New Physics searches at Belle

in (semi-) leptonic *B* decays

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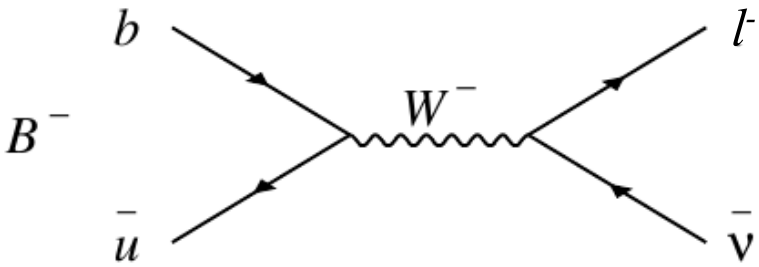
on behalf of the Belle Collaboration

EPS-HEP 2013, Stockholm, 19. July

universitätbonn

Leptonic B decays



helicity suppressed in the SM

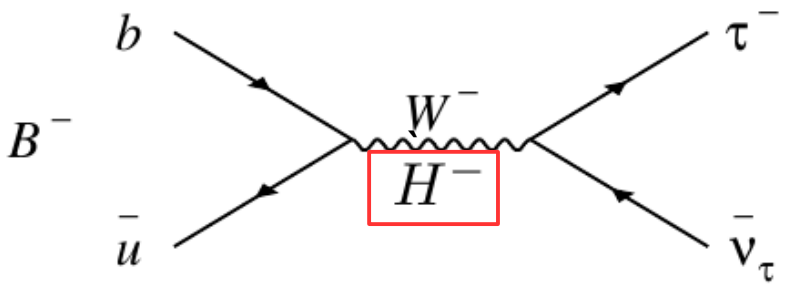
$$\mathcal{B}(B \to \ell\nu)_{\mathrm{SM}} = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

origin of uncertainty
only as product measurable

f_B needs to be derived from theory

	$\mathcal{B}(B \to \ell\nu)_{\mathrm{SM}}$
$B \to \tau\nu$	10^{-4}
$B \to \mu\nu$	10^{-7}
$B \to e\nu$	10^{-11}

New Physics contribution

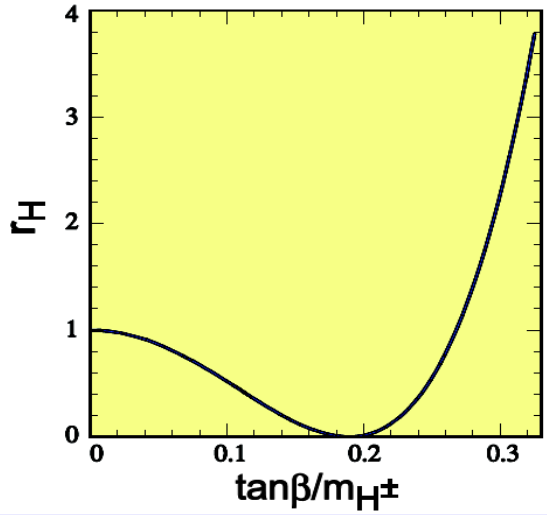


NP contributions might interfere with SM already at tree-level

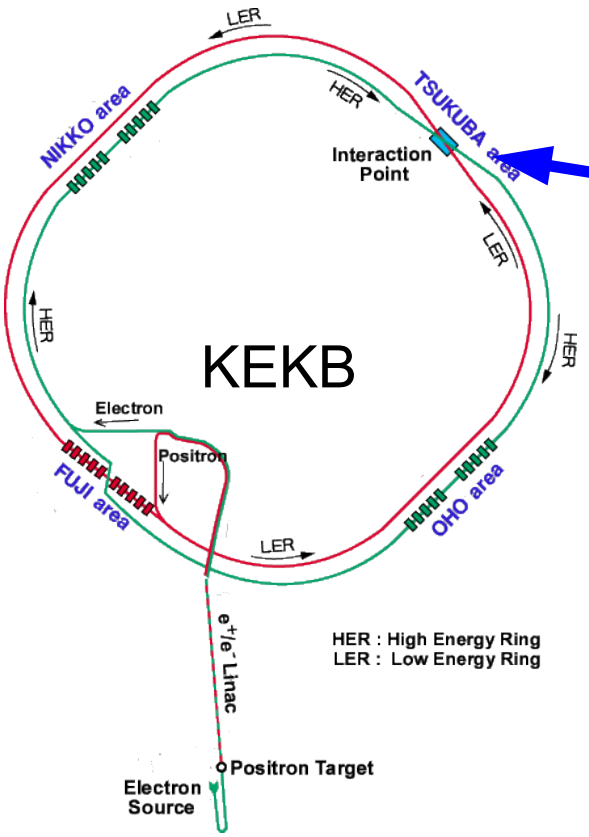
Most prominent: $H^{\pm}$ from 2-Higgs-Doublet-Models (2HDM) as in MSSM

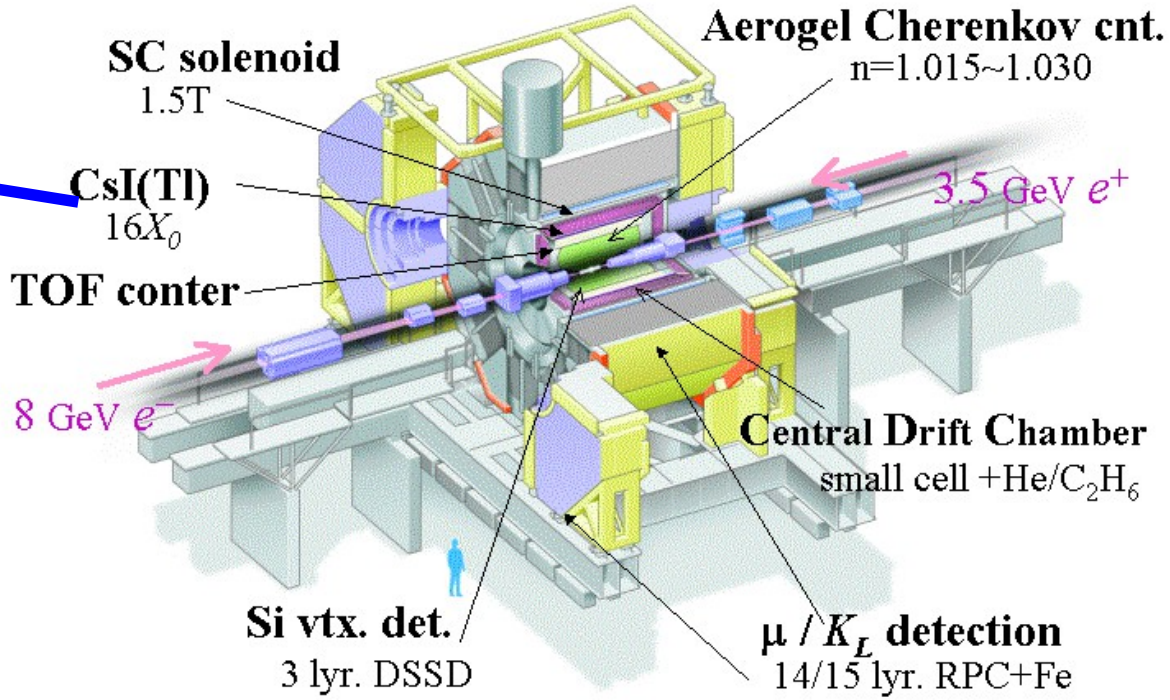
2HDM Type II:

$$r_H = \frac{\mathcal{B}(B \to \ell\nu)}{\mathcal{B}(B \to \ell\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_{H^\pm}^2}\tan^2\beta\right)^2$$



The Belle Experiment





4π detector + known initial state

→ perfect environment for

studies of *B* decays with

multiple *ν*'s in final state!

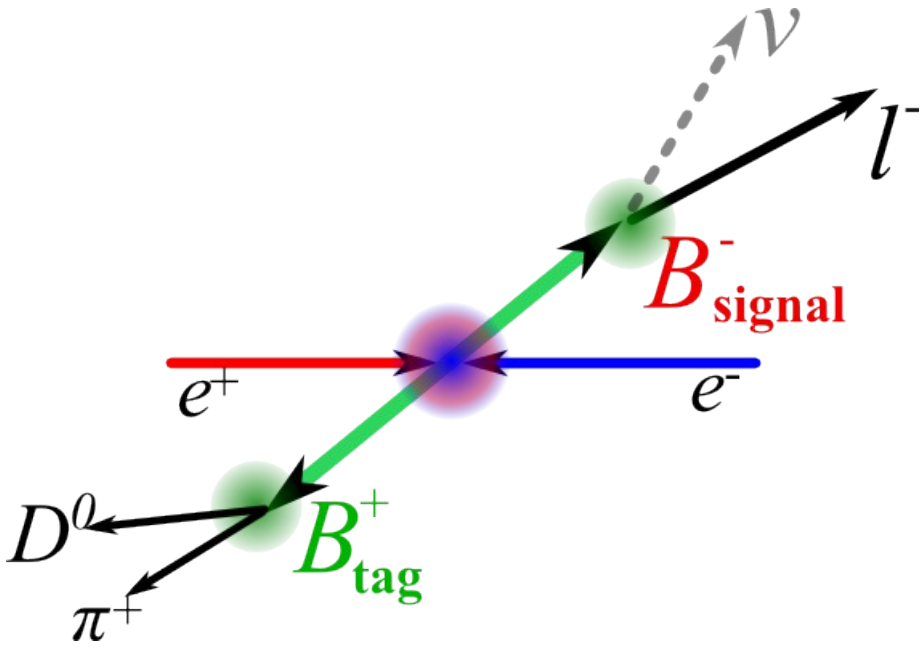
Full Belle dataset:

~710fb^{-1}

in $e^+e^- \to Y(4S) \to B\bar{B}$

→ 772x10^6 $B\bar{B}$ pairs!

Hadronic B-Tagging



Good suppression of $e^+e^- \to q\bar{q}$
$q = udsc$

Knowledge of *charge*
flavour
four-momenutum
of B_{tag} and B_{sig}!

Efficiency ~0.28%
(old method: 0.14%)

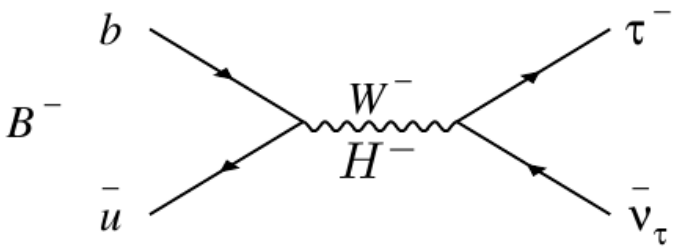
Tagging of a B in Y(4S) → $B\bar{B}$ decays:

new hadronic tag algorithm

full reconstruction of a B_{tag} in a hadronic channel

taking over 1000 decay chains into account

B→τν: Method

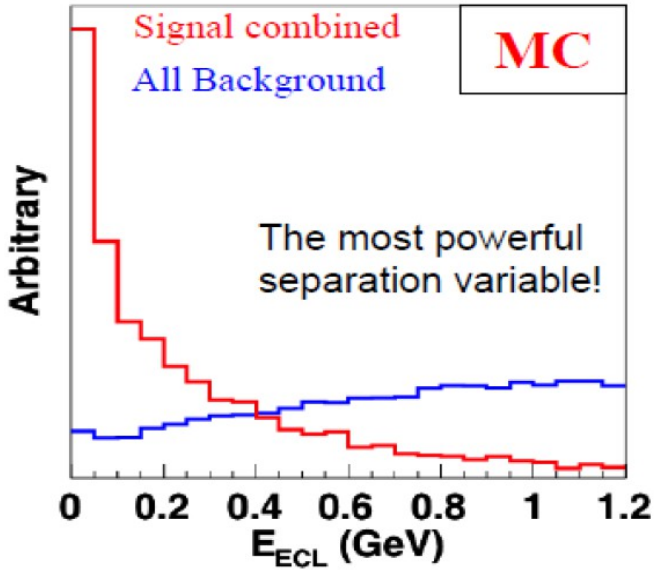


τ reconstructed as $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$ and $\rho\nu$

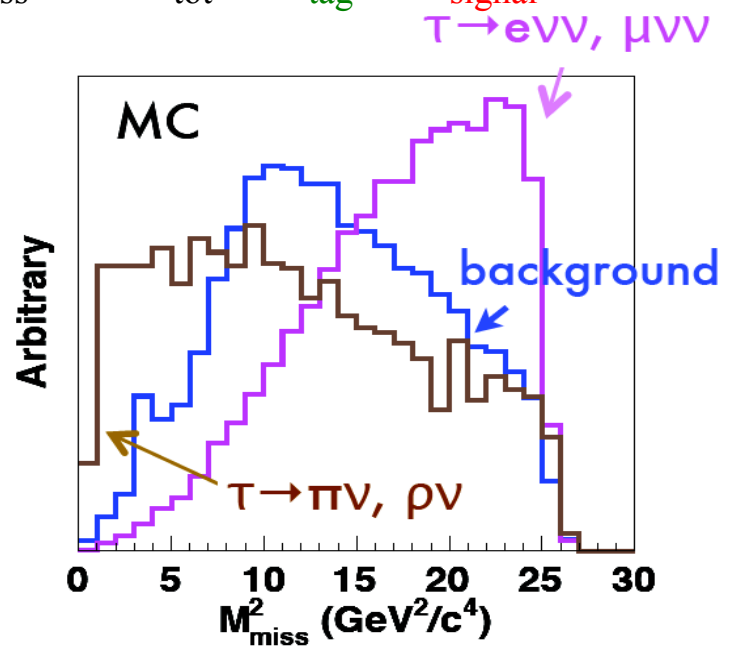
No additional tracks or π^0 except the B_{tag}

Signal extracted from 2D max. Likelihood fit to (E_{ECL}, M^2_{miss})

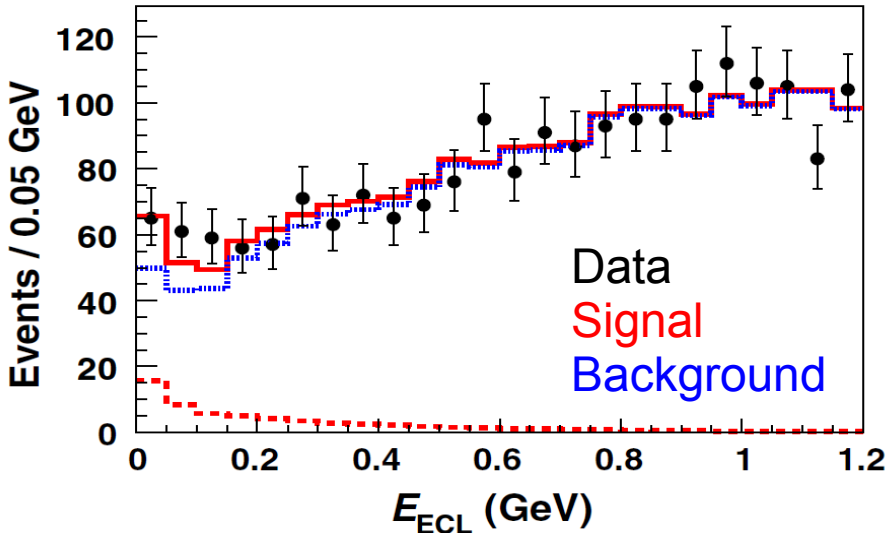
E_{ECL} = residual energy in EM calorimeter

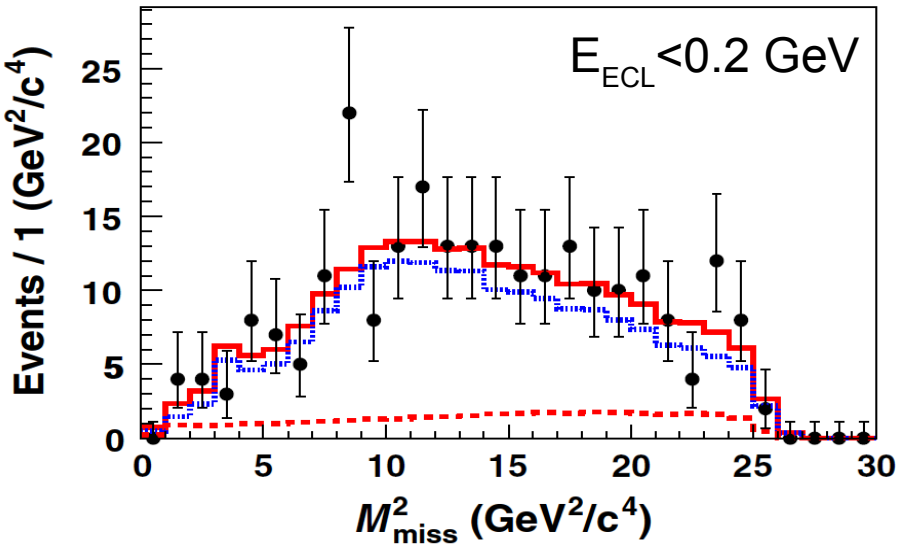


$M^2_{miss} = (p_{tot} - p_{tag} - p_{signal})^2$



B→τν: Signal extraction





PRL 110, 131801 (2013)

observed $62^{+23}_{-22}(\text{stat}) \pm 6(\text{sys})$ signal events

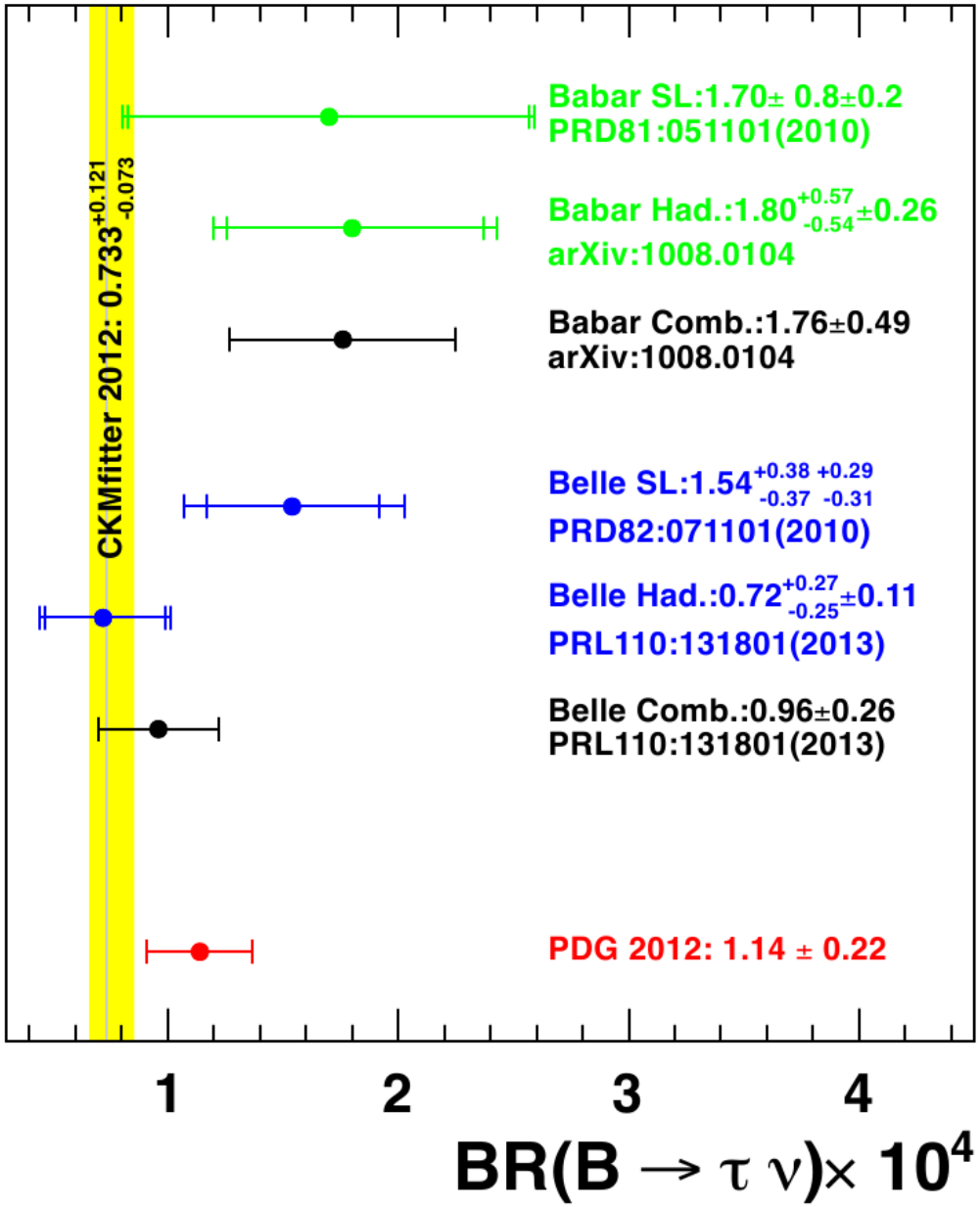
$$\mathcal{B}(B \to \tau\nu) = \left(0.72^{+0.27}_{-0.25}\ (\text{stat}) \pm 0.11\ (\text{sys})\right) \times 10^{-4}$$

PRL **97**, 251802 (2006)

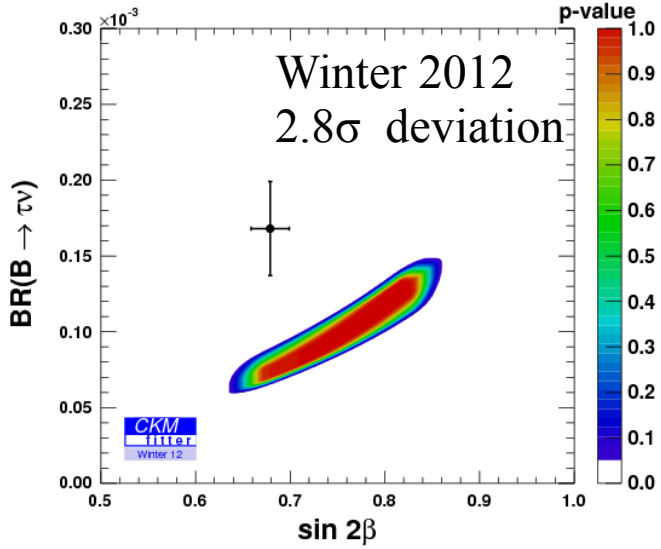
Changes from previous Belle hadronic tag analyses:

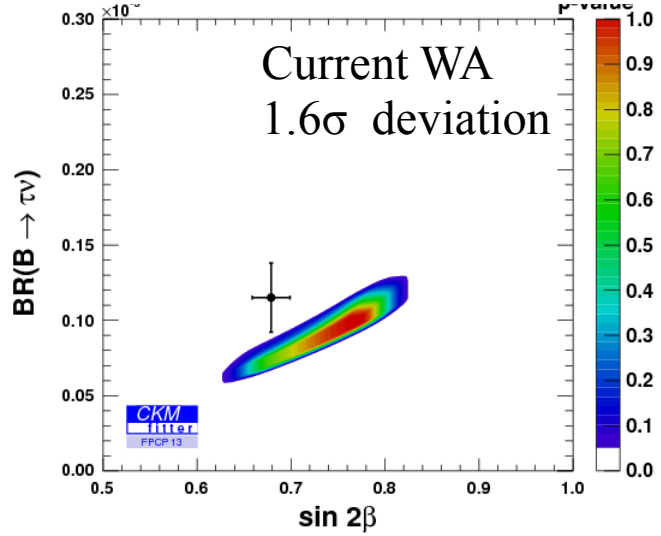
K_L veto	*+5%*
2D max. Likelihood Fit	
Sensitivity for $B\to\tau\nu$ improved by ~20%	
using full Belle data set	*x1.8*
new hadronic tag method	*x1.7*
Number of tagged events 3x larger	

B→τν: Result overview

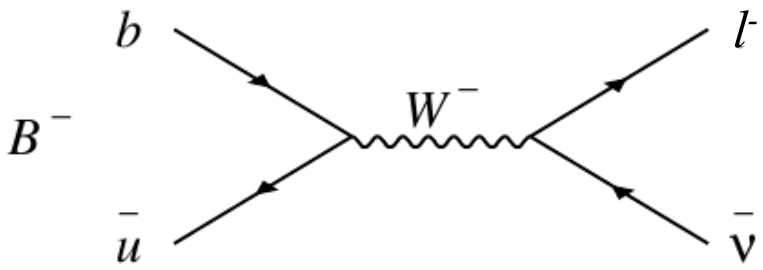


Decreased "tension" from SM prediction



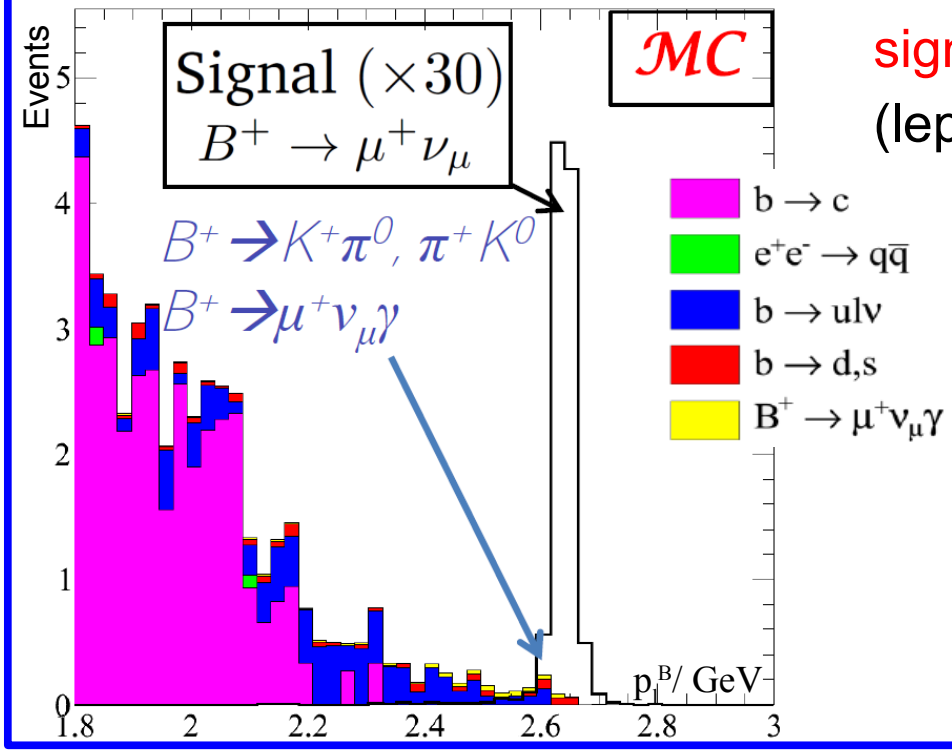


B→lν: Method



On signal side one single track (e or μ) required

2-body decay: clear signature in B_{sig} rest frame



signal extraction variable: p_l^B
(lepton momentum in B_{sig} rest frame)

Fit strategy:

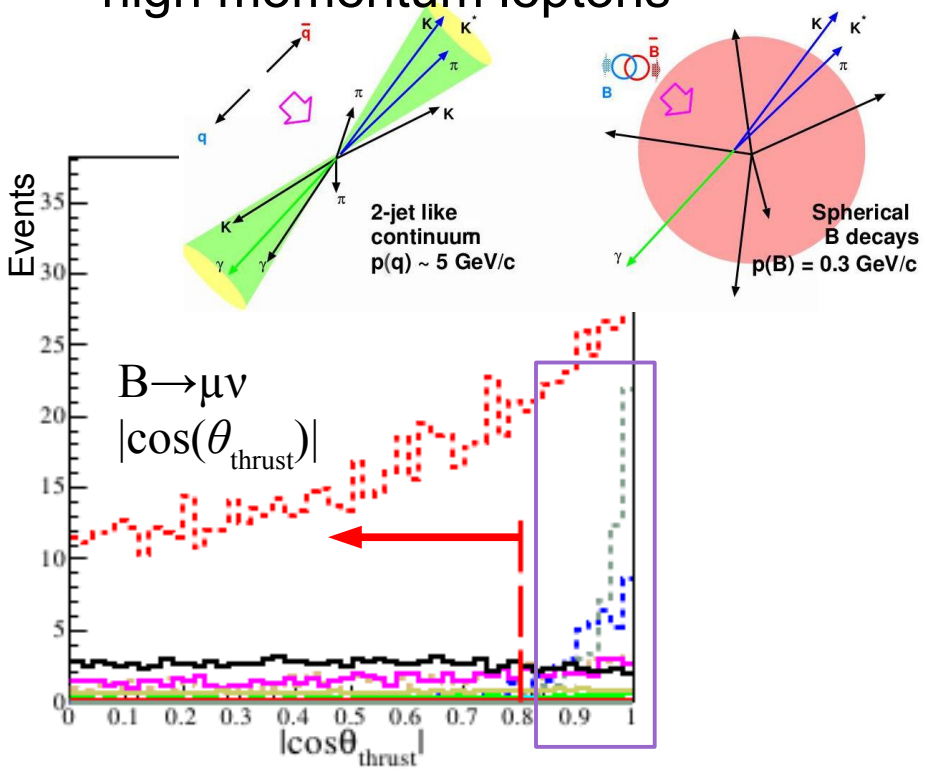
Estimate BG in p_l^B sideband (2 – 2.5 GeV)
→ extrapolate into signal region

Unbinned maximum Likelihood fit

B→lν: Background suppression

$|\cos(\theta_{\text{thrust}})|$

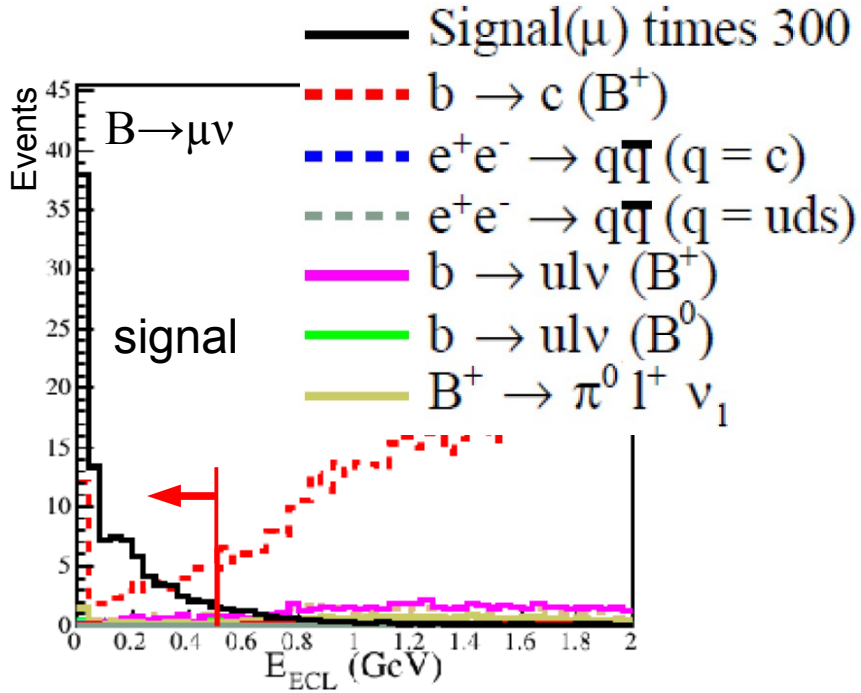
continuum can contain high momentum leptons



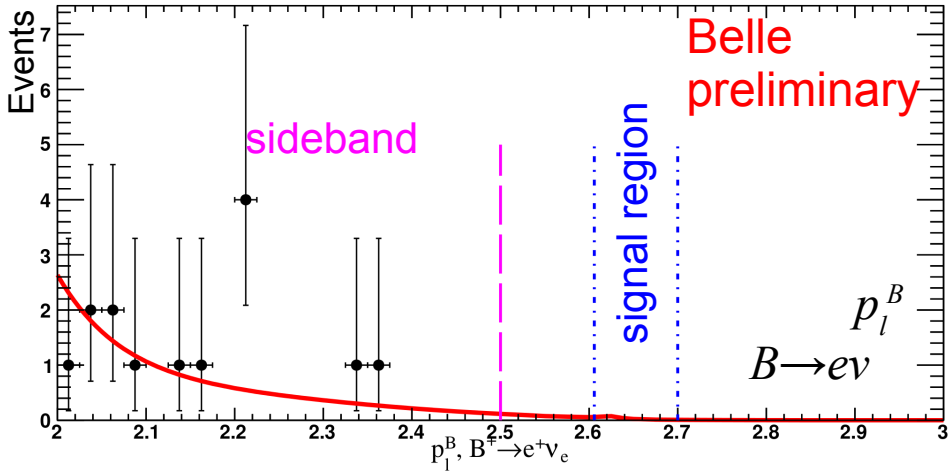
θ_{thrust}: angle between B_{tag} thrust and p_l

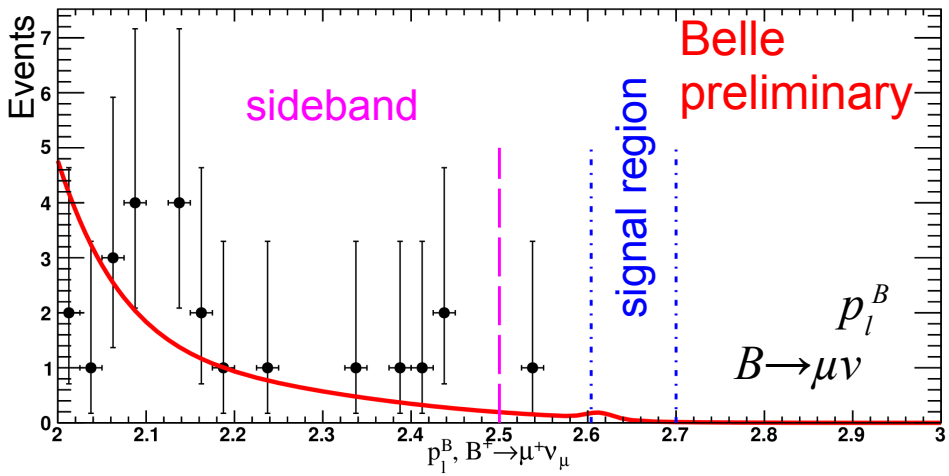
E_{ECL}

no additional energy expected (apart from the lepton and B_{tag})



B→lν: Signal Extraction





$B \to l\nu$	ε_{signal}	N_{BG}	N_{obs}
$e\nu$	0.091	$0.11\ ^{+0.08}_{-0.06}$	0
$\mu\nu$	0.115	$0.33\ ^{+0.10}_{-0.08}$	0

Results: (preliminary)

$$\mathcal{B}(B \to e\nu) < 3.5 \times 10^{-6}$$

$$\mathcal{B}(B \to \mu\nu) < 2.5 \times 10^{-6}$$

@90% CL

no signal events observed → Upper limit calculated using Feldman-Cousins method

previous measurements

Hadronic Tag

$$\mathcal{B}(B \to e\nu) < 5.2 \times 10^{-6}$$

$$\mathcal{B}(B \to \mu\nu) < 5.6 \times 10^{-6}$$

BABAR Collab., PRD 77, 091104 (2008)

Loose Tagging

$$\mathcal{B}(B \to e\nu) < 9.8 \times 10^{-7}$$

Belle Collab., PLB 647, 67 (2007)

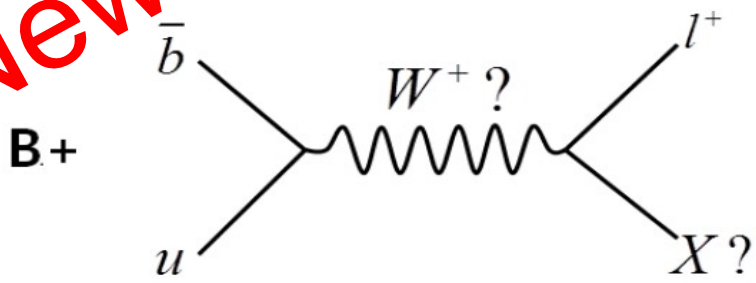
$$\mathcal{B}(B \to \mu\nu) < 1.0 \times 10^{-6}$$

BABAR Collab., PRD 79, 091101 (2009)

@90% CL

B→IX^0

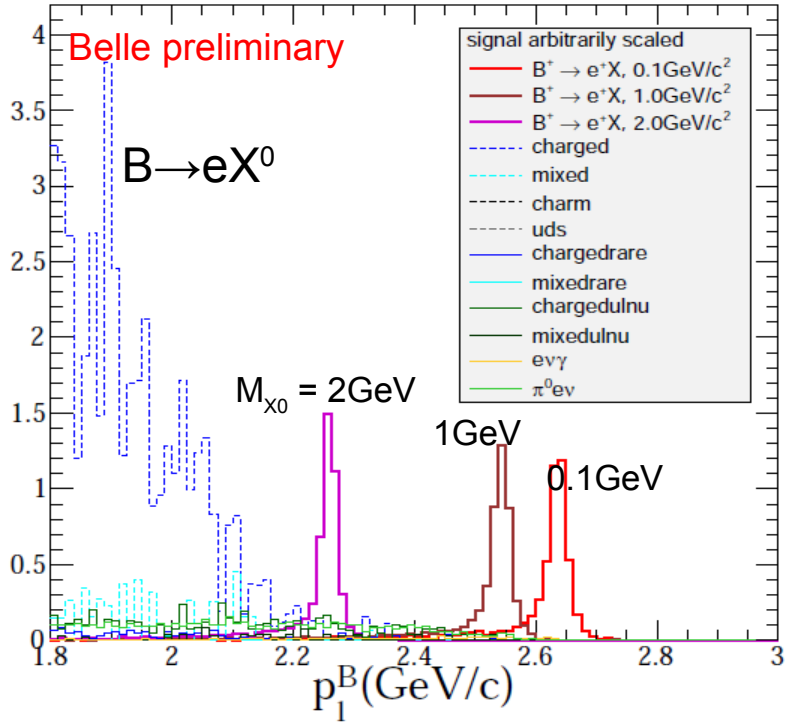
New!



Search for new neutrino-like, heavy fermion X^0

eg from GUT, SUSY or νMSM

Covered mass range: 0.1 – 1.8 GeV
in steps of 0.1 GeV



similar to $B \to l\nu$ analysis

except:

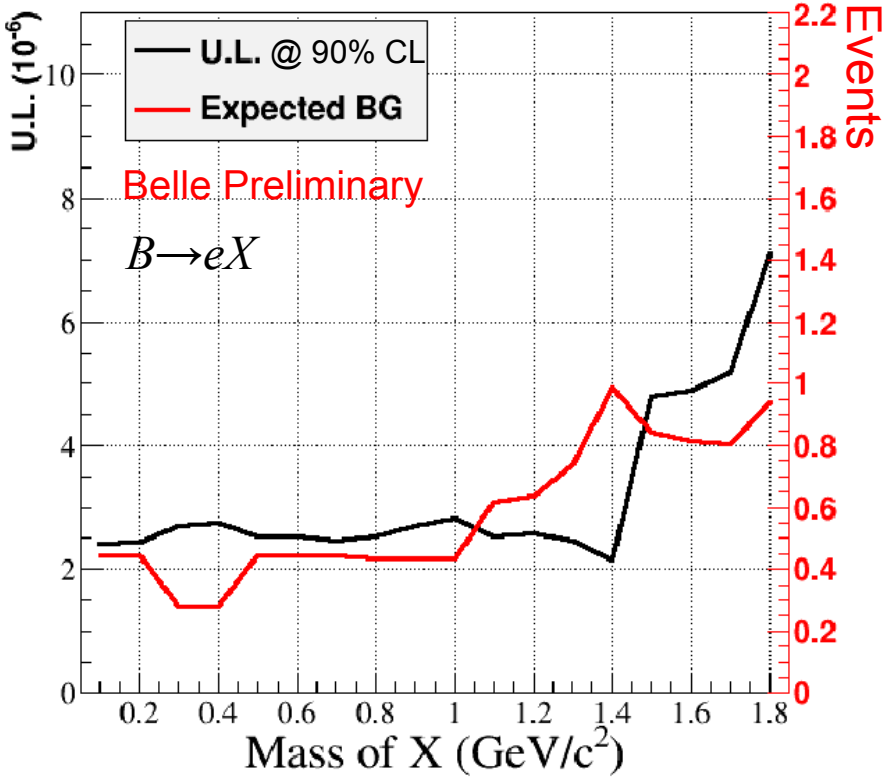
looser momentum cut $p_l^{lab} > 1\,\mathrm{GeV}$
(instead of 1.8GeV)

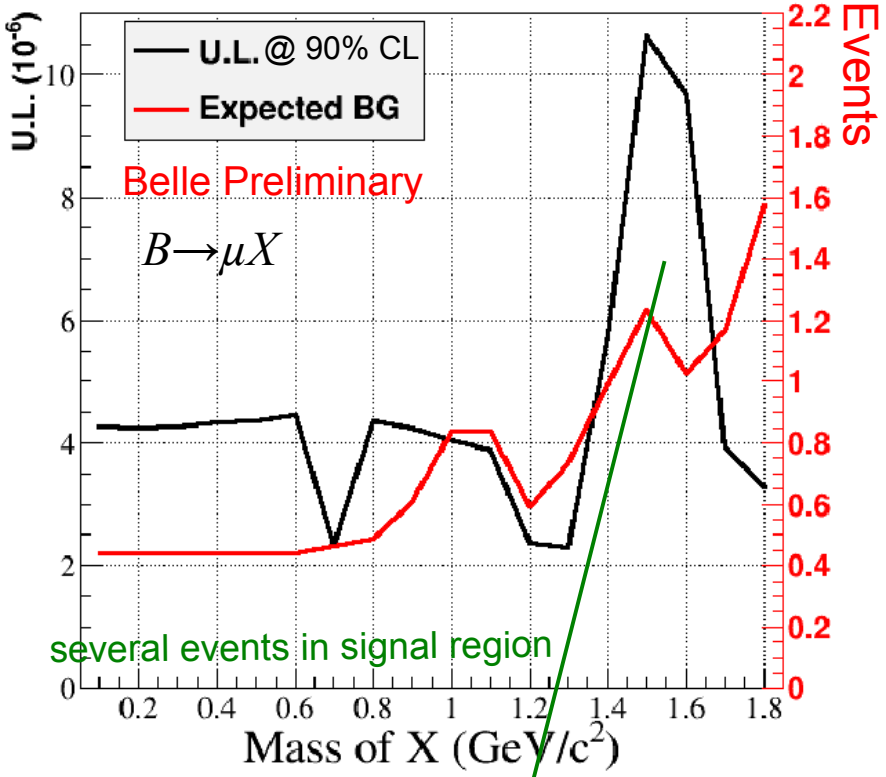
looser impact parameter selection

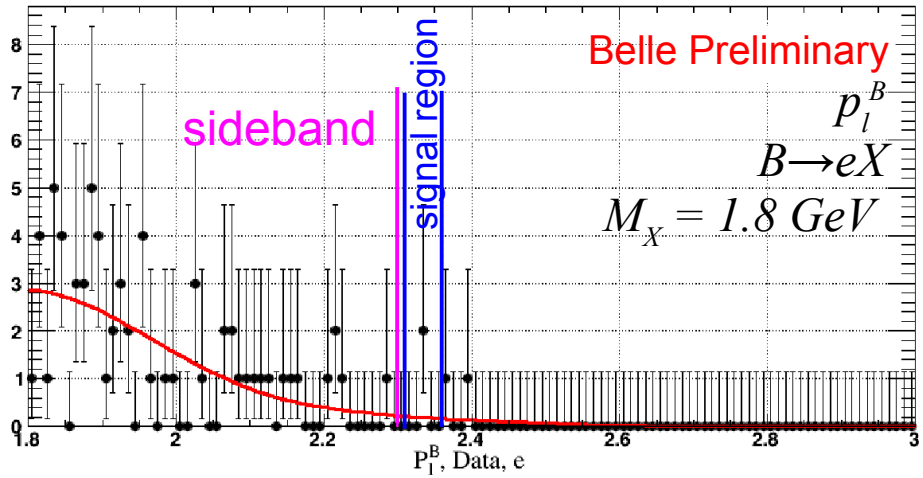
similar systematics

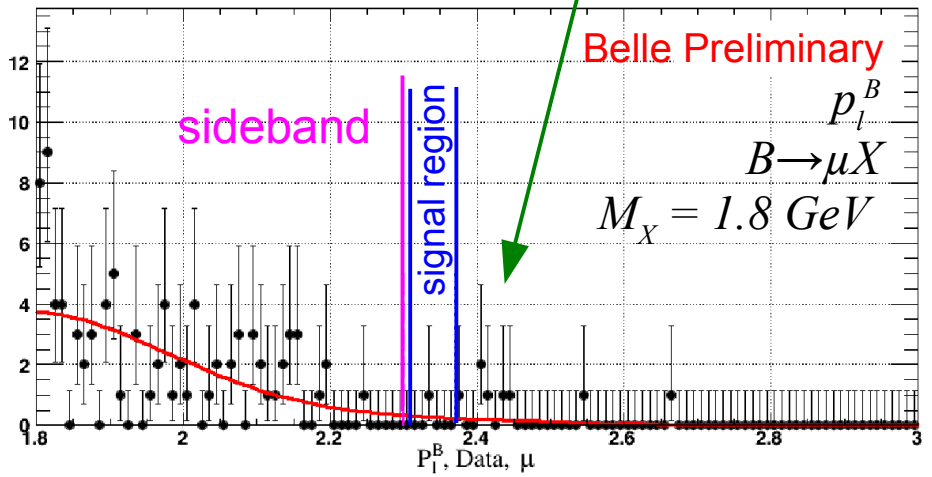
Signal region optimised to
lowest expected upper limit

B→IX^0: Result

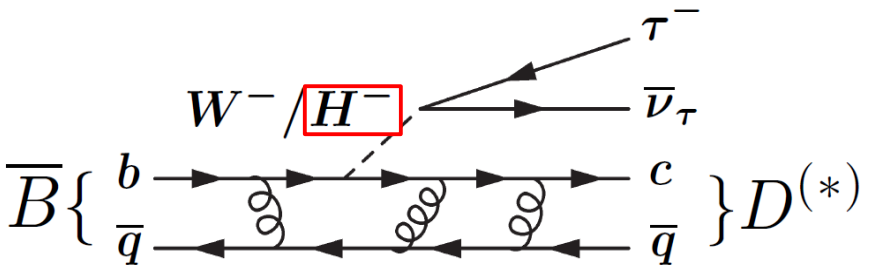

U.L. @ 90% CL
Expected BG
Belle Preliminary
$B \to eX$
U.L. (10^{-6})
Events
Mass of X (GeV/c^2)


U.L. @ 90% CL
Expected BG
Belle Preliminary
$B \to \mu X$
several events in signal region
U.L. (10^{-6})
Events
Mass of X (GeV/c^2)


sideband
signal region
Belle Preliminary
p_l^B
$B \to eX$
$M_X = 1.8$ GeV
P_l^B, Data, e


sideband
signal region
Belle Preliminary
p_l^B
$B \to \mu X$
$M_X = 1.8$ GeV
P_l^B, Data, μ

B → D(*)τν: Measurements



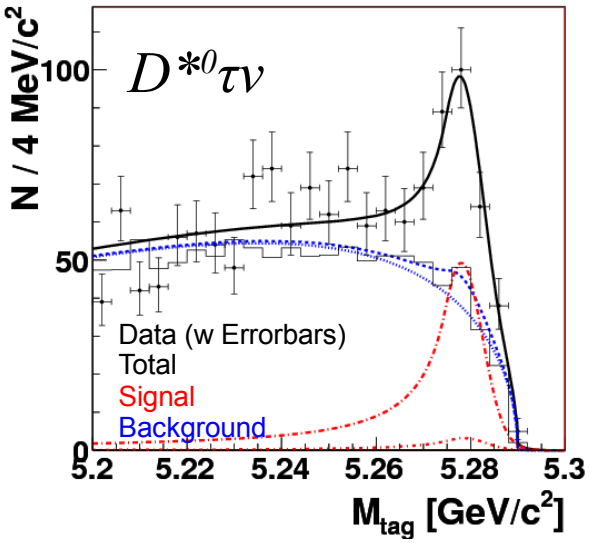
NP charged current might affect $B \to D^{(*)}\tau\nu$ too

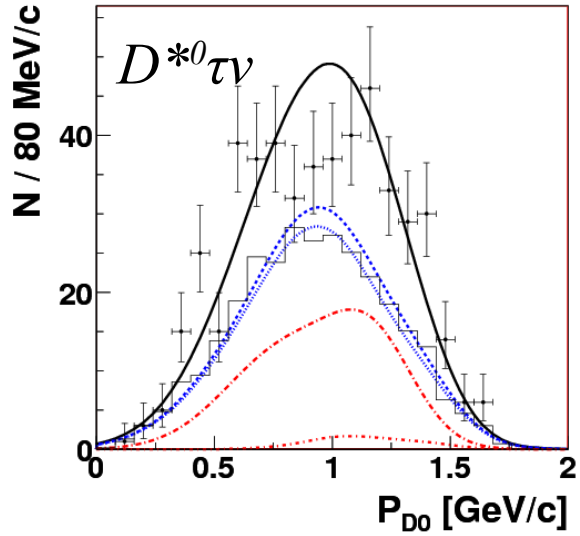
Tagging	Measurement	Data sample
inclusive	$B^0 \to D^{*-}\tau\nu$	69% of full data
PRL 99, 191807 (2007)		
inclusive	$B^\pm \to D^{(*)0}\tau\nu$	85% of full data
PRD 82, 072005(R) (2010)		
hadronic	$B \to D^{(*)}\tau\nu$	85% of full data
arXiv:0910.4301		

publication using full data sample underway

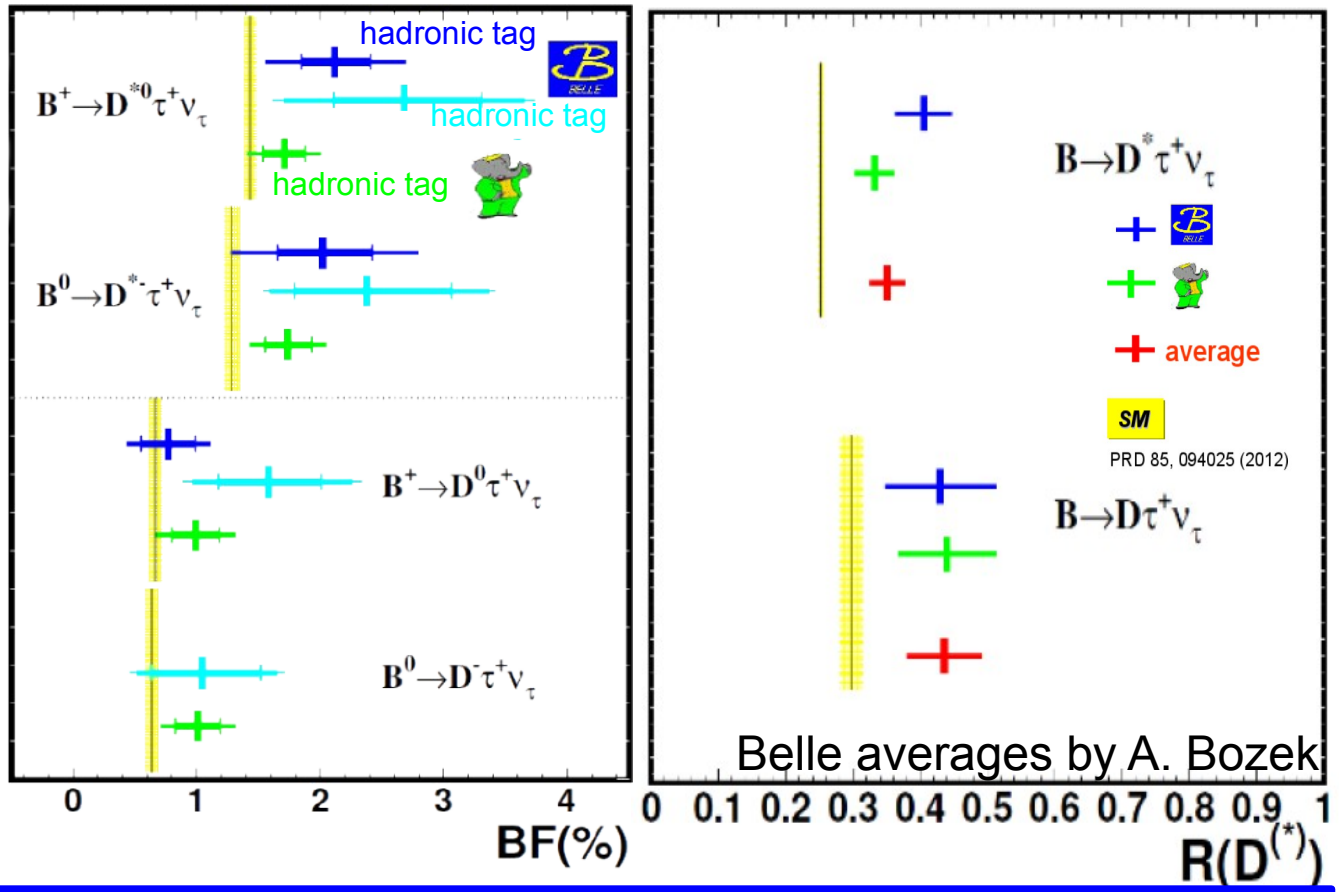
also using new hadronic tag method
2D ML fit in M^2_{miss} & neural Network output

signal extracted in M_{tag} and p^D





$B \to D^{(*)}\tau\nu$



Belle averages by A. Bozek

Look at ratios

→ V_{cb} and some QCD corrections cancel

$$\mathcal{R}(D) = \frac{\mathcal{B}(\overline{B} \to D\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D\ell^-\overline{\nu}_\ell)} \qquad \mathcal{R}(D^*) = \frac{\mathcal{B}(\overline{B} \to D^*\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^*\ell^-\overline{\nu}_\ell)}$$

individual measurements consistent with SM

averages show tension

Belle average

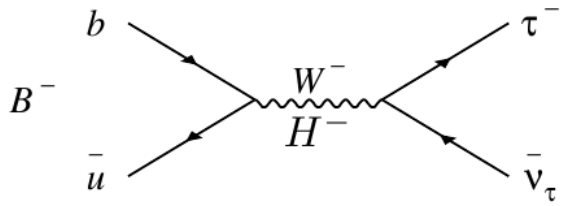
$R(D)$	1.4σ
$R(D^*)$	3.0σ
$R(D^{(*)})$	3.3σ

Belle & BaBar average

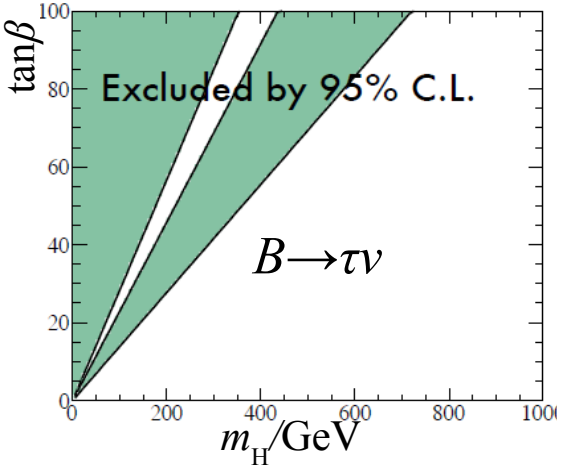
$R(D)$	2.4σ
$R(D^*)$	3.8σ
$R(D^{(*)})$	4.8σ

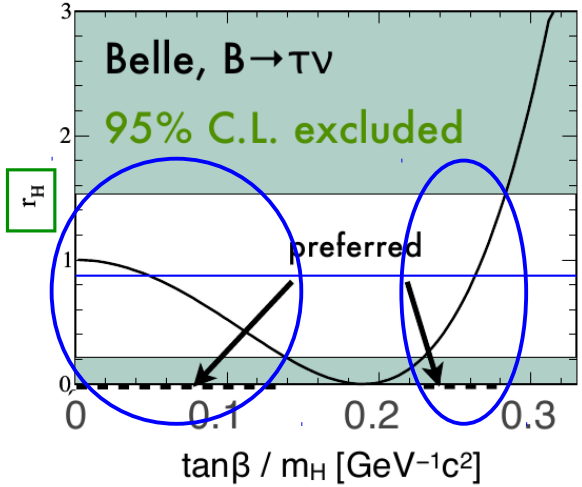
private averages by A. Bozek

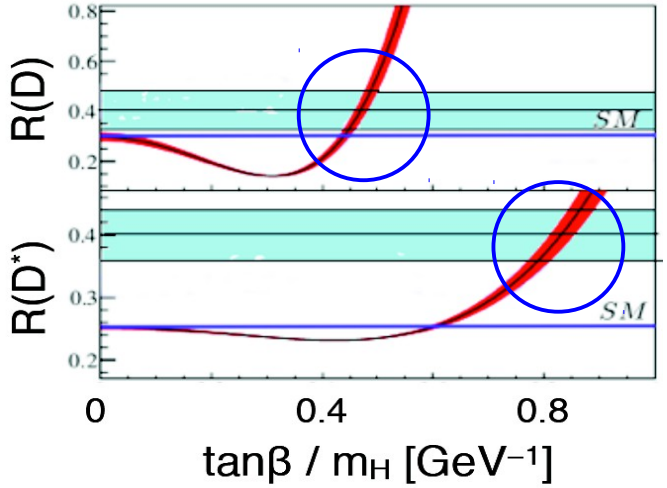
Constraints on 2HDM-Type II



$$r_H = \frac{\mathcal{B}(B \to \ell\nu)}{\mathcal{B}(B \to \ell\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_{H^\pm}^2}\tan^2\beta\right)^2$$







B→τν, *R(D)* and *R(D*)* favour different values of $\tan\beta/m_H$

→ Type II not favoured

using
f_B = 190±13MeV (HPQCD, PRD80, 014503)
$|V_{ub}|$ = (4.15 ± 0.49)x10^{-3} (PDG2012 [incl.+excl. b→ulv])
experimental dependence of *R(D)* and *R(D*)* on $\tan\beta/m_H$ not taken into account

Conclusions

Precise measurement of $\mathcal{B}(B \to \tau\nu)$

Decreases "tension" between WA and SM

$$\mathcal{B}(B \to \tau\nu) = \left(0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{sys})\right) \times 10^{-4}$$

Most stringent limits on $B \to l\nu$ with hadronic tag

$$\mathcal{B}(B \to e\nu) < 3.5 \times 10^{-6}$$

$$\mathcal{B}(B \to \mu\nu) < 2.5 \times 10^{-6}$$

@90% CL

Excess in $R(D)$ and $R(D^*)$

→ hints for New Phyics?

→ upcoming $B \to D^{(*)}\tau\nu$ analysis with full data set

New!

Performed search for $B \to lX$

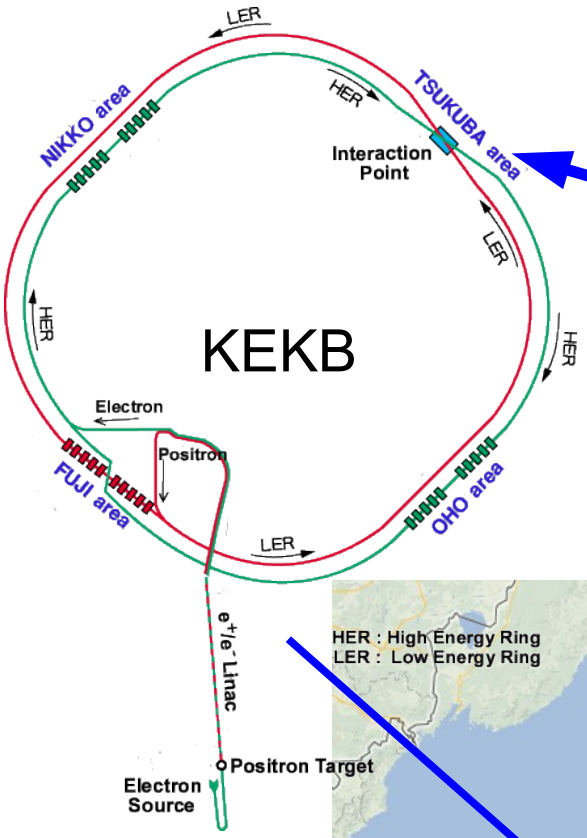
obtained upper limits in $0.1 < M_X < 1.8$ GeV

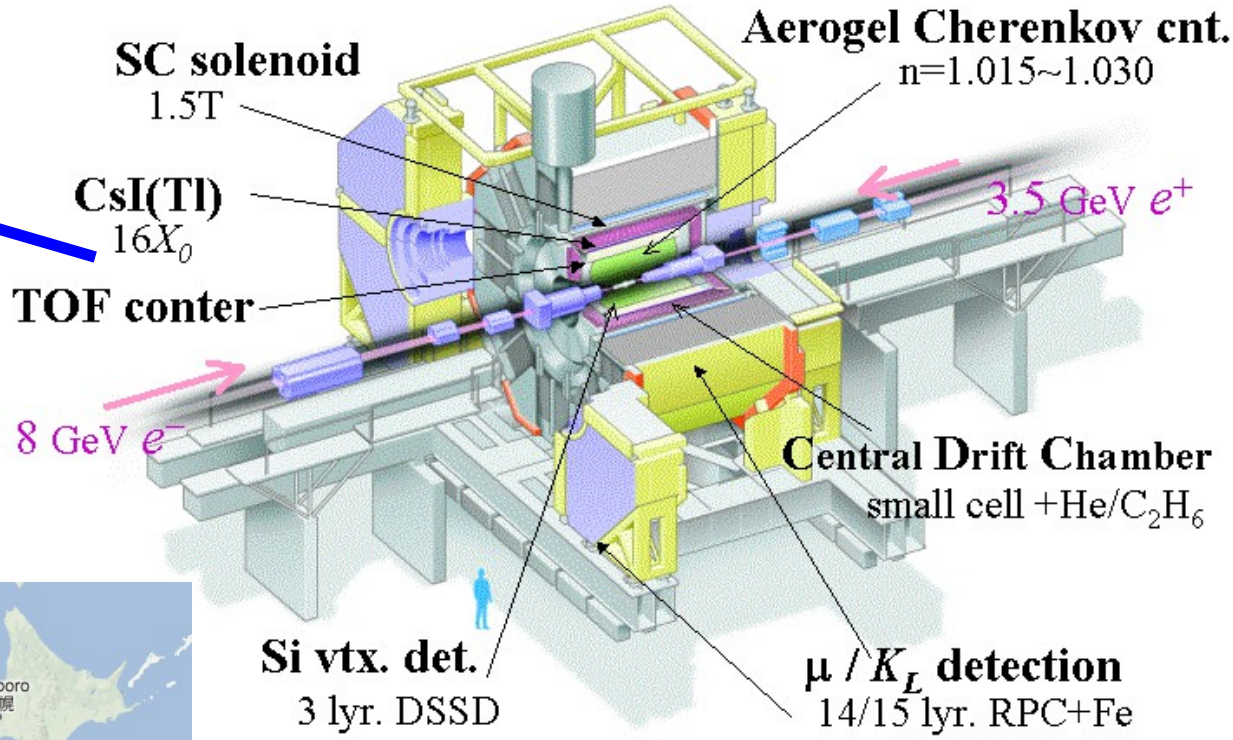
No hints for NP contribution from leptonic B decays

→ Belle II will answer the questions for NP much more precise
e.g. expecting discovery of $B \to \mu\nu$ with < $5 ab^{-1}$

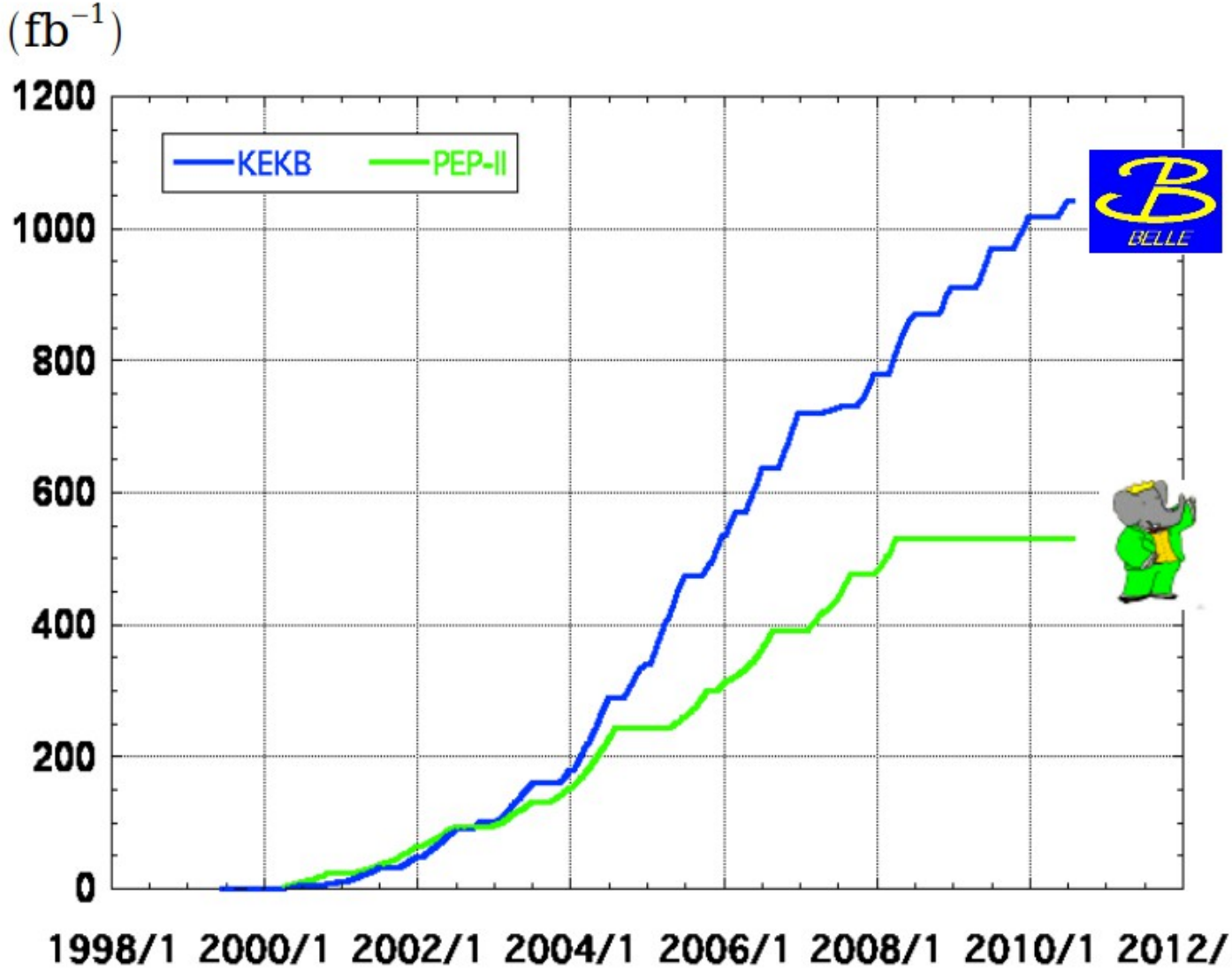
Backup

The Belle Experiment





Integrated luminosity of B factories



> 1 ab^{-1}

On resonance:

Υ(5S): 121 fb^{-1}

Υ(4S): 711 fb^{-1}

Υ(3S): 3 fb^{-1}

Υ(2S): 25 fb^{-1}

Υ(1S): 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

Υ(4S): 433 fb^{-1}

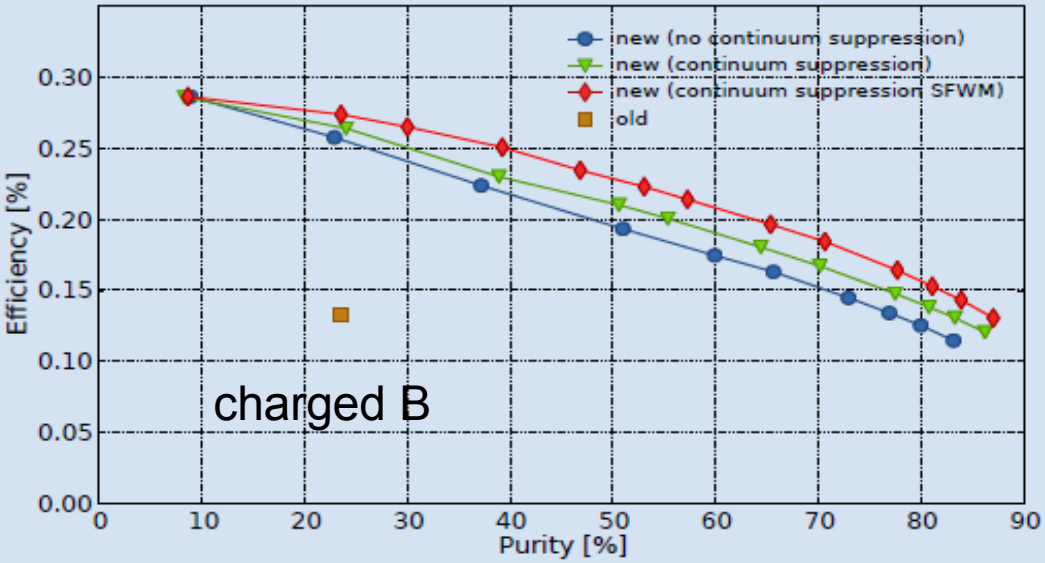
Υ(3S): 30 fb^{-1}

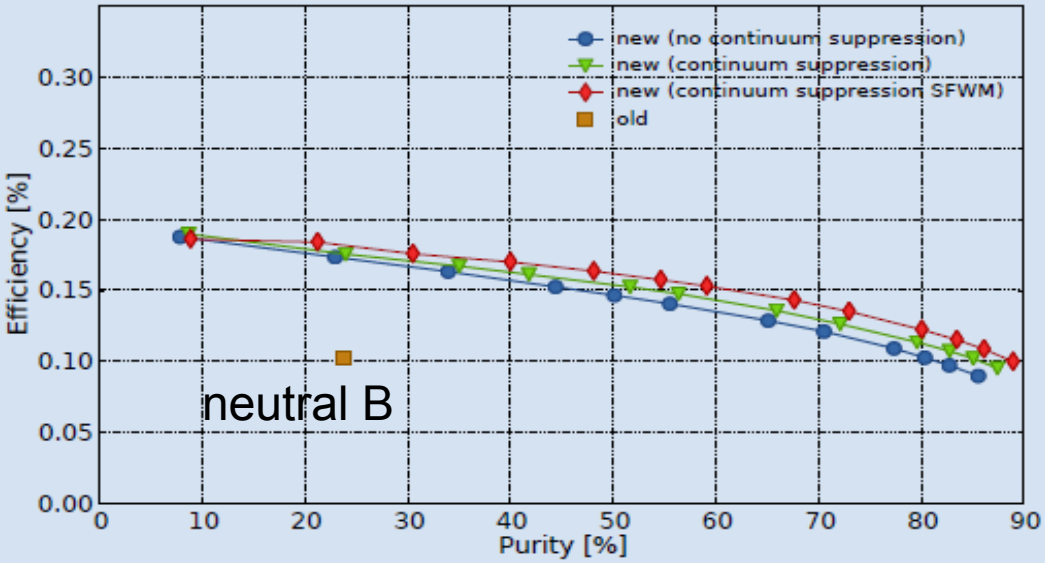
Υ(2S): 14 fb^{-1}

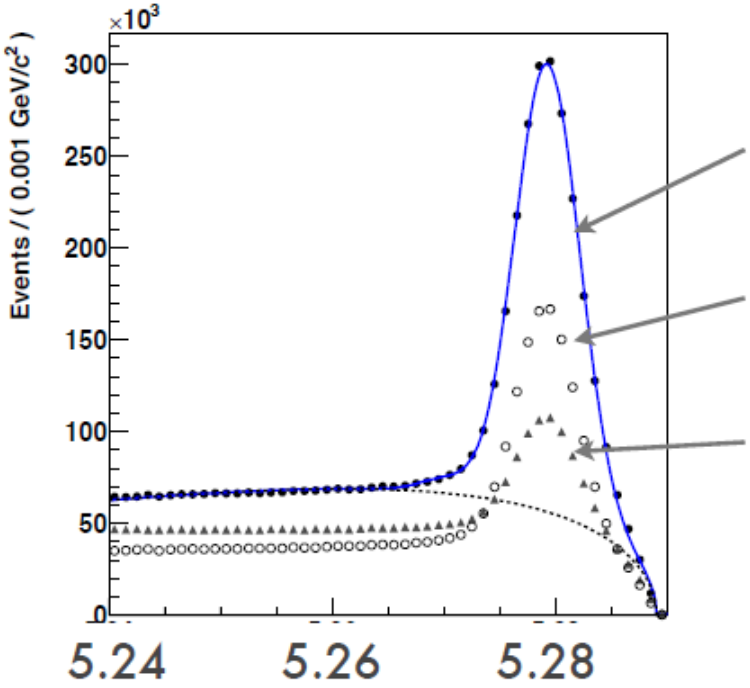
Off resonance:

~ 54 fb^{-1}

B tagging efficiency





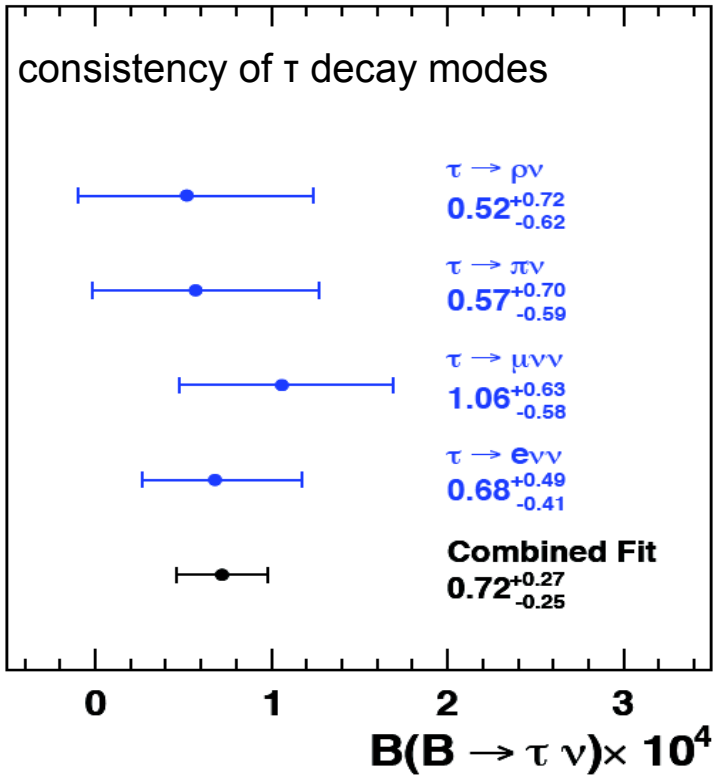


New tag on full data (reprocessed)

New tag on previous data

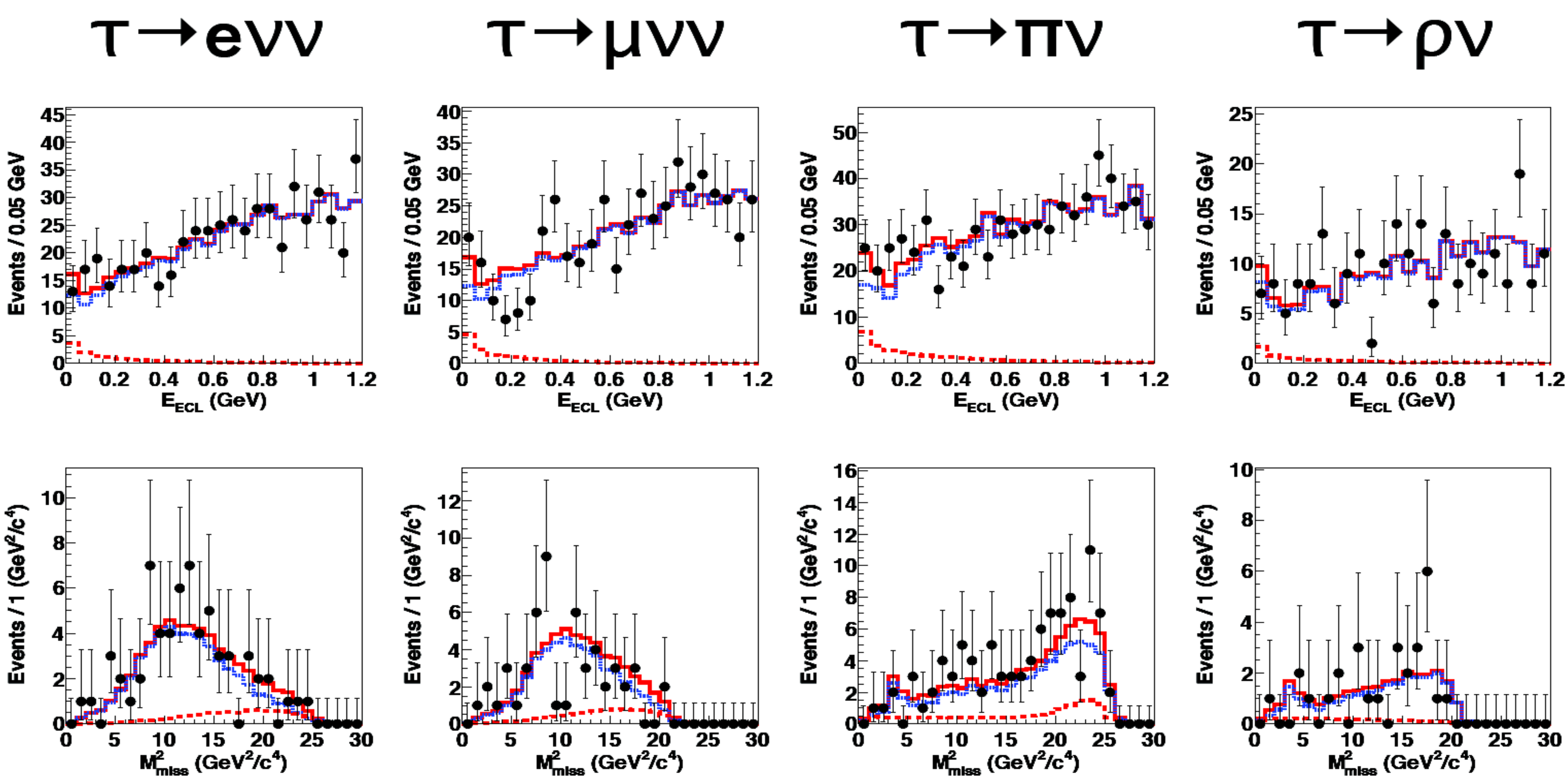
Classical tag on previous data

B→τν



Mode	Number of signal	Efficiency
$e^-\overline{\nu}_e\nu_\tau$	$15.5^{+11.2}_{-9.4}$	2.98×10^{-4}
$\mu^-\overline{\nu}_\mu\nu_\tau$	$25.6^{+15.1}_{-13.8}$	3.12×10^{-4}
$\pi^-\nu_\tau$	$7.8^{+9.5}_{-7.9}$	1.76×10^{-4}
$\rho^-\nu_\tau$	$13.6^{+18.7}_{-16.1}$	3.37×10^{-4}

$B \to \tau\nu$


τ→eνν
τ→μνν
τ→πν
τ→ρν
Events / 0.05 GeV
E_{ECL} (GeV)
Events / 1 (GeV²/c⁴)
M^2_{miss} (GeV²/c⁴)

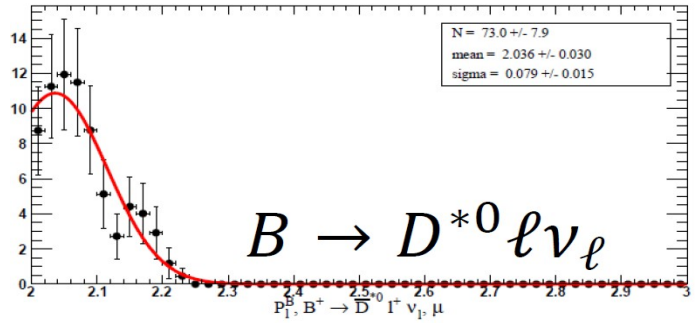
B→τν: Systematics

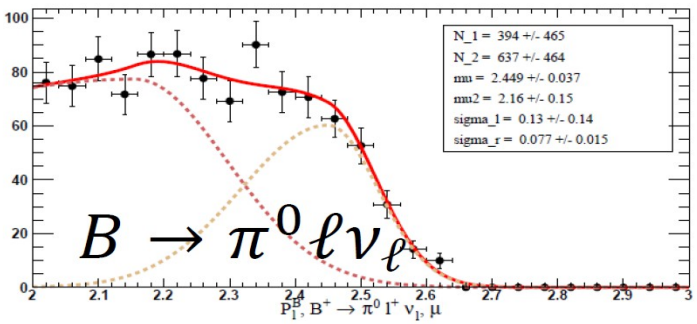
Source	$\mathcal{B}$ syst. error (%)
Signal PDF	4.2
Background PDF	8.8
Peaking background	3.8
B_{tag} efficiency	7.1
Particle identification	1.0
π^0 efficiency	0.5
Tracking efficiency	0.3
τ branching fraction	0.6
MC efficiency statistics	0.4
K_L^0 efficiency	7.3
$N_{B^+B^-}$	1.3
Total	14.7

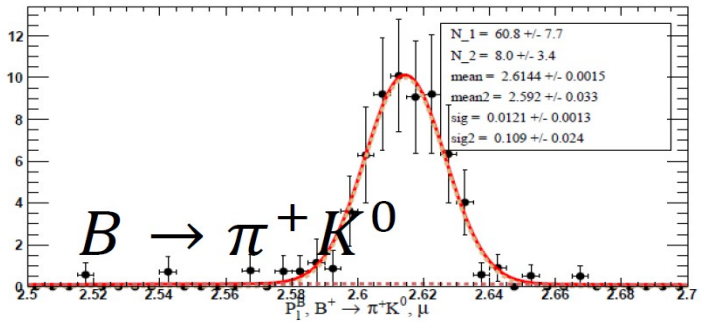
B→lv: Shapes

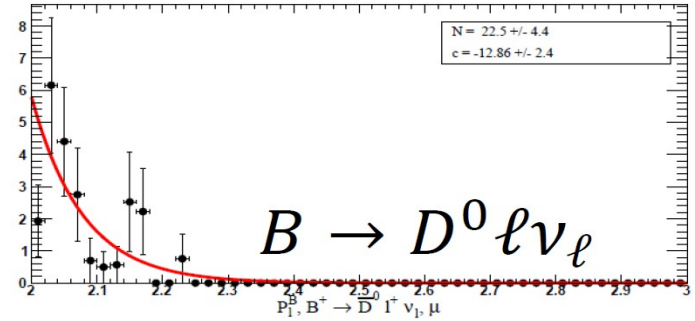
Background PDF shapes for B→μv

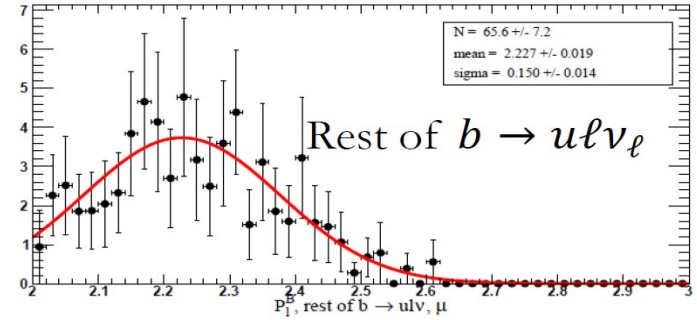
obtained by 1D unbinned max. likelihood fits.

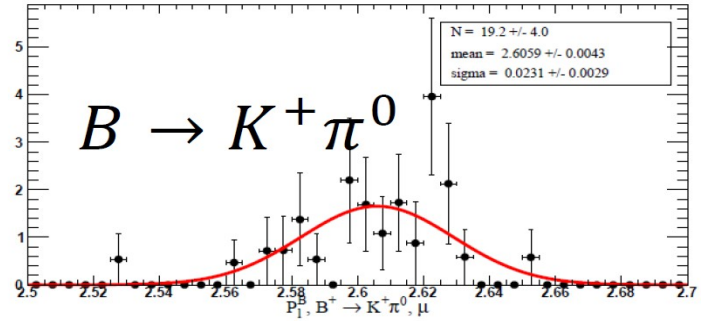


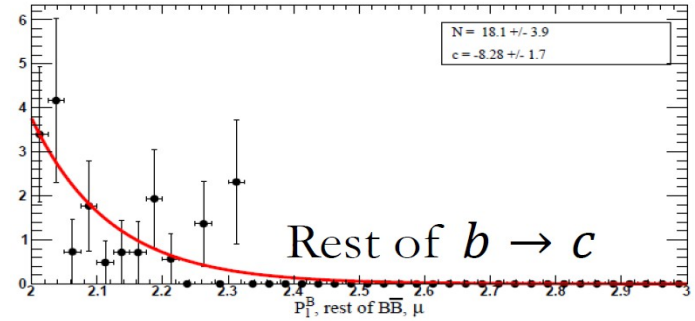


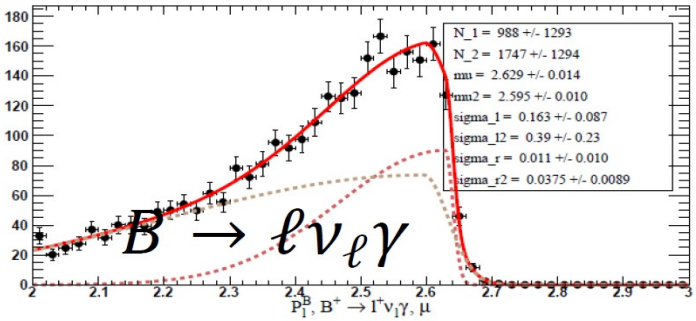


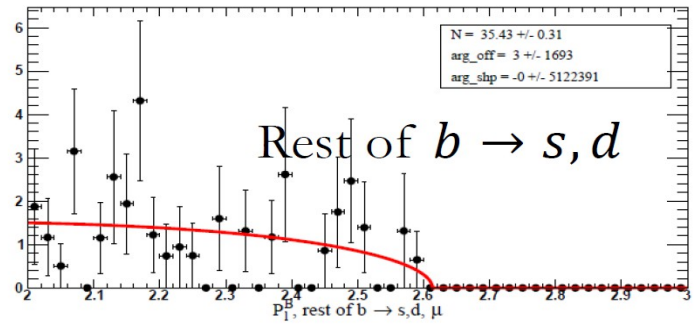










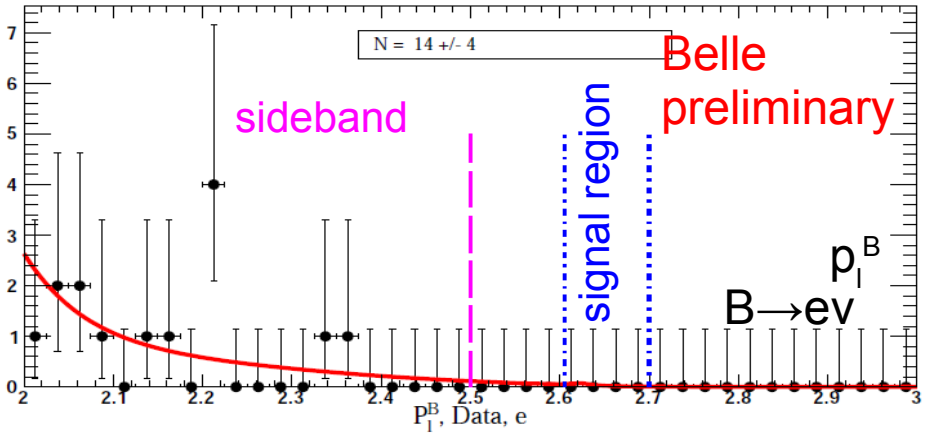


B→lν: Systematics

$$\mathcal{B}(B \to \ell\nu) = \frac{N_{\mathrm{Obs}} - N_{\mathrm{BG}}}{\epsilon_{\mathrm{Signal}} N_{B\overline{B}}}$$

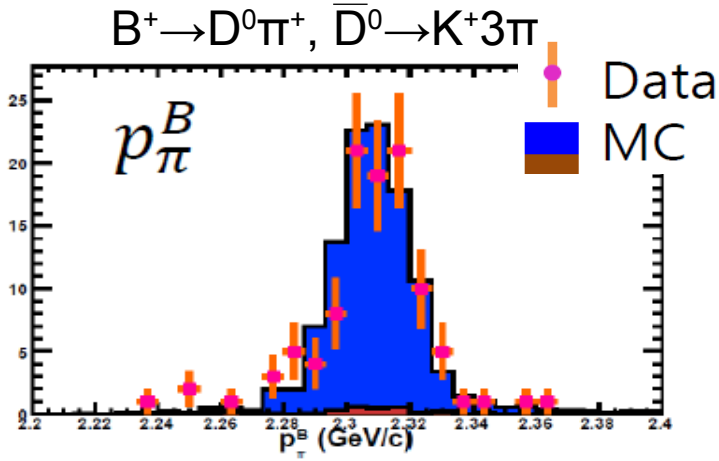
$$N_{BG} = N_{\text{Data (sideband)}} \frac{N^{MC}_{\text{BG (Signal region)}}}{N^{MC}_{\text{BG(Sideband)}}}$$

obtained from MC



Source		Electron Mode	Muon Mode
$N(B\bar{B})$		1.4%	1.4%
Tag efficiency correction		4.2%	4.2%
Signal Efficiency	LID	1.0%	1.0%
	Tracking	0.35%	0.35%
	MC statistics	1.6%	1.5%
	Event shape	11.3%	11.3%
TOTAL(Quadratic Sum)		12.3%	12.3%
$\epsilon_\ell(\%)$		0.092 ± 0.011	0.109 ± 0.013

estimation of plB shape uncertainty in B→Dπ decays



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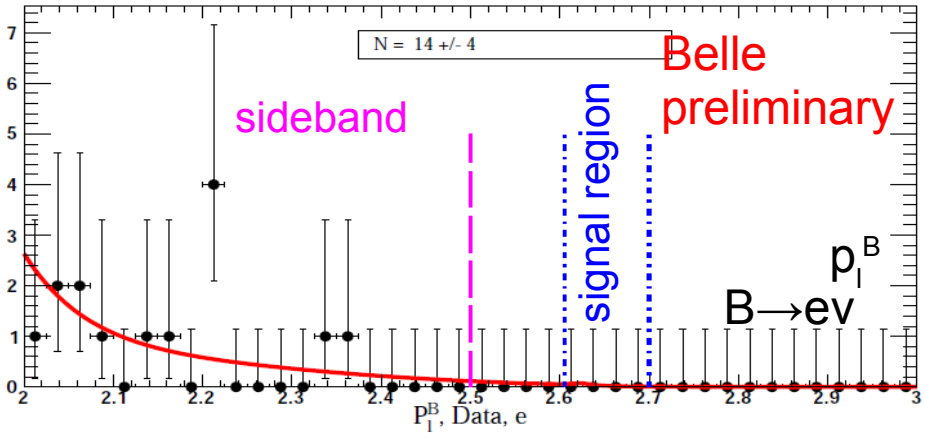

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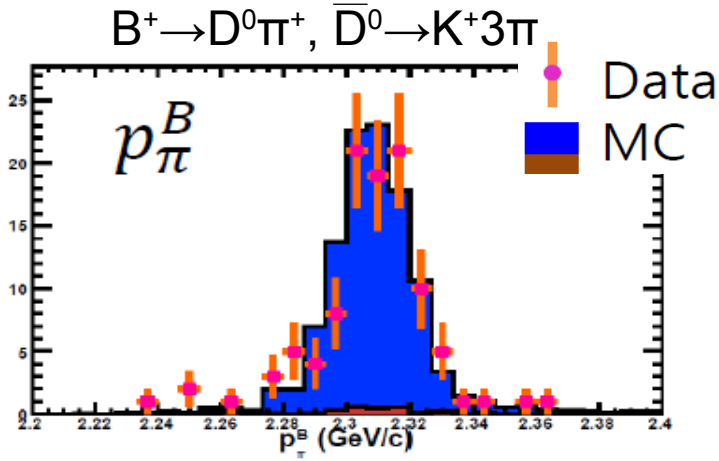
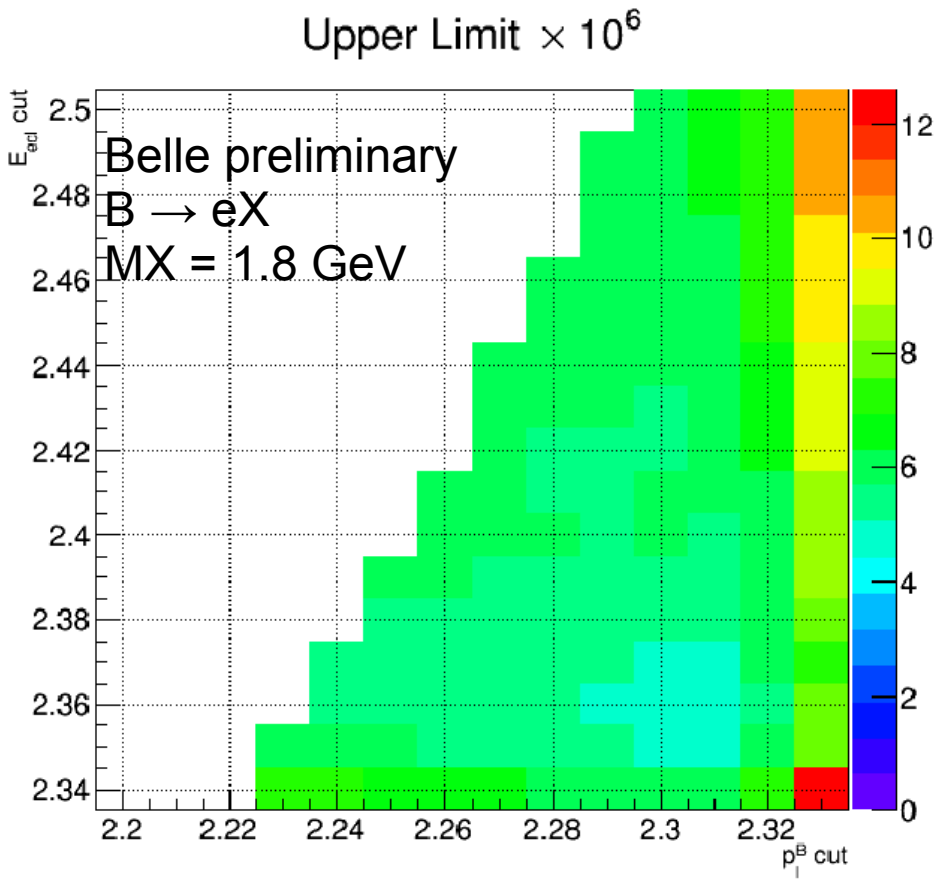
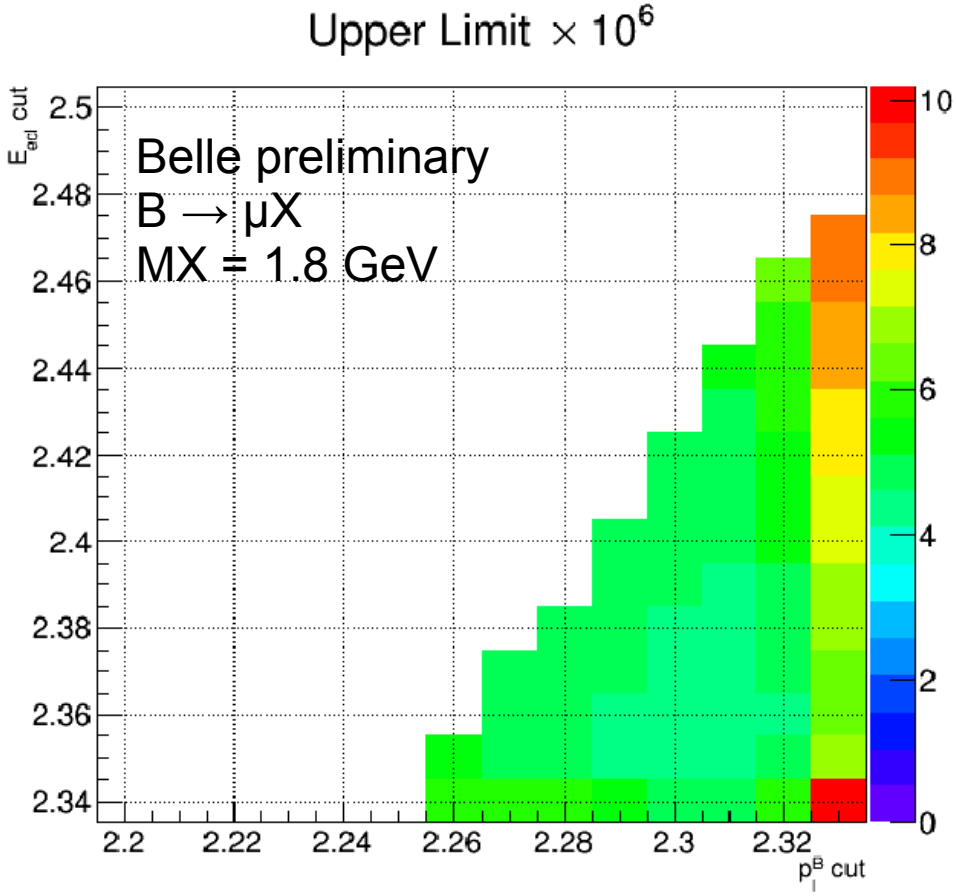


B → lX: Upper limit optimisation





B → Dτν

Tagging	Measurement	Data sample
inclusive	$B^0 \to D^{*-}\tau\nu$	535x10^6 $N_{B\bar{B}}$ PRL 99, 191807 (2007)
inclusive	$B^{\pm} \to D^{(*)0}\tau\nu$	657x10^6 $N_{B\bar{B}}$ PRD 82, 072005(R) (2010)
hadronic	$B \to D^{(*)}\tau\nu$	657x10^6 $N_{B\bar{B}}$ arXiv:0910.4301

Belle II timeline