B Physics Observables for New Physics Discoveries

Working Group Summary

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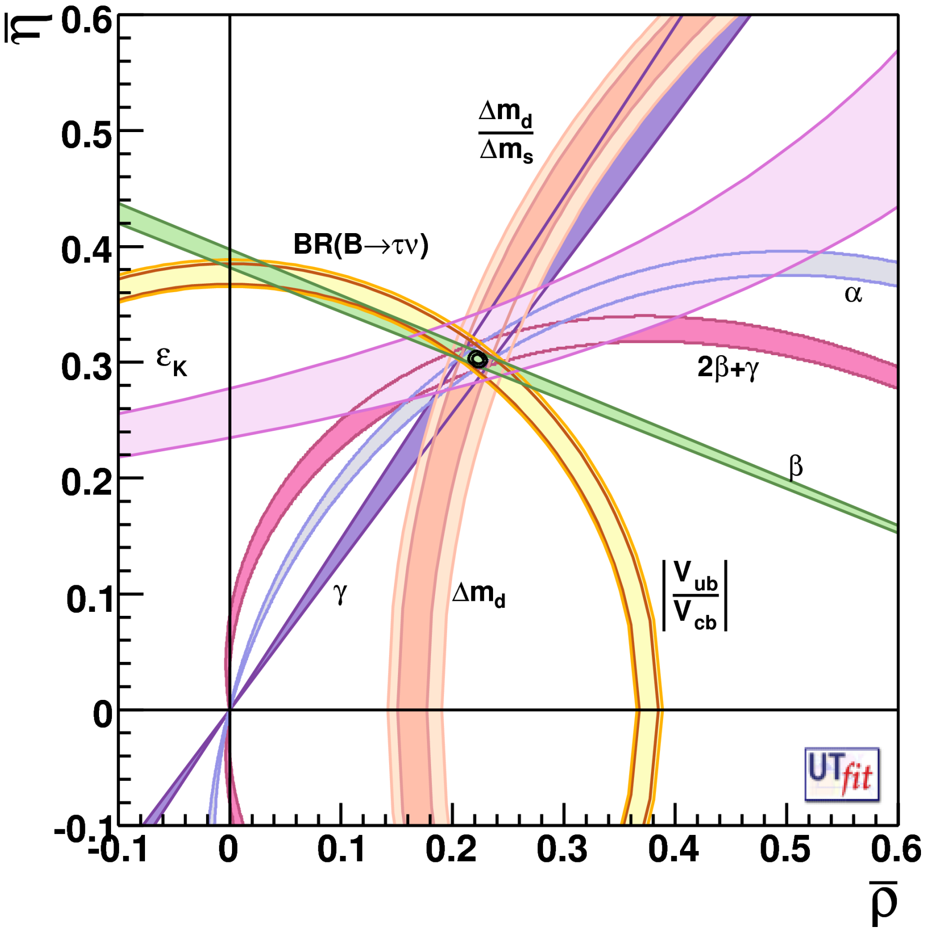
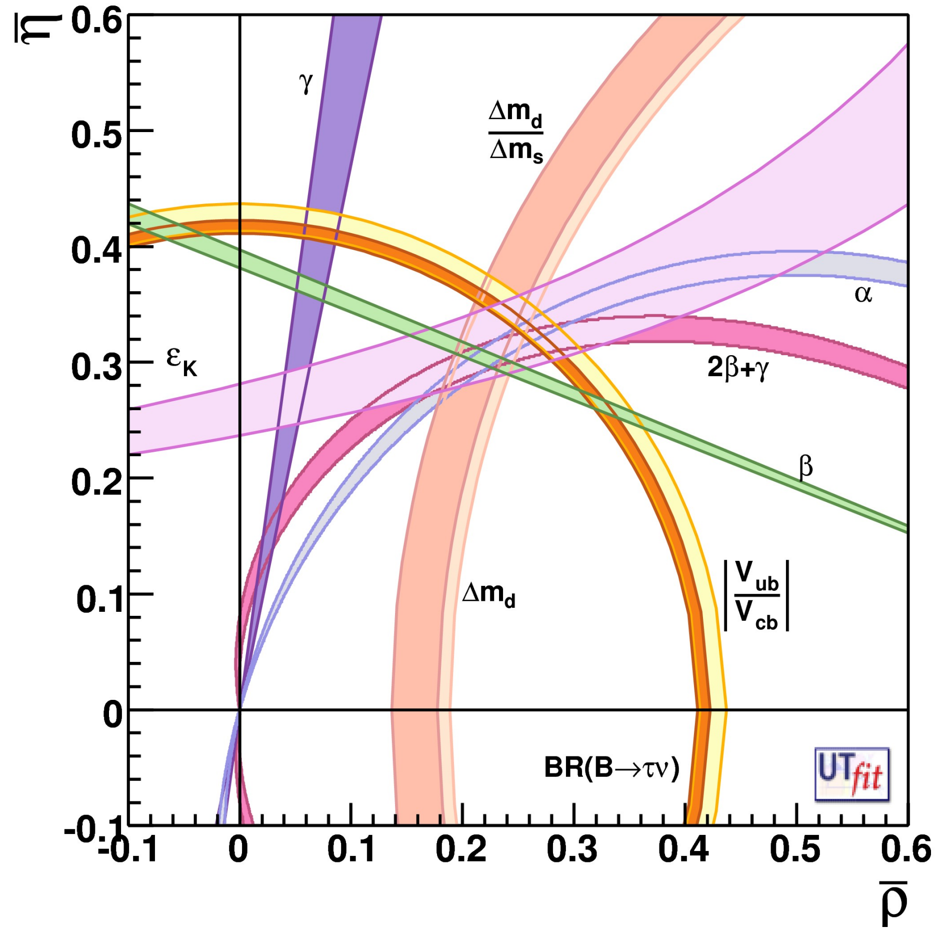
Super*B* UT fit scenarios

"the nightmare"



"the dream"

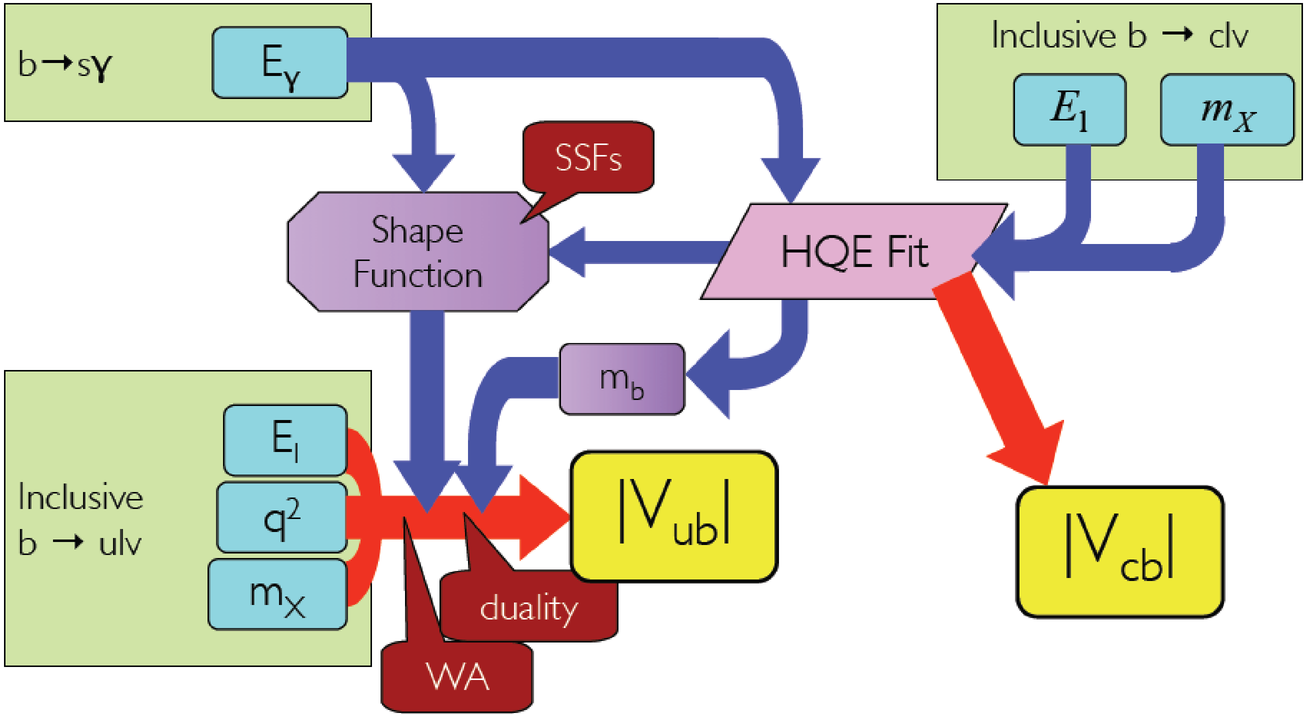


- Possible NP discovery from precise CKM metrology
- Precise knowledge of SM parameters essential in any scenario

How to make the dream reality?

- Need very precise measurements
- Is 2% error on V_{ub} feasible?
  - Experimentally: yes (B.Viaud)
  - Theoretically: maybe (P.Gambino)
  - Note
    - “maybe” is a very positive answer at this stage
    - need to discuss with other experts
    - (endorsed already by I.Bigi)
- (Also - need nature to be kind)

$|V_{ub}|$ determination pattern: complex !



It will be hard to evaluate precisely the Super B factory's potential without a rigorous study (i.e. simulation, as accurate as possible).

-> Too Many things to know, from many th. or exp. sources, having a complicated behavior (w.r.t the backgrounds, for example) to obtain reliable results otherwise...

P. GAMBINO

A new theoretical analysis

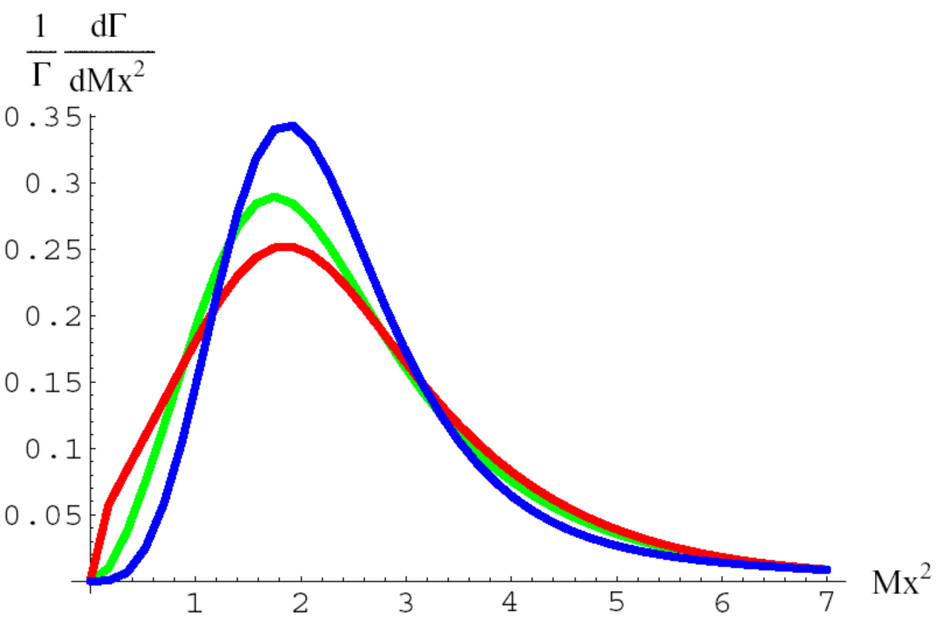
- **kinetic scheme**. Wilsonian infrared cutoff μ~1 GeV: contribution of soft gluons absorbed into definition of OPE parameters AND distribution function(s)
- **Fermi motion**: finite m_b SF, includes all available subleading corrections
- local OPE breaks down at **high q^2**: need to model the tail, consistent with positivity, **WA** naturally emerge.
- Triple differential distribution including all known pert and nonpert effects, c++ code

published in PG, P.Giordano, G.Ossola, N.Uraltsev, JHEP10(2007)058

P. GAMBINO

Theoretical errors

- Parametric errors generally dominant, in particular m_b, 3-4%
- Perturbative corrections 2-3%
- Functional form 1-2%
- Modelling of the q^2 tail and WA depending on cut from 0 to 7%. WA tends to decrease V_{ub}



cuts	$\|V_{ub}\| \times 10^3$	f	exp	par	pert	tail model	q_*^2	X	ff	tot th
A [28]	3.87	0.71	6.7	3.5	1.7	1.6	2.0	$^{+0.0}_{-2.7}$	$^{+2.4}_{-1.1}$	$\pm 4.7^{+2.4}_{-3.8}$
B [28, 29]	4.44	0.38	7.3	3.5	2.6	3.0	4.0	$^{+0.0}_{-5.0}$	$^{+1.4}_{-0.5}$	$\pm 6.6^{+1.4}_{-5.5}$
C [30]	4.05	0.30	5.7	4.2	3.3	1.8	0.9	$^{+0.0}_{-6.2}$	$^{+1.2}_{-0.7}$	$\pm 5.7^{+1.2}_{-6.9}$

A= M_X cut Belle, B= (M_x,q^2) cut Belle+Babar, C= E_l cut Babar

Overall theory errors are 5-9%, depending on the cuts.

P. GAMBINO

Main theoretical desiderata

- know the b mass and the OPE pars precisely
  lattice, $b\to c$ and bsγ moments, pert calculations, goal 15-20 MeV for m_b
- study all the spectra of $b \to u\, l\, \nu$
  to constrain WA and the SFs, complementary to OPE constraints
- be as inclusive as possible
  to minimize dependence on functional forms

Present parametric is 3.5% with δm_b~40 MeV, dominates cleanest cuts.
From $b\to c$ experience, duality violation should be small
Therefore, a 2% goal on $|V_{ub}|$ seems to be realistic.

Rare Decays

- Several talks
  - T.Hurth (b→sγ and b→sll)
  - A.Bevan (B→τν(γ))
  - S.Robertson (b→sll, b→lν and others)
  - F.Renga (b→sll and b→sνν)
  - J.Walsh (b→sγ)
- Recurring theme:
  - Clean environment, hermiticity and very high statistics give SuperB huge advantage for recoil analysis (hadronic tags)

- Nonperturbative corrections $\Lambda^2/m_{b,c}^2$ to $\Gamma(\bar{B} \to X_s\gamma)$ are well under control

- However: Estimation of power corrections of $O(\alpha_s\Lambda/mb)$ should be improved:
  Largest uncertainty (5%) in our new NNLL prediction (see Lee et al)

- Further uncertainties: parametric (3%), higher-order (3%), mc-interpolation (3%)

$$BR(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6\,\text{GeV}} = BR(\bar{B} \to X_c e\bar{\nu})^{\text{exp}} \left[\frac{\Gamma(b \to s\gamma)}{\Gamma(b \to ce\bar{\nu})}\right]_{\text{LO EW}} f\left(\frac{\alpha_s(M_W)}{\alpha_s(m_b)}\right) \times$$

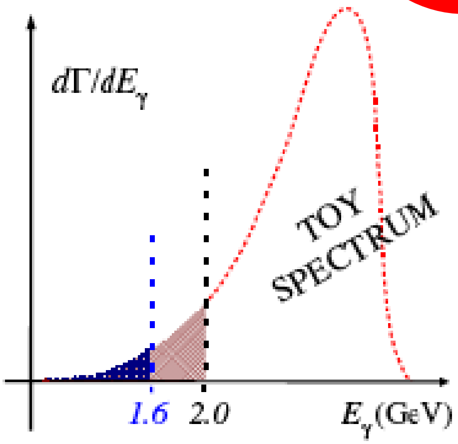
$$\times \left\{1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_{\text{em}}) + \mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right) + \mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right) + \mathcal{O}\left(\frac{\alpha_s\Lambda}{m_b}\right)\right\}$$

NLO NNLO

∼25% ∼7% ∼4% ∼1% ∼3% ∼5%

- Additional sensitivities to nonperturbative physics
  due to necessary cuts in the photon energy spectrum
  to suppress the $B\bar{B}$ background:

  Shape function methods and multi-scale SCET analysis
  ⇒ Additional theoretical uncertainties

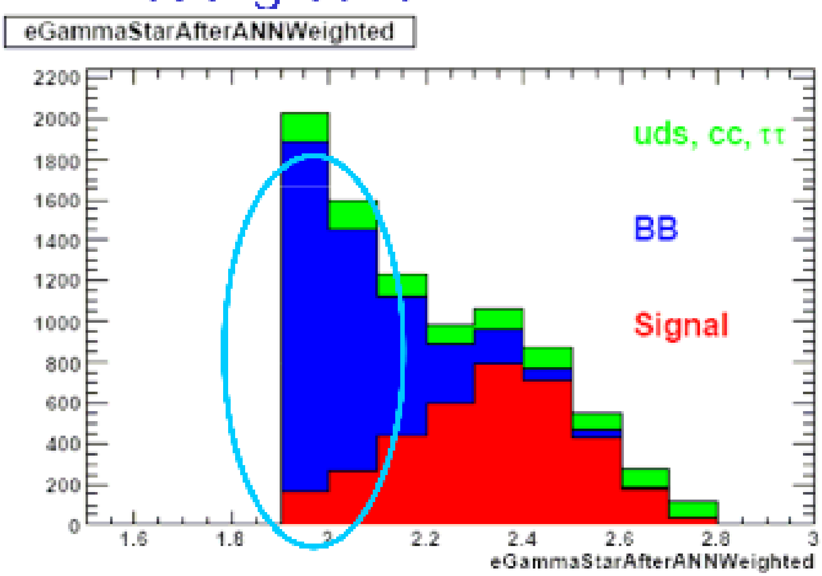


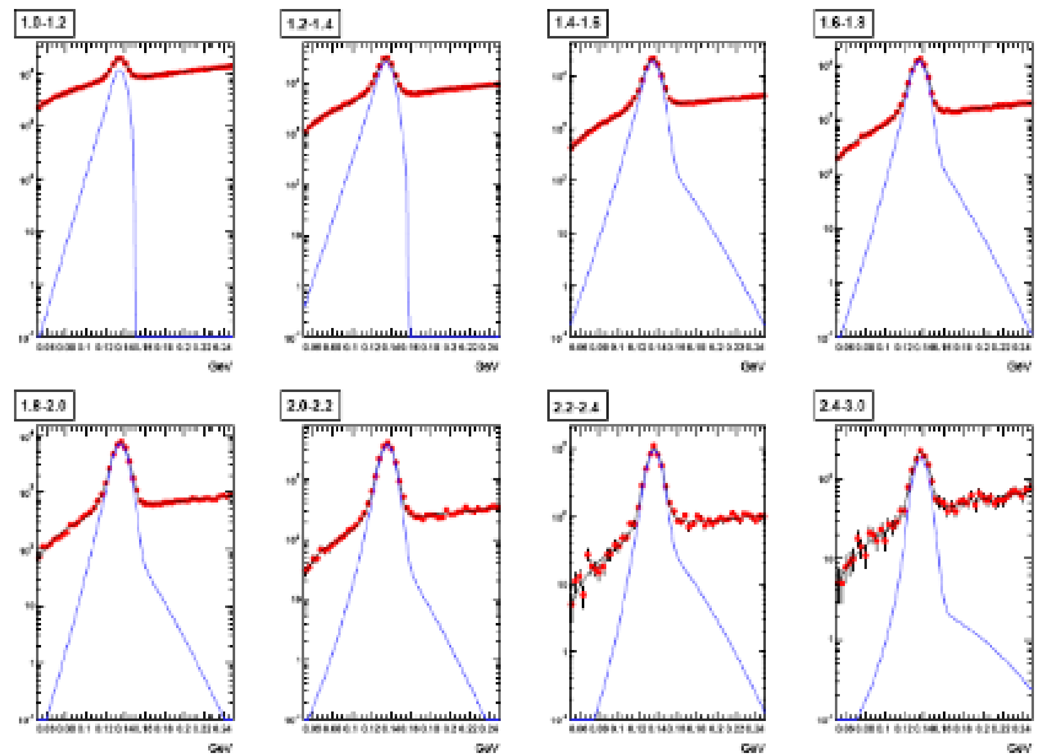
Main source of theoretical uncertainty in B(b→sγ) at present.
If this can be removed, theory error could be 3%.

Inclusive, lepton tag: after selection

- BB background reduced with π^0 and η veto
- Still significant background remains at low $E\gamma$
- Study inclusive π^0 and η production to tune MC of BB background

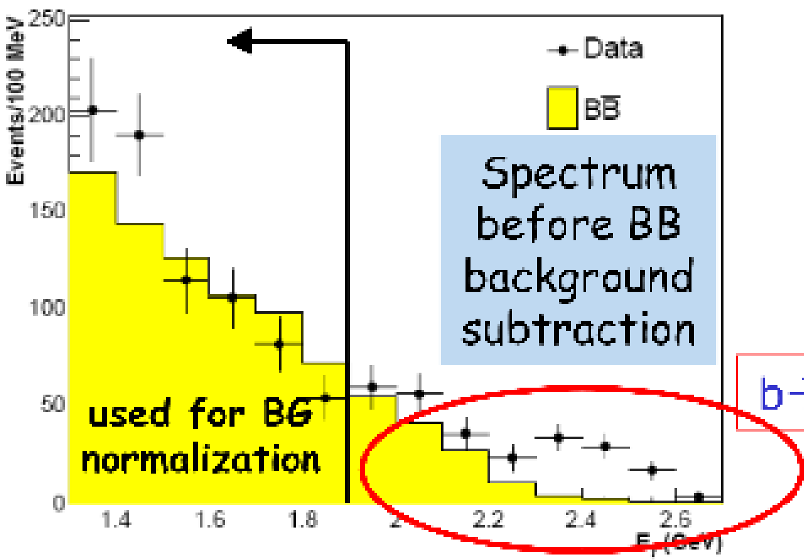
$\gamma\gamma$ invariant mass in bins of π^0 energy



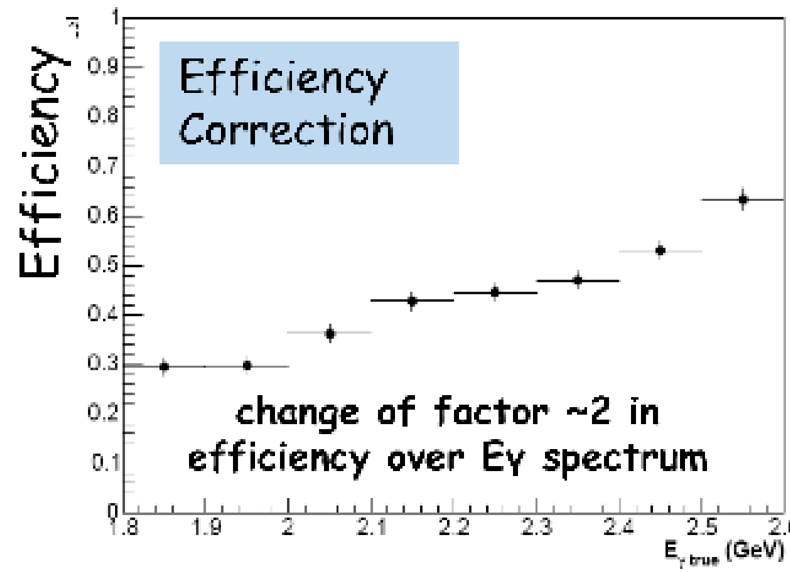


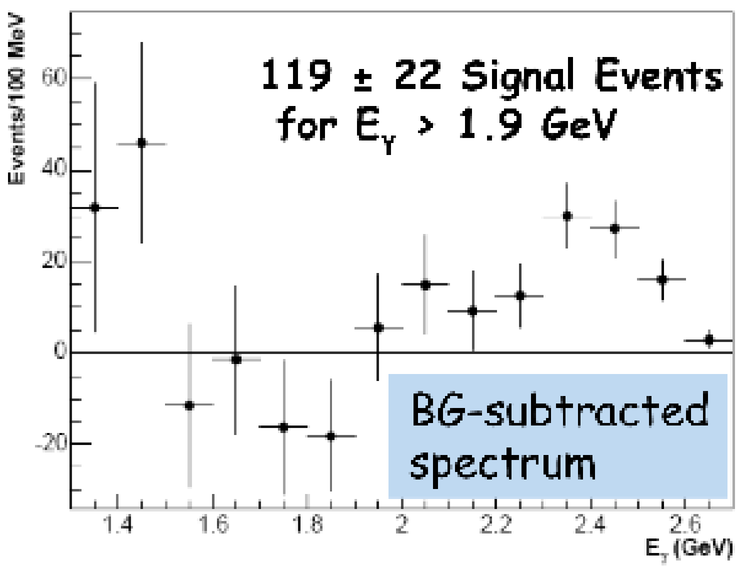
Fits to data and MC

Inclusive, hadronic tags: E_γ Spectrum



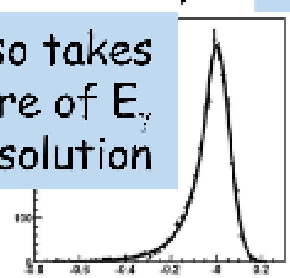
b→sγ signal

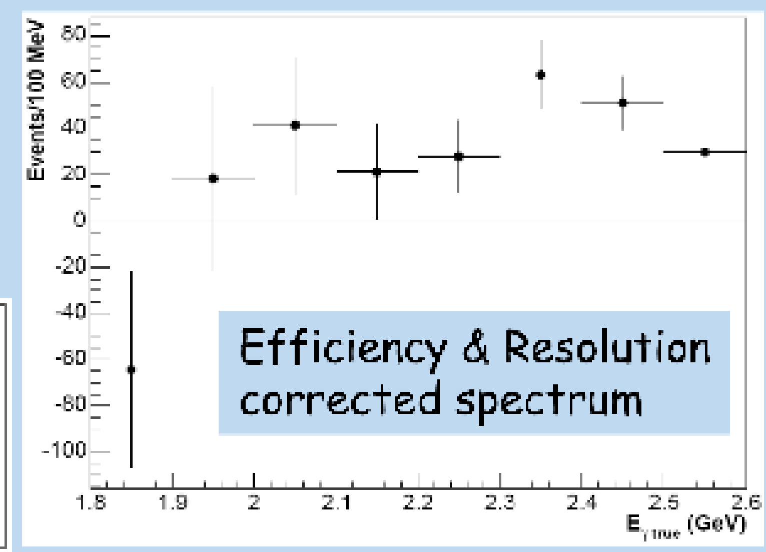




efficiency correction

also takes care of E_γ resolution





Recoil Technique (II)

EXPECTED IMPROVEMENTS at SUPER-B

- The Super-B detector design would introduce significant improvement in the recoil performances;
- HERMITICITY:

  helps to reduce the background when applying a cut on the track multiplicity in the recoil (see M. Mazur talk in Paris) → *30% bkg reduction is realistic*

  - modify the distribution of Eextra (the most important cut) → *effect to be established, see next slide*
- VERTEXING:
  - vertexing informations poorly used at present;
  - bkg reduction is probably possible applying vertexing requirements and secondary vertex informations;
- OTHER (PID, K_L^0 veto, etc.).

Recoil Technique (II)

EXPECTED IMPROVEMENTS at SUPER-B

- The Super-B detector design would introduce significant improvement in the recoil performances;
- HERMITICITY:

  helps t... ng a cut on the tra... M. Mazur talk in... *listic*

  - modify ... t important cut) → ... *slide*

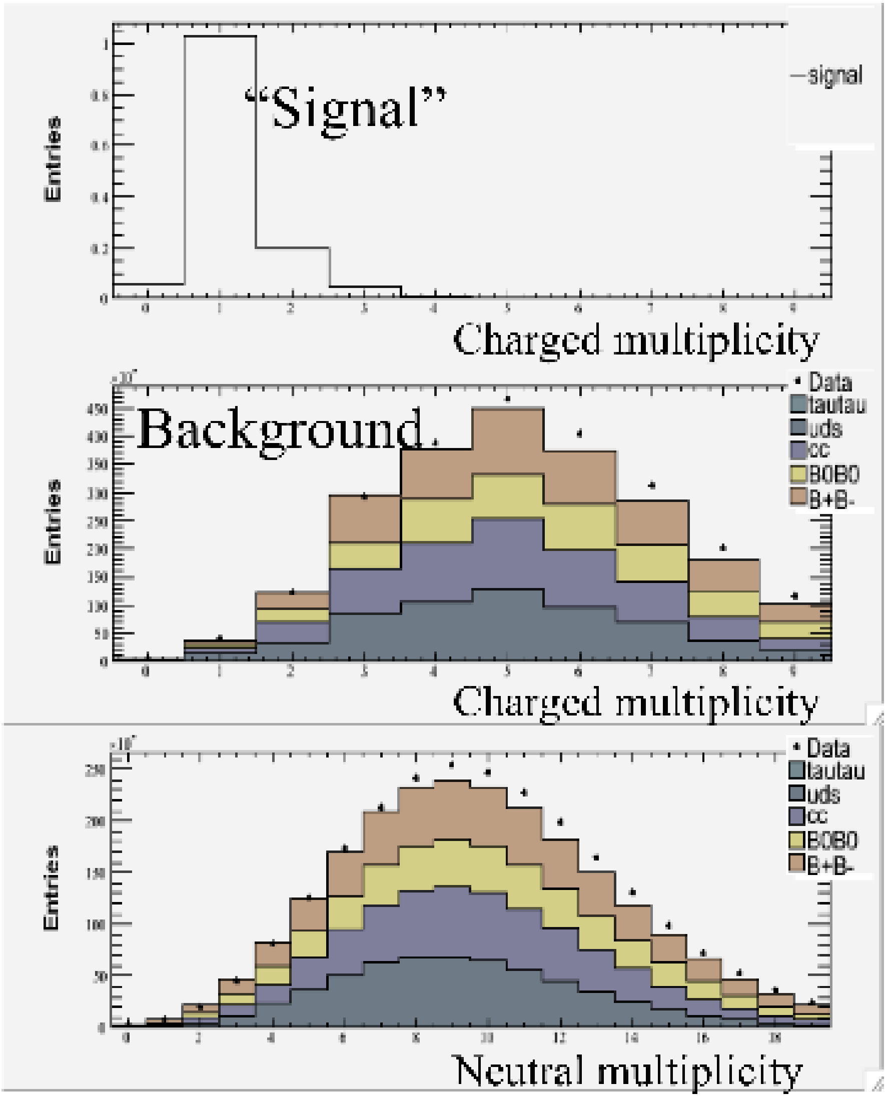
Detailed Simulations Needed to have precise estimates of improvements

- VERTEXING:
  - vertexing informations poorly used at present;
  - bkg reduction is probably possible applying vertexing requirements and secondary vertex informations;
- OTHER (PID, K_L^0 veto, etc.).

Caveats

Searches for modes with missing energy rely heavily on the low multiplicity of the signal to keep backgrounds managable

- higher multiplicity requires harder cuts or additional kinematic handles
- Detector non-hermiticity and/or non-physics "junk" is a killer
- Tag reconstruction is usually CLEANER in these events, so can potentially use tag modes that appear to be too messy in "generic" B decays



Caveats

Tag B reconstruction efficiency scales non-linearly with tracking and calorimeter acceptance

- Not clear what the impact of reduced beam energy asymmetry will be

Need to balance reconstruction efficiency against cleanliness of the reconstruction by careful choice of what modes to reconstruct

- Potential for significant efficiency gain by including e.g. $D^0 \to K^+\pi^-2\pi^0$, or purity gain by including e.g. J/Ψ - seeded decays

Devil is in the details!

- performance of vertexing, kinematic fitting, track-cluster matching, presence of tracking and/or calorimeter artifacts etc etc.

⇒ **Important to study impact of proposed detector design**

Recoil analyses

- Sensitivity to inclusive B($b \to s\gamma$) will be limited by systematics (and theory error)
- Benefit to reduce background from improved hermiticity?
  - Needs simulation study
  - Would allow reduction of photon energy cut
- Hadronic tag gives photon momentum in B rest frame – important for moments analysis
- Best approach may be different for asymmetry measurements

T.HURTH

Recent proposal: normalization to semileptonic $B \to X_u \ell \nu$ decay rate with the same cut reduces the impact of $1/m_b$ corrections in the high-q^2 region significantly. Ligeti,Tackmann,hep-ph/0707.1694

Numerical results Huber, Hurth, Lunghi

$$\mathcal{R}(s_0)^{\rm high}_{\mu\mu} = 2.29 \times 10^{-3}\Big(1 \pm 0.04_{\rm scale} \pm 0.02_{m_t} \pm 0.01_{C,m_c} \pm 0.006_{m_b} \pm 0.005_{\alpha_s} \pm 0.09_{\rm CKM}$$
$$\pm 0.003_{\lambda_2} \pm 0.05_{\rho_1} \pm 0.03_{f_u^0+f_s} \pm 0.05_{f_u^0-f_s}\Big)$$
$$= 2.29 \times 10^{-3}(1 \pm 0.13)$$

Theoretical uncertainty in B(b→sll) quite large at present.
But, in this approach, dominated by CKM factors.

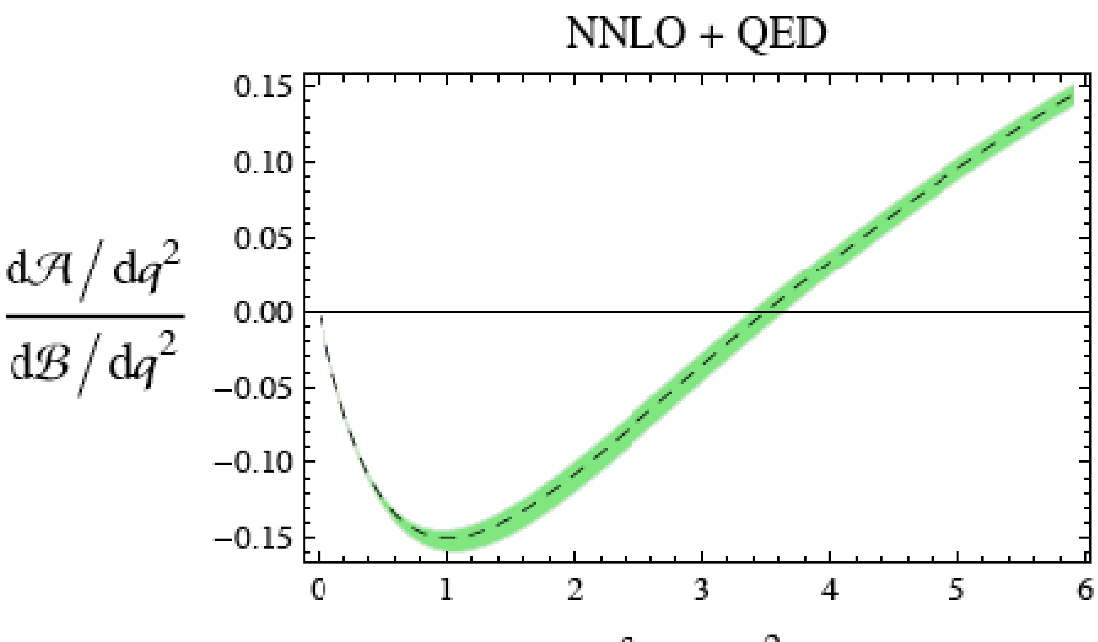
T.HURTH

Numerical results Huber, Hurth, Lunghi arXiv/0712.3009[hep-ph]

- Zero of the forward-backward asymmetry q_0^2:

$$(q_0^2)_{\mu\mu} = \Big[3.50 \pm 0.10_{\text{scale}} \pm 0.002_{m_t} \pm 0.04_{m_c,C} \pm 0.05_{m_b} \pm 0.03_{\alpha_s(M_Z)} \pm 0.001_{\lambda_1} \pm 0.01_{\lambda_2}\Big]\,\text{GeV}^2 = (3.50 \pm 0.12)\,\text{GeV}^2$$

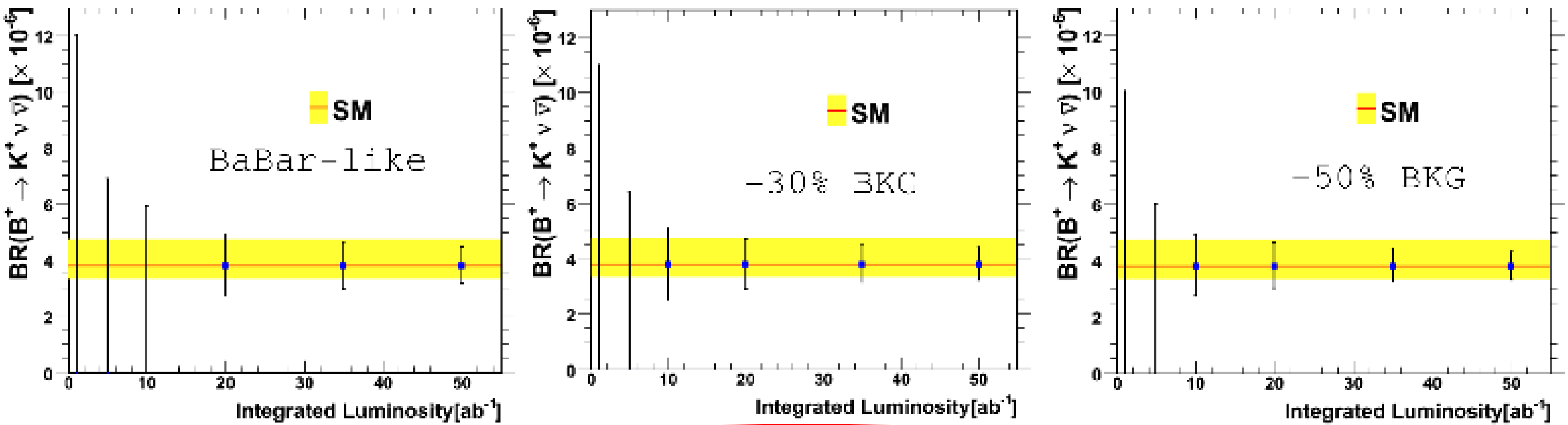
$$(q_0^2)_{ee} = \Big[3.38 \pm 0.09_{\text{scale}} \pm 0.002_{m_t} \pm 0.04_{m_c,C} \pm 0.04_{m_b} \pm 0.03_{\alpha_s(M_Z)} \pm 0.002_{\lambda_1} \pm 0.01_{\lambda_2}\Big]\,\text{GeV}^2 = (3.38 \pm 0.11)\,\text{GeV}^2$$



Forward-backward asymmetry in inclusive b→sll
Theoretically very clean! (Much better than exclusive)

$B^+ \rightarrow K^+ \nu \nu$ (II)

RESULTS at SUPER-B



Observation between 10 and 20 ab^{-1};

Exp. error ~ theoretical error around 30 ab^{-1};

18% error at 50ab^{-1} in the most conservative scenario.

Detector Issues

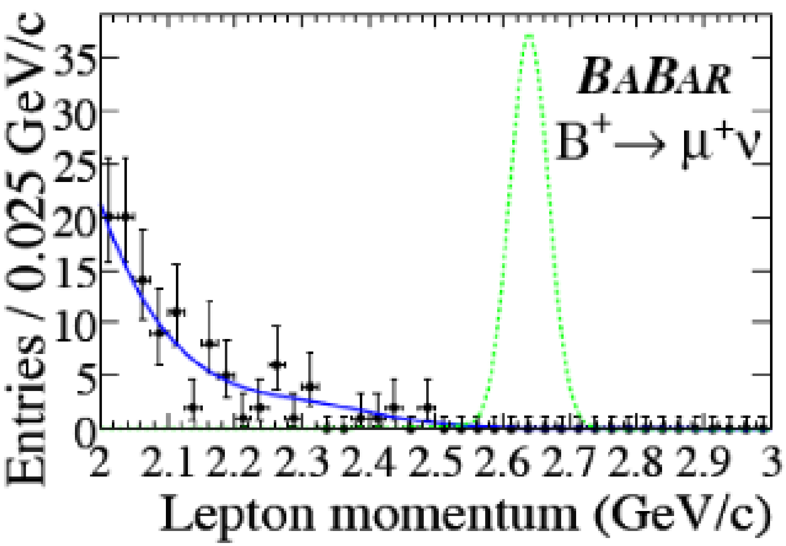
- Current systematic errors related to the detector are:
  - PID : 2% (2-6% for Belle)
  - π^0 : 1.4 (3% for Belle)
  - Tracking : 5.8% (1-3% for Belle)

- How does this channel benefit from:
  - Improved μ/K^0_L efficiency.
  - Improved calorimeter performance/hermiticity.
  - Improved PID performance/hermiticity.

- SuperB beam background conditions?

Tagged $B^+ \to l^+\nu$ ($l = e, \mu$)

- Signal lies at kinematic endpoint in lepton p* for B decays, hence essentially no B background
- Continuum background can produce high p* leptons, but this background can be directly determined from data using the tag B m_{ES} sideband
- Narrow signal peak would lead to a very compelling signal with a very small number of events



	$e^+\nu$	$\mu^+\nu$
$\epsilon_{tot} \times 10^5$	135 ± 4	120 ± 4
n_b^* MC	2.66 ± 0.13	5.74 ± 0.25
n_b^*	2.67 ± 0.19	5.67 ± 0.34
n_s^*	-0.07 ± 0.03	-0.11 ± 0.05
$\mathcal{B} \times 10^{-6}$	$-0.1^{+2.6}_{-1.7}$	$-0.2^{+2.7}_{-1.8}$
$\mathcal{B}^{90\%\ C.L.}$	5.2×10^{-6}	5.6×10^{-6}

Leptonic Decays

- $B \to \tau\nu$ will be limited by systematics at some stage
  - CDR estimate of precision may be optimistic
- $B \to \mu\nu$ does **not** suffer the same problem
  - Will become “golden channel” for leptonic B decays at some luminosity (likely above 10/ab)
- Also allows universality test

Benchmarks

- Presentation from F.Ronga
- Work done so far on SPS1a
- Discussion with F.Ronga & S.Heinemayer

The SPS1a benchmark point

A (too) good point for LHC!

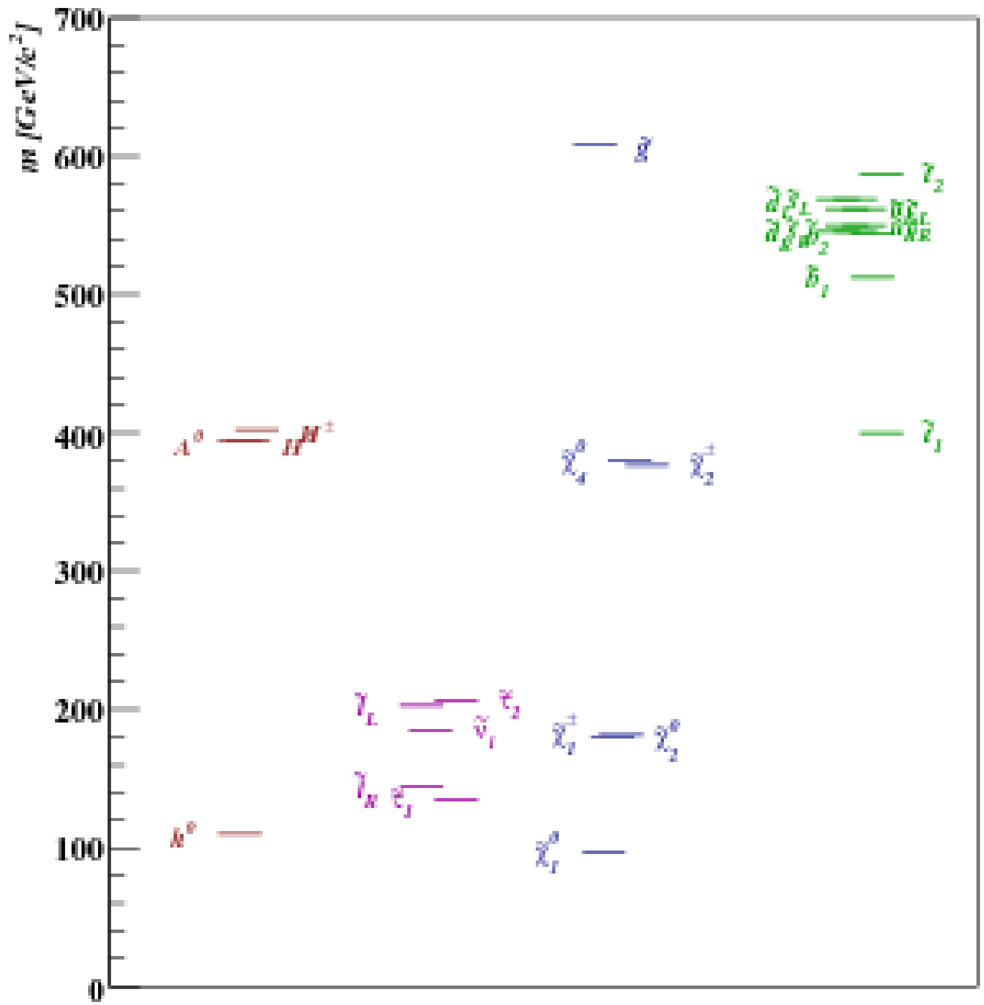
$$\begin{aligned} M_0 &= +100\ \mathrm{GeV}/c^2 \\ M_{1/2} &= +250\ \mathrm{GeV}/c^2 \\ A_0 &= -100\ \mathrm{GeV}/c^2 \\ \tan\beta &= +10 \\ \mathrm{sign}(\mu) &= +1 \end{aligned}$$

Allows cascade decay
$\tilde{q}_L \to \tilde{\chi}^0_2 q \to \tilde{\ell}_R \ell q \to \tilde{\chi}^0_1 \ell\ell q$
for "edge" measurements:

$$\left(m^2_{ll}\right)^{\mathrm{edge}} = \frac{\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R}\right)\left(m^2_{\tilde{l}_R} - m^2_{\tilde{\chi}^0_1}\right)}{m^2_{\tilde{l}_R}}$$

$$\left(m^2_{qll}\right)^{\mathrm{edge}} = \frac{\left(m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2}\right)\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\chi}^0_1}\right)}{m^2_{\tilde{\chi}^0_2}}$$

$$\left(m^2_{ql}\right)^{\mathrm{edge}}_{\mathrm{min}} = \frac{\left(m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2}\right)\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R}\right)}{m^2_{\tilde{\chi}^0_2}}$$



SUSY spectrum at SPS1a

Note: *SPS1a is close to the overall preferred minimum with today's data.*

LHC performance at SPS1a [hep-ph/0410364]

Performance based on 300/fb (2014)

SUSY spectrum [GeV]

	Mass	Error
$\tilde{\chi}_1^0$	96.9	4.8
$\tilde{\chi}_2^0$	179.8	4.7
$\tilde{\chi}_4^0$	375.6	5.1
$\tilde{e}_R$	144.1	4.8
$\tilde{e}_L$	202.6	5.0
$\tilde{\mu}_R$	144.1	4.8
$\tilde{\mu}_L$	202.6	5.0
$\tilde{\tau}_1$	134.7	8.0
$\tilde{q}_R$	547.5	12.0
$\tilde{q}_L$	565.0	8.7
$\tilde{b}_1$	514.9	7.5
$\tilde{b}_2$	544.1	7.9
$\tilde{g}$	608.0	8.0
h^0	112.9	0.25

Edge measurements [GeV]

$(m_{\ell\ell})^{\mathrm{edge}}$	58.878	0.085
$(m_{q\ell\ell})^{\mathrm{edge}}$	451.1	4.5
$(m_{ql})^{\mathrm{edge}}_{\mathrm{min}}$	317.5	3.1

⇒ Impact on CMSSM parameters

- include this spectrum as constraints;
- combine with today's constraints;
- get best fit values and errors:

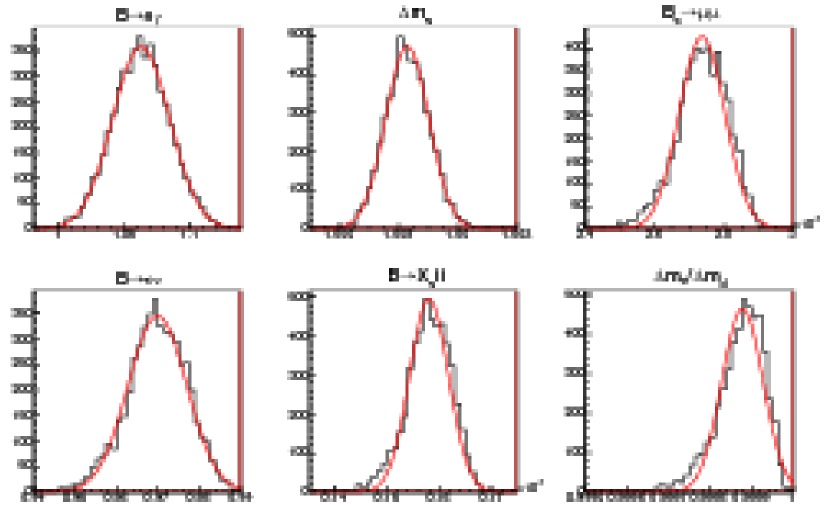
$$M_0 = 100.0 \pm 1.5$$
$$M_{1/2} = 250.0 \pm 1.1$$
$$A_0 = 100 \pm 30$$
$$\tan\beta = 9.8 \pm 1.2$$

All ideal masses generated by `SoftSusy`

Flavour Physics predictions

Strong impact of LHC constraints on Flavour Sector!

$$
\begin{aligned}
R(B \to s\gamma) &= 1.063 \pm 0.022 \\
R(\Delta m_s) &= 1.0582 \pm 0.0007 \\
R(B \to \tau\nu) &= 0.970 \pm 0.007 \\
R(B \to X_s \ell\ell) &= 0.910 \pm 0.003 \\
R(\Delta m_s / \Delta m_d) &= 0.99988 \pm 0.00005 \\
B_s \to \mu\mu &= 2.736\text{e-}09 \pm 0.066\text{e-}9 \\
B_d \to \mu\mu &= 1.580\text{e-}10 \pm 0.038\text{e-}10
\end{aligned}
$$

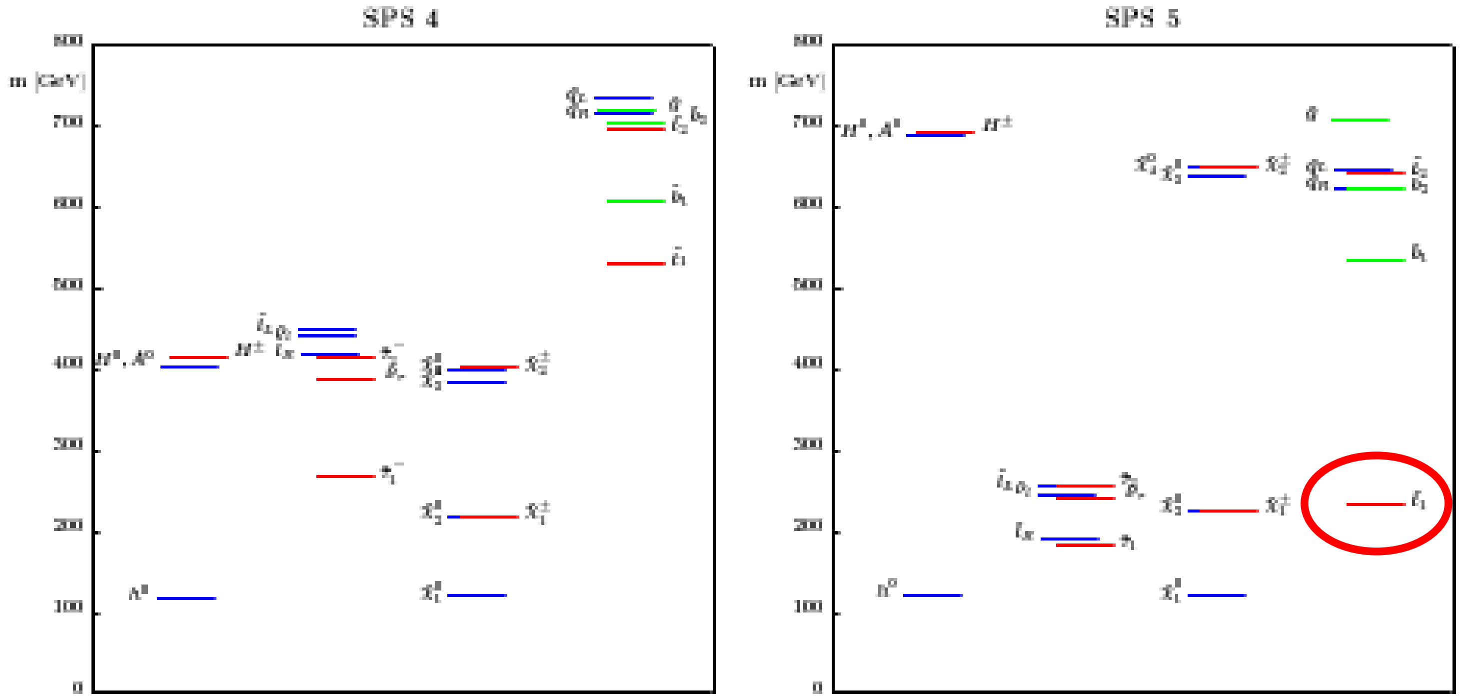


But...

- this point is especially good for L(H)C;
- we assumed MFV;
- correlations are not taken into account.

Benchmarks

- Presentation from F.Ronga
- Work done so far on SPS1a
- Discussion with F.Ronga & S.Heinemayer
  - Request to include more observables
    - $b \to s\nu\nu$
    - Forward backward asymmetry in $b \to sll$ (inclusive)
  - Add new benchmark points
    - SPS4 and SPS5 (do LHC sensitivity estimates exist?)
    - Points with non-MFV flavour structure



SPS 4: mSUGRA scenario with large $\tan\beta$

The large value of $\tan\beta$ in this scenario has an important impact on the phenomenology in the Higgs sector. The couplings of A, H to $b\bar{b}$ and $\tau^+\tau^-$ as well as the $H^\pm t\bar{b}$ couplings are significantly enhanced in this scenario, resulting in particular in large associated production cross sections for the heavy Higgs bosons.

Point:

$$m_0 = 400\,\text{GeV}, \quad m_{1/2} = 300\,\text{GeV}, \quad A_0 = 0, \quad \tan\beta = 50, \quad \mu > 0.$$

This point equals mSUGRA point 3 of the "Points d'Aix" and is similar to BDEGMOPW point I.

Expect observable flavour signatures for these MFV points

SPS 5: mSUGRA scenario with relatively light scalar top quark

This scenario is characterized by a large negative value of A_0, which allows consistency of the relatively low value of $\tan\beta$ with the constraints from the Higgs search at LEP, see Ref. [34].

Point:

$$m_0 = 150\,\text{GeV}, \quad m_{1/2} = 300\,\text{GeV}, \quad A_0 = -1000, \quad \tan\beta = 5, \quad \mu > 0.$$

This point equals mSUGRA point 4 of the "Points d'Aix".

How to Add Flavour Structure?

- Explicit models (T.Shindou & collaborators)
  - mSUGRA (MFV)
  - MSSM + r-h-neutrinos
  - SU(5) SUSY with r-h-neutrinos
  - MSSM with U(2) flavour symmetry
- Alternative, general, approach:
  - MSSM with mass-insertions
    - M.Ciuchini & L.Silvestrini, work in CDR, update ongoing

MSSM

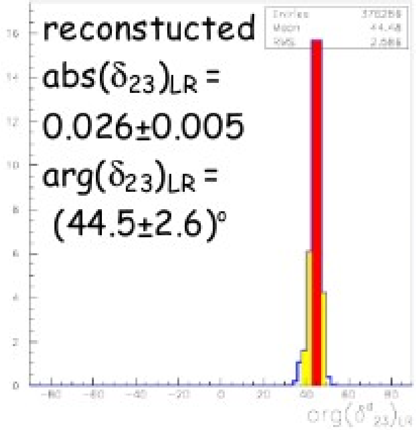
$M^2_{\tilde d} =$

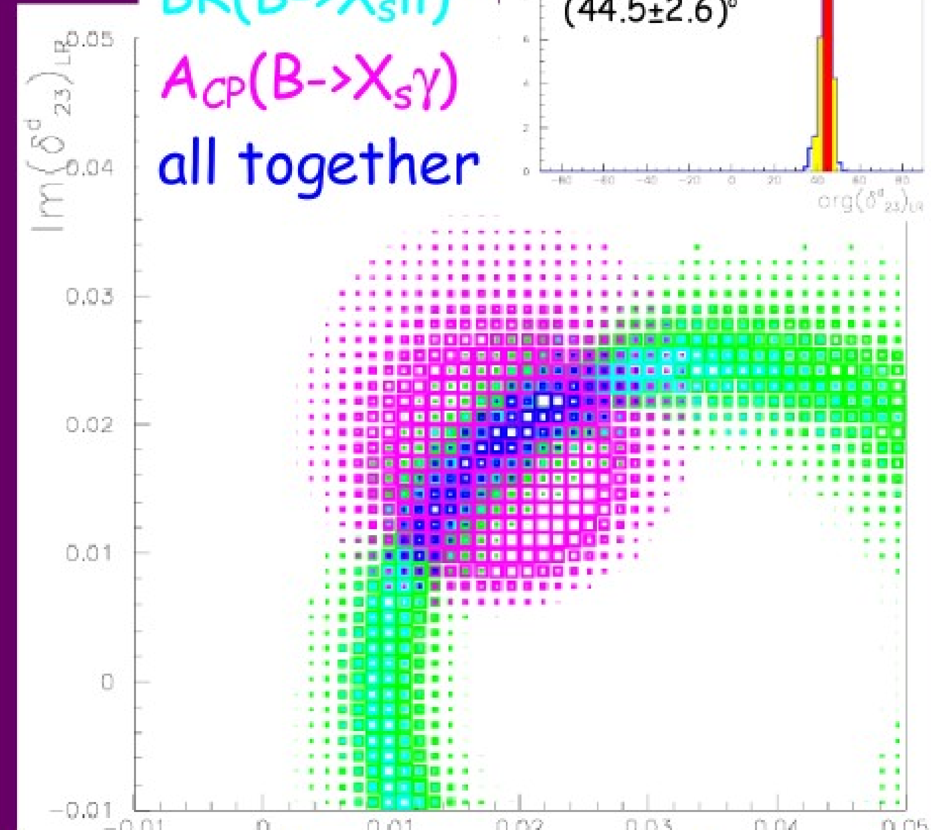
$$\begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d-\mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s-\mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b-\mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

SuperB

LHC, ILC - HE frontier

Mass Insertions
$(\delta^d_{ij})_{AB} = (\Delta^d_{ij})_{AB}/m^2_{\tilde q}$

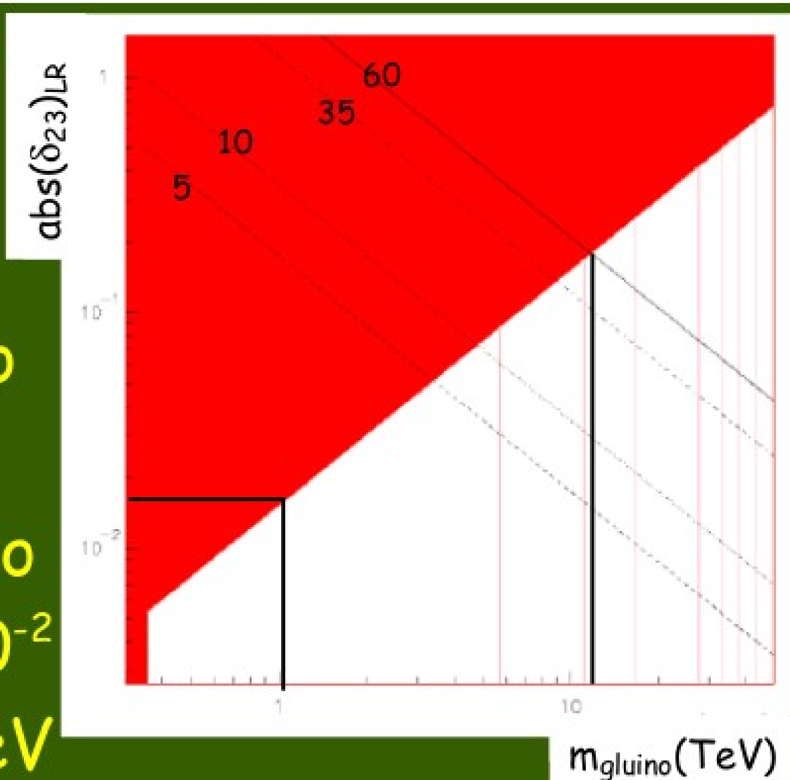




$Im(\delta^d_{23})_{LR}$ vs $Re(\delta^d_{23})_{LR}$

Reconstruction of $(\delta^d_{23})_{LR} = 0.028\, e^{i\pi/4}$ for $\Lambda = m_{\tilde g} = m_{\tilde q} = 1$ TeV

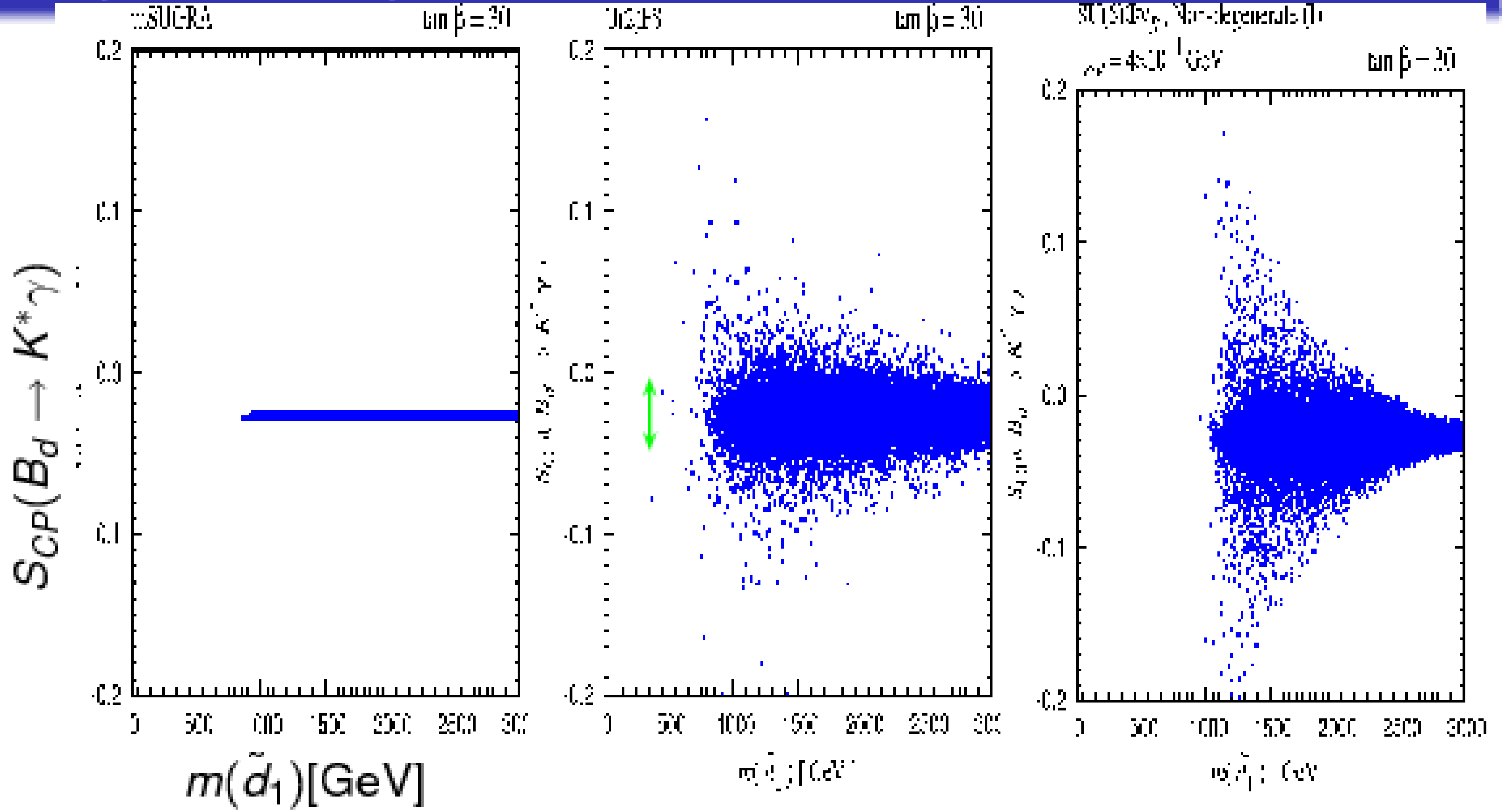
3σ from 0 sensitivity plot



i) sensit. to $\Lambda < 20$ TeV

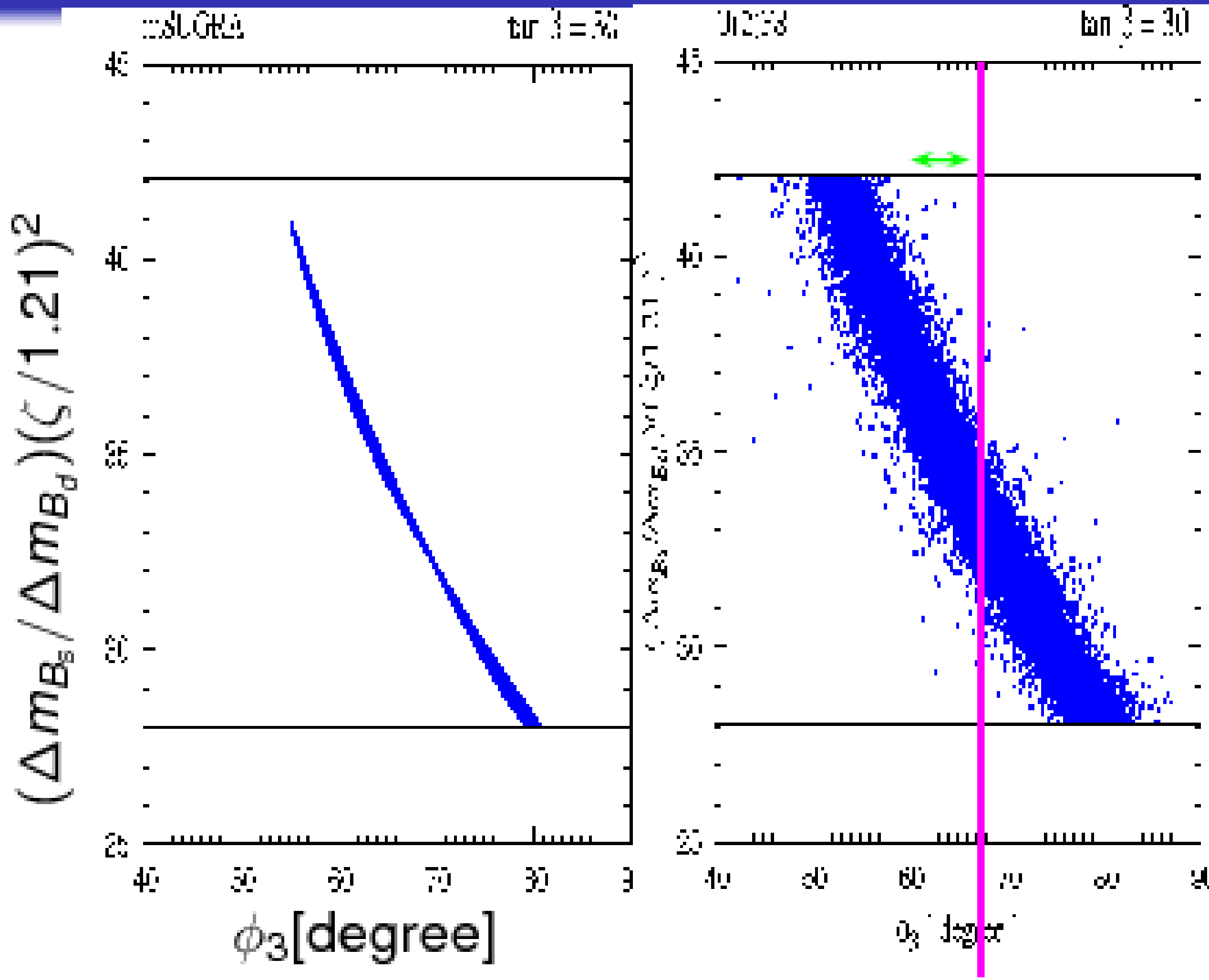
ii) sensit. to $|(\delta^d_{23})_{LR}| > 10^{-2}$ for $\Lambda < 1$ TeV

$S_{CP}(B_d \to K^*\gamma)$



mSUGRA U(2) SU(5) Non-Degen. (I)

Correlation between ϕ_3 and $\Delta m_{B_s}/\Delta m_{B_d}$

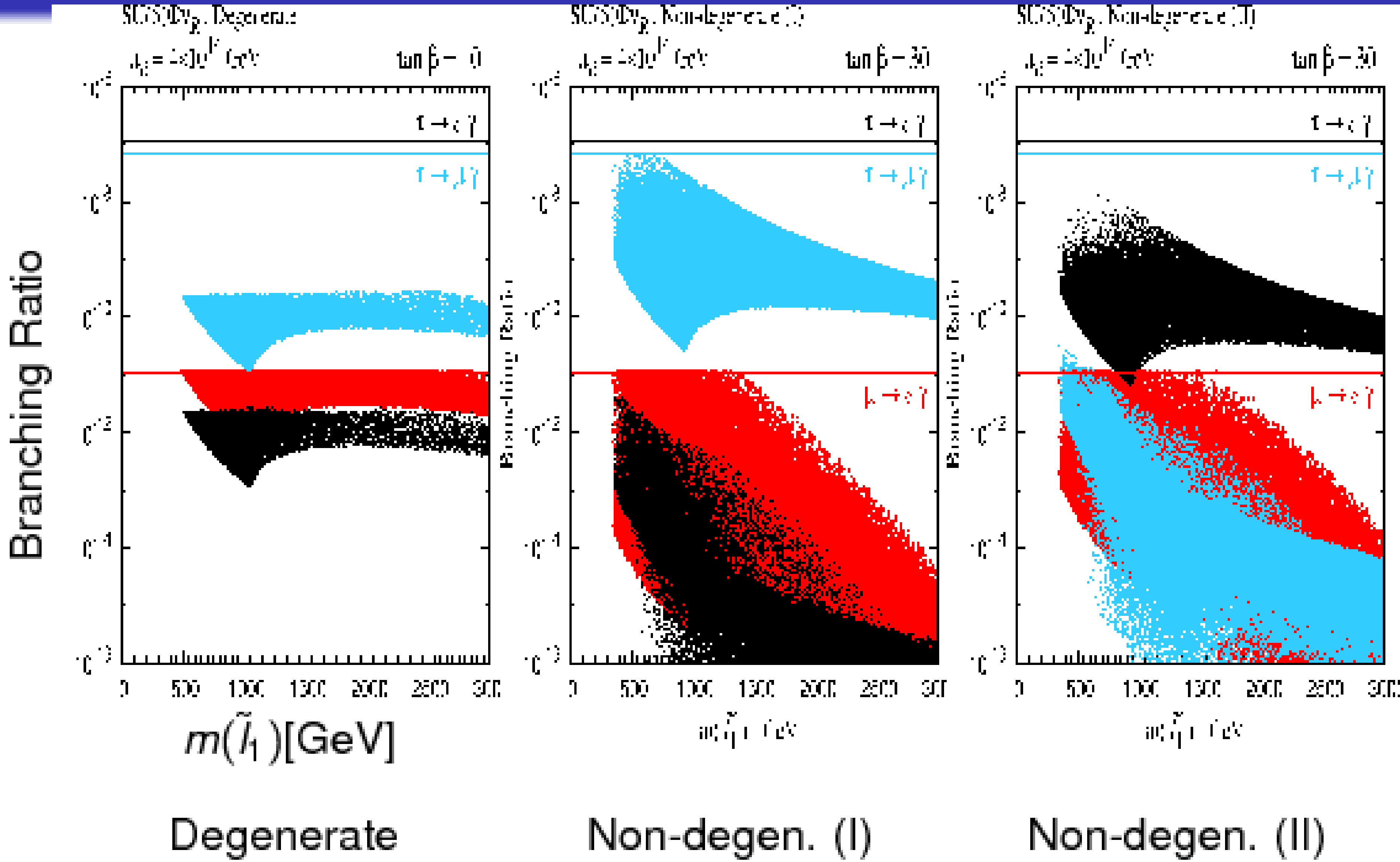


mSUGRA

U(2)

Need <1° precision on γ in UT fit

LFV in SU(5)+RN

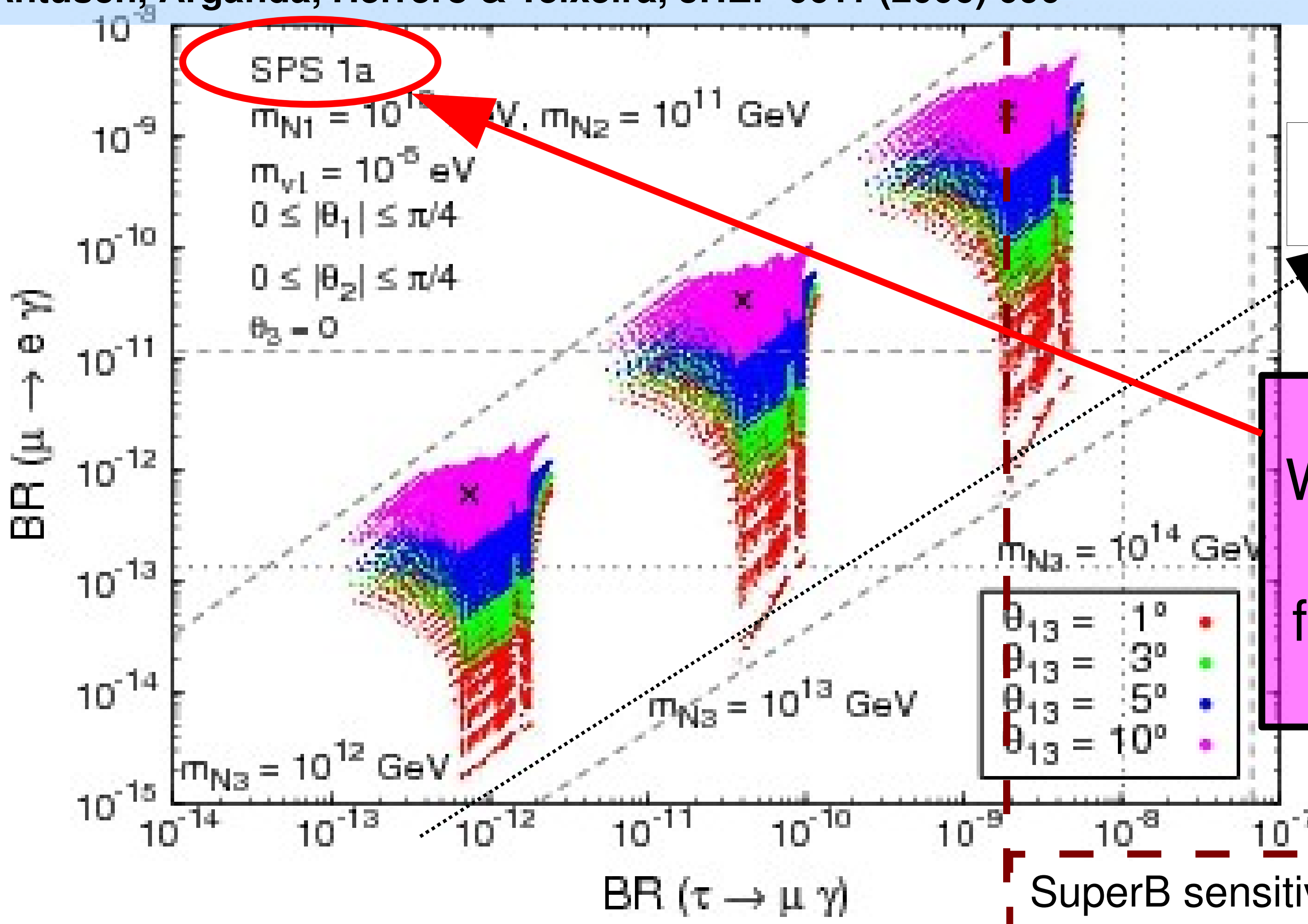


Link with lepton sector (tau lepton flavour violation)

Lepton Flavour & Neutrino Physics

- In many scenarios, LFV rates are linked to (both low and high energy) neutrino parameters

Antusch, Arganda, Herrero & Teixeira, JHEP 0611 (2006) 090



increasing Majorana neutrino mass

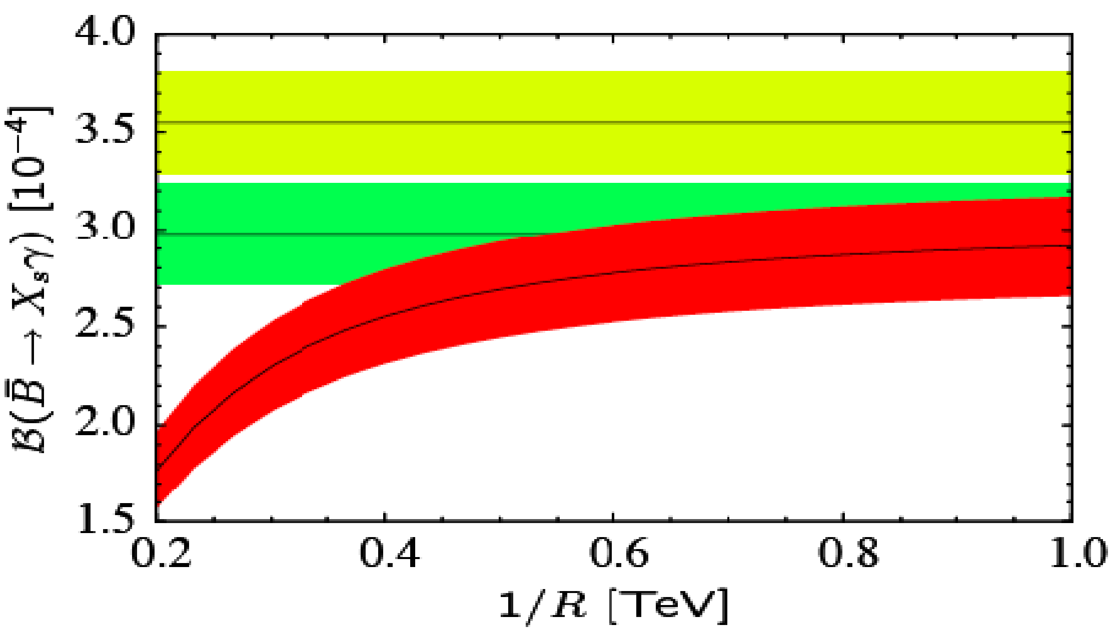
Will contact authors and request plots for SPS4 and SPS5

SuperB sensitivity

NP models

- Most discussion on SUSY and MSSM
- Remember that flavour is generically sensitive to NP – illustrate with a few other models
  - Little Higgs (brief discussion in CDR)
  - Extra dimensions (talk by E.Kou, also T.Hurth)
  - NMSSM (talk by F.Domingo)

Example: Bound on minimal universal extra dimensions $\Rightarrow 1/R \succ 600\mathrm{GeV}$ at 95%CL



Red: LO-UED, Green: SM Theory, Yellow: Experiment By far best bound !

Haisch,Weiler,hep-ph/0703064

Note: Flavour non-universal boundary terms arise radiatively.

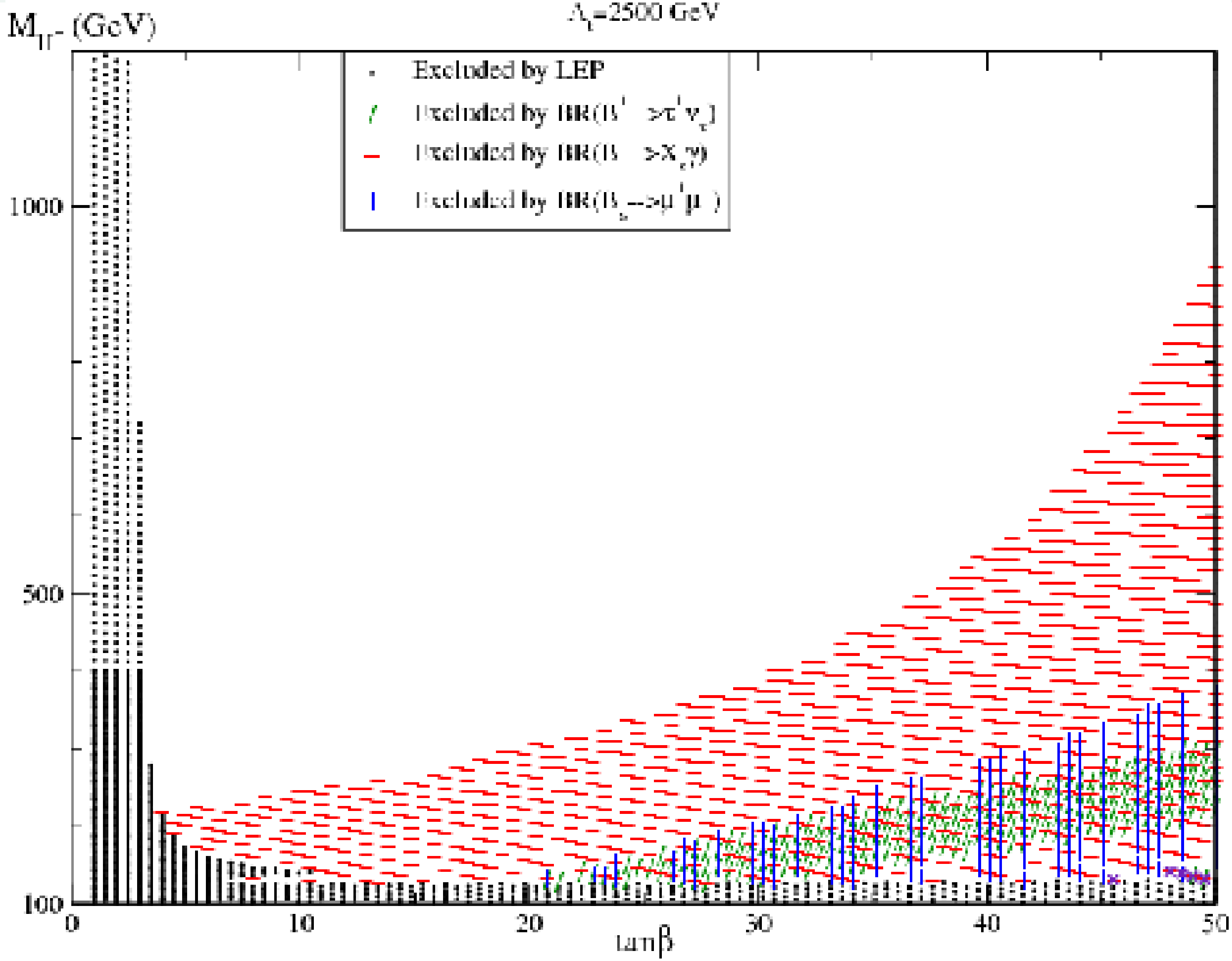
NMSSM specific effects relative to B constraints with respect to the MSSM…

Peculiarities concerning B processes

- Extended Unconstrained Parameter Space: in the NMSSM, low values of $\tan\beta$ (~ 1.5) are not excluded by LEP;
- Charged Higgs Mass: the NMSSM parameter λ gives a negative contribution to $M_{H^\pm}$, which allows for slight modulations on $\bar{B} \to X_s\gamma$;
- The effect of the extended neutralino sector is negligibly small;
- Light pseudoscalars (below 10 GeV) escape LEP constraints, but they are significantly constrained by ΔM_q and $BR(\bar{B}_s \to \mu^+\mu^-)$.

F.DOMINGO

B constraints on the (M_{H^+},tan β) plane



F.DOMINGO

Beginning work on the document

Report from Working Group on B Physics

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Abstract

In this note we summarise the activity of the working group on B physics at the scientific retreat, "SuperB Workshop VI: New Physics at the Super Flavour Factory Super$B$." This consists of two main parts. The first is a description of work done since the writing of the CDR, including work done during the retreat itself, and plans for further work to sharpen the physics case of Super$B$. The second part is an attempt to answer prototype questions, similar to those expected from the International Review Committee.

Prototype Questions

- Comparison between SuperB and KEKB upgrade
  - Some quantative work in progress
  - Emphasise qualitative differences
- Discovery potential of SuperB
- “Golden processes”
  - Many golden processes in B physics
  - Work ongoing to select those with nicest plots
- Benchmarks

From TG presentation at BNM2006

Translations

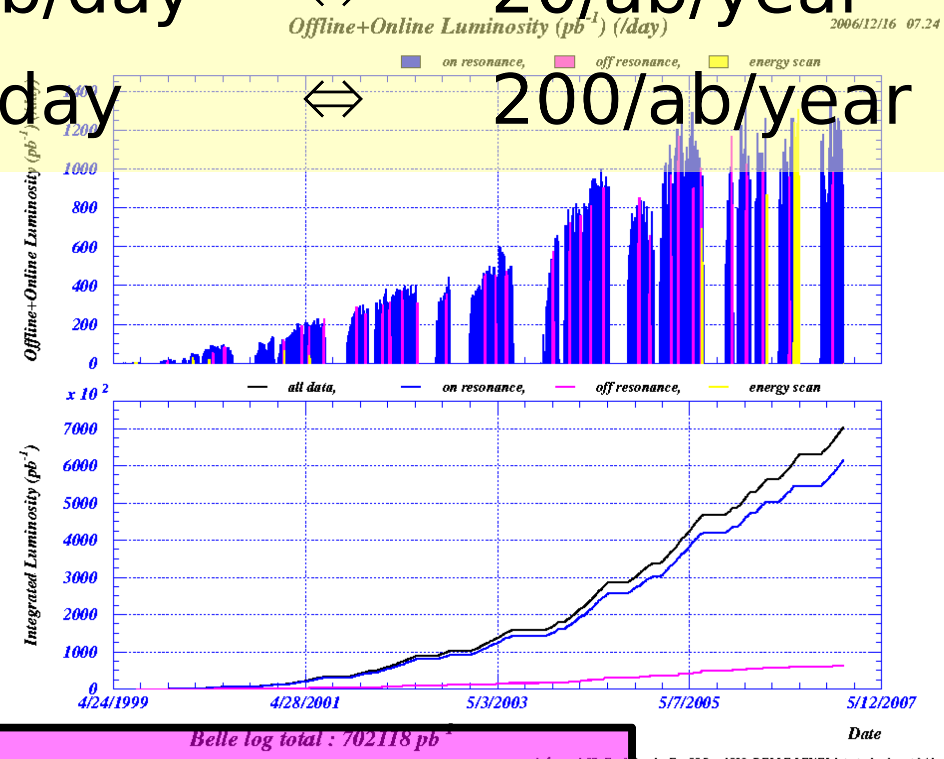
$\mathcal{L}_{peak} = 10^{34}/cm^2/s$	⇔	1/fb/day	⇔	200/fb/year
$\mathcal{L}_{peak} = 10^{35}/cm^2/s$	⇔	10/fb/day	⇔	2/ab/year
$\mathcal{L}_{peak} = 10^{36}/cm^2/s$	⇔	100/fb/day	⇔	20/ab/year
$\mathcal{L}_{peak} = 10^{37}/cm^2/s$	⇔	1/ab/day	⇔	200/ab/year

Assumes that:

- operating stability
- data taking efficiency
- useability of data

all remain similar to now

NB. 1000/ab = 1/zb



To answer Ikaros ...

Thanks

- Would like to thank all participants of the working group
  - We ask a lot of you ...
  - ... and we will ask for more in future
- Special thanks to the local organizers