Ricerca di decadimenti rari del B con energia mancante a SuperB

Elisa Manoni
(INFN Perugia)

Incontri di Fisica delle Alte Energie
Perugia 27-29 Aprile 2011

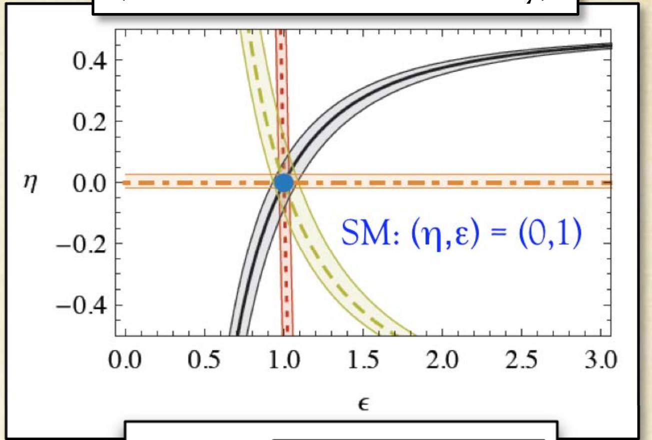
Outline

- Theoretical motivations
- Experimental analysis strategy
- Current experimental status
- Expected sensitivity in SuperB
- Conclusions
- All results should be considered as PRELIMINARY

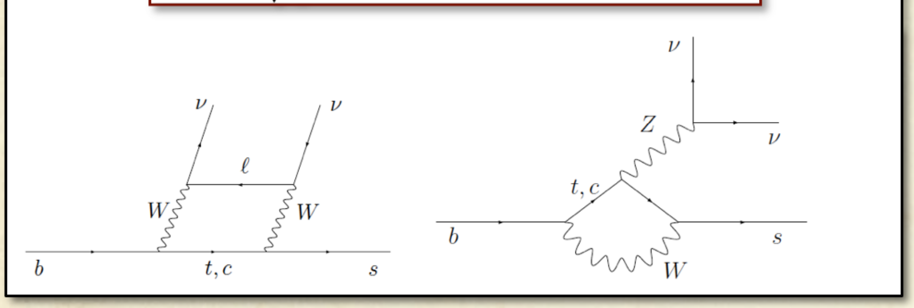
Theoretical motivations : $B \to K^{(*)}\nu\nu$

- Standard Model (SM) prediction (TUM-HEP-709-09) :
  - $B(B \to K\nu\nu) = (4.5 \pm 0.7) \times 10^{-6}\ (1-2\eta)\varepsilon^2$
  - $B(B \to K^*\nu\nu) = (6.8 \pm 1.1) \times 10^{-6}\ (1+1.31\eta)\varepsilon^2$
  - $F_L(B \to K^*\nu\nu) = (0.54 \pm 0.01)\ (1+2\eta)/(1+1.31\eta)$

(theoretical errors only)



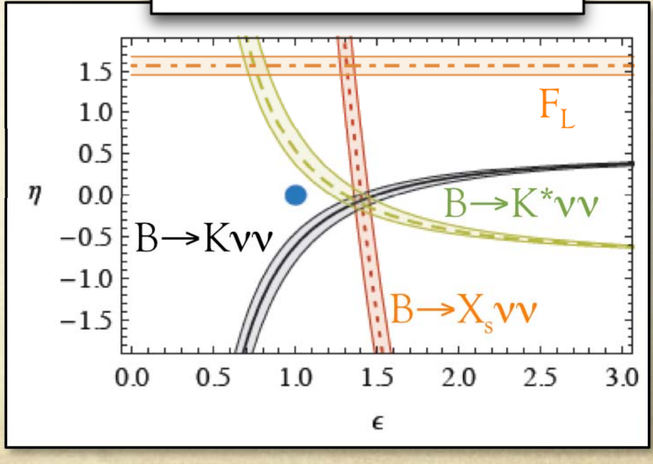
$$\mathcal{H} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* (\mathcal{C}_L^\nu \mathcal{O}^\nu{}_L + \mathcal{C}_R^\nu \mathcal{O}^\nu{}_R) + h.c.$$

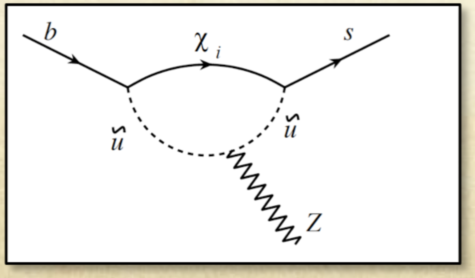


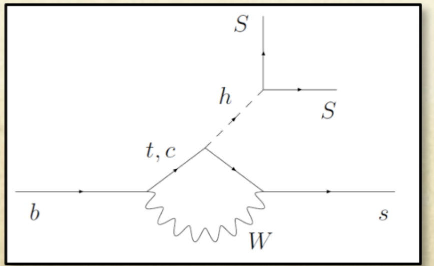
$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{SM}|}$$

$$\eta = \frac{-Re(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

- New Physics (NP) effects
  - Non Standard Z-couplings
  - New sources of missing energy





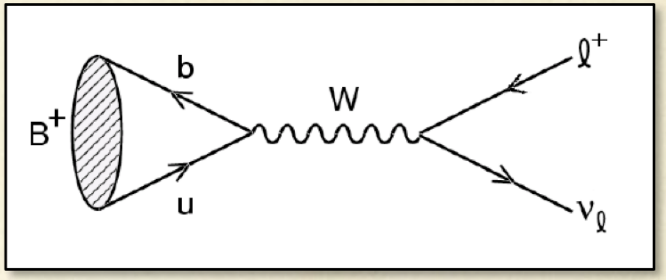


Theoretical motivations : B→lν

- SM prediction

$$\mathcal{B}(B^- \to \ell^- \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

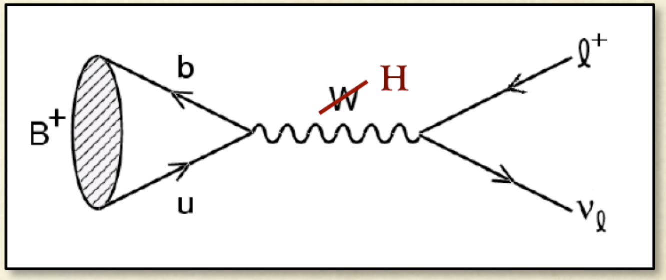
- With this SM inputs:
  - $|V_{ub}|$ = (4.32 ± 0.33) x 10^{-4} (HFAG)
  - f_B = (190 ± 13) MeV (PRD80,014503,2009)
  - τ_B = (1.638 ± 0.011) ps (PDG)



$\mathcal{B}(B\to\tau\nu)_{SM}$ = (1.20 ± 0.20) x 10^{-4}

$\mathcal{B}(B\to e\nu)_{SM} \approx O(10^{-7})$

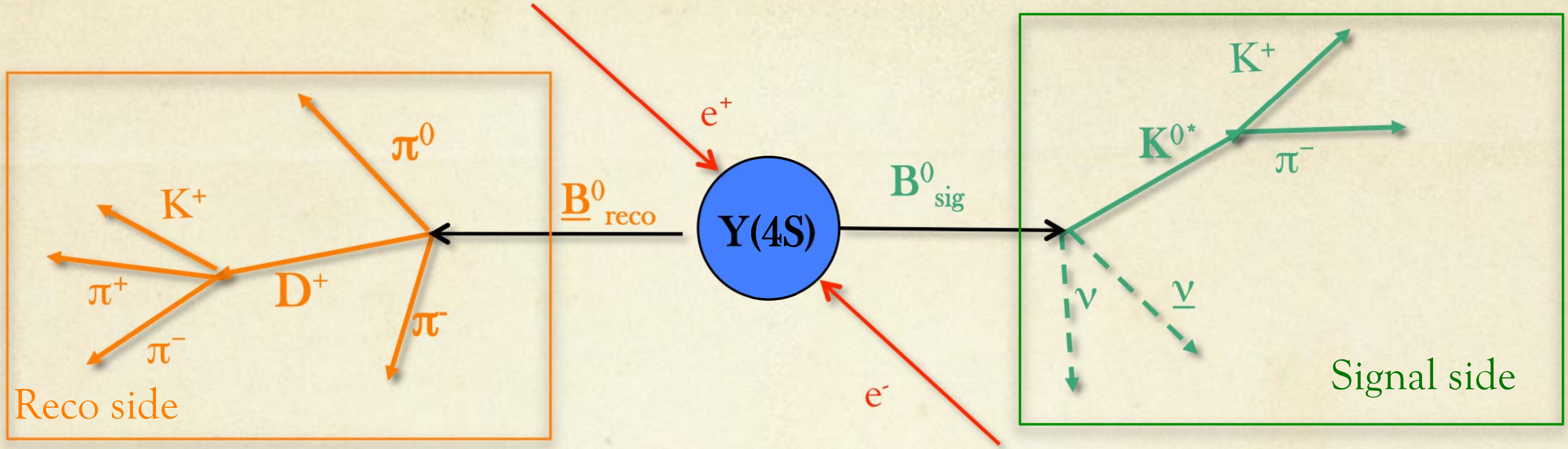
$\mathcal{B}(B\to\mu\nu)_{SM} \approx O(10^{-12})$



- 2 Higgs Doublet Model:

$$\mathcal{B}(B^- \to \ell^- \nu_\ell) = \mathcal{B}(B^- \to \ell^- \nu_\ell)_{SM}\left(1 - tan^2\beta\frac{m_B^2}{m_H^2}\right)^2$$

Recoil technique(I)



- B_{reco} side: full/partial reconstruction of hadronic/semileptonic B final states

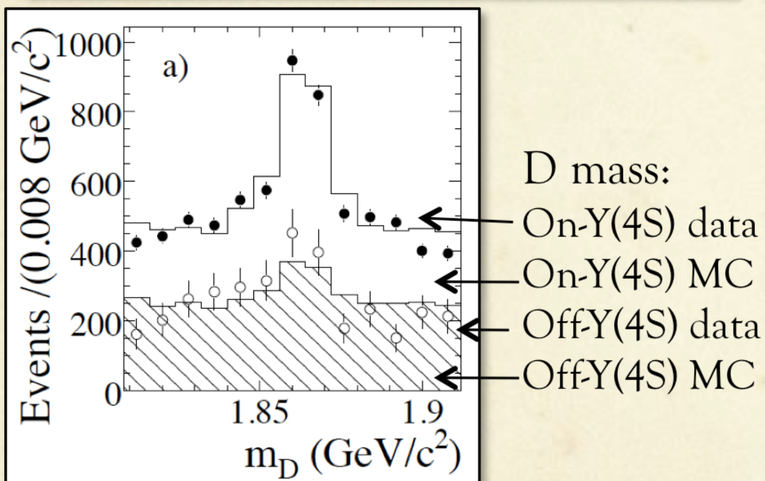
- B_{sig} side: use tracks and neutrals not involved in the reco side reconstruction and look for a $K^{(*)}$/lepton not accompanied by additional (charged or neutral) particles + missing energy

- RECOIL TECHNIQUE @ b-FACTORIES → search for rare decays ($\mathcal{B} \leq O(10^{-5})$) with MISSING ENERGY, NOT FEASIBLE @ HADRONIC MACHINE

Recoil technique(II)

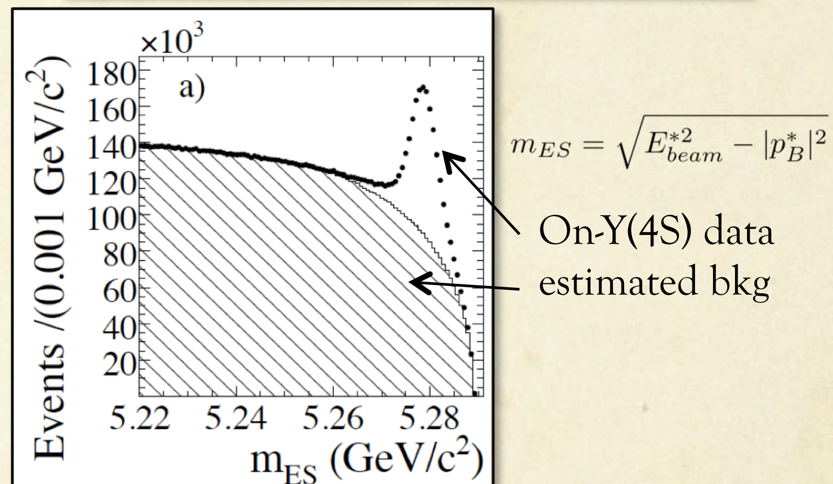
- Aim: collect as many as possible reconstructed B mesons to study the recoil property
- Reconstruction steps:
  - reconstruct $D^{(*)}$ meson in hadronic modes
  - add a high momentum lepton or $X = n\pi\ mK\ pK_S\ q\pi^0$ with $n+m+p+q<6$

$B \rightarrow D^{(*)} l \nu$: semileptonic (SL) Breco



- 18 B modes
- 1 missing $\nu \rightarrow$ unconstrained kinematics
- High reconstruction efficiency (~2%)

$B \rightarrow D^{(*)} X$: hadronic (HAD) Breco

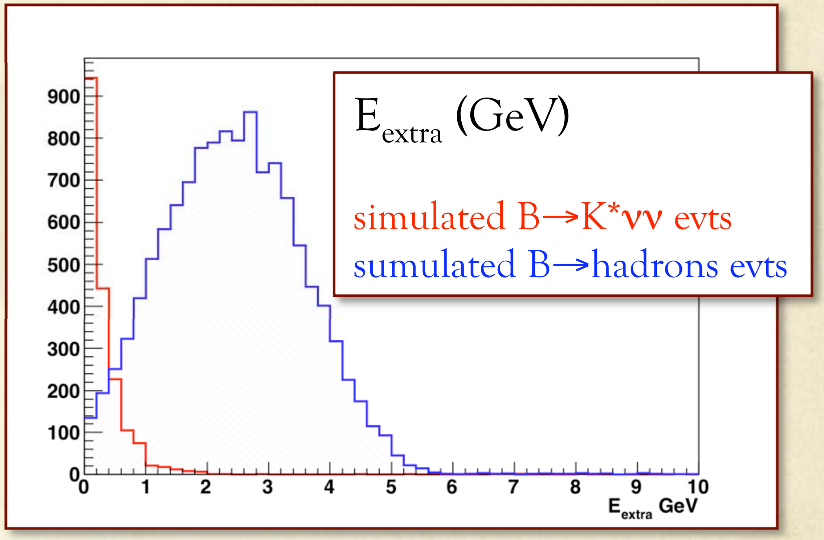


- ~1100 B modes
- closed kinematics
- lower reco efficiency wrt SL (~0.4%)

Analysis steps

- Once the B_{reco} has been reconstructed:
  - search for signal signature in the recoil
  - B_{reco}-B_{sig} charge correlation and no extra-trks
  - cut on event-shape and kinematic variables
  - most discriminant variables
    - $P_{miss} = E_{beam}$ – E(reco neutrals and tracks)
    - E_{extra} = Extra neutral energy in Elettr.

    Cal (EMC) not associated to B_{sig} or B_{reco}



- Signal yield extraction
  - Cut-and-count analysis
  - Fit to E_{extra}
  - combine discriminant variables in a Neural Network and fit output distribution
- Systematics
  - largely dominated by MC statistics (i.e. PDF modeling)
  - irreducible syst important for $\mathcal{B}$ measurement at high statistics

Current experimental status

- $B \to K^* \nu\nu$: BaBar HAD+SL recoil combined (PRD78,072007,2008) (used for SuperB extrapolation)

  $\mathcal{B}(B^+ \to K^{*+} \nu\nu) < 8.0 \times 10^{-5}$

  $\mathcal{B}(B^0 \to K^{*0} \nu\nu) < 12.0 \times 10^{-5}$

- $B \to K \nu\nu$: Belle HAD recoil (PRL99,221802,2007)

  $\mathcal{B}(B^+ \to K^+ \nu\nu) < 1.4 \times 10^{-5}$

  $\mathcal{B}(B^0 \to K_S \nu\nu) < 1.6 \times 10^{-4}$

  - used for SuperB extrapolation: BaBar SL Recoil Analysis (PRD82,112002,2010)

  $\mathcal{B}(B^+ \to K^+ \nu) < 5.6 \times 10^{-5}$

- $B \to \tau\nu$: HFAG world average

  $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.64 \pm 0.34) \times 10^{-4}$

  - used for SuperB extrapolation: BaBar HAD Recoil Analysis

    (preliminary hep-ex:1008.0104)

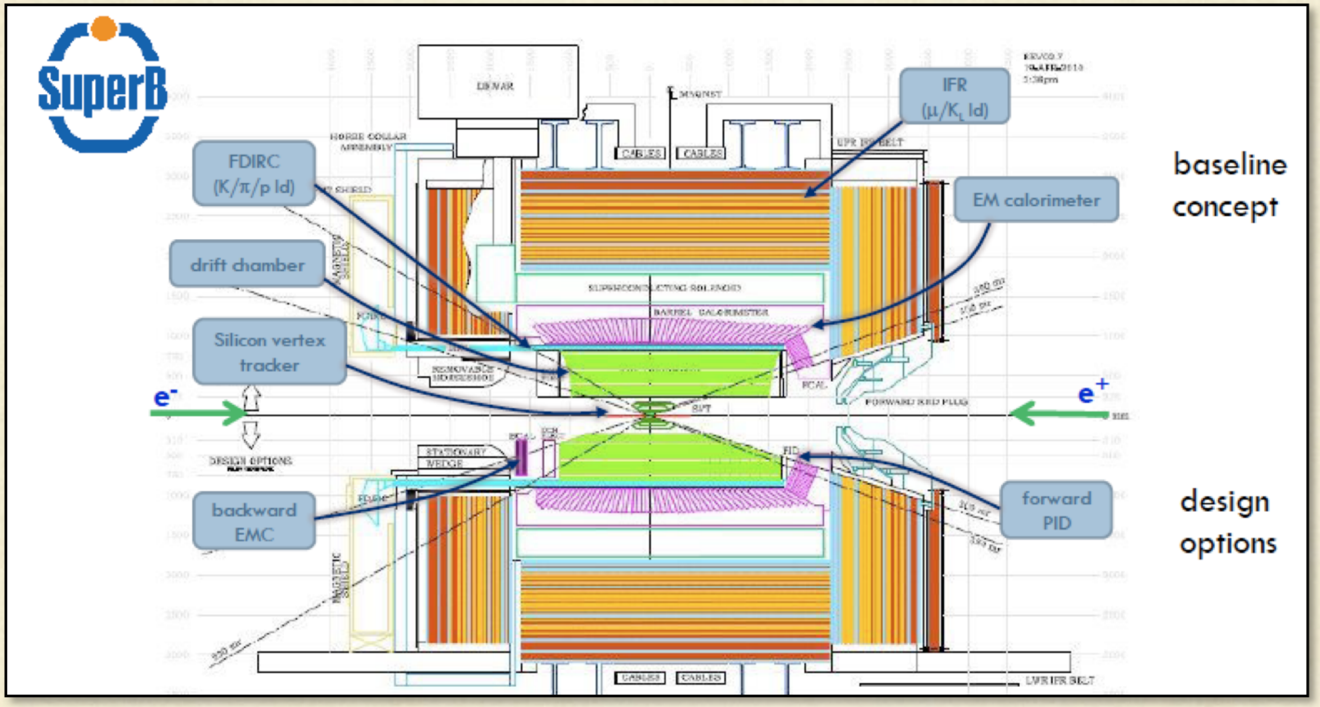
  $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$

From B-factories to SuperB: strategy

- Apply cut-and-count analysis "a-la-BaBar"
  - use SuperB Fast Simulation, most relevant machine backgrounds included
- Evaluate gain on signal efficiency and background rejection due change in boost
- Evaluate gain in efficiency due to improvements in detector design. Two additional components under study
  - Particle Identification device in forward region (FWD PID)
  - Sampling Electromagnetic Calorimeter in the backward region (BWD EMC)
- Consider BaBar results
  - signal and background yields, signal efficiencies, normalizations
- Extrapolate to SuperB luminosity (75 ab^{-1} ~ 5 years of data taking)
  - account for efficiency changes
  - $B \to K^* \nu\nu$: assume syst error ~ stat error
  - $B \to \tau\nu$: account for irreducible syst

What's new in SuperB : Boost

- start from BaBar experience (and re-usable parts) to obtain equal or better performances in an higher background environment and with different beam conditions (boost)

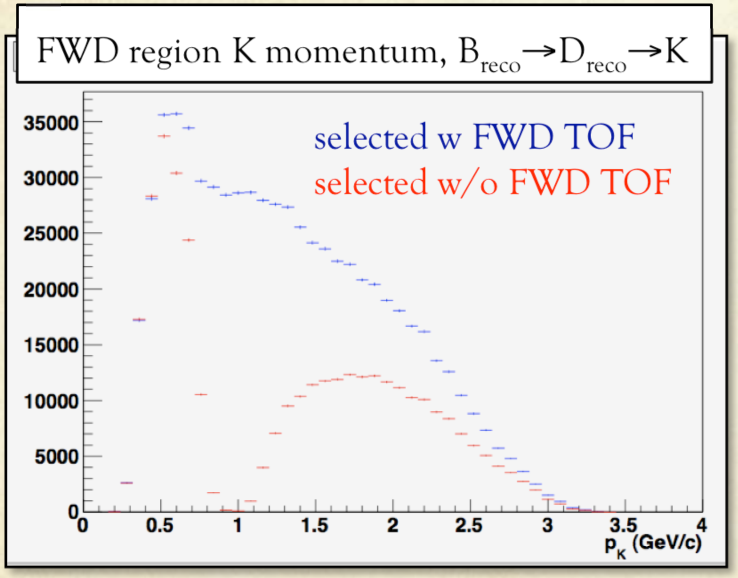


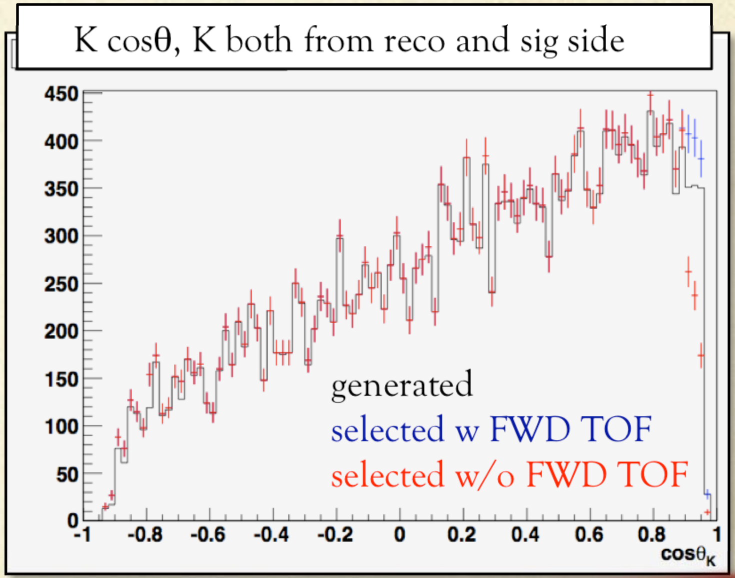
- Lower boost (from $\beta\gamma$=0.56 to 0.24): higher geometrical acceptance
  - +20% gain in reconstruction efficiency
  - -10% bkg reduction due to cuts on tracks multiplicity

PRELIMINARY

What's new in SuperB: FWD PID

- Possibility of PID device in the FWD region under study
  - one option : FWD Time Of Flight (TOF)
  - Single channel time resolution σ_t ~ 50 ps
  - Expect 3-4σ K-π separation @ 3 GeV
- Impact of FDW TOF
  - ~ 5% Kaons in the Fwd region, recuperate K with p_K>0.6 GeV





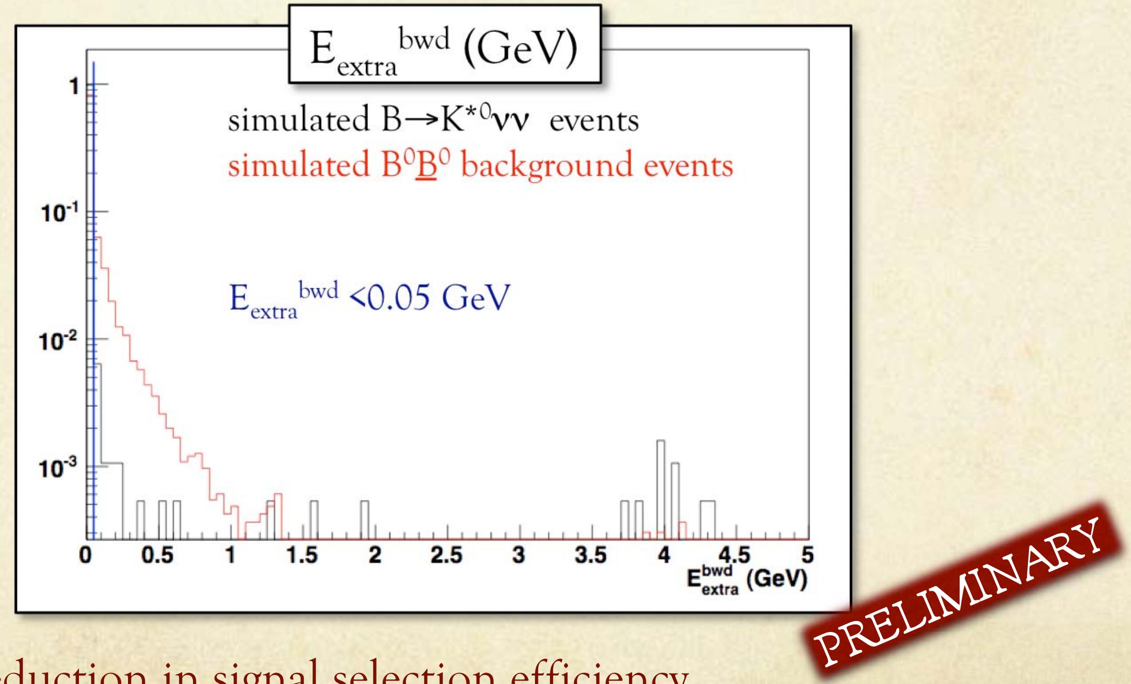
PRELIMINARY

  - +2.5-5% gain in signal selection efficiency, background efficiency ~ unchanged

What's new in SuperB: BWD EMC

- Possibility of EMC device in the BWD region under study
  - PB-scintillator sandwich (12 X0)
  - Resolution $\sigma(E)/E = 14\%/(E(GeV))^{1/2} \oplus 3.0\%$

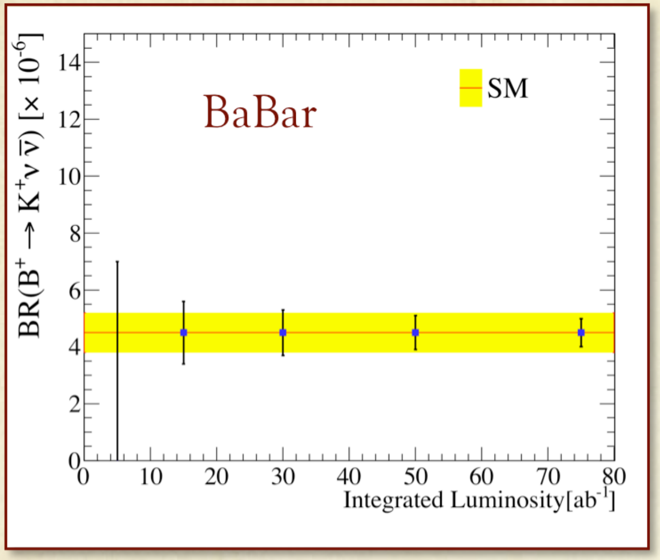
- Use as veto device
  - reject B_{sig} and B_{reco} candidates with daughters hitting Bwd EMC
  - cut on E_{extra} compute with extra neutrals in the bwd region

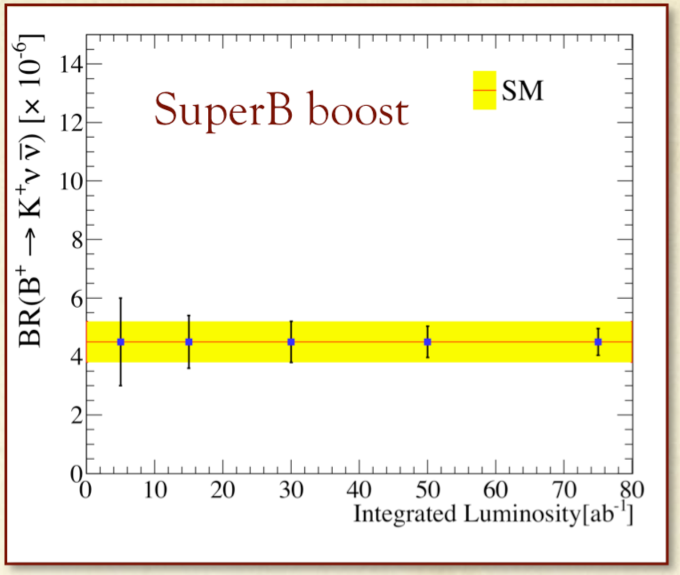


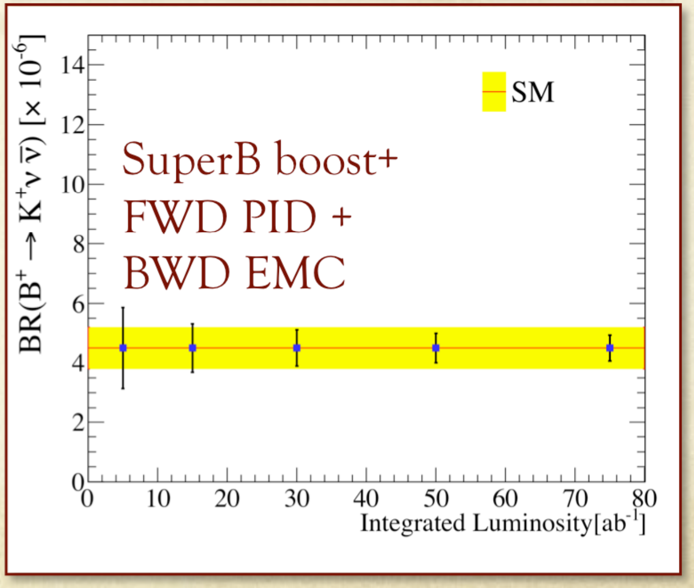
- -2% reduction in signal selection efficiency

  -15% reduction in background selection efficiency

$B^+ \to K^+ \nu\nu$: SuperB expected sensitivity





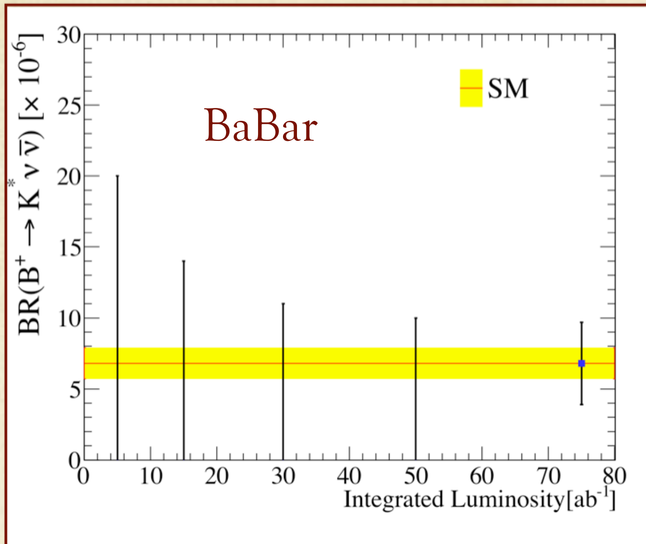


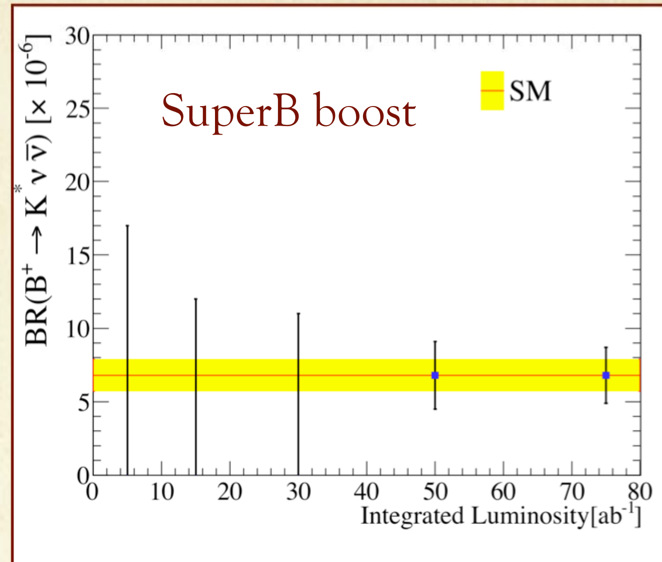
- assume SM branching fraction
- 3σ significance @
  - BaBar : 8 ab^{-1}
  - SuperB-boost : 5 ab^{-1}
  - SuperB+boost+ PID +EMC : 4 ab^{-1}

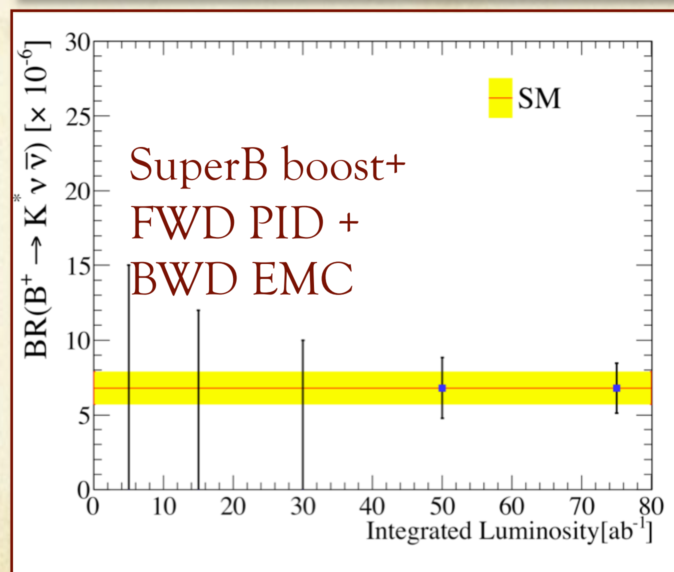
with ~ 30% precision on $\mathcal{B}$

- 75 ab^{-1} SuperB boost + PID + EMC precision : ~ 10%

$B \rightarrow K^* \nu\nu$: SuperB expected sensitivity







- assume SM branching fraction
- 3σ significance @
  - BaBar : 75 ab^{-1}
  - SuperB-boost : 50 ab^{-1}
  - SuperB+boost+ PID +EMC : 42ab^{-1}

with ~ 30% precision on $\mathcal{B}$

- 75 ab^{-1} SuperB boost + PID + EMC precision : ~ 25%

$B \rightarrow K^* \nu \nu$: helicity angle measurement

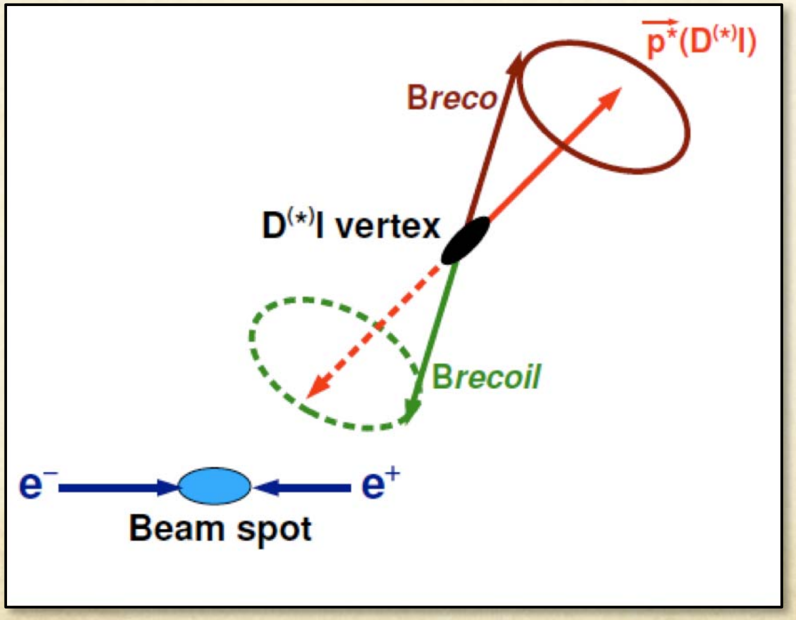
- K^* helicity angle distribution sensitive to NP
  - θ = angle between K^* direction in B_{sig} rest frame and K direction in K^* rest frame
  - F_L = fraction of longitudinally polarized K^*

$$\frac{d\Gamma}{dcos\theta} \propto \frac{3}{4}(1- < F_L >)sin^2\theta + \frac{3}{2} < F_L > cos^2\theta$$

- A proposed analysis strategy : Simultaneous fit to E_{extra} and $\cos\theta$ to measure $\mathcal{B}$ and F_L
- θ determination:
  - HAD recoil: infer Bsig rest frame from Breco kinematics (closed)
  - SL recoil: kinematics not closed due to undetected neutrino, θ estimated with poorer resolution wrt HAD analysis

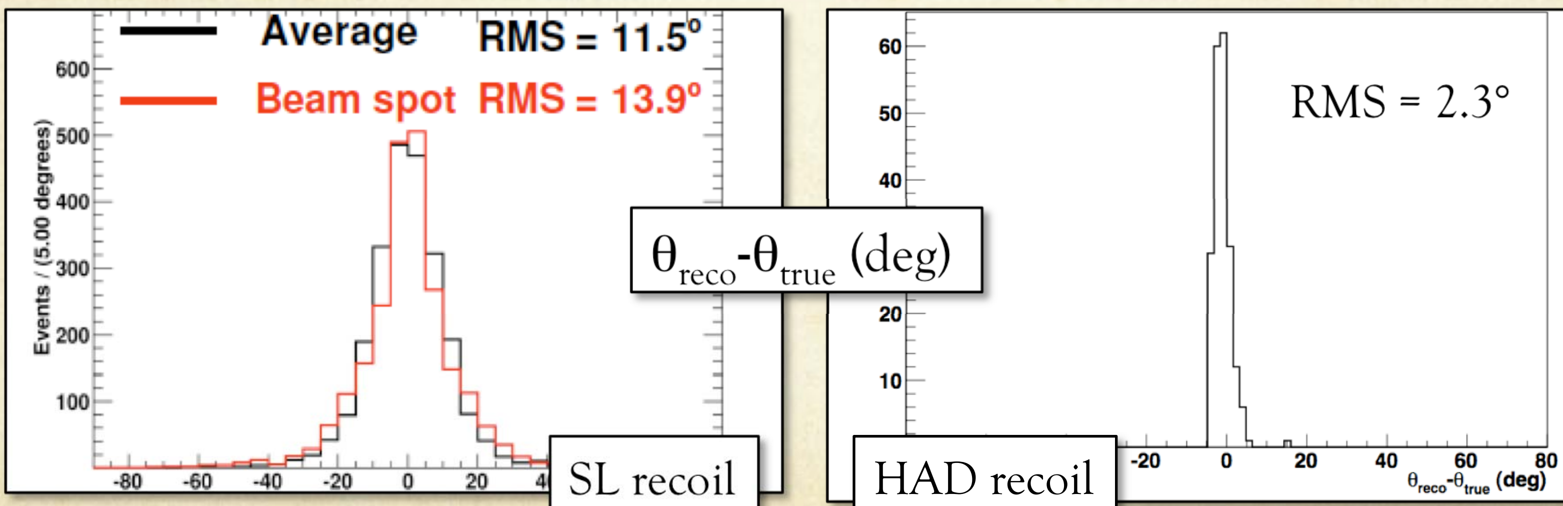
$B \rightarrow K^* \nu\nu$: helicity angle resolution

- SL recoil
  - determination of Bsig 4-momentum: from $D^{(*)}l$ vertex and B_{reco} p3, find a cone where B_{reco} 4-momentum should lie, and infer the B_{sig} cone
  - AVERAGE METHOD: for each B_{sig} 4-momentum in the cone, computeθ_i. $\theta = \langle\theta_i\rangle$
  - BEAM SPOT METHOD: for each B_{sig} vector obtain the min distance between the beam-spot and the line through the Dl vertex with the B_{sig} direction. $\theta = \theta$ from B_{sig} with smallest min-dist



$B \to K^* \nu\nu$: helicity angle resolution

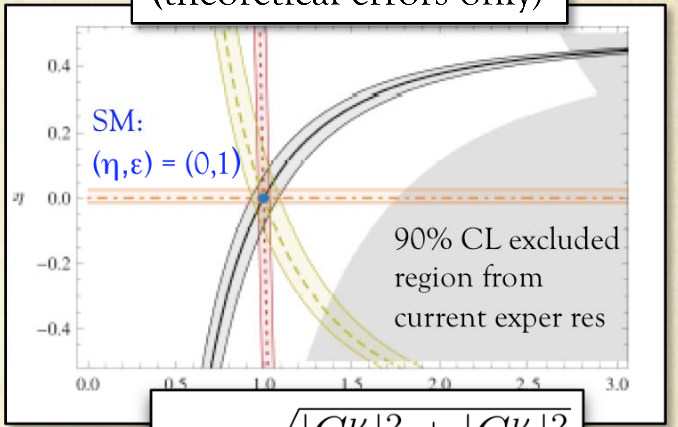
- SL recoil
  - determination of Bsig 4-momentum: from $D^{(*)}l$ vertex and B_{reco} p3, find a cone where B_{reco} 4-momentum should lie, and infer the B_{sig} cone
  - AVERAGE METHOD: for each B_{sig} 4-momentum in the cone , computeθ_i. $\theta = \langle\theta_i\rangle$
  - BEAM SPOT METHOD: for each B_{sig} vector obtain the min distance between the beam-spot and the line through the Dl vertex with the B_{sig} direction. $\theta = \theta$ from B_{sig} with smallest min-dist



$B \to K^{(*)}\nu\nu$: constraints on NP

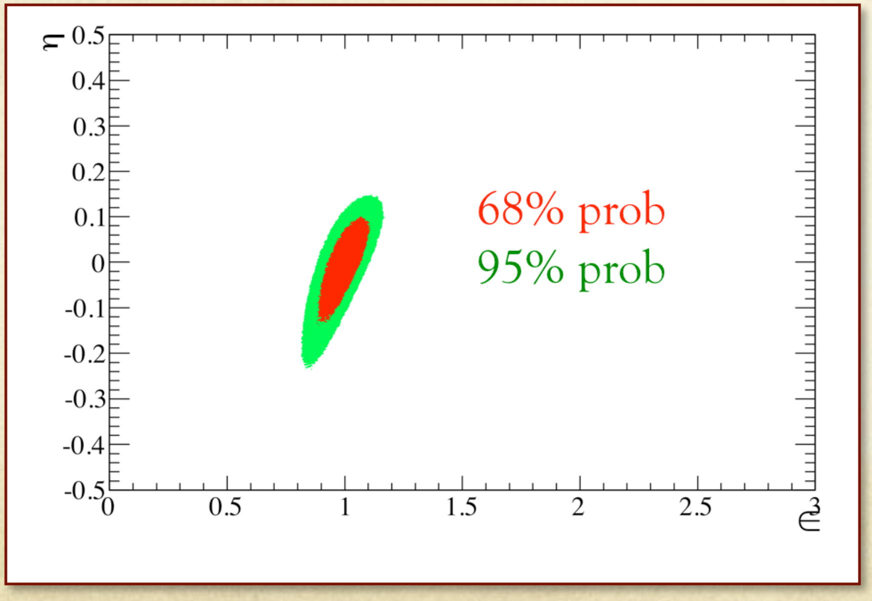
- Toy experiments @ 75 ab^{-1}: 2D fit to E_{extra}/NN_{output} to extract $\mathcal{B}$ and F_L
- F_L from $B^0 \to K^{0*}\nu\nu$ only, syst errors not included
- Assume:
  - $\mathcal{B}(B \to K^*\nu\nu) = (6.8 \pm 1.7) \times 10^{-6}$
  - $\mathcal{B}(B \to K^*\nu\nu) = (4.5 \pm 0.5) \times 10^{-6}$
  - $F_L(B \to K^*\nu\nu) = 0.54 \pm 0.27$

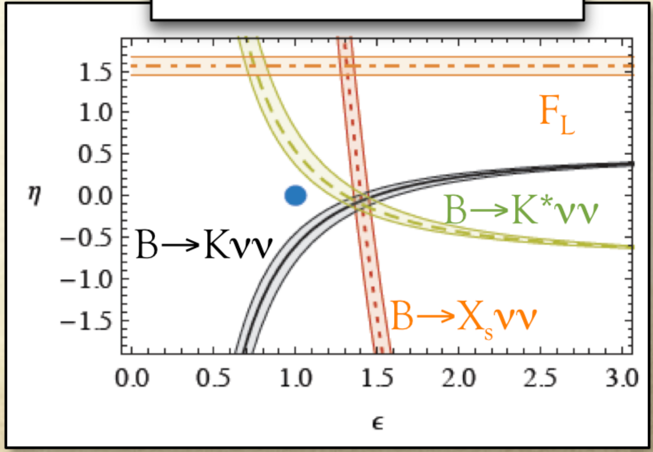
(theoretical errors only)



$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{SM}|}$$

$$\eta = \frac{-Re(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$



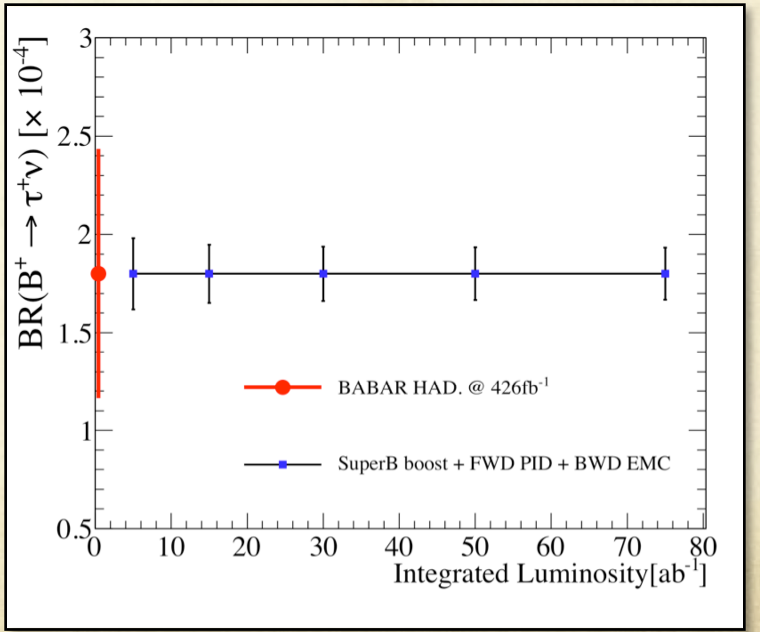


$B \to \tau\nu$: SuperB expected sensitivity

- Consider BaBar HAD analysis only
  - $\mathcal{B}(B^+ \to \tau^+\nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$
  - @ 426 fb^{-1}: $\sigma_{stat} / \mathcal{B}$ ~ 32%,
    $\sigma_{syst} / \mathcal{B}$ ~ 15%
- systematic uncertainties
  - dominant: statistical in origin,
    scale with luminosity (~12 % on signal yield)
  - not considering analysis improvements,
    treat some syst as irreducible
    (~7% on signal yield)
- 75 ab^{-1} SuperB boost + PID + EMC

precision : ~ 7%

Source of systematics	BF uncertainty (%)
B counting	0.5
Tag B efficiency	5.0
Background PDF	12
Signal PDF	1.7
MC statistics	0.8
Electron identification	2.6
Muon identification	4.7
Kaon identification	0.4
Tracking	1.4
Total	14

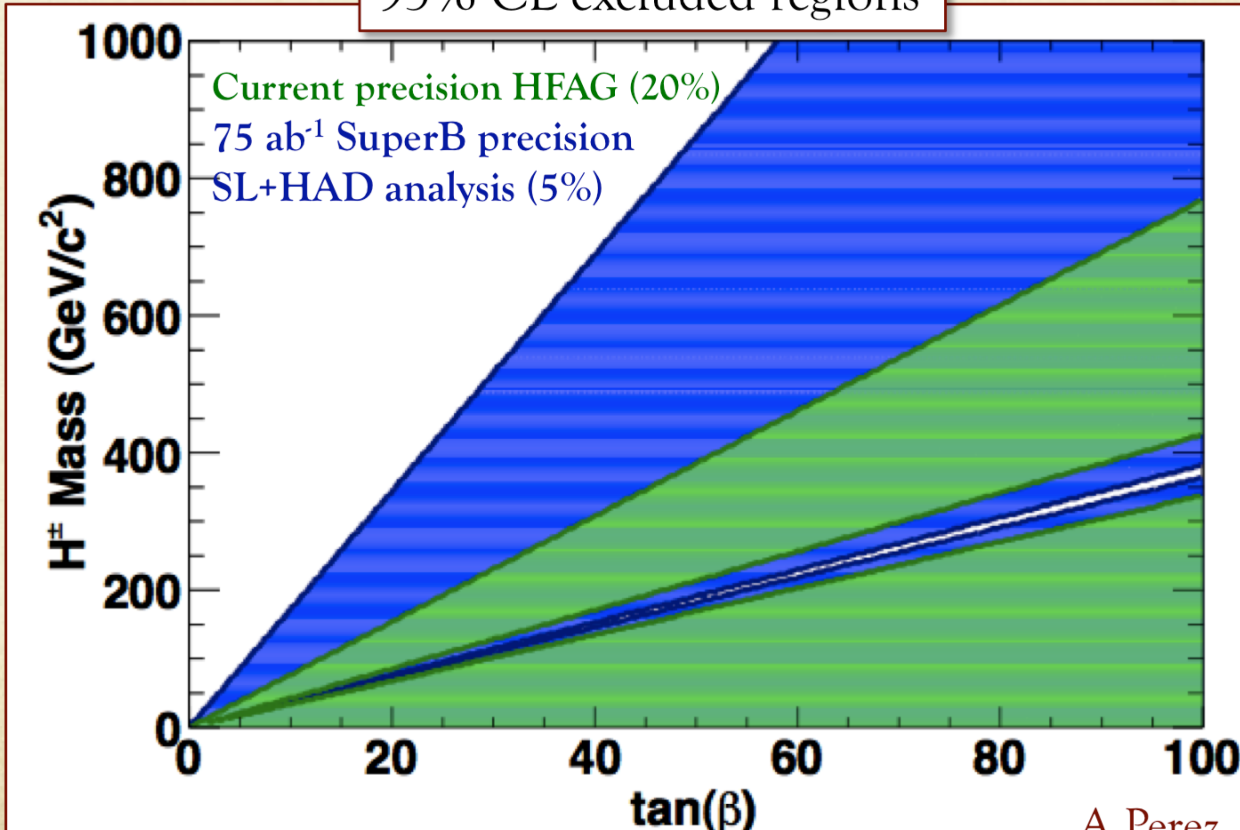


B→τν: constraints on NP

- $\mathcal{B}$(B→τν) expectation value = $\mathcal{B}_{SM}$(B→τν)
- $\mathcal{B}_{SM}$(B→τν) = (1.20 ± 0.20) x 10^{-4}

$$\mathcal{B}(B^- \to \ell^- \nu_\ell) = \mathcal{B}(B^- \to \ell^- \nu_\ell)_{SM} \left(1 - tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

95% CL excluded regions



Conclusions

- B decays to final states with invisible particle:
  - optimal ground to search for NP
  - search feasible only at Super Flavour Factory with recoil technique
- Benefits from a SuperB factory: high luminosity, but not only
  - improvements due to high detector coverage (+20% reconstruction efficieny, 10% bkg reduction)
  - 2 additional subdetector options under study
    - FWD PID : +2.5-5% signal efficiency
    - BWD EMC: -15% bkg efficiency
- Perspectives for $B \rightarrow K^{+} \nu\nu$: evidence @ 4 ab^{-1} with 30% precision on $\mathcal{B}$
- Perspectives for $B \rightarrow K^{*} \nu\nu$: evidence @ 42 ab^{-1} with 30% precision on $\mathcal{B}$
- Perspectives for $B \rightarrow \tau\nu$: conservative estimate of 7% precision @ 75ab^{-1}
- All results are PRELIMINARY: detailed evaluation on benefits from FWD PID and BWD EMC and impact of machine background still under study

Back-up slides