The SuperB Project

A major new particle physics centre

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On behalf of the SuperB Project
STORI 2011, October 11th 2011

Outline

- Key Features
- Tour of SuperB Physics
- Accelerator Design Status
- Detector Design Status
- Project Funding
- Latest News
- Conclusion and Outlook

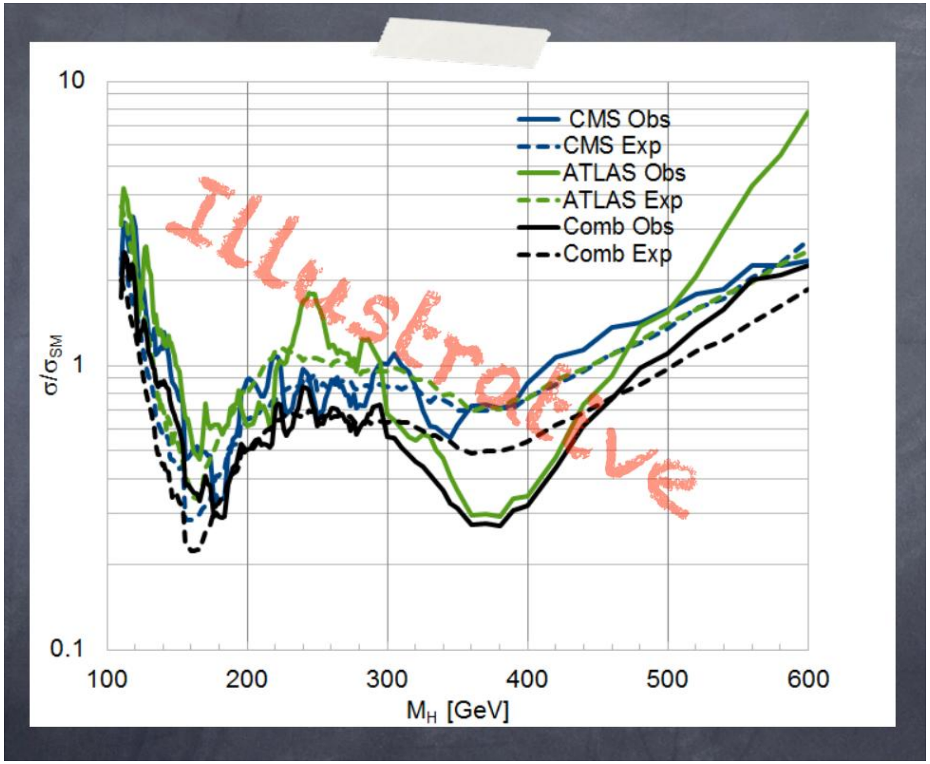
Key Features

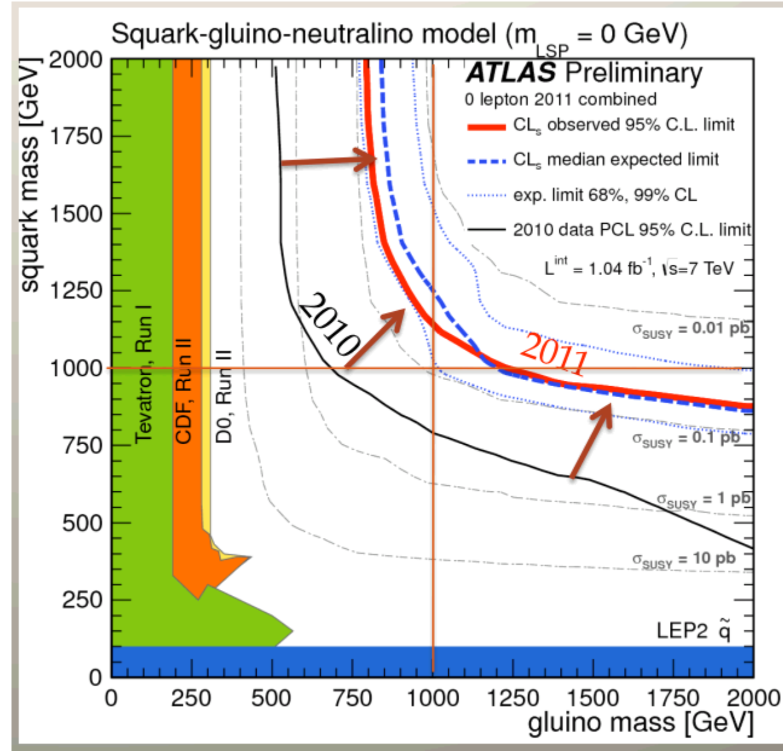
- New European Accelerator Facility to be sited in Italy, ready by ~2016
  - At $\Upsilon(4S)$, 6.7 GeV positrons on 4.18 GeV electrons, 1.3 km circumference
  - $\Upsilon(4S)$ decays primarily to B-meson pairs.
- High Luminosity (100 x current records)
  - $\geq 10^{36}$ cm^{-2} s^{-1} : 15 ab^{-1}/year rising to 40 ab^{-1}/year in later years
  - 1 ab^{-1} => 1 billion B-meson pairs, 1 billion D-mesons and 1 billion tau pairs
  - 75 ab^{-1} by ~2022
- Polarization
  - 60%-85% polarization of electron beam
  - Improves physics reach by factor of 2 in some regions
- $\psi(3770)$ to $\Upsilon(5S)$ and beyond
  - Can scan a large energy range.
- Charm Threshold Running
  - ~4 months running at 10^{35} cm^{-2} s^{-1} equivalent to 20 x future BES-III dataset.
- Light Source
  - 30 x brighter than ESRF or Diamond Light Source.
- Computing
  - On the scale of a non-upgraded LHC experiment.

SuperB Physics Goals – Executive Summary

- Identify the flavour structure of New Physics.
- Sensitive to New Physics through flavour properties; CP Violation asymmetries in B and D decays; and rare decays.
- Probe New Physics scales up to 10-100 TeV through indirect measurements.
- Different New Physics models predict a different hierarchy of results => multiple measurements needed.
- Search in both the quark and lepton sectors.
- Golden Channels (good SM prediction + good experimental resolution) e.g. inclusive $b \to s\gamma$, $B \to K\upsilon\bar{\upsilon}$, $B \to \tau\upsilon$, $\tau \to \mu\upsilon\bar{\upsilon}$
- Physics capabilities published in arXiv:1008.1541 and arXiv:1109.5028

Higgs / SUSY after Summer 2011





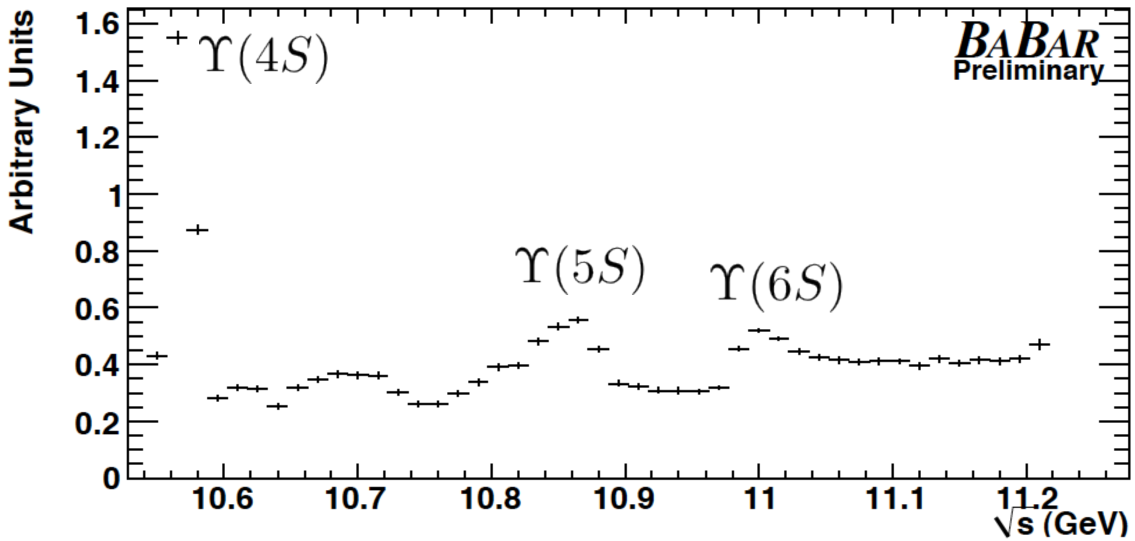
Low Mass Higgs: compatible with Standard Model and SUSY

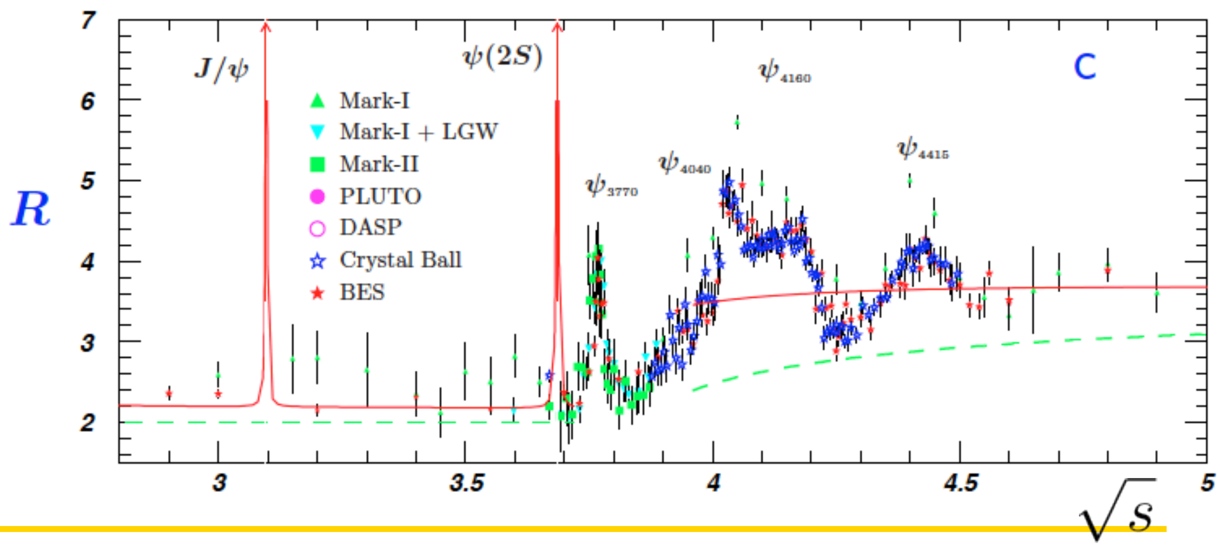
High Mass Higgs or **no Higgs**: need to probe higher mass scales.

"Trivial" SUSY is looking increasingly unlikely – need to probe more parameters

The SuperB data sample

- $\Upsilon(4S)$ region:
  - o 75ab^{-1} at the $\Upsilon(4S)$
  - o Also run above / below the $\Upsilon(4S)$
  - o ~75x10^9 B, D and τ pairs
- ψ(3770) region:
  - o ~150 fb^{-1} per month at threshold running
  - o Also run at nearby resonances
  - o ~2 x 10^9 D pairs





Physics: What will the CKM matrix look like in 2022?

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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

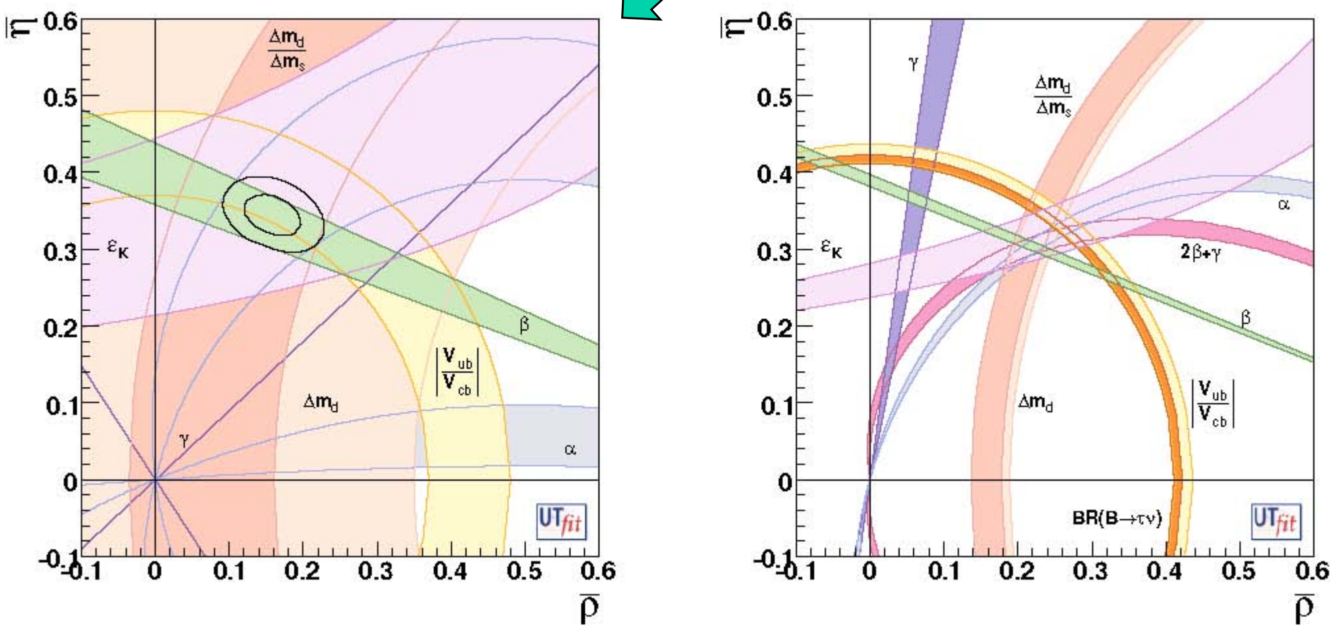


Figure 2-1. *Regions corresponding to 95% probability for $\bar{\rho}$ and $\bar{\eta}$ selected by different constraints, assuming present central values with present errors (left) or with errors expected at SuperB (right).*

Physics: Interplay – The Golden Matrix

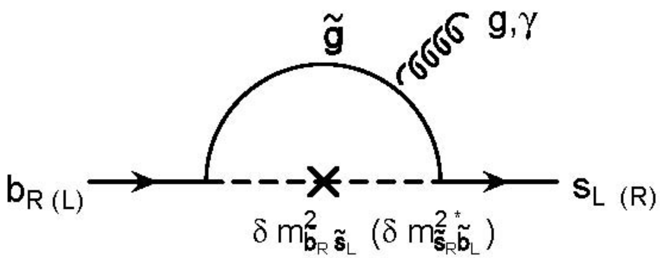
➢ Combine measurements to elucidate structure of new physics.

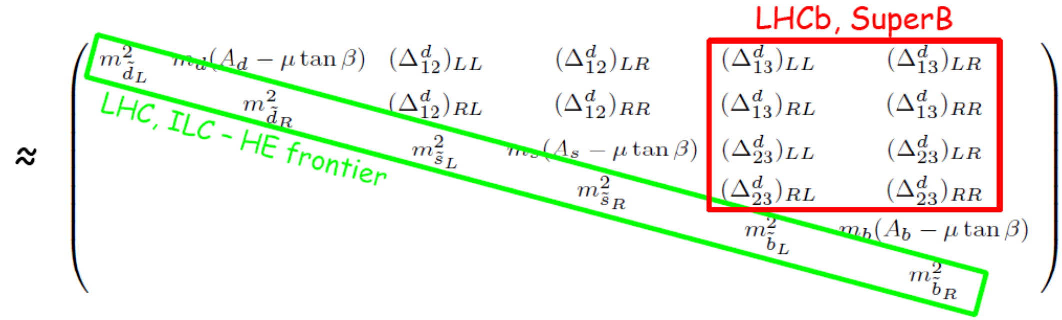
	Observable/mode	H^+ high $\tan\beta$	MFV	non-MFV	NP Z penguins	Right-handed currents	LTH	SUSY AC	SUSY RVV2	SUSY AKM	SUSY δLL	SUSY FBMSSM
✓	$\tau \to \mu\gamma$							★★★	★★★	★	★★★	★★★
✓	$\tau \to \ell\ell\ell$						★★★					
✓	$B \to \tau\nu, \mu\nu$	★★★(CKM)										
✓	$B \to K^{(*)+}\nu\overline{\nu}$			★	★★★			★	★	★	★	★
✓	S in $B \to K^0_S\pi^0\gamma$					★★★						
✓	S in other penguin modes			★★★(CKM)		★★★		★★★	★★	★	★★★	★★★
✓	$A_{CP}(B \to X_s\gamma)$			★★★		★★		★	★	★	★★★	★★★
✓	$BR(B \to X_s\gamma)$		★★★	★		★						
✓	$BR(B \to X_s\ell\ell)$			★	★	★						
✓	$B \to K^{(*)}\ell\ell$ (FB Asym)							★	★	★	★★★	★★★
	$B_s \to \mu\mu$							★★★	★★★	★★★	★★★	★★★
	β_s from $B_s \to J/\psi\phi$							★★★	★★★	★★★	★	★
✓	a_{sl}						★★★					
✓	Charm mixing							★★★	★	★	★	★
✓	CPV in Charm	★★									★★★	

✓= SuperB can measure these modes

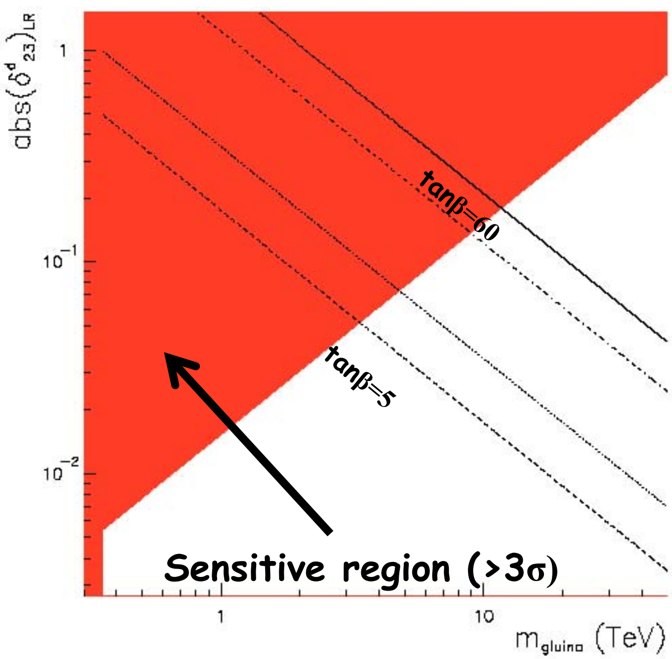
More information on the golden matrix can be found in arXiv:1008.1541, arXiv:0909.1333, and arXiv:0810.1312.

Physics: Overlap with the LHC

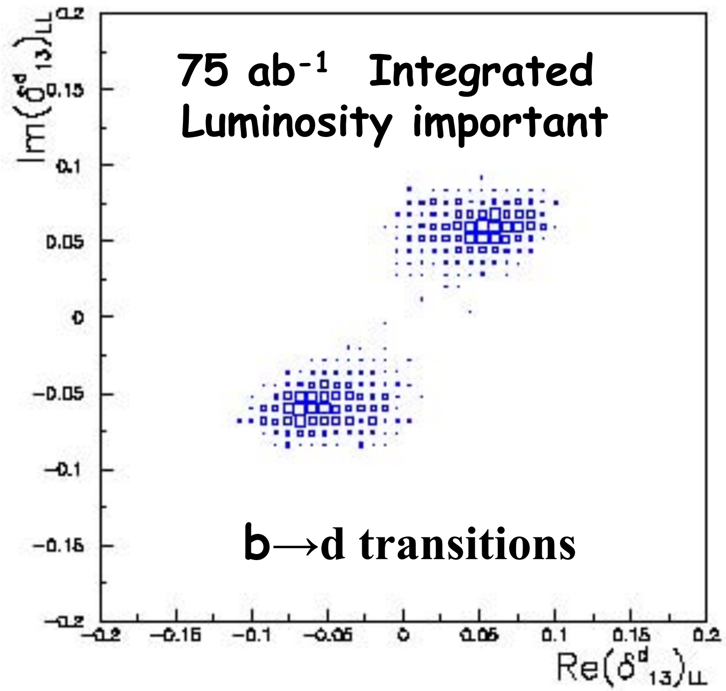




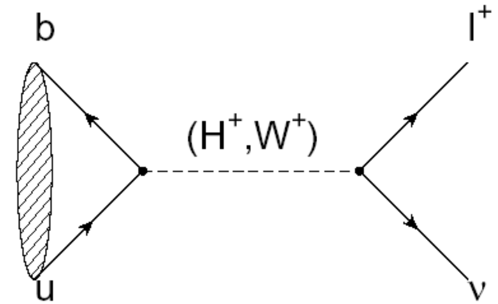
and similarly for $M^2_{\tilde{u}}$



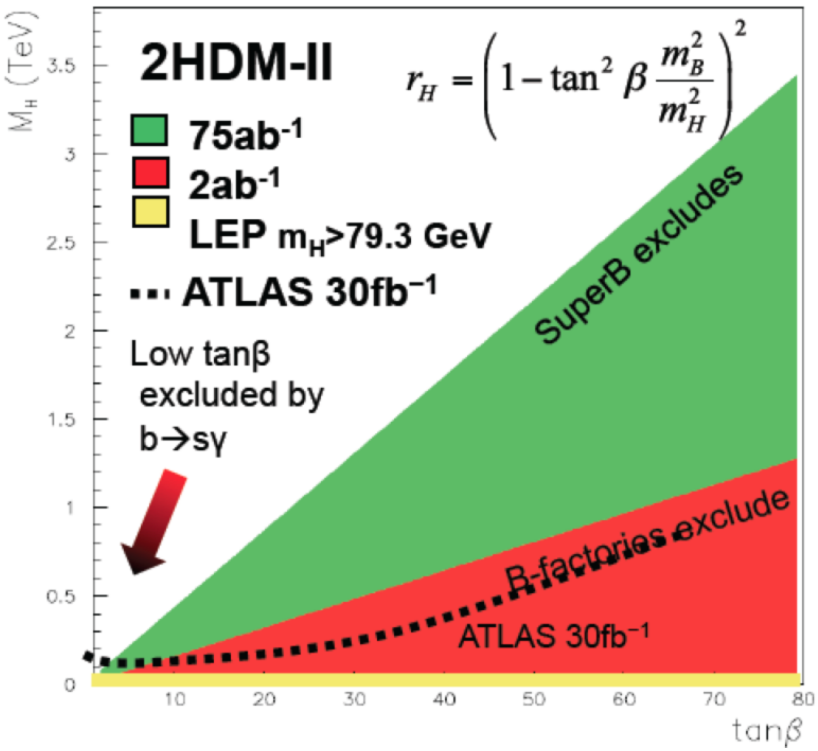
b→s transitions

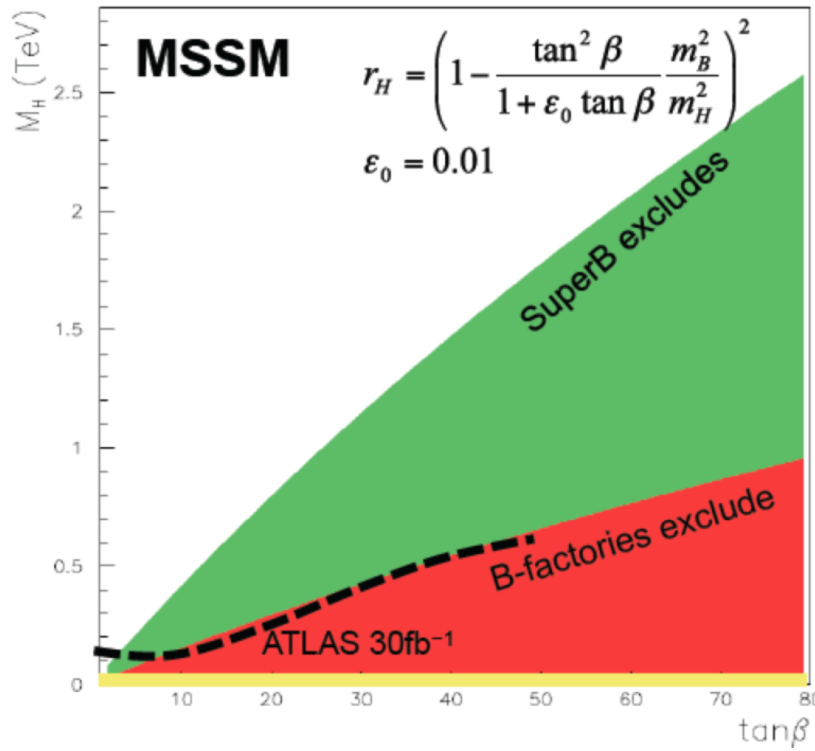


Physics: Charged Higgs (2HDM and MSSM)



- Higgs-mediated Minimal Flavour Violation
- Multi-TeV search capability for large tan(β).
- Includes SM uncertainty ~20% from V_{ub} and f_B.
- $B^0 \to l^+ l^-$ and $B^0 \to l^- \tau^+$ also sensitive to non-SM Higgs

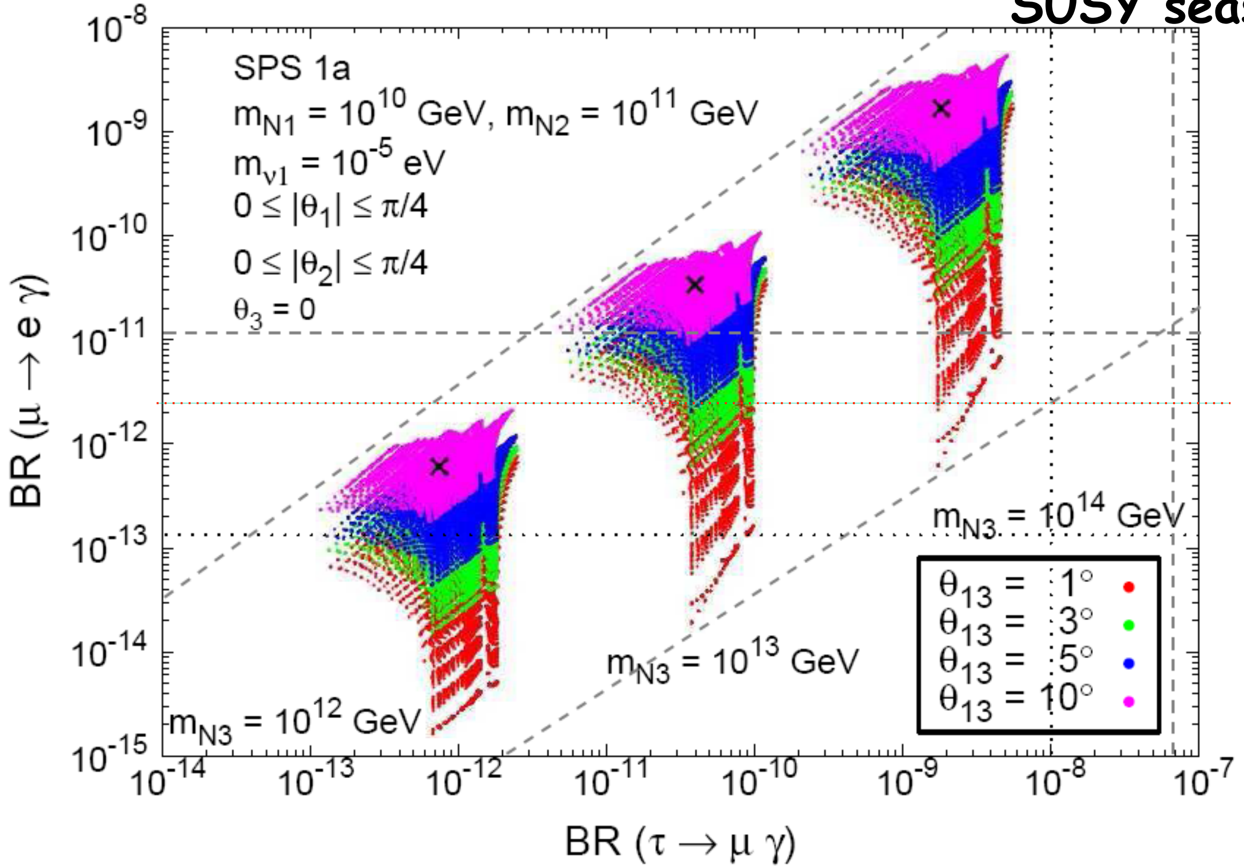




Physics: $\tau \to \mu\gamma$

- $\tau \to \mu\gamma$ upper limit can be correlated to θ_{13} (neutrino mixing/CPV, T2K etc.) and also to $\mu \to e\gamma$ (MEG).

SUSY seasaw model



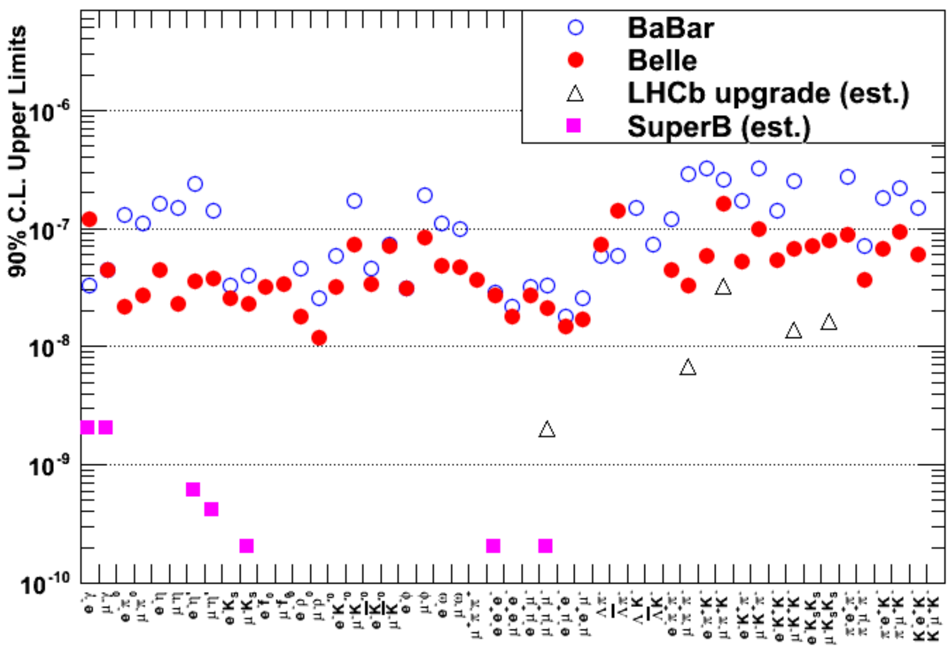
Correlated results from T2K, MEG and SuperB

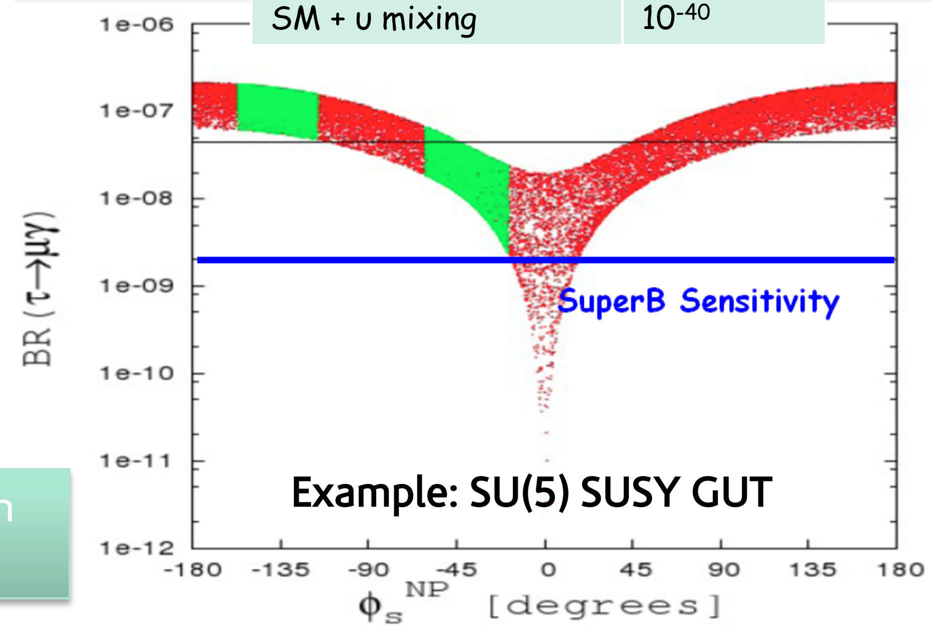
Arganda et al., JHEP, 06:079, 2008.

Physics: Lepton Flavour Violation

- Many models predict LFV at the level that can be detected at SuperB
- LFV also sensitive to other observable such as μ->eγ (MEG), θ_{13} (T2K) and B_s mixing phase (LHCb)
- Polarization doubles sensitivity (not included in numbers below)

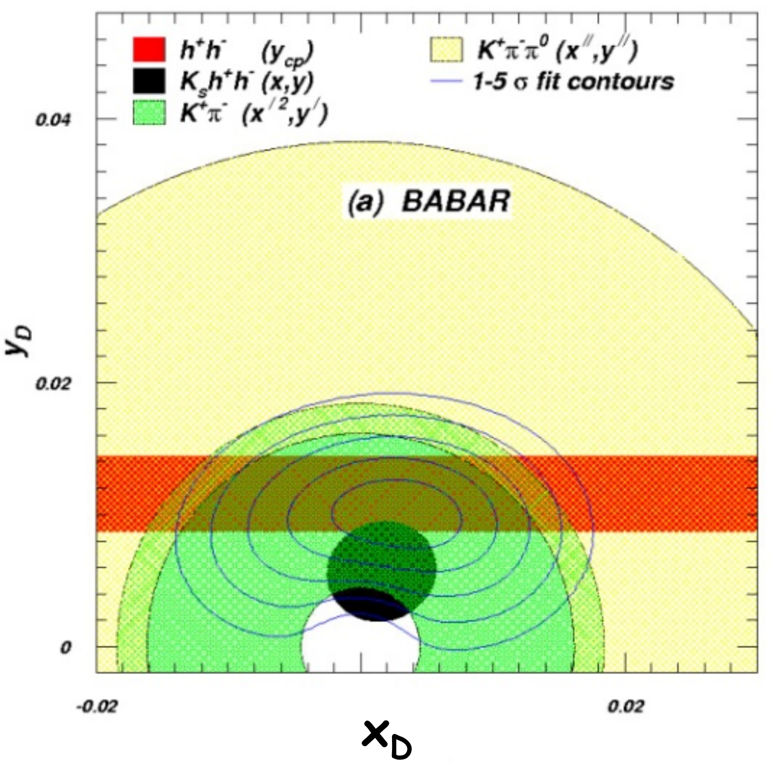
Model	BF(τ→μγ)
mSUGRA+seesaw	10^{-7}
SUSY+SO(10)	10^{-8}
SM+seesaw, Z'	10^{-9}
SUSY+Higgs	10^{-10}
SM + υ mixing	10^{-40}

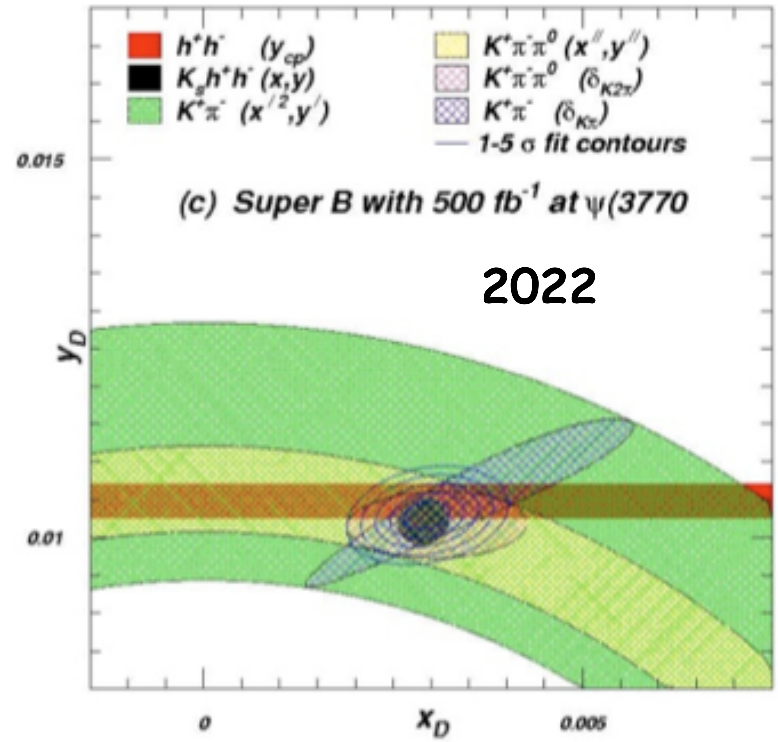




Over 50 τ decays can be measured (not to mention spectral functions, second class currents, α_s etc...)

Physics: Charm and Charm CPV





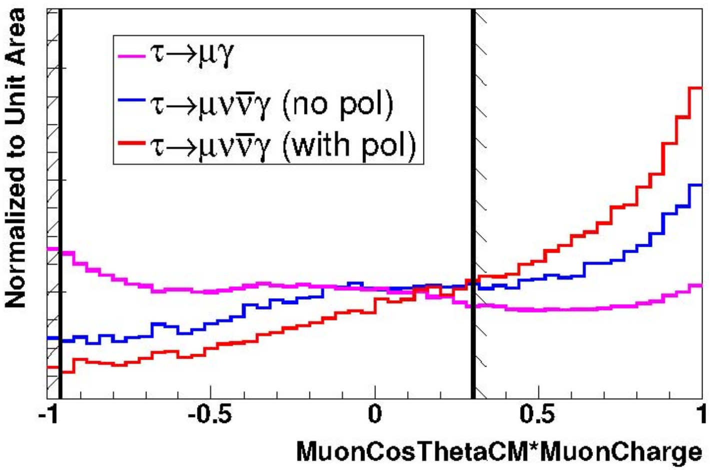
- CPV in SM very small (<1%)=> CPV indicates New Physics
- Charm Unitarity Triangle (β_c, $|V_{cd}|$, $|V_{cs}|$) and more

See arXiv:1106.5075

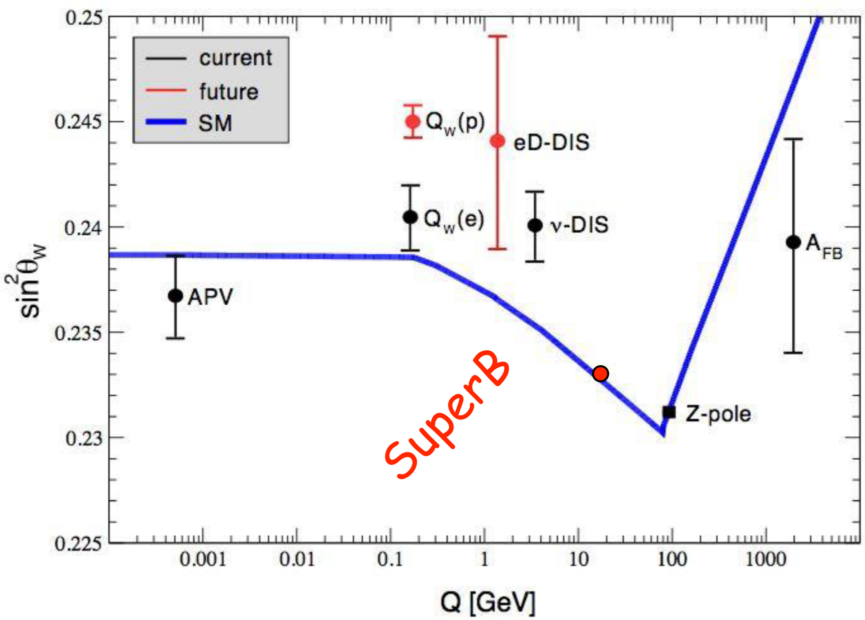
	Now	2022
x ($\times 10^3$)	±3	±0.2
y ($\times 10^3$)	±2	±0.1
$\delta_{k\pi}$	±10°	±1°
$\delta_{k\pi\pi}$	±20°	±1°

Physics: Benefits of Polarized Electron Beam

1) LFV: Doubles Precision



3) τ CP Violation:
Angular distributions



2) τ EDM, τ g-2:

Measurement could prove or disprove discrepancy in $\Delta\,\alpha_\mu$ due to New Physics.

EDM sensitivity ~ 2 x 10^{-19} e cm

- **$\Delta\alpha_\tau$ (SM) ~ 10^{-6}**
- **$\Delta\alpha_\tau$ (SUSY) <~ 10^{-5}**
- **$\Delta\alpha_\tau$ (SuperB) precision~ 10^{-6}**

4) Electroweak:

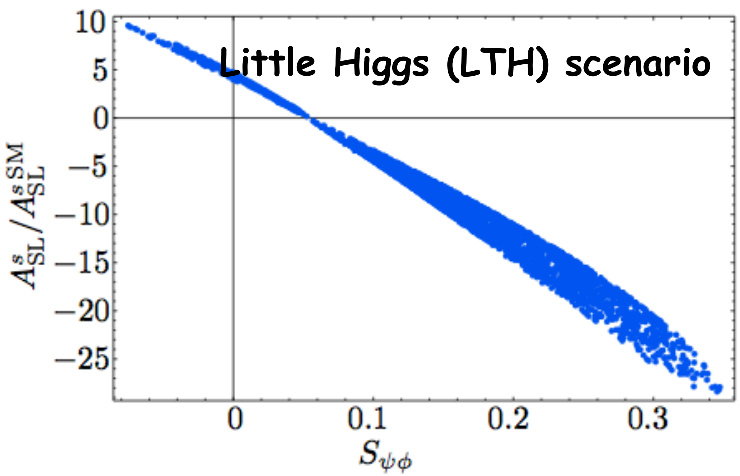
- Investigate LEP A_{FB} v. SLD A_{LR} discrepancy.
- Investigate NuTev discrepancy.
- Constrain Higgs mass
- $\sin^2\theta_W$ resolution ±0.00018
- Perhaps measure even at ψ(3770)

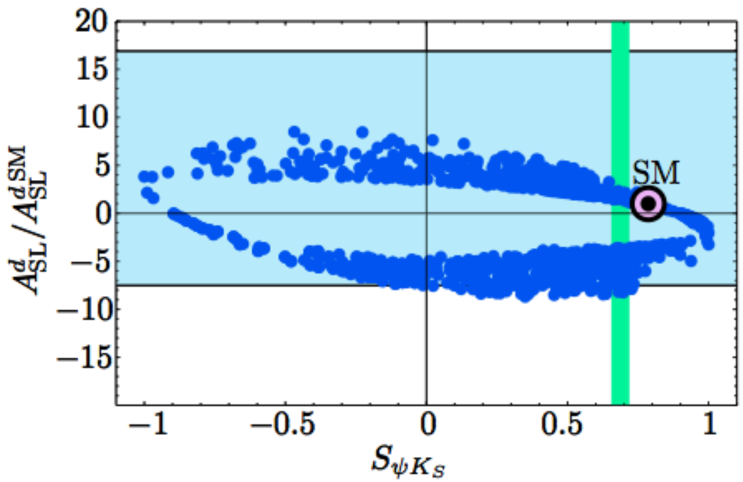
Physics: B_s decays

- SuperB will complement LHCb in some areas
- Can cleanly measure A^s_{SL} using $\Upsilon(5S)$ data

$$A^s_{SL} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) - \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)}{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) + \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)} = \frac{1-|q/p|^4}{1-|q/p|^4}$$

$$\sigma(A^s_{SL}) \sim 0.004 \text{ with a few } ab^{-1}$$

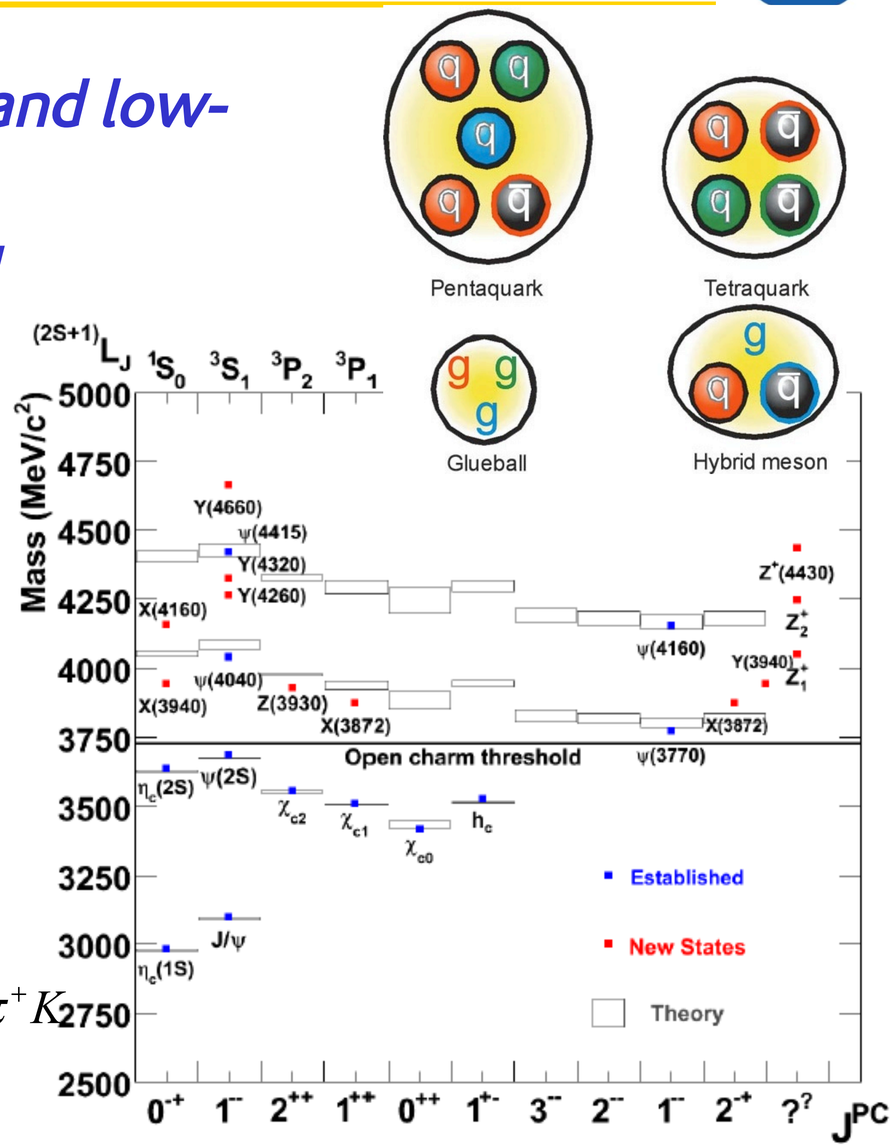




- SuperB can study rare decays with many neutral particles, such as $B_s \to \gamma\gamma$, which can be enhanced by SUSY.

Physics: Spectroscopy and exotic resonances

- *Ideal laboratory for testing high- and low-energy QCD.*
- *Search for hybrids, molecules and tetraquarks.*



Some expected samples in $50ab^{-1}$:

$B \to X(3872)K$: ~10,000 events

$\mathrm{Y}(4260) \to \mathrm{J}/\psi\pi^+\pi^-$: ~30,000 events

$\mathrm{Y}(4350) \to \psi(2\mathrm{S})\pi^+\pi^-$: ~3000 events

$\mathrm{Y}(4660) \to \psi(2\mathrm{S})\pi^+\pi^-$: ~3000 events

$Z^+(4050), Z_2^+(4430)$: $10^3 - 10^6$ $B \to \mathrm{J}/\psi\pi^+K, \psi(2\mathrm{S})\pi^+K$

Accelerator: Parameters are stable

Table 3.1: Super*B* parameters for baseline, low emittance and high current options, and for tau/charm running.

		Base Line		Low Emittance		High Current		Tau-charm	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY	$cm^{-2} s^{-1}$	1.00E+36		1.00E+36		1.00E+36		1.00E+35	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrad	66		66		66		66	
β_x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
Emittance x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
Emittance y	pm	5	6.15	2.5	3.075	10	12.3	13	16
Bunch length (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Ion gap	%	2		2		2		2	
RF frequency	MHz	476.		476.		476.		476.	
Revolution frequency	MHz	0.238		0.238		0.238		0.238	
Harmonic number	#	1998		1998		1998		1998	
Number of bunches	#	978		978		1956		1956	
N. Particle/bunch (10^{10})	#	5.08	6.56	3.92	5.06	4.15	5.36	1.83	2.37
σ_x effective	μm	165.22	165.30	165.22	165.30	145.60	145.78	166.12	166.67
σ_y @ IP	μm	0.036	0.036	0.021	0.021	0.054	0.0254	0.092	0.092
Piwinski angle	rad	22.88	18.60	32.36	26.30	14.43	11.74	8.80	7.15
Σ_x effective	μm	233.35		233.35		205.34		233.35	
Σ_y	μm	0.050		0.030		0.076		0.131	
Hourglass reduction factor		0.950		0.950		0.950		0.950	
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.097	0.097	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Longitudinal damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.17
Momentum compaction (10^{-4})		4.36	4.05	4.36	4.05	4.36	4.05	4.36	4.05
Energy spread (10^{-4}) (full current)	dE/E	6.43	7.34	6.43	7.34	6.43	7.34	6.43	7.34
CM energy spread (10^{-4})	dE/E	5.0		5.0		5.0		5.0	
Total lifetime	min	4.23	4.48	3.05	3	7.08	7.73	11.4	6.8
Total RF Wall Plug Power	MW	16.38		12.37		28.83		2.81	

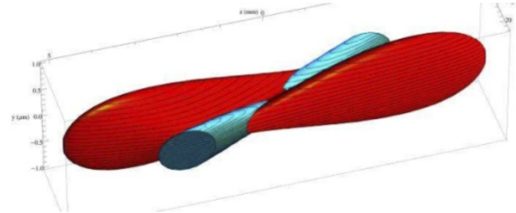
arXiv:1009.6178

Tau/charm threshold running

Flexibility built in, no single critical element

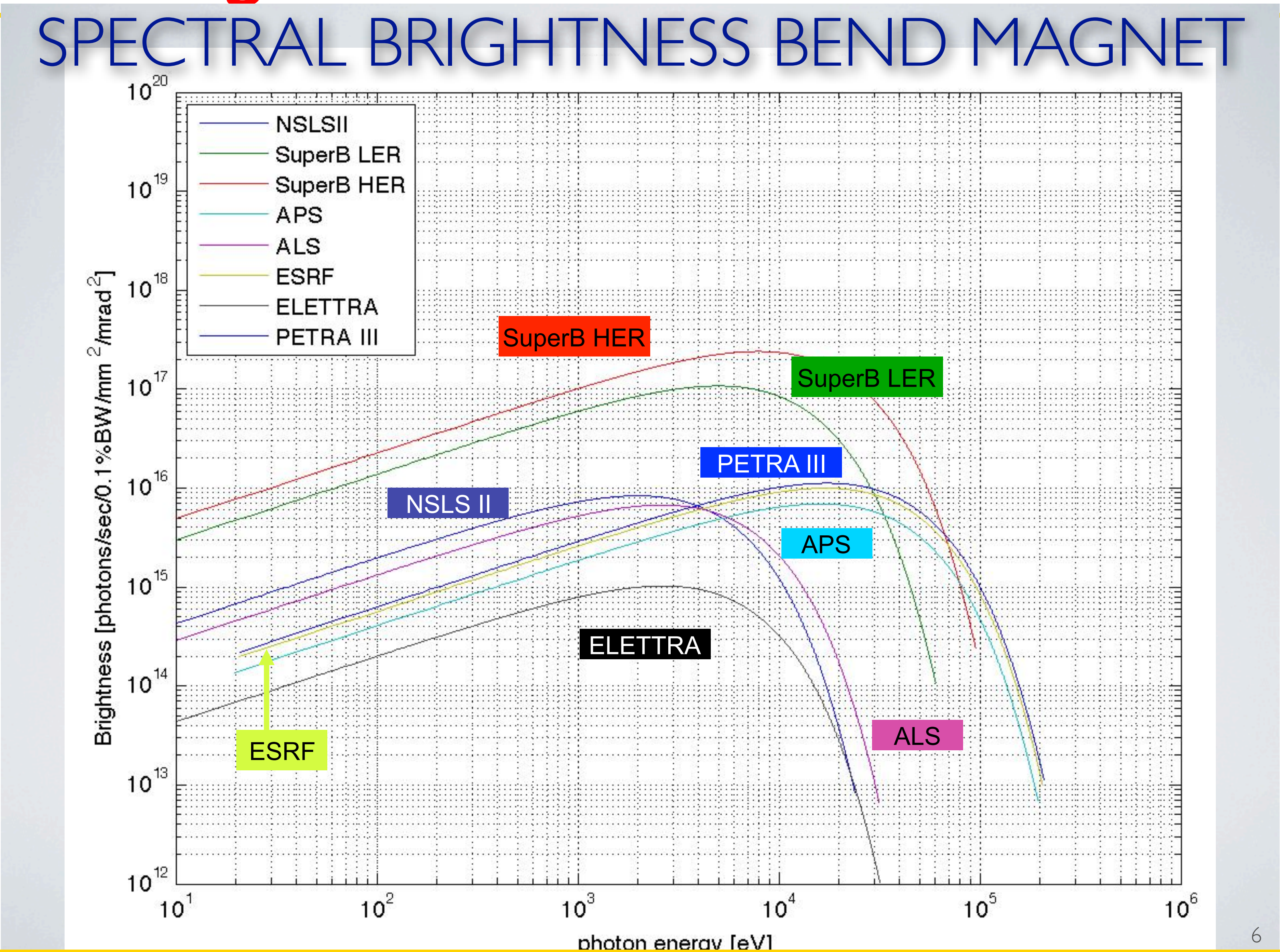
Upgradable to 4x higher lumi

Piwinski angle and crab-waist crossing test at DaΦne



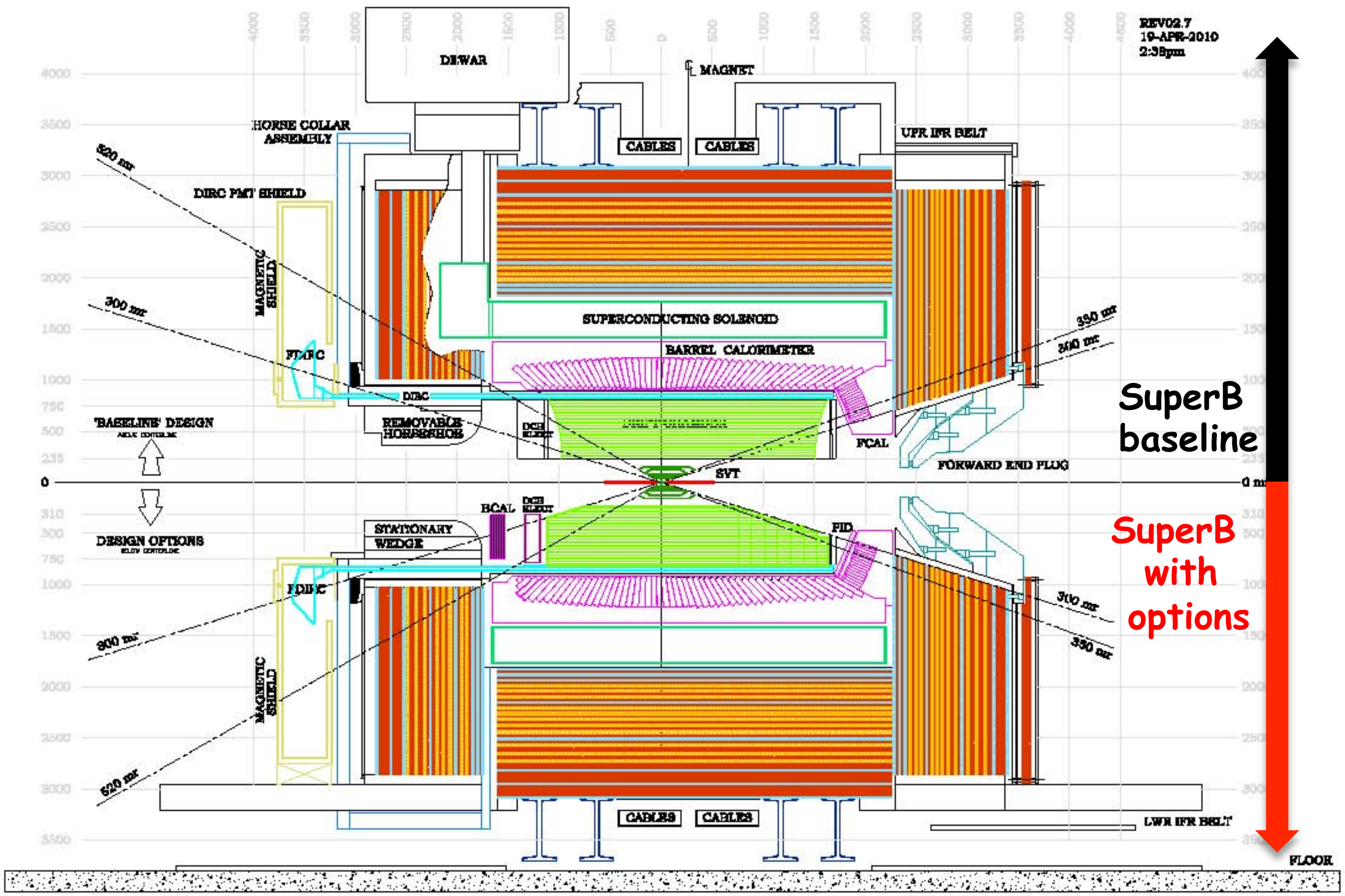
Low power < 20MW

Photon Light Source



Detector: Design [arXiv:1007.4241]

Reuses much of BaBar e.g. CsI crystals



Improve Vertex resolution x 2

Improved hermiticity

TOF Forward PID

Cluster counting in drift chamber (improves dE/dx)

Backward EMC

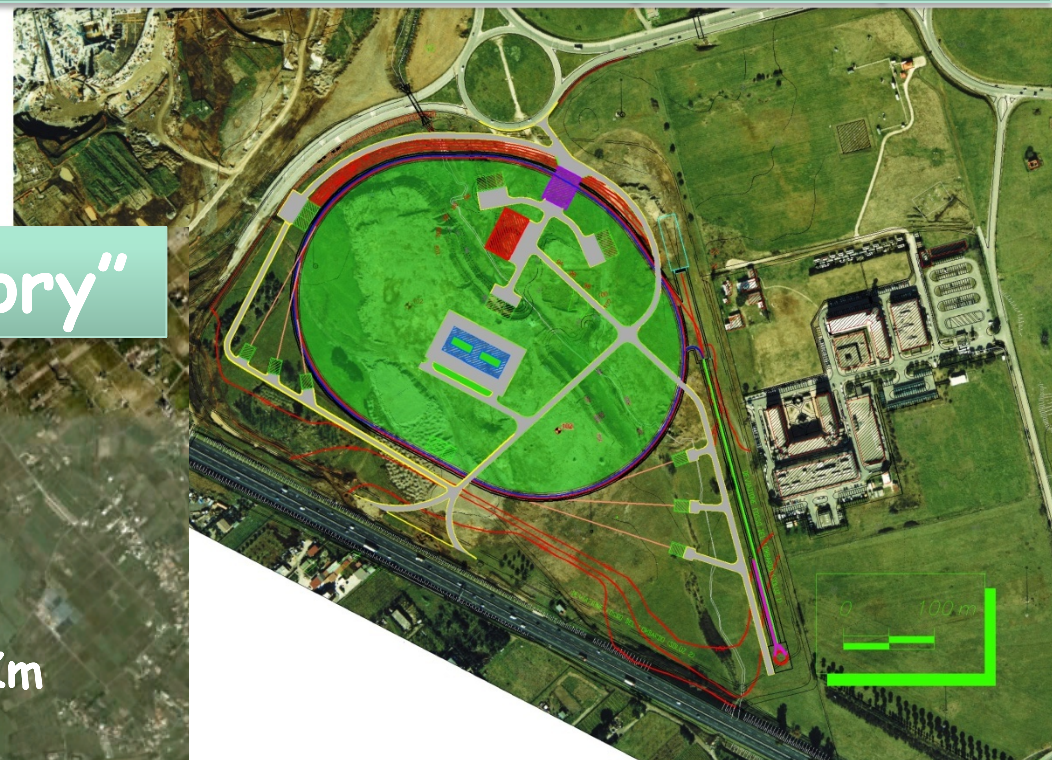
Optimized Muon Detector

SuperB – Funding and Developments

- SuperB approved through primary law by Italian parliament, December 14th/15th 2010.
- Parliament also approved INFN "Piano Triennale" 2010-2012 funding profile which includes SuperB.
- SuperB is an Italian national flagship project.
- Funding:
  - 19M€ in 2010, 50M€ per year thereafter until EOY 2015. SuperB is the only project receiving multi-year funding so far.
  - ~120M$ in-kind contribution from US through use of PEP-II machine components and BaBar detector.
  - 50M€ allocated for Tier 2 Grid computing centres in Southern Italy.
  - Italian Institute of Technology (IIT) may contribute to beam-lines for photon science.
- Only ~25M€ needed from international collaborators for detector

Site Decision announced May 30th 2011

Tor Vergata University Campus



"N. Cabibbo Laboratory"

Italian Government approval given on September 29 2011

Conclusion and Outlook

- August 2010: Physics, Accelerator, Detector reports published.
- December 2010: SuperB approved by the Italian Government, as a "Flagship" project.
- May 30th 2011: Site selection announced.
- September 29th 2011: N. Cabibbo Lab approved by Government
- A unique opportunity for Europe and International Collaboration.
- The necessary funding is in place.
- First beams in 5 to 6 years. 15 ab^{-1}/year rising to 40 ab^{-1}/year.
- Collaboration is still growing. Working towards TDR. Opportunities in detector, accelerator, computing and physics.

Backup

Golden measurements: General

Experiment:	No Result	Moderately precise	Precise	Very precise
Theory:		Moderately clean	Clean, needs Lattice	Clean

Observable/mode Luminosity	Current $\sim 1\,\mathrm{ab}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory	
τ Decays						
$\tau \to \mu\gamma$						Benefit from polarised e^- beam
$\tau \to e\gamma$						
$B_{u,d}$ Decays						
$B \to \tau\nu, \mu\nu$						very precise with improved detector
$B \to K^{(*)+}\nu\overline{\nu}$						Statistically limited: Angular analysis with $>75\mathrm{ab}^{-1}$
S in $B \to K^0_S\pi^0\gamma$						
S (other penguin modes)						Right handed currents
A_{CP} $(B \to X_s\gamma)$						
BR$(B \to X_s\gamma)$						SuperB measures many more modes
BR$(B \to X_s ll)$						systematic error is main challenge
BR$(B \to K^{(*)} ll)$						control systematic error with data
B_s Decays						SuperB measures e mode well, LHCb does μ
$B_s \to \mu\mu$						
β_S from $B_s \to J/\psi\,\phi$						
$B_s \to \gamma\gamma$						
a_{sl}						
D Decays						
Mixing parameters						Clean NP search
CP Violation						
Precision Electroweak						
$\sin^2\theta_W$ at $\Upsilon(4S)$						Theoretically clean
$\sin^2\theta_W$ at Z-Pole						b fragmentation limits interpretation

Golden Measurements: CKM

- Comparison of relative benefits of SuperB ($75 ab^{-1}$) vs. existing measurements and LHCb ($5 fb^{-1}$) and the LHCb upgrade ($50 fb^{-1}$).

Observable/mode Luminosity	Current $\sim 1\,\mathrm{ab}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super*B* (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
α	Blue	Blue	Green	Blue	Yellow
β from $b \to c\bar{c}s$	Blue	Blue	Green	Green	Green
$B_d \to J/\psi \pi^0$	Yellow	Red	Green	Red	Green
$B_s \to J/\psi K_S^0$	Red	Yellow	Red	Blue	Green
γ	Yellow	Blue	Green	Green	Green
$\lvert V_{ub}\rvert$ inclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{ub}\rvert$ exclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{cb}\rvert$ inclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{cb}\rvert$ exclusive	Blue	Yellow	Green	Blue	Blue

LHCb can only use $\rho\pi$

β theory error B_d
β theory error B_s

Need an e^+e^- environment to do a precision measurement using semi-leptonic B decays.

	Red	Yellow	Blue	Green
Experiment:	No Result	Moderately precise	Precise	Very precise
Theory:		Moderately clean	Clean, needs Lattice	Clean

CKM Matrix and Unitarity Triangle

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Complex and unitary

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

If angles and sides disagree then Standard Model is wrong