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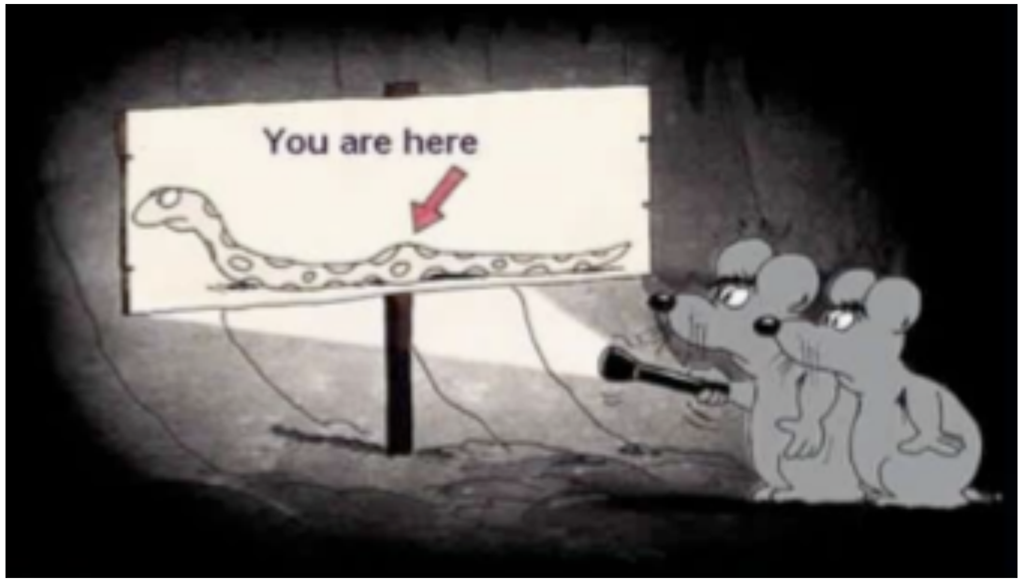
Rare Decays at B-Factories

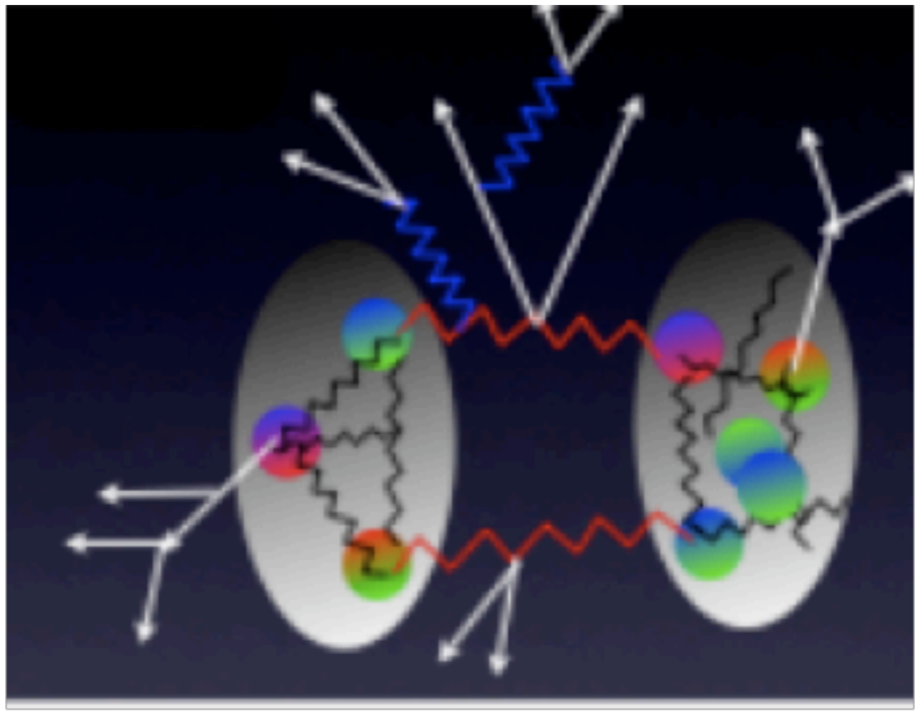
Roma, 26th March 2009

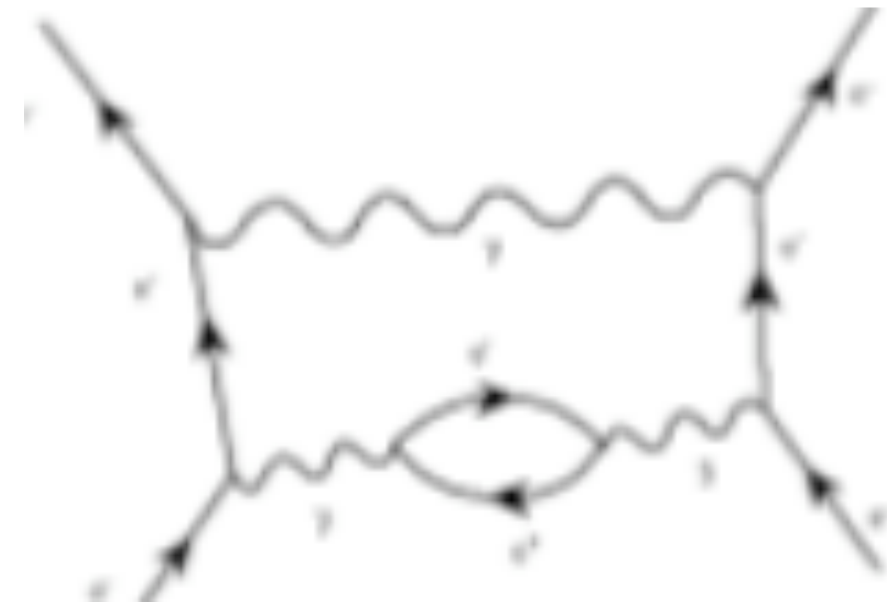
Where we are

- The SM has been able to explain in coherent framework (almost) all the experimental evidence of weak, strong and electromagnetic interactions
- CKM picture has been able to explain all the measurements in flavour sector
- BUT we know this is not the ultimate theory
- Everybody is eager for New Physics:
  - Explore energy frontiers (Tevatron, LHC)
  - Measure precisely virtual processes which can test high energy scales



Beyond the SM





Energy frontier

New particles produced increasing c.m. energy

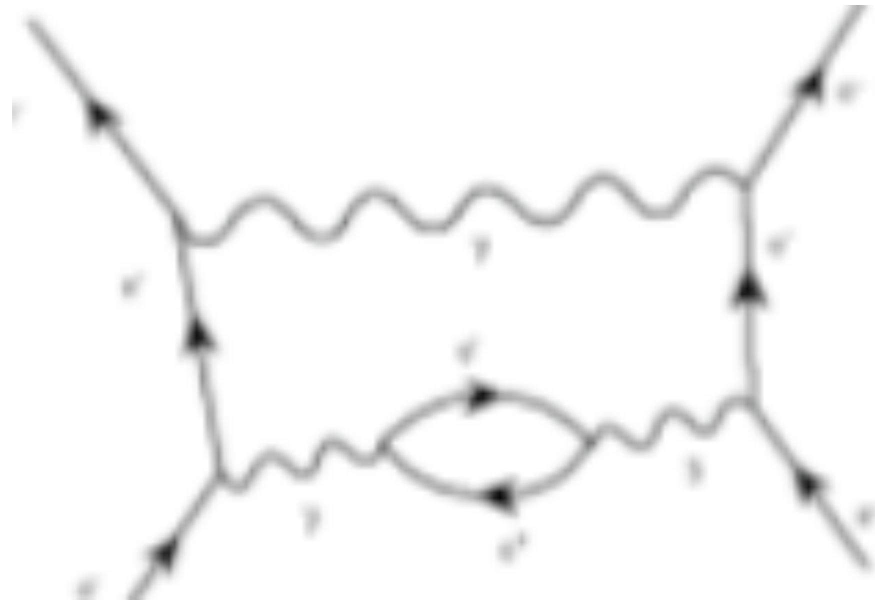
Mass spectra and couplings will discriminate among different NP

Precision frontier

Virtual processes can indirectly test NP energy scales with effective theories

Correlations among deviations w.r.t SM prediction in different processes can establish general NP features

Beyond the SM



- Rare decays provide many clean probes:
  - If a suppressed decay is observed, clear sign of NP
  - If an UL is set, NP scenarios are constrained

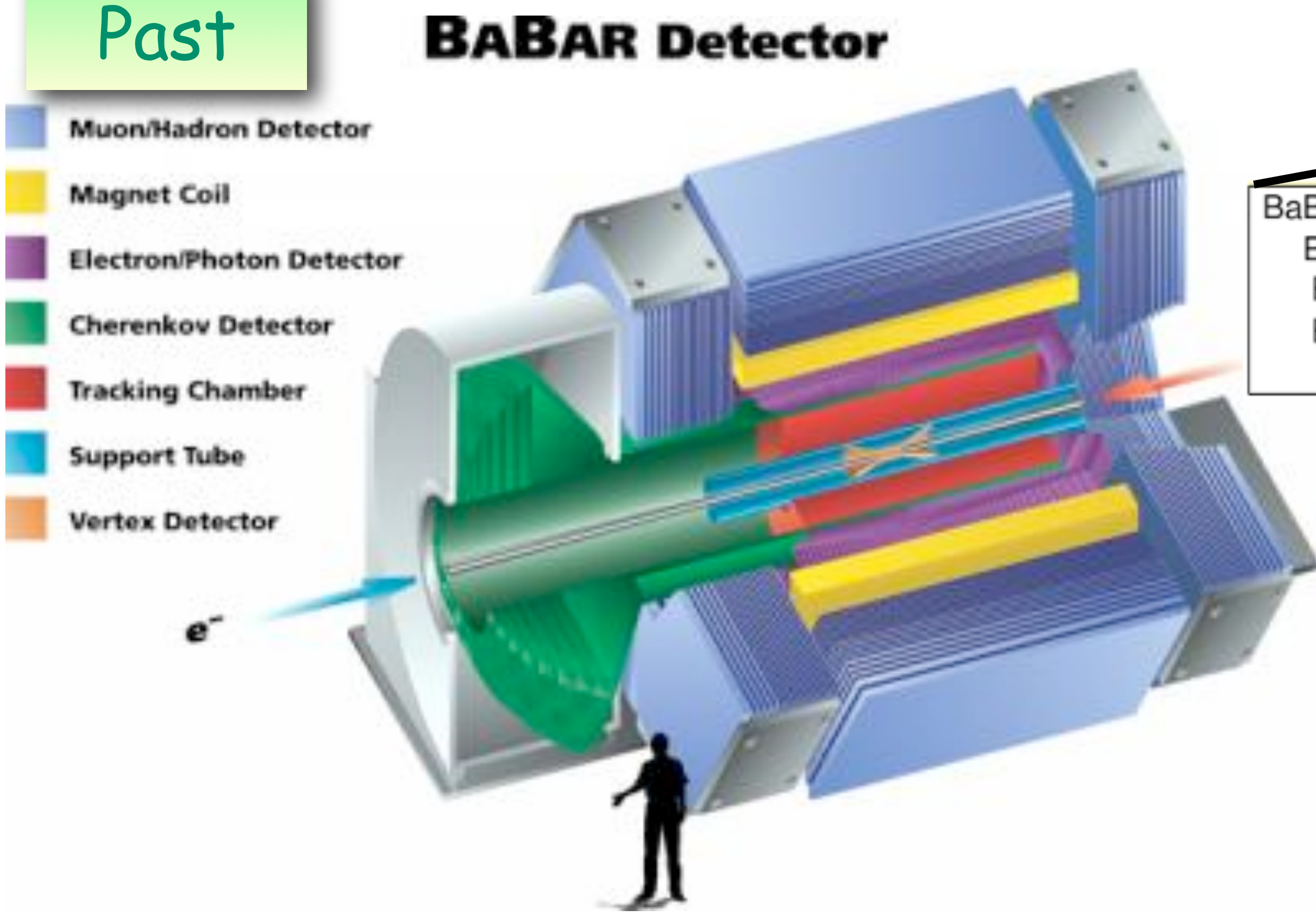
Precision frontier

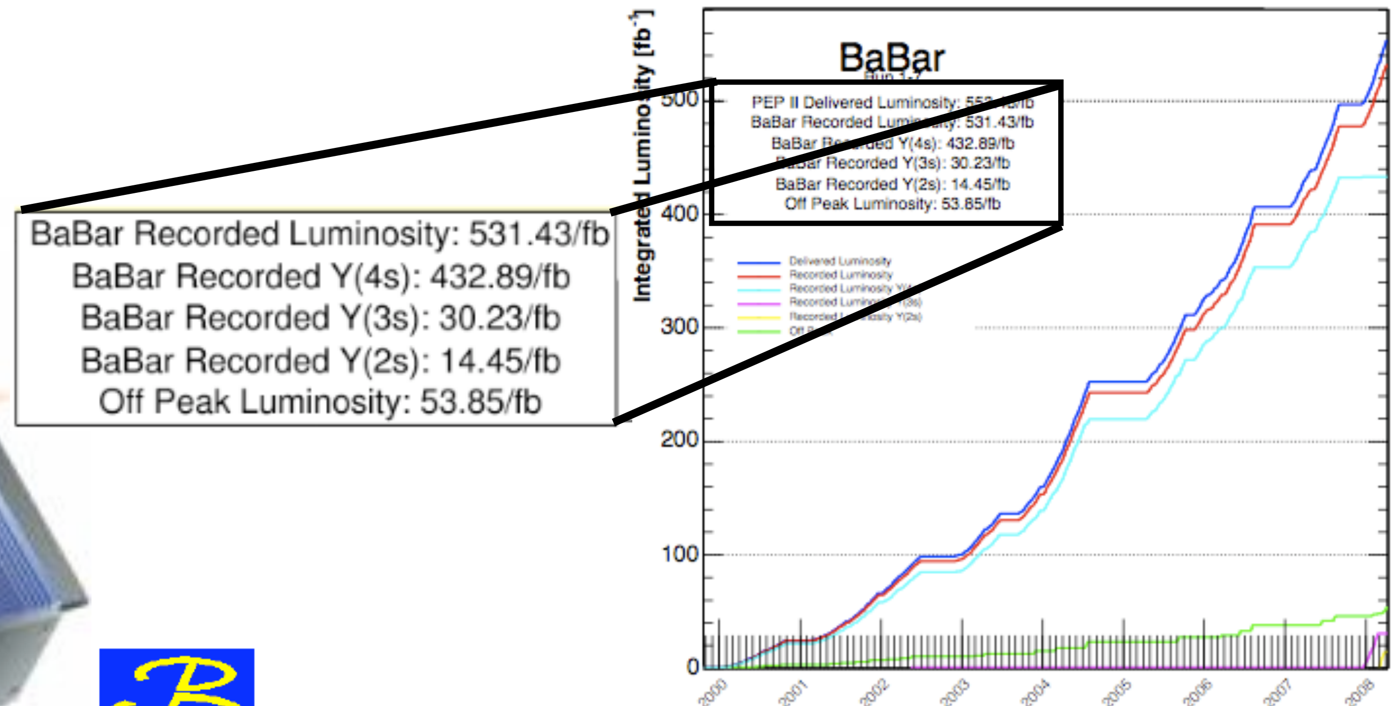
Virtual processes can indirectly test NP energy scales with effective theories

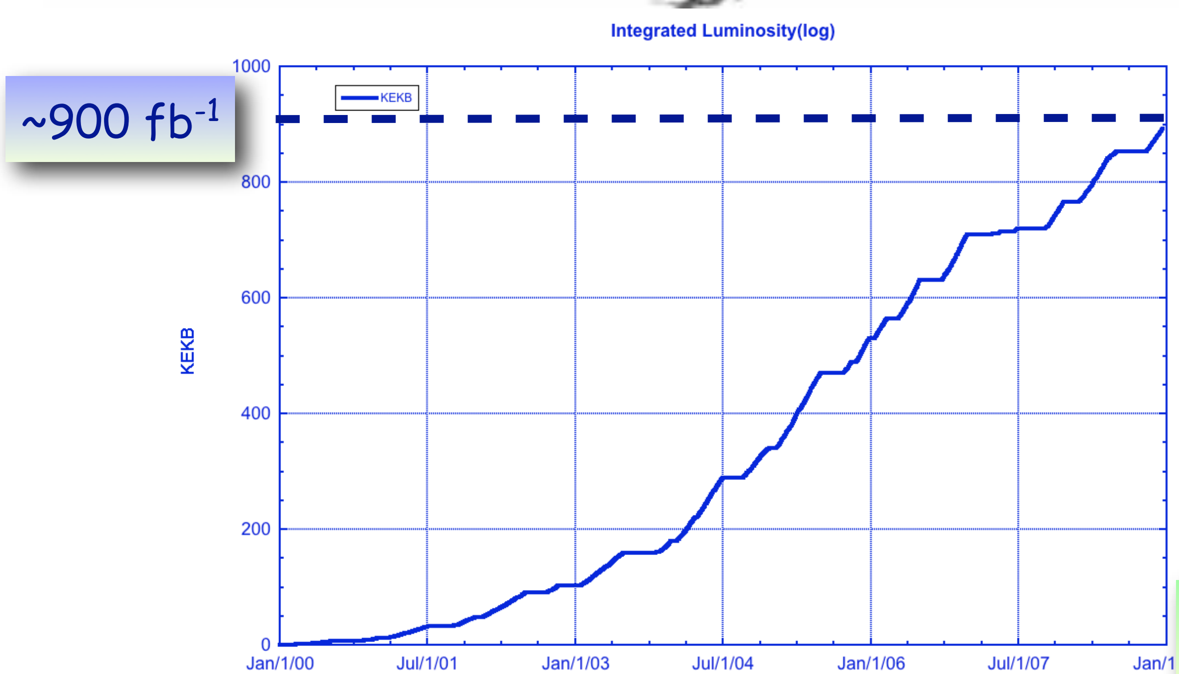
Correlations among deviations w.r.t SM prediction in different processes can establish general NP features

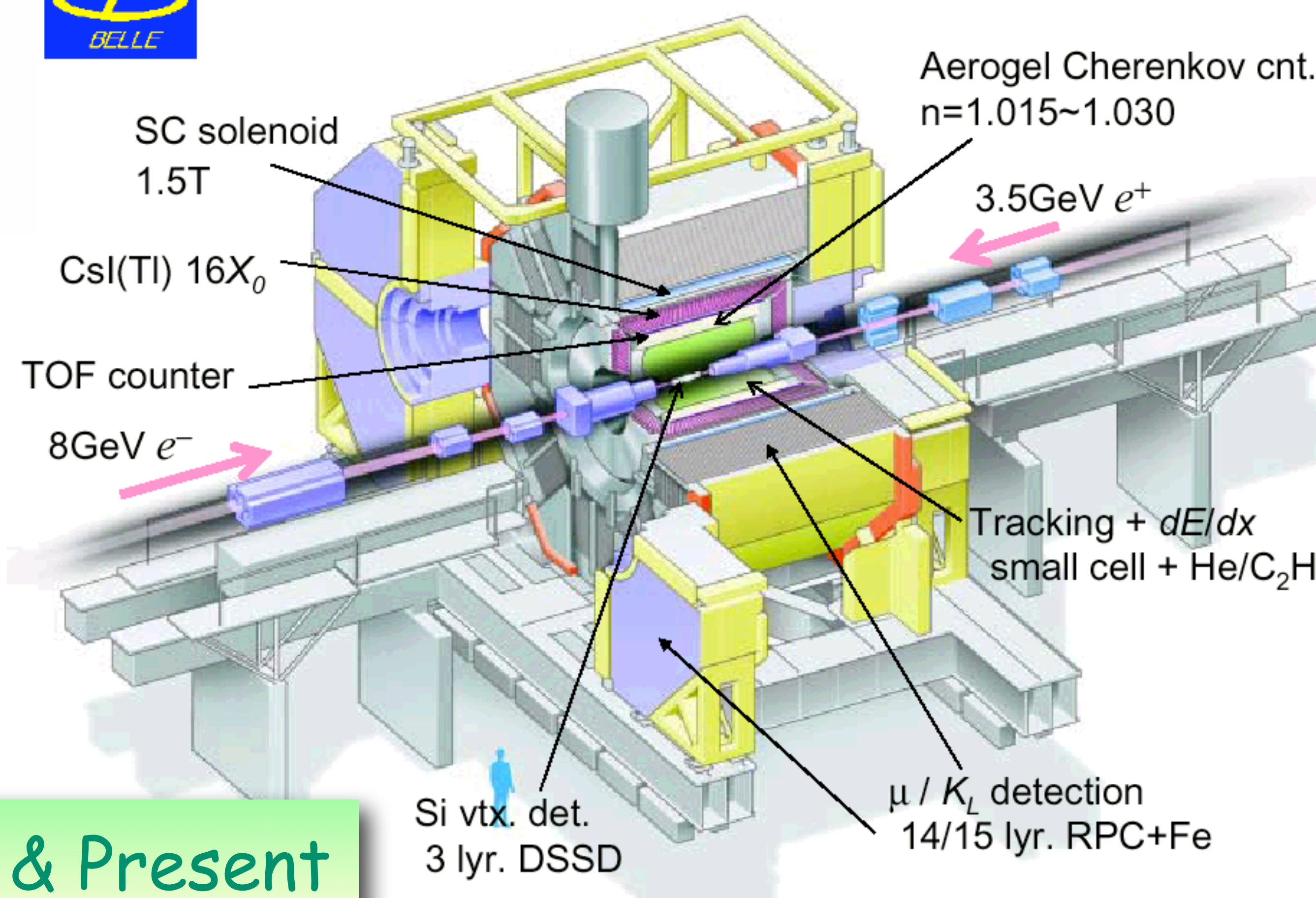
Detectors & Datasets

Past







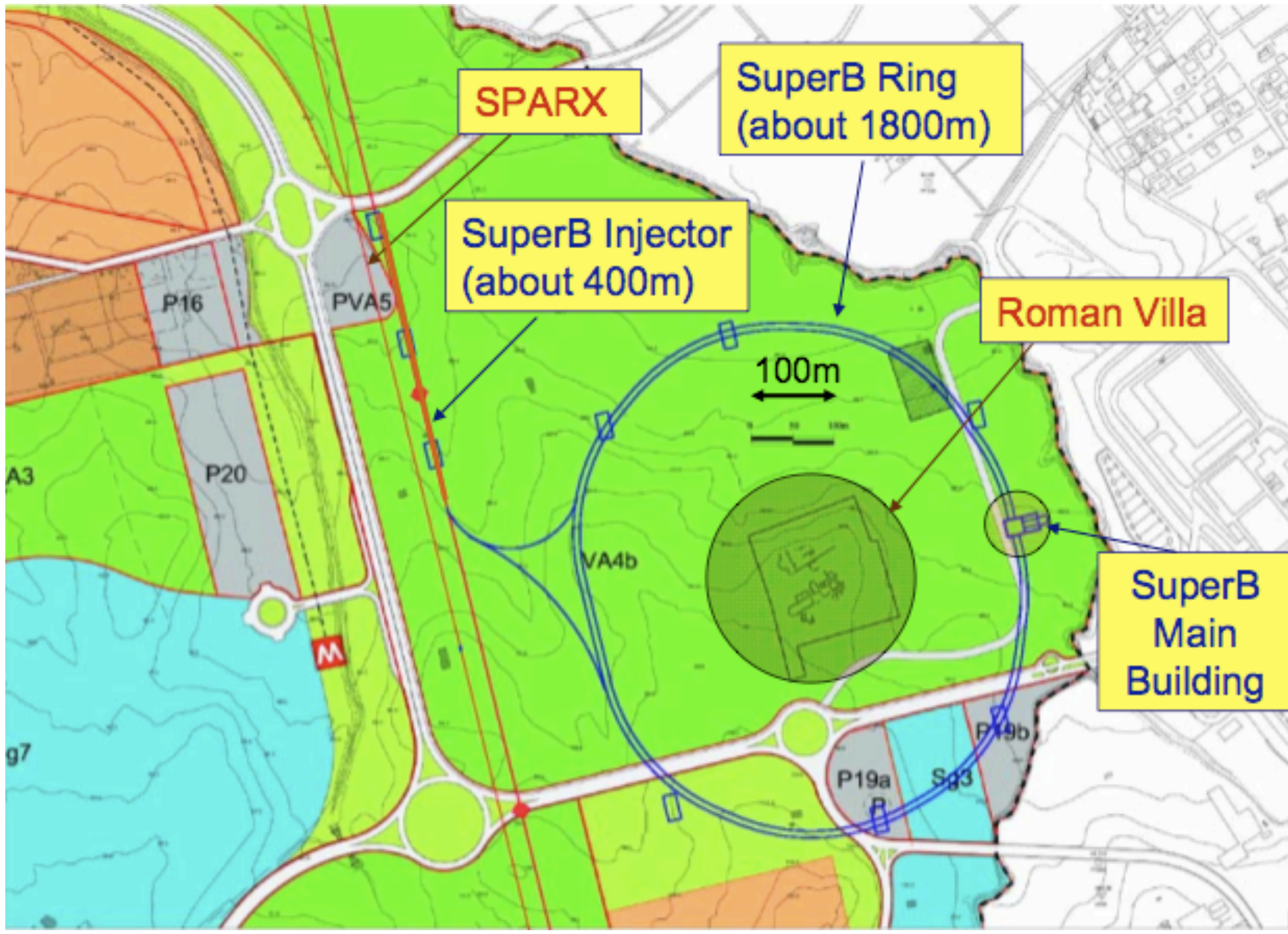


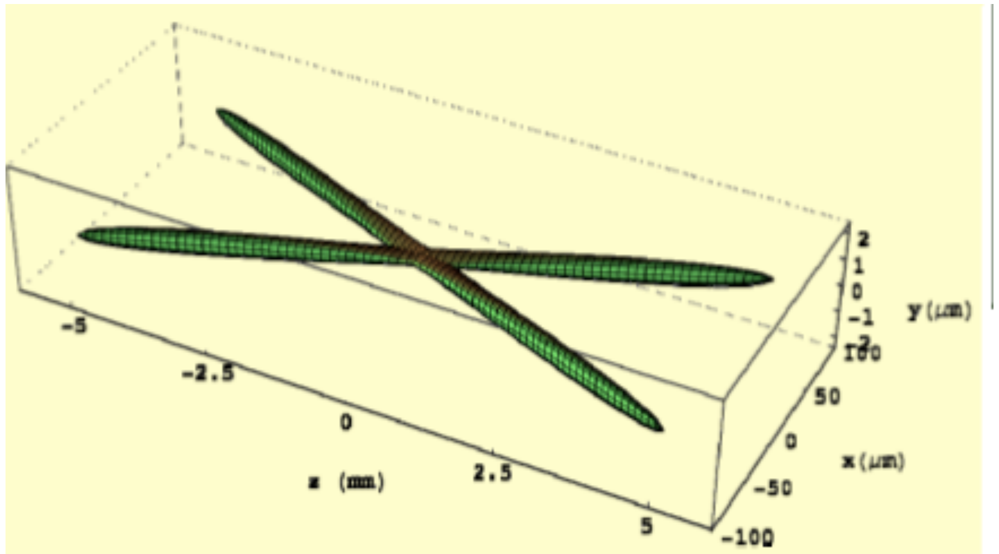
Past & Present

Detectors & Datasets: Future

Super Flavour Factory

- Asymmetric e^+e^- collider with low emittance operation (like ILC)
- Target luminosity 10^{36} cm^{-2} s^{-1},
- Polarization and running at various $\Upsilon(nS)$ possible
- Crab Waist technique developed for these goals
- SAME BACKGROUND (and wall power) as current B Factories





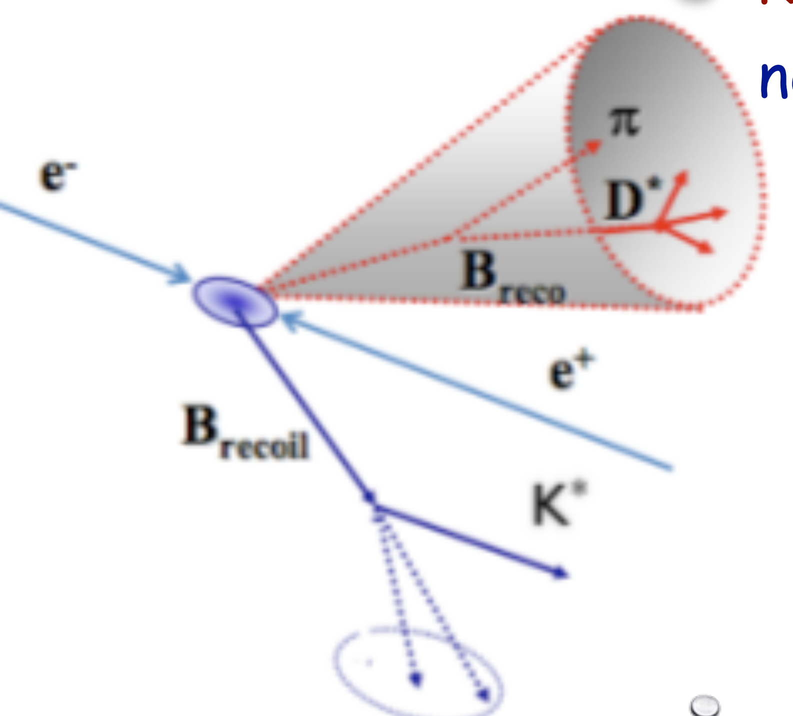
IP beam distributions for SuperB

Outline

- $B^{\pm} \to l^{\pm} \nu$ ($l = e, \mu, \tau$) — $\tan\beta$ vs $m_{H^{\pm}}$ & LFV
- $B \to h^{(*)} \nu \bar{\nu}$ — Dark Matter/SUSY
- $B \to K^{(*)} ll$ — SUSY
- $B^{\pm} \to K^{\mp} \pi^{+} \pi^{-} / K^{+} K^{-} \pi^{\mp}$ — $b \to dd\bar{s}$ & $b \to ss\bar{d}$

Analyses Overview

- Analyses with undetectable particles from signal B decay:
  - Recoil technique: low efficiency (1% - 0.1%) but HIGH resolution--> necessary when more than one neutrino is present
    - Semileptonic tagged recoil: higher efficiency but lower purity
    - Hadronic tagged recoil: lower efficiency but higher purity



$B^\pm \to \tau^\pm \nu$ / $B \to h^* \nu \nu$

  - Totally inclusive reconstruction exploiting kinematic constraints: HIGH efficiency but low resolution

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

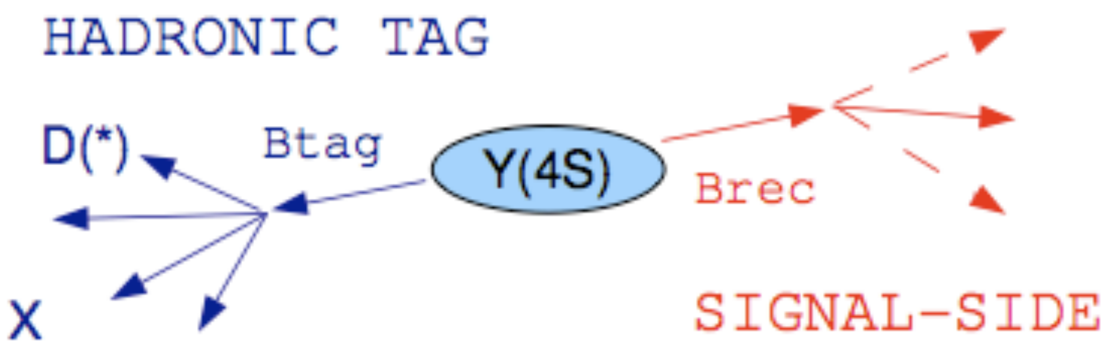
- Analyses with all detectable particles from signal B decay:
  - Full kinematical reconstruction of the event possible

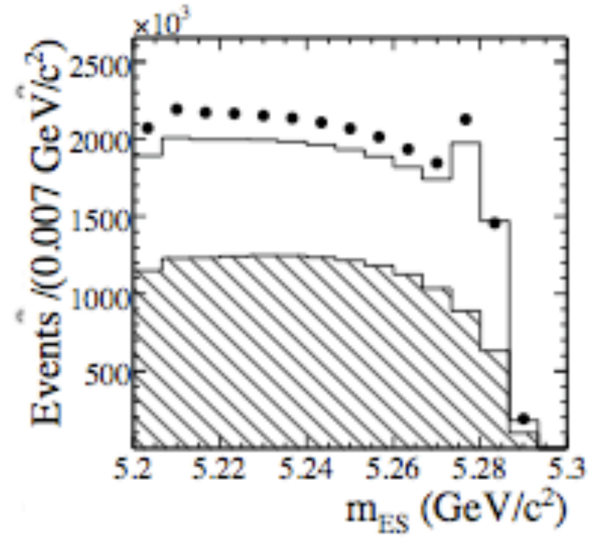
$B^\pm \to K^\mp \pi^+ \pi^- / K^+ K^- \pi^\mp$

$B^0 \to K^* ll$

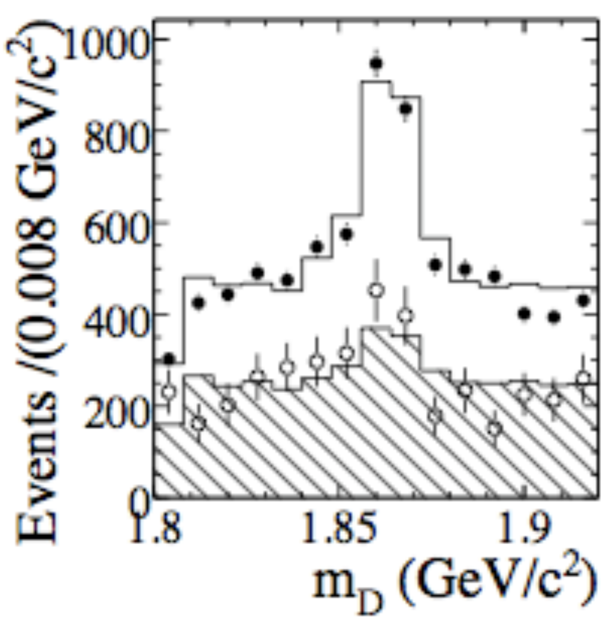
Recoil Technique

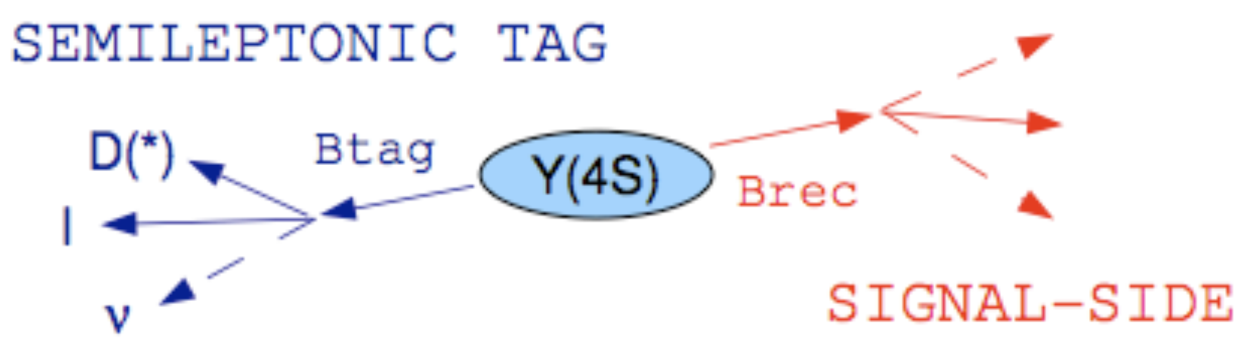
Powerful technique providing a pure and clean B sample which you pay with a low efficiency ~ O(0.01) - O(0.001)





$$m_{ES} = \sqrt{s/4 - \vec{p}_B^{*2}}$$





Improvements @ Super B
(hermeticity, PID & vertex)

- CONSERVATIVE: same efficiency and background than BaBar;
- REALISTIC: 30% reduction of background;
- OPTIMISTIC: 50% reduction of background.

$B^{\pm} \rightarrow l^{\pm} \nu$

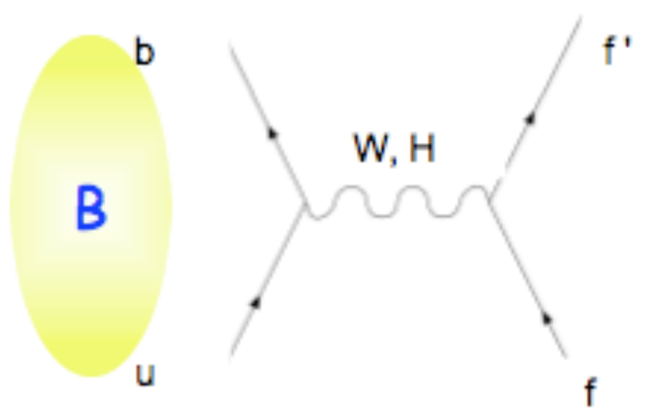
In the SM $\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$

$\tau\ \nu = (1.2 \pm 0.4) \times 10^{-4}$

$\mu\ \nu = (5.6 \pm 0.4) \times 10^{-7}$

$e\ \nu = (1.3 \pm 0.4) \times 10^{-11}$

...using inclusive V_{ub}....



Annihilation process : helicity suppression allows charged Higgs to be competitive with SM
Directly test Yukawa interactions

* In a general SUSY scenario $\frac{\mathcal{B}(B^+ \to l^+ \nu_l)_{\rm exp}}{\mathcal{B}(B^+ \to l^+ \nu_l)_{\rm SM}} \approx (1 - \tan^2\beta \frac{m_B^2}{M_H^2})^2.$

W.S. Hou
Phy.Lett. D 48, 2342

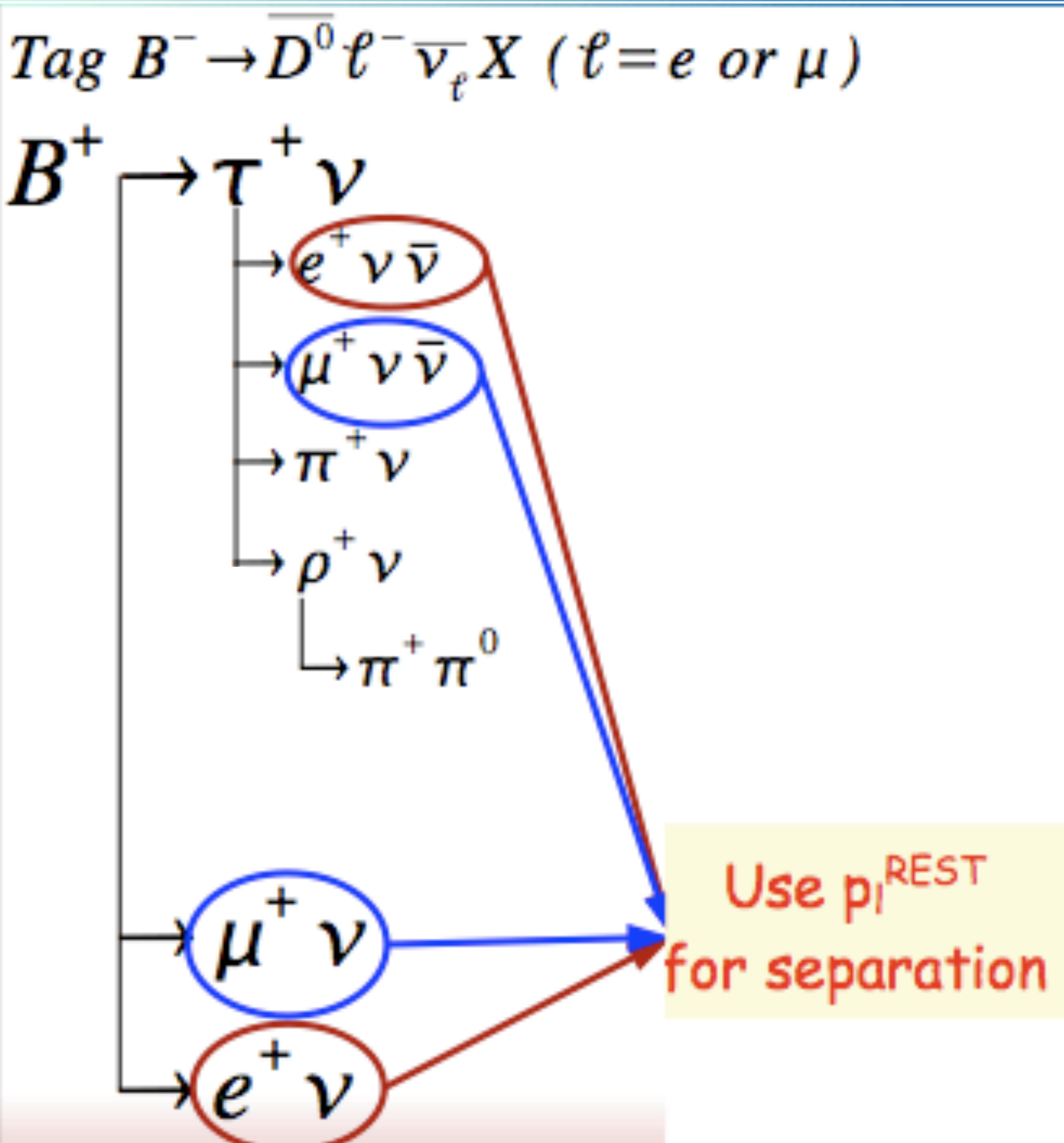
* In a particular MFV scenario with non minimal LFV $R^B_{\mu\tau} = \frac{\Gamma(B^+ \to \mu^+ \nu)}{\Gamma(B^+ \to \tau^+ \nu)}$ $R^B_{e\tau} = \frac{\Gamma(B^+ \to e^+ \nu)}{\Gamma(B^+ \to \tau^+ \nu)}$

$\Delta \sim 10\% \ (R^B_{\mu\tau})^{SM}$ $\sim 10^3 \times (R^B_{e\tau})^{SM}$

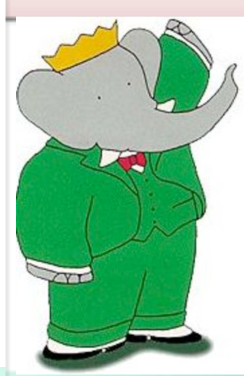
G.Isidori & P.Paradisi
Phy.Lett. B 639, 499

$B^\pm \to l^\pm \nu$ with SL recoil

418 fb^{-1}



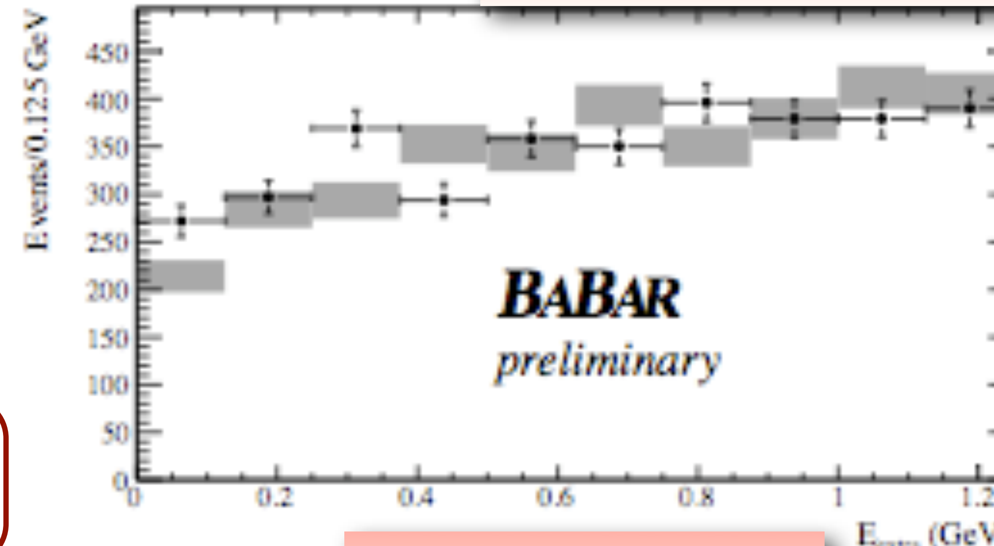
- Most powerful variables: E_{extra} and momentum of signal lepton in B rest frame (p_l^{REST})
- Remaining variables considered for likelihood ratios (LHRs) of PDFs separated for continuum and $B\overline{B}$ background
- Cuts optimized separately for each mode
- Background estimate from E_{extra} sideband data rescaled with MC



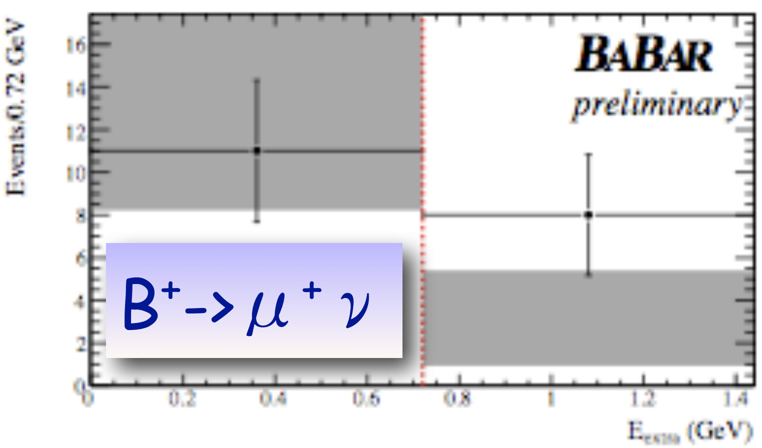
$B^{\pm} \to l^{\pm} \nu$ with SL recoil

arXiv:0809.4027

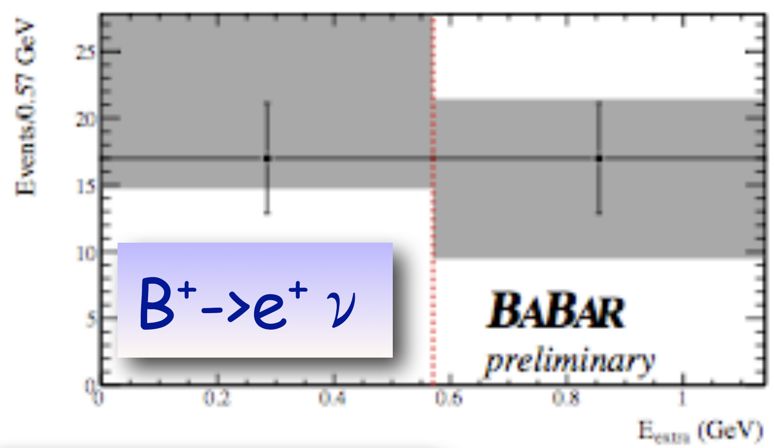
Mode	Expected Background (N_{BG})	Observed Events (N_{obs})	Overall Efficiency (ε)	Branching Fraction
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$	91 ± 13	148	$(3.08 \pm 0.14) \times 10^{-4}$	$(4.0 \pm 1.2) \times 10^{-4}$
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$	137 ± 13	148	$(2.28 \pm 0.11) \times 10^{-4}$	$\left(1.0^{+1.2}_{-0.9}\right) \times 10^{-4}$
$\tau^+ \to \pi^+ \bar{\nu}_\tau$	233 ± 19	243	$(3.89 \pm 0.15) \times 10^{-4}$	$\left(0.6^{+1.1}_{-0.5}\right) \times 10^{-4}$
$\tau^+ \to \pi^+ \pi^0 \bar{\nu}_\tau$	59 ± 9	71	$(1.30 \pm 0.07) \times 10^{-4}$	$\left(2.0^{+1.4}_{-1.3}\right) \times 10^{-4}$
$B^+ \to \tau^+ \nu_\tau$	521 ± 31	610	$(10.54 \pm 0.41) \times 10^{-4}$	$(1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$
$B^+ \to \mu^+ \nu_\mu$	15 ± 10	11	$(27.1 \pm 1.2) \times 10^{-4}$	$< 11 \times 10^{-6}$ @ 90% CL
$B^+ \to e^+ \nu_e$	24 ± 11	17	$(36.9 \pm 1.5) \times 10^{-4}$	$< 7.7 \times 10^{-6}$ @ 90% CL



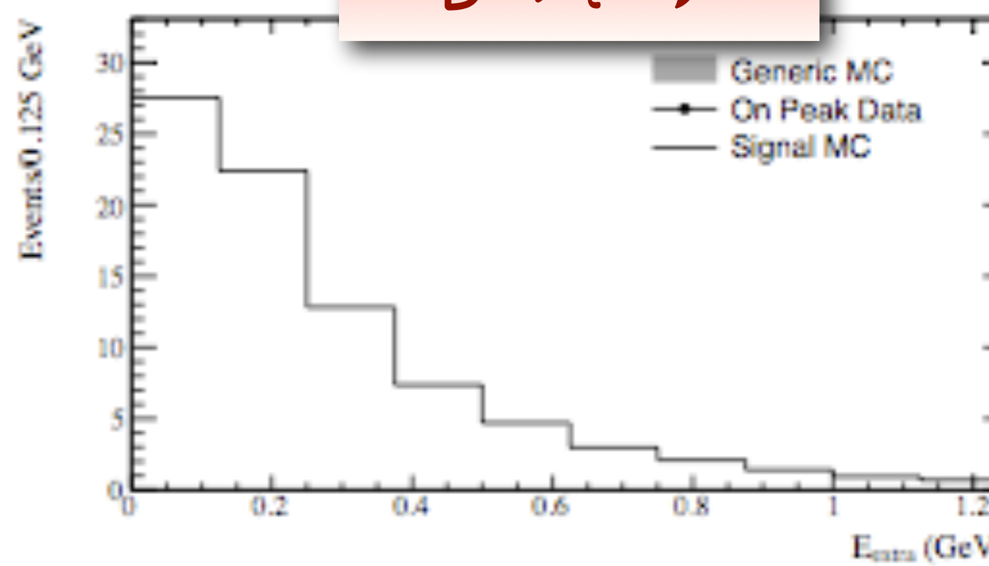
$B^+ \to \tau^+ \nu$



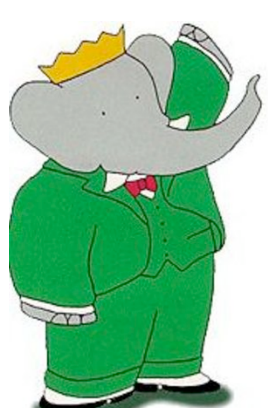
$B^+ \to \mu^+ \nu$



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



PRD 77, 011107



- Combined with previous BaBar measurement with HAD recoil:

$B^+ \to \tau^+ \nu = (1.8 \pm 0.6) \times 10^{-4}$

- Using $|V_{ub}| = (4.43 \pm 0.54) \times 10^{-3}$

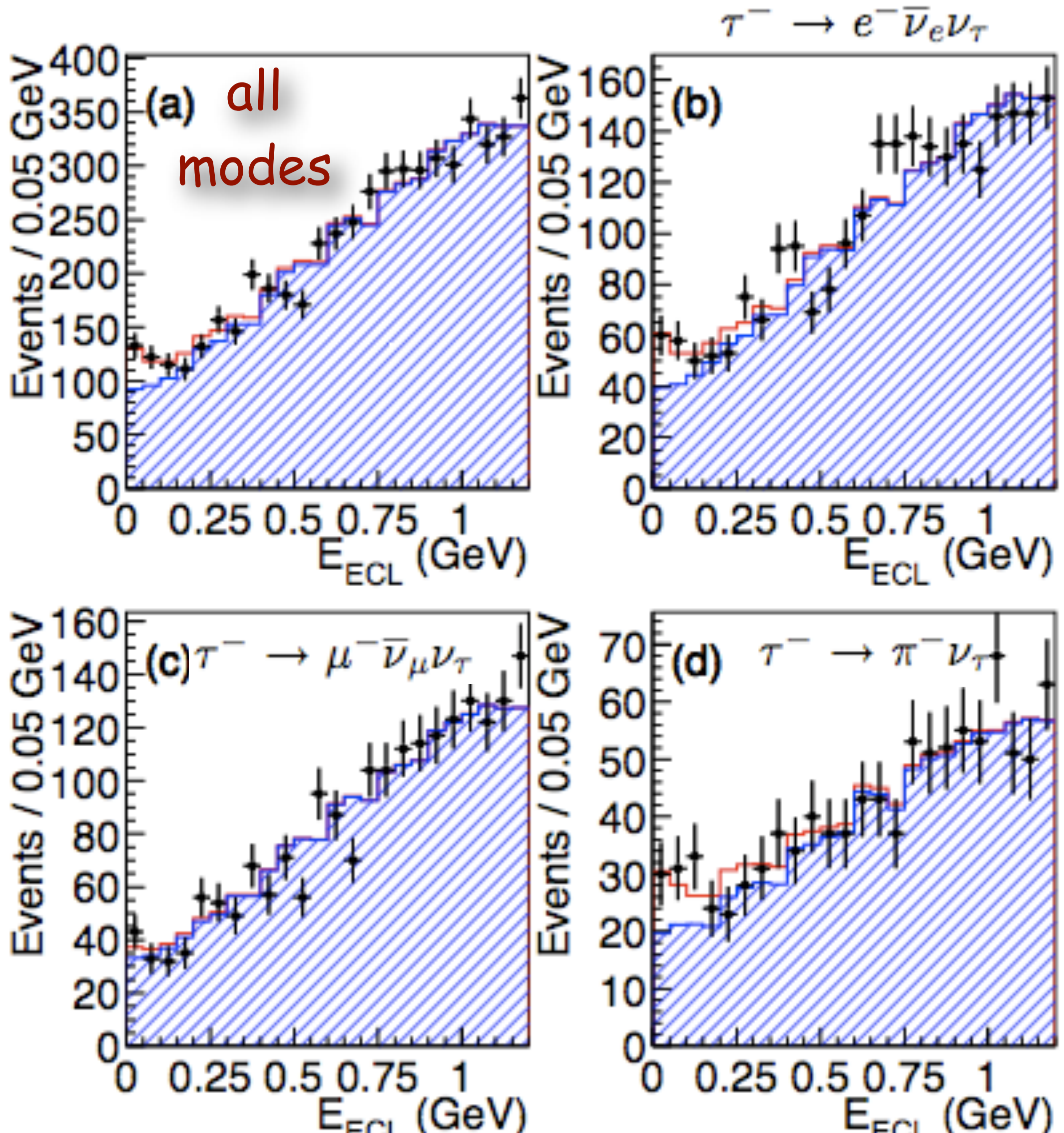
$f_B = 230 \pm 57$ MeV

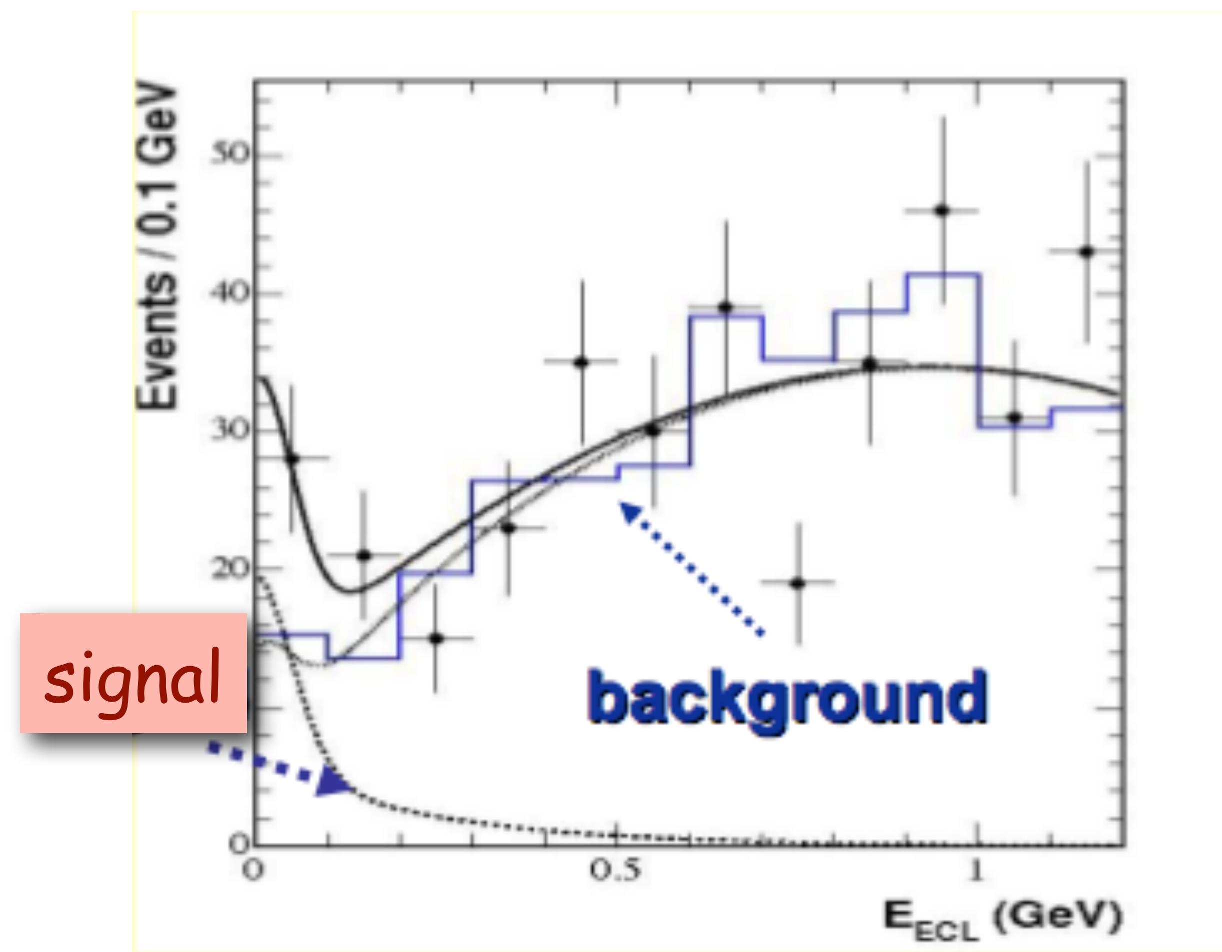
Latest lattice QCD
$f_B = 216 \pm 22$
A. Gray et al.,PRL 95, 212001

$B^{\pm} \to \tau^{\pm} \nu$ @ Belle

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = (1.65^{+0.38}_{-0.37}(\text{stat})^{+0.35}_{-0.37}(\text{syst})) \times 10^{-4}.$$

$$\mathcal{B}(B^- \to \tau^- \nu_\tau) = (1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})) \times 10^{-4}$$



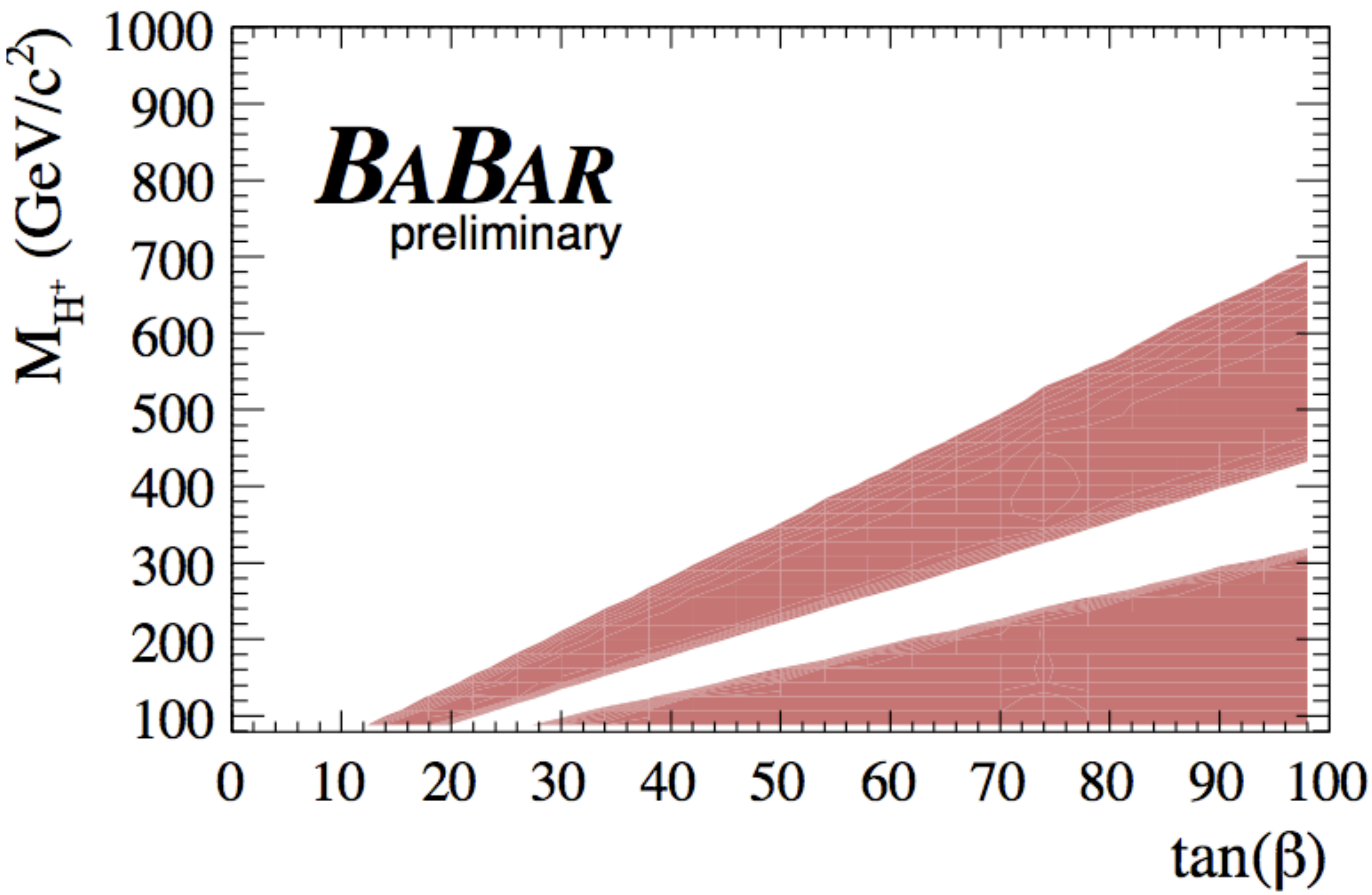


New result on SL recoil
arXiv:0809.3834

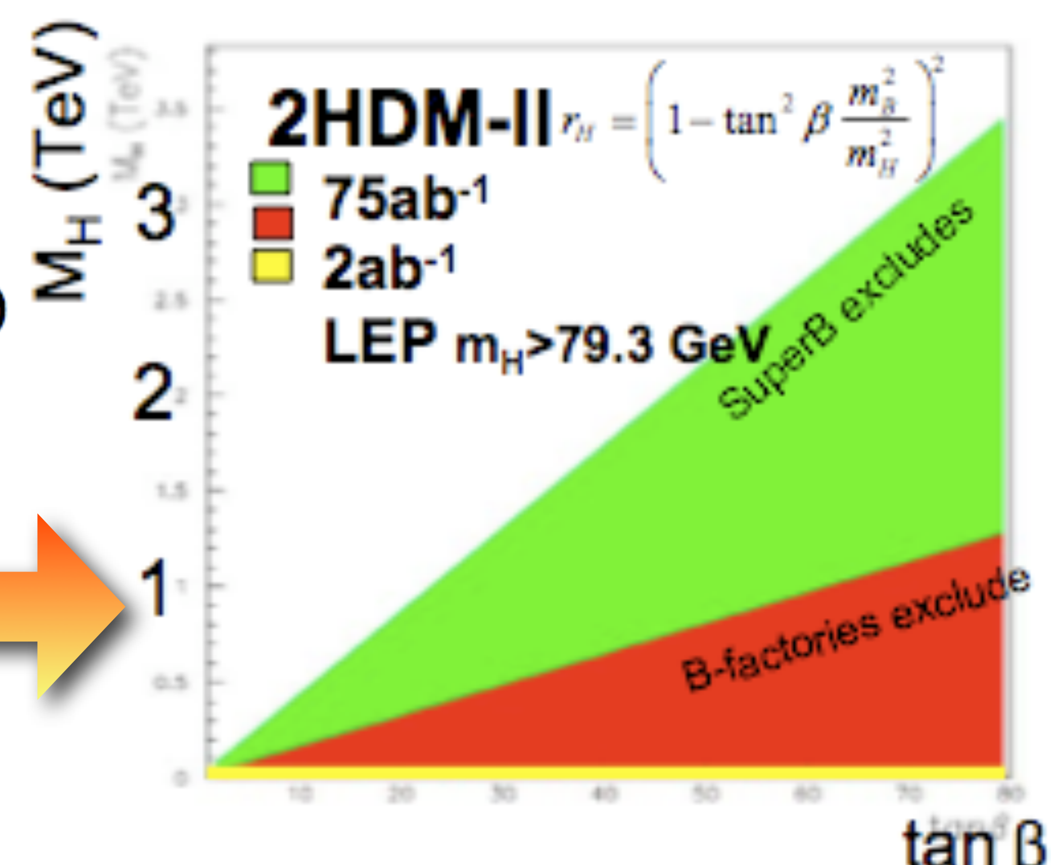
BELLE

First evidence on HAD recoil
PRL 97 (251802) 2006

$B^{\pm} \to \tau^{\pm} \nu$ constraint



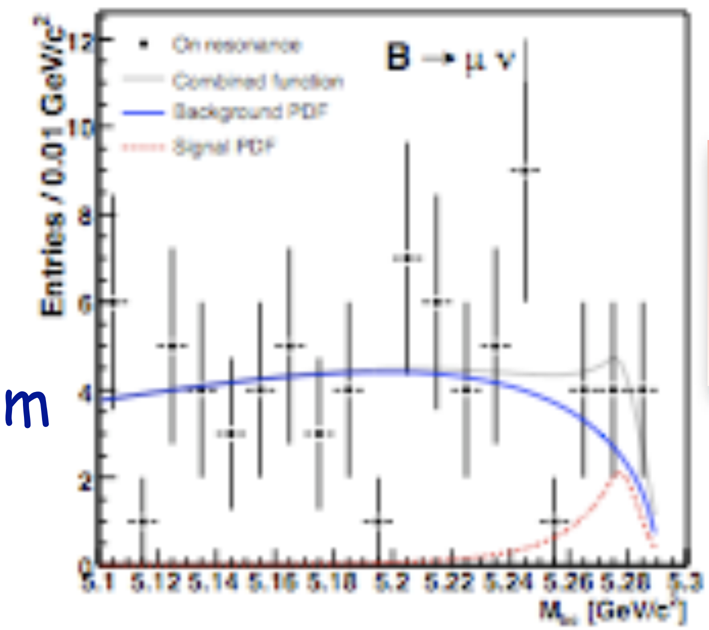
@ a Super Flavour Factory



$B^{\pm} \to l^{\pm} \nu$ (l=e, μ) inclusive

253 fb^{-1}

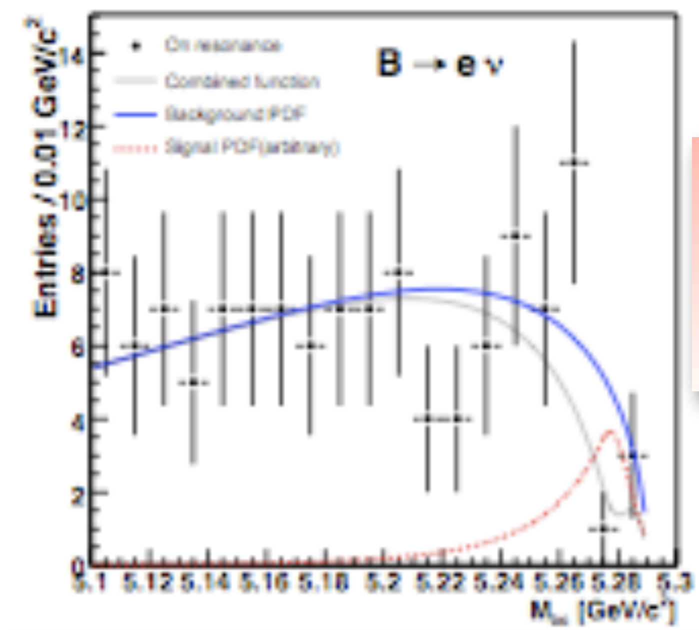
- Look for the highest momentum lepton in the event and use all other tracks and neutral to reconstruct B_{tag}
- Tight requirement on lepton PID and momentum
- Typical background:
  - qq, $B \to X_u l \nu$
- B_{tag} requirement on ΔE
- Background suppression: modified R_2 in Fisher, p_T^{miss}>1.75 GeV and cos θ^{miss}<0.84 (0.82)
- ML fit to B_{tag} m_{BC}
- UL extraction integrating 90% of likelihood



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

Efficiency (2.2 ± 0.1)%

Yield 4.1 ± 3.1



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

Efficiency (2.4 ± 0.1)%

Yield -1.8 ± 3.3

$B^{\pm} \to \mu^{\pm} \nu < 1.7 \times 10^{-6}$

$B^{\pm} \to e^{\pm} \nu < 9.8 \times 10^{-7}$

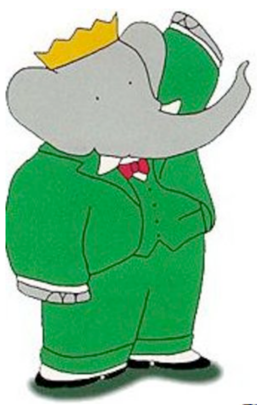
Phys.Lett. B 647, 67

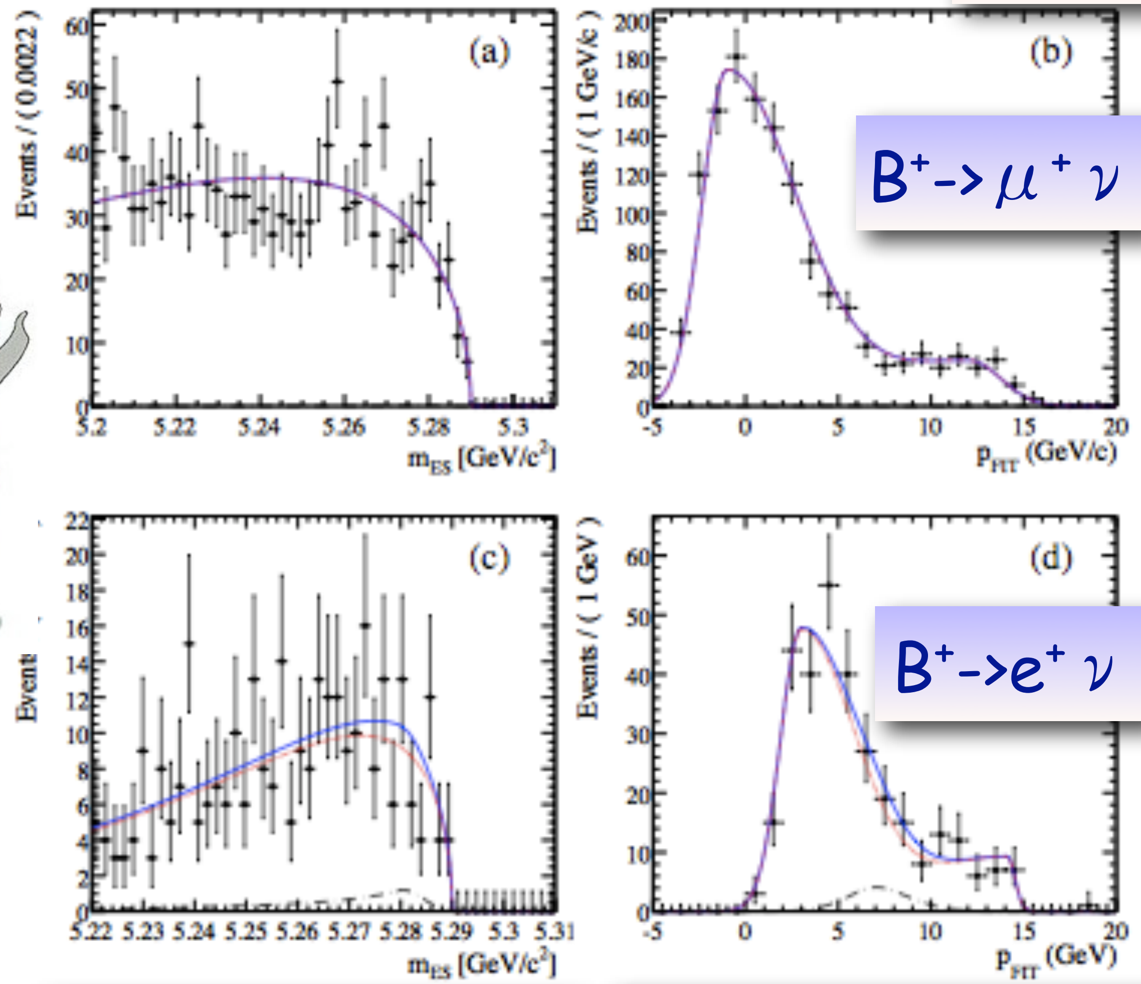
BELLE

$B^{\pm}\rightarrow l^{\pm}\nu$ ($l=e,\mu$) inclusive

426 fb^{-1}

- Reconstruction technique similar to Belle's
- Additional background from two photon processes for electron mode
- B_{tag} requirement on ΔE (and p_T)
- Background suppression: topological and kinematical Fisher optimized separately for each mode on 5 different variables
- ML fit to B_{tag} m_{ES} and linear combination of signal lepton momentum in B rest frame and c.m. frame
- UL extraction in Bayesian approach





$B^+\to\mu^+\nu$	$B^+\to e^+\nu$
Efficiency (6.1 ± 0.2)%	Efficiency (4.7 ± 0.3)%
Yield 1.4 ± 17.2	Yield 17.9 ± 17.6

arXiv:0903.1220
Preliminary, submitted to Phys.Rev. D

$B^{\pm}\rightarrow\mu^{\pm}\nu < 1.0 \times 10^{-6}$

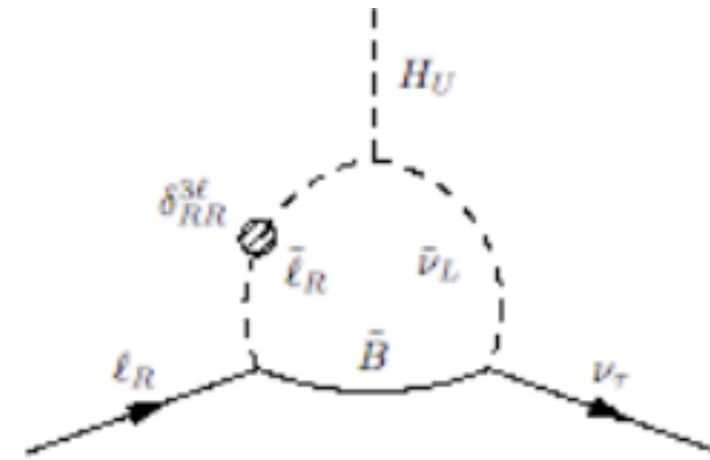
$B^{\pm}\rightarrow e^{\pm}\nu < 1.9 \times 10^{-6}$

$B^\pm \to \mu^\pm \nu$ constraint

M = π,K,D,B...

$$R_M^{j/k} = \frac{\sum_i \Gamma(M \to l_j \nu_i)}{\sum_i \Gamma(M \to l_k \nu_i)} \qquad i,j,k = e,\mu,\tau.$$

$$(R_M^{j/k})^{\rm MSSM}_{\rm LFV} = (R_M^{j/k})^{\rm SM}\left[1+\frac{1}{R_{Mk\nu}}\left(\frac{m_M^4}{M_{H^\pm}^4}\right)\left(\frac{m_k^2}{m_j^2}\right)|\Delta_R^{\tau j}|^2\frac{\tan^6\beta}{(1+\epsilon\tan\beta)^2}\right]$$



With K decays, tau not accessible so only Δ_{13}

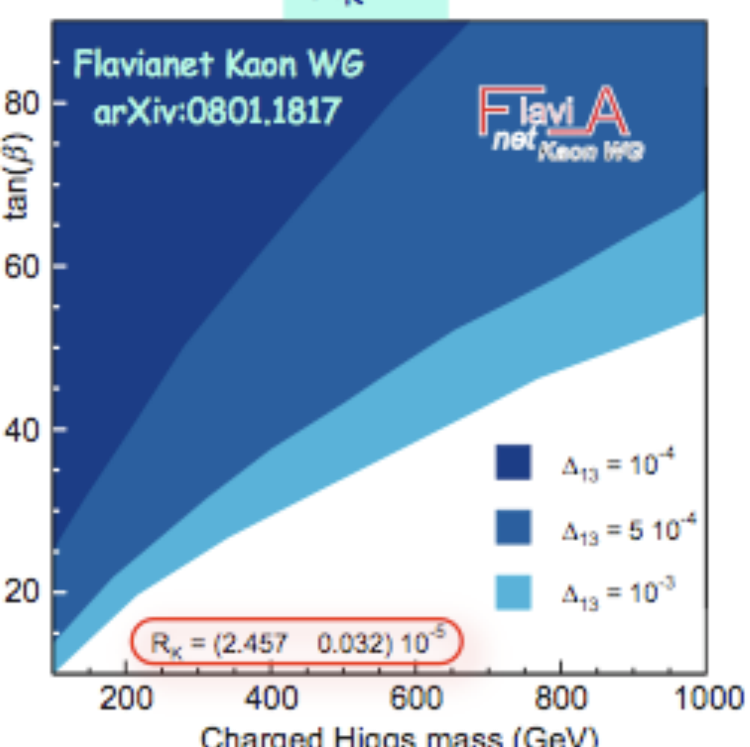
R_K measured at O(1%) accurancy

With B decays, Δ_{13} AND Δ_{23}

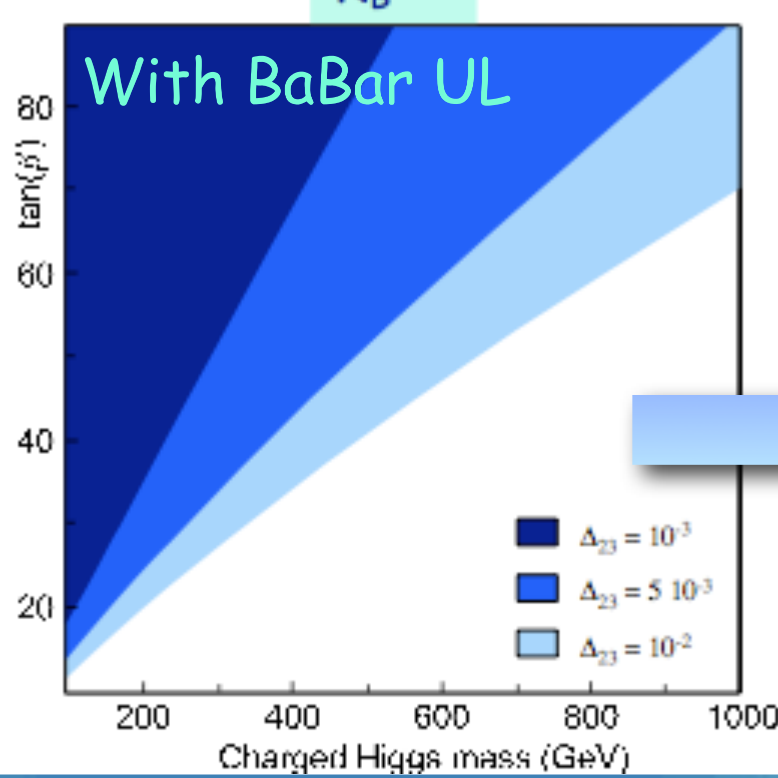
Only UL on R_B but similar constraint!!!!

Isidori & Paradisi Phys.Lett. B 639, 499

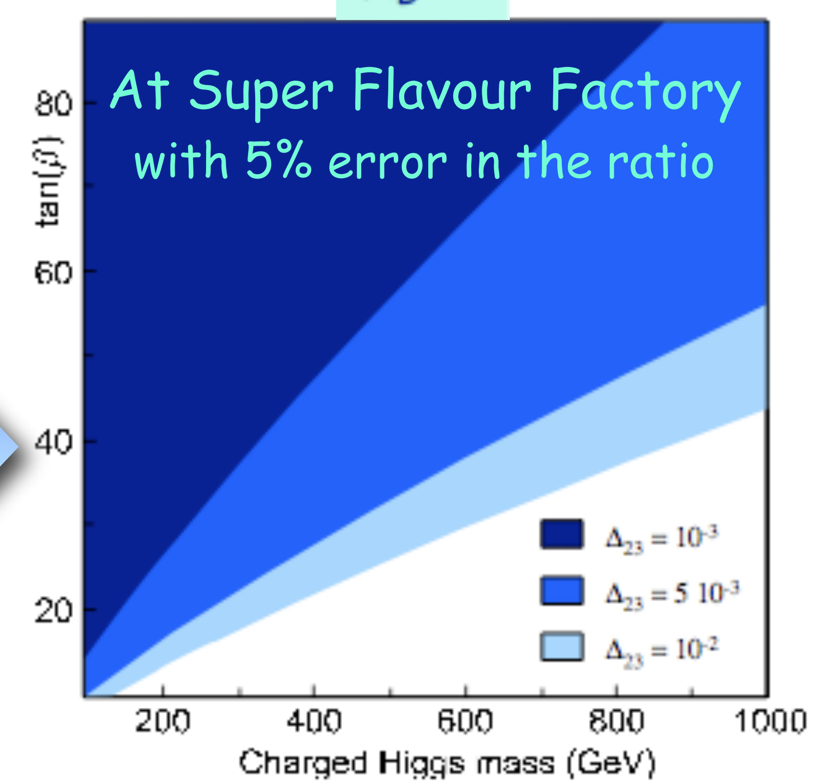
$R_K^{e/\mu}$



$R_B^{\mu/\tau}$

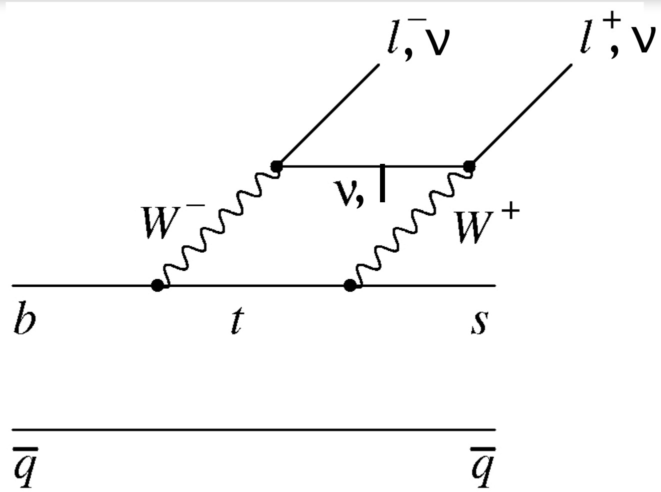


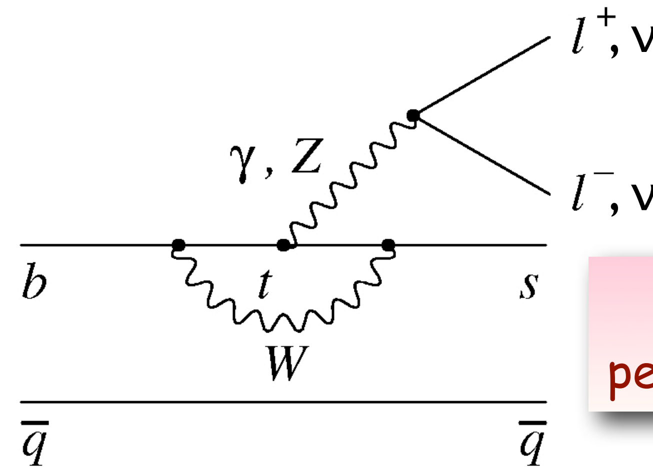
$R_B^{\mu/\tau}$



b→s ν ν /b→s ll

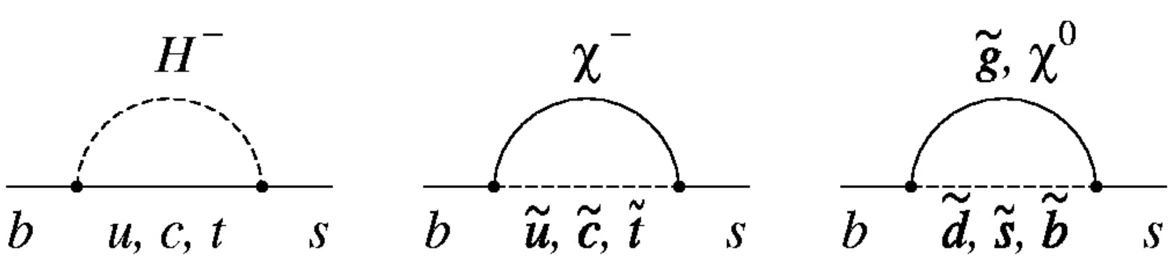
FCNC standard probe for NP ↔ forbidden at tree level in SM





Proceed to photon/Z penguin or W box diagrams

- NP can enter at same order as SM contributions



- Typically, it affects the decay kinematics in terms of the invariant mass of the two leptons/neutrinos

- Operator products expansion:

$$H_{Eff} \propto \sum_{i=1}^{10} C_i O_i$$

Short-distance/ perturbative (C_i)

Long-distance/ non-perturbative (O_i)

- C_7^{eff} from γ penguing

- C_9^{eff} (C_{10}^{eff}) from vector (axial-vector) W,Z box

$b \to s \nu \nu$

$$\mathcal{B}(B \to K^* \nu\bar{\nu})|_{\rm SM} = (6.8^{+1.0}_{-1.1}) \times 10^{-6}$$
$$\mathcal{B}(B \to K \nu\bar{\nu})|_{\rm SM} = (4.5 \pm 0.7) \times 10^{-6}$$

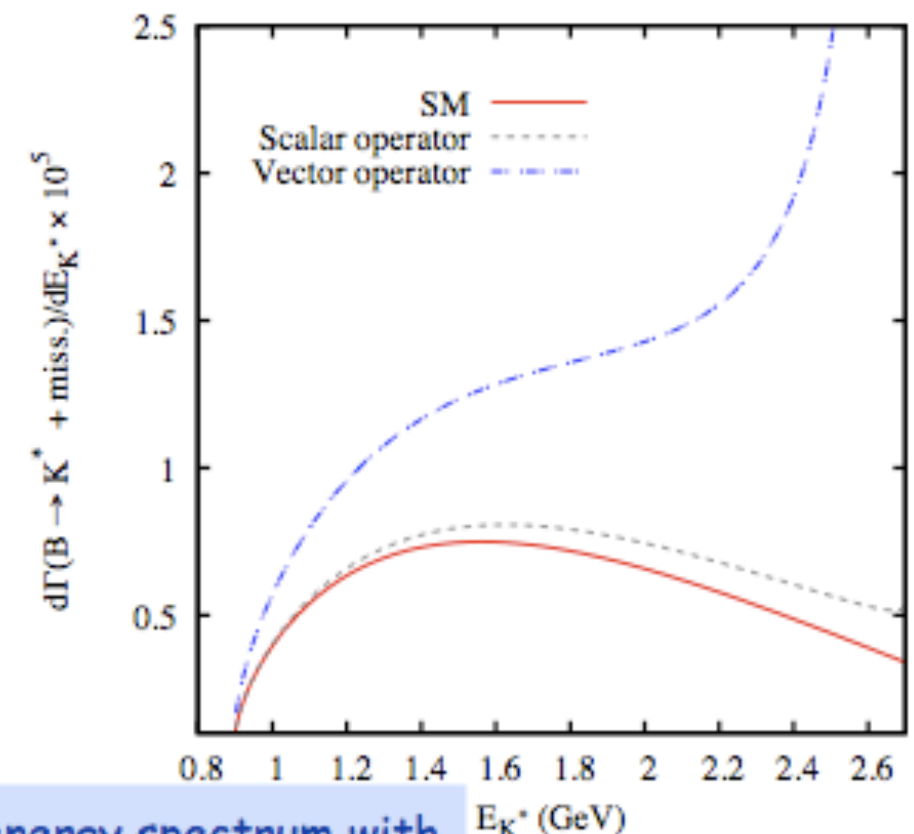
Altmannshofer et al.
arXiv:0902.0160

* NP can enter through several exotic scenarios
  * Non-Standard Z Couplings
  * Unparticle Physics
  * Light Dark Matter

G. Buchalla et al, PRD 63, 014015
T.M.Aliev et al arXiv:0705.4542
C. Bird et al PRL 93, 201803

* SUSY, Unparticle etc. can strongly affect the kinematic in terms of $s_{\nu\nu} = m^2_{\nu\nu}/m^2_B$

Theoretical calculations for these processes particularly reliable due to the absence of long distance interactions which affect B-> h*ll

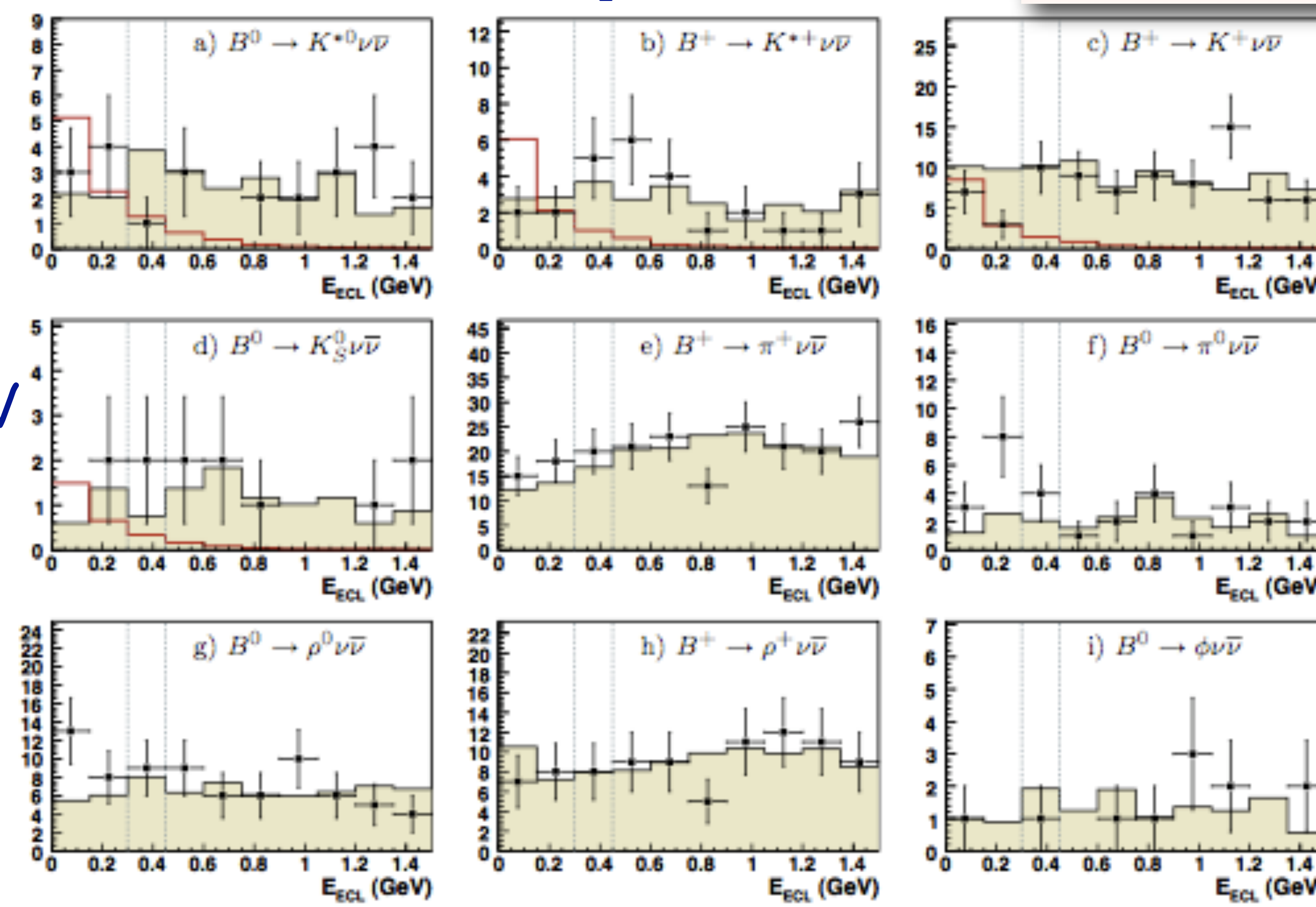


K* energy spectrum with unparticles

$B \to h^{(*)} \nu \nu$ analysis

492 fb^{-1}

- $h = K^+, K_S^0, K^{*0}, K^{*+}, \pi^+, \pi^0, \rho^+, \rho^0$
- Hadronic recoil
- B_{sig} selected with $E_{ECL} = E_{tot} - E_{reco} < 0.3$ GeV
- (Standard) Model dependence introduced applying cuts on signal h* kinematics
- Cut & count yield extraction
- Feldman-Cousins UL extraction @ 90% CL



PRL 99, 221802

$K^{*0} \nu \nu < 3.4 \times 10^{-4}$

$K^{*+} \nu \nu < 1.4 \times 10^{-4}$

$K^+ \nu \nu < 1.4 \times 10^{-5}$

$K^0 \nu \nu < 1.6 \times 10^{-4}$

Mode	N_{obs}	N_{bkg}	eff($\times 10^{-5}$)
$K^{*0} \nu \nu$	7	4.2±1.4	5.1±0.3
$K^{*+} \nu \nu$	4	5.6±1.8	5.8±0.7
$K^+ \nu \nu$	10	20.0±4.0	26.7±2.9
$K^0 \nu \nu$	2	2.0±0.9	5.0±0.3

$B \rightarrow K^{*} \nu \nu$ analyses

* Semileptonic and Hadronic Recoil : two analyses in close synergy in order to combine the final results more easily

* B tag reconstructed into

$$B \rightarrow Dl\nu X \quad (X = \gamma, \pi)$$

$$B \rightarrow DX \quad \begin{pmatrix} X = n\pi + mK + rK_S^0 + q\pi^0 \\ n+m+r+q<6 \end{pmatrix}$$

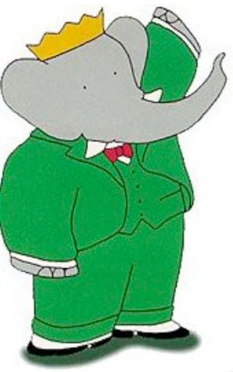
$$K^{*+} \rightarrow K_S^0(\pi^+\pi^-)\pi^+$$
$$K^{*+} \rightarrow K_S^0(\pi^0\pi^0)\pi^+(\mathrm{SL})$$
$$K^{*+} \rightarrow K^+\pi^0$$
$$K^{*0} \rightarrow K^+\pi^-$$

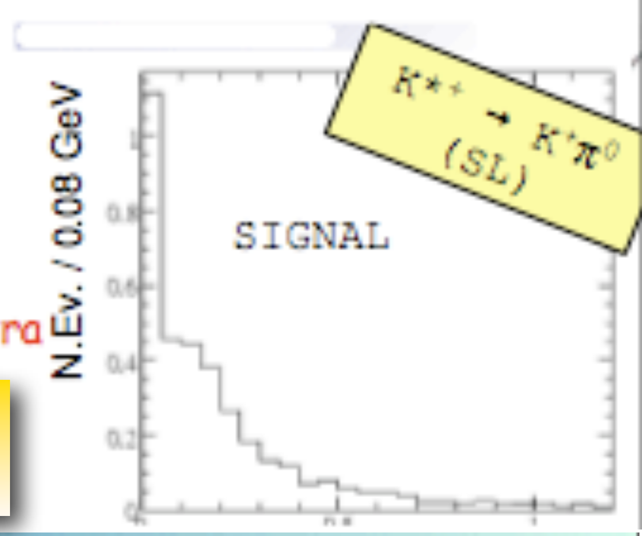
* Selection variables $E_{miss} + p_{miss}$, $\cos\theta_{miss}$, M_{K^*}, M_{Ks}, E_{extra}

* Most important variable E_{extra} : " Neutral energy that remains in the EMC after all tag and signal side tracks and neutral clusters have been accounted for"

  * SL analysis: fit to E_{extra}

  * HAD analysis : ML fit to Neural Network including E_{extra}





First completely model independent analyses!!

B→K* ν ν analyses

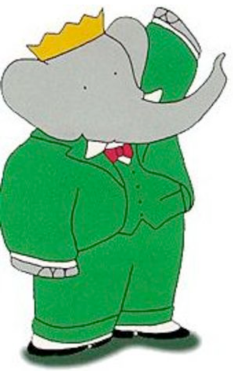
PRD 78, 072007

413 fb^{-1}

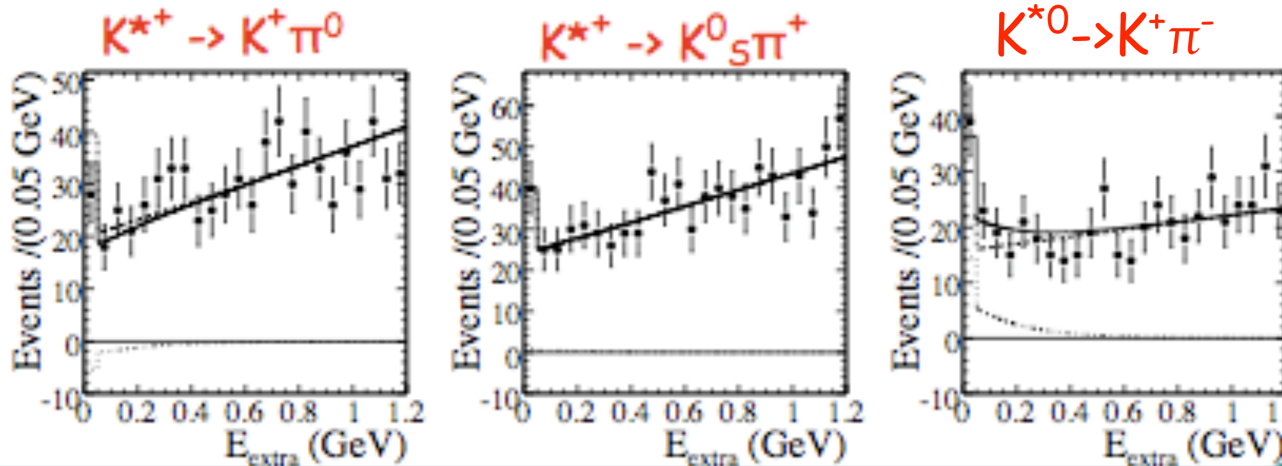
* Semileptonic Recoil : ML fit to E_{extra} distribution
  * Discontinuous due to minimum photon energy 0.05 Gev
  * Use ad-hoc likelihood
* Hadronic Recoil: ML fit to Neural Network distribution
  * NN variables: R_2, $\cos\theta_{Btag/T}$, E_{miss} + p_{miss} , $\cos\theta_{miss}$, M_{K^*}, M_{Ks}, E_{extra}

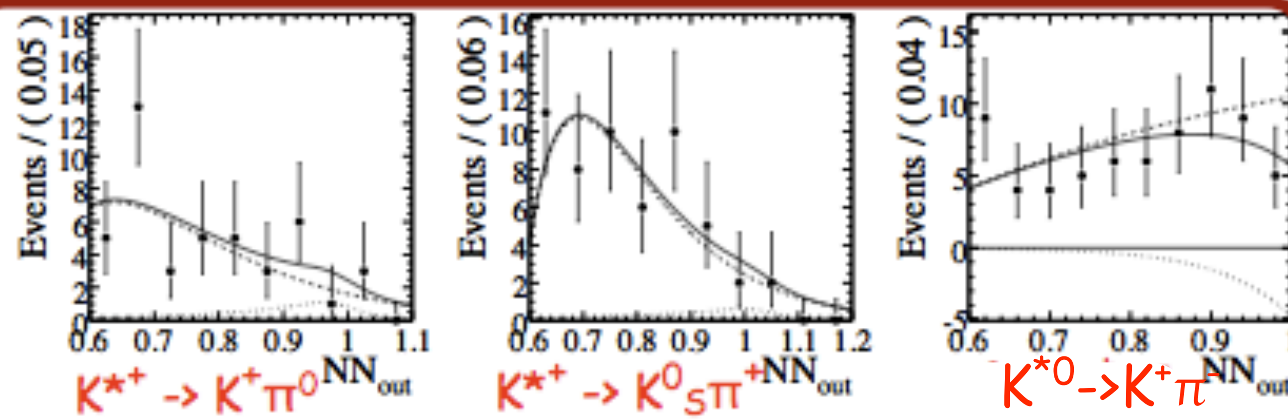
	SL	HAD
$K^{*0}\nu\nu$	< 18 × 10^{-5}	< 11 × 10^{-5}
$K^{*+}\nu\nu$	< 9 × 10^{-5}	< 21 × 10^{-5}

Combined	
$K^{*0}\nu\nu$	< 12 × 10^{-5}
$K^{*+}\nu\nu$	< 8 × 10^{-5}
$K^{*}\nu\nu$	< 8 × 10^{-5}



E_{extra} Fit Results			
N_s	-22 ± 16 ± 14	3 ± 17 ± 15	35 ± 13 ± 9
N_b	754 ± 32	869 ± 34	476 ± 25
ε ($\times10^{-4}$)	5.6 ± 0.7	4.3 ± 0.6	6.9 ± 0.8
N_{BB} ($\times10^{6}$)	454 ± 5		
UL (90% CL)	18 × 10^{-5}	9 × 10^{-5}	



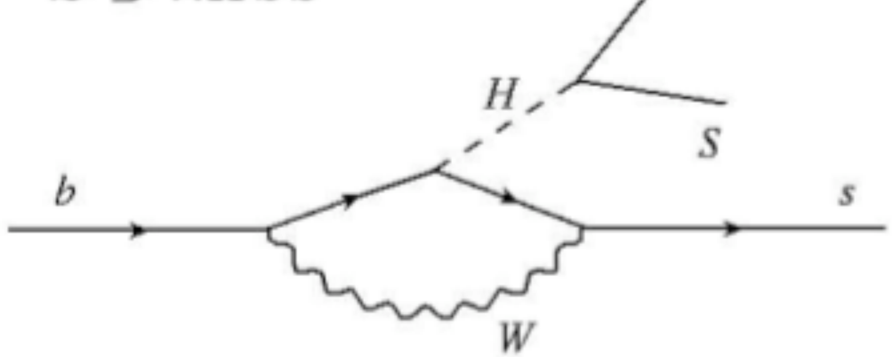


NN Fit Results			
N_s	5 ± 6 ± 4	3 ± 7 ± 4	-10 ± 9 ± 6
N_b	39 ± 9	51 ± 10	77 ± 13
$\varepsilon_{B_{sig}}$ ($\times10^{-2}$)	5.8 ± 0.5	5.2 ± 0.6	16.6 ± 1.4
$N_{B_{had}}$ ($\times10^{5}$)	10.128 ± 0.010 ± 0.344		7.175 ± 0.008 ± 0.222
UL (90% CL)	21 × 10^{-5}		11 × 10^{-5}

Limits on Dark Matter

- Let's suppose there is a light (<2.5 GeV) scalar dark matter candidate S

$$\mathcal{L} \supset \lambda HSS$$



- The UL can be translated into S mass & coupling constraint

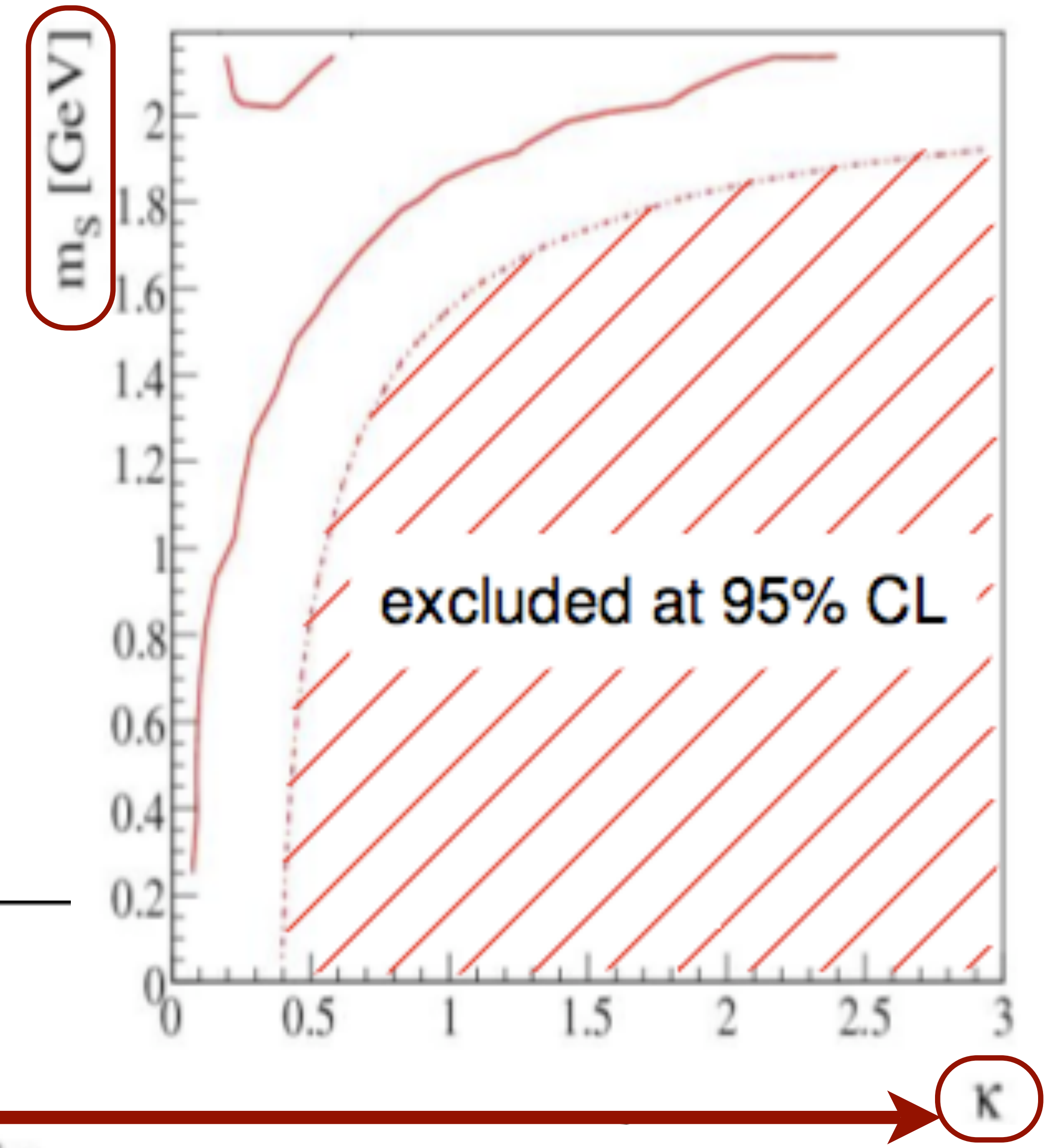
N.B. the H->SS decay would saturate the Higgs decay rate, making impossible the Higgs discovery at LHC!!

Burgess et al.
Nucl.Phys. B619, 709

$$\kappa^2 = \lambda^2 \left(\frac{100\,\mathrm{GeV}}{m_h}\right)^4$$

$\sim O(1)$ from cosmological constr.

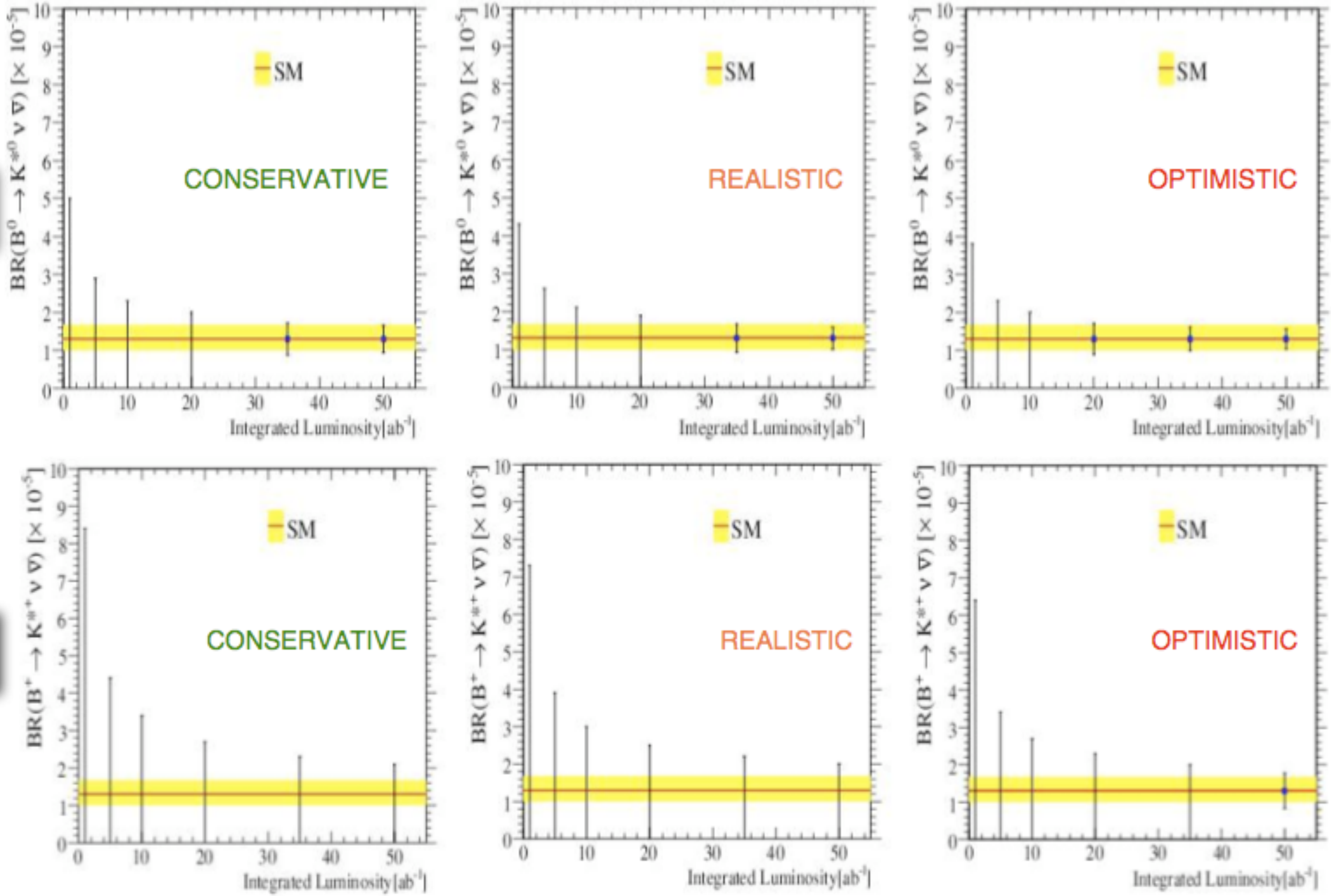
From BaBar UL
(using C. Bird et al)



B→K* ν ν @ SuperB

K*0 ν ν

K*+ ν ν



$B \to K/K^* ll$

- Lots of different observables: BR, direct CP, LFV, isospin and angular asymmetries 

- Theoretical predictions affected by long distance effects 

- Reconstruct 10 different final states

$$B \to \left\{ \begin{matrix} K^+,\ K^0_S(\to \pi^+\pi^-) \\ K^{\pm}\pi^{\mp},\ K^{\pm}\pi^0,\ K^0_S\pi^{\pm} \end{matrix} \right\} \left\{ \begin{matrix} e^+e^- \\ \mu^+\mu^- \end{matrix} \right\}$$

- Suppress random combinatoric background from B/D semileptonic decays with NN/Likelihood ratio of event shape variables

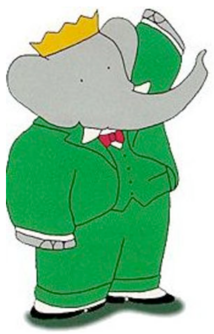
- Veto J/ψ and $\psi(2S)$ dilepton mass ranges

- Cut on NN and $\Delta E = E^*_B - E^*_{beam}$

- Signal yield from ML fit to $m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_B}$

B→K/K*ll BR

- Babar 349 fb^{-1} branching fraction results:
  - $\mathcal{B}(B \to K \ell^+\ell^-)$ = (3.9 ± 0.7 ± 0.2) x 10^{-7} (7.3σ)
  - $\mathcal{B}(B \to K^* \ell^+\ell^-)$ = (11.1 ± 1.9 ± 0.7) x 10^{-7} (7.7σ)
- Good agreement with Ali '02 SM predictions



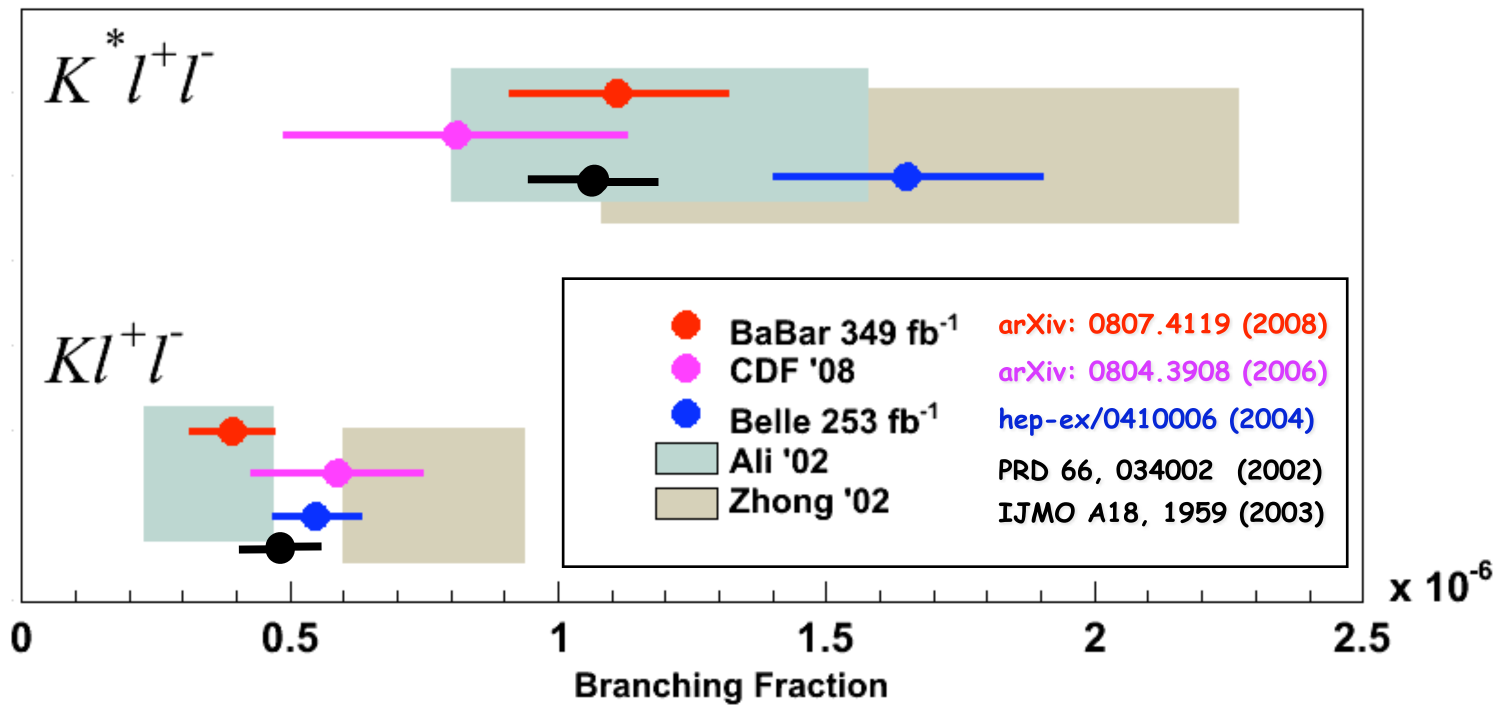
arXiv:0807.4119

New result from Belle in black

$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (10.8^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7},$$
$$\mathcal{B}(B \to K\ell^+\ell^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}.$$

Belle

(Belle arXiv:0810.0335, 657M $B\bar{B}$)



Please note: we are measuring a O(10^{-7}) BRs !!!!

B→K/K*ll Isospin Asymmetry

$$A_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - r\mathcal{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + r\mathcal{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)} \qquad r = \frac{\tau_{B^0}}{\tau_{B^+}}$$

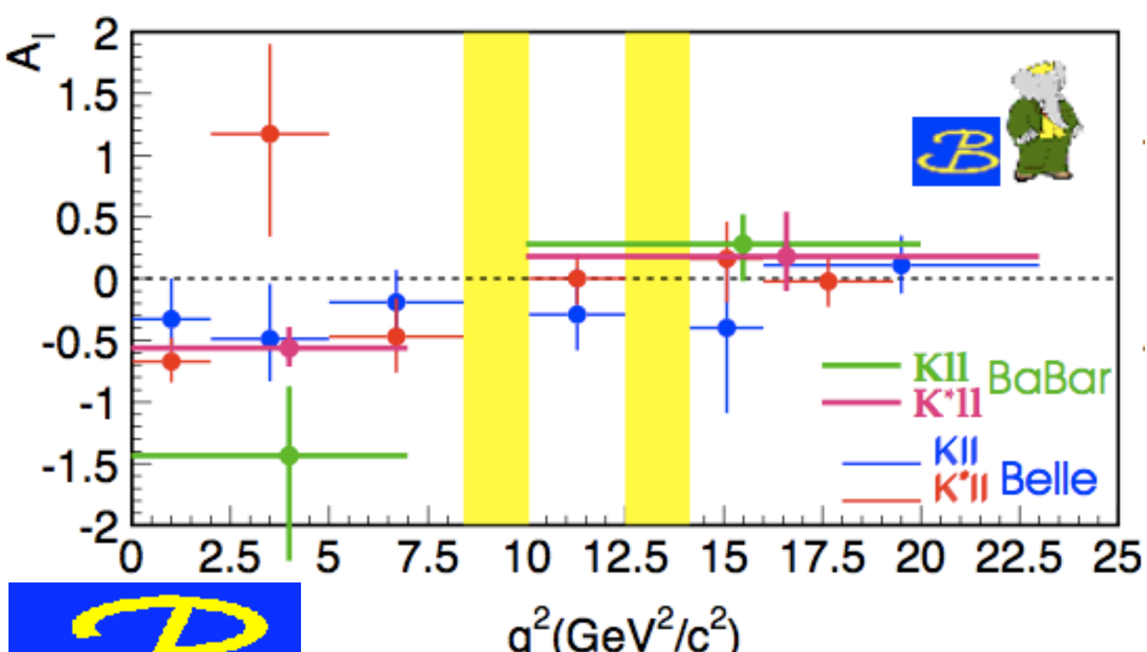
- $|A_I|_{SM} <$ ~0.01
- No significant asymmetry in high mass region
- In low mass region, significance of excluding A_I=0:

K ll 3.2 σ

K* ll 2.7 σ

K(*) ll 3.9 σ

Belle's data consistent with null asymmetry



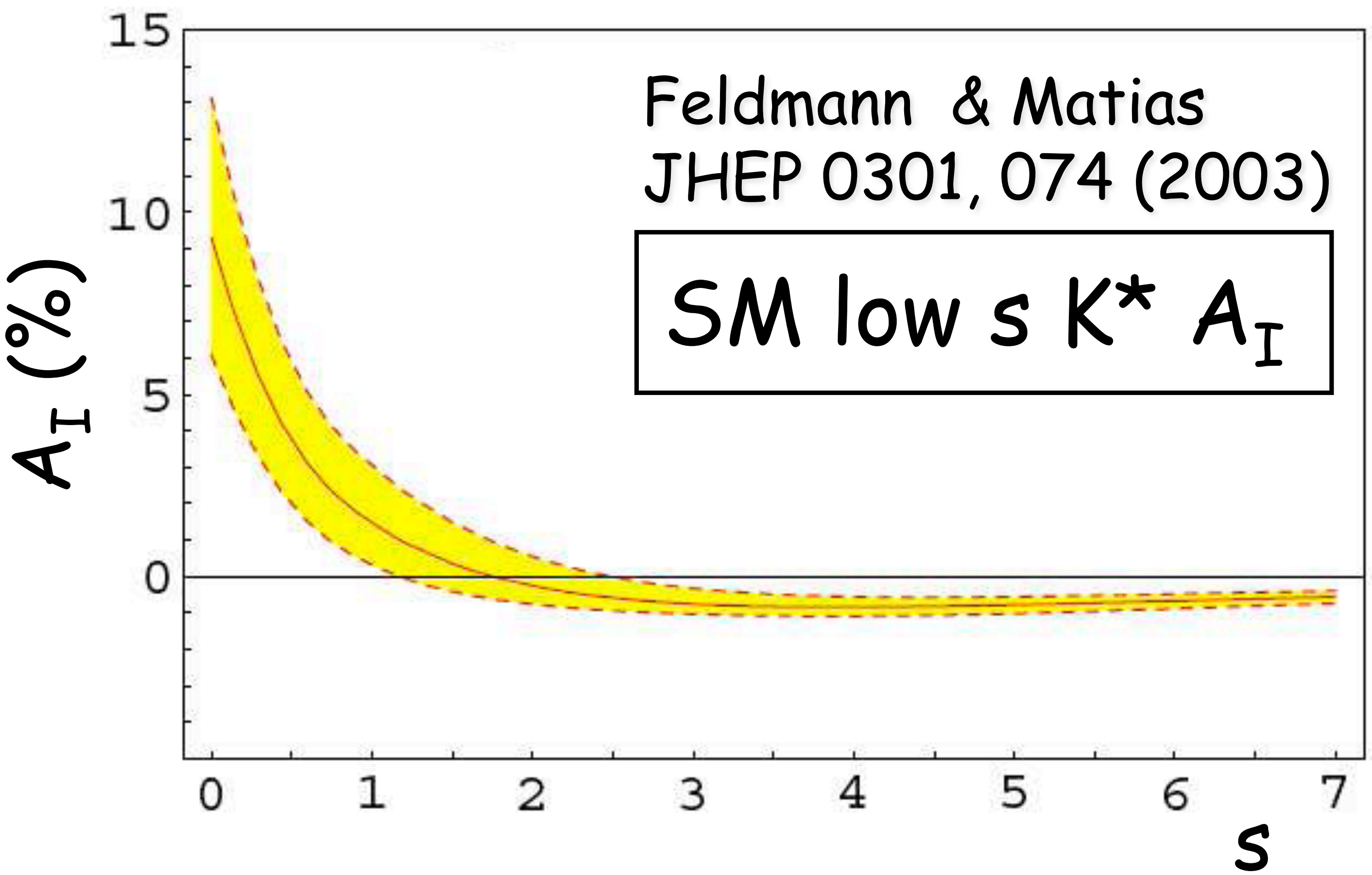
arXiv:0810.0335

Mode	combined q^2	low q^2	high q^2
$K\mu^+\mu^-$	$0.13^{+0.29}_{-0.37} \pm 0.04$	$-0.91^{+1.2}_{-\infty} \pm 0.18$	$0.39^{+0.35}_{-0.46} \pm 0.04$
Ke^+e^-	$-0.73^{+0.39}_{-0.50} \pm 0.04$	$-1.41^{+0.49}_{-0.69} \pm 0.04$	$0.21^{+0.32}_{-0.41} \pm 0.03$
$K\ell^+\ell^-$	$-0.37^{+0.27}_{-0.34} \pm 0.04$	$-1.43^{+0.56}_{-0.85} \pm 0.05$	$0.28^{+0.24}_{-0.30} \pm 0.03$
$K^*\mu^+\mu^-$	$-0.00^{+0.36}_{-0.26} \pm 0.05$	$-0.26^{+0.50}_{-0.34} \pm 0.05$	$-0.08^{+0.37}_{-0.27} \pm 0.05$
$K^*e^+e^-$	$-0.20^{+0.22}_{-0.20} \pm 0.03$	$-0.66^{+0.19}_{-0.17} \pm 0.02$	$0.32^{+0.75}_{-0.45} \pm 0.03$
$K^*\ell^+\ell^-$	$-0.12^{+0.18}_{-0.16} \pm 0.04$	$-0.56^{+0.17}_{-0.15} \pm 0.03$	$0.18^{+0.36}_{-0.28} \pm 0.04$

arXiv:0807.4119

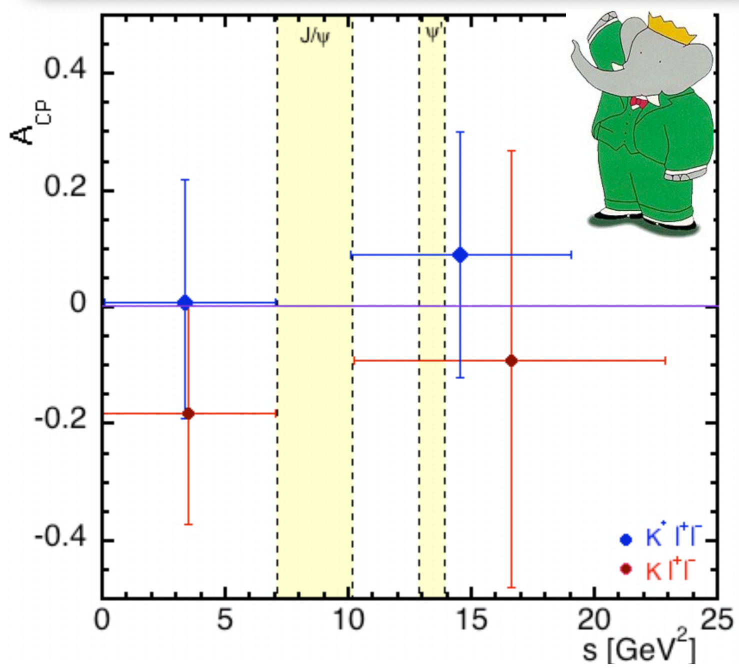
$B \to K/K^* ll$ Isospin Asymmetry

- In the SM, expectation for K* asymmetry dominated by positive contribution at very low dilepton mass arising from coupling exclusively to photon penguin
- No expectation of any SM K isospin asymmetry



B→K/K*ll CP Asymmetry and LF ratio

Direct CP Asymmetry

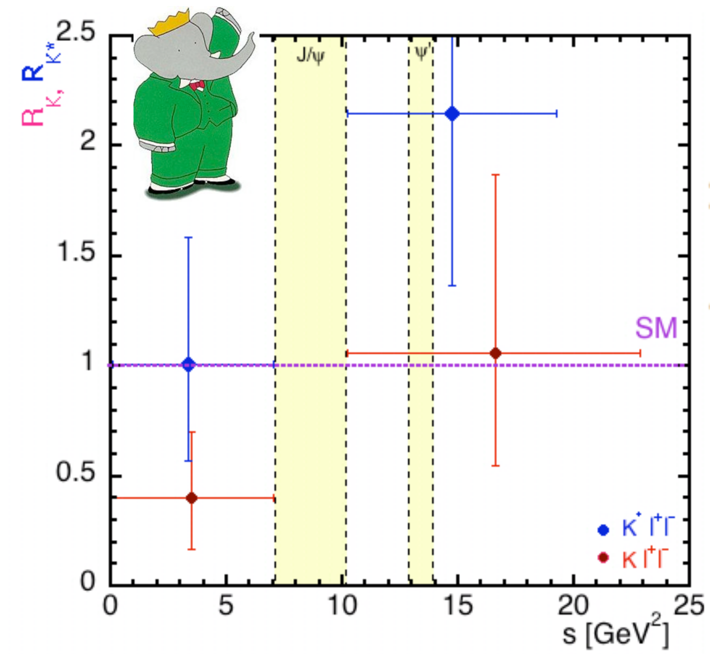


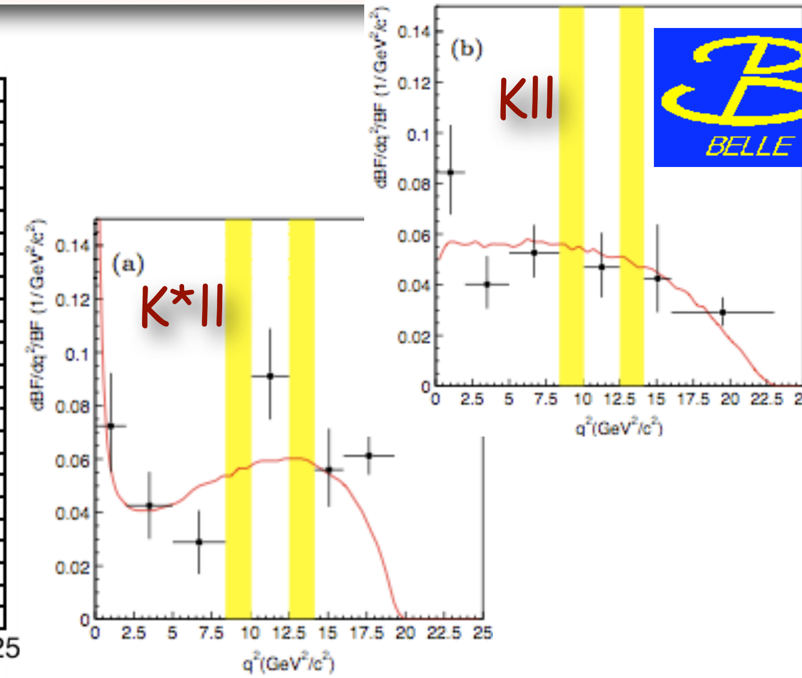
$$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+\ell^-) - \mathcal{B}(B \to K^{(*)} \ell^+\ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+\ell^-) + \mathcal{B}(B \to K^{(*)} \ell^+\ell^-)}$$

- Null SM expectation
- All measurement consistent with 0

Mode	all q^2	low q^2	high q^2
$K^+\ell^+\ell^-$	$-0.18^{+0.18}_{-0.18} \pm 0.01$	$-0.18^{+0.19}_{-0.19} \pm 0.01$	$-0.09^{+0.36}_{-0.39} \pm 0.02$
$K^{*0}\ell^+\ell^-$	$0.02^{+0.20}_{-0.20} \pm 0.02$	$-0.23^{+0.38}_{-0.38} \pm 0.02$	$0.17^{+0.24}_{-0.24} \pm 0.02$
$K^{*+}\ell^+\ell^-$	$0.01^{+0.26}_{-0.24} \pm 0.02$	$0.10^{+0.25}_{-0.24} \pm 0.02$	$-0.18^{+0.45}_{-0.55} \pm 0.04$
$K^*\ell^+\ell^-$	$0.01^{+0.16}_{-0.15} \pm 0.01$	$0.01^{+0.21}_{-0.20} \pm 0.01$	$0.09^{+0.21}_{-0.21} \pm 0.02$

Lepton Flavour ratio R_{K/K^*}





$$R_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

- Dimuon can be enhanced by large tan beta neutral Higgs
- Belle results integrated over q^2 compatible with SM
- ~2 σ deviation from SM in low q^2 R_K

Babar data

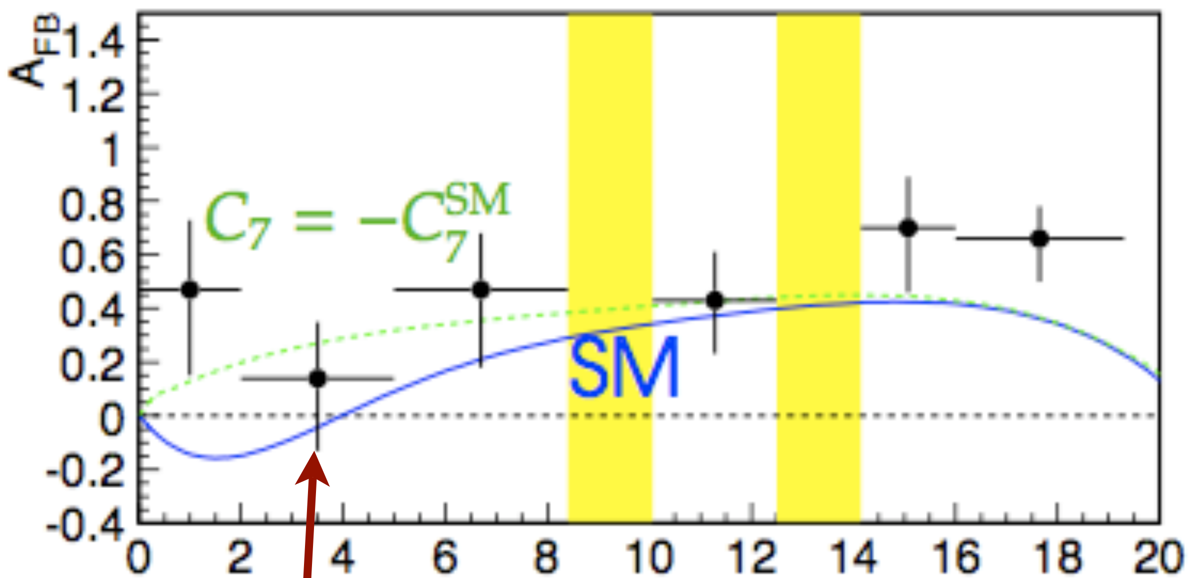
B→K/K*ll FB Asymmetry and F_L

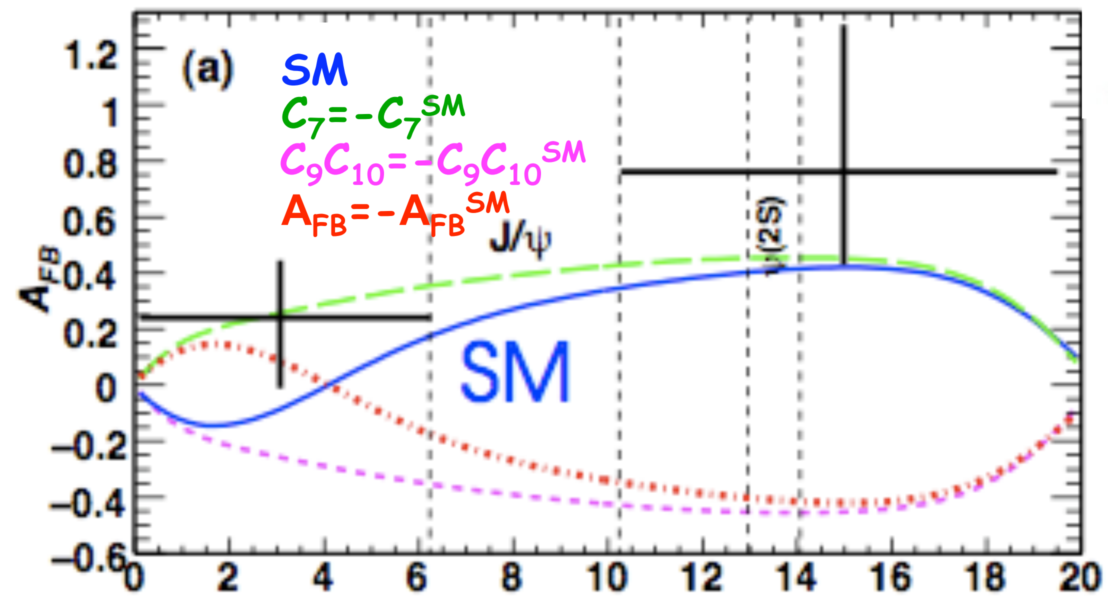
Belle

BaBar

A_{FB} (Belle arXiv:0810.0335, 657M $B\bar{B}$)

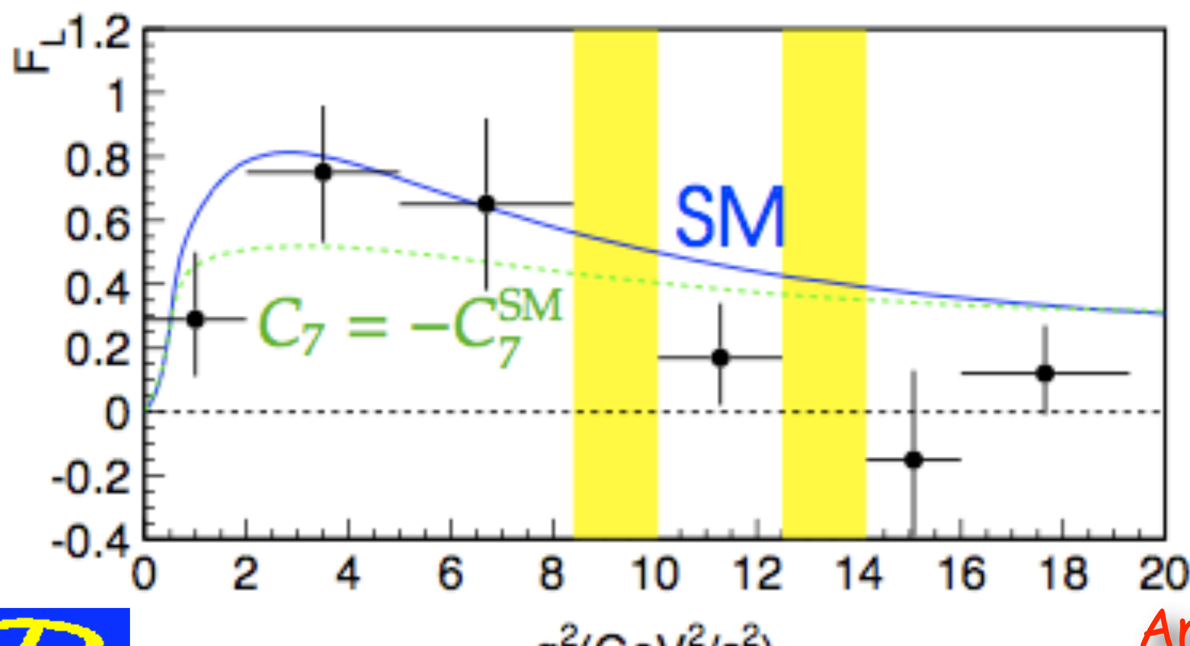
(BaBar arXiv:0804.4412, 384M $B\bar{B}$)

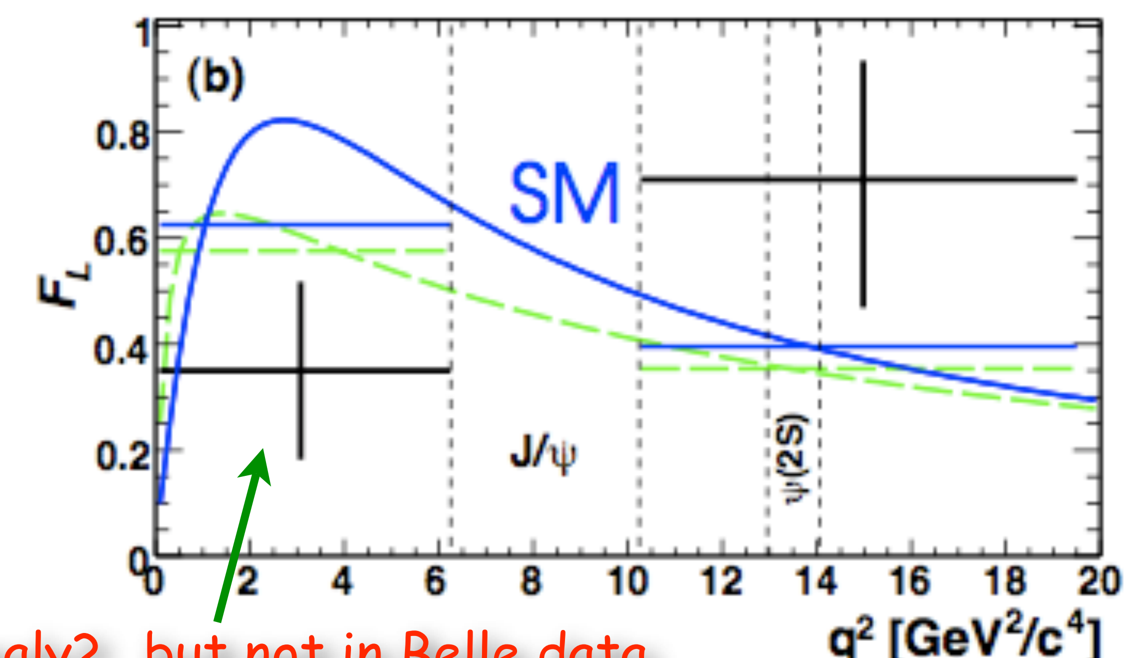




No crossing (opposite sign C_7)? ...not enough statistic...

F_L

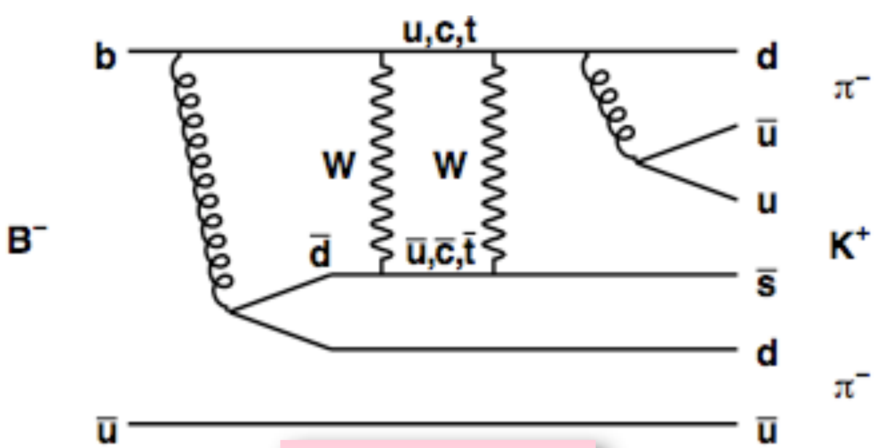




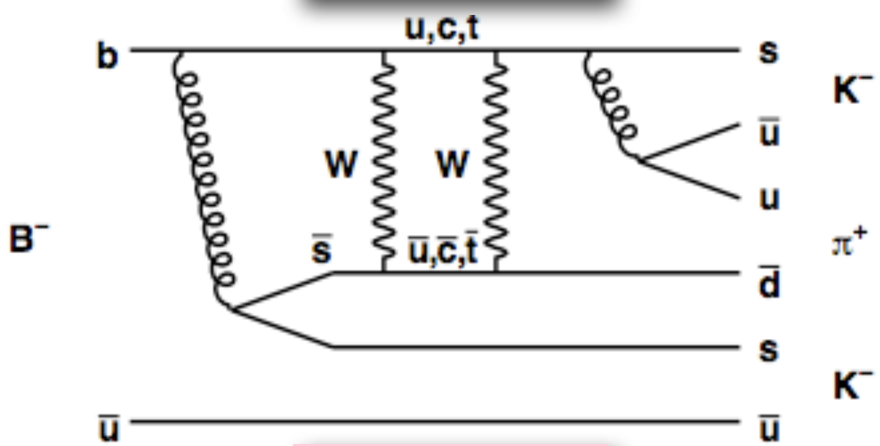
Anomaly? ..but not in Belle data..

$B^+ \to K^-\pi^+\pi^- / K^-K^+\pi^-$

$$b \to q q \bar{s} / b \to q q \bar{d} \simeq (V_{td}V_{ts}^* \sim \lambda^5 \simeq 3 \cdot 10^{-5}) \cdot b \to q \bar{q} s / b \to q \bar{q} d$$



~O(10⁻¹¹)



~O(10⁻¹⁴)

$$\mathcal{H}_{\text{eff.}} = \sum_{n=1}^{5} \left[C_n \mathcal{O}_n + \tilde{C}_n \tilde{\mathcal{O}}_n \right],$$

$$\mathcal{O}_1 = \bar{d}^i_L \gamma^\mu b^i_L \bar{d}^j_R \gamma_\mu s^j_R,$$
$$\mathcal{O}_2 = \bar{d}^i_L \gamma^\mu b^j_L \bar{d}^j_R \gamma_\mu s^i_R,$$
$$\mathcal{O}_3 = \bar{d}^i_L \gamma^\mu b^i_L \bar{d}^j_L \gamma_\mu s^j_L,$$
$$\mathcal{O}_4 = \bar{d}^i_R b^i_L \bar{d}^j_L s^j_R,$$
$$\mathcal{O}_5 = \bar{d}^i_R b^j_L \bar{d}^j_L s^i_R,$$

Z'

SM

MSSM

RPV

$$\Gamma^{(MS)SM}_{\pi\pi K} = \left| C_3^{(MS)SM} \right|^2 \times 2.0 \times 10^{-3}\ \text{GeV}^5,$$
$$\Gamma^{RPV}_{\pi\pi K} = \left| C_4^{RPV} + \tilde{C}_4^{RPV} \right|^2 \times 9.2 \times 10^{-3}\ \text{GeV}^5,$$
$$\Gamma^{Z'}_{\pi\pi K} = \left| C_1^{Z'} + \tilde{C}_1^{Z'} \right|^2 \times 1.0 \times 10^{-2}\ \text{GeV}^5 + \left| C_3^{Z'} + \tilde{C}_3^{Z'} \right|^2 \times 1.3 \times 10^{-3}\ \text{GeV}^5 + \text{Re}\left[\left(C_1^{Z'} + \tilde{C}_1^{Z'} \right) \left(C_3^{Z'} + \tilde{C}_3^{Z'} \right)^* \right] \times 6.7 \times 10^{-3}\ \text{GeV}^5.$$

Can constrain RPV :

$$\left| \sum_{n=1}^{3} \left(\frac{100\ \text{GeV}}{m_{\tilde{\nu}_n}} \right)^2 \lambda'_{n21} \lambda'^*_{n13} \right| < 8.9 \times 10^{-5},$$

$B^+ \to K^-\pi^+\pi^- / K^-K^+\pi^-$ analysis

$B^- \to K^+\pi^-\pi^+ < 1.8 \times 10^{-6}$

$B^- \to K^+K^-\pi^+ < 1.3 \times 10^{-6}$

BaBar, Phys.Rev.Lett. 91, 051801 (2003)

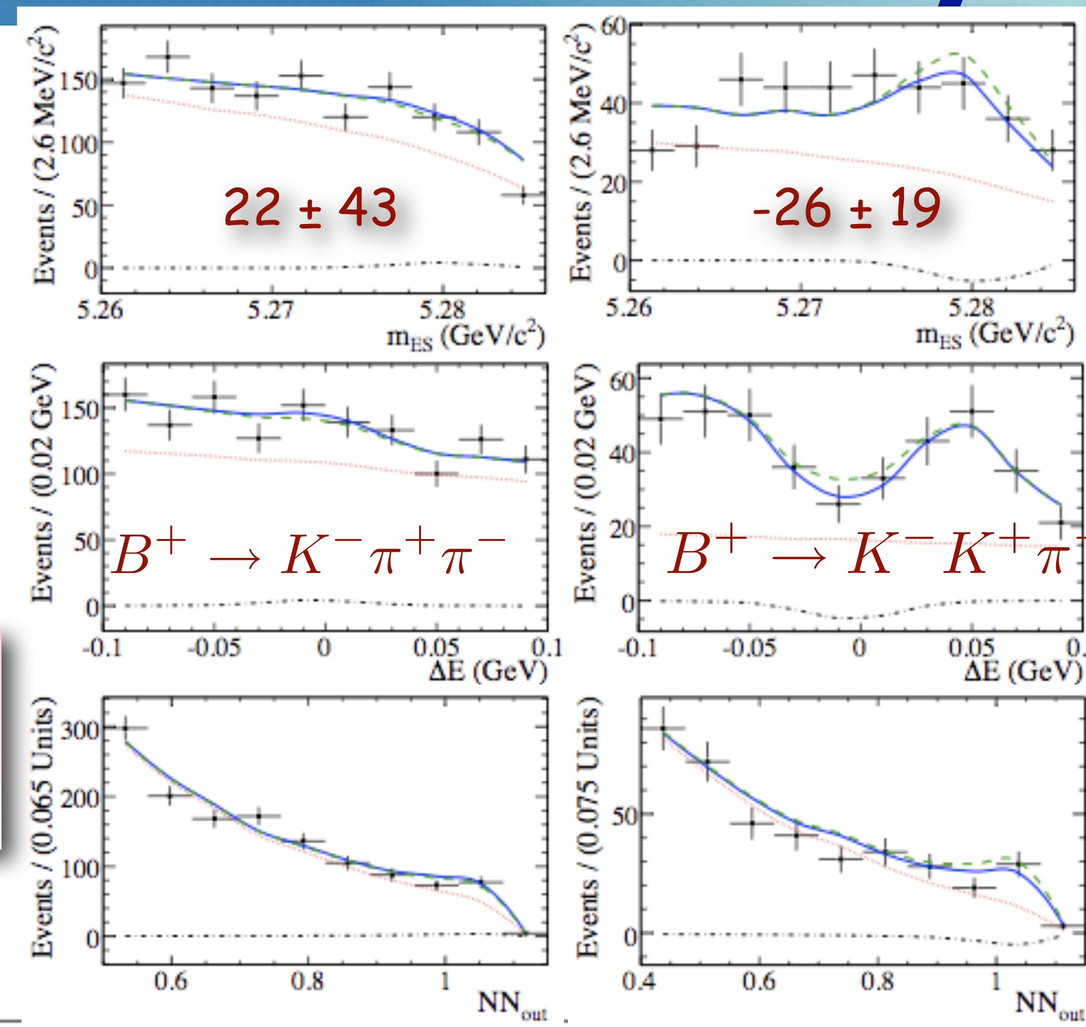
- J/ψ, D^0 and $\psi(2S)$ vetos
- Efficiencies: 21.6% / 17.8%
- NN variables: L_2/L_0, $|\cos\theta_{beam}|$, $|\cos\theta_{thrust}|$, B_{tag} flavour, $\Delta t/\sigma_{\Delta t}$
- Four specific bkg categories + BB generic + continuum
- Feldman-Cousins UL @ 90%:

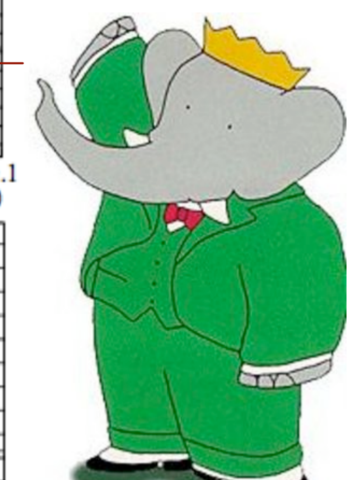
$B^\pm \to K^\mp\pi^+\pi^- < 7.4 \times 10^{-7}$

$B^\pm \to K^+K^-\pi^\mp < 4.2 \times 10^{-7}$

Phys.Rev.D 78 091102

426 fb^{-1}





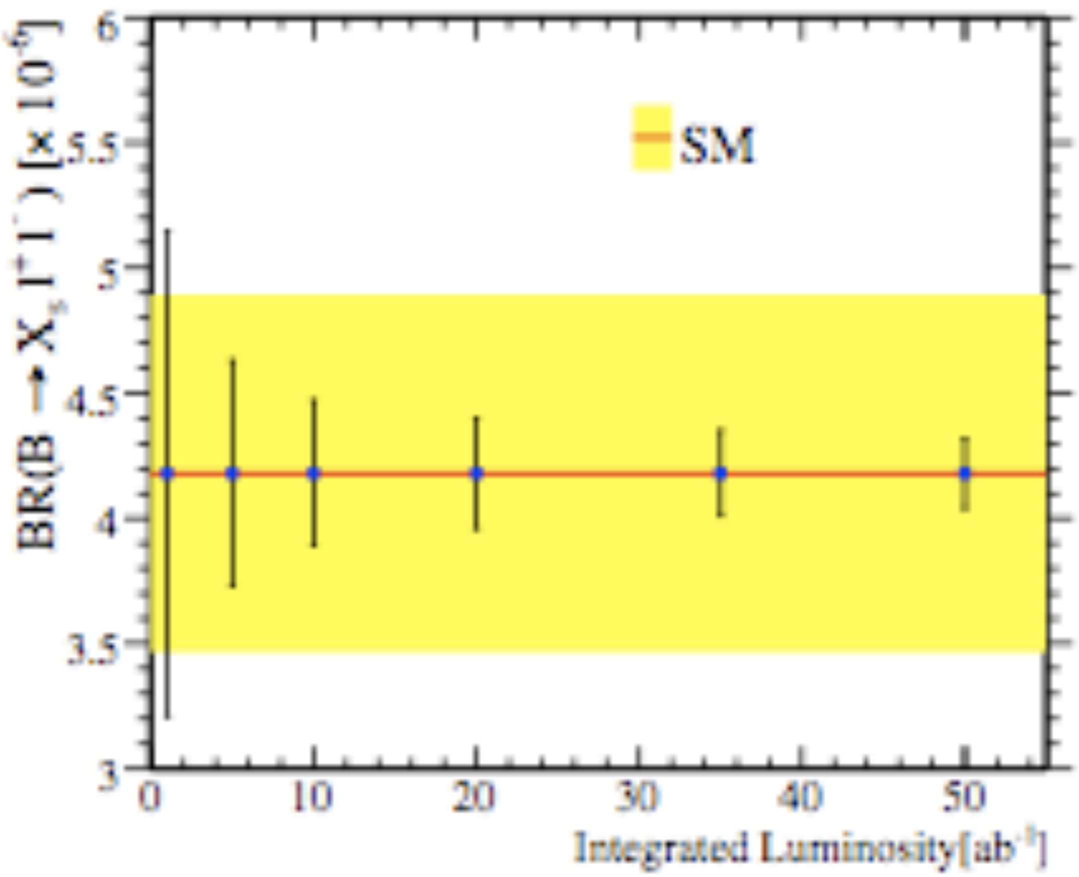
$B^- \to K^+\pi^-\pi^-$				
Category	1	2	3	4
Dominant mode(s)	$B^- \to D^0\pi^-$; $D^0 \to K^-K^+$	$B^- \to \pi^-\pi^+\pi^-$	$B^- \to K^-\pi^+\pi^-$ & $B^0 \to K^+\pi^-\pi^0$	$B^0 \to K^+\pi^-$
Number of expected events	80 ± 3	57 ± 4	472 ± 24	43 ± 1
Number of observed events	61 ± 70	-153 ± 94	1116 ± 347	-26 ± 152
m_{ES} Structure	Peaking	Peaking	Broad peak	Broad peak
ΔE Structure	Left peak	Right peak	Broad peak	Right peak
$B^- \to K^-K^-\pi^+$				
Category	1	2	3	4
Dominant mode(s)	$B^- \to K^-K^+K^-$	$B^- \to K^-\pi^+\pi^-$	$B^- \to D^0\pi^-$; $D^0 \to K^-\pi^+\pi^0$	Generic B^+B^-
Number of expected events	190 ± 9	198 ± 9	61 ± 4	312 ± 11
Number of observed events	213 ± 41	240 ± 37	-34 ± 55	380 ± 117
m_{ES} Structure	Peaking	Peaking	Broad peak	Broad peak
ΔE Structure	Left peak	Right peak	Left peak	Continuum-like

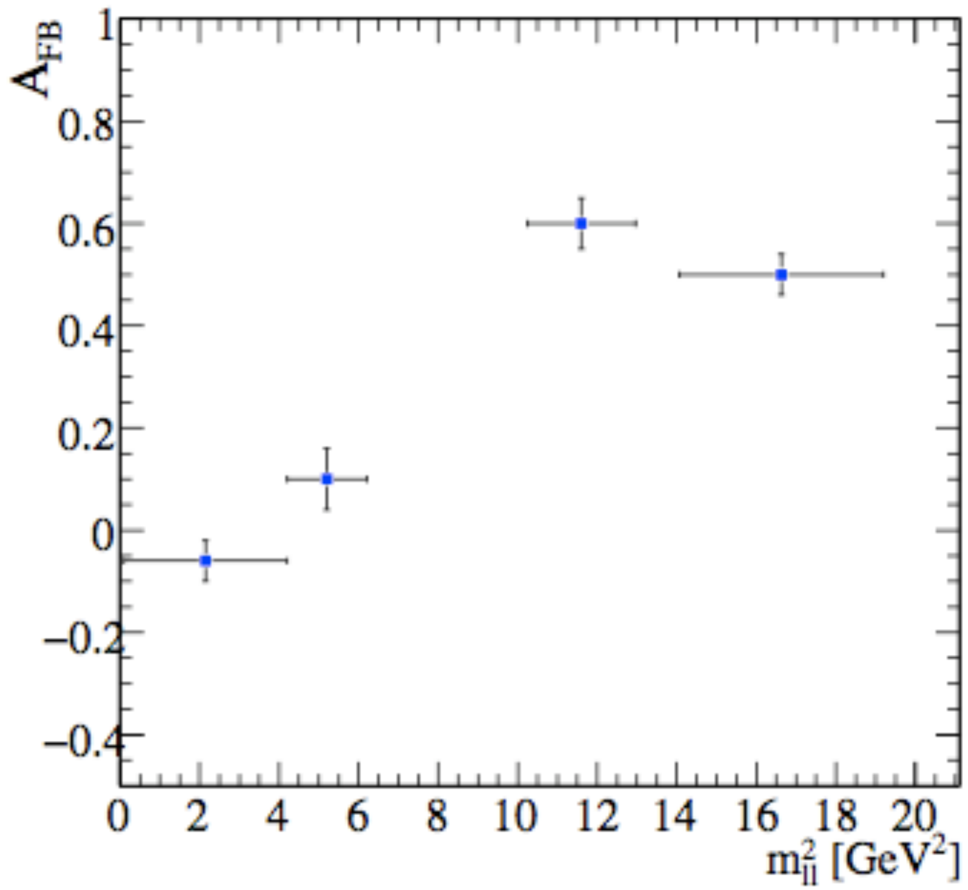
Conclusion & Outlook

- Rare decays are standard probes for NP searches given the low decay rates
- They are complementary to the direct exploration of energy frontier and can access even higher scales
- Thanks to the improved analysis techniques and the huge integrated luminosity, today is possible to reach $O(10^{-6}\text{-}10^{-7})$ in sensitivity
- Even if only UL, rare decays are already able to impose interesting constraints on various NP scenarios
- Nonetheless, decays with undetectable particles in the final state will not be measurable at the LHC and a Super Flavour Factory will be needed in order to obtain improved measurements

Backup Slides

b→sll at Super Flavour Factory



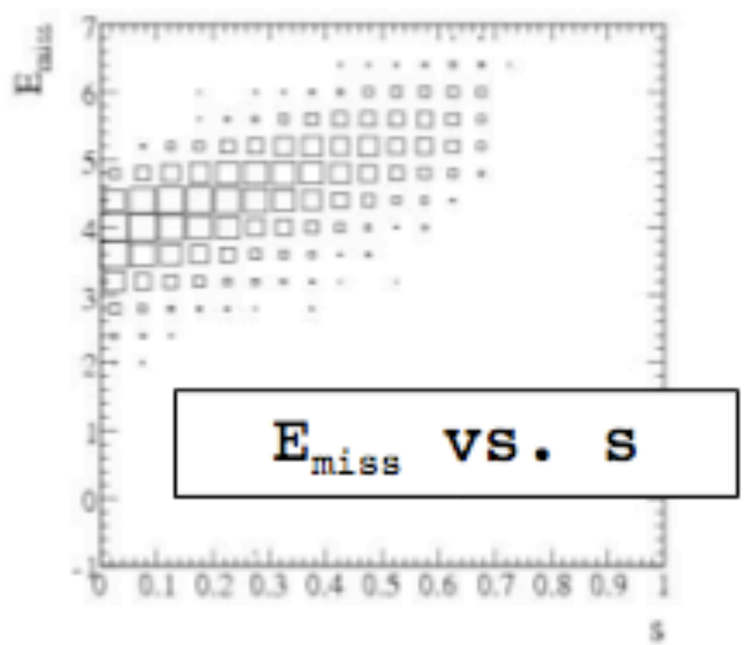


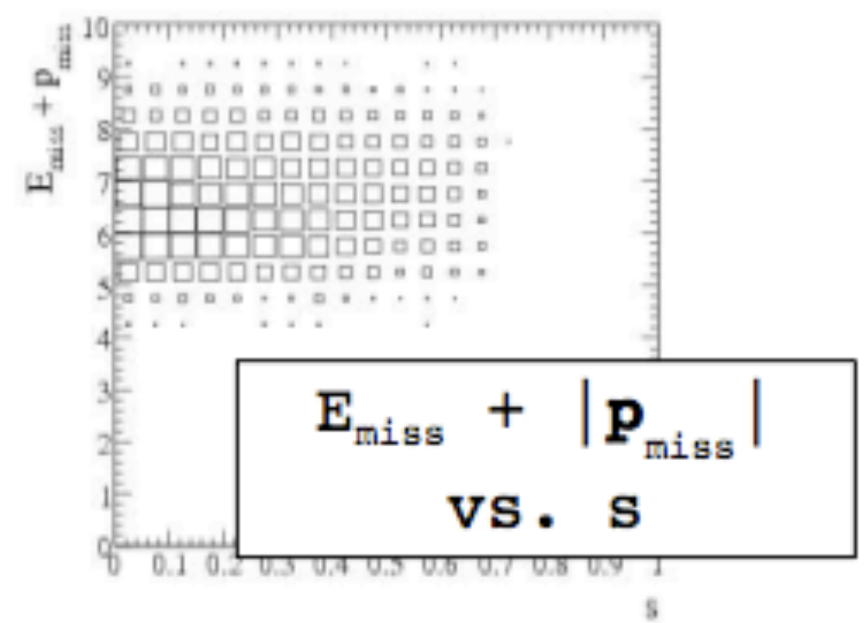
$B \rightarrow K^* \nu \nu$ Model Un-dependence

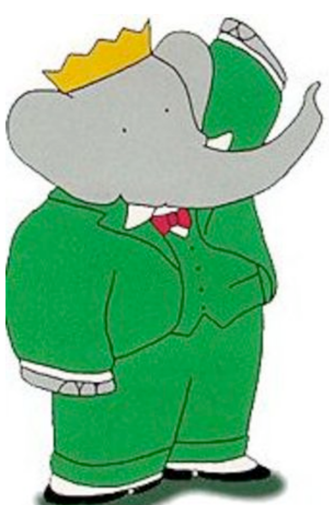
Selection and Fit Variables chosen in order to minimize the dependence on the kinematical model
(i.e. use variables with NO correlation to $s = m_{\nu\nu}^2/m_B^2$)

missing 4-momentum:

$p_{miss} = p_{beams} - p_{Dl} - p_{K^*}$





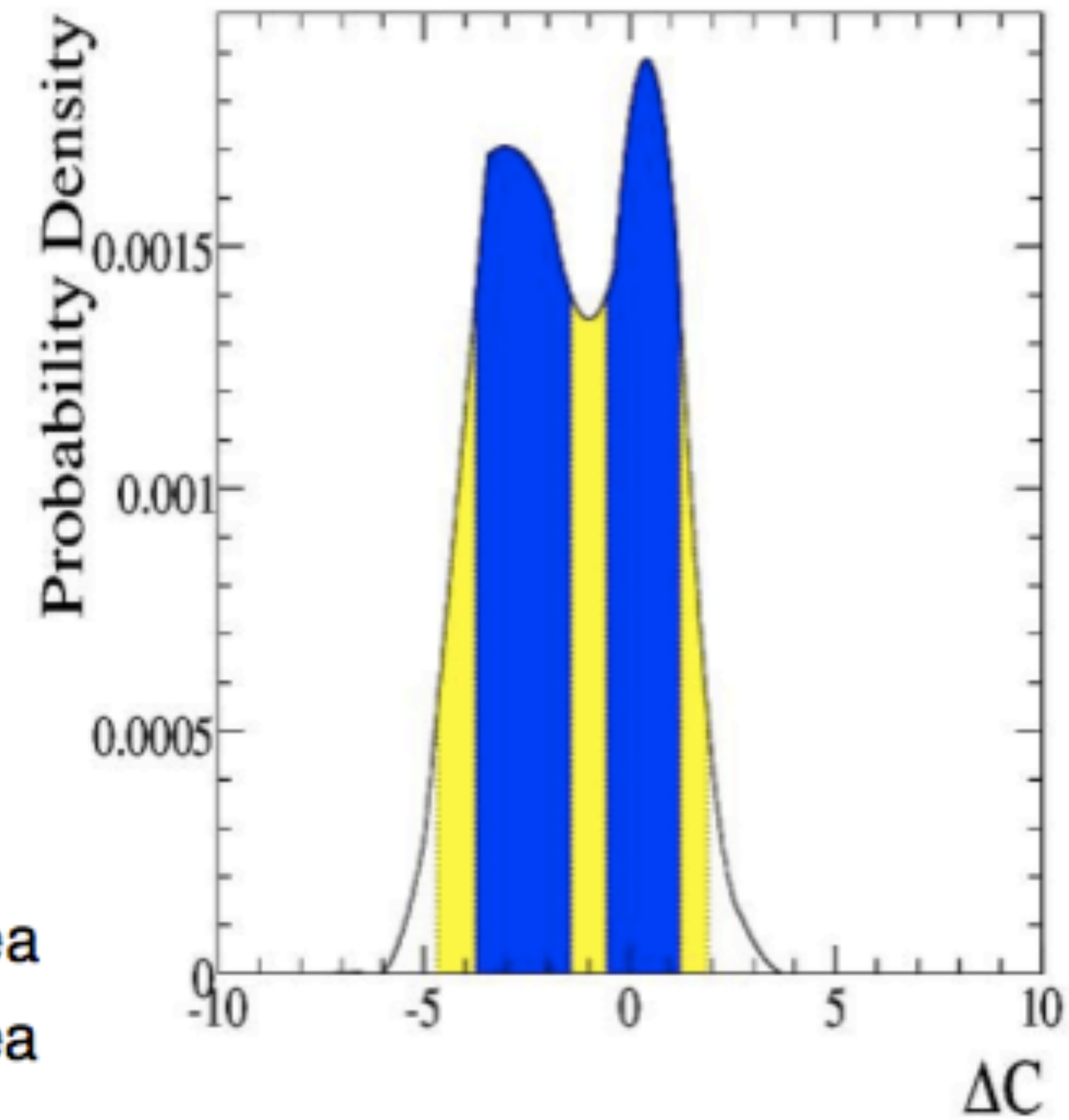


$B \to K^* \nu \bar{\nu}$ and MFV SUSY

- Assume a Minimal Flavor Violation (MFV) scenario:
  - NP enters only through modifications of the functions $B(x_t)$ and $C(x_t)$;
- NP in $B(x_t)$ expected to give small contributions;
- Set a limit on $\Delta C = C - C_{SM}$ assuming $B = B_{SM}$.

All the most recent results for $B \to K^{(*)} \nu \bar{\nu}$ are used

NP in C as large as 6 times the SM can be excluded at 95% C.L.

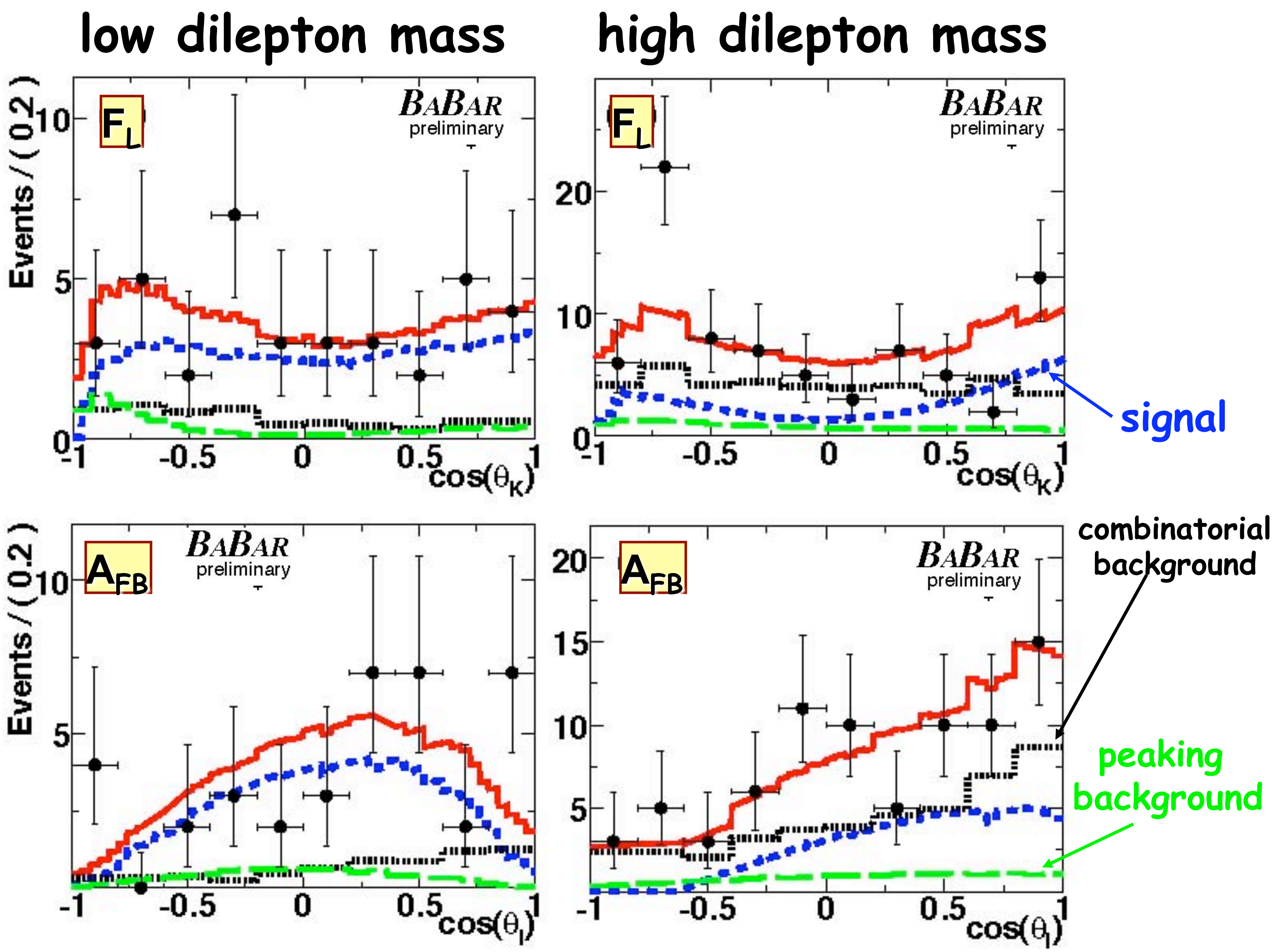


68% prob. area
95% prob. area

B→K/K*ll

Angular Fits

- Fit 1: Extract signal, background yields from m_{ES} fit
- Fit 2: Extract F_L from cos θ_K fit to events in m_{ES} > 5.27 signal region
- Fit 3: Extract A_{FB} from cos θ_ℓ fit to events in m_{ES} > 5.27 signal region



Photon Fusion Event