HQL 2010 – Laboratori Nazionali di Frascati – Oct. 12th 2010

Status, open problems and prospects of the decay $B^+ \to l^+ \nu$

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SEZIONE DI PISA

SuperB

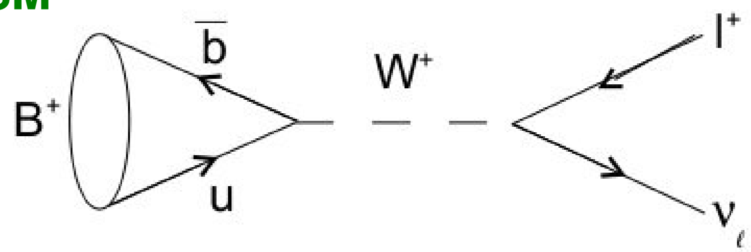
Outline

- **Introduction**
  - Theoretical motivation
  - The experimental technique (Recoil Analysis):
    - Semi-leptonic (SL)
    - Hadronic (HD)
  - The main kinematic variables
- **Experimental status**
  - $B^+ \to e^+\nu$ and $B^+ \to \mu^+\nu$
  - $B^+ \to \tau^+\nu$
- **SuperB detector layout improvements:**
  - Reduced boost (from $\beta\gamma = 0.56$ to $\beta\gamma = 0.24$)
  - Forward particle ID device (Fwd-PID)
  - Backward Electromagnetic Calorimeter (Bwd-EMC)
- **Some prospects for SuperB**
- **Summary and outlook**

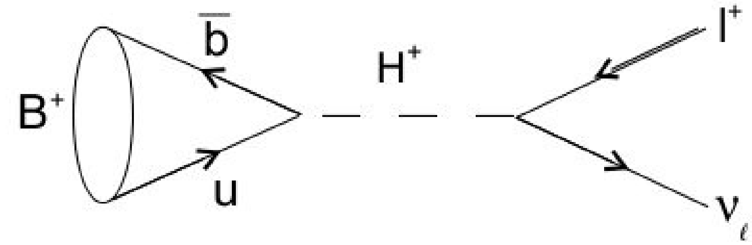
Introduction

$B^+ \to l^+ \nu$: Theoretical Motivation

SM



New Physics



$$Br(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Expected BR ~10^{-4} for $B^+ \to \tau^+ \nu$

- Much smaller for
  - $B^+ \to \mu^+ \nu$ (~10^{-7})
  - $B^+ \to e^+ \nu$ (~10^{-11})

  due to helicity suppression

- Latest analyses use up to 468M (BaBar) and 657M (Belle) BB pairs

- New Physics (NP) contributions can significantly enhance the rate

$$Br(B \to l\nu) = B_{SM} \times r_H$$

- 2HDM

(W. S. Hou, PRD 48 (1993) 2342)

$$r_H = \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

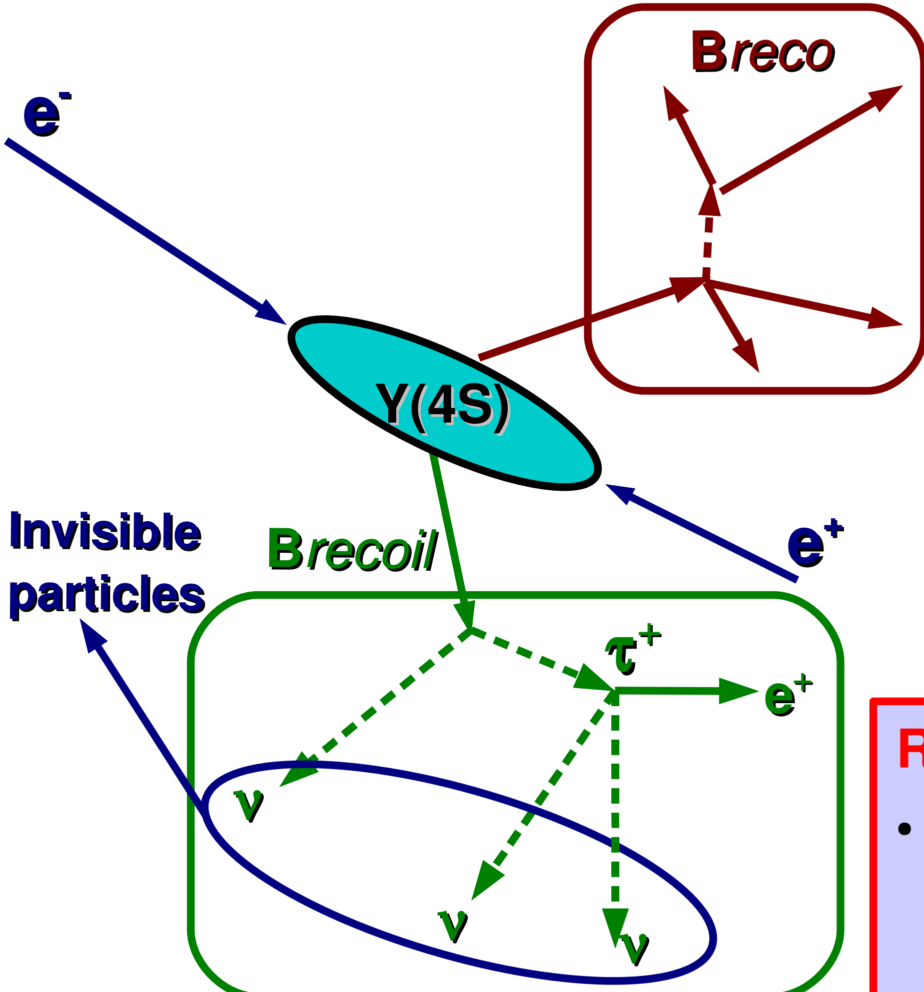
- SUSY

(A. G. Akeroyd et al., J. Phys G 29 (2003) 2311)

$$r_H = \left(1 - \frac{\tan^2\beta}{1 + \bar{\epsilon}_0 \tan\beta} \frac{m_B^2}{m_H^2}\right)^2$$

Recoil Analysis Technique

Use a well-reconstructed B meson as a "tag"



Use the fact that the B mesons are actually produced through Υ(4S) at B-factories

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

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

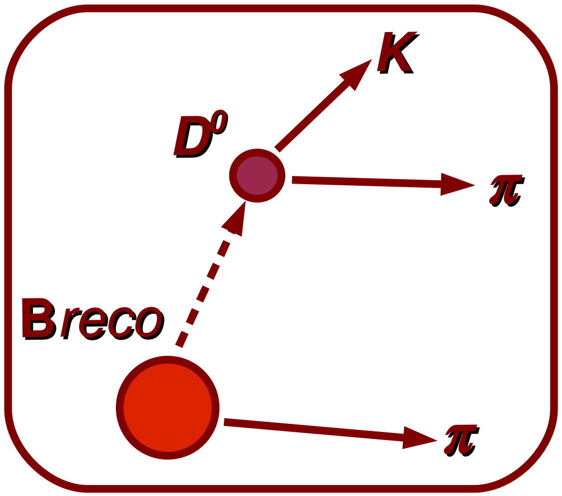
Recoil technique at B-Factories:

- search for rare decays (~10^{-5}) with missing energy

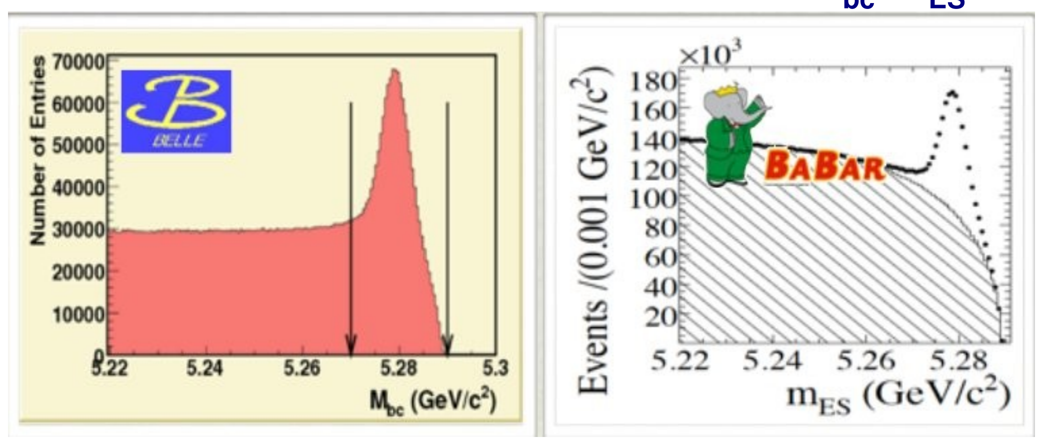
  (Not possible at hadronic machines)

Breco meson in Hadronic Channels

- BaBar and Belle use similar techniques:
  - Belle: Fully reconstruct B mesons in one of the hadronic channels, e.g. $D^{(*)}\pi$, $D^{(*)}\rho$, $D^{(*)}a_1$, $D^{(*)}D_s^{(*)}$, etc
  - BaBar: Fully reconstruct with $D^{(*)}$ + many light hadrons (up to 5 K^+/π^+, up to 2 K^0_S, up to 2 π^0)



Identify the signal using ΔE and M_{bc}/M_{ES}

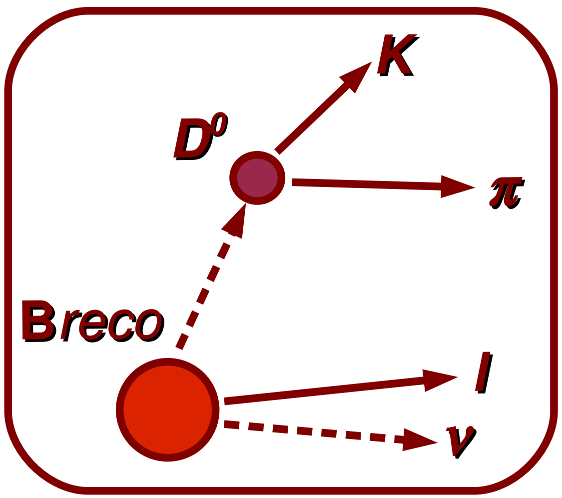


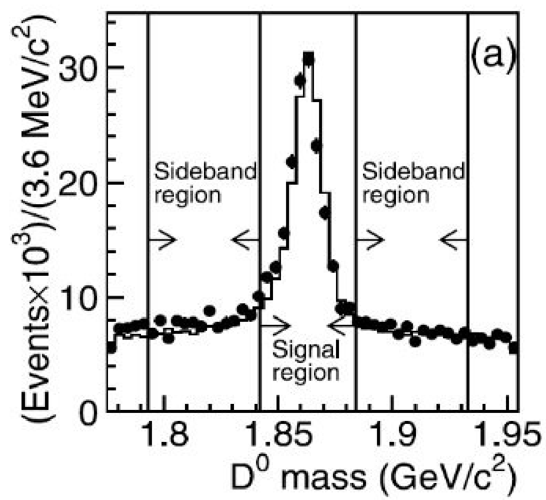
Pro: higher purity, higher resolution, full kinematics can be examined

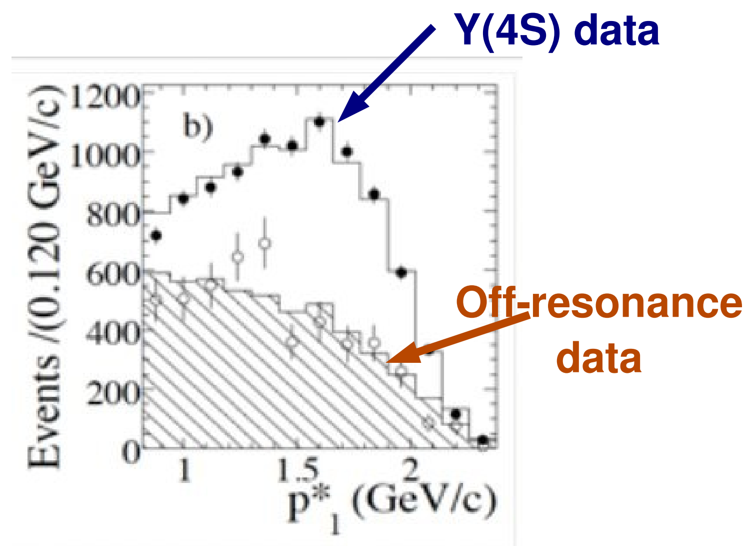
Con: Lower efficiency (as low as ~0.4%)

Breco meson in Semi-Leptonic Channels

- BaBar and Belle use the same technique:
  - Reconstruct a $B \to D^{(*)} l \nu$ decay with a clean $D^{(*)}$ meson plus a high momentum charged lepton ($e^{\pm}$, $\mu^{\pm}$)



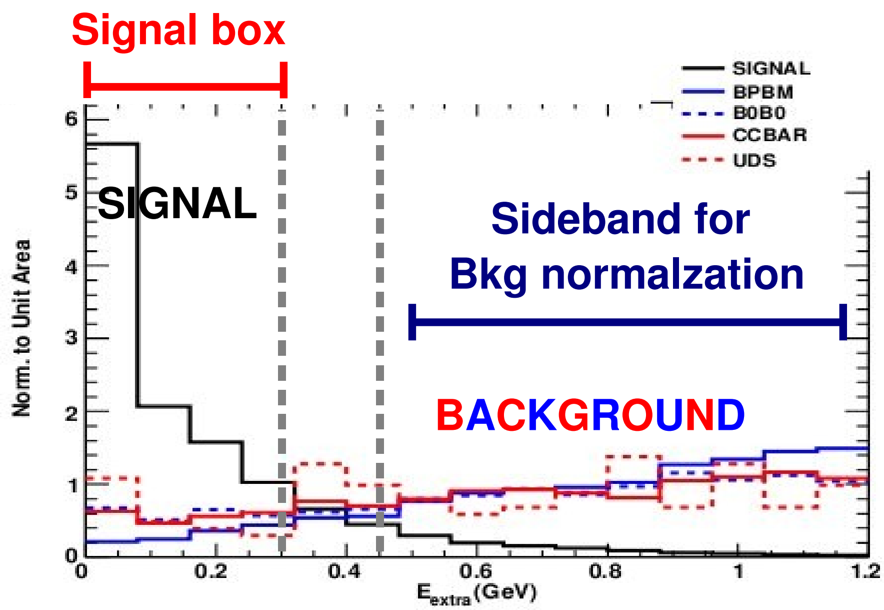




Pro: higher efficiency

Con: Lower purity, bad resolution, additional neutrino

Main Kinematic Variables

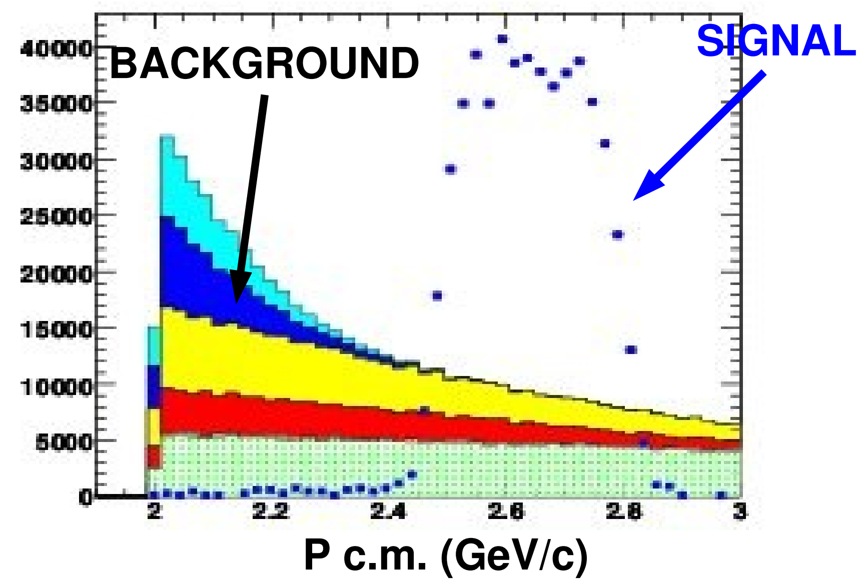


Extra energy in calorimeter

- The most powerful variable for separating signal and background
- Sum up neutral clusters not associated to Breco and Brecoil
- Signal: zero or tiny extra energy from beam background (possible issue for SuperB)

Momentum of visible Brecoil daughters

- $B^+ \to e^+\nu$ and $B \to \mu^+\nu$: decay produces mono-energetic charged lepton in the Brecoil rest frame
- $B \to \tau^+\nu$: provides some discrimination against backgrounds

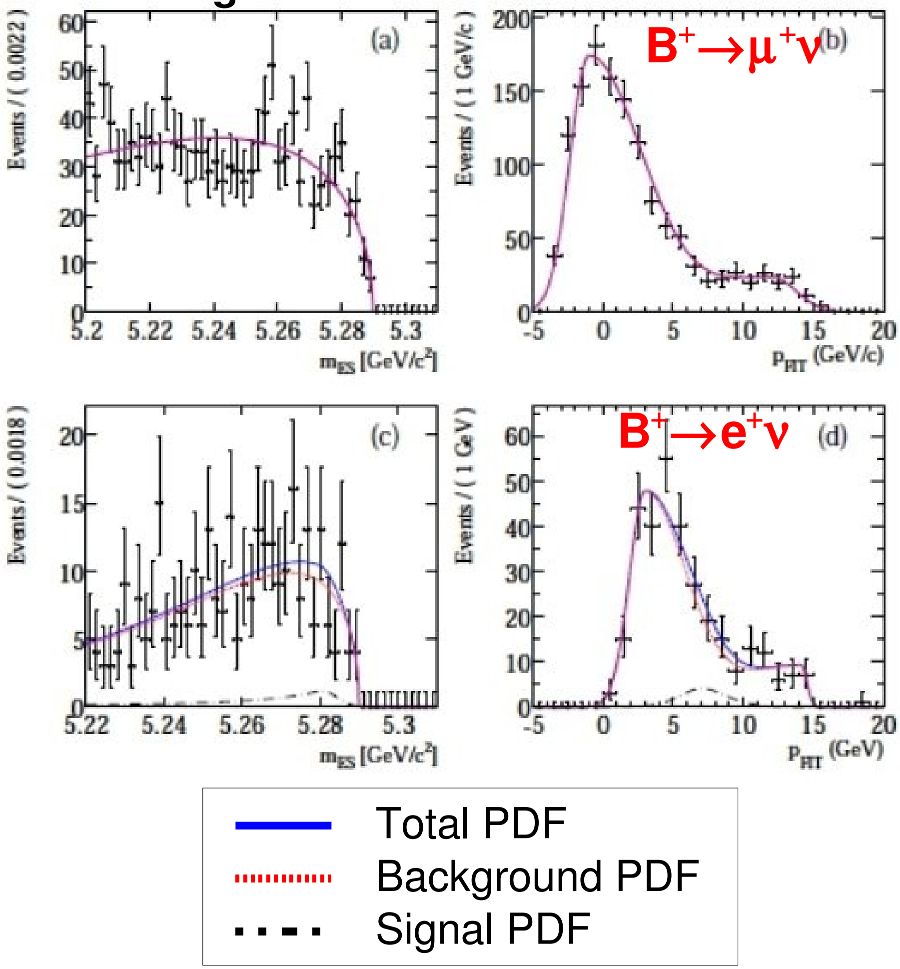


Experimental Status

$B^+\to e^+\nu$ and $B^+\to\mu^+\nu$

BaBar Hadronic tag

Reconstructed Btag mass | **Lepton p(c.m.) and p'(Bsig-CM) Fisher**



- No events seen. All upper limits (90% C.L.) above SM value
- BaBar hadronic tag:

  Phys.Rev.D79:091101, 2009. arXiv:0903.1220

  - $Br(B^+\to e^+\nu) < 1.9\times10^{-6}$
  - $Br(B^+\to\mu^+\nu) < 1.0\times10^{-6}$
- BaBar semileptonic tag:

  Phys.Rev.D81:051101, 2010. arXiv:0809.4027

  - $Br(B^+\to e^+\nu) < 0.8\times10^{-5}$
  - $Br(B^+\to\mu^+\nu) < 1.1\times10^{-5}$
- Belle report the limits:

  Phys.Lett. B 646, 67 (2007)

  - $Br(B^+\to e^+\nu) < 0.98\times10^{-6}$
  - $Br(B^+\to\mu^+\nu) < 1.70\times10^{-6}$

$B^+ \to \tau^+\nu$: BaBar results

- Plot shows excess energy for τ^+ decays to e^+, μ^+, π^+ and ρ^+ with hadronic tags
- Signal excess near zero
  ⇒ consistent excess for all 4 channels

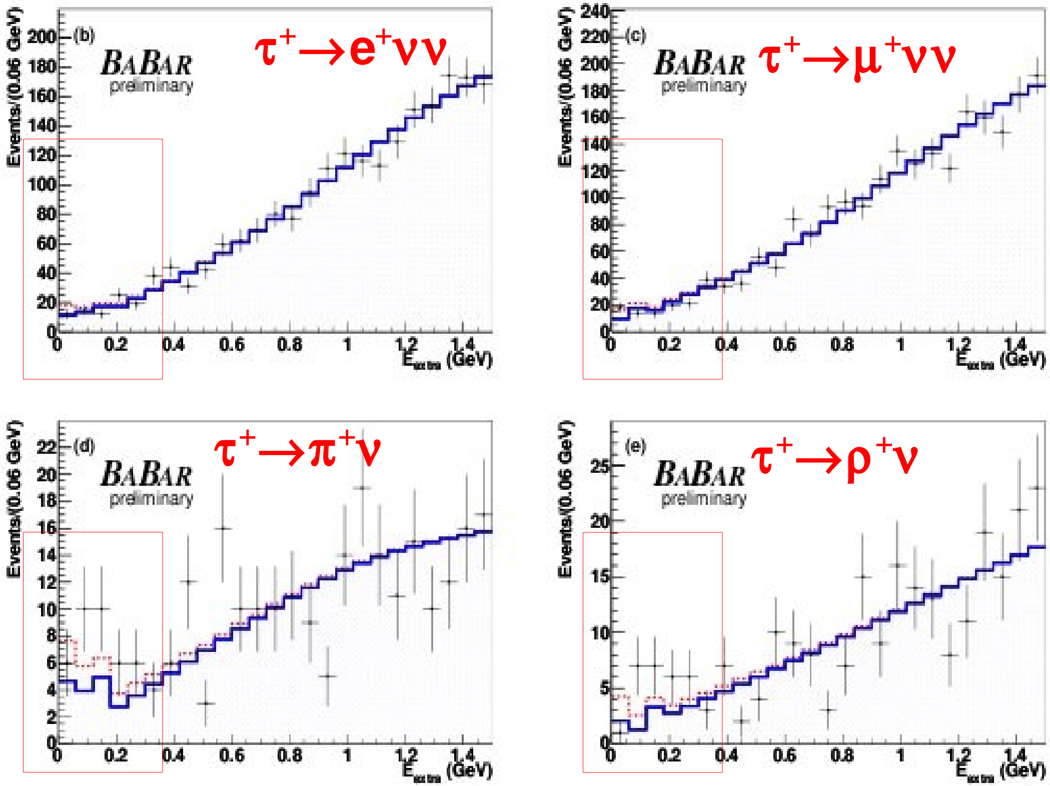
- Combined hadronic tag result (preliminary) arXiv:1008.0104

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

- Combined semileptonic tag result Phys.Rev.D81:051101, 2010

$$Br(B \to \tau^+\nu) = (1.7 \pm 0.8 \pm 0.2) \times 10^{-4}$$

BaBar Hadronic tag



E_{extra} (GeV)

$B^+ \to \tau^+ \nu$: Belle results

- Plot shows excess energy for all τ^+ decays and for decays to e^+, μ^+ and π^+ with semileptonic tags
- Signal excess near zero

  ⇒ consistent excess for all 4 channels

- Combined hadronic tag result

  Phys.Rev.D97:251802, 2006

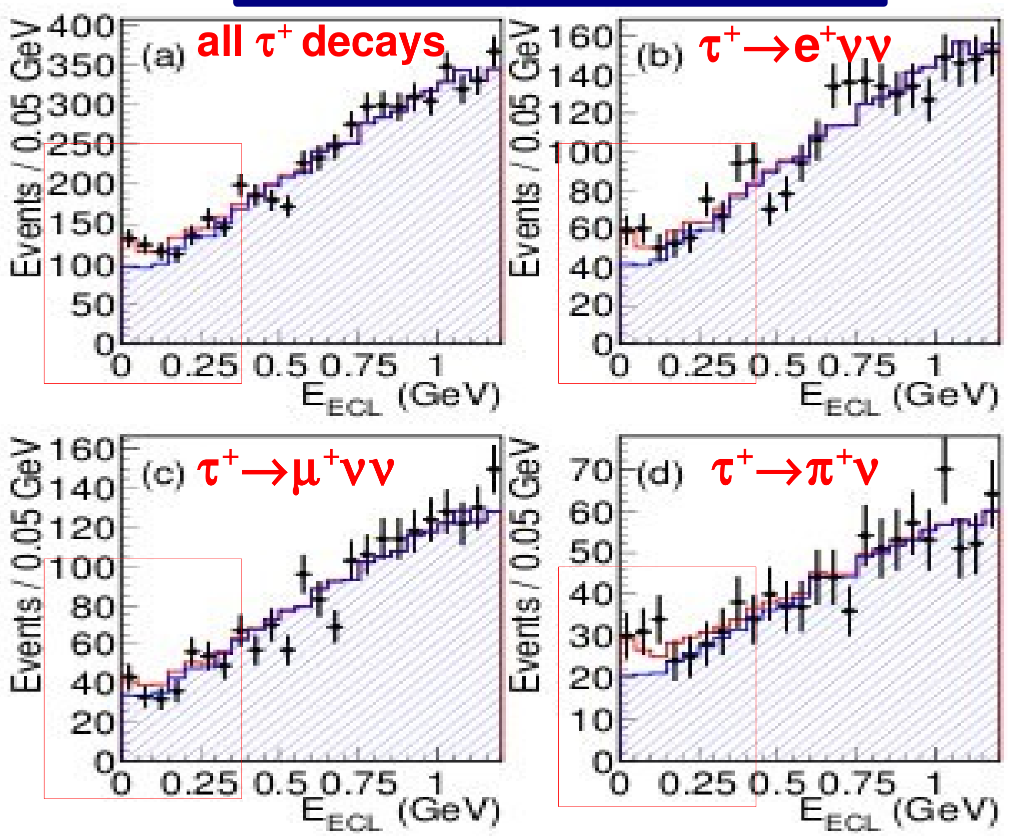
$$Br(B \to \tau^+ \nu) = (1.79\ {}^{+0.56}_{-0.49}\ {}^{+0.46}_{-0.51}) \times 10^{-4}$$

- Combined semileptonic tag result

  arXiv: 1006.4201

$$Br(B \to \tau^+ \nu) = (1.54\ {}^{+0.38}_{-0.37}\ {}^{+0.29}_{-0.31}) \times 10^{-4}$$

Belle Semi-Leptonic tag



$B^+ \to \tau^+ \nu$: Combination and Higgs Limits

- BaBar ($\times 10^{-4}$):
  - Hadronic tag (**NEW**): $(1.80^{+0.57}_{-0.54} \pm 0.26)$
  - Semilep tag: $(1.7 \pm 0.8 \pm 0.2)$

- Belle ($\times 10^{-4}$):
  - Hadronic tag: $(1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51})$
  - Semilep tag (**NEW**): $(1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31})$

Combined result: $(1.64 \pm 0.34) \times 10^{-4}$ (**HFAG**)

Well established decay

Consistent with SM value: $(1.20 \pm 0.25) \times 10^{-4}$

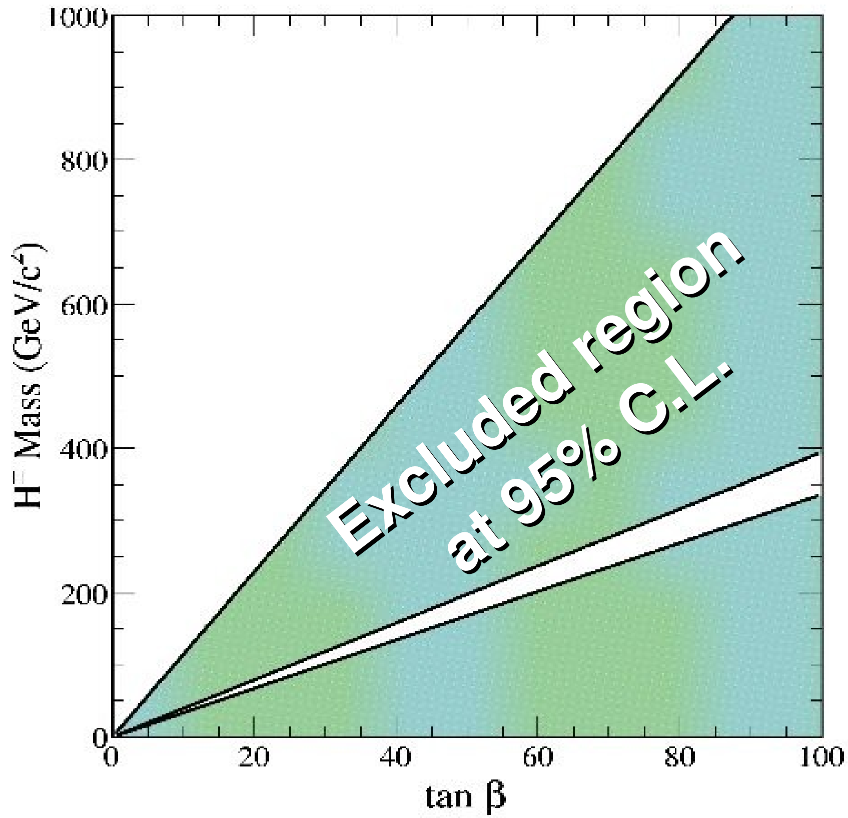
f_B = 190 ± 13 MeV (HPQCD)

$V_{ub} = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$ (**HFAG**)

- Simple "Type II" 2HDM:

$$Br(B \to l\nu) = B_{SM} \times \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

- This result excludes large values of tanβ
- Other models are more complicated



Plot from Trabelsi @ ICHEP 2010

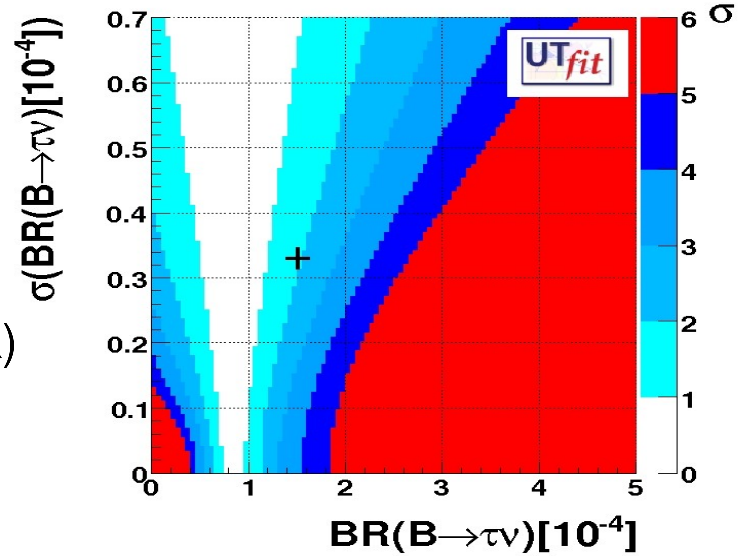
$B^+ \to \tau^+ \nu$: tension with CKM results

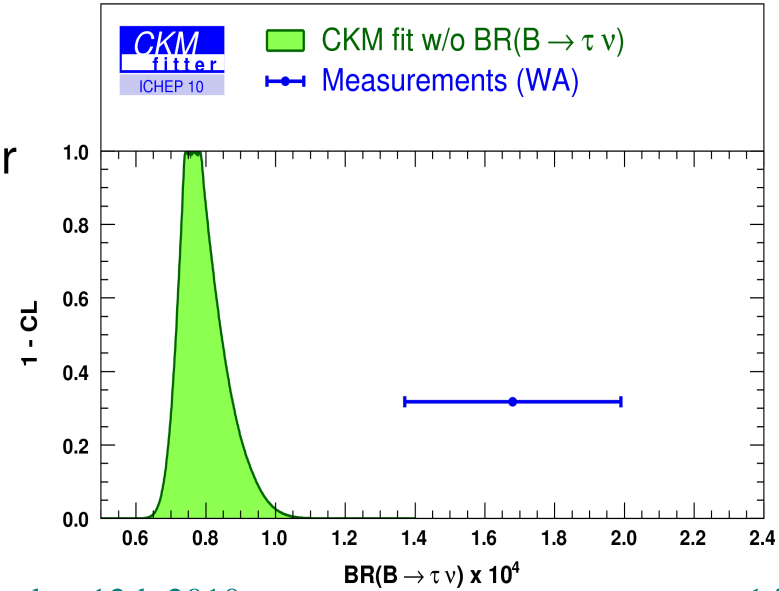
- UTfit: prediction (Tarantino's ICHEP10 talk)
  $Br(B^+ \to \tau^+ \nu) = (0.805 \pm 0.071) \times 10^{-4}$
  2.6σ disagreement with experimental value

- CKMfitter: prediction (T'Jampens ICHEP10 talk)
  $Br(B^+ \to \tau^+ \nu) = (0.763^{+0.114}_{-0.061}) \times 10^{-4}$
  2.8σ disagreement with experimental value

- Fit to all measurements, including f_B

- The different statistical approaches give similar messages:
  some tension between V_{ub} and sin2β

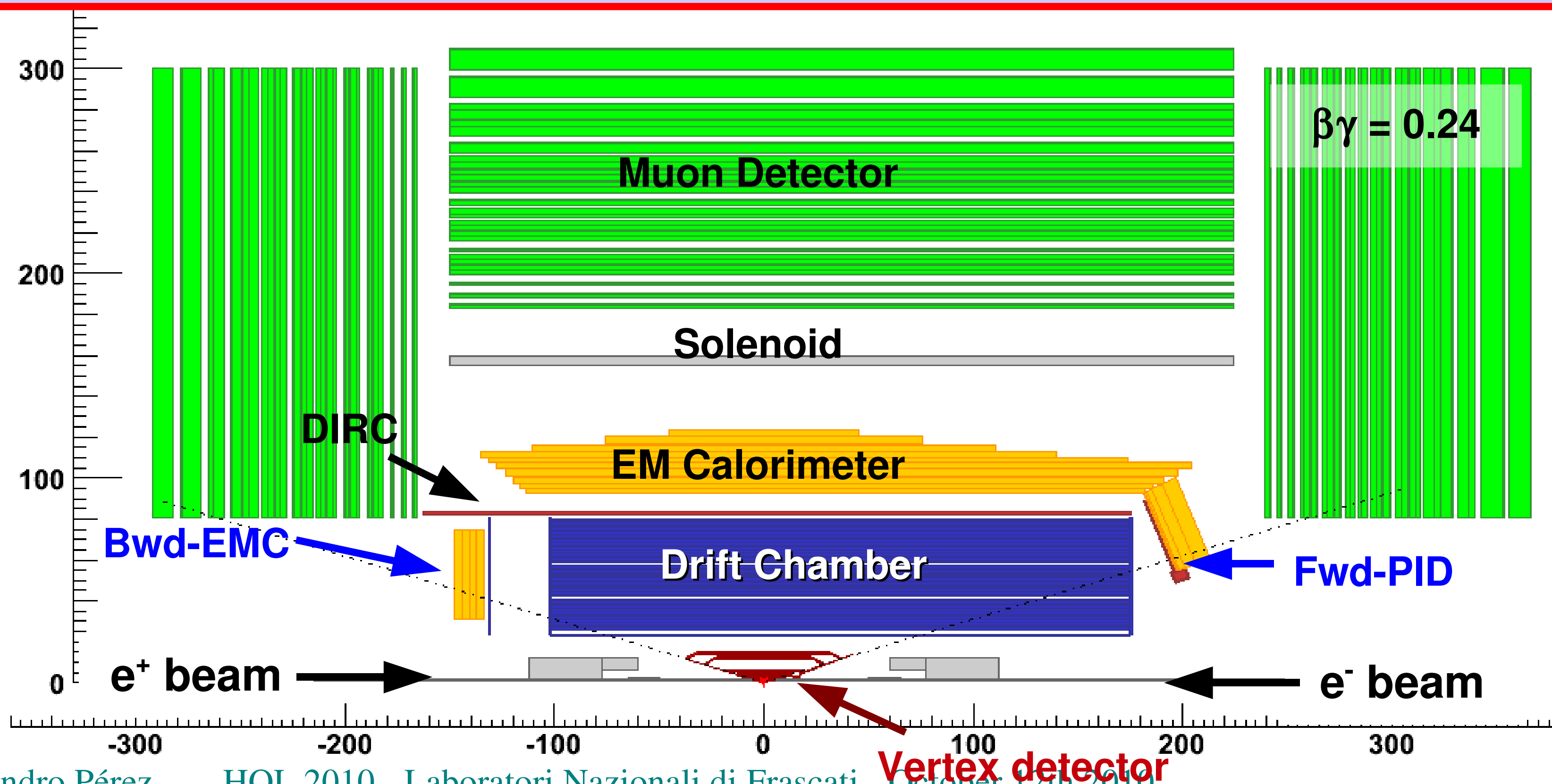




SuperB Prospects

SuperB Detector Layout

- Baseline configuration: BaBar with a reduced boost ($\beta\gamma$ = 0.24 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)



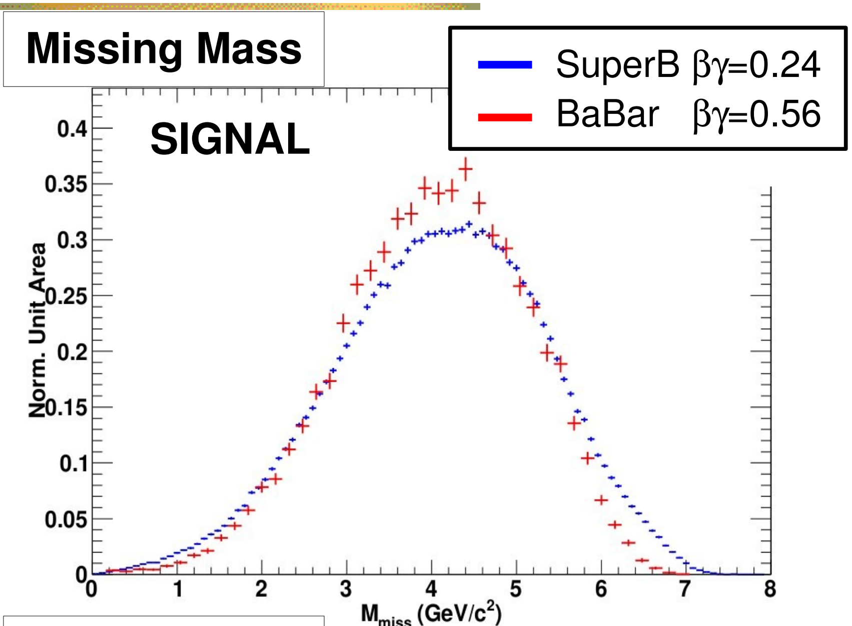
From βγ = 0.56 to βγ = 0.24

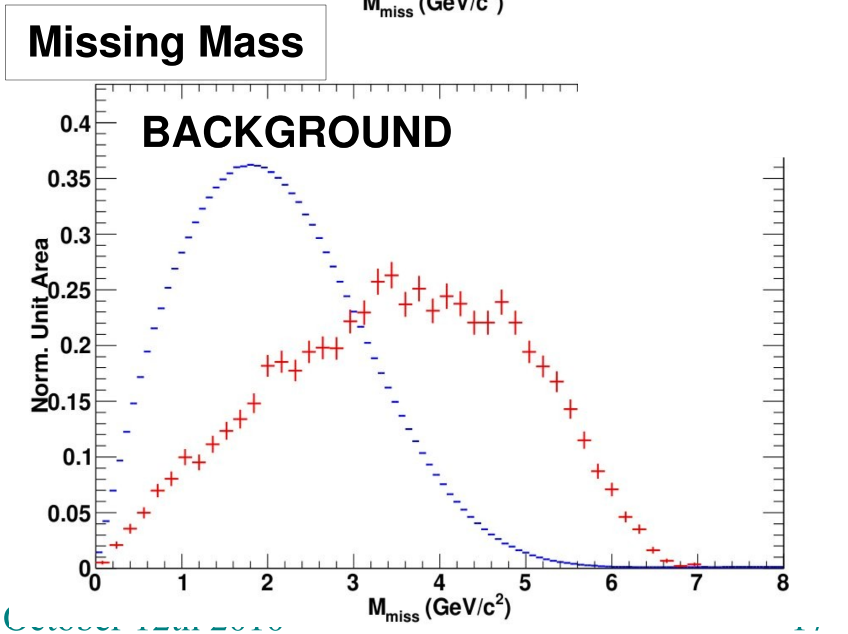
- Reducing the collision boost increases the detector acceptance ⇒ fewer particles get lost through the beam pipe
- This increases the number of selected events for signal and background (bkg)

- But for the missing Mass:
  - Marginal effect for signal
  - Significant effect for bkg (shifted to zero)

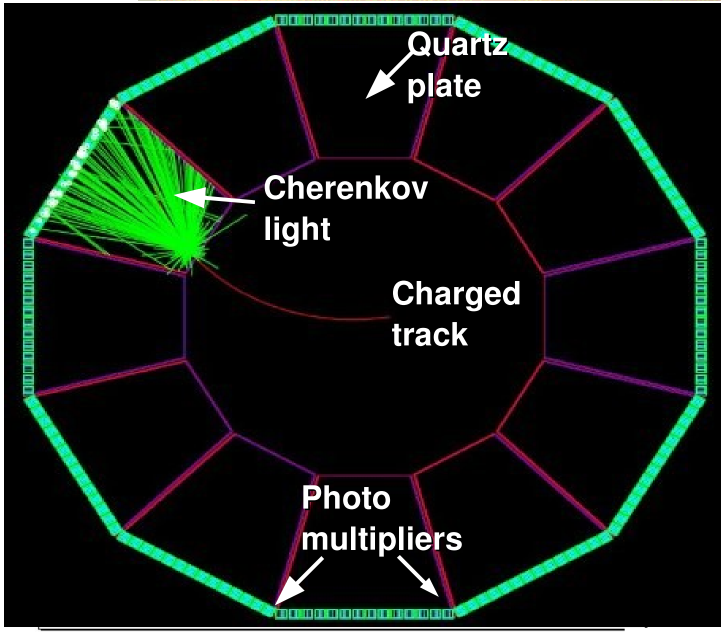
  ⇒ variable more efficient to separate signal and background

- Gain on the S/B ratio:
  - Signal efficiency: relative increase of ~7%
  - Bkg efficiency: relative decrease of ~6%

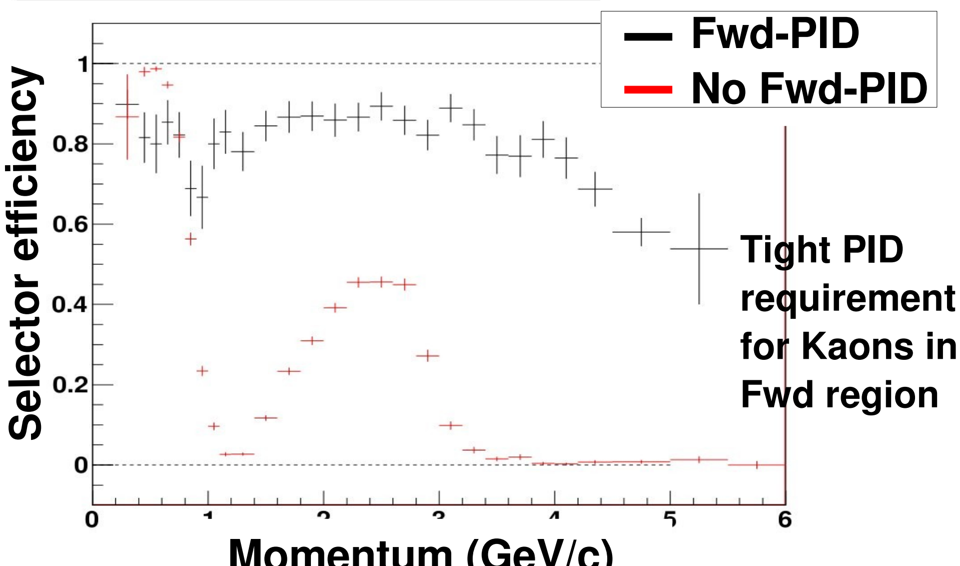


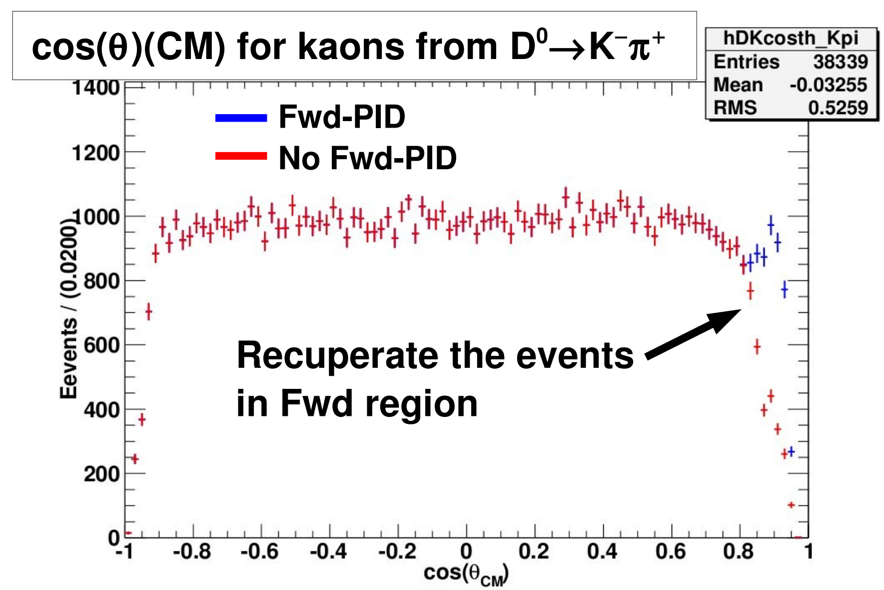


The Fwd-PID: the device (fTOF)

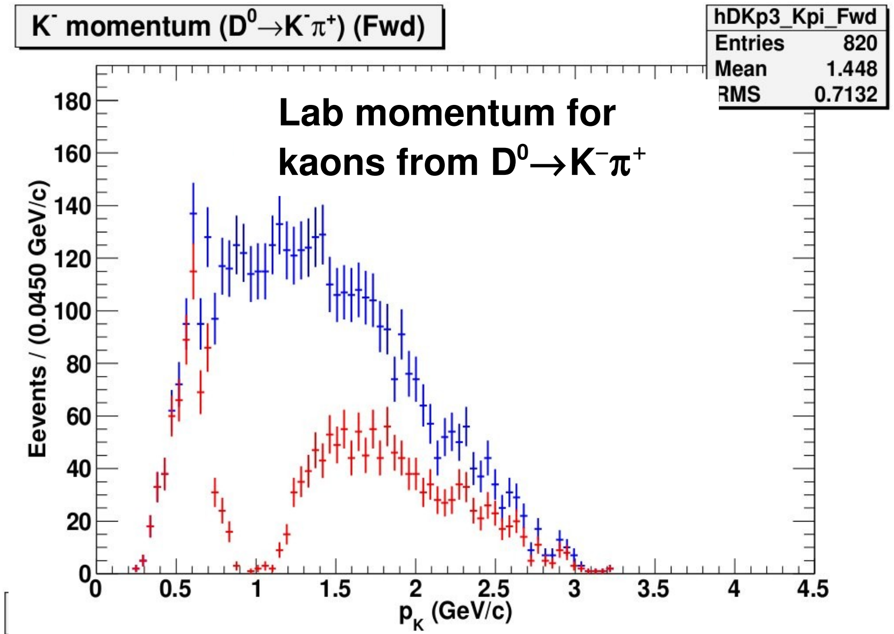


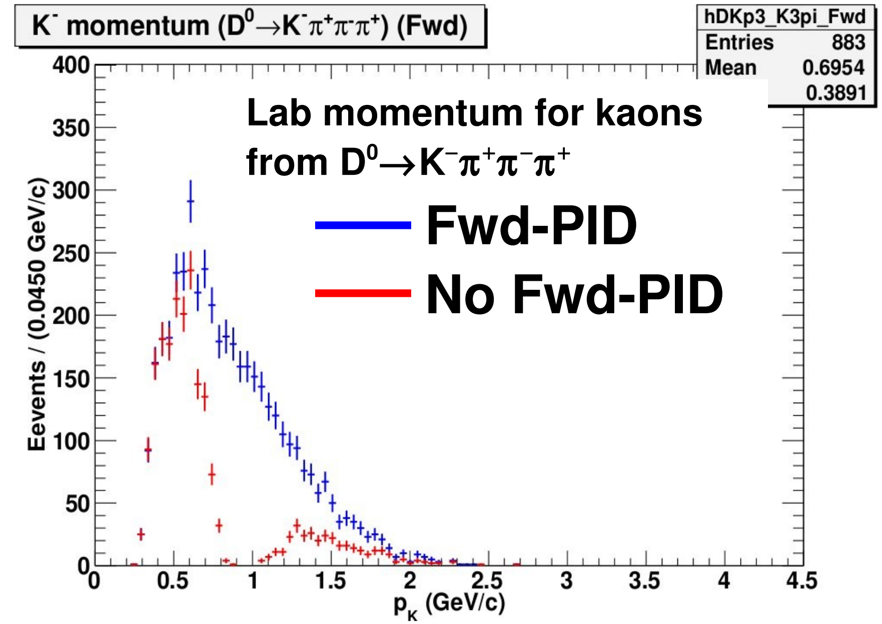
- Time of flight device: $\Delta t = t_1 - t_2 = (Lc/2p^2)(m_1^2 - m_2^2)$
  $t_1 = 0$ beam crossing, t_2 = hit with device
- 2D measurement of time vs PMT channel
- Single channel resolution $\sigma_t \sim 50$ps
- Expects 3-4σ K/π separation @ 3GeV/c

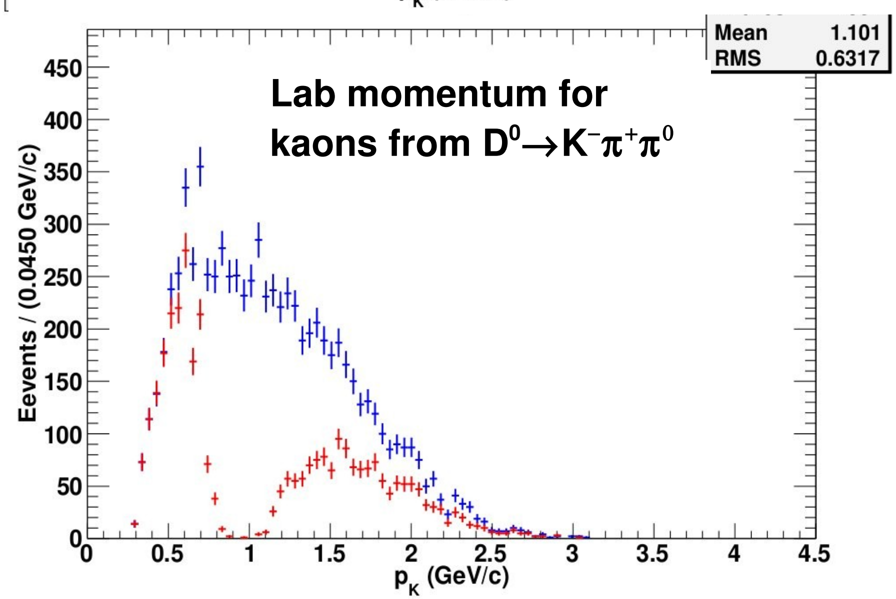




The Fwd-PID: fTOF in action







- With reduced boost ($\beta\gamma = 0.24$) only ~4.4% of kaons go to Fwd region
- Using fTOF: number of events in the Fwd gets doubled

  $\Rightarrow$ relative gain on tag-side side efficiency ~2.5%

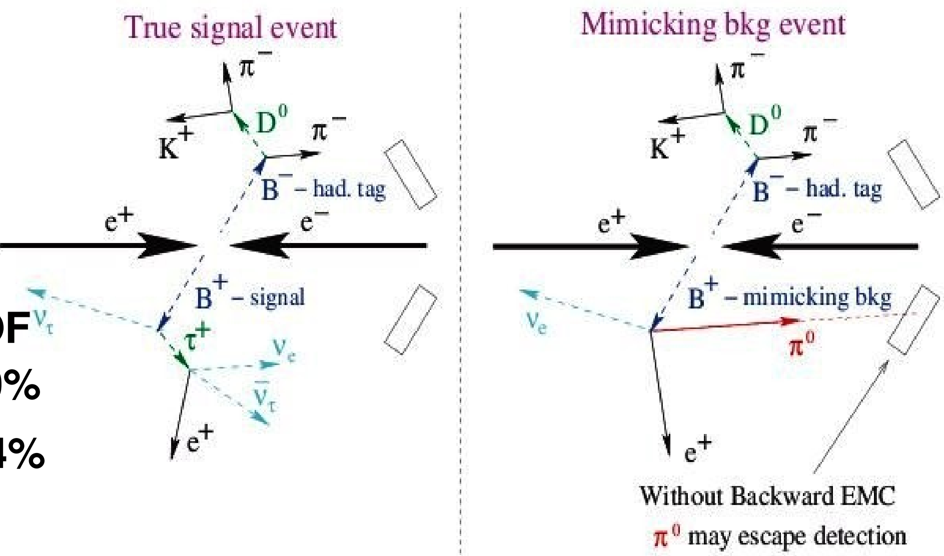
The Bwd-EMC: Veto device

- Pb-scintillator sandwich (12 X_0)
- Left/right logarithmic spiral strips alternating with radial strips
- MPPC/SiPM photo-detector

  τ_{scin} = 2.2ns, τ_{fiber} = 2.3ns, τ_{MPPC} ~0.1ns

  ⇒ bkg suppression; potential use for TOF
- Bwd: $\sigma_E/E = 14.0\%/(E(GeV))^{1/2} \oplus 3.0\%$

  Barrel-Fwd: $\sigma_E/E = 2.3\%/(E(GeV))^{1/4} \oplus 1.4\%$

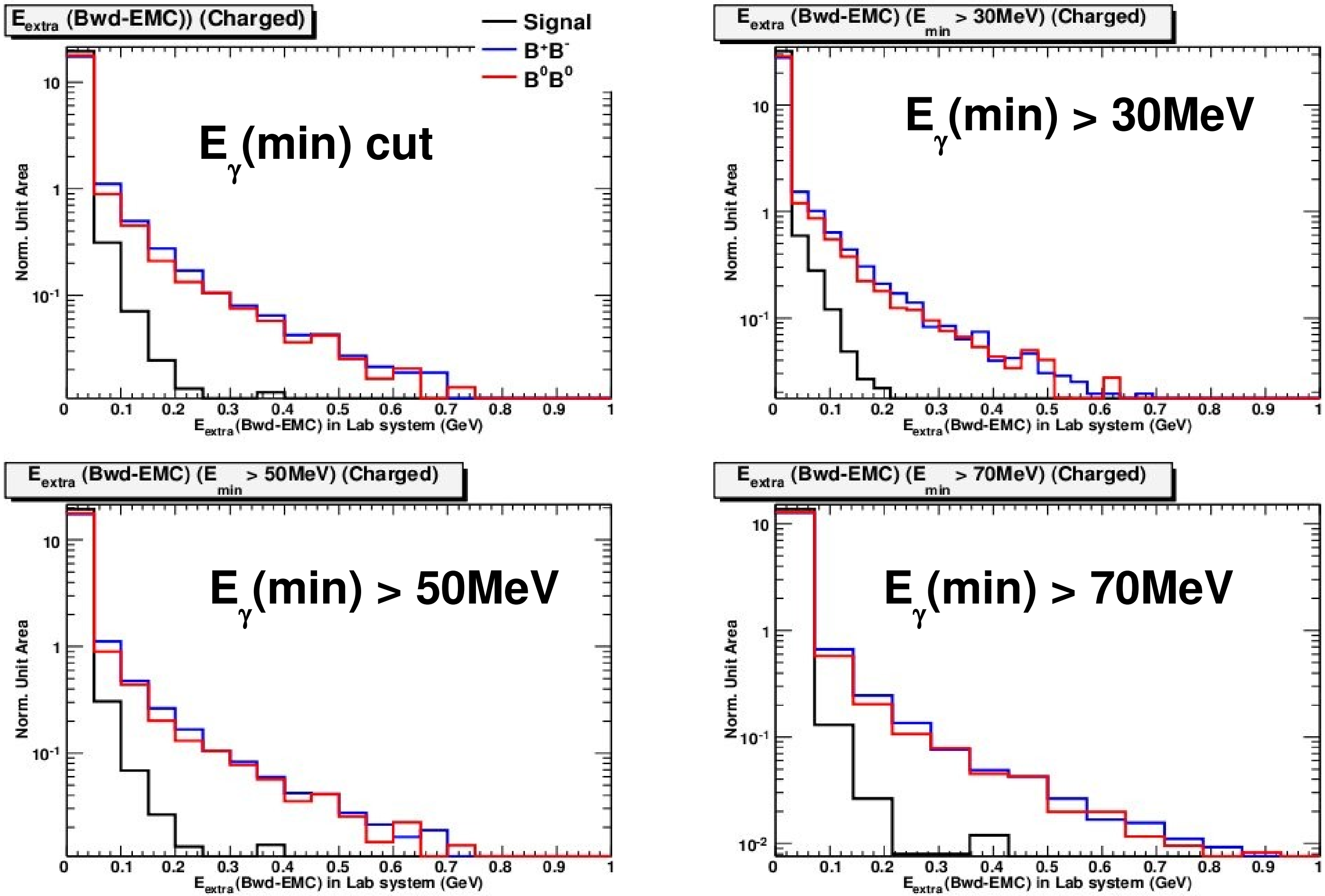


Use of Bwd-EMC:

- No B_{tag} and B_{sig} candidates with neutrals from Bwd-EMC
- Two E_{extra} variables:
  - E_{extra}(Barrel-Fwd) = Σ(extra neutrals on Barrel-Fwd EMC) (**to fit on**)
  - E_{extra}(Bwd) = Σ(extra neutrals on Bwd EMC) (**to cut on**)
- Test different $E(\gamma)_{min}$ cut for Bwd-EMC photons (none, 30, 50, 70 MeV)
- Try to define an optimum cut that maximizes a figure of merits ⇒ $S/\sqrt{(S+B)}$

The Bwd-EMC in action (I)

Signal
B^+B^-
B^0B^0



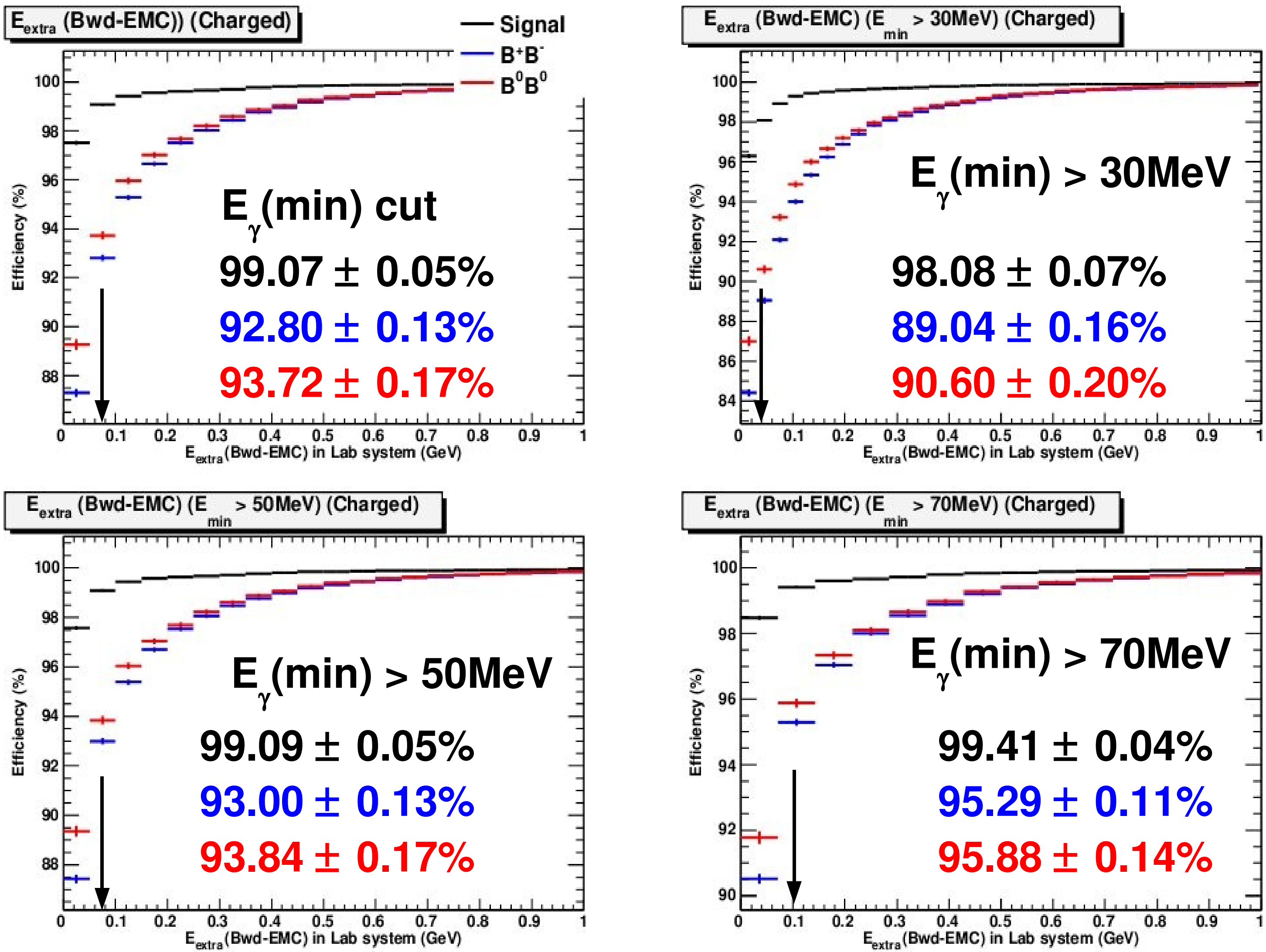
E_{extra}(Bwd-EMC) (GeV)

Warning:
log-scale in the vertical axis

Signal essentially in first bin

Backgrounds have longer tails to high values

The Bwd-EMC in action (II)



E_{extra}(Bwd-EMC) (GeV)

Signal
B^+B^-
B^0B^0

Seems that it is better to use E_γ(min) > 30MeV

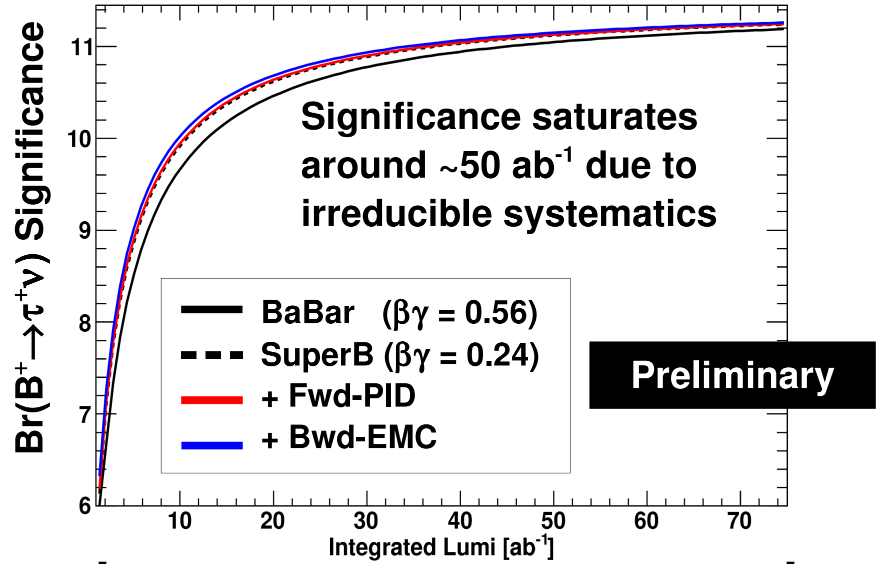
Can reduce bkgs by about ~10% with marginal effect on signal

Reduction will critically depend on the amount of machine bkgs

Some prospects for SuperB: $B^+ \to \tau^+ \nu$ (I)

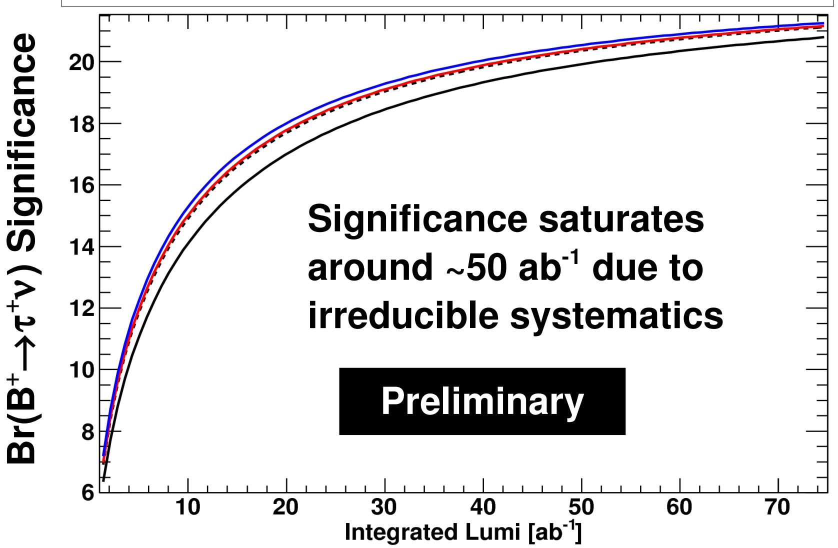
- **Assumptions:**
  - statistical error scales with luminosity
  - Main systematic error (E_{extra} bkg PDF) mainly due to MC statistics,
    $\Rightarrow$ assume it scales with luminosity
  - Syst. on tag/signal efficiencies and BB counting (7%⊕5%⊕1.1% = 8.7%) seems to be irreducible (conservative approach)

SuperB prospects (conservative approach)



5 years of data taking

SuperB prospects (systematic reduced by 50%)

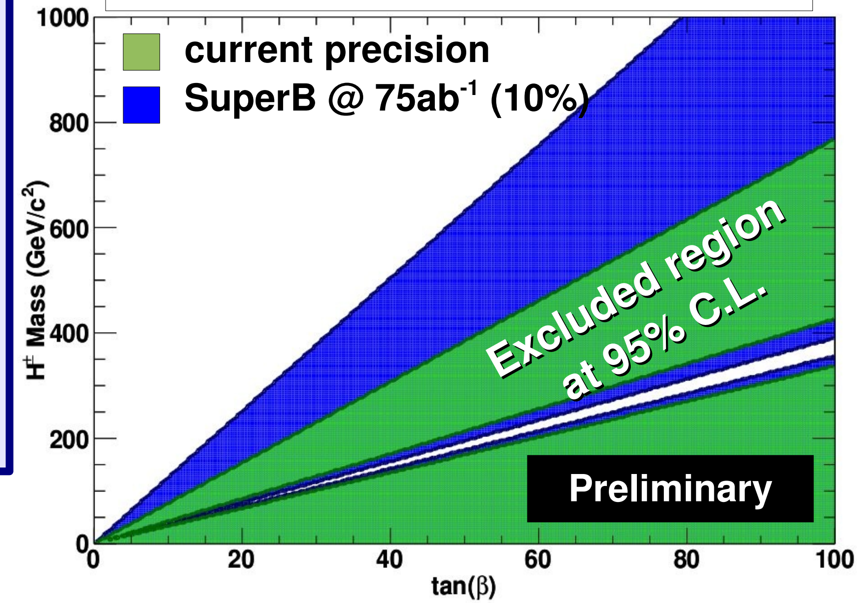


- Irreducible systs. due to data/MC mismatch on tracking and π^0 reconstruction and PID
- Evaluate them using well-characterized control samples
- Experience shows they can be reduced
- Not so conservative approach:
  Irreducible syst. error down by ~50%

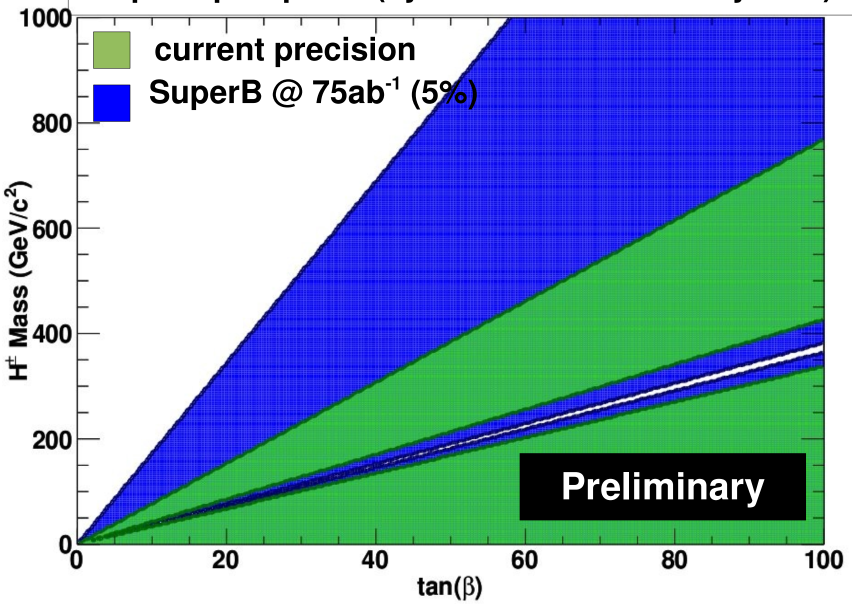
Some prospects for SuperB: $B^+ \to \tau^+ \nu$ (II)

- **Assumptions:**
  - BR_{exp} central value is SM value
  - $BR_{SM} = (1.20 \pm 0.20) \times 10^{-4}$ uncertainties mainly due to
    $f_B = 190 \pm 13$ MeV, $V_{ub} = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$
  - f_B error (lattice QCD): 1.0-1.5% for SuperB[(1)]
  - V_{ub}: 1st error is statistical (scales with lumi)
    2nd error is systematics (irreducible)

SuperB prospects (conservative approach)



SuperB prospects (systematics reduced by 50%)



- Not so conservative approach:
  Irreducible syst. error down by ~50%

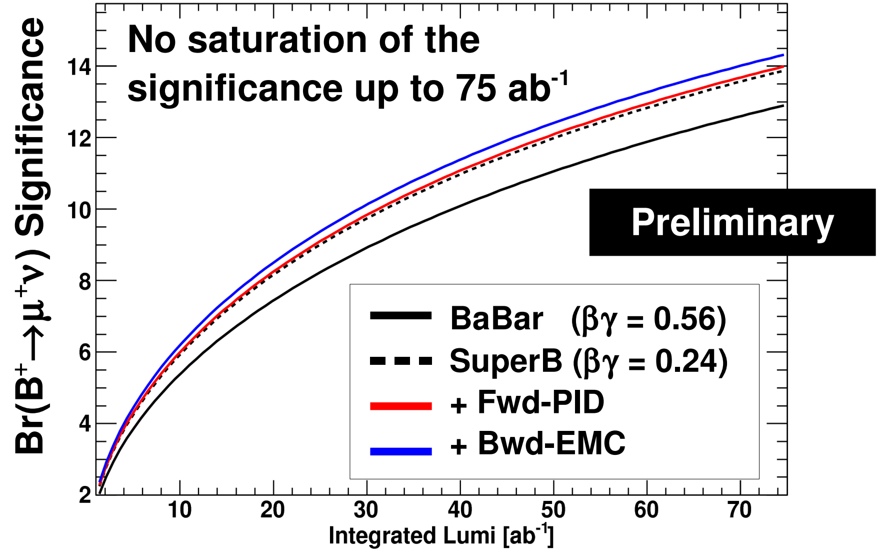
- Current precision on $BR(B^+ \to \tau^+ \nu)$ is ~20%
- With SuperB can double the excluded region on NP parameter space
- Measurement will be systematic dominated
  ⇒ need to get these uncertainties down

(1) Vittorio Lubicz @ HQL10

Some prospects for SuperB: $B^+\to\mu^+\nu$ (I)

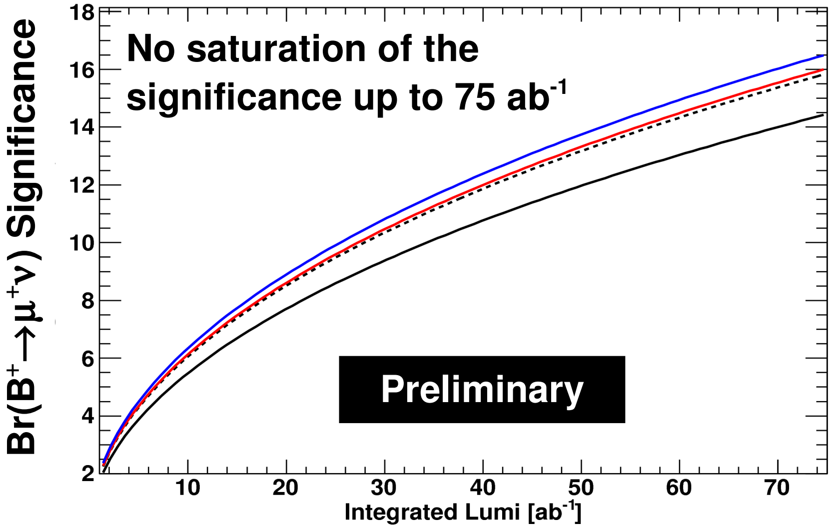
- **Assumptions:**
  - statistical error scales with luminosity
  - Main systematic error (bkg PDF) mainly due to MC statistics,
    $\Rightarrow$ assume it scales with luminosity
  - Syst. on tag+signal efficiencies and BB counting ($3.8\%\oplus1.1\% = 4\%$) seems to be irreducible (conservative approach)

SuperB prospects (conservative approach)



5 years of data taking

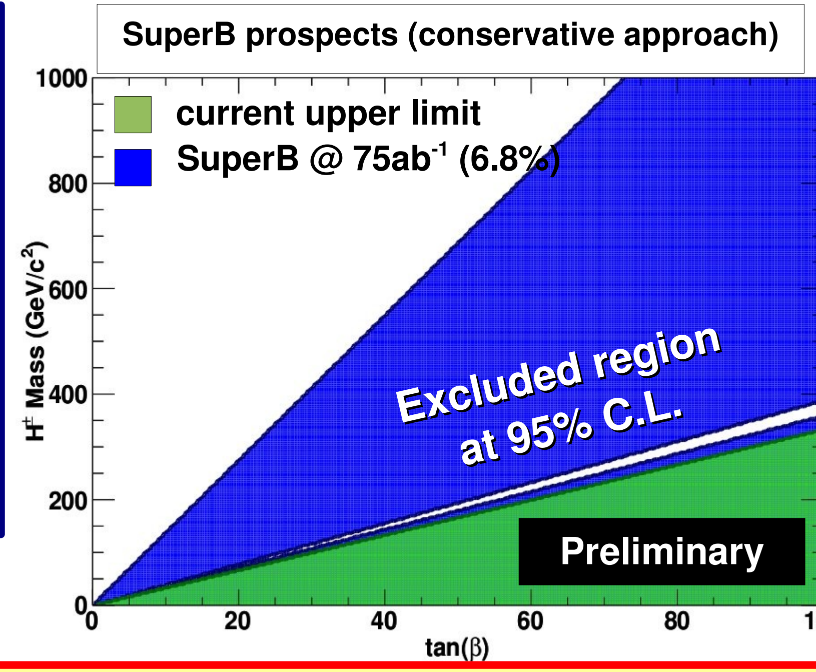
SuperB prospects (systematic reduced by 50%)

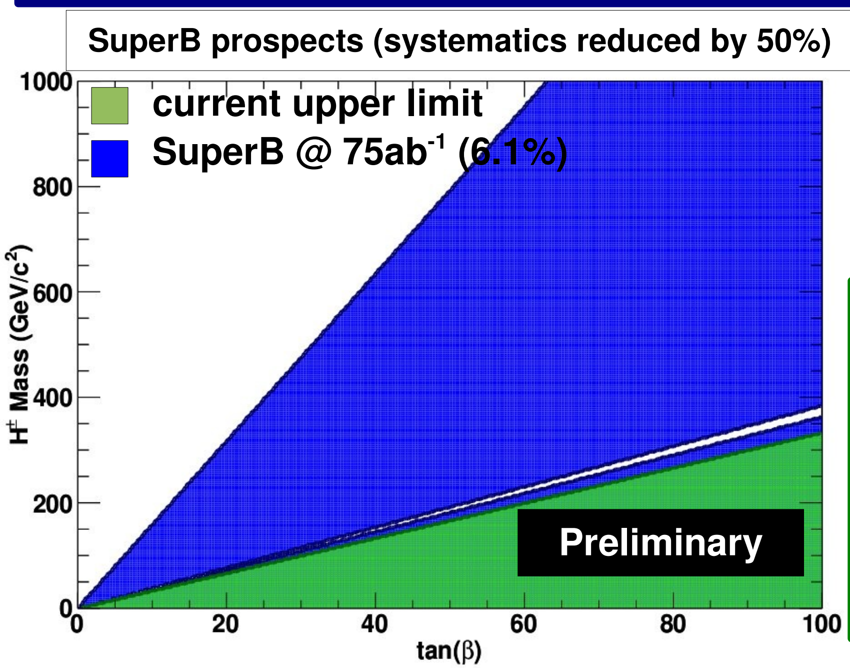


- Irreducible systs. due to data/MC mismatch on tracking and π^0 reconstruction and PID
- Evaluate them using well-characterized control samples
- Experience shows they can be reduced
- Not so conservative approach:
  Irreducible syst. error down by ~50%

Some prospects for SuperB: $B^+ \to \mu^+ \nu$ (II)

- **Assumptions:**
  - BR_{exp} central value is SM value
  - $BR_{SM} = (5.4 \pm 1.1) \times 10^{-7}$ uncertainties mainly due to
    $f_B = 190 \pm 13$ MeV, $V_{ub} = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$
  - f_B error (lattice QCD): 1.0-1.5% for SuperB[1]
  - V_{ub}: 1st error is statistical (scales with lumi)
    2nd error is systematics (irreducible)





- Not so conservative approach:
  Irreducible syst. error down by ~50%

- Currently the upper limit is in agreement with SM value
- With SuperB can significantly extend the excluded region on NP parameter space
- It seems that the measurement will not be systematic dominated

(1) Vittorio Lubicz @ HQL10

Summary and outlook

- **Measurement of $B^+ \to \tau^+ \nu$ is a strong constraint on BSM models (Currently a source of tension with the CKM fit)**
- **SuperB factory will not only increase the luminosity 100 times**
  - Reduced boost ($\beta\gamma$ = 0.24): signal (bkg) efficiency increase (reduction) by ~7% (6%)
  - Fwd-PID: global increase of signal and bkg efficiencies by ~2.5%
  - Bwd-EMC (veto device): reduction of bkg by ~10% with marginal effect on signal
- **Prospects $B^+ \to \tau^+ \nu$:**
  - With current systematics $B^+ \to \tau^+ \nu$ measurement will be systematic dominated
  - Still the panorama looks good ⇒ precision of ~10% (~5%) for conservative (not so conservative) scenarios
  - Can significantly reduce the parameter space of NP models
  - Important message: systematics need to be studied and reduced
- **Prospects $B^+ \to \mu^+ \nu$:**
  - It seems that the measurement wont be dominated by systematics
  - Competitive with $B^+ \to \tau^+ \nu$ to reduce the parameter space of NP models
  - Panorama looks good ⇒ precision of ~6.8% (~6.1%) for conservative (not so conservative) scenarios

Backup

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 ...