B_s studies at a SuperB: physics case and experimental potentialities

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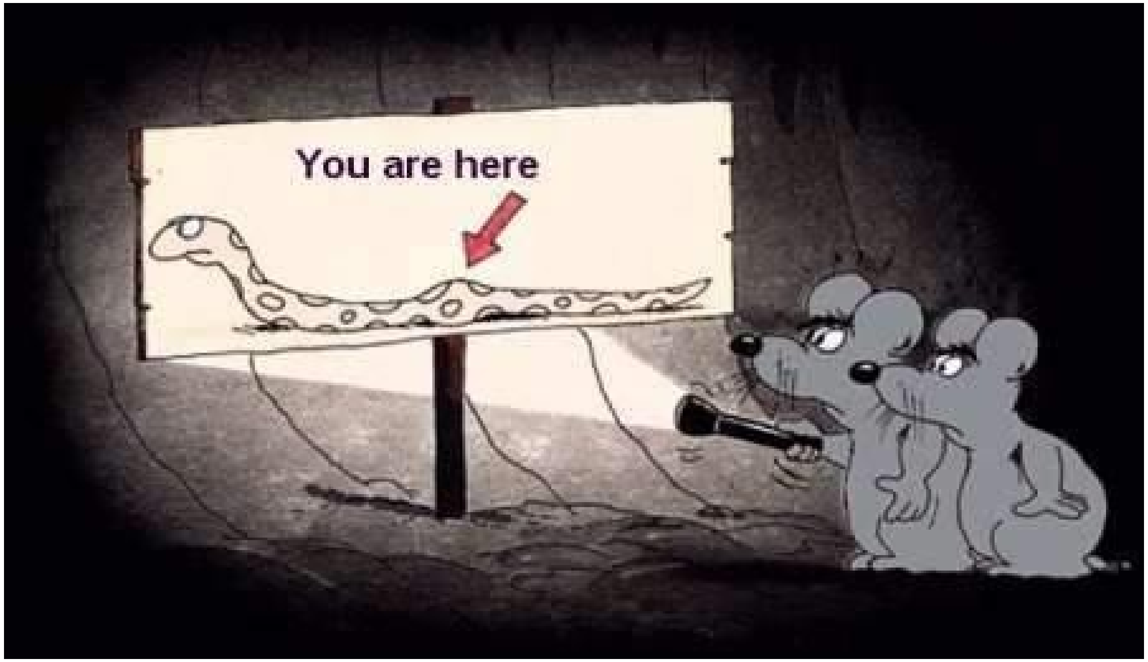
Outline

- Where we stand:
  - The *Unitarity Triangle (UT)* in the *SM picture*;
  - The *UT* and *New Physics (NP)*;
- Experimental Challenges @ $\Upsilon(5S)$;
- Opportunities @ $\Upsilon(5S)$:
  - Analyses: some example;
  - Simulations' results;
- Physics Reach:
  - Impact on the *UT* analysis.

Where we stand

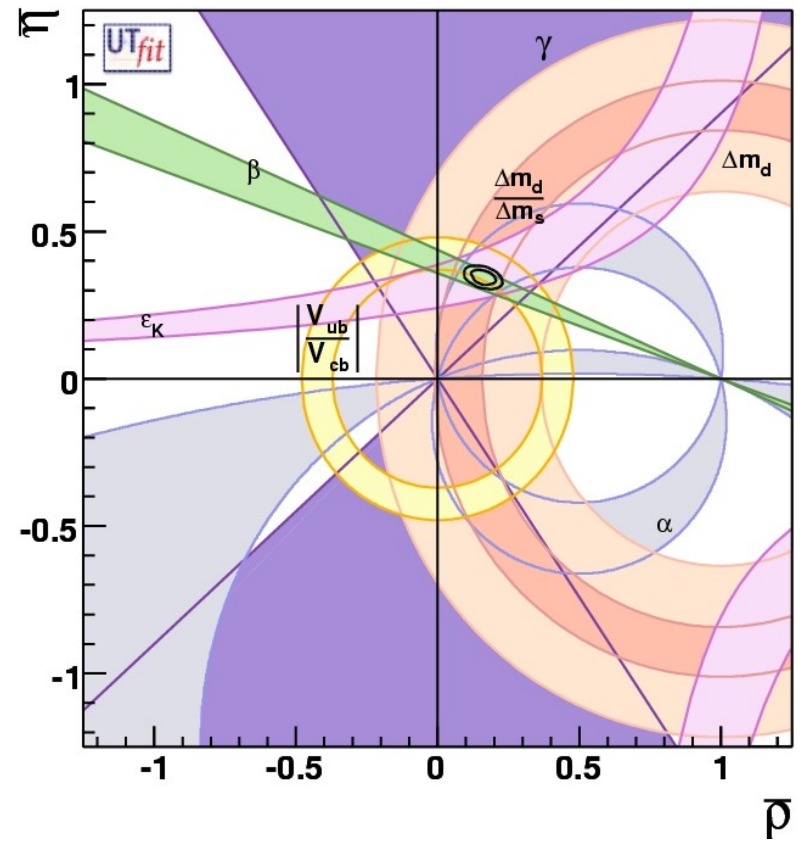


The UT in the SM picture

- 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.

- The LHC era:
  - *UT* precision measurements from LHCb;
  - **Do we really need** for new machines to improve the $\bar{\rho}$ and $\bar{\eta}$ determination?



Main motivation for new machines only to look for NP effects (HOW? WHERE?)

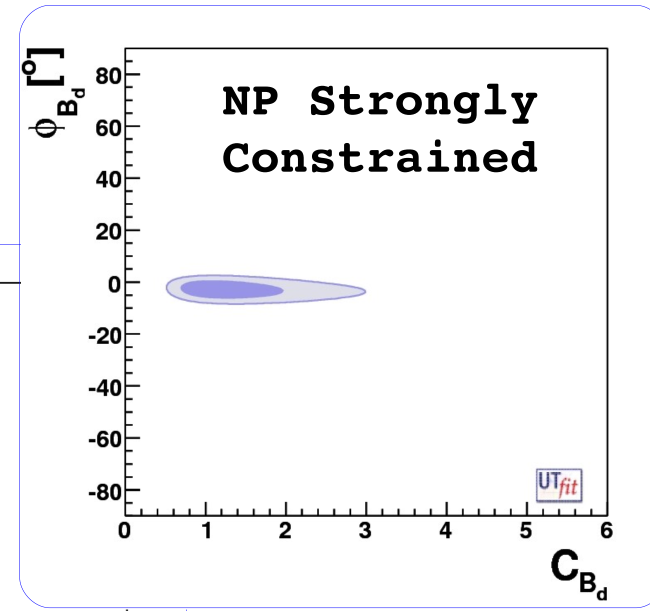
The UT and NP

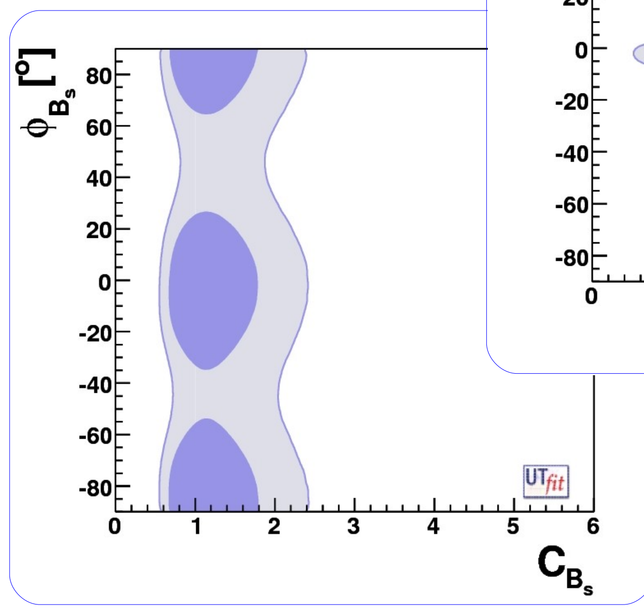
MODEL INDEPENDENT

- 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
$(V_{ub}/V_{cb})^{SM}$, γ^{SM}	***tree level***	$(V_{ub}/V_{cb})^{SM}$, 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 → d & Rare Decays

- Many precision measurement already available.
- Super-B factory can provide a lot of precision measurement:
  - Physics of Flavour – very difficult with hadronic machines!!!

BUT...

- At present:
  - No evidence for NP effects;
  - Strong constraints for NP phases in the b → d sector;
- In this sector the present results strongly favor *Minimal Flavour Violation (MFV)* (see later):
  - mixing process insensitive to NP;

WHERE: b → s

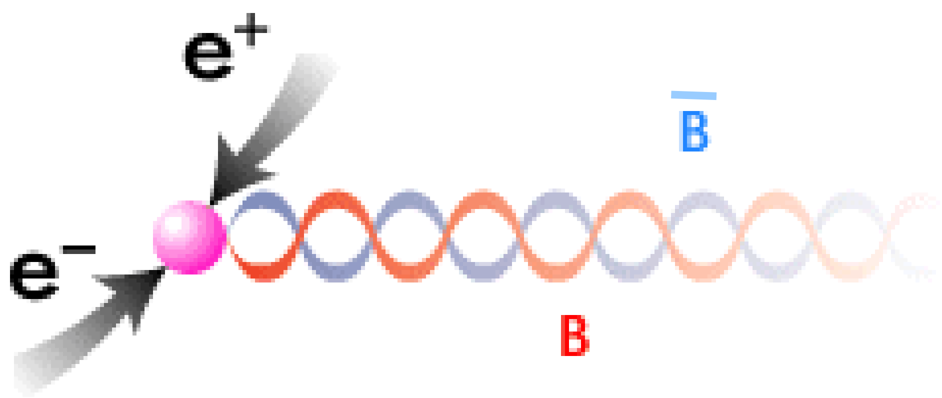
- Large NP effect not yet ruled out in the b → s sector.
- A traditional B-factory (at high statistics) can study:
  - Radiative penguins ($B \to K^*\gamma, \ldots$);
  - CP asymmetries in charmless hadronic B decays.

known experimental techniques and high statistics BUT LARGE THEORETICAL UNCERTAINTIES 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



Υ(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%)

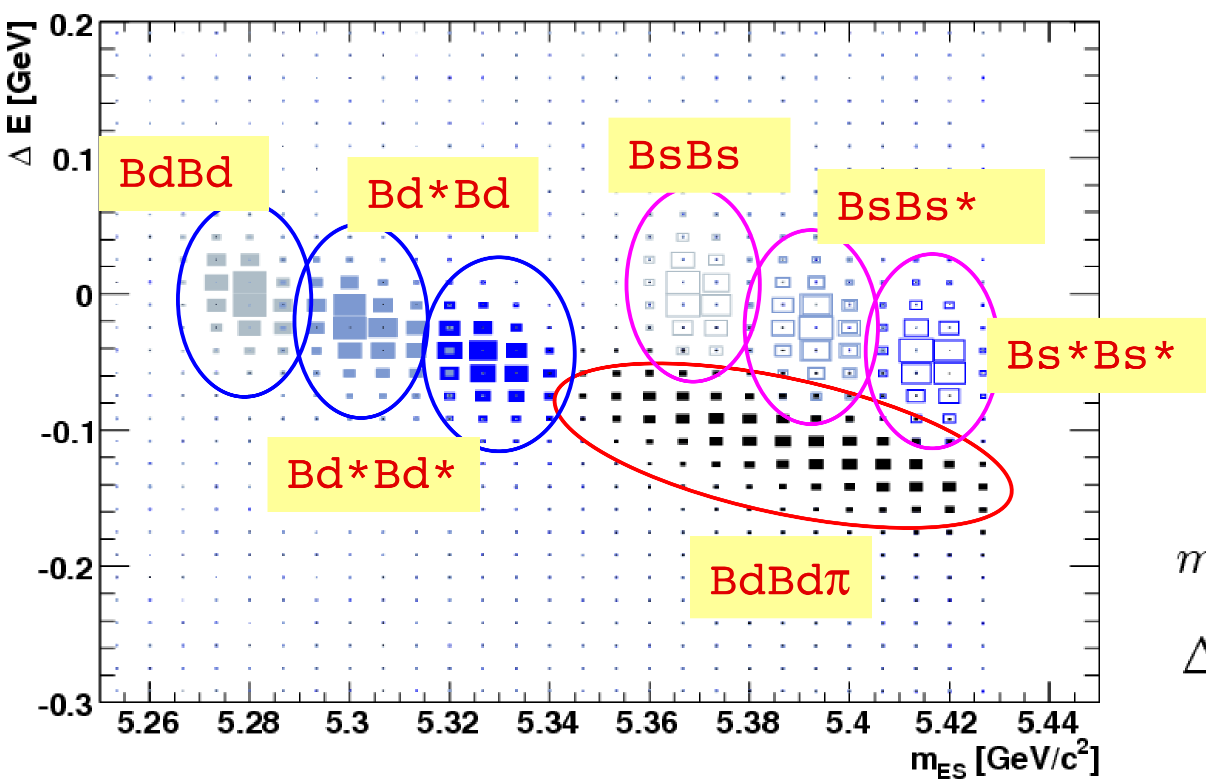
$B_s^{0*} B_s^{0*}$
(~ 94%)

For a given luminosity (w/o the BB cont.):
~ 17% of $B_{d,u}$ w.r.t. the Υ(4S);
~ 16% of B_s w.r.t. the number of B_d at the Υ(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 Υ(5S) decay chain;
  - separation of different components using kinematic variables.



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

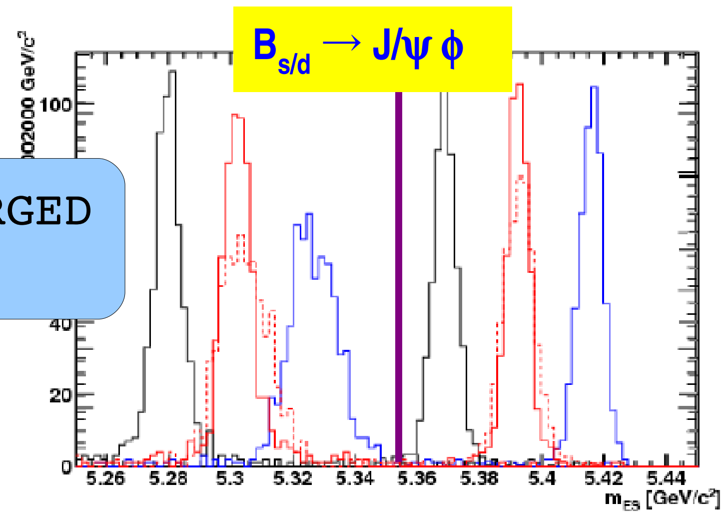
$$m_{\rm ES} = \sqrt{(s/2 + {\rm p}_i \cdot {\rm p}_B)^2 / E_i^2 + p_B^2}$$

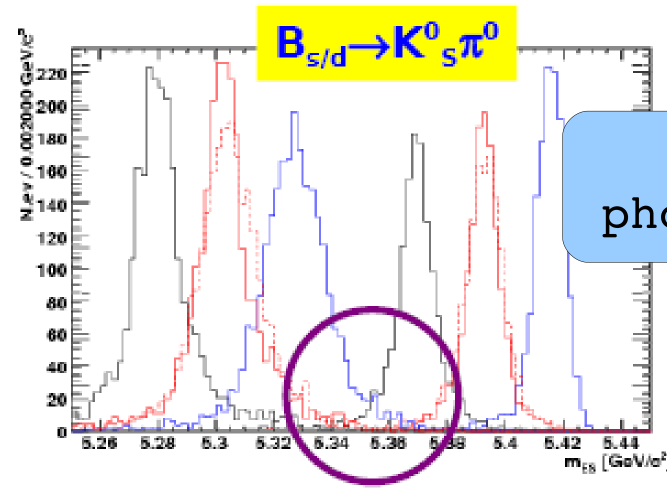
$$\Delta E = E_B^* - \sqrt{s}/2$$

Event reconstruction

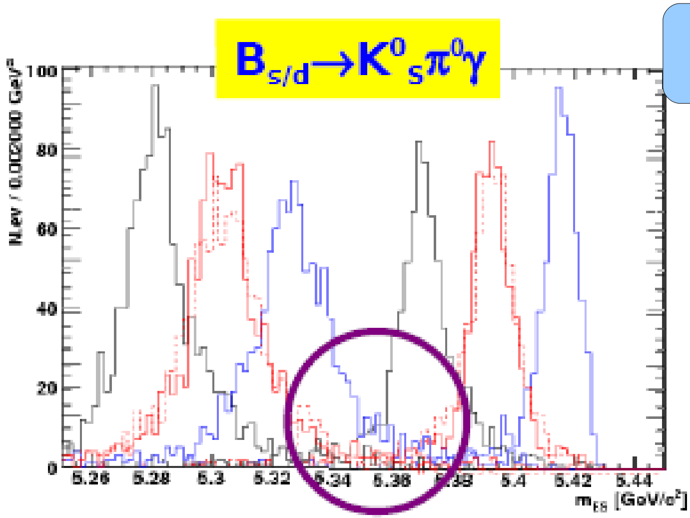
3 SCENARIOS...

ALL CHARGED TRACS





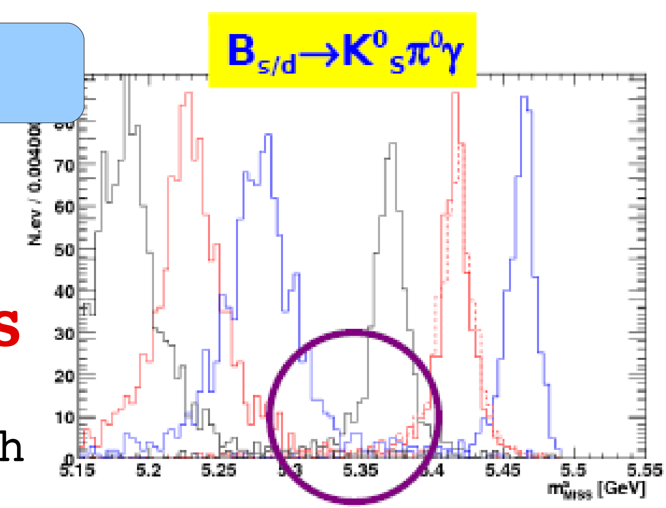
2 photons



3 photons

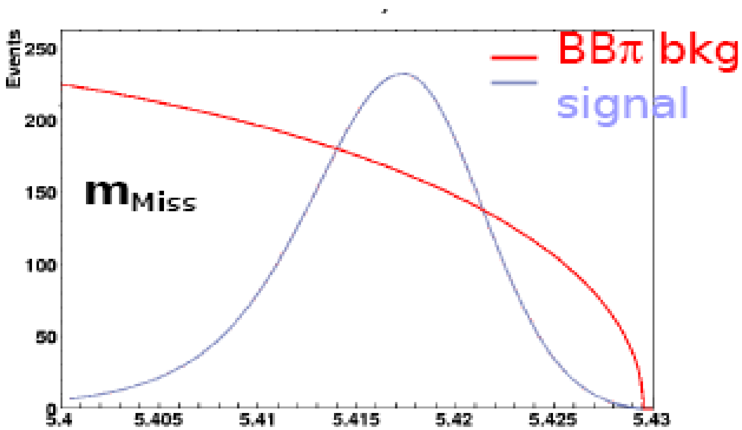
from mES to mMISS

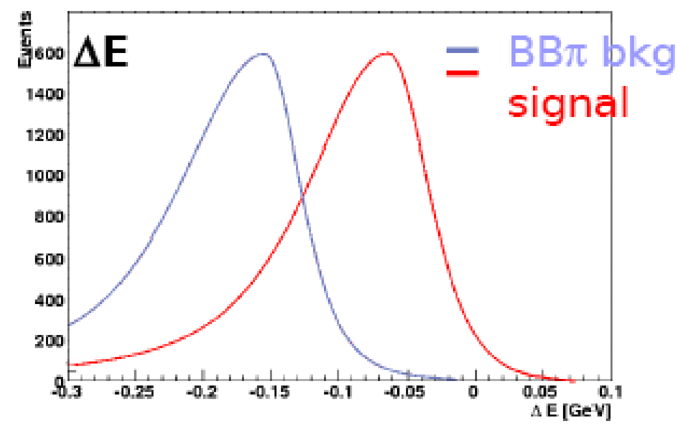
(the mass of the other B obtained with a mass constraint)



Event reconstruction

BBπ vs. BB SEPARATION





CAVEAT: the BBπ background can be important in final states with an odd number of s quarks ($K^*\gamma$, $K\pi$, etc.):

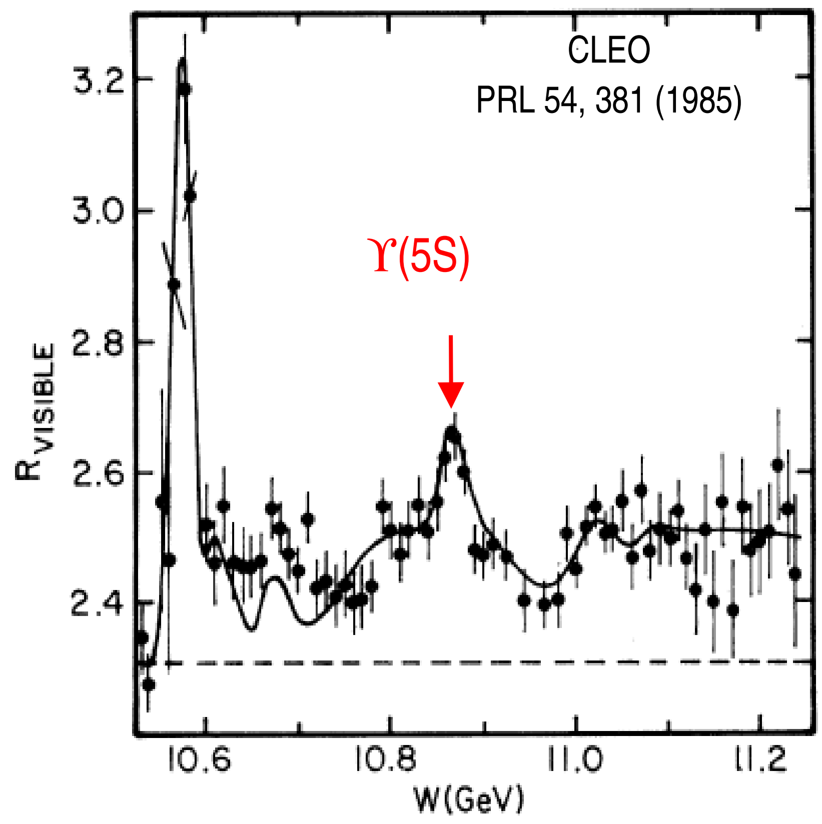
- B_s decays CKM suppressed w.r.t. B_d decays;
- B_s decays (sometimes) suppressed by dynamic (penguins or annihilation vs tree).

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

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 (paper in preparation) 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 $\Upsilon(4S)$;
  - $B_{s,d}^*B_{s,d}$ the state is symmetric → different time evolution;
- The coherence in the $B_{s,d}^*B_{s,d}^*$ case and the possibility to isolate this component using kinematic variables allows to take into account time dependent analysis (see later).

Opportunities @ $\Upsilon(5S)$

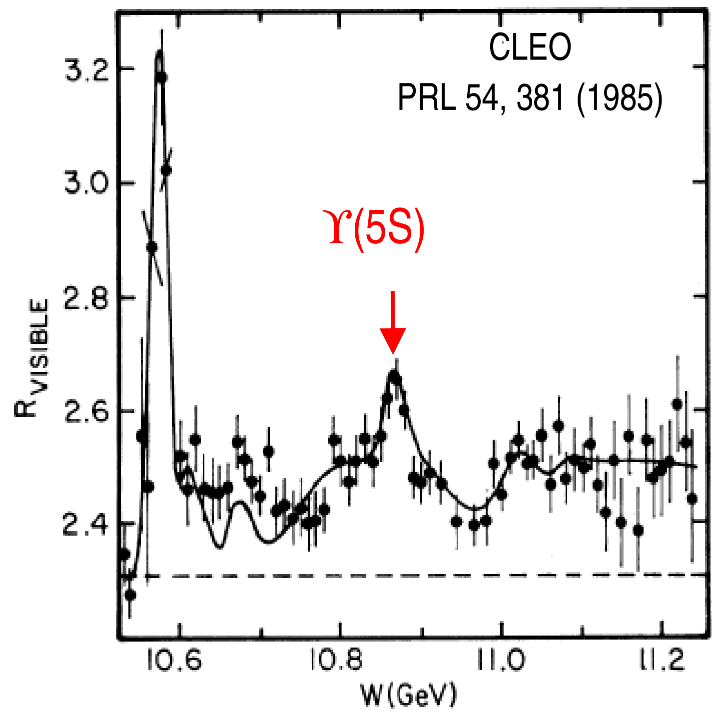


The Method

- We assume:
  - The same detector performances of BaBar;
  - SU(3) symmetry to estimate unknown B_s Branching Ratios;
  - Same $q\bar{q}$ background shapes than for $\Upsilon(4S)$ events;
  - full detector simulator to extract the signal shapes;
- We scale the number of signal and background events to take into account:
  - Different luminosities;
  - $\Upsilon(5S)$ production cross section (~ 1/3 w.r.t. $\Upsilon(4S)$);
  - $\Upsilon(5S)$ branching fractions;
- We perform a set of Toy Experiments to estimate the errors on the interesting quantities;

Opportunities @ $\Upsilon(5S)$

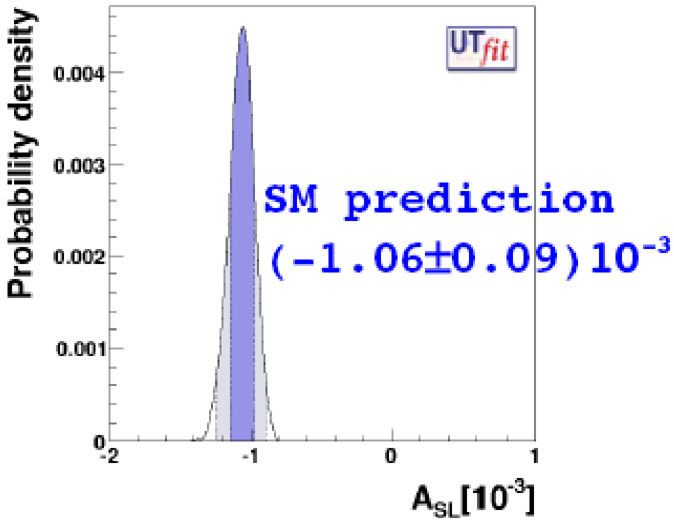
1 – Looking for a NP phase



Semileptonic Asymmetry

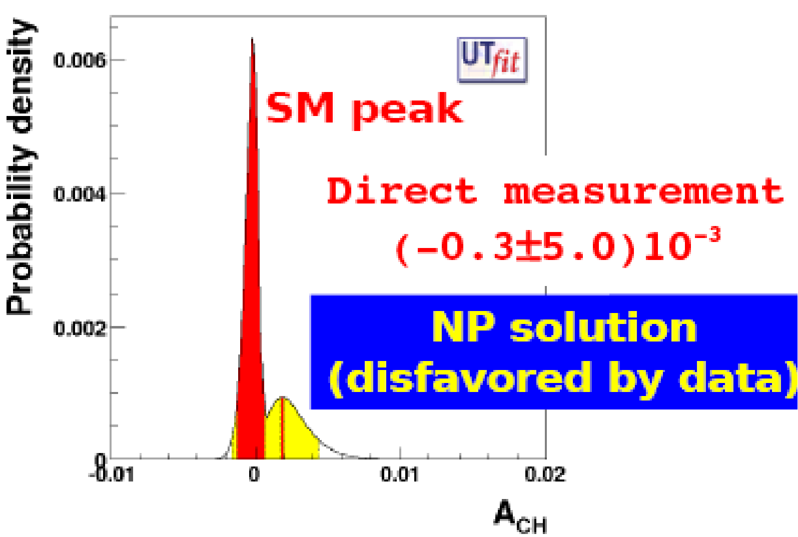
$$A_{SL} \equiv \frac{\Gamma(\overline{B^0} \to l^+ X) - \Gamma(\overline{B^0} \to l^- X)}{\Gamma(\overline{B^0} \to l^+ X) - \Gamma(\overline{B^0} \to l^- X)} =$$
$$= -\mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\sin(2\phi_{Bd})}{C_{Bd}} + \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\cos(2\phi_{Bd})}{C_{Bd}}$$

- 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

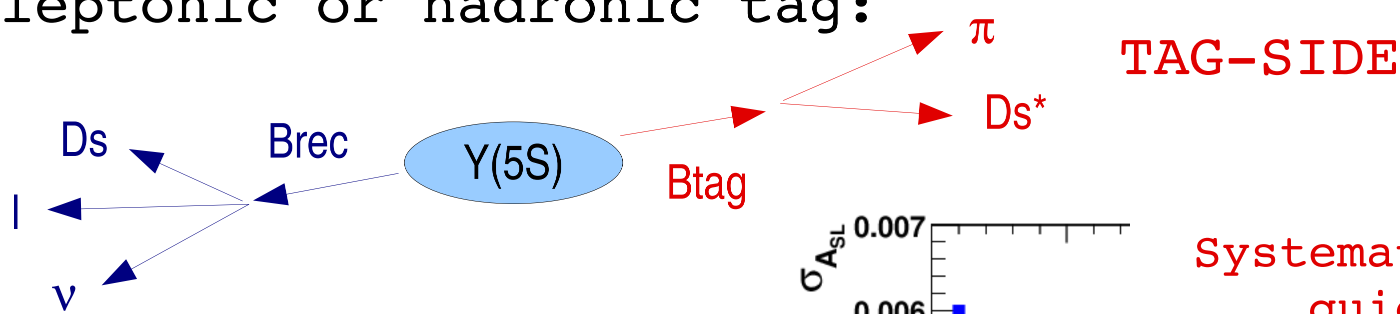
Super-B @ $\Upsilon(5S)$ can access A_{CH} and eventually $A^{s,d}_{SL}$ if Bd/Bs separation is possible



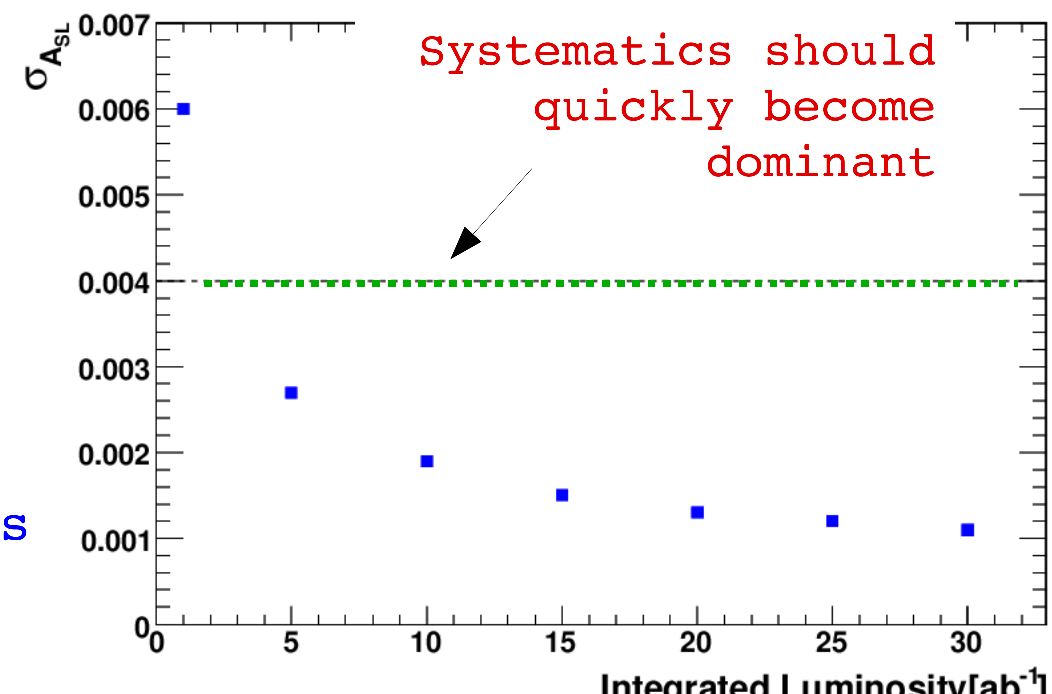
Semileptonic Asymmetry

$D_s(*)\ l\ \nu$

- Counting $D_s(*)^+ l^- \nu$ and $D_s(*)^- l^+ \nu$ events against a semileptonic or hadronic tag:



- qq Background killed by the full reconstruction of the other B;
- BBπ background killed by CKM suppression on reco and tag sides
- ~ 15% background from other Bs decays.
- Systematic uncertainties (due to detection asymmetries) taken from the current experiments.



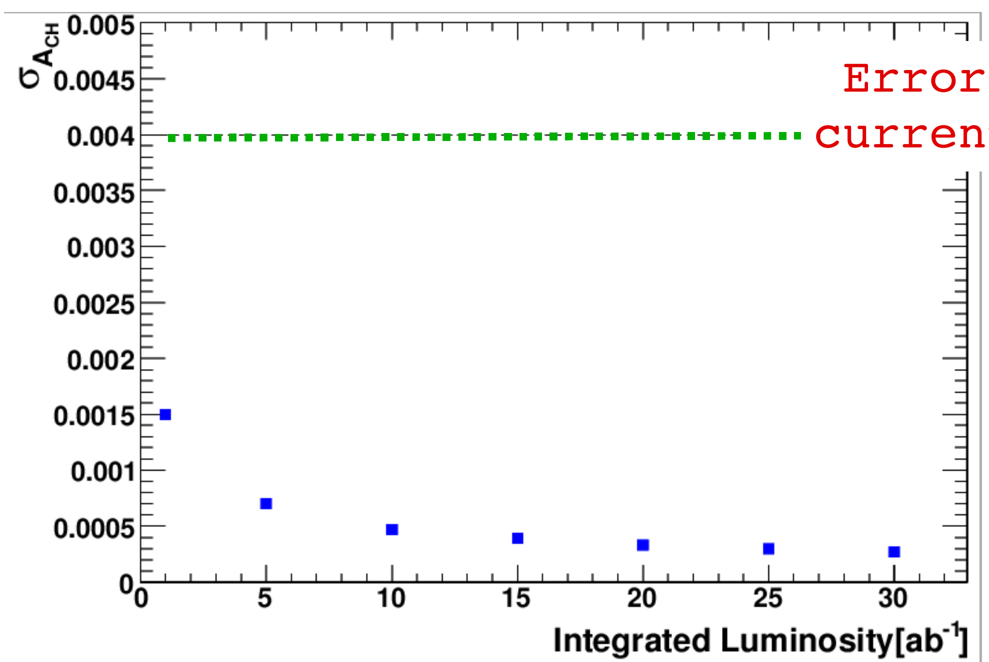
A^s_{SL} accessible only @ e^+e^- machines

Semileptonic Asymmetry

DILEPTONS

* but different admixture w.r.t. D0 due to different production factors

- Counting dileptons pairs:
  - separation of signal and background trough time evolution;
  - Possibility to access A_{CH} (combined Bs-Bd asymmetry *);
  - Possibility to access both $A^{s,d}_{SL}$ (Bs-Bd separation trough time evolution);
  - crossing-background (bkg from Bs to Bd and *vice versa*);



Errors extrapolated from current dileptons analyses

Systematic dominated, but also the syst. uncertainty should decrease (MC stat., control samples, off-peak, etc.).

Lifetime Difference $\Delta\Gamma$

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

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

- Sensitive to NP phase;
- Several experimental methods suggested to access $\Delta\Gamma_s$, $\Delta\Gamma_s\cos(\phi)$, $\Delta\gamma_s\cos^2(\phi)$

Dighe et al. hep-ph/9511363

Grossman hep-ph/9603244

Dighe et al. hep-ph/9804253

Dunietz et al. hep-ph/0012219

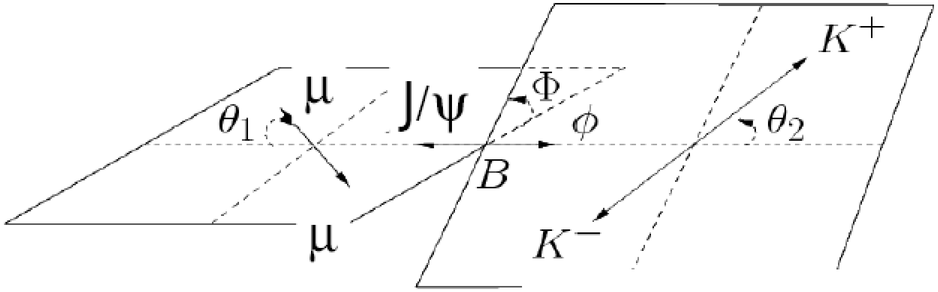
- We considered the method that use the *Angular Distribution in $B_s \rightarrow J/\psi\phi$ decays*

IN THE STANDARD MODEL....

- CPV in the B_s mixing negligible, $B_H = B_{CP+}$, $B_L = B_{CP-}$, so:

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

- $(J/\psi\,\phi)_{odd}$ and $(J/\psi\,\phi)_{even}$ can be separated trough ANGULAR ANALYSIS;



Lifetime Difference $\Delta\Gamma$

IN THE STANDARD MODEL....

SM time & angular PDF

$$\frac{d^4\mathcal{P}(\vec{\rho},t)}{d\vec{\rho}\,dt} \propto |A_0|^2 e^{-\Gamma_L t} \cdot f_1(\vec{\rho}) + |A_{||}|^2 e^{-\Gamma_L t} \cdot f_2(\vec{\rho}) + |A_\perp|^2 e^{-\Gamma_H t} \cdot f_3(\vec{\rho}) + \mathrm{Re}(A_0^* A_{||}) \cdot f_5(\vec{\rho}) e^{-\Gamma_L t}$$

$\vec{\rho} = (\phi, \cos\theta, \cos\psi)$

WITH A NP PHASE...

- NP phase modify the time & angular PDF in such a way that this analysis can access BOTH $\Delta\Gamma$ AND THE NEW PHASE...

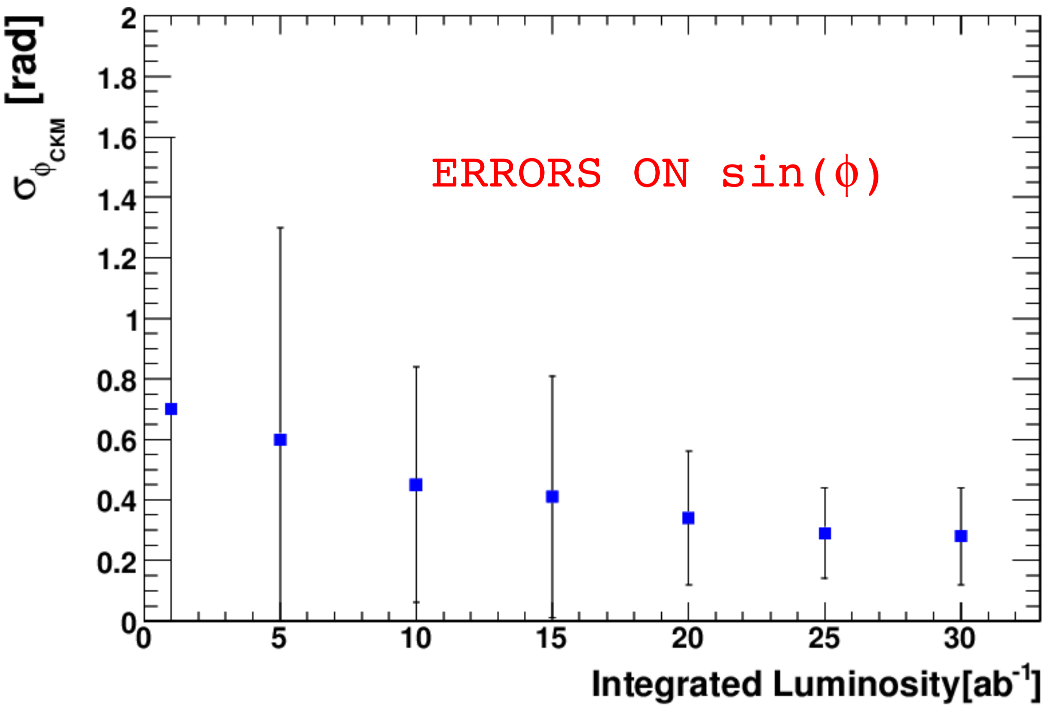
$$\frac{d^4\mathcal{P}(\vec{\rho}\,,t)}{d\vec{\rho}\,\mathrm{dt}} = [\ldots \sin(\phi_{\mathrm{CKM}})]e^{-\Gamma_L t} + [\ldots \sin(\phi_{\mathrm{CKM}})]e^{-\Gamma_H t}$$

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

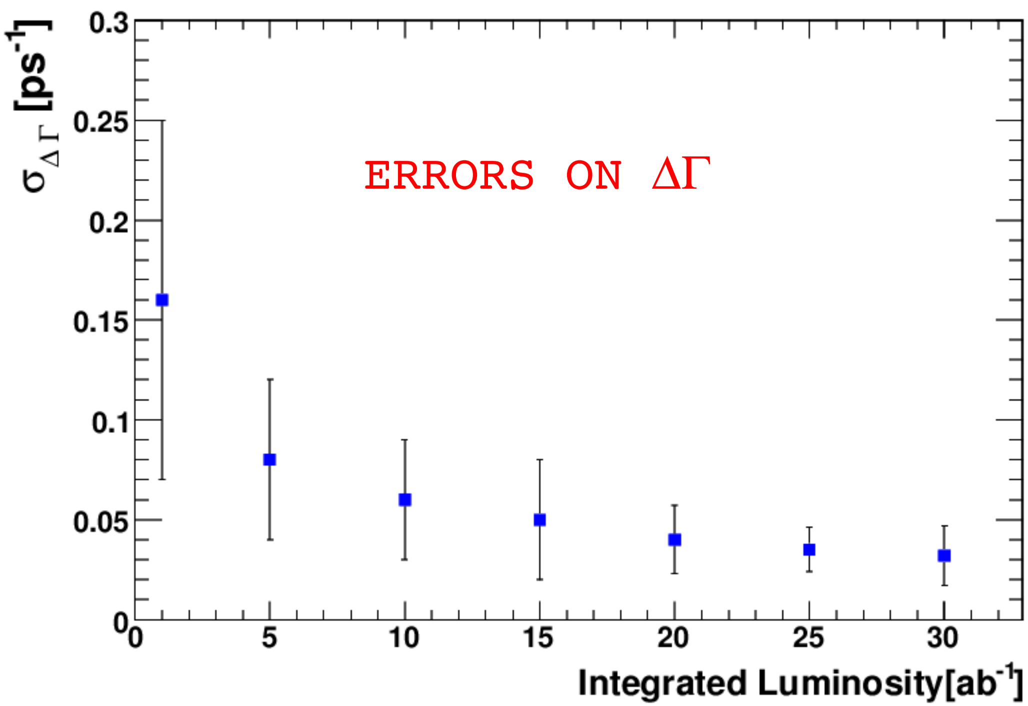
SM + NP

Lifetime Difference $\Delta\Gamma$

RESULTS



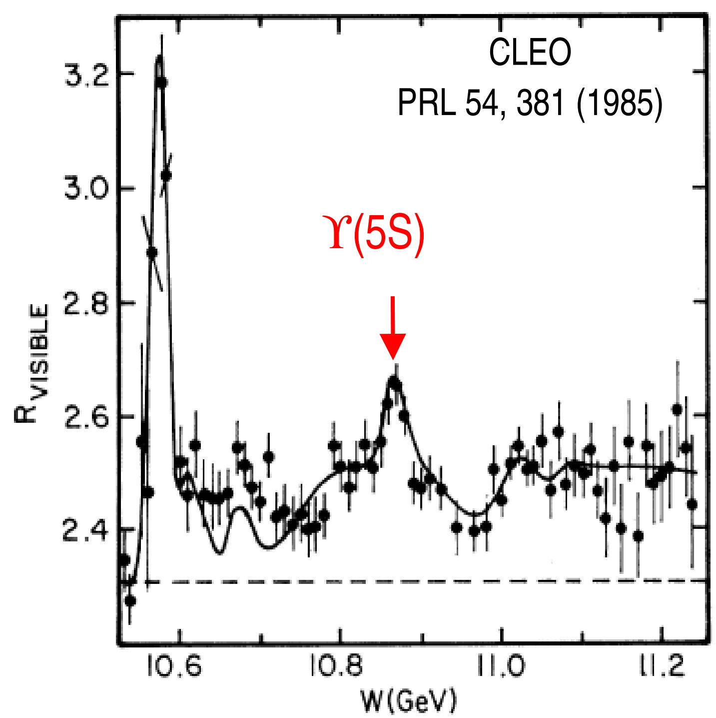
CAVEAT: problems with correlations between ϕ and $\Delta\Gamma$ already experienced by D0.



Error bars: RMS of the error distribution

Opportunities @ $\Upsilon(5S)$

2 – Bounds on CKM parameters



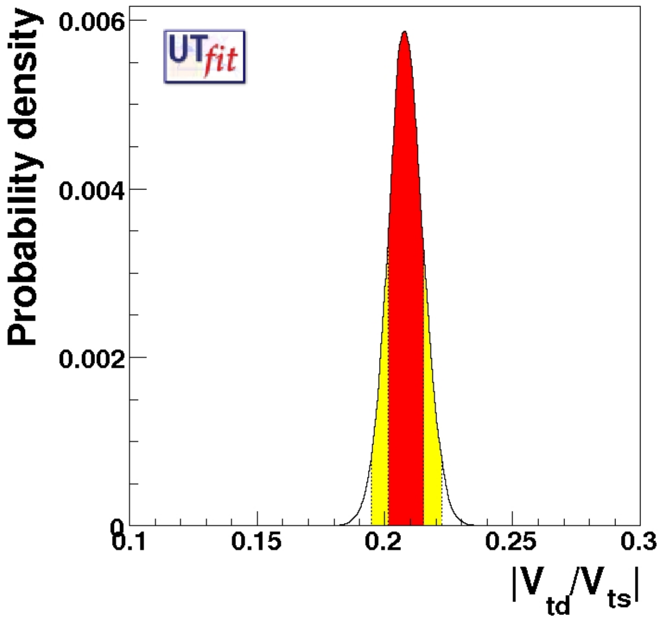
V_{td}/V_{ts}

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



$\Upsilon(4S)$

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

SU(3) breaking

theo. uncertainty on additional contribution

$\Upsilon(5S)$

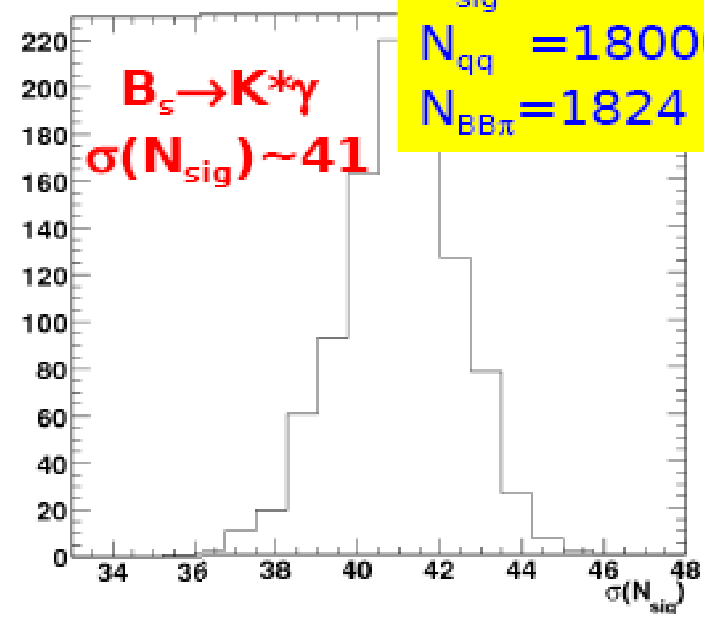
$$\frac{BR(B_s \to K^* \gamma)}{BR(B_d \to K^* \gamma)} = \frac{1}{\xi^2} \frac{|V_{td}|}{|V_{ts}|}$$

No theo. uncertainties from additional contributions

V_{td}/V_{ts}

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

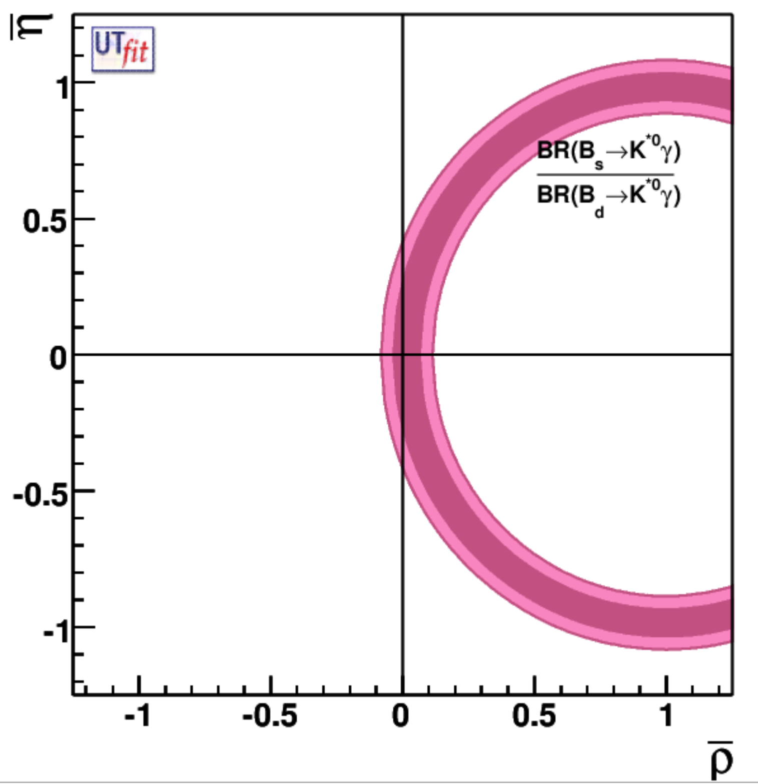
N_{sig} =289
N_{qq} =18000
$N_{BB\pi}$=1824

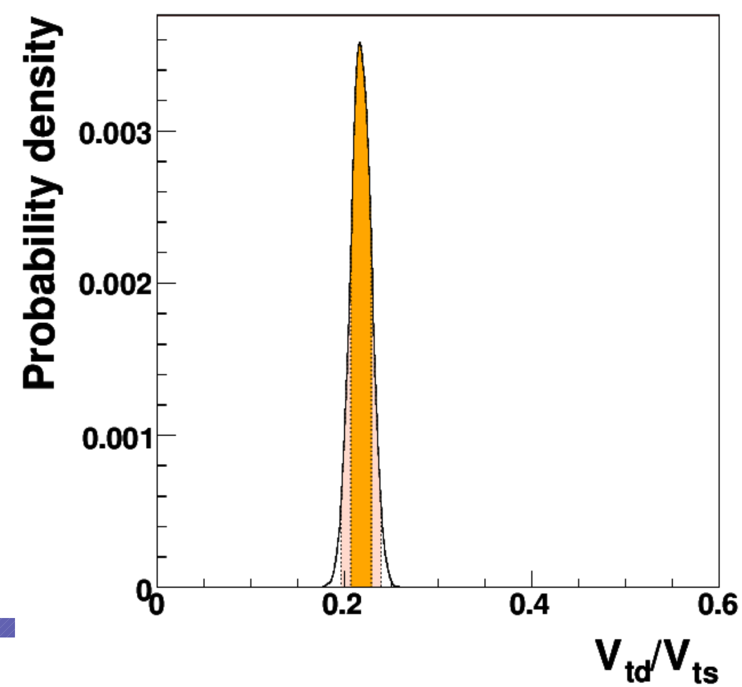


Results @ 30 ab^{-1}

V_{td}/V_{ts} = 0.22 ± 0.01

Total error dominated by statistics



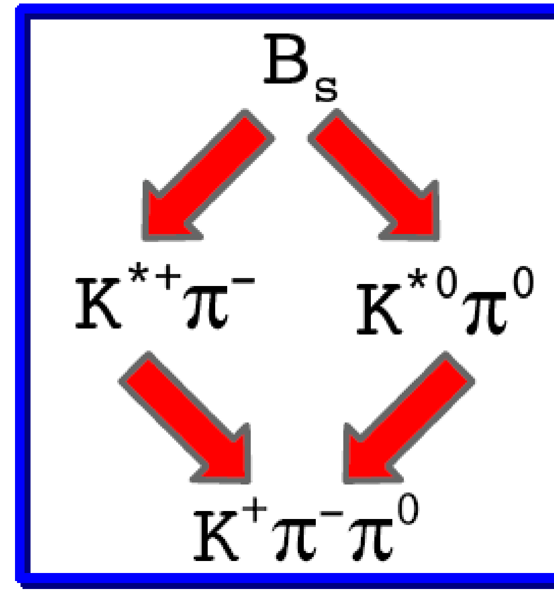


γ from Kππ

Ciuchini et al.
(hep-ph/0602207)

- $B_s \to K\pi\pi$ Dalitz analysis can access the amplitudes:

$$
\begin{aligned}
A_s^{K^*\pi} &= A(B_s \to K^{*-}\pi^+) + \sqrt{2}A(B_s \to \bar{K}^{*0}\pi^0) \\
&= -V_{ub}^* V_{ud}(E_1 + E_2)\,, \\
\bar{A}_s^{K^*\pi} &= A(\bar{B}_s \to K^{*+}\pi^-) + \sqrt{2}A(\bar{B}_s \to K^{*0}\pi^0) \\
&= -V_{ub} V_{ud}^*(E_1 + E_2)\,,
\end{aligned}
$$



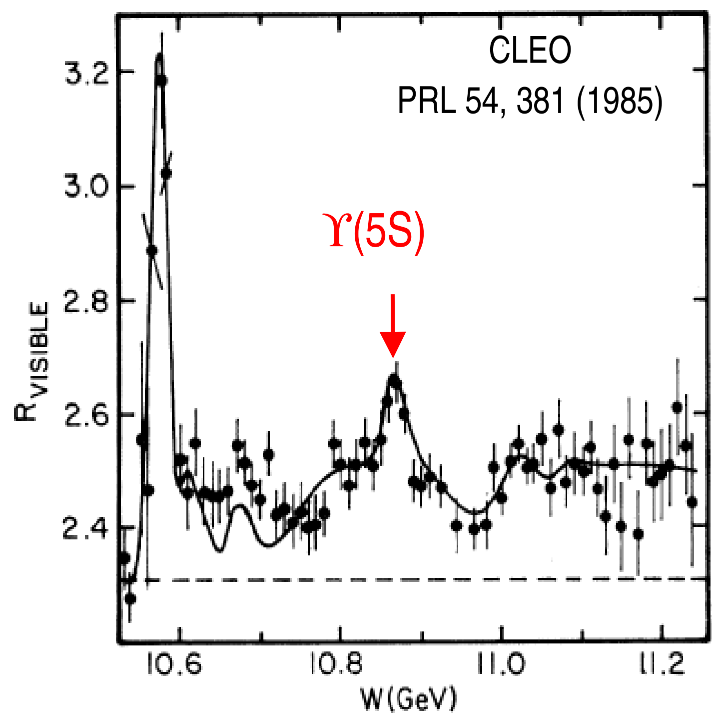
- γ from the ratio:

$$
R_d = \frac{\bar{A}_s^{K^*\pi}}{A_s^{K^*\pi}} = \frac{V_{ub} V_{ud}^*}{V_{ub}^* V_{ud}} = e^{-2i\gamma}
$$

- NP can generate a different result w.r.t. the tree level estimate of γ ;
- in a Super-B factory, better π^0 resolution than LHCb
- relative phase between B and $\bar{B}$ amplitudes needed (TD or LHCb)

Opportunities @ $\Upsilon(5S)$

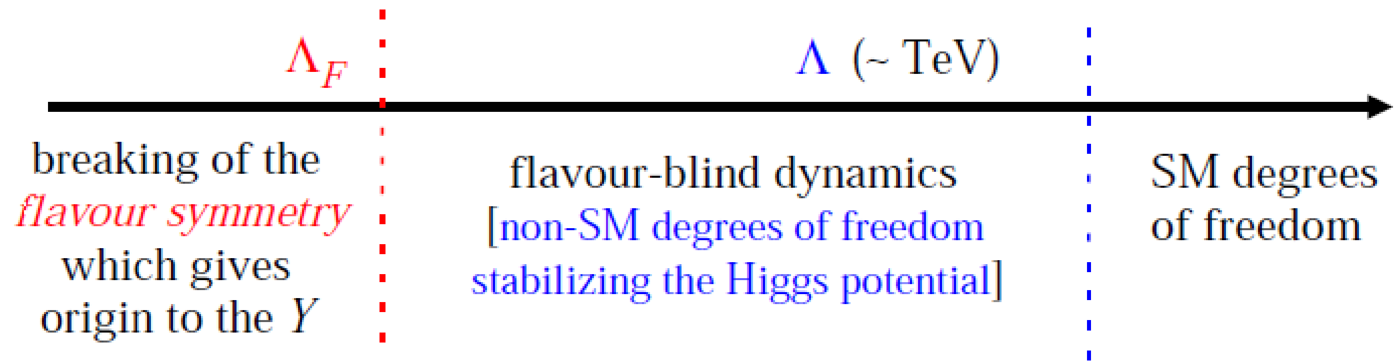
3 – Constraining NP models



Minimal Flavour Violation

- In the b → d sector the present results strongly favor *Minimal Flavour Violation (MFV)*:

G.Isidori, Heavy Quarks & Leptons 2006



  - All FCNC amplitudes with the same CKM structure as in the SM;
  - No NP phases;
  - NP observable only in BR shift.

- *MFV* scenarios already constrained by b → sγ and b → sll;

- Need for high statistics to investigate *MFV* in *RARE LEPTONIC* and *RADIATIVE* decays;

$B_s \to \mu\mu$

$B_s \to \mu\mu$ and MFV

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

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

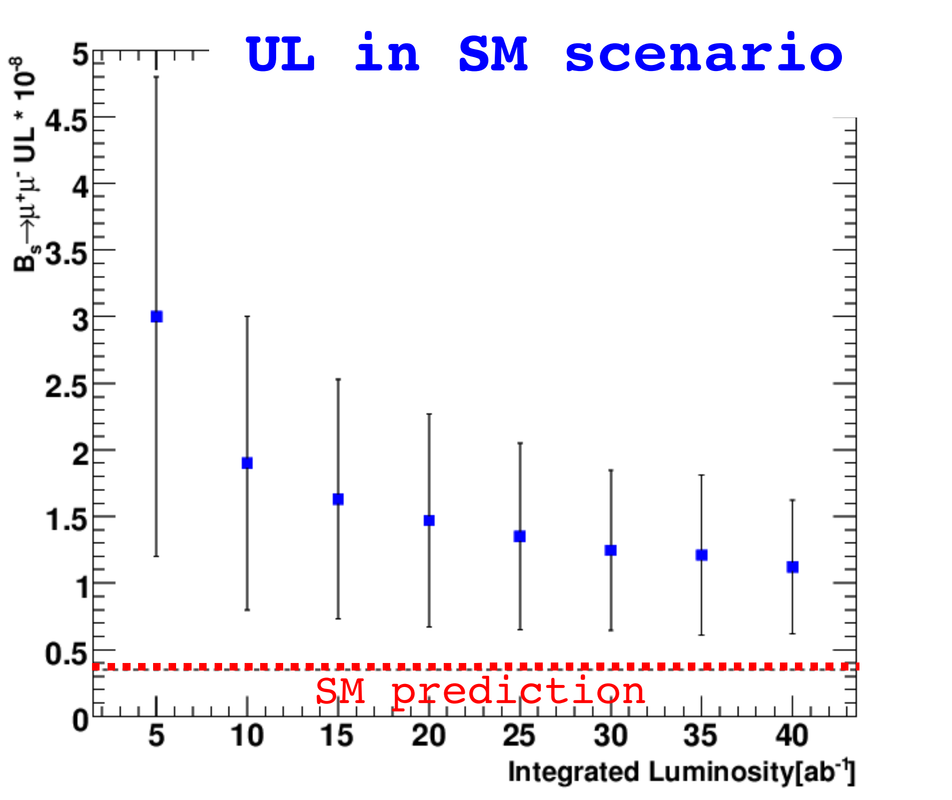
- Deviations of the BR from the SM (~ $3.5 \cdot 10^{-9}$) are possible in a MFV scenario, but a strong enhancement is already ruled out by $b \to s\gamma$ and $b \to sll$ measurements;

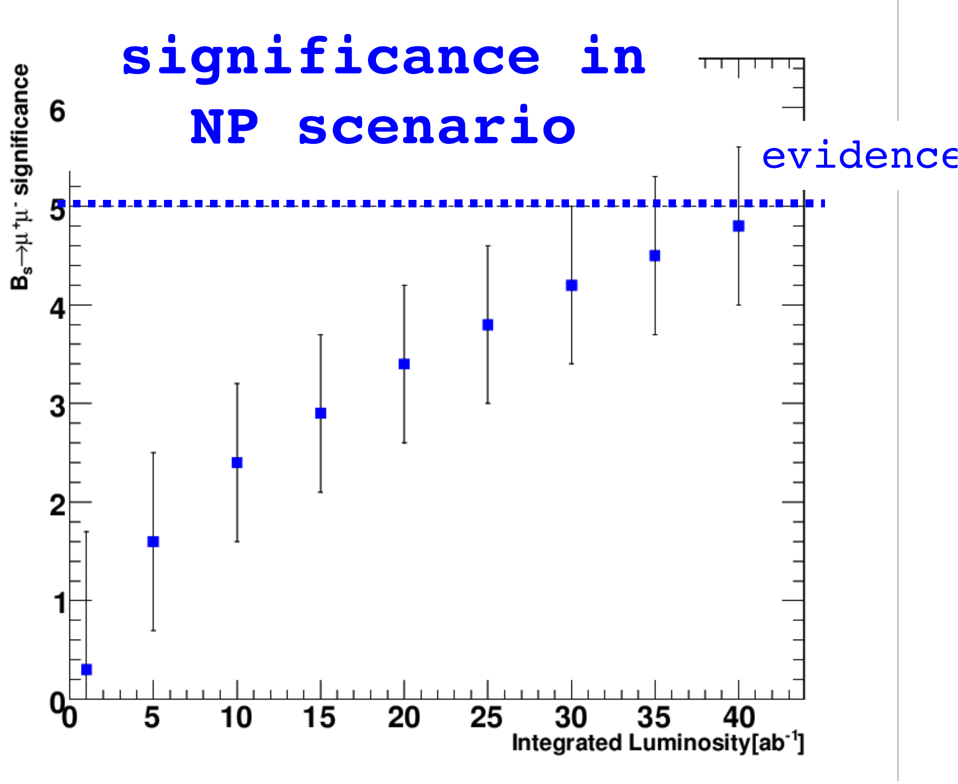
- An observation of the BR above the SM value will rule out SM & MFV
- An observation of the BR below the SM prediction will strongly confirm MFV

$B_s \rightarrow \mu\mu$

- This is the worst case w.r.t. hadronic machines
- Simulation with SM BR ~ $3.5*10^{-9}$ and NP (BR = 10*SM)

CDF UL 90% CL $8*10^{-8}$





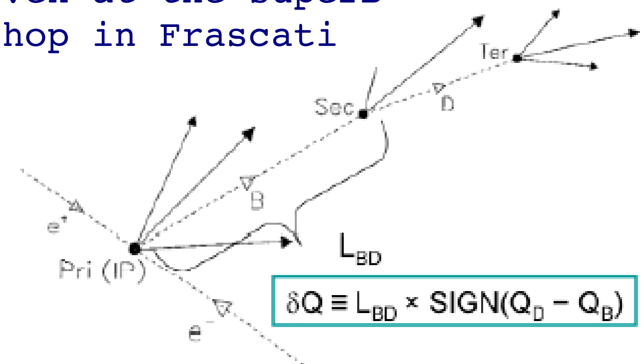
UL 90% CL $10*10^{-8}$ @ $1ab^{-1}$

$B_s \rightarrow \mu\mu$

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

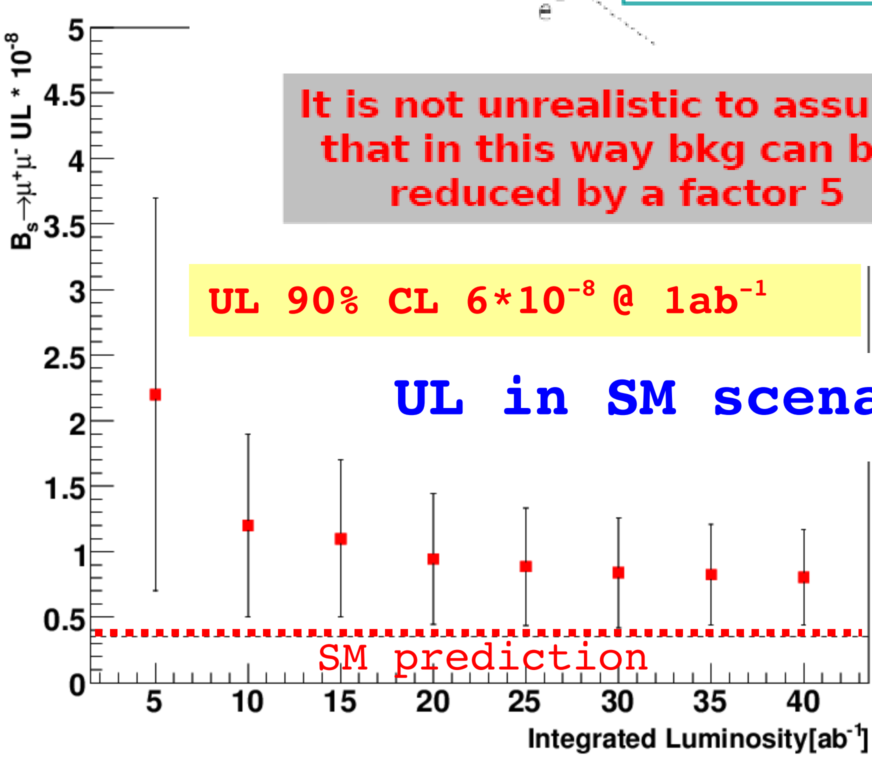
N.Neri and M.Pierini talk given at the superB workshop in Frascati

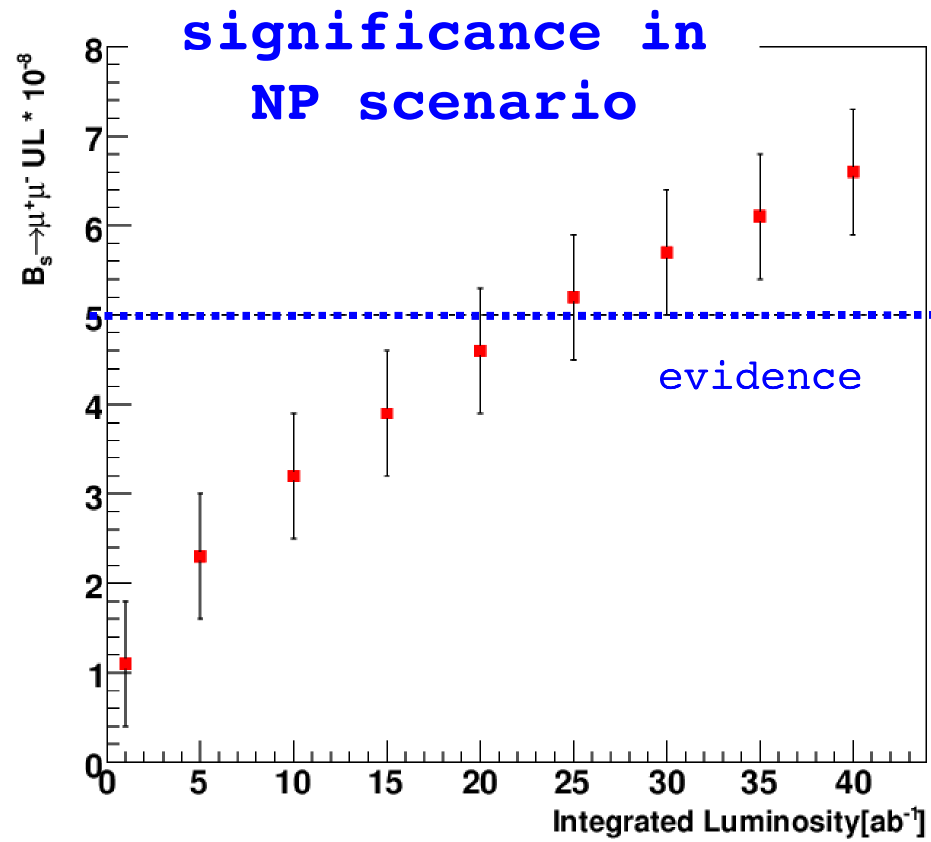
Just an example: improving vertexing performances in such a way that B and D vertex can be separated on the tag side



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

UL 90% CL $6*10^{-8}$ @ $1ab^{-1}$





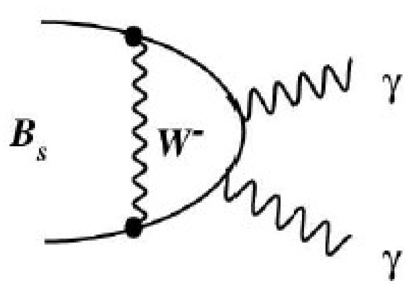
$B_s \to \gamma\gamma$

- 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.

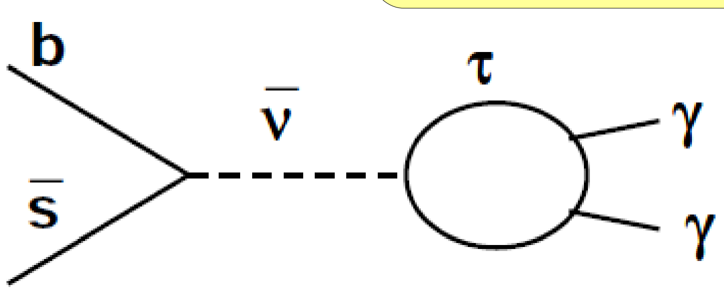
e.g. R-Parity violating SUSY

up to 1 order of magnitude of enhancement

SM + **NP**



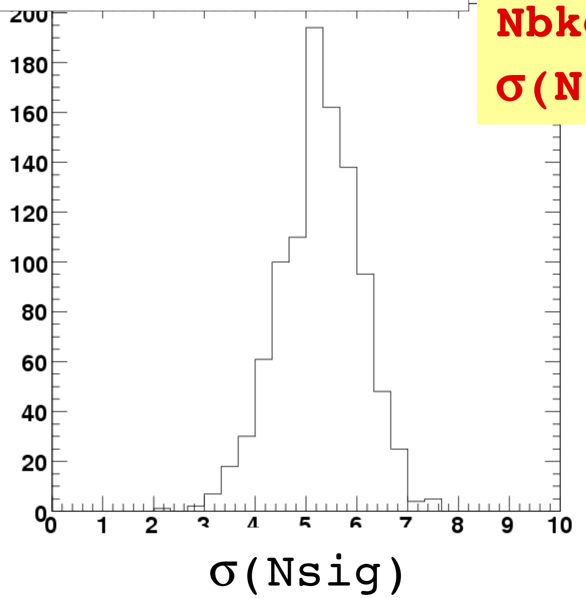
+



$B_s \to \gamma\gamma$

Results @ 1 ab^{-1}

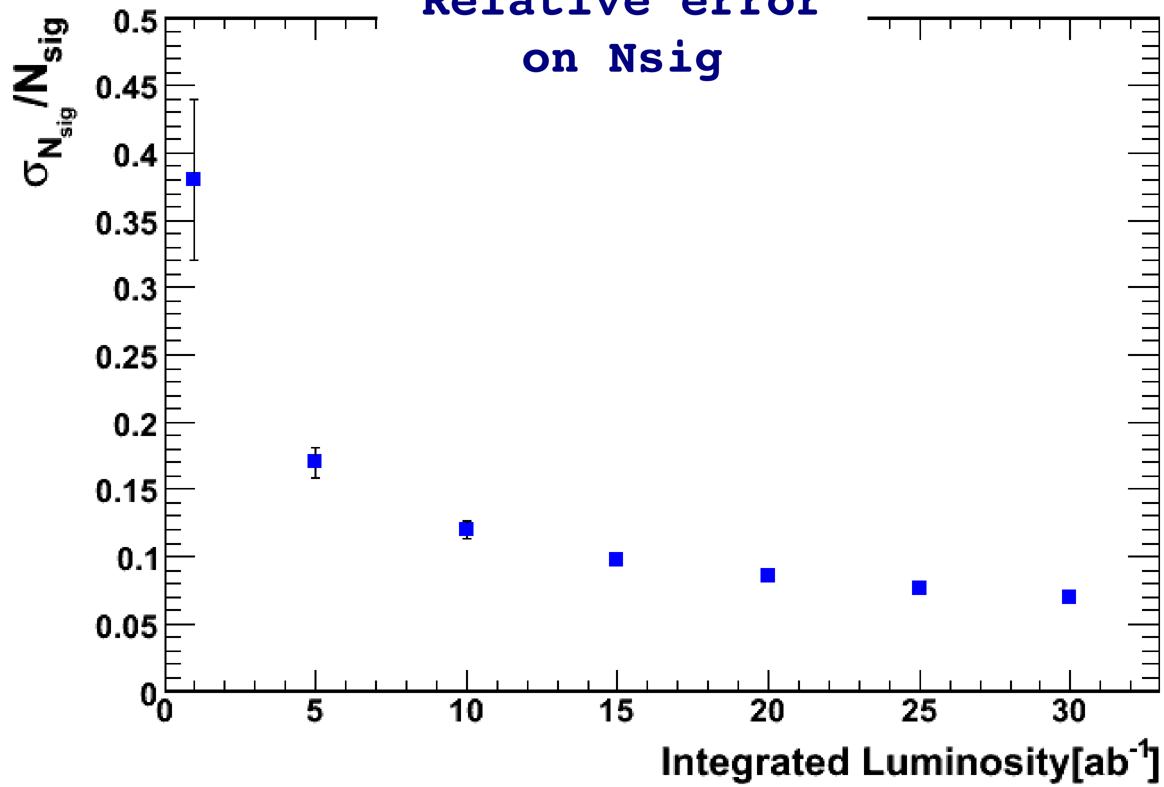
Nsig = 14
Nbkg = 20
σ(Nsig) ~ 5



First evidence at low statistics

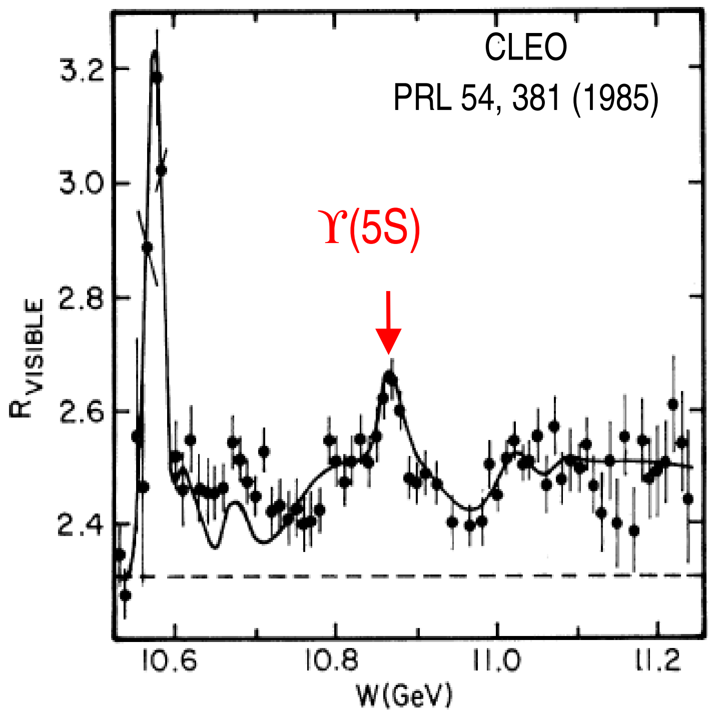
7% in 30ab^{-1}

Relative error on Nsig



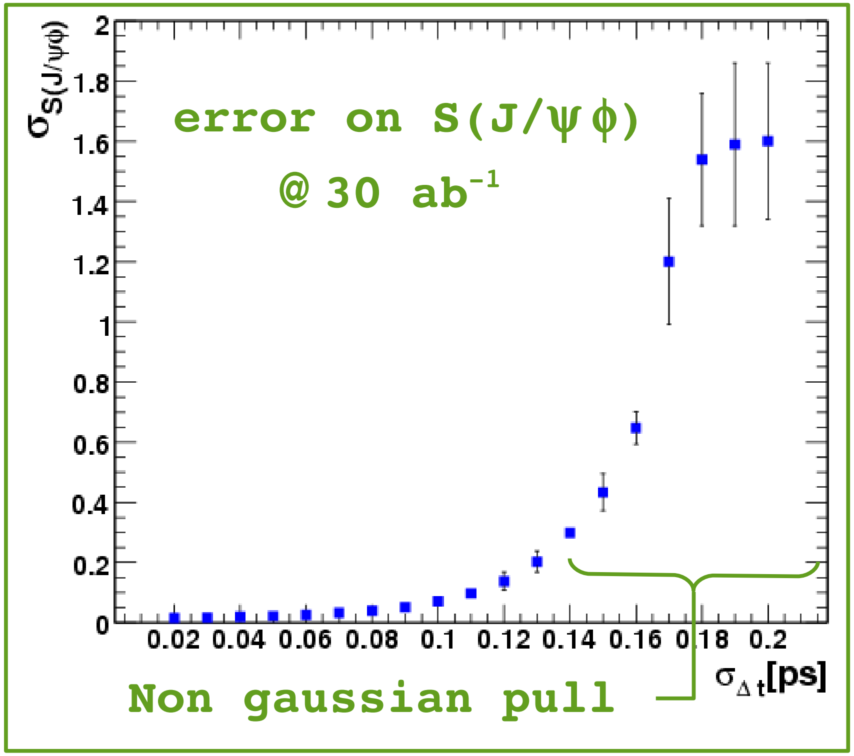
Opportunities @ $\Upsilon(5S)$

4 – What about Time Dependent analyses?



Time Dependent analyses

- Main Question: Which Δt resolution do we need to be sensitive to TD-related quantities (S and C)?
  - New simulations confirm the results we presented at the II Super-B workshop in Frascati (March '06).

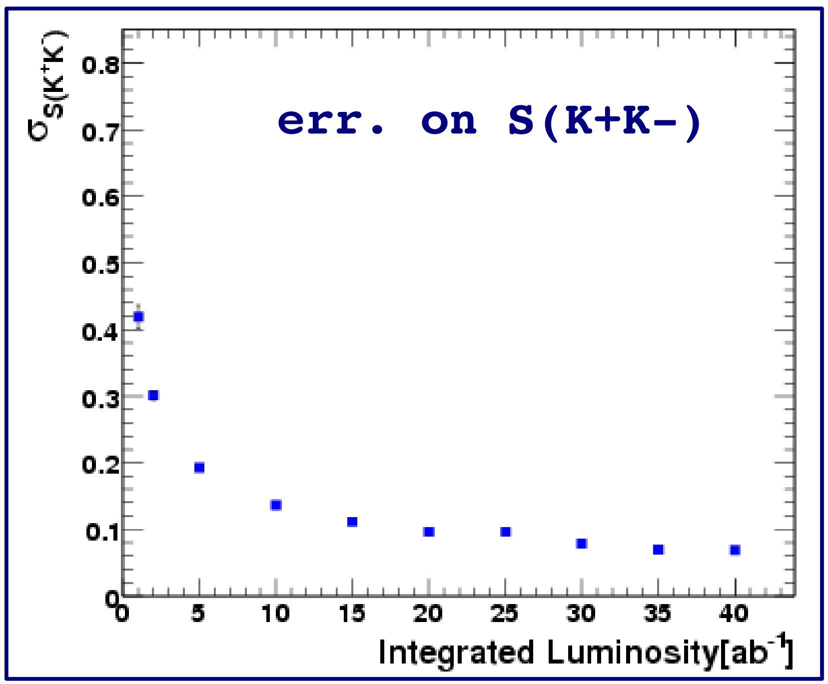


requested Δt resolution ~ 0.1 ps

Time Dependent analyses

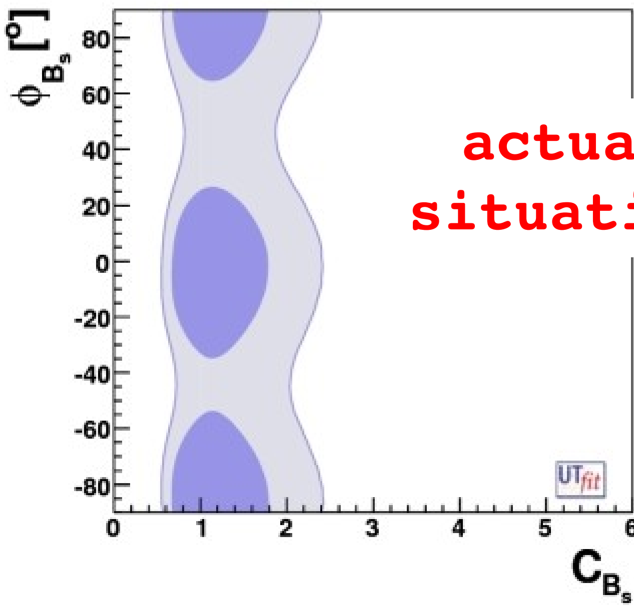
- $\sigma_{\Delta t}$ = 0.1ps: what does it mean?
  - $\sigma_{\Delta t} = \sigma_{\Delta z}/\beta\gamma$.
  - Current BaBar Resolution ~ 0.7ps with $\beta\gamma$ = 0.56;
- *Conclusion: B_s TD analyses unfeasible in a B-factory;*

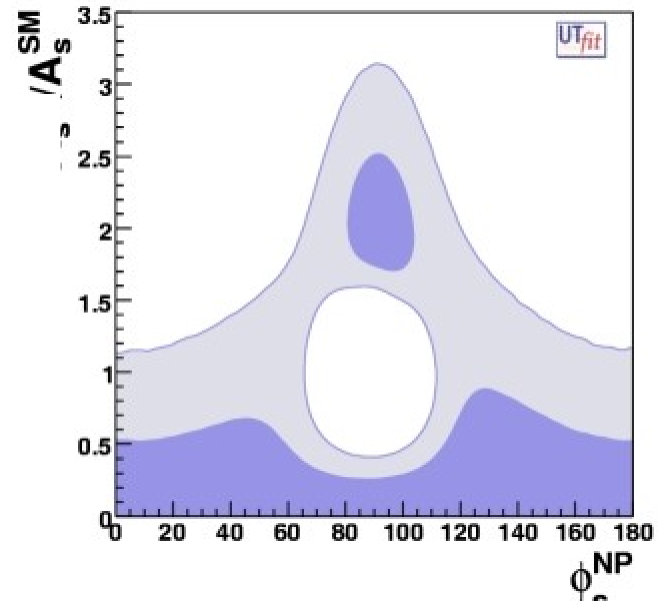
ANYWAY, ASSUMING $\sigma_{\Delta t}$ = 0.1ps...



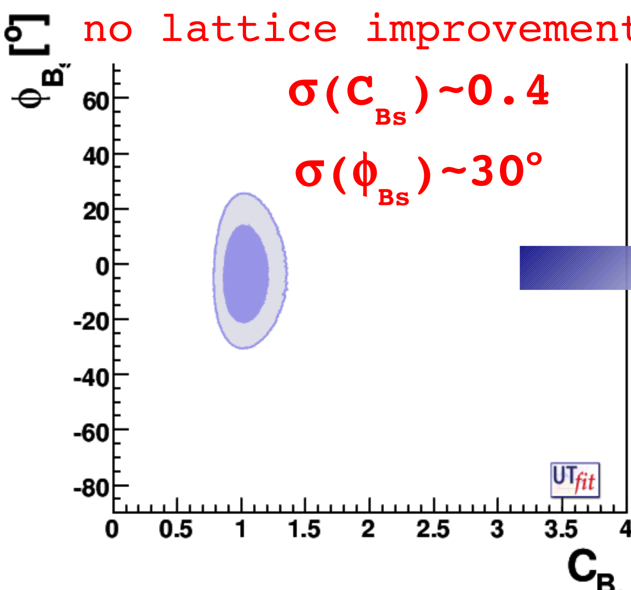
Physics Reach
(and a Rich Physics!)

Constraints on NP

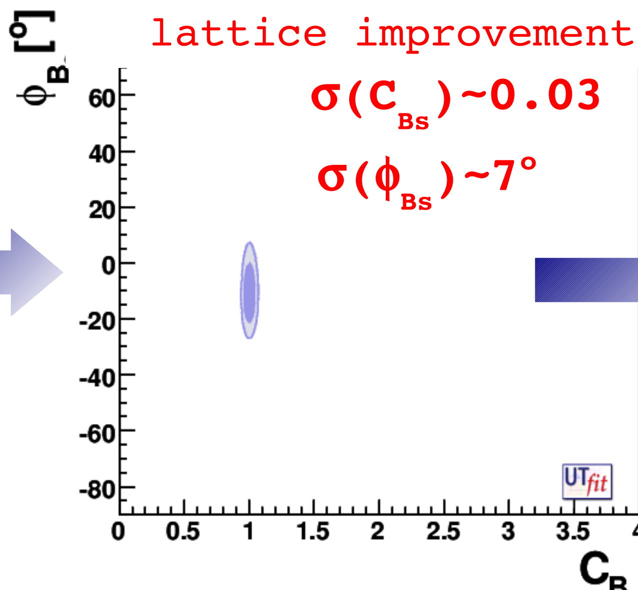




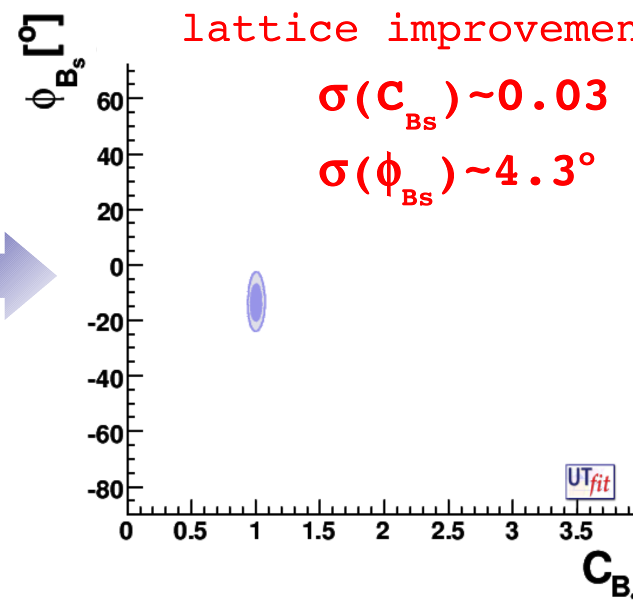
1 ab^{-1}
no lattice improvement



10 ab^{-1}
lattice improvement



30 ab^{-1}
lattice improvement



For lattice improvement see V.Lubicz talk @ IV superB workshop

Conclusions and Outlook

- The CKM picture is well established and new hadronic machines will further improve our knowledge → *new machines oriented towards new physics*;
- Large NP phases in B_d mixing mainly ruled out → *look for NP phases in B_s mixing*;
- Υ(5S) offers the possibility to investigate **both Bd and Bs** decays – we can:
  - look for NP phases in B_s mixing;
  - add independent constraints on CKM parameters;
  - bound different NP scenarios;
- Sensitivity on several physical quantities has been shown;
- **Significant results even at not too high statistic;**

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:

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

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

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 → $J/\psi\,\phi$ for $\Delta\Gamma$ and $\sin(\phi)$

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

- ✓ LHCb: 125k Bs→$J/\psi\phi$ 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 $J/\psi\eta$, $J/\psi\eta'$ (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?

$B_s \to \phi\gamma$

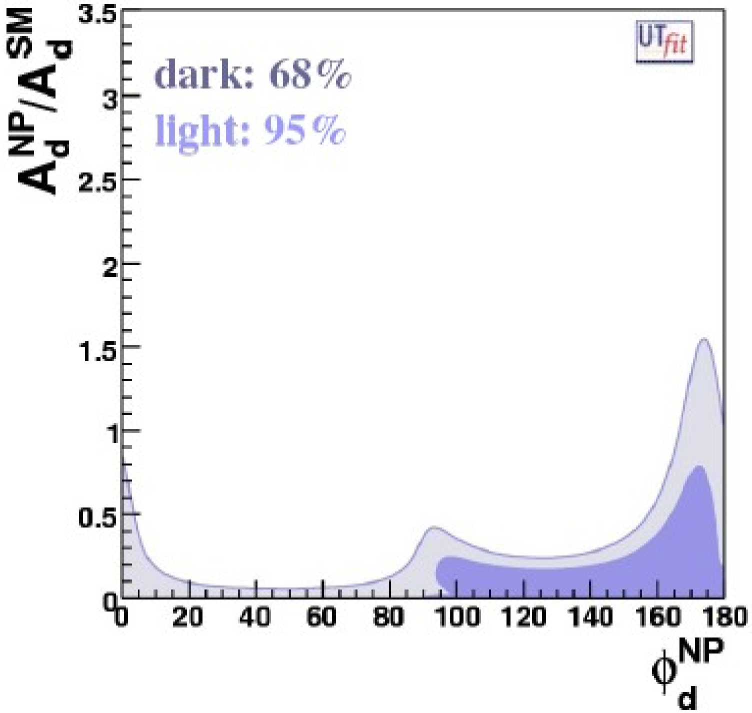
In 1 year LHCb expects triggered and reconstructed:
35k events $B^0 \to K^{0*} (K^+\pi^-)\gamma$; S/B>1.4
9.4k events $B_s \to \phi (K^+K^+)\gamma$; S/B>0.4

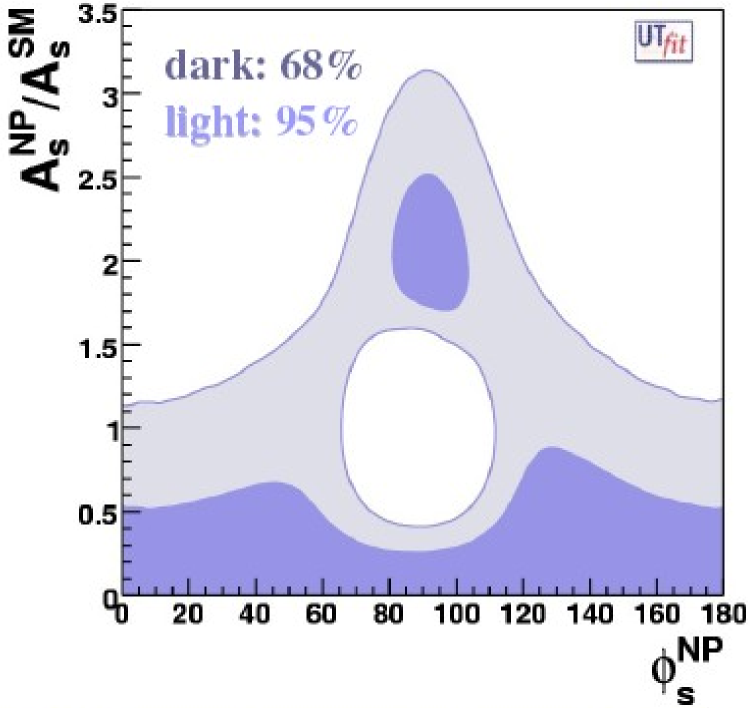
ATLAS expected signal events/year:
$B_d \to K^{*0}\gamma$: ~3.3k ev. ; $S/\sqrt{BG} > 5$
$B_s \to \phi\gamma$: ~1.1k ev. ; $S/\sqrt{BG} > 7$

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

Bounds on NP size and phase

$$C_{B_d} e^{2i\phi_{B_d}} = \frac{A_{\rm SM} e^{2i\beta} + A_{\rm NP} e^{2i(\beta+\phi_{\rm NP})}}{A_{\rm SM} e^{2i\beta}}$$





The allowed NP amplitude is still large for small phase shift
MFV scenarios are strongly favored at this point, but we still have some chance to see a NP phase