The physics case of running SuperB at the $\Upsilon(5S)$ resonance

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This talk is based on hep-ph/0703258

Outline

- Why the $\Upsilon(5S)$ Resonance?
- Experimental Challenges @ $\Upsilon(5S)$;
- CP Asymmetries @ $\Upsilon(5S)$:
  - BB coherence;
  - Time Integrated CP Asymmetries; **NEW**
- Accessing the B_s–$\bar{B}_s$ Mixing Phase:
  - Time Integrated Measurements to extract the same informations than Time Dependent Analyses;
  - The "Δt sign" method; **NEW**
- Rare B_s Decays;
- The Impact on Flavour Physics.

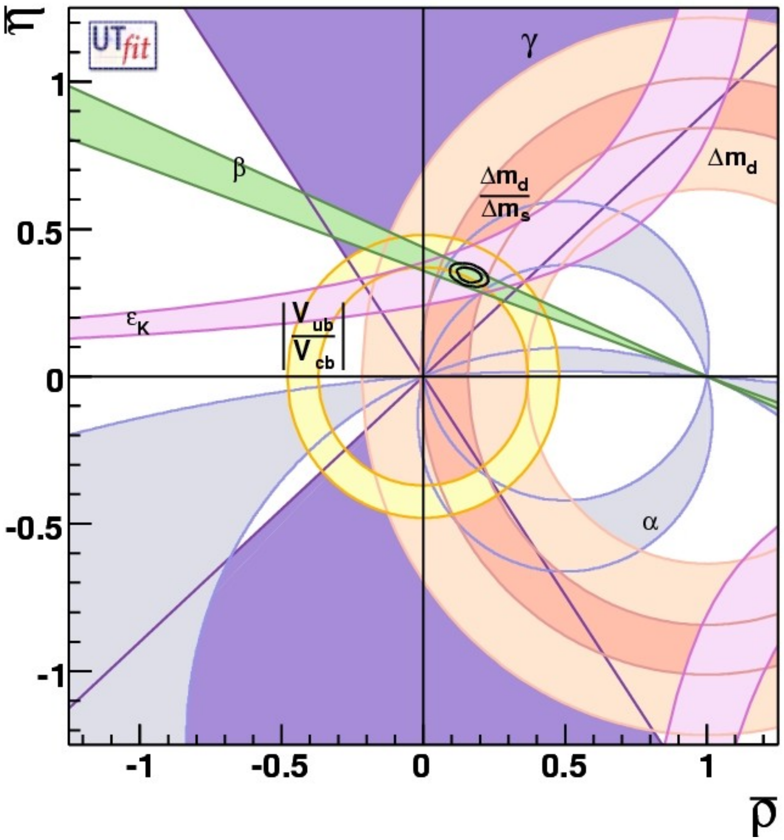
Why the $\Upsilon(5S)$ resonance?

The UT in the SM picture

- The B-factories' legacy at present:
  - Good knowledge of the SM free parameters;
  - Consistency of *UT* and SM picture;
  - No deviations from the SM yet;

Most likely, NP effects in B_d mixing too small to be measured at present machines (i.e. ~ 1ab^{-1}).

- The LHC era:
  - *UT* precision measurements from LHCb;



Main motivation for new flavour physics experiments only to look for NP effects (HOW? WHERE?)

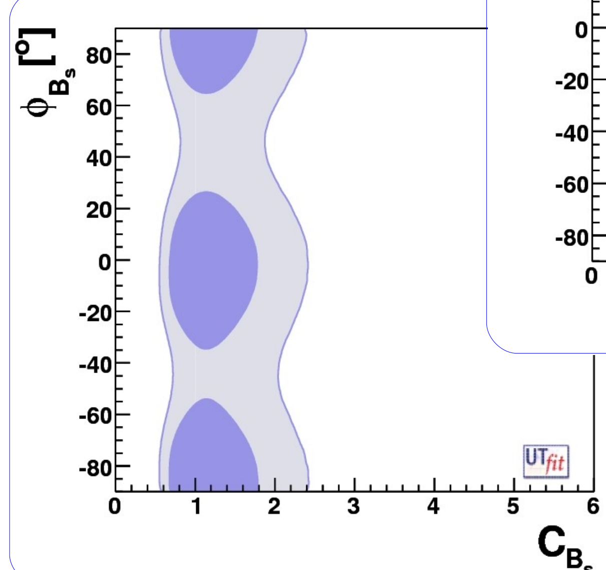
The UT and NP

MODEL INDEPENDENT

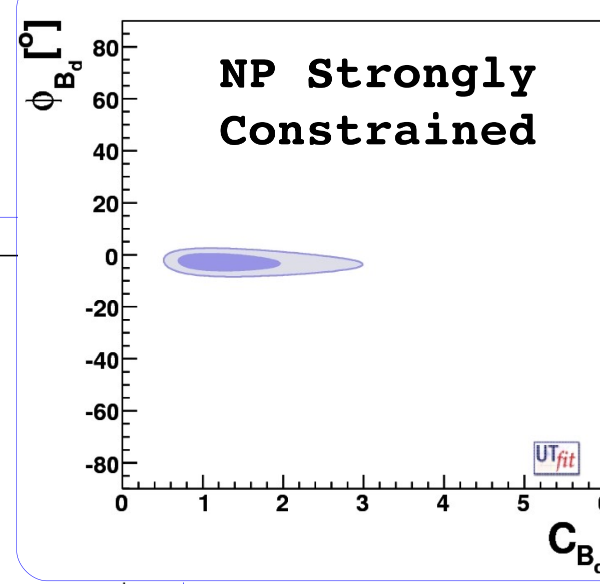
- The abundance of experimental informations allows to determine the *UT* and the *NP* parameters simultaneously;
- SM expectation clean and limited only by computational power (e.g. lattice QCD);

SM		SM+NP
$(V_{ub}/V_{cb})^{SM}$	**tree level**	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}		γ^{SM}
	Bd Mixing	
β^{SM}		$\beta^{SM}+\phi_{Bd}$
α^{SM}		$\alpha^{SM}-\phi_{Bd}$
Δm_d		$C_{Bd}\Delta m_d$
	Bs Mixing	
Δm_s^{SM}		$C_{Bs}\Delta m_s^{SM}$
β_s^{SM}		$\beta_s^{SM}+\phi_{Bs}$
	K Mixing	
ε_K^{SM}		$C_{\varepsilon_K}\,\varepsilon_K^{SM}$

dark: 65%
light: 95%



First Bound



WHERE: $b \to d$ vs. $b \to s$

$b \to d$

- Many precision measurement already available;
- More measurements with a SuperB at the $\Upsilon(4S)$;

BUT...

- At present, no evidence for NP.

$b \to s$

- Large NP effects not ruled out by present measurements;
- Can be studied using through Radiative Penguins and CP asymmetries in the B_d sector

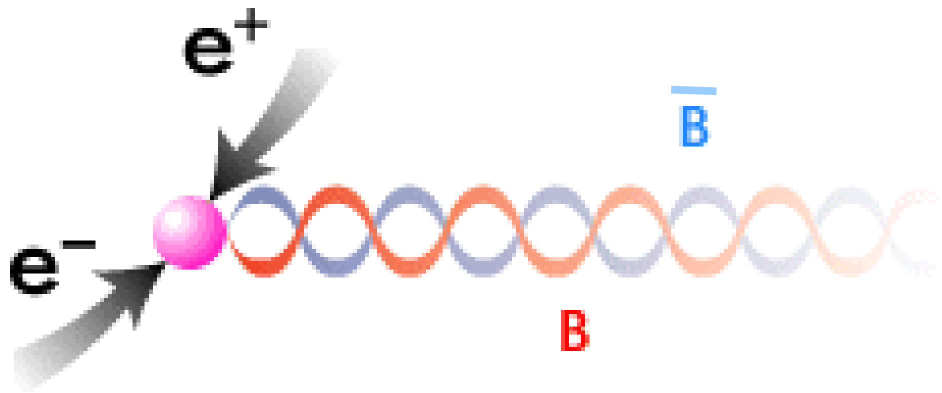
BUT...

- Large theoretical uncertainties in the B_d sector w.r.t. the experimental reach

- A new approach – *constraining the Bs mixing phase*:
  - lifetime difference $\Delta\Gamma_s$;
  - CP asymmetry in mixing (A_{SL});

} Running at the $\Upsilon(5S)$ resonance!

Experimental Challenges



$\Upsilon(5S)$ Production & Decays

e^+e^- @ 10.86 GeV

$\sigma(e^+e^- \to \Upsilon(5S)) \sim 0.3\text{nb}$

$\left[\sigma(e^+e^- \to \Upsilon(4S), s = 10.58\,\text{GeV}) \sim 1\,\text{nb}\right]$

u,d,c,s continuum

BBπ, BBππ, etc.
(BB continuum)

$B_d^{0(*)} B_d^{0(*)}, B^+B^-$
(~ 58%)

$B_s^{0(*)} B_s^{0(*)}$
(~ 26%)

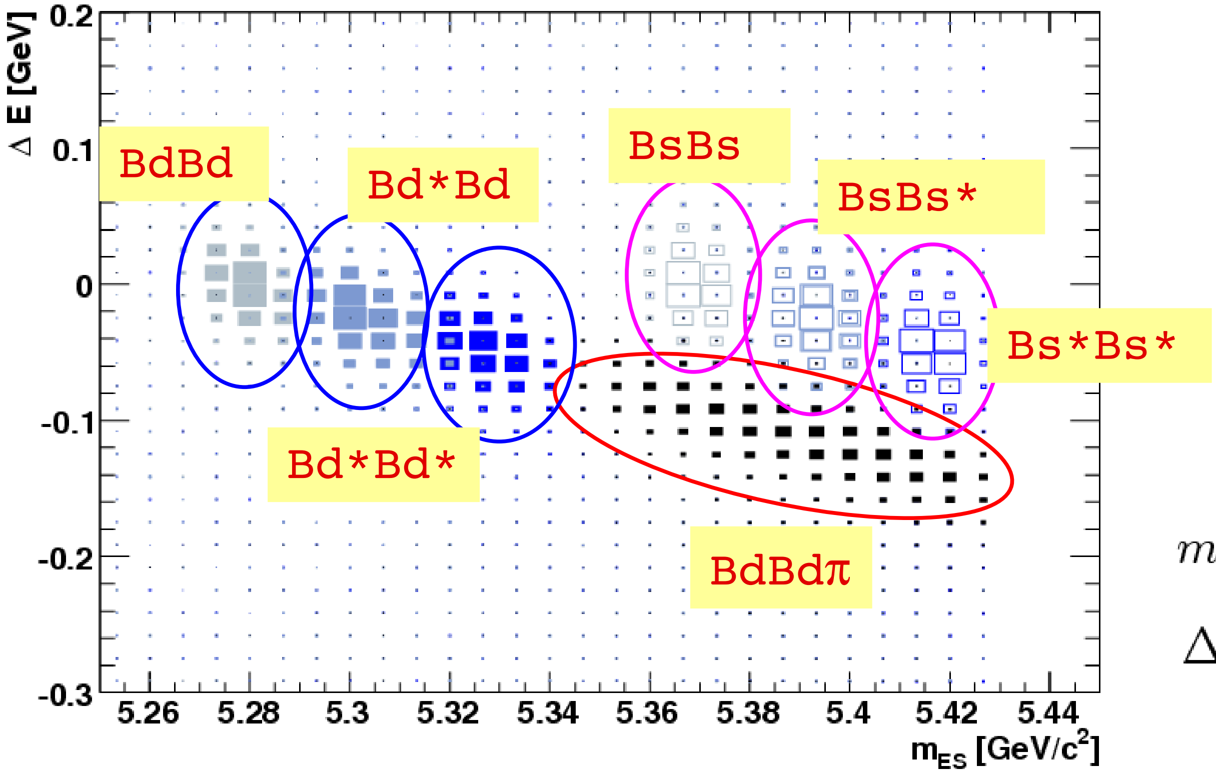
$B_s^{0*} B_s^{0*}$
(~ 94%)

For a given luminosity (w/o the BB cont.):
~ 17% of $B_{d,u}$ w.r.t. the $\Upsilon(4S)$;
~ 16% of B_s w.r.t. the number of B_d at the $\Upsilon(4S)$;

References: CLEO (hep-ex/0607080) & Belle (hep-ex/0605110)

Event reconstruction

- Reconstruction techniques inherited from current B-*factories*:
  - We don't reconstruct the additional particles (π, γ) produced in the $\Upsilon(5S)$ decay chain;
  - separation of different components using kinematic variables.



- Good separation between Bd and Bs in mES (next slide)
- BBπ discriminated by the (continuum like) mES shape

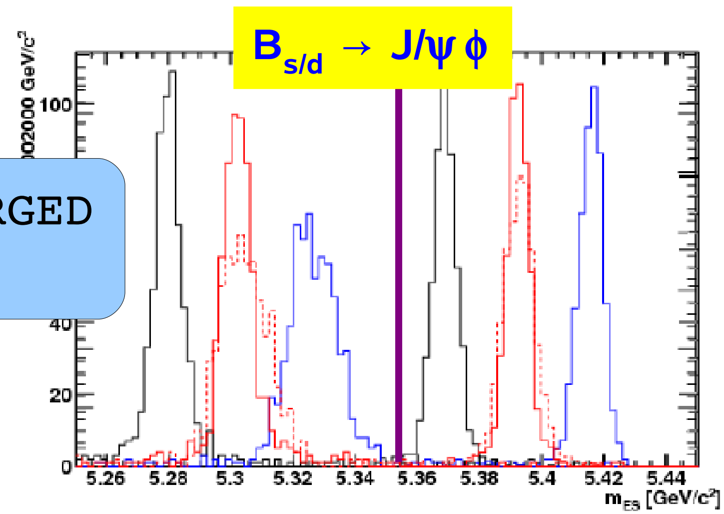
$$m_{\rm ES} = \sqrt{(s/2 + {\rm p}_i \cdot {\rm p}_B)^2/E_i^2 + p_B^2}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

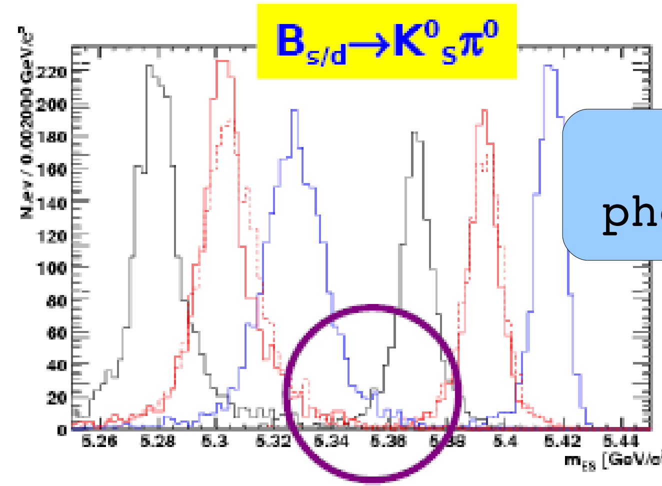
Event reconstruction

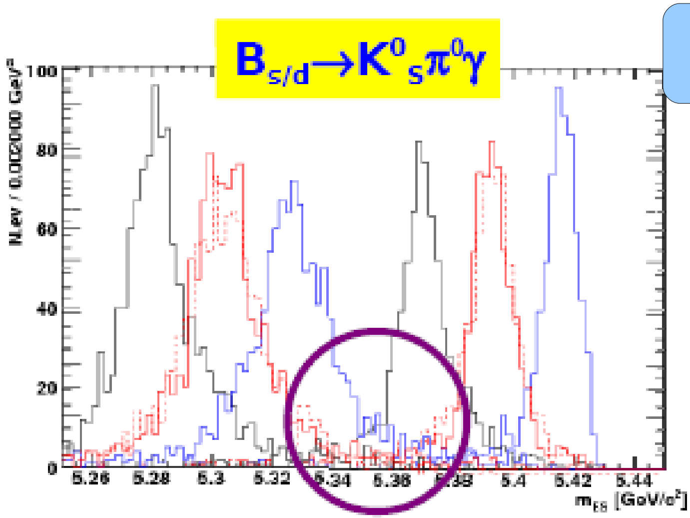
3 SCENARIOS...

ALL CHARGED TRACS



2 photons

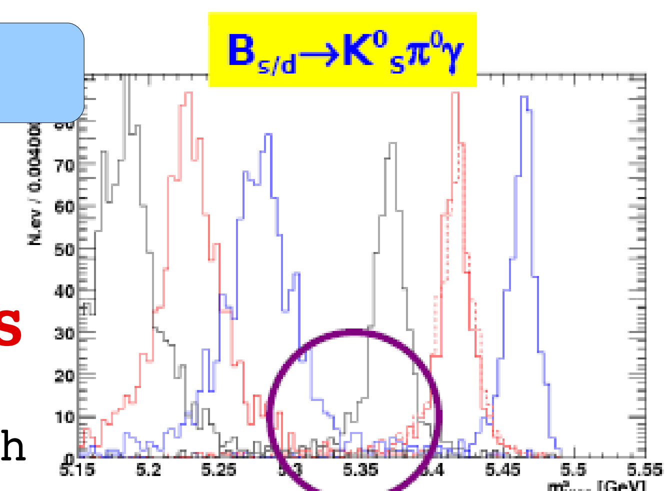




3 photons

from mES to mMISS

(the mass of the other B obtained with a mass constraint)



CP Asymmetries at the Υ(5S) resonance

B pairs coherence

- B pairs at the $\Upsilon(5S)$ mainly produced in association with photons;
- What about the coherence of the B pairs?
- It can be shown that:

In the $B_{s,d}{}^*B_{s,d}{}^*$ case and in the $B_{s,d}B_{s,d}$ case the final pair is in an antisymmetric state → the time evolution of the B pair is the same than at the (4S);

B_d TD analyses still possible

$B_{s,d}{}^*B_{s,d}$ the state is symmetric → different time evolution;

New $B_{s,d}$ Time Integrated measurement

Time Integrated Analysis

NEW

- BB pairs from B*B events have CP = + ;
- Different time dependence w.r.t. BB pairs at a $\Upsilon(4S)$ B-factory (at a given time both B have the same flavour);
- The integrated asymmetry between B → f and $\bar{B}$ → f for a CP eigenstate *f* is:

$$A_{CP}^{f} = \left(\frac{1-y^2}{1+x^2}\right)^2 \frac{(1-x^2)(1-|\lambda_{CP}^{f}|^2)+4x\mathcal{I}m(\lambda_{CP}^{f})}{(1+y^2)(1+|\lambda_{CP}^{f}|^2)-4y\mathcal{R}e(\lambda_{CP}^{f})}$$

$$\lambda_{CP}^{f} = \frac{q}{p}\frac{\bar{A}_f}{A_f}$$

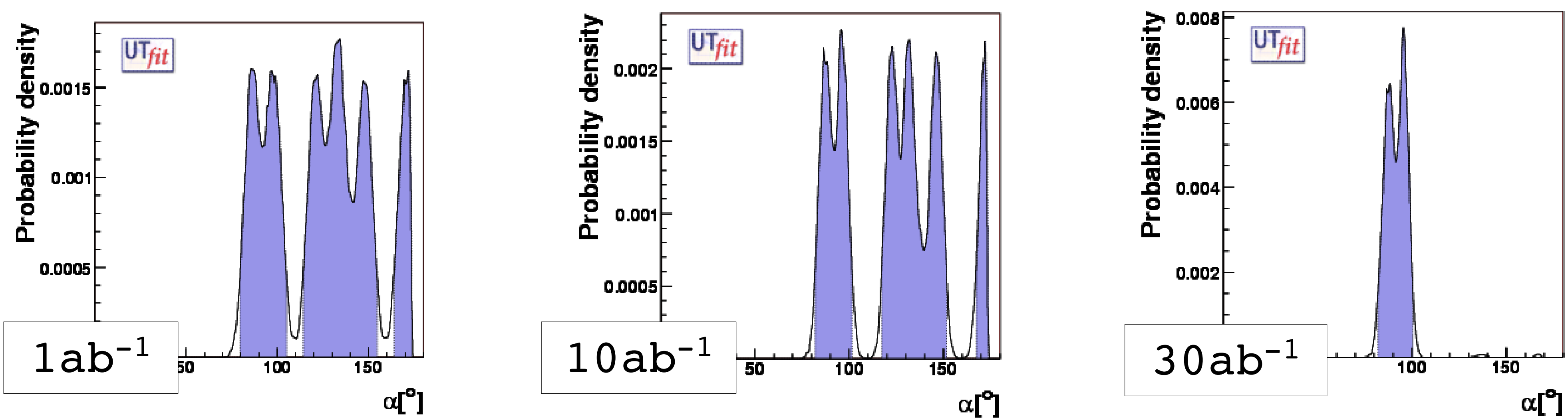
$$x = \Delta m/\Gamma,\ y = \Delta\Gamma/2\Gamma$$

- New perspectives for both B_d and B_s, in these channels for which TD analyses are not enough sensitive to determine both Re(λ) and Im(λ) (e.g. neutral channels).
- EXAMPLE: impact on the α measurement with $B_d \rightarrow \pi^0\pi^0$

Time Integrated Analysis

NEW

- $B_d \rightarrow \pi^0\pi^0$:
  - Rate and asimmetry used to determine α through an isospin analysis ⟶ ambiguity;
  - TD analysis at the $\Upsilon(4S)$ not enough sensitive to extract both Re(λ) and Im(λ) (or equivalently S and C);
  - Time Integrated Analysis at the $\Upsilon(5S)$ allow to constraint Im(λ) and reduce the amiguity.



Accessing the B_s mixing phase

Using the Δt sign

NEW

- Δt distribution for Bs*Bs* events, with one B into a CP eigenstate and the other one into a tagging state:

$$P(\Delta t) \propto e^{\frac{-|\Delta t|}{\tau}} \left[\kappa_1 \cosh\left(\frac{\Delta\Gamma_s \Delta t}{2}\right) + \kappa_2 \cos(\Delta m_s \Delta t) + \kappa_3 \sinh\left(\frac{\Delta\Gamma_s \Delta t}{2}\right) + \kappa_4 \sin(\Delta m_s \Delta t) \right]$$

sine and hyp. sine terms give a $\Delta t > 0$ vs. $\Delta t < 0$ asymmetry

$$\kappa_1 = \frac{1}{2}(1 + |\lambda^f_{CP}|^2) \qquad \kappa_2 = -q_{tag}\frac{1}{2}(1 - |\lambda^f_{CP}|^2)$$

$$\kappa_3 = -\mathcal{R}e\lambda^f_{CP} \qquad \kappa_4 = -q_{tag}\mathcal{I}m\lambda^f_{CP}.$$

$$N_{\Delta t>0,q_{\rm tag}}(\mathcal{R}e\lambda, \mathcal{I}m\lambda) = N_{\rm tot}\int_0^{\infty} P(\Delta t, q_{\rm tag}) \otimes R(\Delta t) d(\Delta t)$$

$$N_{\Delta t<0,q_{\rm tag}}(\mathcal{R}e\lambda, \mathcal{I}m\lambda) = N_{\rm tot}\int_{-\infty}^{0} P(\Delta t, q_{\rm tag}) \otimes R(\Delta t) d(\Delta t)$$

resolution function

Use with the measured yields to set a constraint on Re(λ) and Im(λ)

Using the Δt sign

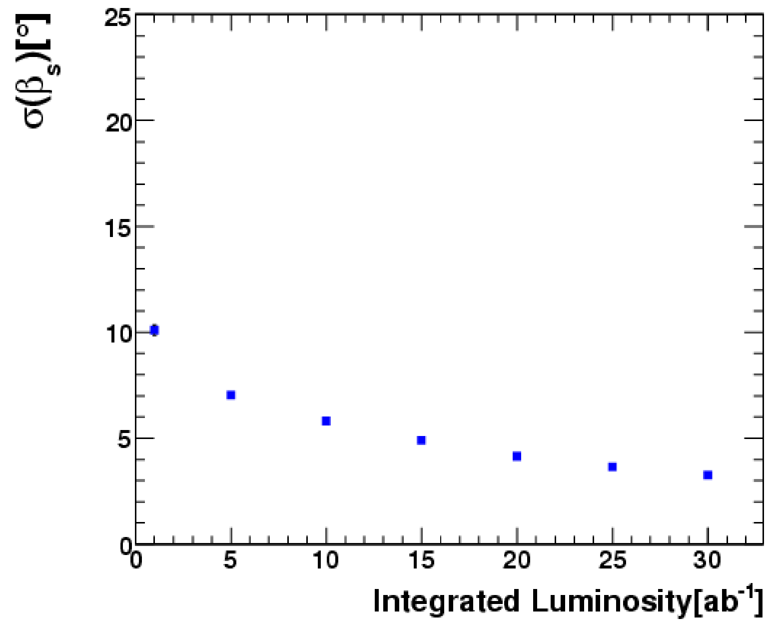
NEW

THE SIMULATION

- Full detector simulation (with BaBar performances) to determine signal and background shapes of the discriminating variables ΔE, m_{ES};
- BaBar efficiencies, Δt resolution & tagging;
- Toy MC experiments to extract the sensitivity on Re(λ) and Im(λ).

TEST

- β_s from $B_s \to J/\psi\,\phi$ (assuming only one polarization and $|\lambda| = 1$):



Using the Δt sign

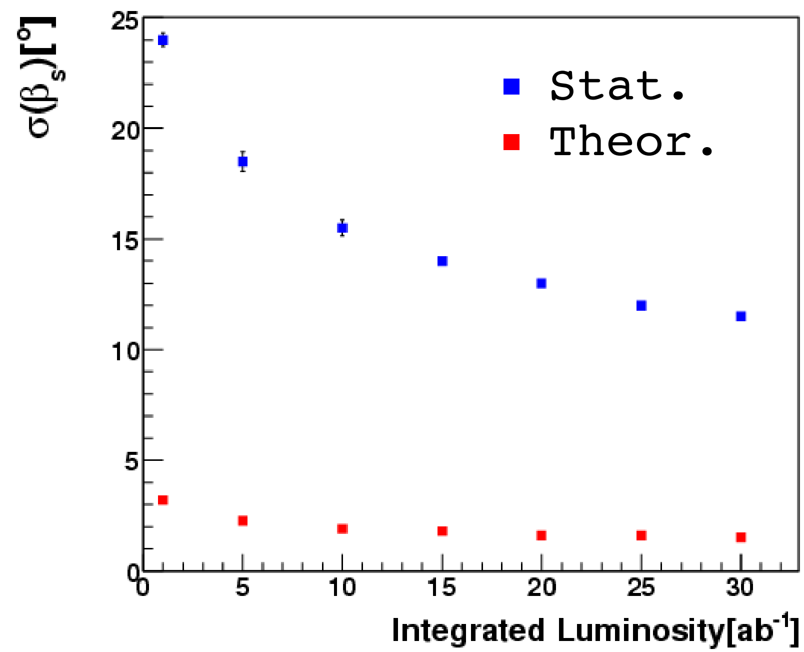
NEW

β_s from penguin modes

- The same technique can be applied to extract β_s from penguin modes (e.g. $B_s \to K^0K^0$, penguin dominated as $B_d \to \phi K_S^0$);

$$\mathcal{A}(B_s \to K^0 \bar{K}^0) = - V_{us}V_{ub}^* P_s^{\mathrm{GIM}} - V_{ts}V_{tb}^* P_s$$

- The theory error induced by P^{gim} can be estimated (hep-ph/0703137):
  - Evaluate P_d^{GIM} contributions in $B_d \to K^0K^0$;
  - Estimate the maximum P_s^{GIM} value from a 100% interval around P_d^{GIM} (to take into account SU(3) breaking);
  - Use this maximum value to estimate the theoretical uncertainty.



Semileptonic Asymmetry

$$A_{\mathrm{SL}} \equiv \frac{\Gamma(\overline{B^0}\to l^+X)-\Gamma(\overline{B^0}\to l^-X)}{\Gamma(\overline{B^0}\to l^+X)-\Gamma(\overline{B^0}\to l^-X)} =$$

$$= -\mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\mathrm{SM}} \frac{\sin(2\phi_{\mathrm{Bd}})}{C_{\mathrm{Bd}}} + \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\mathrm{SM}} \frac{\cos(2\phi_{\mathrm{Bd}})}{C_{\mathrm{Bd}}}$$

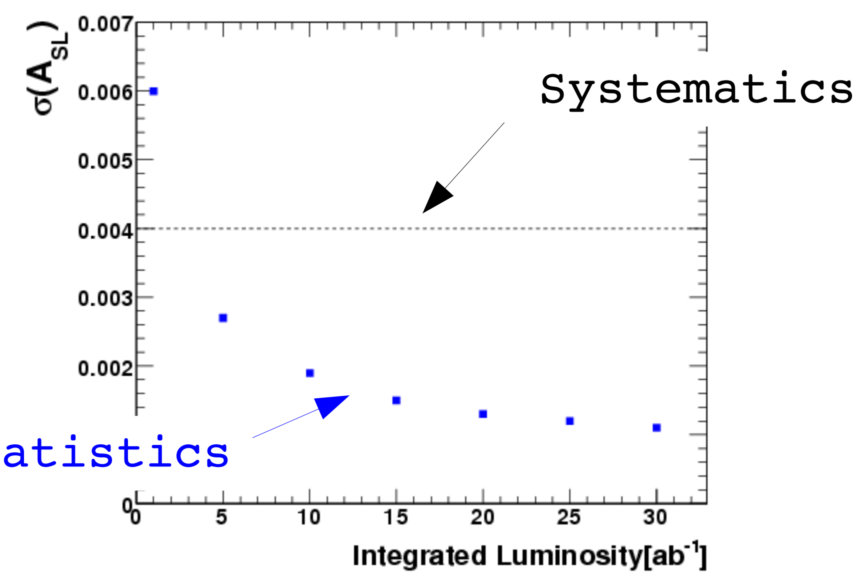
- B_d sector:
  - Current experimental sensitivity cannot bound CKM in the SM;
  - Bounds on NP parameter space;
- $B_d - B_s$ admixture:
  - measurements from D0 (dimuons charge asymm.);
  - A_{CH} sensitive to NP effects;
  - Experimental precision at Tevatron is not expected to improve

Semileptonic Asymmetry

Super-B @ $\Upsilon(5S)$ can access A_{CH} and eventually $A^{s,d}_{SL}$ if Bd/Bs separation is possible

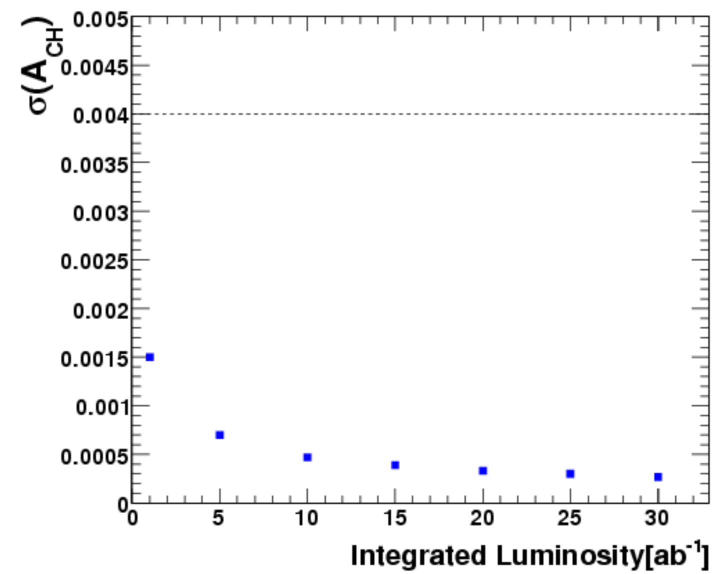
D(*) l ν

- Counting $Ds(*)^{+}l^{-}\nu$ and $Ds(*)^{-}l^{+}\nu$ events against a semileptonic or hadronic tag;



DILEPTONS

- Counting dilepton pairs;
- Possibility to access A_{CH};



Lifetime Difference $\Delta\Gamma$

LIFETIME DIFFERENCE $\Delta\Gamma_s = \Gamma_L - \Gamma_H$

$$\frac{\Delta\Gamma_q}{\Delta m_q} = -2\frac{\kappa}{C_{B_q}}\left\{\cos(2\phi_{B_q})\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{\cos(\phi_q^{\rm SM} + 2\phi_{B_q})}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) + \frac{\cos(2(\phi_q^{\rm SM} + \phi_{B_q}))}{R_t^{q^2}}\right.$$
$$\left.\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + \cos(\phi_q^{\rm Pen} + 2\phi_{B_q})\, C_q^{\rm Pen}\left(n_4 + n_9\frac{B_2}{B_1}\right) - \cos(\phi_q^{\rm SM} + \phi_q^{\rm Pen} + 2\phi_{B_q})\frac{C_q^{\rm Pen}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

- Sensitive to NP phase;
- Several experimental methods suggested...

Dighe et al. hep-ph/9511363

Grossman hep-ph/9603244

Dighe et al. hep-ph/9804253

Dunietz et al. hep-ph/0012219

$\phi = 2\beta_s$

...to access $\Delta\Gamma_s$, $\Delta\Gamma_s\cos(\phi)$, $\Delta\Gamma_s\cos^2(\phi)$, all available @ $\Upsilon(5S)$ (we investigated the theoretically cleanest).

Lifetime Difference $\Delta\Gamma$

- We considered the method that use the *Angular Distribution in $B_s \to J/\psi\phi$ decays* (hep-ph/9804253):

IN THE STANDARD MODEL....

$$\frac{d\Gamma(B \to f_{CP-odd})}{dt} \propto e^{-\Gamma_L t}$$

$$\frac{d\Gamma(B \to f_{CP-even})}{dt} \propto e^{-\Gamma_H t}$$

+ angular analysis to disentangle $(J/\psi\phi)_{odd}$ and $(J/\psi\phi)_{even}$

WITH A NP PHASE...

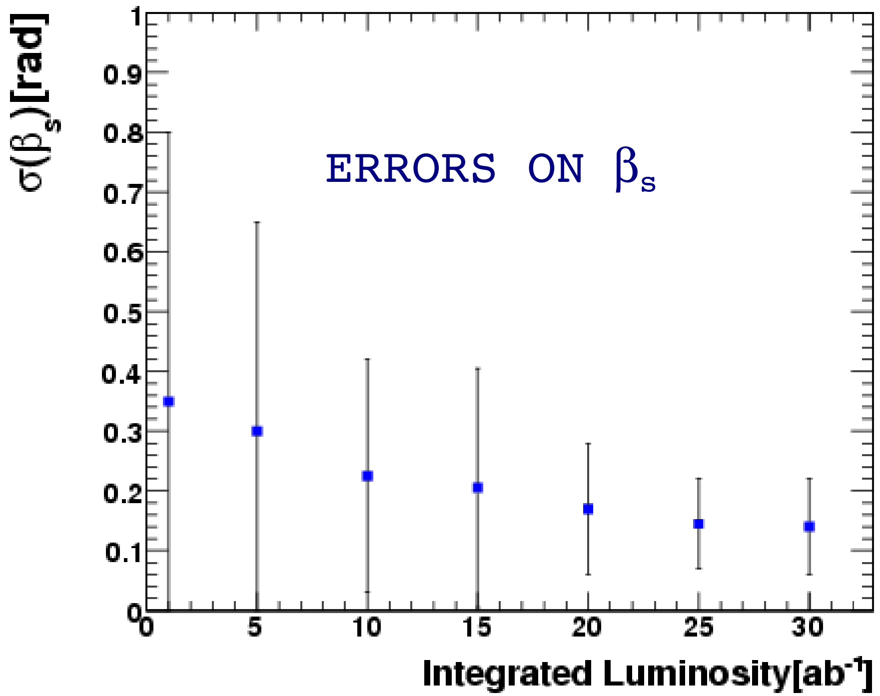
$$\frac{d^4\mathcal{P}(\vec{\rho},t)}{d\vec{\rho}\,dt} = [\ldots.\sin(\phi_{CKM})]e^{-\Gamma_L t} + [\ldots.\sin(\phi_{CKM})]e^{-\Gamma_H t}$$

...where ϕ_{CKM} is the CP violating weak phase ($\phi_{CKM} = 2\beta_s = 2(\beta_s^{SM} + \phi_{Bs})$)

SM + NP

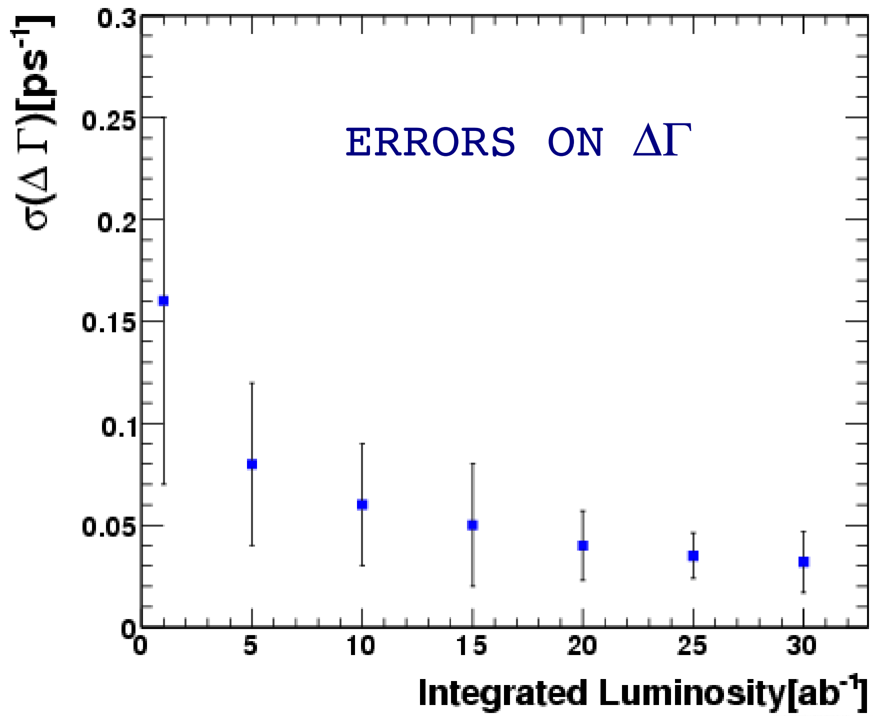
Lifetime Difference $\Delta\Gamma$

RESULTS



Error bars: RMS of the error distribution

CAVEAT: problems with correlations between ϕ and $\Delta\Gamma$ already experienced by D0.



Rare B_s decays

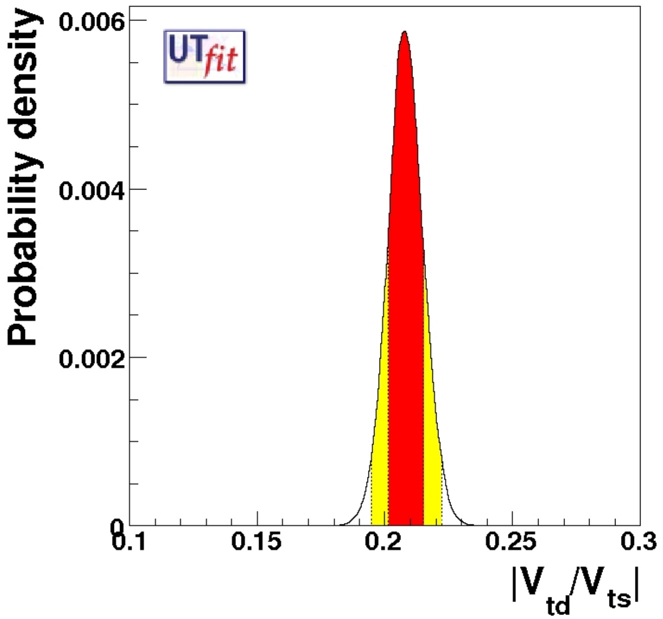
V_{td}/V_{ts}

$|V_{td}/V_{ts}|$ measurement

- Sensitive to NP;
- Clean determination from UT fit via:

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d} \hat{B}_{B_d}}{m_{B_s} f_{B_s} \hat{B}_{B_s}} \frac{|V_{td}|^2}{|V_{ts}|^2}$$

- Additional constraint could come from radiative decays:



Υ(4S)

$$\frac{\mathcal{BR}(B^0 \to \rho^0\gamma)}{\mathcal{BR}(B^0 \to K^*\gamma)} = \frac{|V_{td}|}{|V_{ts}|}\frac{1}{\xi^2}(1+???)$$

SU(3) breaking

theo. uncertainty on additional contribution

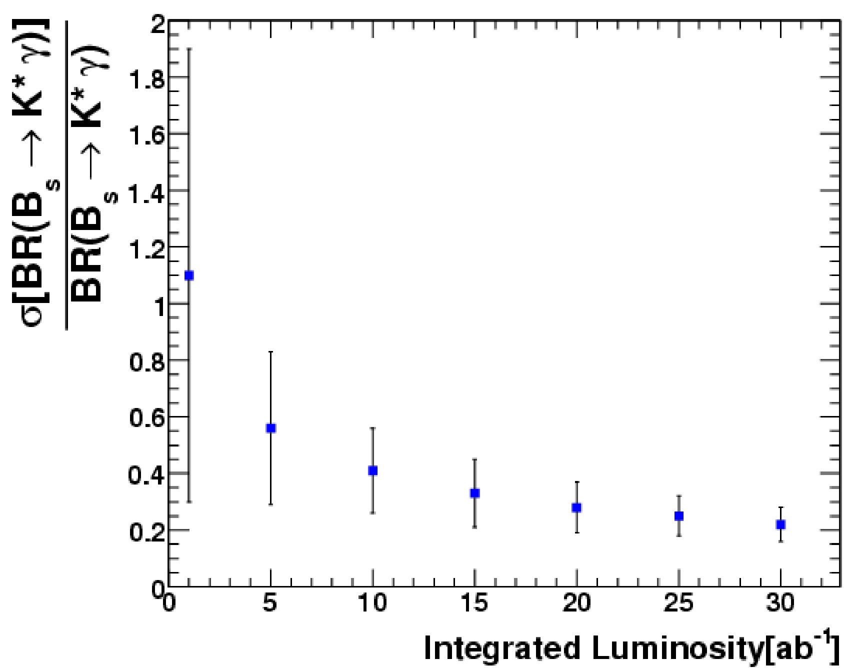
Υ(5S)

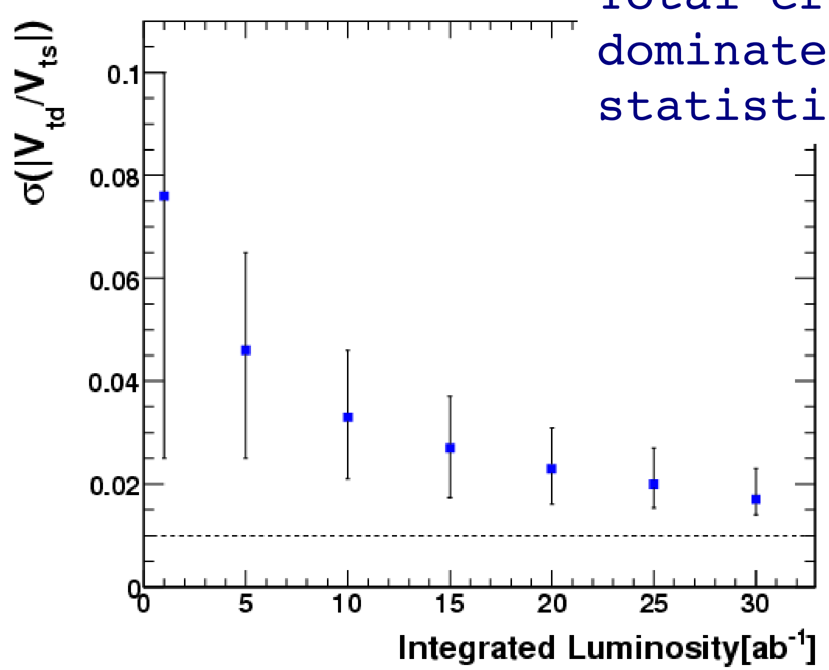
$$\frac{\mathcal{BR}(B_d^0 \to K^{*0}\gamma)}{\mathcal{BR}(B_s^0 \to K^{*0}\gamma)} = \frac{|V_{td}|}{|V_{ts}|}\frac{1}{\xi^2}$$

No theo. uncertainties from additional contributions

V_{td}/V_{ts}

$$\frac{\mathcal{BR}(B_d^0 \to K^{*0}\gamma)}{\mathcal{BR}(B_s^0 \to K^{*0}\gamma)} = \frac{|V_{td}|}{|V_{ts}|}\frac{1}{\xi^2}$$





Total error dominated by statistics

$B_s \to \mu\mu$

$B_s \to \mu\mu$ and MFV

- $B_s \to \mu\mu$ is one of the most promising decay to look for NP effects in a MFV scenario:

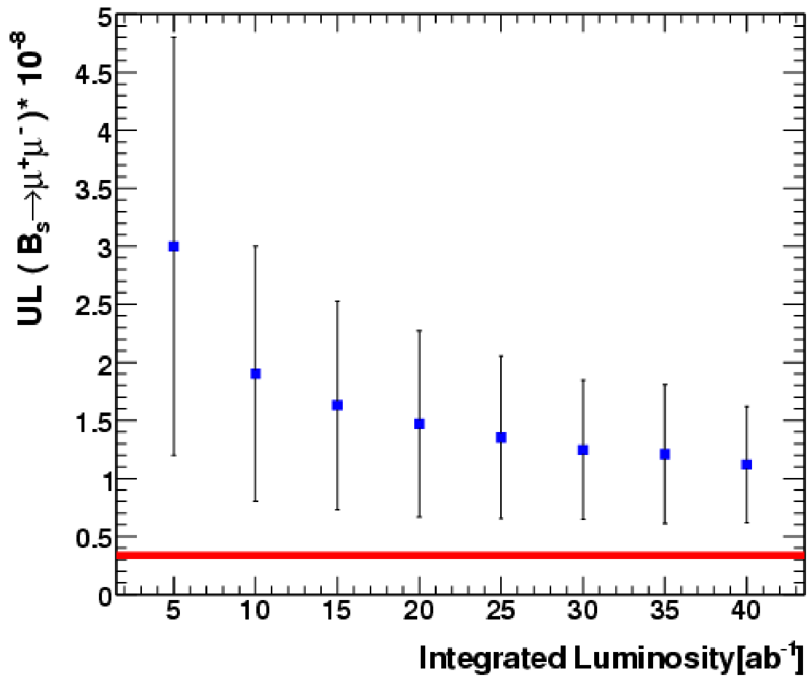
$$\mathcal{B}(B_s \to \mu^+\mu^-)\Big|_{\rm MSSM} \approx 3\times 10^{-6}\frac{r^6}{\left(\frac{2}{3}+\frac{1}{3}r\right)^4}\left(\frac{200\ \text{GeV}}{M_A}\right)^4\left(\frac{\mu A f(x_{\mu L}, x_{RL})}{M^2_{\tilde{t}_L}}\right)^2 \quad (r=\tan\beta/50.)$$

- Deviations of the BR from the SM (~ $3.5 \cdot 10^{-9}$) are possible in a MFV scenario, but a strong enhancement is already ruled out by $b \to s\gamma$ and $b \to sll$ measurements;
  - An observation of the BR above the SM value will rule out SM & MFV
  - An observation of the BR below the SM prediction will strongly confirm MFV

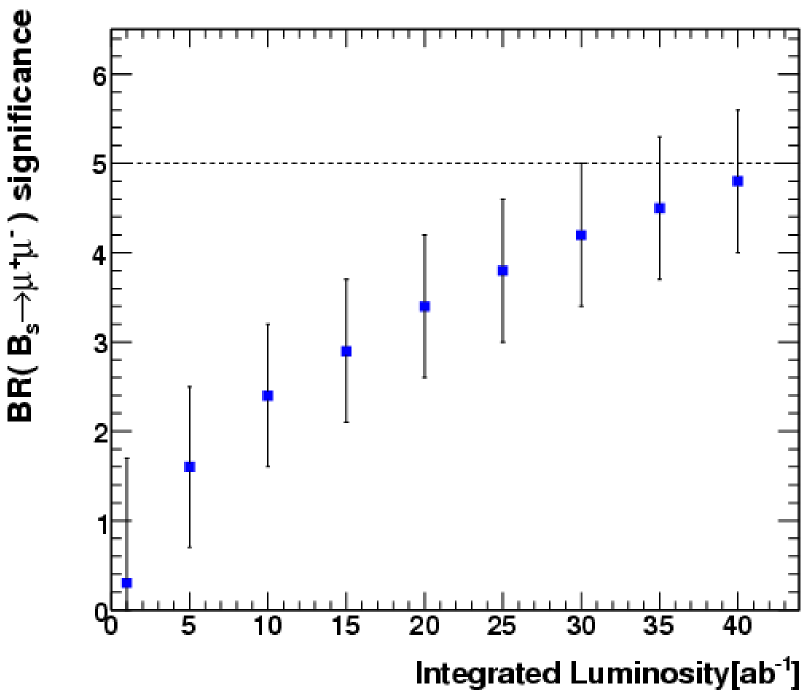
$B_s \to \mu\mu$

- This is the worst case w.r.t. hadronic machines;
- Simulation with SM BR ~ $3.4*10^{-9}$ and NP (BR = 10*SM) ;

SM BR (only an UL)



NP BR (10 * SM)



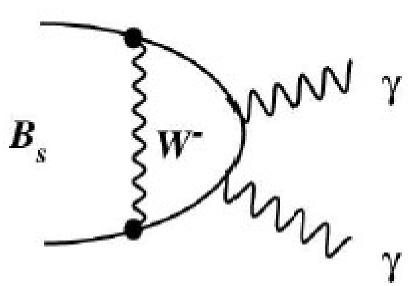
$B_s \to \gamma\gamma$

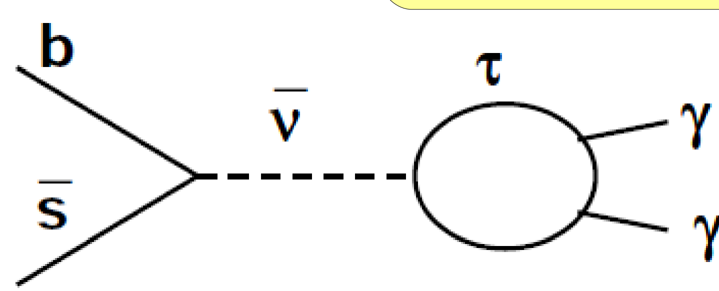
- Important probe for NP:
  - Branching ratio SM expectation = $(0.5 - 1.0)*10^{-6}$;
  - NP can enhance the BR up to two orders of magnitude;
  - Bounds on several models, golden mode in a couple of scenarios.

e.g. R-Parity violating SUSY

up to 1 order of magnitude of enhancement

SM + **NP**

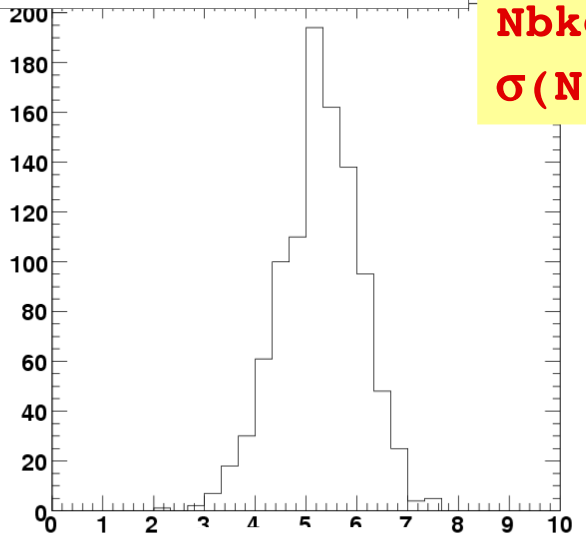




$B_s \to \gamma\gamma$

Results @ 1 ab^{-1}

N_{sig} = 14
N_{bkg} = 20
$\sigma(N_{sig})$ ~ 5

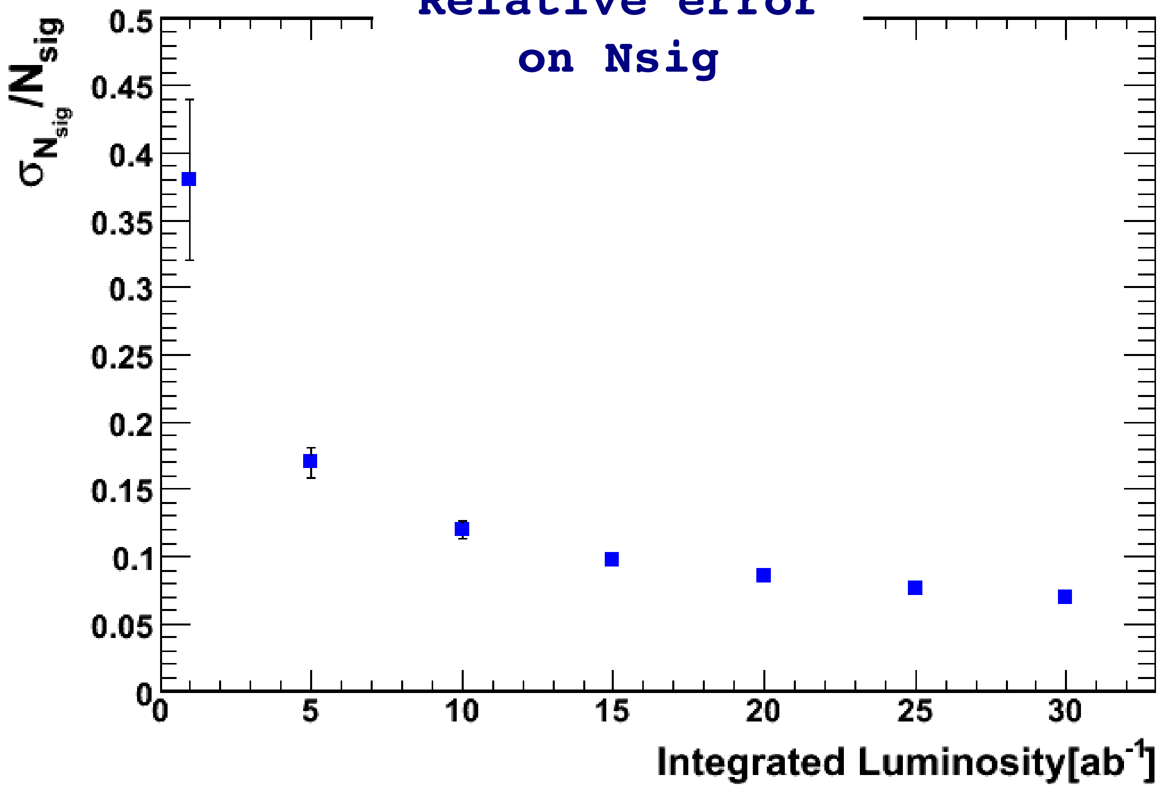


σ(Nsig)

First evidence at low statistics

7% in 30ab^{-1}

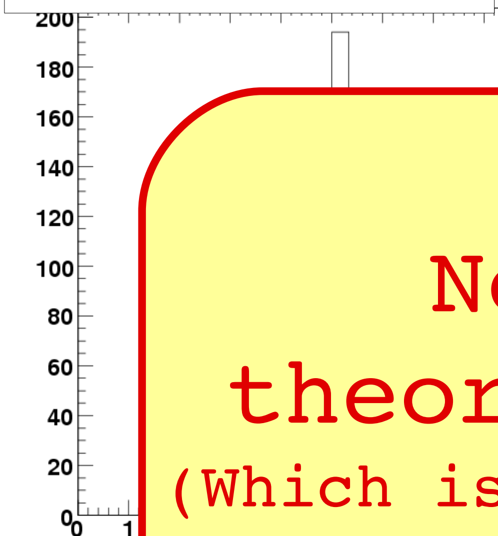
Relative error on Nsig



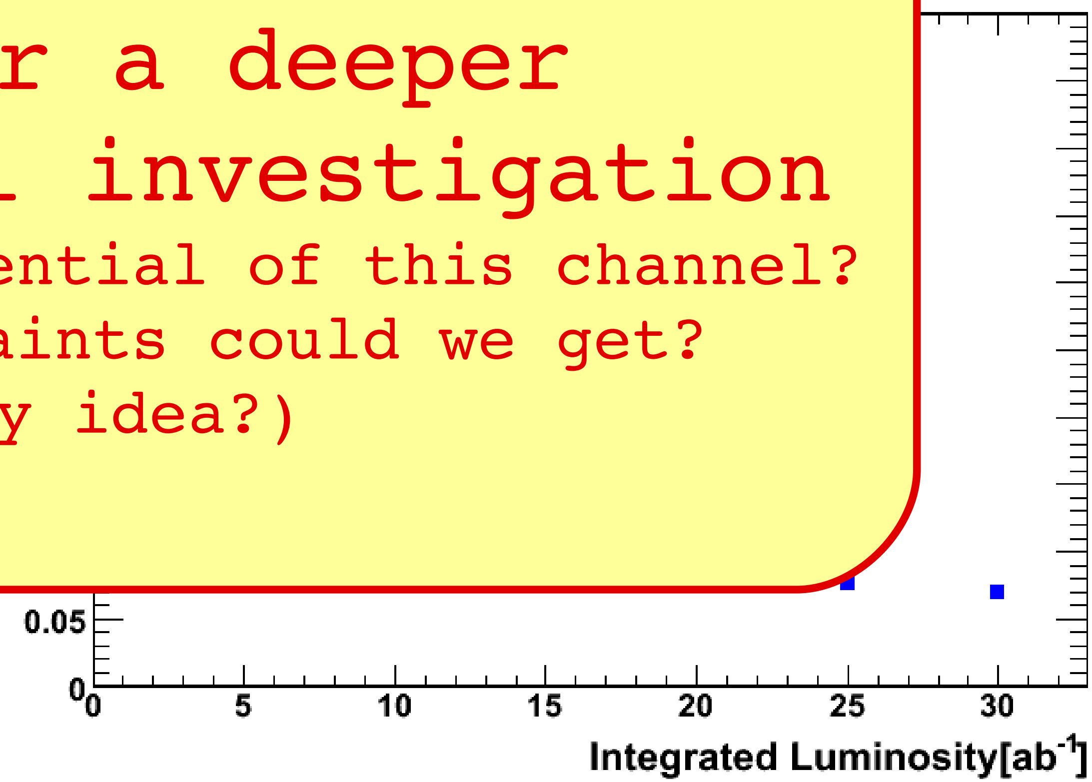
$B_s \to \gamma\gamma$

Results @ 1 ab^{-1}

Nsig = 14
Nbkg = 20



7% in $30ab^{-1}$



Need for a deeper theoretical investigation

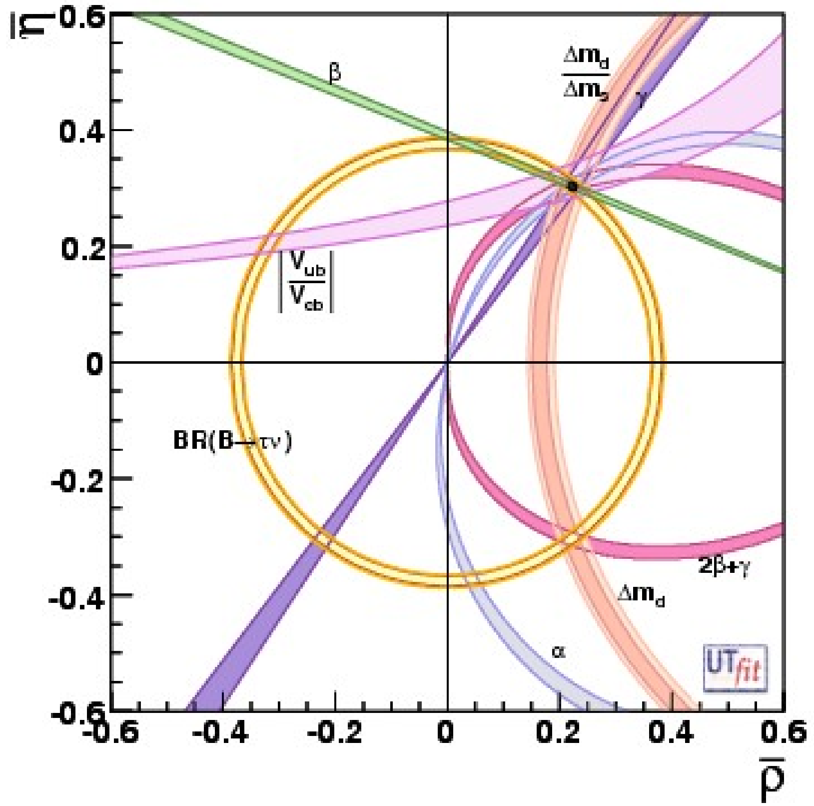
(Which is the potential of this channel?
Which constraints could we get?
Any idea?)

First evidence at low statistics

Impact on Flavour Physics

UT in the SM

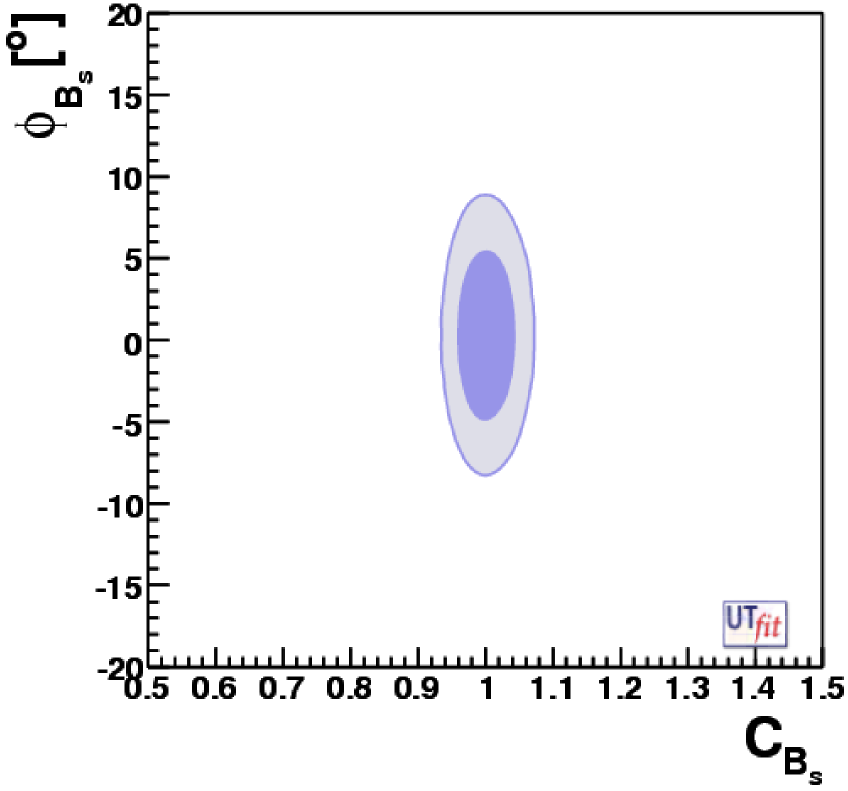
ASSUMING $75ab^{-1}$ at the $\Upsilon(4S)$ and $30ab^{-1}$ at the $\Upsilon(5S)$



$\delta\rho = 2.3\%$
$\delta\eta = 1.8\%$

UT beyond the SM

ASSUMING $75ab^{-1}$ at the $\Upsilon(4S)$ and $30ab^{-1}$ at the $\Upsilon(5S)$



$\delta\phi = 1.9°$

$\delta C = 0.026$

Conclusions

- The physics case of a SuperB factory running also at the $\Upsilon(5S)$ resonance has been investigated (see also *hep-ph/0703258*);
- Different final states with BB + photons can be produced:
  - Experimental issue: disentangle the different states → can be easily done with the usual kinematical variables;
  - Time Integrated Asymmetry using B*B events;
- B_s mixing phase can be accessed also without Time Dependent Analyses → Δt sign analysis, angular $J/\psi\phi$ analysis,...;
- Additional and independent constraints on CKM parameters can be added → Vtd/Vts,...;
- Rare B_s decays can be investigated;

We showed that an additional $\Upsilon(5S)$ run can complete the results of the main $\Upsilon(4S)$ run to improve the knowledge on CKM Matrix and look for Physics Beyond the SM.

Investigating The Physics Case of Running a B-Factory at the $\Upsilon(5S)$ Resonance

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Backup slides

Time Dependent analyses

γ from Time Dependent analysis

- TD analysis can provide additional determinations of CKM parameters;
- In the B_s sector, at a B-factory, this kind of analysis is usually affected by smaller theoretical uncertainties w.r.t. B_d sector or hadronic machines;
- The most promising case: $B_s \to K^+K^-$ & $B_s \to K^0\overline{K^0}$

In the RGI formalism:

$$\mathcal{A}(B_s \to K^0\bar{K}^0) = - V_{us}V_{ub}^* P^{\mathrm{GIM}} - V_{ts}V_{tb}^* P$$
$$\mathcal{A}(B_s \to K^+K^-) = - V_{us}V_{ub}^* \left(E_1 + A_2 - P^{\mathrm{GIM}}\right) + V_{ts}V_{tb}^* P$$

6 exp. measurements (BR, S and C for each decay)

7 unknown quant. (γ + 3 compl. P^{GIM}, P, E1+A2) - 1 arbitrary phase

FIT FOR γ

What about LHC?

Bs → μμ (Super-B: Nsig = 2.5, Nbkg = 3500)

	1 year	$B_s \to \mu^+\mu^-$ signal (SM)	b→μ, b→μ background	Inclusive bb background	Other backgrounds
LHCb	2 fb^{-1}	30	< 100	< 7500	
ATLAS	10 fb^{-1}	7	< 20		
CMS (1999)	10 fb^{-1}	7	< 1		

Bs → J/ψ ϕ for ΔΓ and sin(ϕ)

Expected sensitivity: (at $\Delta m_s = 20\ ps^{-1}$)

- ✓ LHCb: 125k Bs→J/ψϕ signal events/year
  - → $\sigma_{stat}(\sin\phi_s)$~0.031, $\sigma_{stat}(\Delta\Gamma_s/\Gamma_s)$~ 0.011 /(1year, 2$fb^{-1}$)
  - → $\sigma_{stat}(\sin\phi_s)$~0.013 after first 5 years, adding pure CP modes like J/ψη, J/ψη' (small improvement)
- ✓ ATLAS: similar event rate as LHCb but less sensitive
  - → $\sigma_{stat}(\sin\phi_s)$~0.08 (1year, 10$fb^{-1}$)
- ✓ CMS: > 50k events/year, sensitivity study ongoing

Exploiting Δm_s sensitivity (TD analisys)

What about LHC?

Bs $\to \phi\gamma$

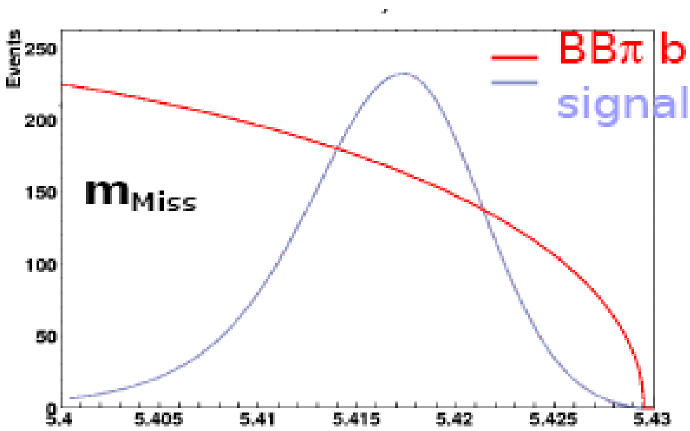
In 1 year LHCb expects triggered and reconstructed:
35k events $B^0 \to K^{0*} (K^+\pi^-) \gamma$; S/B>1.4
9.4k events $B_s \to \phi (K^+K^+) \gamma$; S/B>0.4

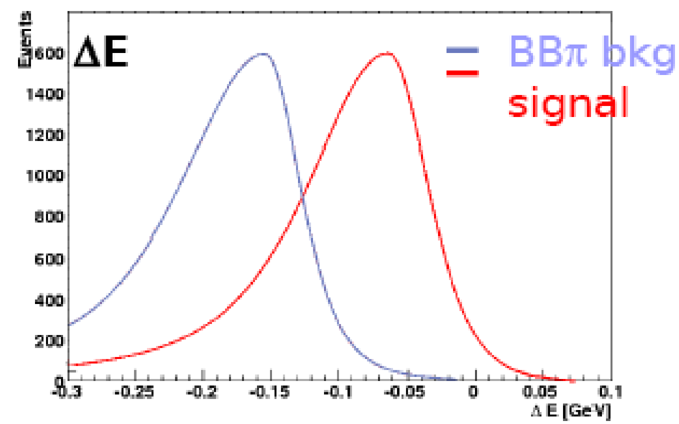
ATLAS expected signal events/year:
$B_d \to K^{*0} \gamma$: ~3.3k ev. ; S/√BG > 5
$B_s \to \phi \gamma$: ~1.1k ev. ;S/√BG > 7

We studied Bs $\to \phi\gamma$ and
found:
7.9k events
and
S/B = 1.9; S/sqrt(B) > 100

Event reconstruction

BBπ vs. BB SEPARATION



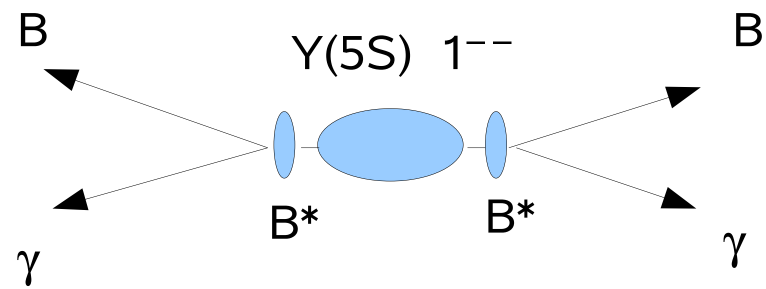


CAVEAT: the BBπ background can be important in final states with an odd number of s quarks (K*γ, Kπ, etc.):

- B_s decays CKM suppressed w.r.t. B_d decays;
- B_s decays (sometimes) suppressed by dynamic (penguins or annihilation vs tree).

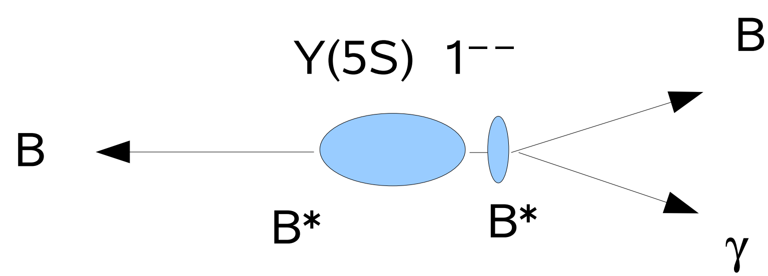
NOTE: Only UL for the BBπ BR – We use the UL (worst case).

BB coherence at the $\Upsilon(5S)$



- $C_{Y(5S)} = -1$;
- $C_{\gamma\gamma} = +1$;

BB in an antisymmetric state, like at the Y(4S)

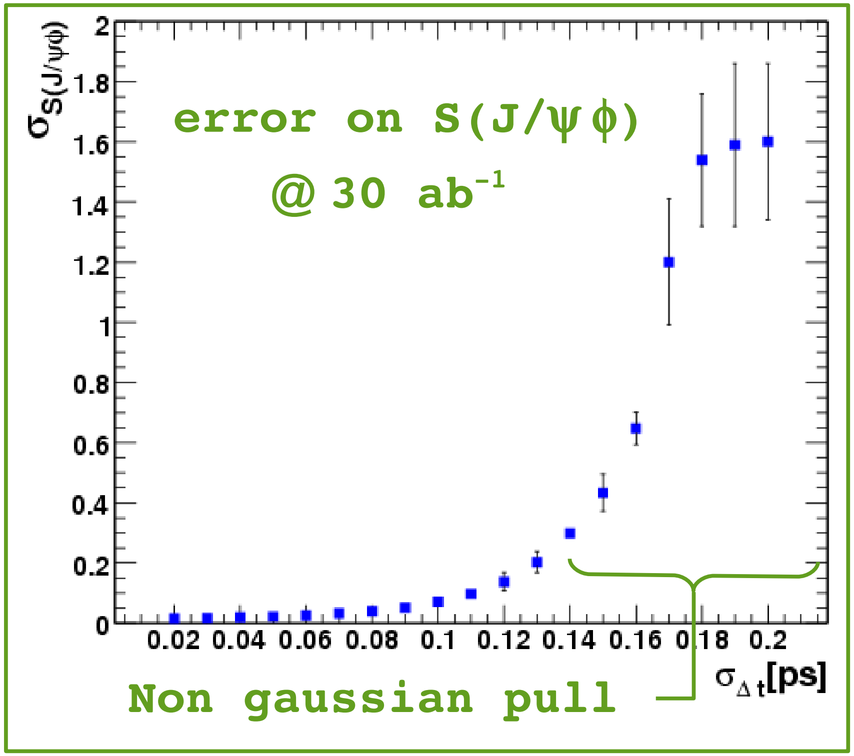


- $C_{Y(5S)} = -1$;
- $C_{\gamma} = -1$;

BB in a symmetric state

Time Dependent analyses

- Main Question: Which Δt resolution do we need to be sensitive to TD-related quantities (S and C)?



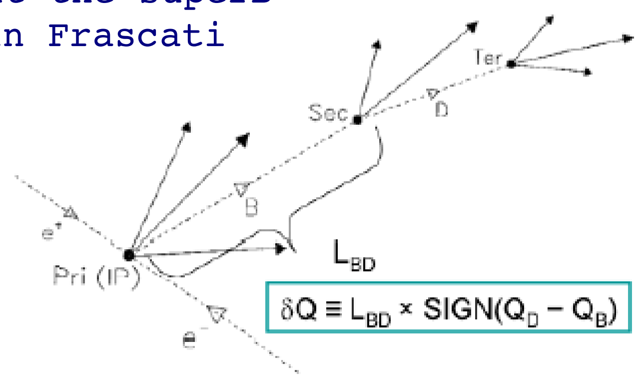
requested Δt resolution ~ 0.1 ps

$B_s \rightarrow \mu\mu$

- ...realistic improvements on the detector performances can turn into important improvements in the rasult.

Just an example: improving vertexing performances in such a way that B and D vertex can be separated on the tag side

N.Neri and M.Pierini
talk given at the superB
workshop in Frascati



N sig = 41 ± 12 (4 σ)
(BR~10SM value)

SM: 90% prob UL of < 2.2 * 10^{-8}

It is not unrealistic to assume that in this way bkg can be reduced by a factor 5