Rare Decays with Missing Energy at SuperB

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SuperB

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Outline

- **Theoretical motivation**
- **The experimental technique (Recoil Analysis):**
  - Semi-leptonic (SL)
  - Hadronic (HD)
- **Experimental status**
- **SuperB detector layout**
  - Fwd-PID
  - Bwd-EMC (veto devise)
- **Analysis strategy**
  - $B \to K\nu\nu$
  - $B^* \to K^*\nu\nu$
- **Expected sensitivity on New Physics (NP) searches**
- **Summary and outlook**

Golden Matrix for B-Physics

	H^+ high $\tan\beta$	Minimal FV	Non-Minimal FV (1-3)	Non-Minimal FV (2-3)	NP Z-penguins	Right-Handed currents
$\mathcal{B}(B \to X_s\gamma)$		X		O		O
$A_{CP}(B \to X_s\gamma)$				X		O
$\mathcal{B}(B \to \tau\nu)$	X-CKM					
$\mathcal{B}(B \to X_s l^+ l^-)$				O	O	O
$\mathcal{B}(B \to K\nu\overline{\nu})$				O	X	
$S(K_S\pi^0\gamma)$						X
β			X-CKM			

X **The GOLDEN channel for the given scenario**

O **Not the GOLDEN channel for the given scenario, but can show experimentally measurable deviations from SM.**

Rare decays with missing energy

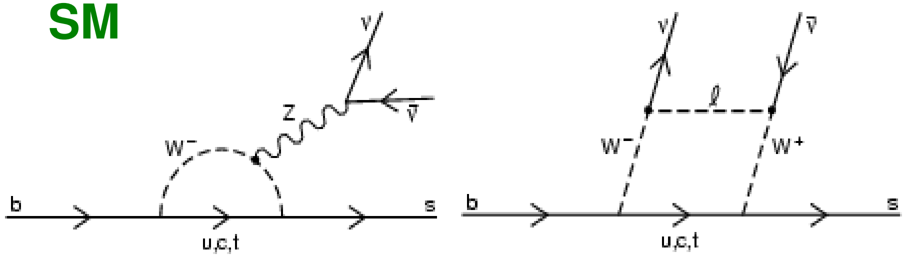
Super B specifics

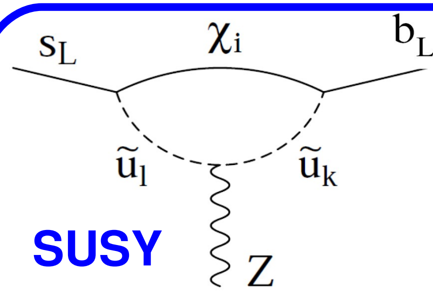
- Inclusive analyses
- Channels with π^0, γ, ν, Ks ...

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

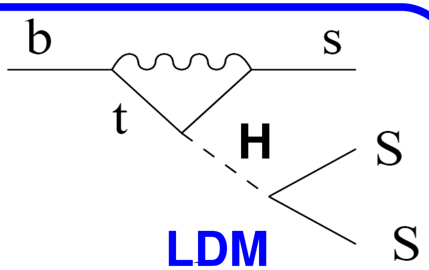
- **Electroweak penguin (loop diagram) radiated processes ($b \to s$):**
  - **Flavor changing neutral current (FCNC) prohibited in SM at tree level**
  - **Sensitive New Physics (NP): Susy particles, light dark matter (LDM), ...**

SM





SUSY



LDM

- **$b \to s\nu\nu$ model independent phenomenology:** (W. Altmannshofer et al. TUM-HEP-709-09)
  - $BR(B \to K\nu\nu) = (4.5 \pm 0.7) \times 10^{-6}(1-2\eta)\varepsilon^2$
  - $BR(B \to K^*\nu\nu) = (6.8 \pm 1.1) \times 10^{-6}(1+1.31\eta)\varepsilon^2$
  - $F_L(B \to K^*\nu\nu) = (0.54 \pm 0.01)(1+2\eta)/(1+1.31\eta)$

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

θ(helicity) = angle between:
- **K* direction in B rest frame**
- **K direction in K* rest frame**

$$\varepsilon = \frac{\sqrt{|C^\nu_L|^2 + |C^\nu_R|^2}}{|(C^\nu_L)^{SM}|}$$

$$\eta = \frac{-Re(C^\nu_L C^\nu_R{}^*)}{|C^\nu_L|^2 + |C^\nu_R|^2}$$

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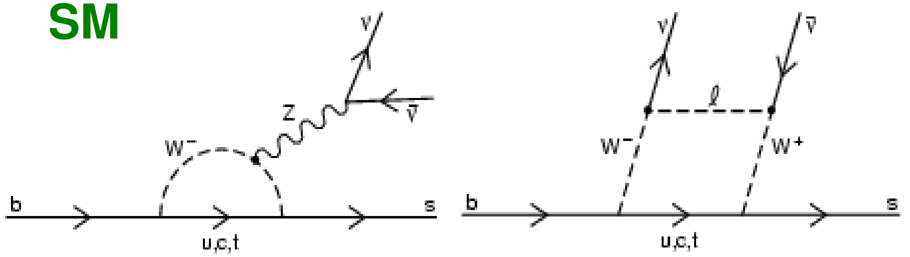

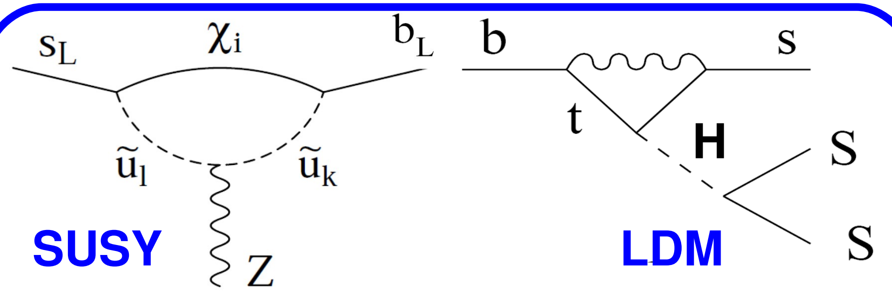

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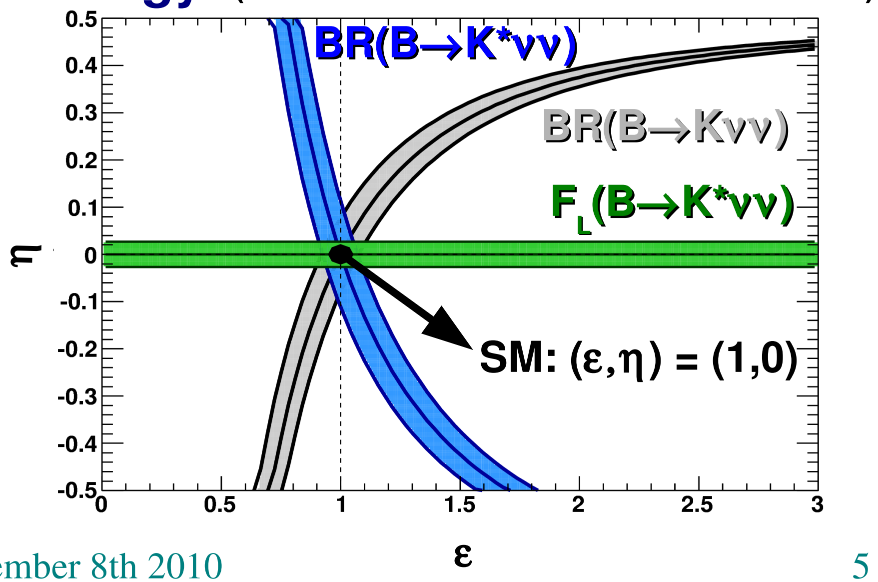

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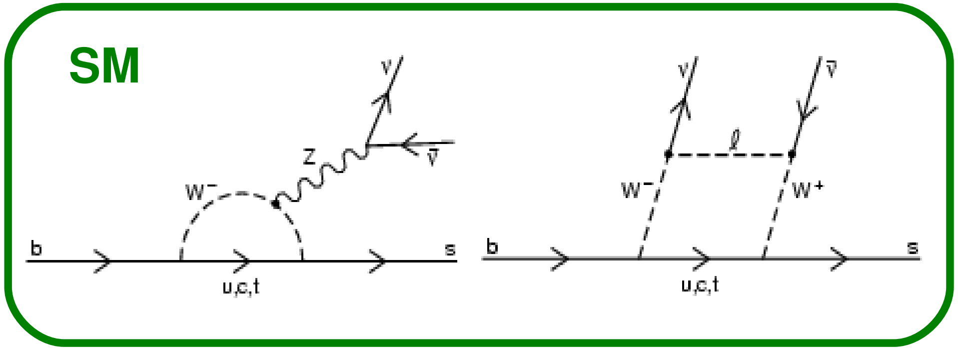

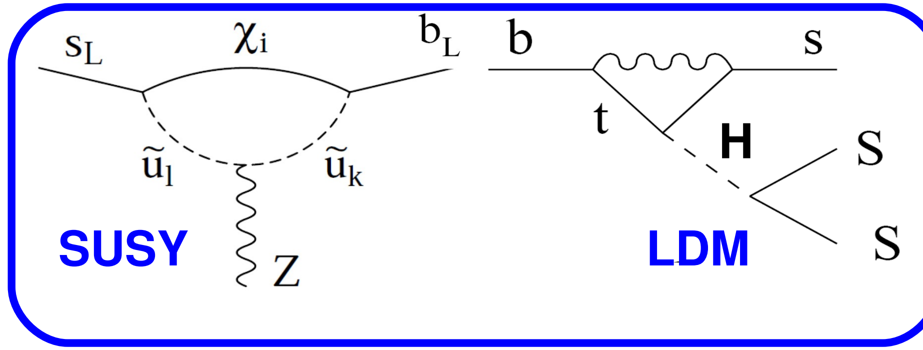

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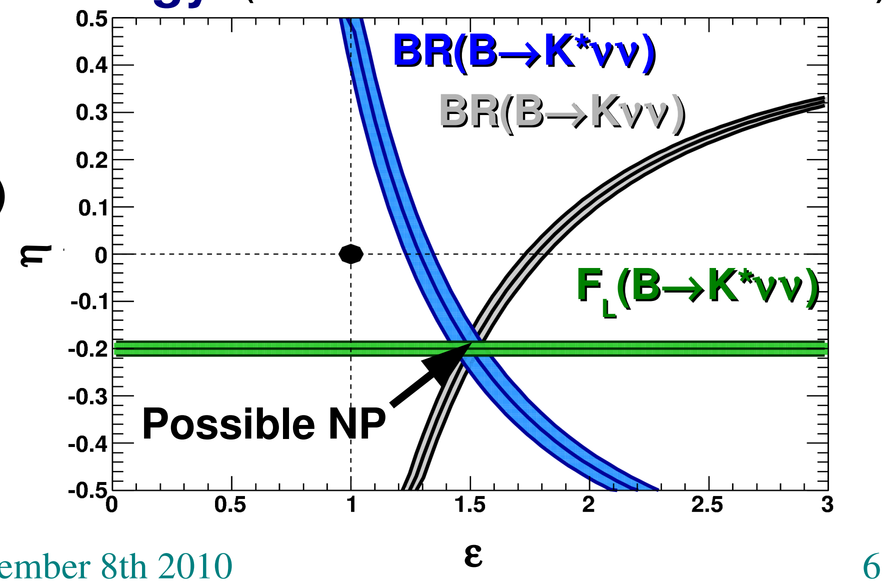
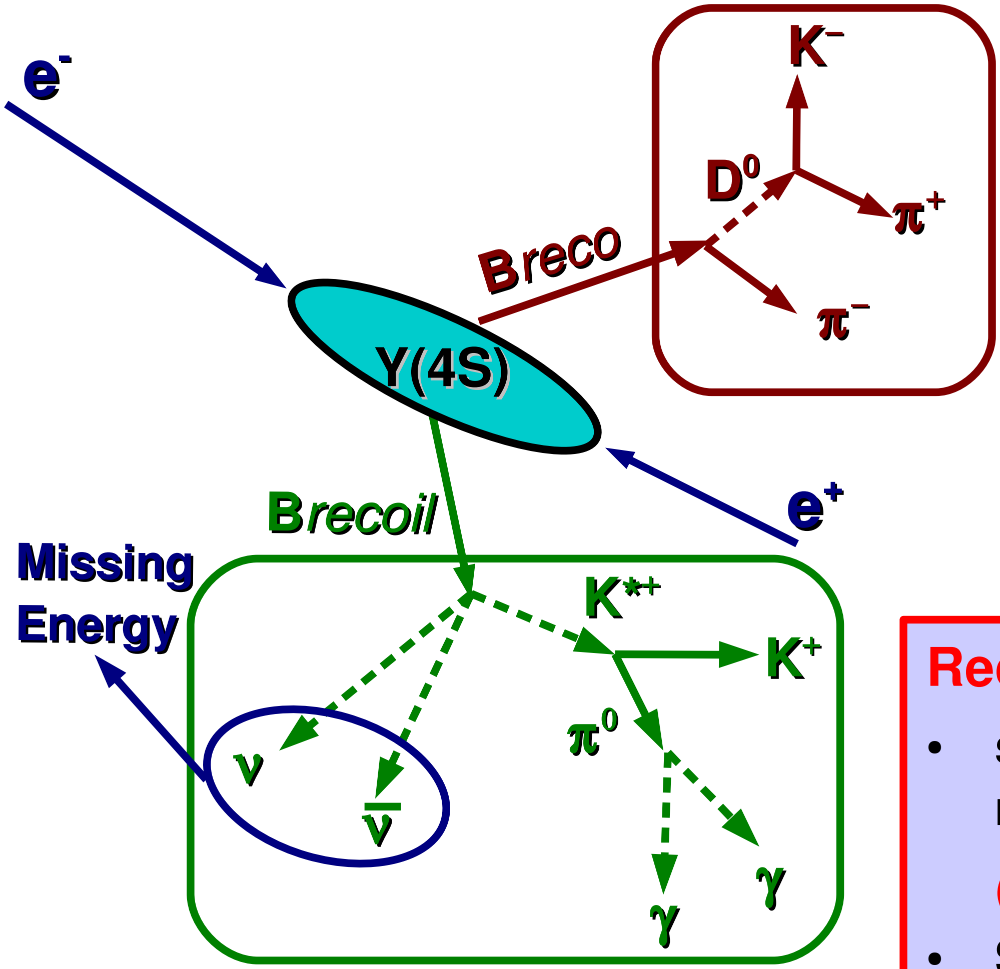


Recoil Analysis Technique (I)

- Most of the searches for rare B decays exploit the **Recoil Technique**:



B*reco* : full (partial) reconstruction of one B into a hadronic (semi-leptonic) final state

B*recoil* : look for the signal signature, e.g. $K^{(*)}$ not accompanied by additional (charged+neutral) particles + **Missing Energy**

Recoil technique at B-Factories:

- search for rare decays ($\sim 10^{-5}$) with missing energy
  (Not possible at hadronic machines)
- Several benchmark channels at SuperB: $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$, ...

Recoil Analysis Technique (II)

- Aim: collect as many as possible fully/partially reconstructed B mesons in order to study the properties of the Brecoil
- 1st step: reconstruction D→hadrons

$D^{*+} \to D^0\pi^+$
$D^{*0} \to D^0\pi^0$
$D^{*0} \to D^0\gamma$

$D^0 \to K^-\pi^+$
$D^0 \to K^-\pi^+\pi^0(\gamma\gamma)$
$D^0 \to K^-\pi^+\pi^+\pi^-$
$D^0 \to K^0_S\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^-$
$D^+ \to K^-\pi^+\pi^-\pi^0$
$D^+ \to K^0_S\pi^+$
$D^+ \to K^0_S\pi^+\pi^-\pi^+$
$D^+ \to K^0_S\pi^+\pi^0$

2nd step:

Hadronic B*reco*: B→DX

- Use D as a seed and add X to have system compatible with B hypothesis

  ($X = n\pi^{\pm}\ mK^{\pm}\ rK^0_s\ q\pi^0$ and n+m+r+q<6)

- Sample of 1100 B decay modes with different purities
- Kinematics completely constrained ☺
- Low reconstruction efficiencies ☹

  (~0.4%)

Semi-Leptonic B*reco*: B→D^(*)lν

- Use D as a seed and a lepton to form a Dl pair ($l = e^{\pm},\mu^{\pm}$)
- Sample of 14 B decay modes
- Kinematics is unconstrained due to neutrino ☹
- Higher reconstruction efficiencies ☺ (~2.0%)

Experimental Status

SL Recoil (90 million BB pairs)[2]:

$BF(B^+ \to K^+ \nu\nu) < 5.2\times10^{-5}$

Had Recoil (351 million BB pairs)[3]:

$BF(B^+ \to K^+ \nu\nu) < 4.2\times10^{-5}$

Had+SL Recoil (454 million BB pairs)[4]:

$BF(B^+ \to K^{*+} \nu\nu) < 8.0\times10^{-5}$

$BF(B^0 \to K^{*0} \nu\nu) < 12.0\times10^{-5}$

Had Recoil (535 million BB pairs)[1]:

$BF(B^+ \to K^+ \nu\nu) < 1.4\times10^{-5}$

$BF(B^0 \to K^0_S \nu\nu) < 1.6\times10^{-4}$

$BF(B^+ \to K^{*+} \nu\nu) < 1.4\times10^{-4}$

$BF(B^0 \to K^{*0} \nu\nu) < 3.4\times10^{-4}$

All measurements are upper limits! Still consistent with SM expectation

1 K. F. Chen et al. [BELLE Collaboration], Phys. Rev. Lett. 99, 221802 (2007).

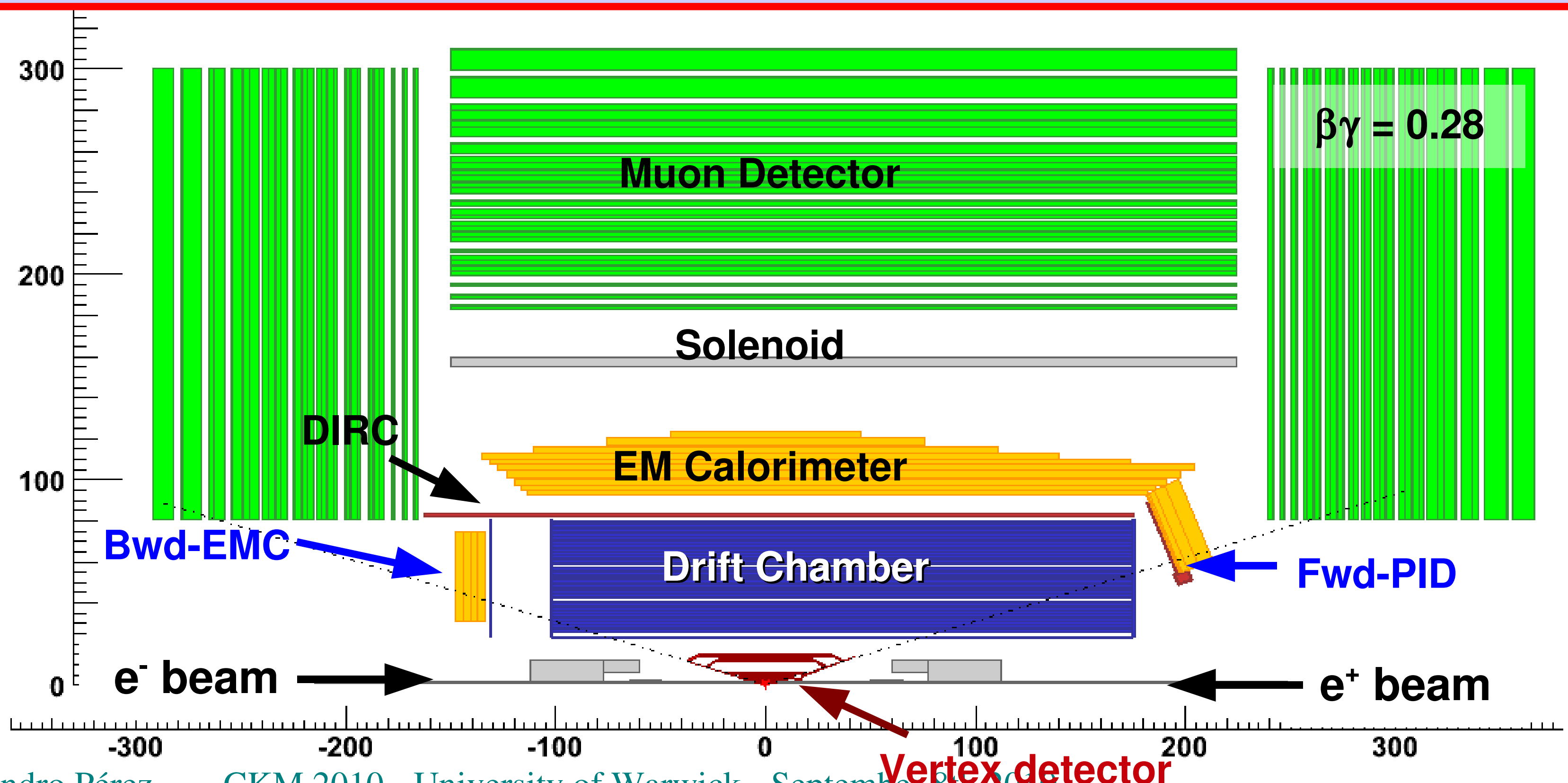
2 B. Aubert et al. [BaBar collaboration], Phys.Rev. Lett. 101801 (2005)

3 H.Kim on behalf of the BaBar collaboration, arXiv:hep-ex/08052365 (2008).

4 B. Aubert et al. [BaBar collaboration], Phys.Rev.D78:072007,2008

SuperB Detector Layout

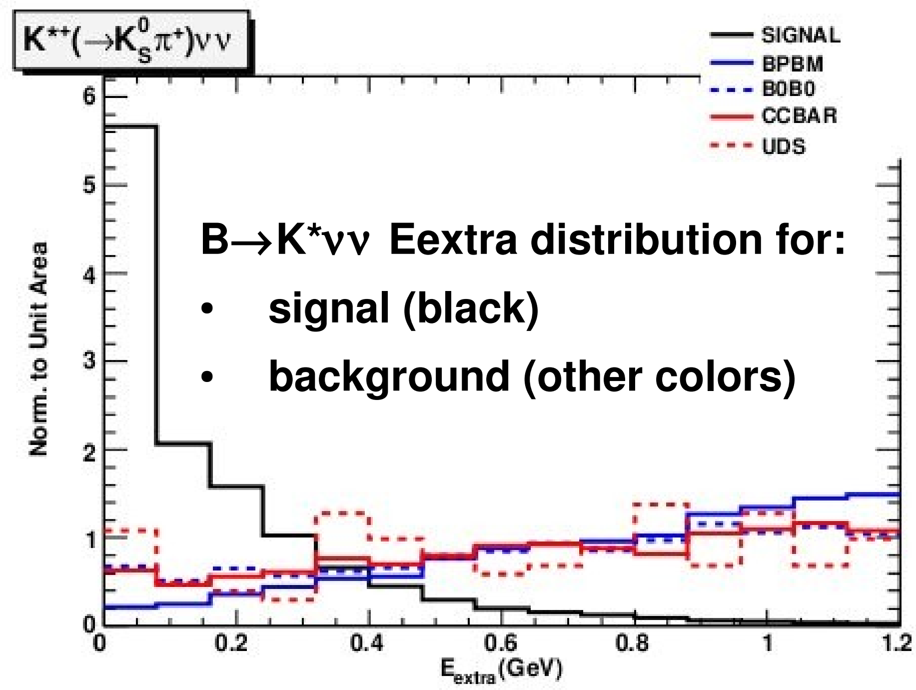
- Baseline configuration: BaBar with a reduced boost ($\beta\gamma = 0.28$ instead of 0.56)
  $\Rightarrow$ higher geometrical acceptance $\Rightarrow$ higher efficiency
- Additional detector components proposed:
  - Forward particle identification device (Fwd-PID)
  - Backward electromagnetic calorimeter (Bwd-EMC)



$B \to K^{(*)}\nu\nu$ Analysis strategy (I)

Signal-side selection:

- $B \to K\nu\nu$: look for a single K^+ (K^0_S) in B*recoil*
- $B^* \to K^*\nu\nu$: look for a K^{*+} (K^{*0}) in B*recoil.* Several modes:
  $K^{*+} \to K^0_S(\to\pi^+\pi^-)\pi^+$, $K^0_S(\to\pi^0\pi^0)\pi^+$, $K^+\pi^0$ (charged); $K^{*0} \to K^+\pi^-$ (neutral)
- Opposite (same) charges of B*reco* and B*recoil* for charged (neutral) modes
- No extra tracks in the event
- Kinematic cuts: K^0_S and K* mass
- Kaon (K^+,K^0_S) K* CM momentum
- Missing energy (E_{beams} – energy of charged and neutral objects in event)
- <u>Main discriminant variable:</u>
  Eextra = Σ(extra neutrals in the EMC)



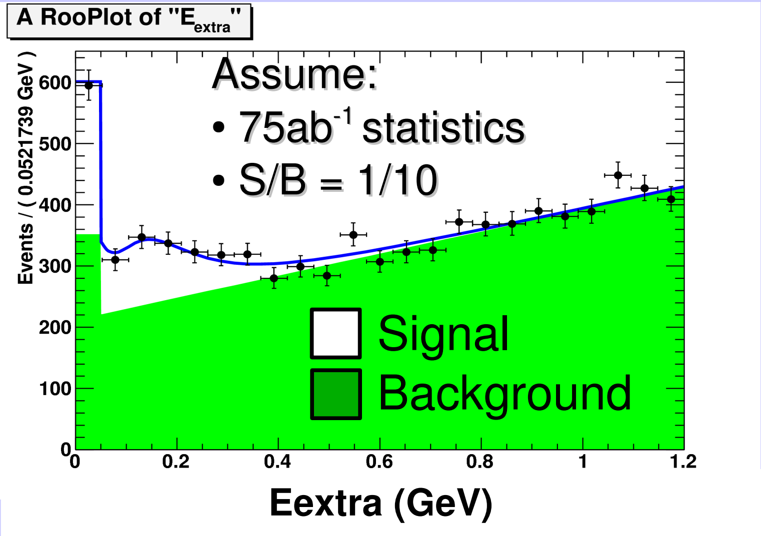
$B \to K^*\nu\nu$ Eextra distribution for:

- **signal (black)**
- **background (other colors)**

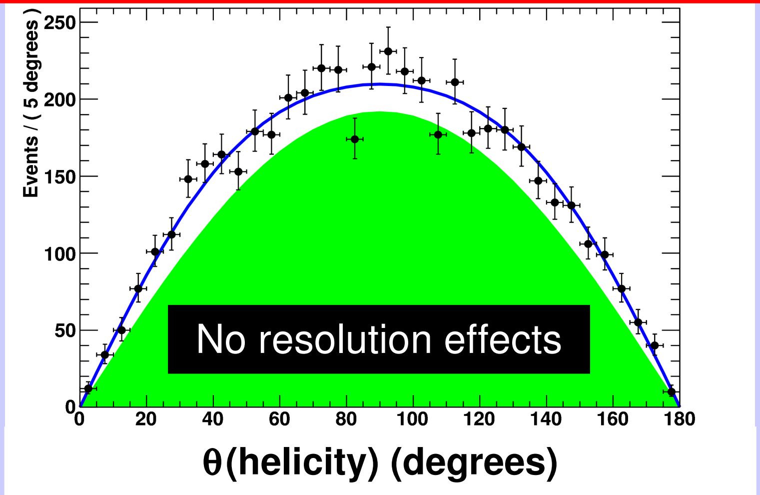
$B \to K^{(*)}\nu\nu$ Analysis strategy (II)

Fit strategy for $B \to K^*\nu\nu$ analysis:

- The plan is to extract BR and F_L by performing a 2D fit on Eextra and θ(helicity)



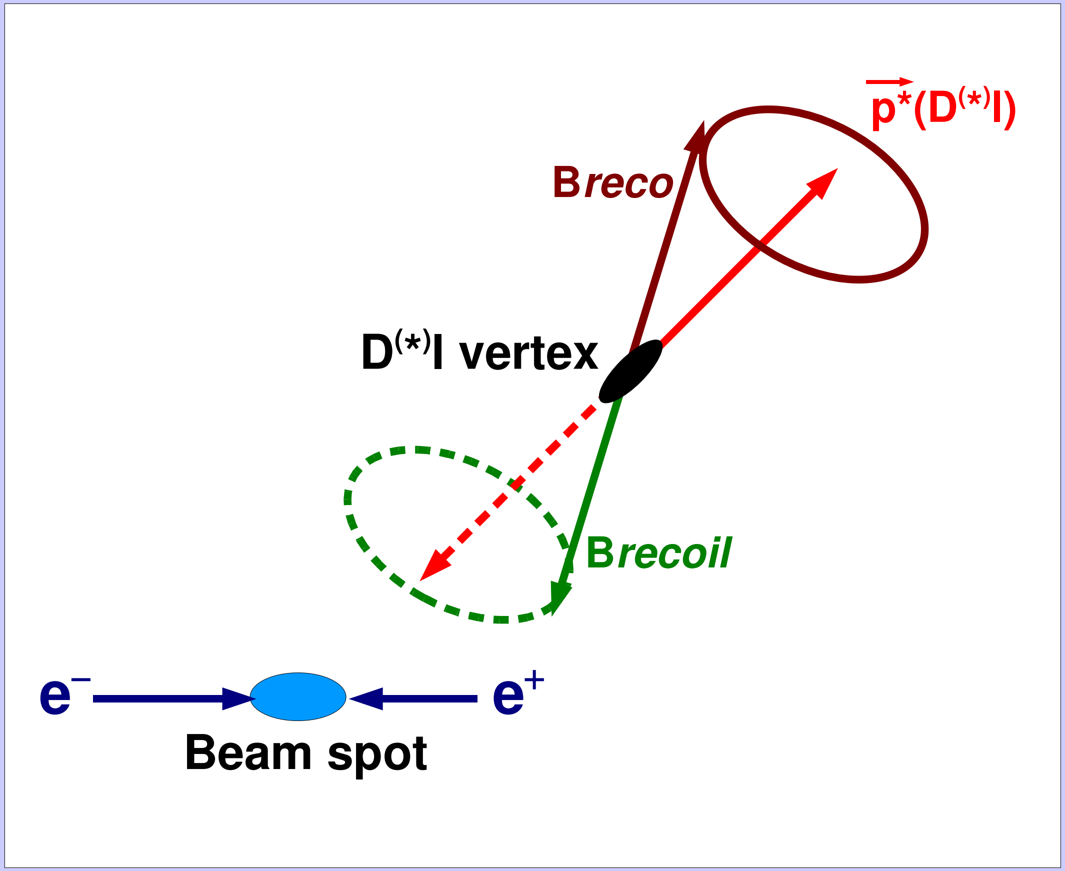
Signal enhanced by cut on Eextra < 0.3 GeV



- Drawback for angular analysis: need to know Brecoil reference frame (RF)
  - Hadronic Breco: constrained kinematics ⇒ Brecoil RF can be infered from Breco reconstruction and beams information
  - Semi-leptonic Breco: unconstrained kinematics due to neutrino
    - Still can use the available information to build an estimator for θ(helicity)
    - Expect worse resolution effects w.r.t Hadronic Breco

Angular Analysis: SL recoil (I)

- **Available experimental information for θ(helicity) measurement:**
- **$D^{(*)}l$ vertex in Lab RF and 4-momentum in CM**
- **Module of B*reco* 3-momentum in CM**
- **Cosine of the angle between the B*reco* and $D^{(*)}l$ in CM: B*reco* is in a cone around $D^{(*)}l$**



Two estimators for θ:

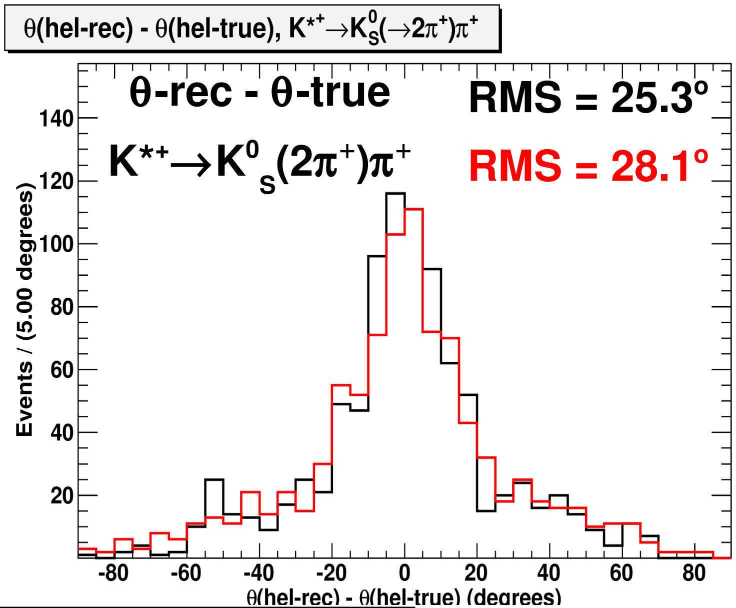
- **Average:**

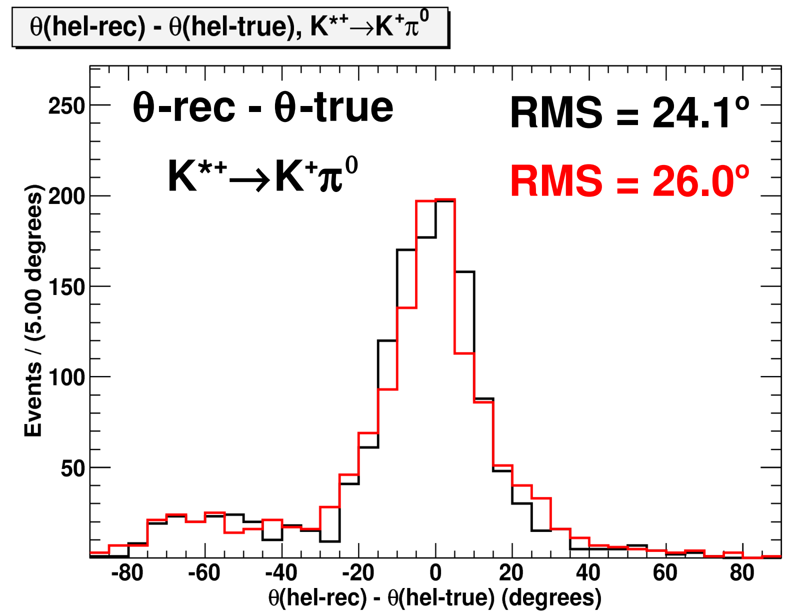
  use all possible Brecoil vectors around $D^{(*)}l$ cone to calculate θ. Then average out.

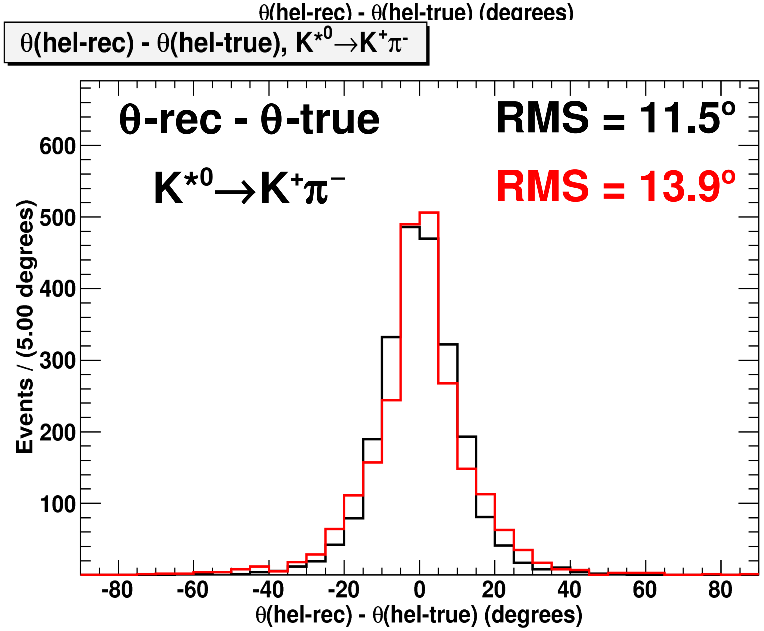
- **Beam spot:**

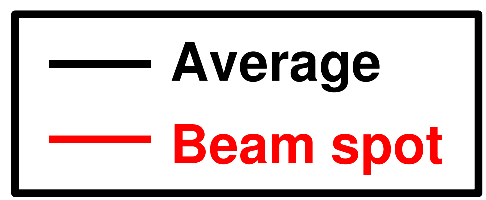
  for each Brecoil vector obtain the min-distance (d-min) between the beam spot and the line through the Dl vertex with Brecoil direction. θ(helicity) calculated with the Brecoil giving the smallest d-min

Angular Analysis: SL recoil (II)









- Events with 80° < θ-true < 100°
- It seems that average method is slightly better (better resolution) than beam spot method

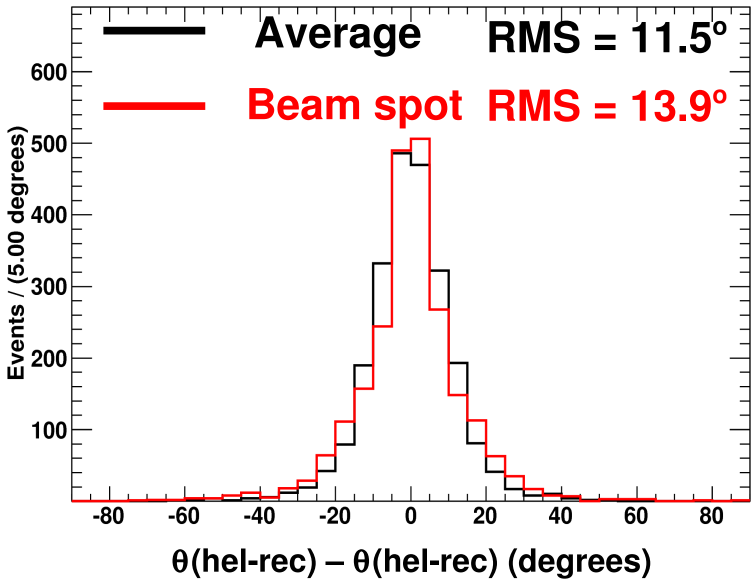
Angular Analysis: SL and HD recoil

- Events with 80º < θ-true < 100º
- Hadronic recoil has a lower resolution (5 times better) due to the constrained kinematics

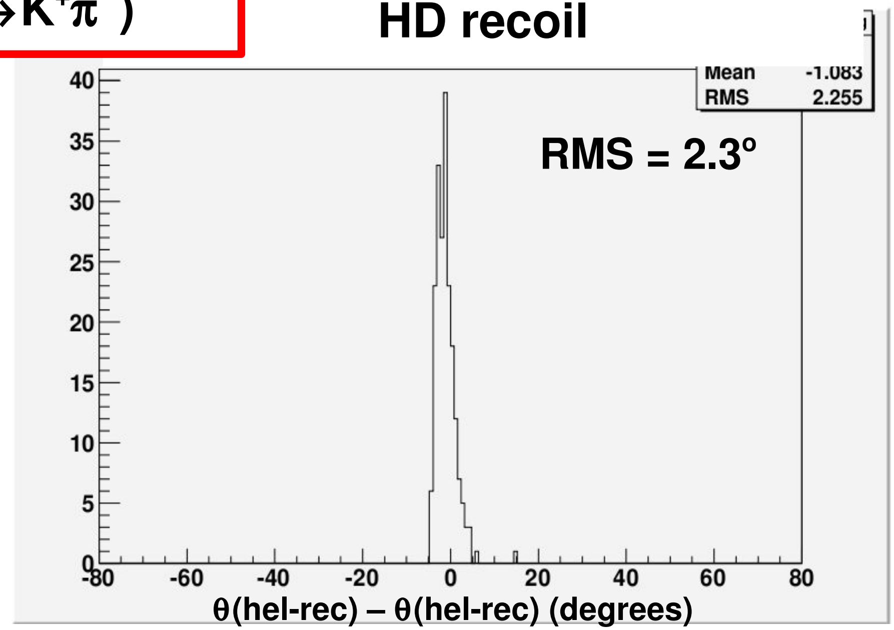
θ-rec - θ-true

($K^{*0} \to K^{+}\pi^{-}$)

SL recoil

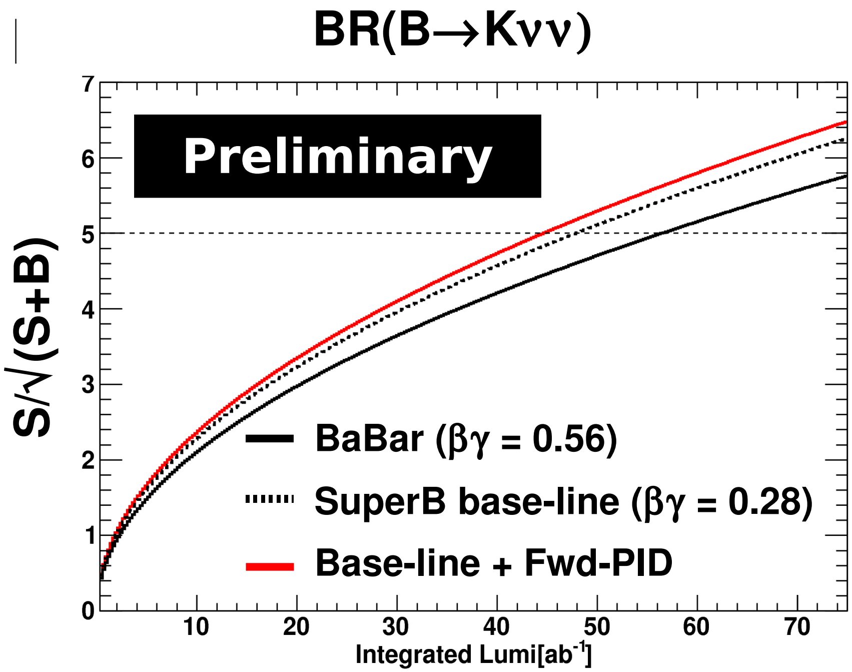


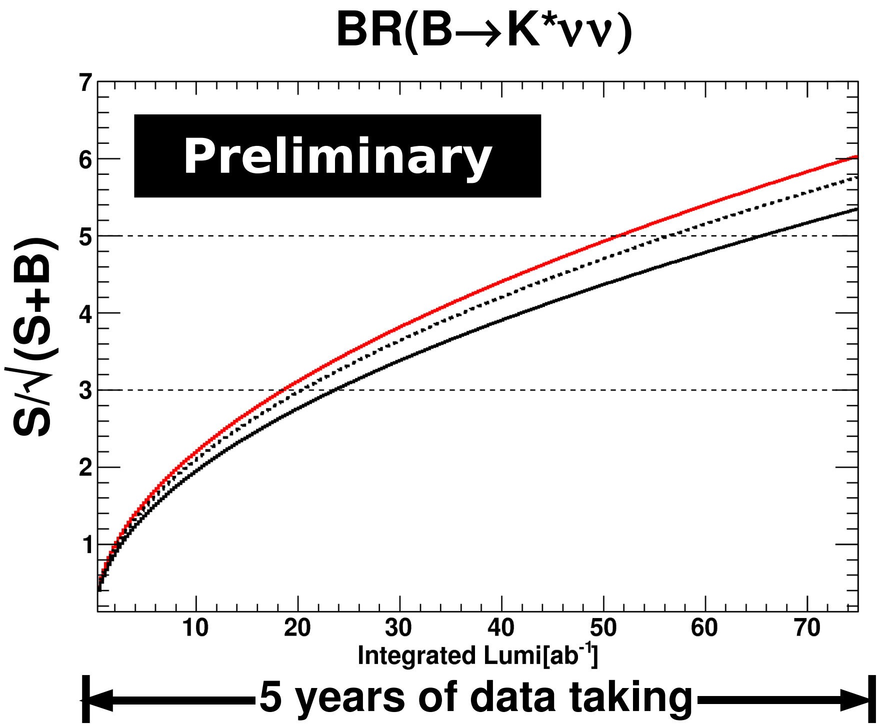
HD recoil



$B \to K^{(*)}\nu\nu$ (SL): Expected Sensitivity

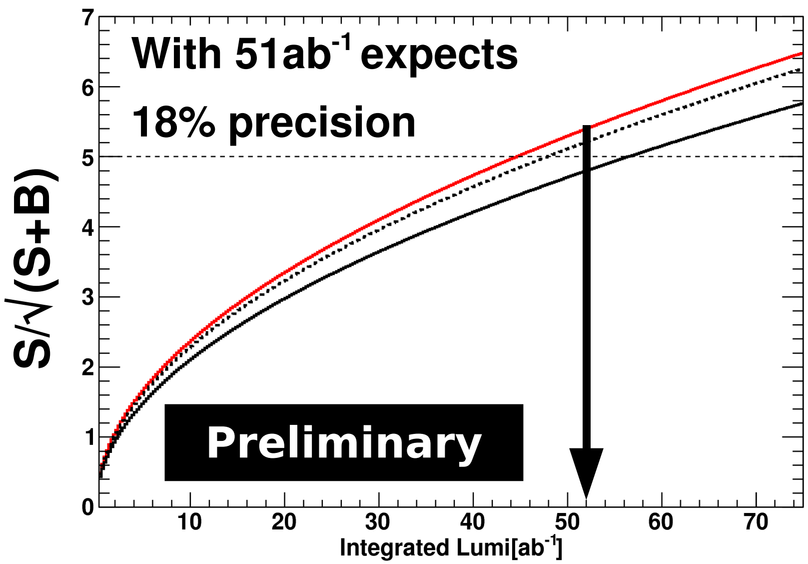
- Performed a very simple cut and count analysis
- Not enough statistics for background samples for studying background reduction
- Only estimate efficiency gains on signal samples: ~5% to 10%
- Pessimistic assumption: backgrounds increases in efficiency such that S/B ratio stays constant ⇒ overall increase in statistics for all samples

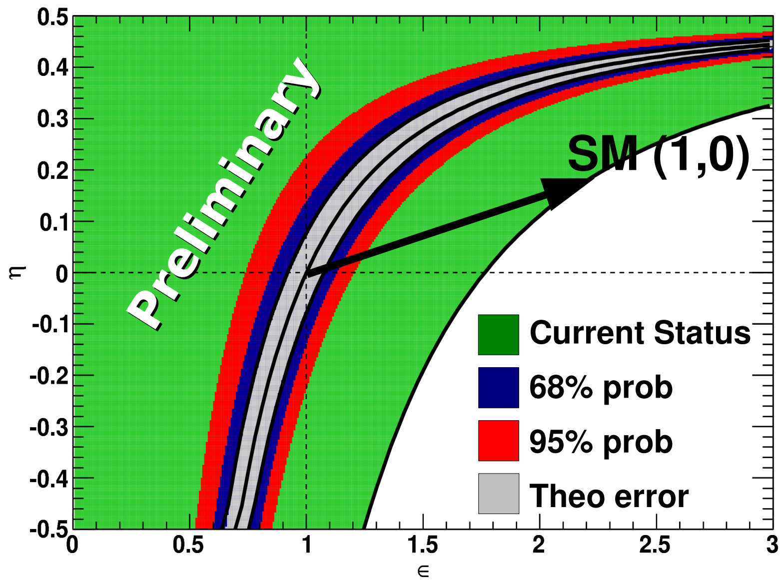




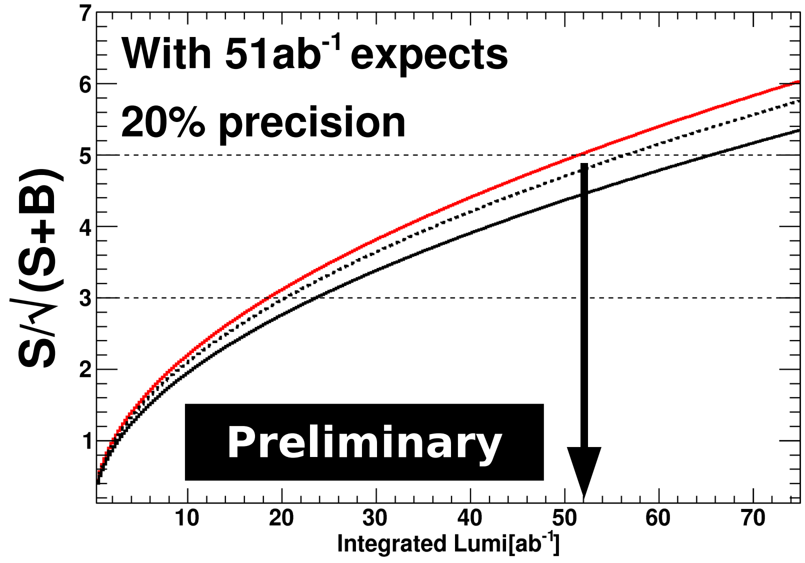
Expected constrains on NP

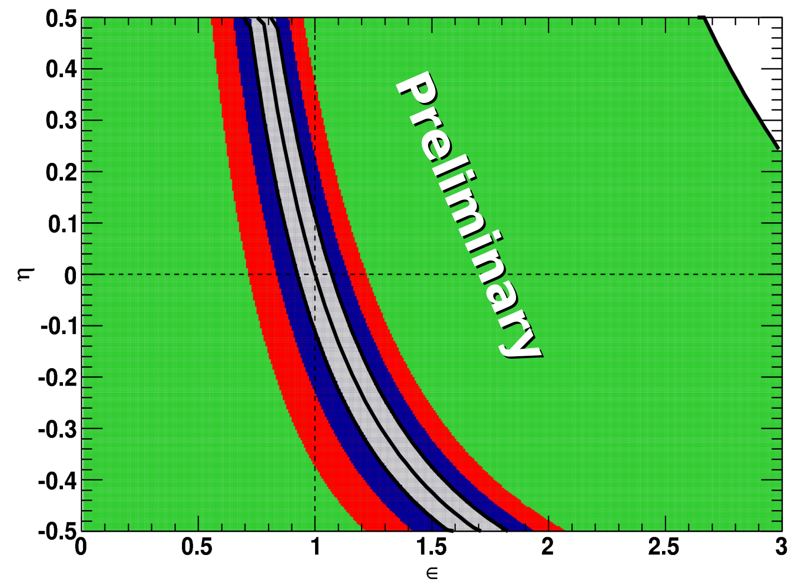
BR(B→Kνν)





BR(B→K*νν)





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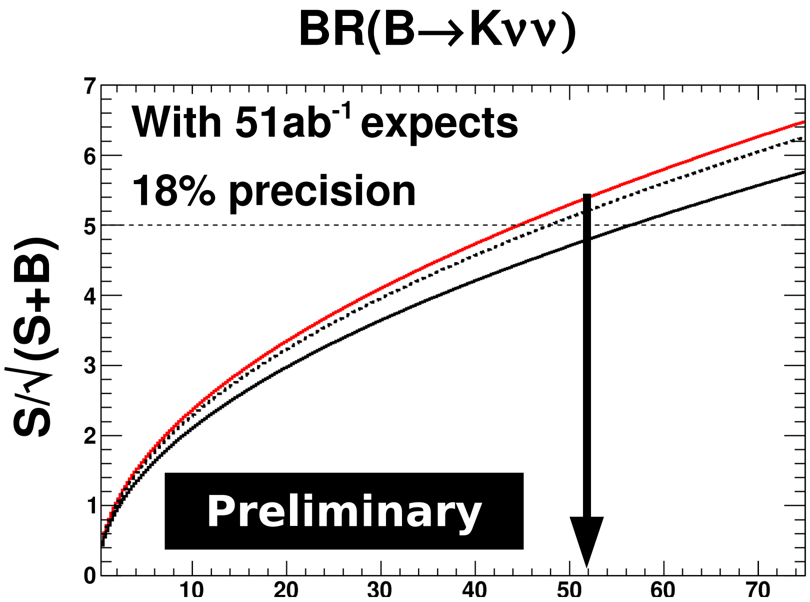

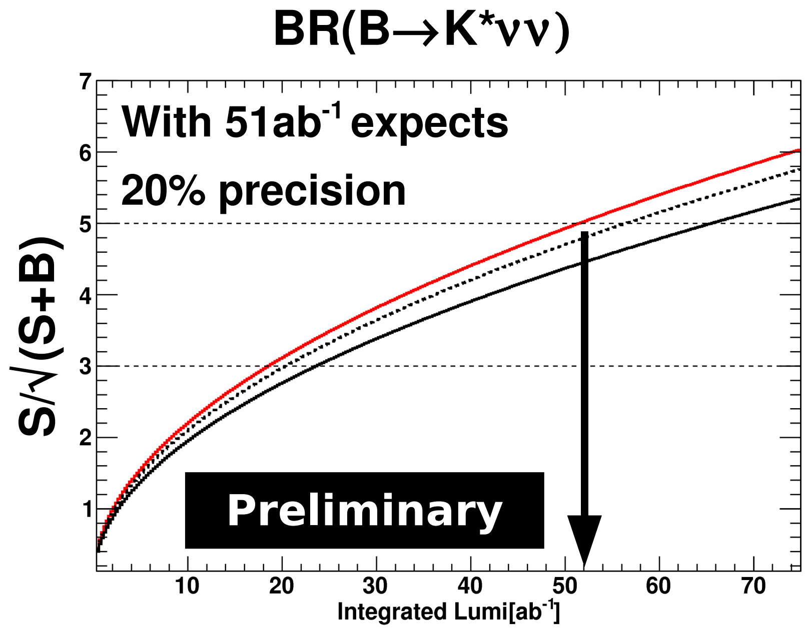

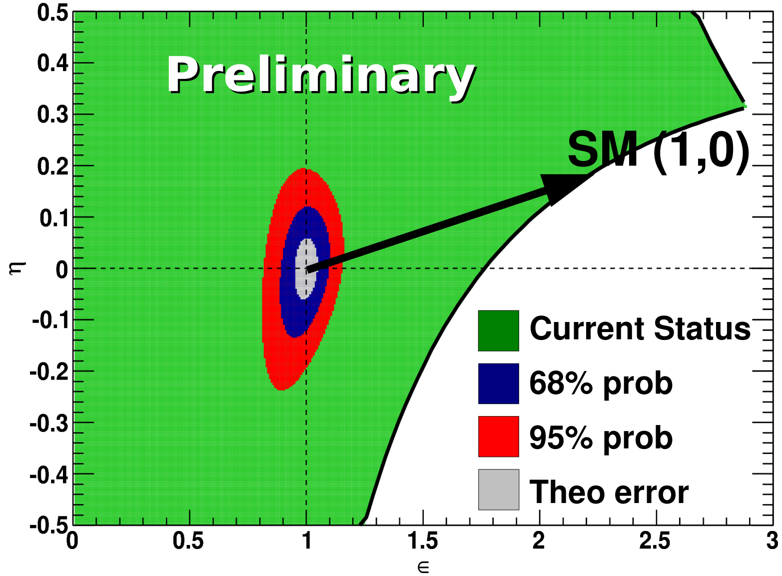

- Warning: very preliminary results
- Still need to quantify the effect of:
  - Bwd-EMC on background rejection
  - SuperB machine backgrounds rates

Summary and outlook

- **Rare decays with missing energy are golden modes for spotting NP**
- **SuperB clean experimental environment allows to study those decays**
  (not possible at hadronic machines)

- **$B \to K^{(*)} \nu\nu$ modes have potential for NP searches:** overconstrained model independent phenomenology $\Rightarrow$ 3 observables and 2 parameters (ε,η)
- **SuperB will be able to significantly reduce NP parameter space with a reduced fraction of its total dataset** ($51 ab^{-1} \Leftrightarrow$ ~3.4 years of data taking)
- **Expect better results with additional detector improvements (Bwd-EMC)**

- **Still some work to do**
  - Simultaneous extraction of $BR(B \to K^{(*)} \nu\nu)$ and $F_L(B \to K^{(*)} \nu\nu)$ with a 2D fit on Eextra and θ(helicity)
  - Additional FL measurement should improve constrain on (ε,η) plane
- **Hopefully NP effects will be spotted after a couple of years of running!**

Backup