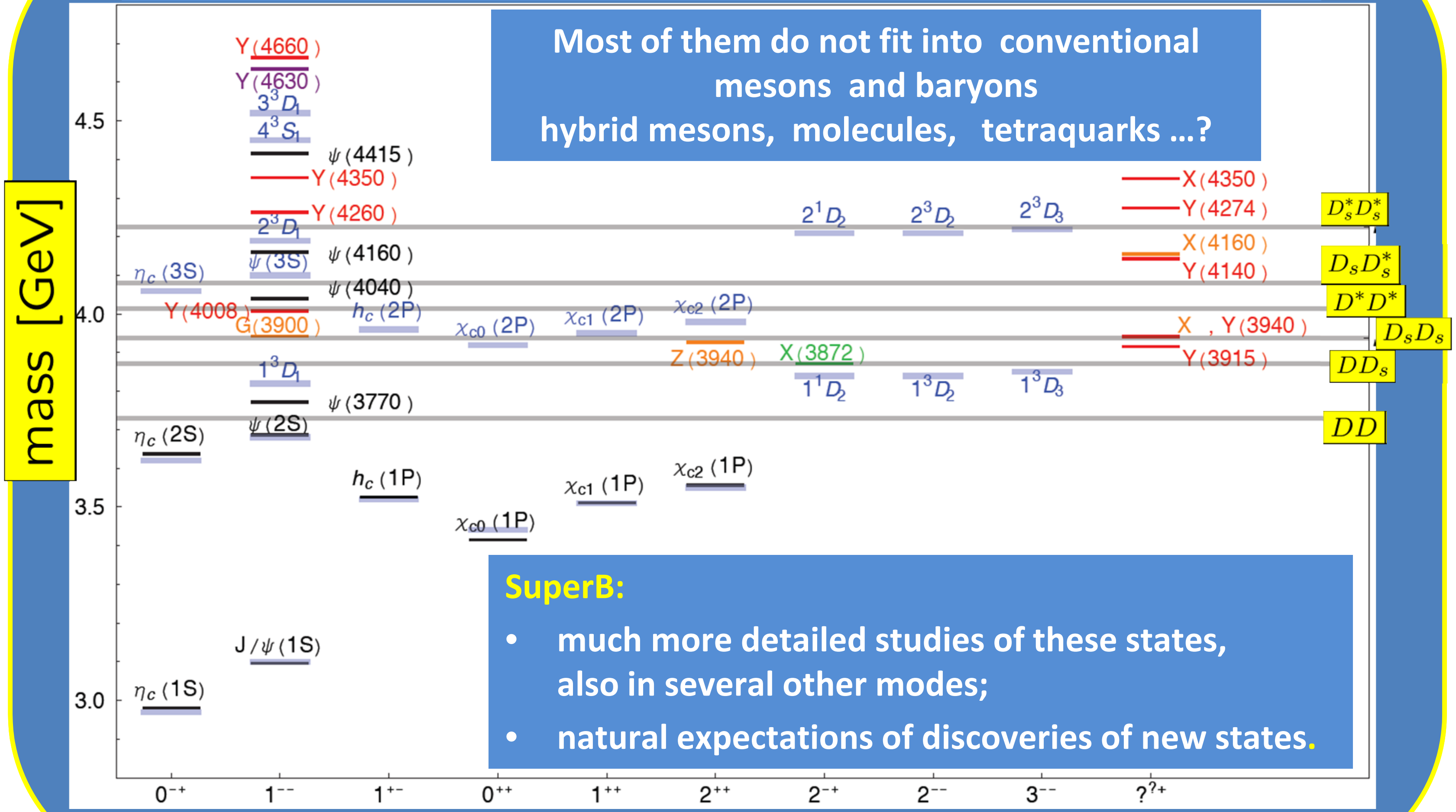
SuperB with 500 fb^{-1} at ψ(3770)

Observable	Experimental estimate	Theoretical (SM) expectation	SuperB ($75\ ab^{-1}$)
x	$(0.63 \pm 0.20)\%$	$\sim 10^{-2}$	0.02%
y	$(0.75 \pm 0.12)\%$	$\sim 10^{-2}$	0.01%
$\|q/p\|$	$(0.91 \pm 0.17)\%$	$\sim 10^{-3}$	2.7%

„The impact of SuperB on flavour physics” **arXiv:1109.5028 [hep-ph]**

Spectroscopy

B factories: a plethora of new states (red and green ones on the picture).



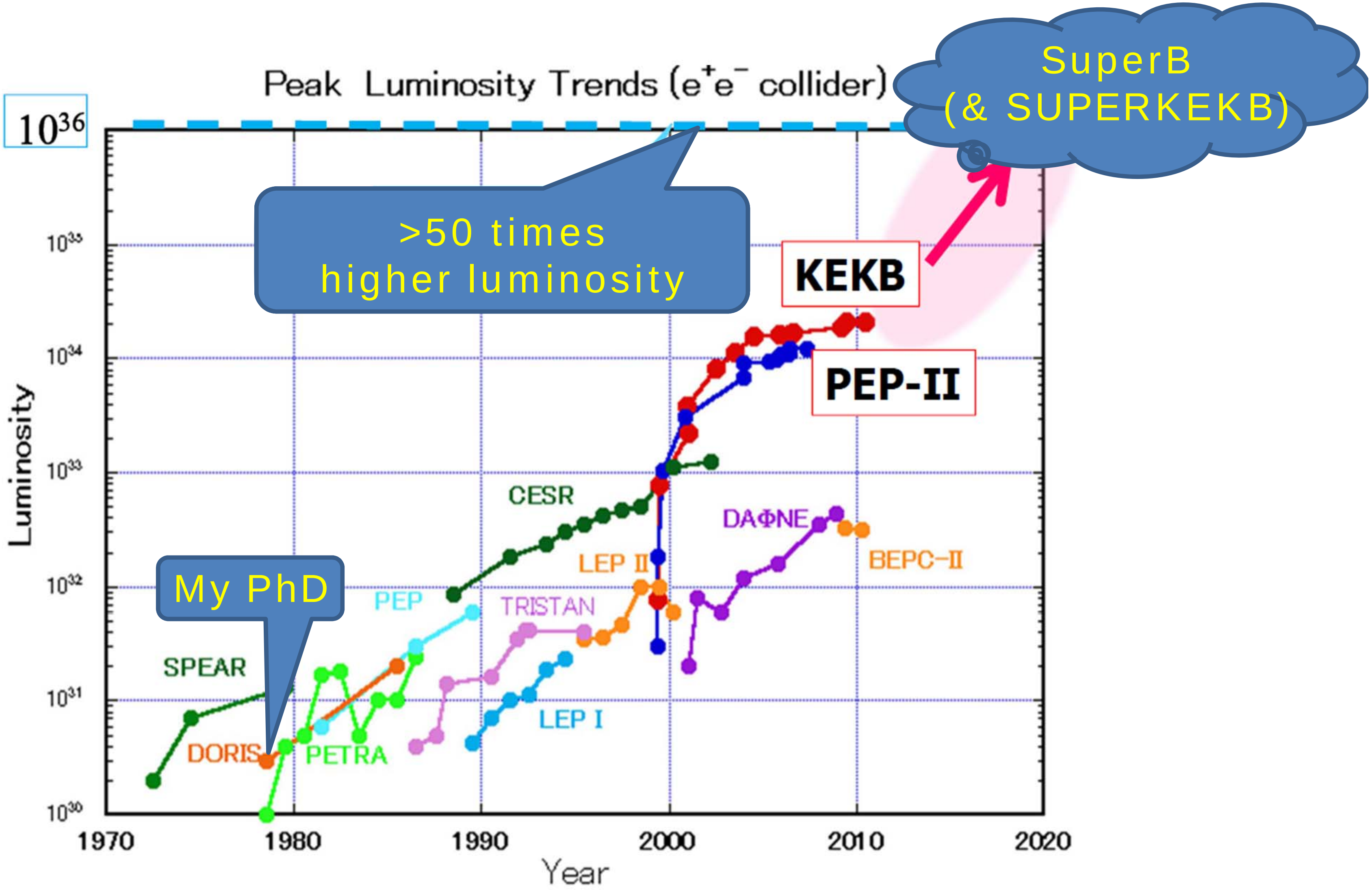
Most of them do not fit into conventional mesons and baryons
hybrid mesons, molecules, tetraquarks …?

SuperB:

- much more detailed studies of these states, also in several other modes;
- natural expectations of discoveries of new states.

3. Infrastructure (Accelerator and Detector)

The Quest for Luminosity



SuperB
(& SUPERKEKB)

>50 times
higher luminosity

My PhD

The Quest for Luminosity

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

Keep the same power and squeeze the beam (ILC)

Moderate beam requirements:

- 1.9/2.5 A beam current
- moderate RF power (17 MW)
- 5 mm bunch length (σ_z)
- Low emittance:

$$\epsilon^*_x \times \epsilon^*_y = 2\text{nm} \times 5\text{pm}$$

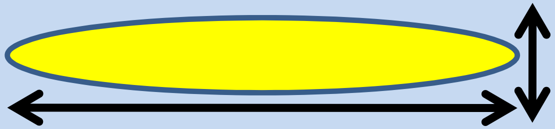
- continuous injection

All of these have been done at other facilities !

Tight focus at the IP

$$\sigma^*_x \times \sigma^*_y = 8\mu\text{m} \times 0.35\mu\text{m}$$

smaller than done so far

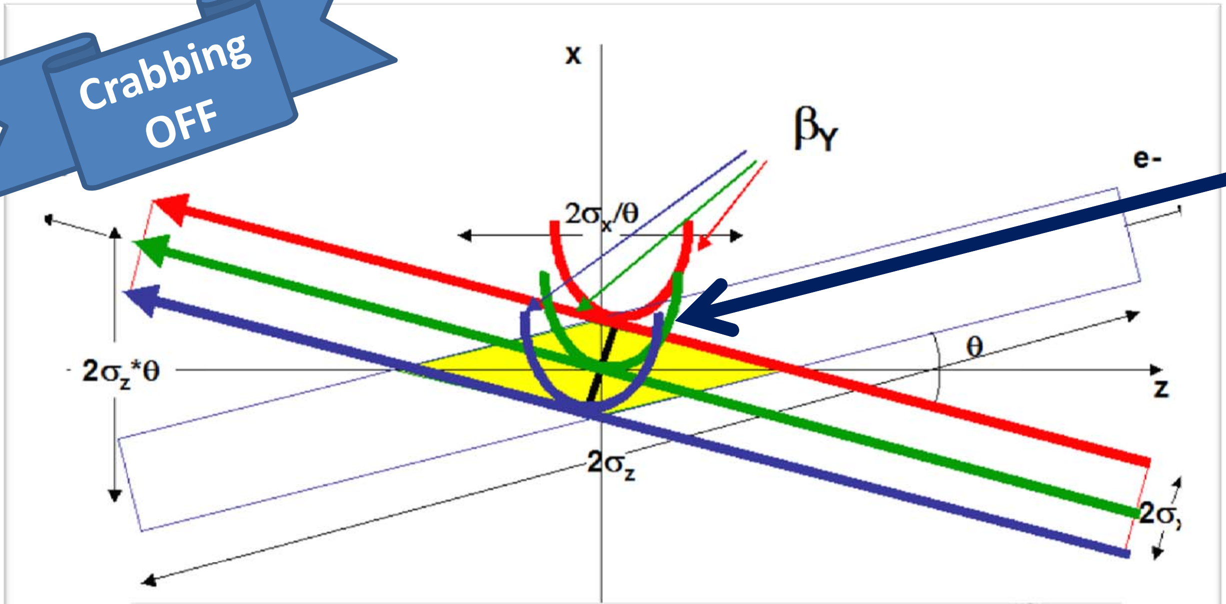


0.035 μm
=35 nm

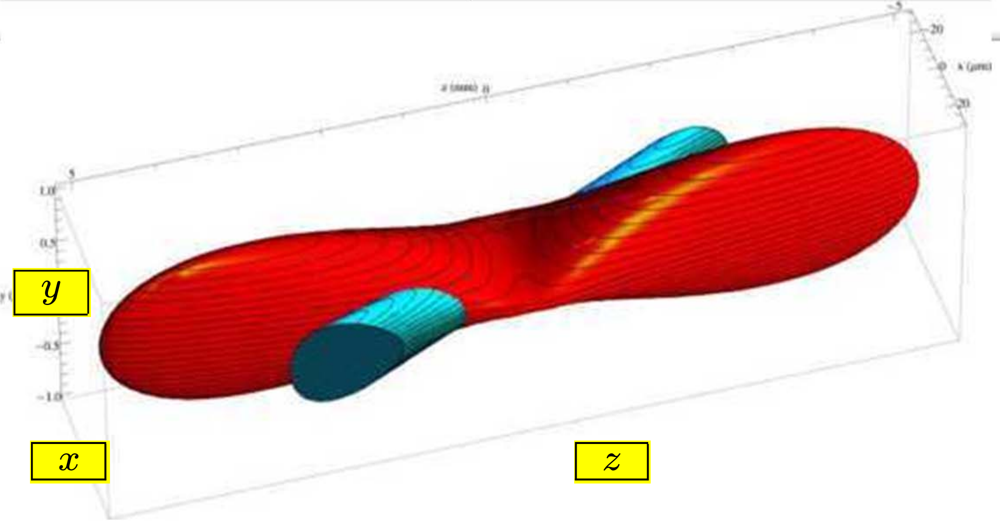
8 μm

The Crab Waist

Crabbing OFF

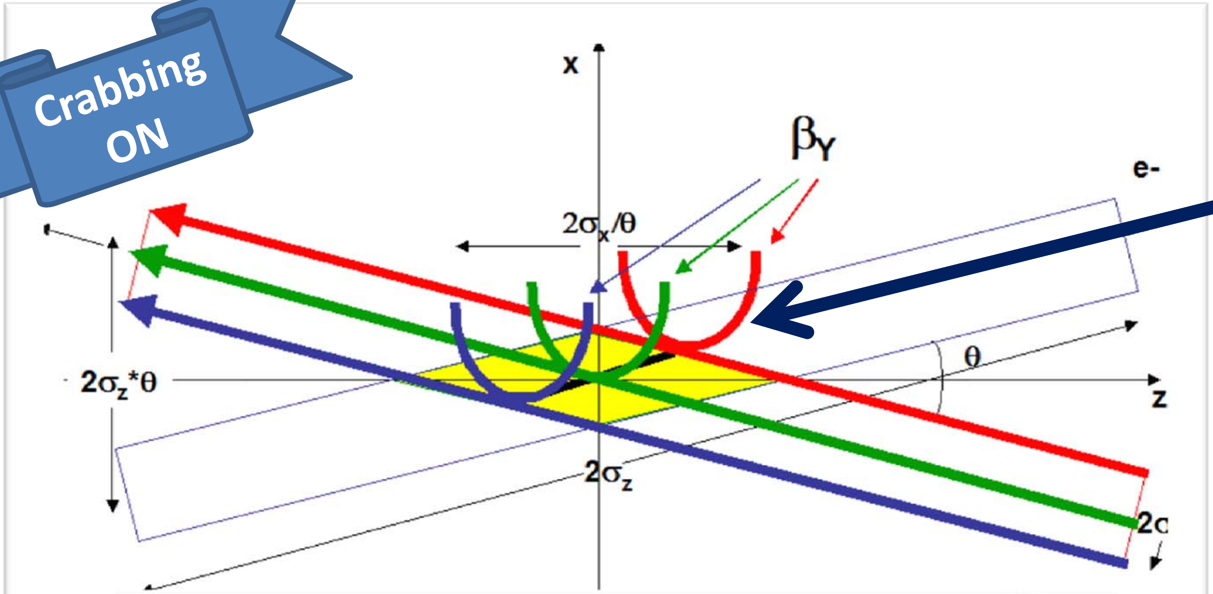


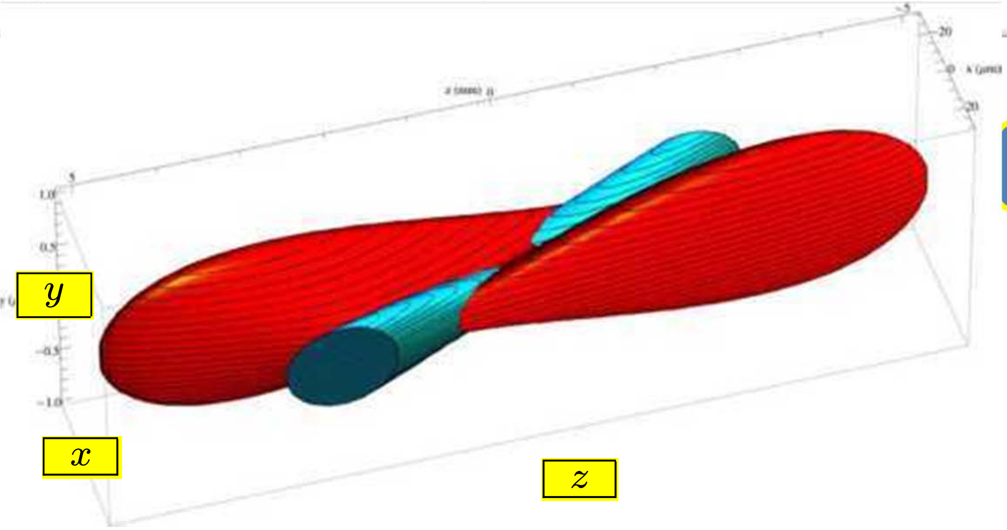
the waist line
is perpendicular
to the axis
of the beam



The Crab Waist

Crabbing ON





the waist line
is perpendicular
to the axis
of the other beam

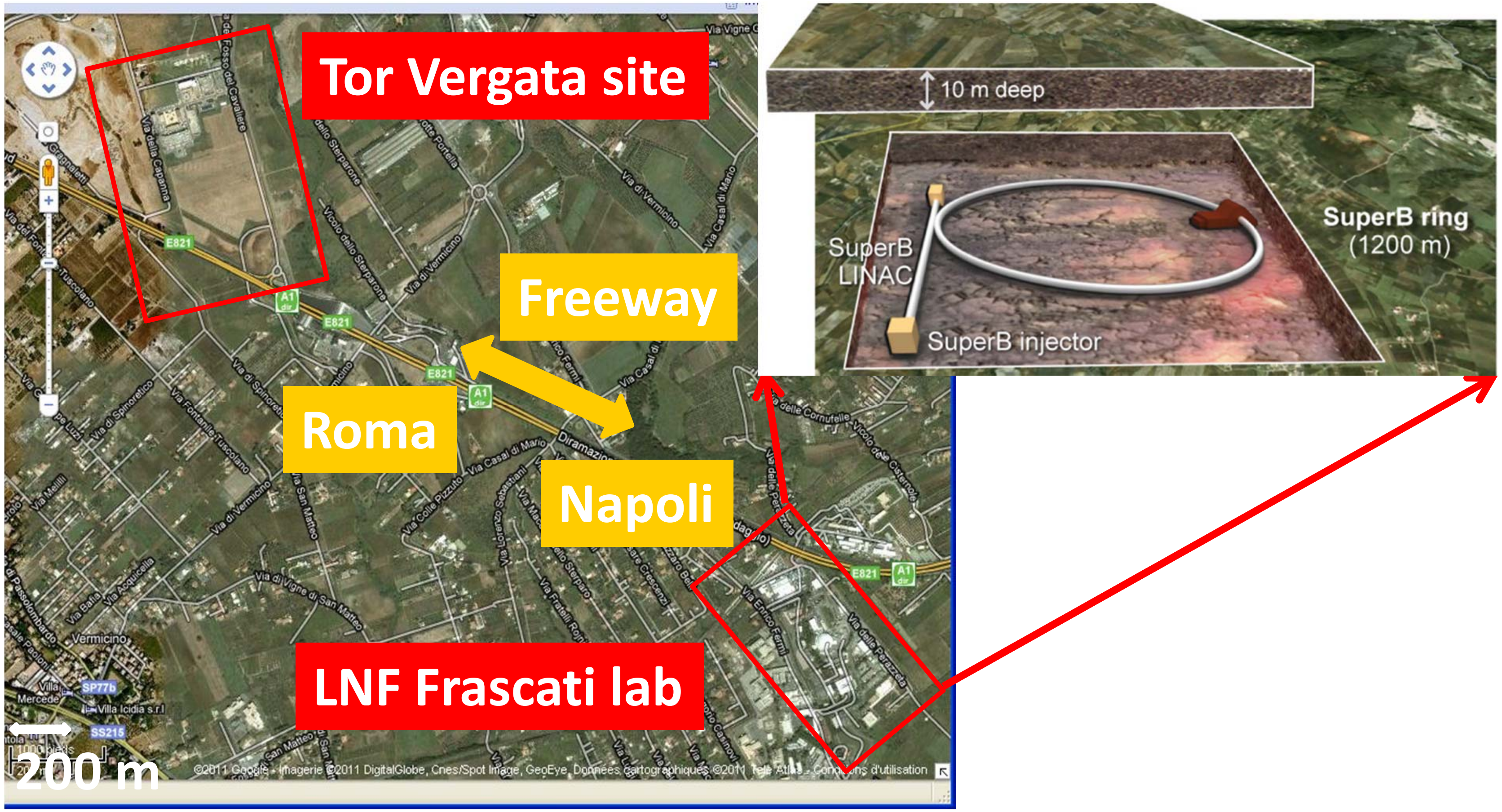
Luminosity improvement by a factor 2-4

Suppression of synchro-beta resonances

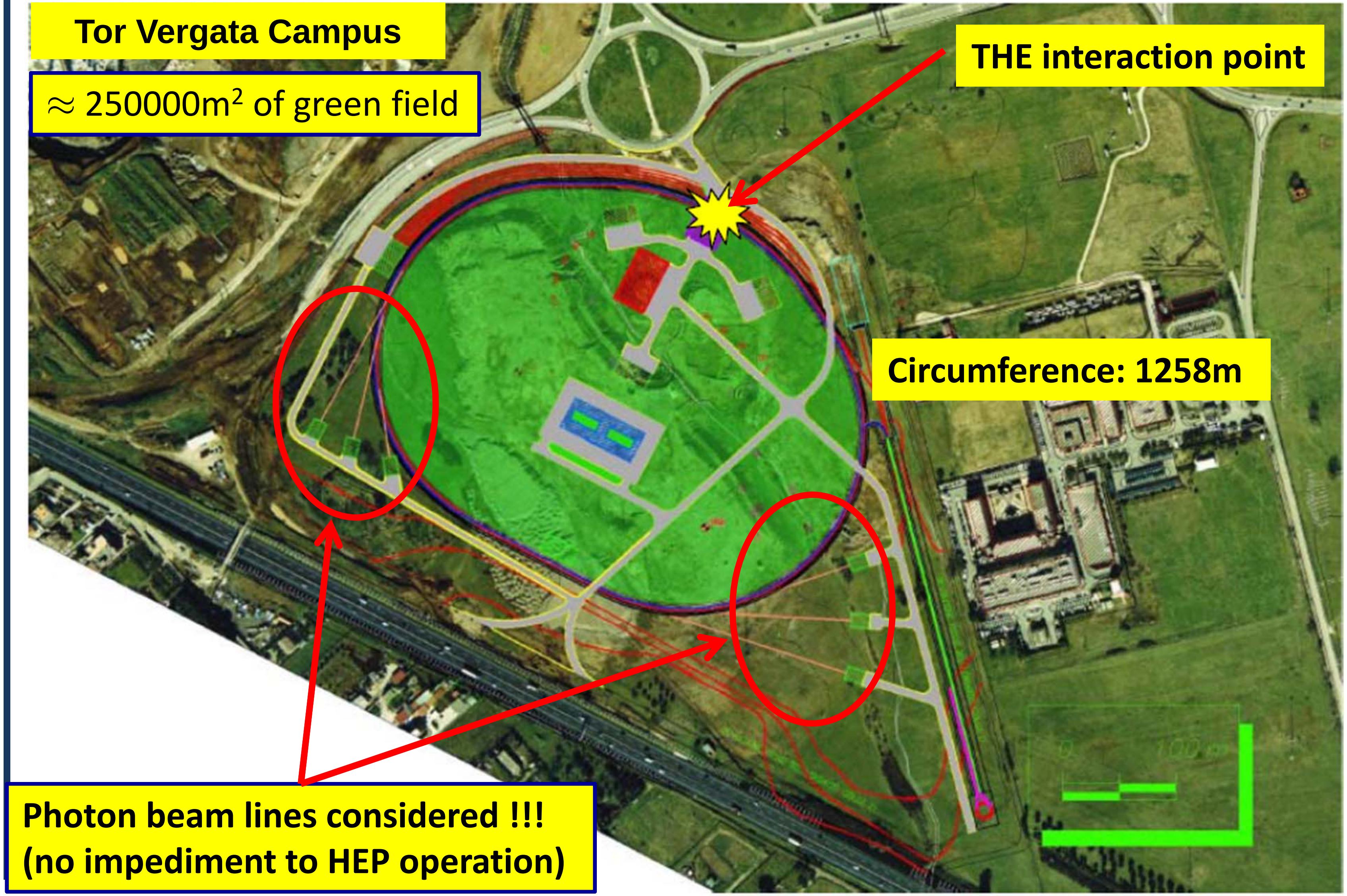
Positive tests at DA©NE

Realization:
sextupole
&
anti-sextupole
on both sides
of the IR

The N.Cabibbo Lab (Tor Vergata)



The N.Cabibbo Lab (Tor Vergata)



Tor Vergata Campus

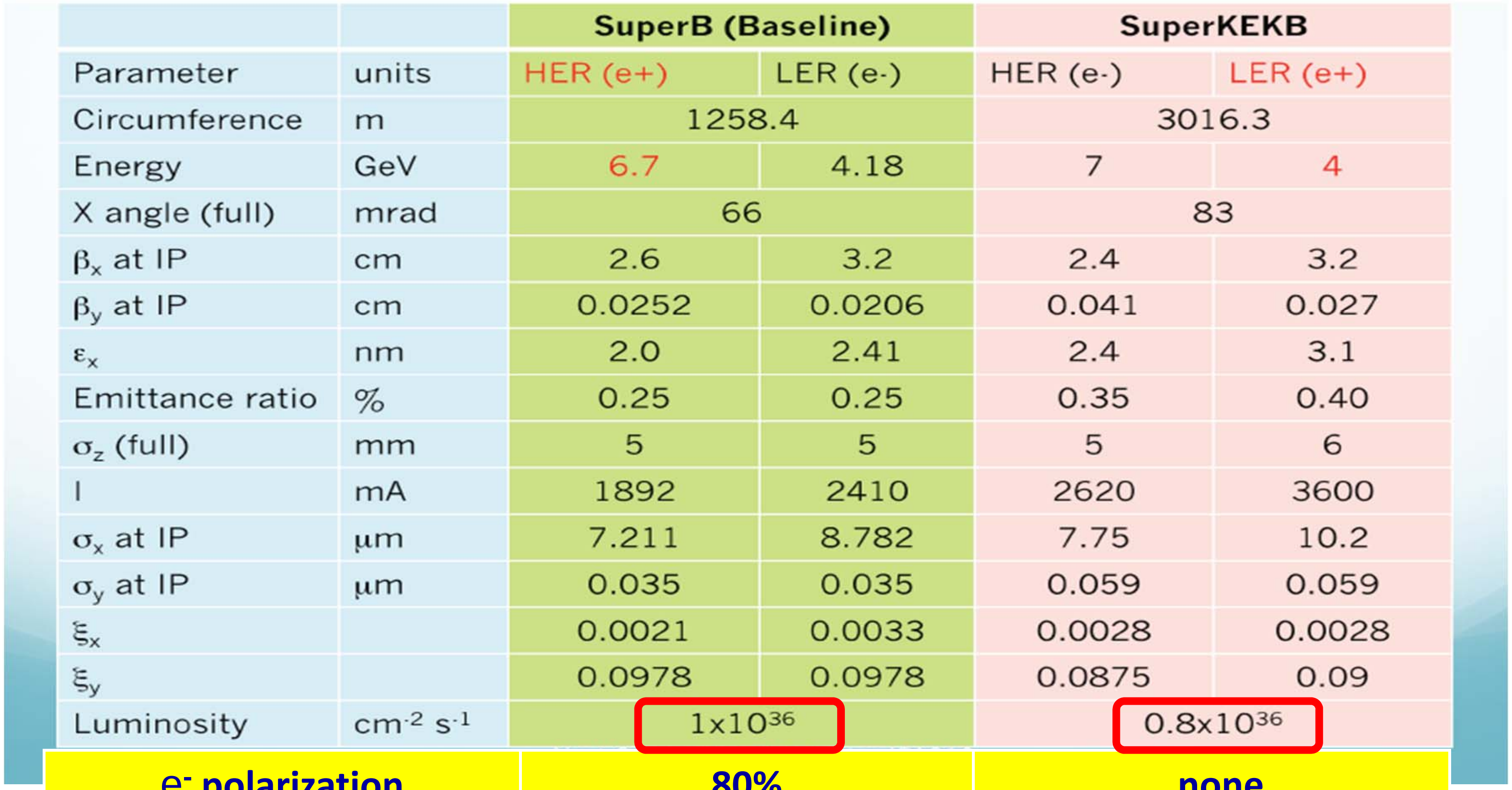
≈ 250000m^2 of green field

THE interaction point

Circumference: 1258m

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

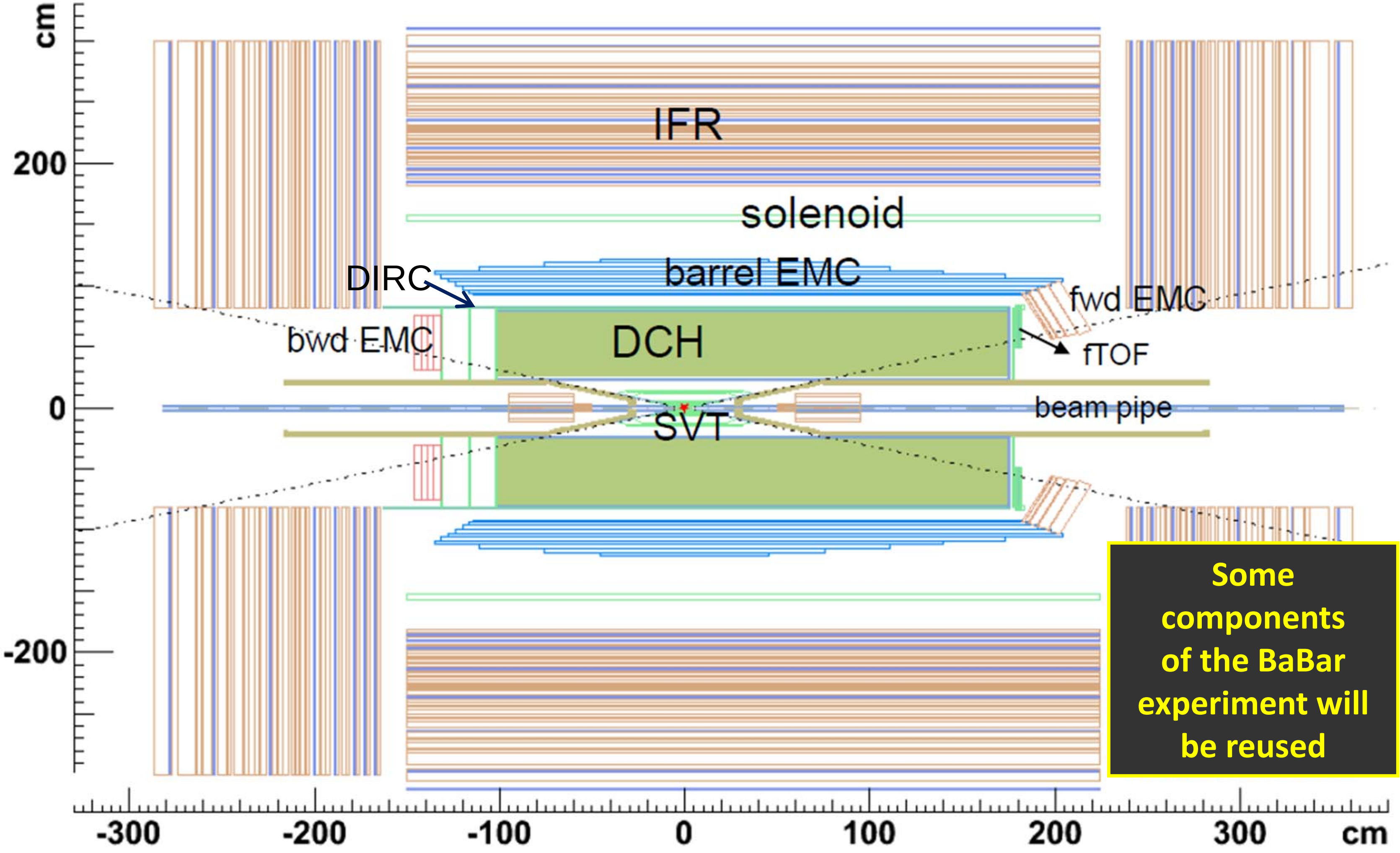
SuperB vs SuperKEKB



		SuperB (Baseline)		SuperKEKB	
Parameter	units	HER (e+)	LER (e-)	HER (e-)	LER (e+)
Circumference	m	1258.4		3016.3	
Energy	GeV	6.7	4.18	7	4
X angle (full)	mrad	66		83	
β_x at IP	cm	2.6	3.2	2.4	3.2
β_y at IP	cm	0.0252	0.0206	0.041	0.027
ε_x	nm	2.0	2.41	2.4	3.1
Emittance ratio	%	0.25	0.25	0.35	0.40
σ_z (full)	mm	5	5	5	6
I	mA	1892	2410	2620	3600
σ_x at IP	μm	7.211	8.782	7.75	10.2
σ_y at IP	μm	0.035	0.035	0.059	0.059
ξ_x		0.0021	0.0033	0.0028	0.0028
ξ_y		0.0978	0.0978	0.0875	0.09
Luminosity	cm^{-2} s^{-1}	1x10^{36}		0.8x10^{36}	

e$^-$ polarization	**80%**	**none**
Run at ψ(3770)	yes	No

SuperB Detector



Some components of the BaBar experiment will be reused

4. Project Status

SuperB Status

December 2010 - approval of the Project by the Italian Gov.
- funding 250 M EUR

SENATO DELLA REPUBBLICA
Segretariato Generale
Data -6 DIC. 2010

Ministero dell' Istruzione, dell' Università e della Ricerca
DIPARTIMENTO PER L'UNIVERSITÀ, L'ALTA FORMAZIONE ARTISTICA,
MUSICALE E COREUTICA E PER LA RICERCA
DIREZIONE GENERALE PER IL COORDINAMENTO E LO SVILUPPO DELLA RICERCA

Prot. 1417

Roma, 3 DIC. 2010

Al Presidente del Senato della Repubblica
Palazzo Madama
00186 ROMA

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

CABIBBO LAB
Laboratorio Nicola Cabibbo

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

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

End of 2012 - TDRs for the accelerator and detector

waiting for the beginning of civil engineering works

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.

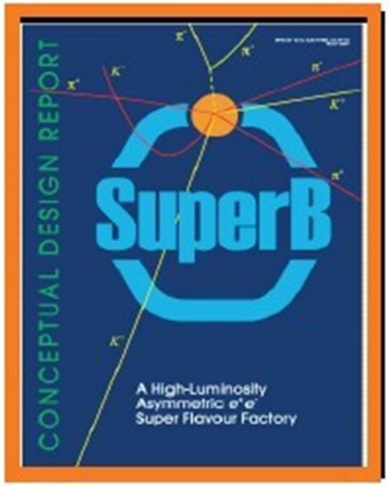
The SuperB offers the highest luminosity

AND two unique features:

1. **polarization of e^- beam (vital for tau and EW 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]



CONCEPTUAL DESIGN REPORT

SuperB

A High-Luminosity
Asymmetric e^+e^-
Super Flavour Factory

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**
- ✓ **Valencia workshop proceedings, arXiv:0810.1312 [hep-ex]**
- ✓ **The impact of SuperB on flavour physics, arXiv: 1109.5028[hep-ph]**

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