Search for $B^+ \rightarrow l^+ X$ with hadronic tagging method at Belle Experiment

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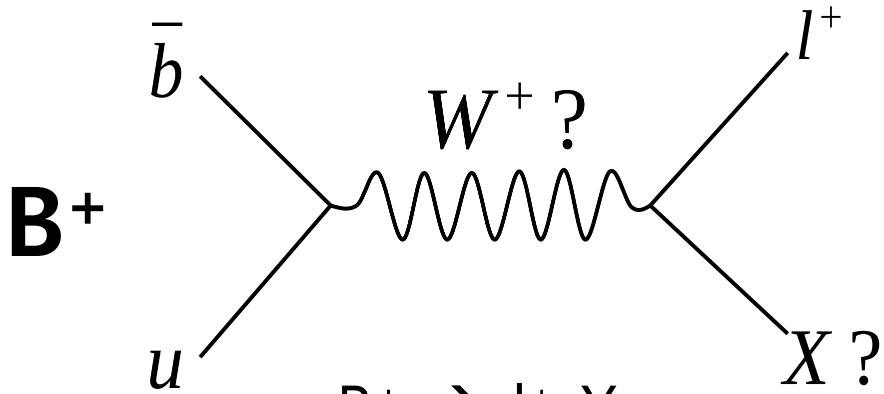
Contents

Motivation



$B^+ \rightarrow l^+ X$

- X : invisible, neutral, massive, spin 1/2 particle
- We search for X in the mass range of 0.1 - 1.8 GeV/c^2
- World first try-out

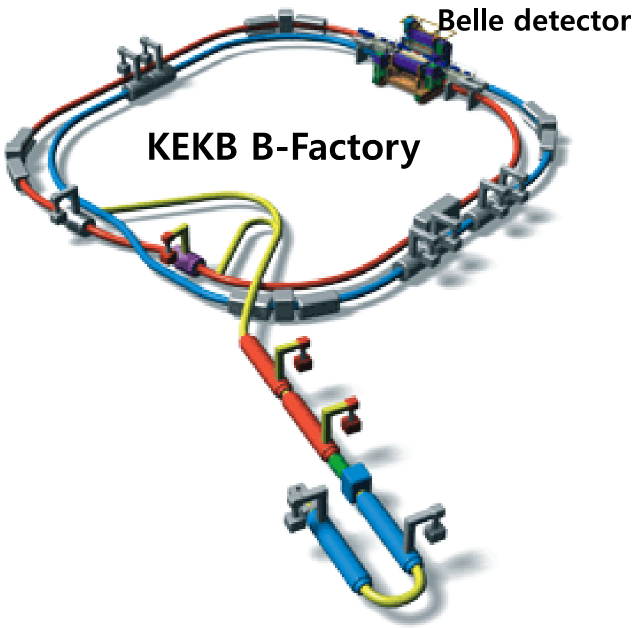
Belle and KEKB

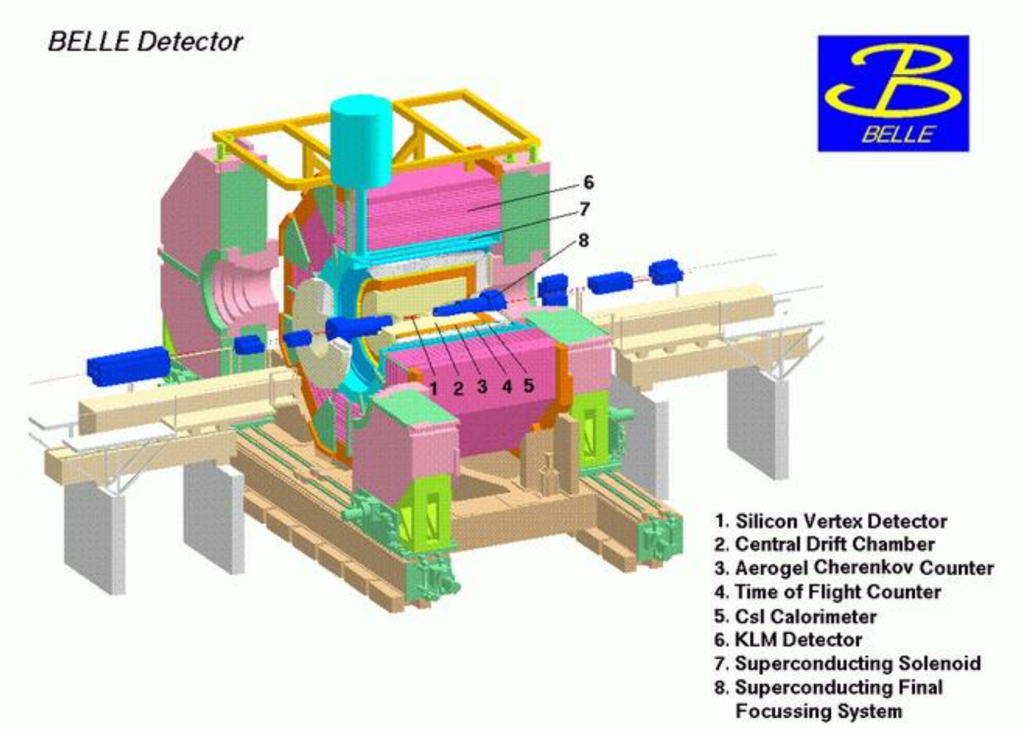
Data collected with Belle detector at KEKB asymmetric e^+e^- collider

Total of 711 fb^{-1} of data collected at $\Upsilon(4S)$

→ 772M BB pairs

e^+ : 3.5 GeV
e^- : 8.0 GeV





Belle and KEKB

Data collected with Belle detector at KEKB asymmetric e^+e^- collider

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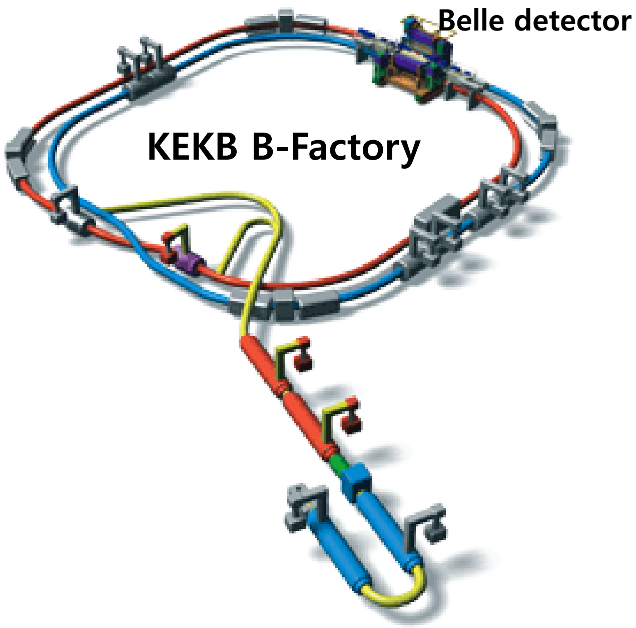
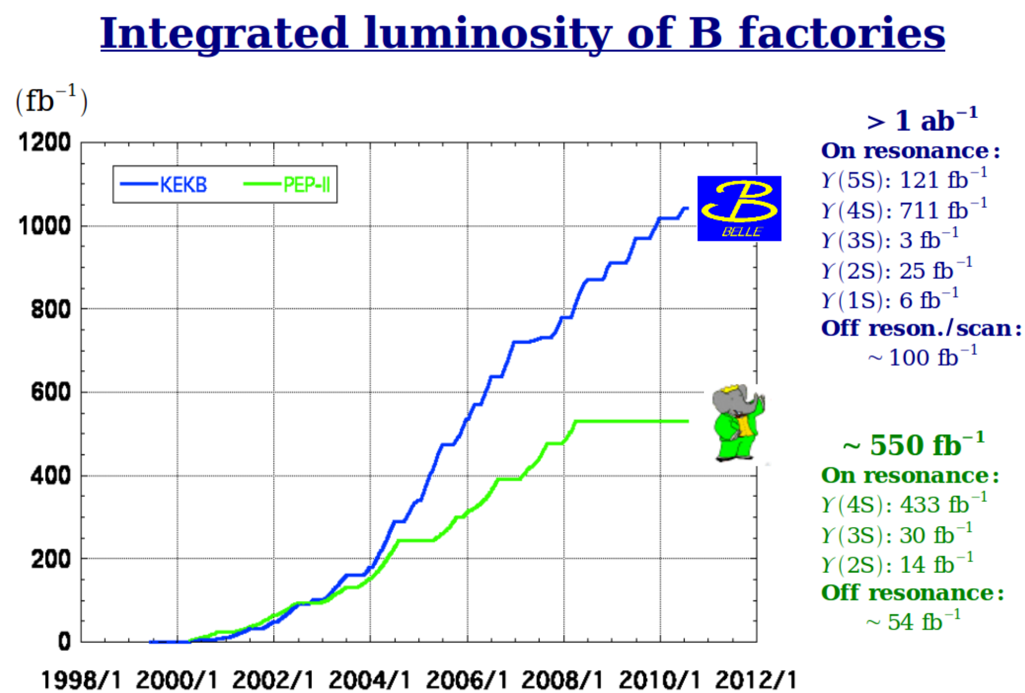
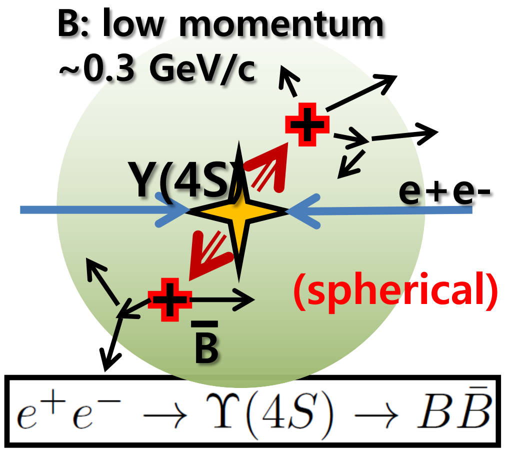


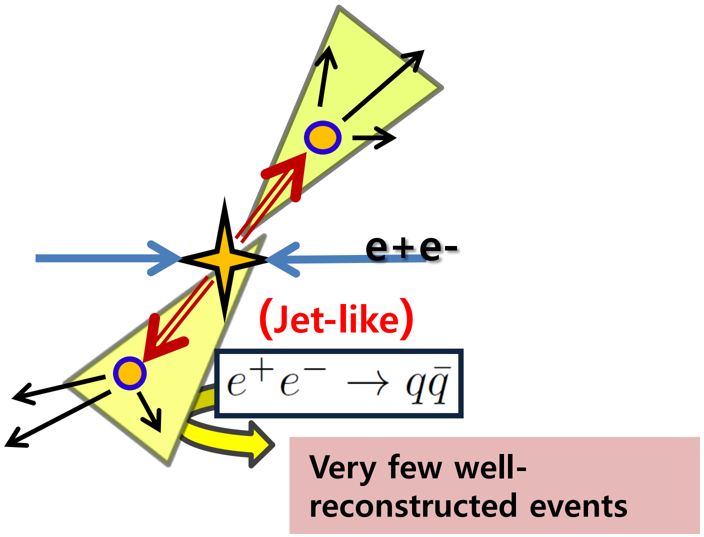


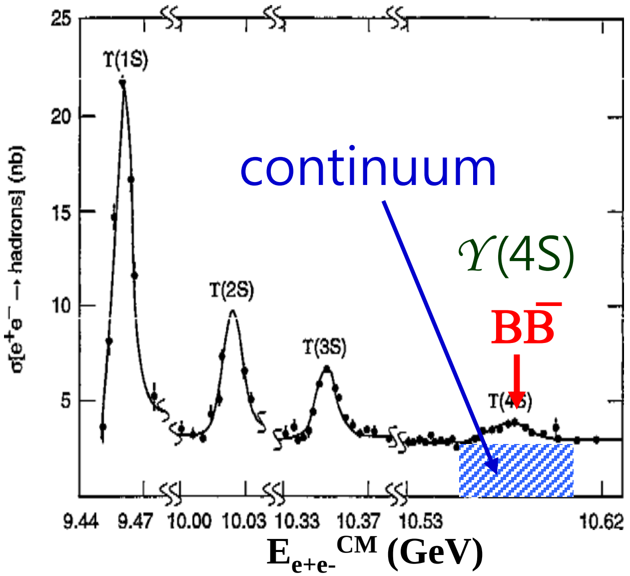
Hadronic tagging method



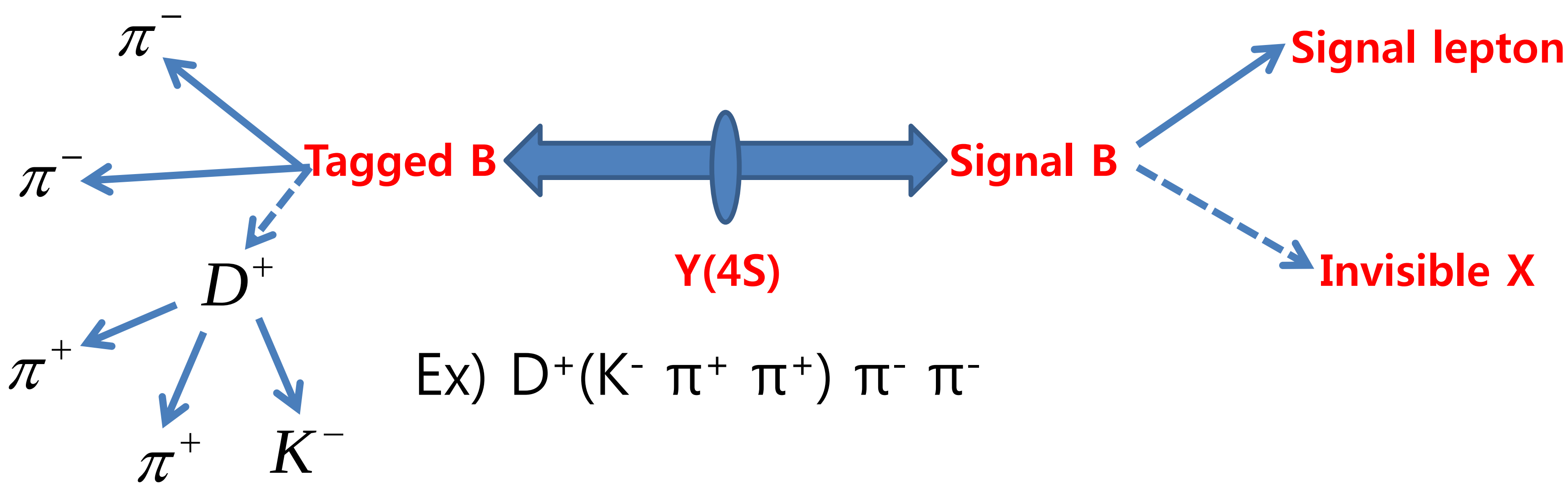
- e+e- collision at Y(4S) energy → ¾ are continuum backgrounds
- By requiring completely reconstructed B meson at one side

→ **Continuum suppression**





Hadronic tagging method



Ex) $D^+(K^- \pi^+ \pi^+) \pi^- \pi^-$

>96% of Y(4S) → BB with nothing else produced

one B-meson is completely reconstructed from known b → c decays without ν

efficiency is low, but purity is high

Good way to reconstruct modes with invisible particle

Sample used for analysis

Data ; 711fb^{-1} at Y(4S) resonance → 772 Millions of B meson pairs

Signal MC

mode	Mass of X	Amount
$B^+ \rightarrow e^+ X$	0.1, 0.2, … 1.8 GeV	2,000,000 events for each mass of X
$B^+ \rightarrow \mu^+ X$	0.1, 0.2, … 1.8 GeV	2,000,000 events for each mass of X

Background MC

Mode	Process	Amount
Generic MC	BB, qq	5 streams
RareB	b → s, d, leptonic	50 streams
Ulnu	$B \rightarrow X_u l\nu$	20 streams
$e\nu\gamma$	$B^+ \rightarrow e\nu\gamma$	1000 streams
$\mu\nu\gamma$	$B^+ \rightarrow \mu\nu\gamma$	1000 streams
π^+K^0	$B^+ \rightarrow \pi^+K^0$	500 streams
$\pi^0 e\nu$	$B^+ \rightarrow \pi^0 e\nu$	300 streams
$\pi^0 \mu\nu$	$B^+ \rightarrow \pi^0 \mu\nu$	300 streams

Separately generated! (the last five modes, $e\nu\gamma$ to $\pi^0 \mu\nu$)

Event selection

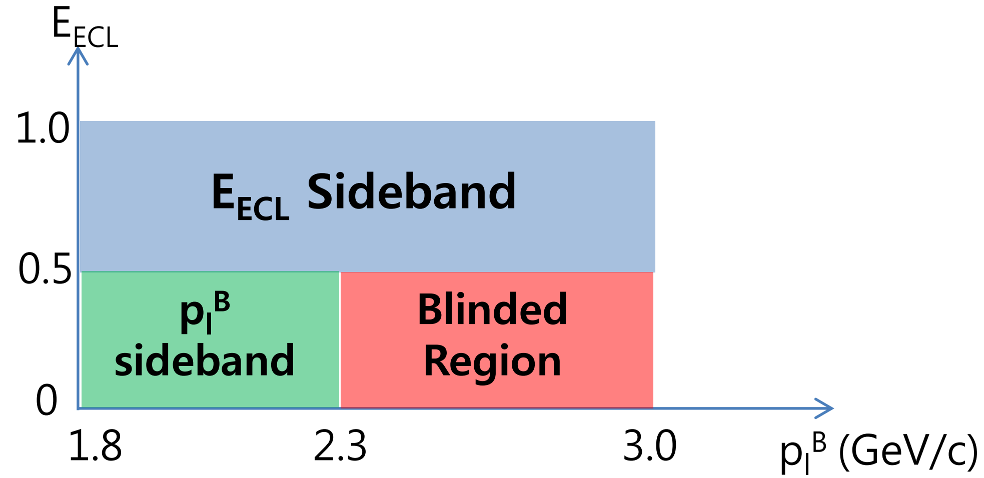
Particle Identity	Track quality	Continuum suppression
$L_e > 0.9$	$\|Dz\| < 2$ cm	$\|\cos\theta_{thrust}\| < 0.9$ for $B^+ \to e^+ X$
$L_\mu > 0.9$	$Dr < 0.5$ cm	$\|\cos\theta_{thrust}\| < 0.8$ for $B^+ \to \mu^+ X$

Quality of tagged-B meson

$|\Delta E| < 0.05$ GeV

$M_{bc} > 5.27$ GeV/c^2

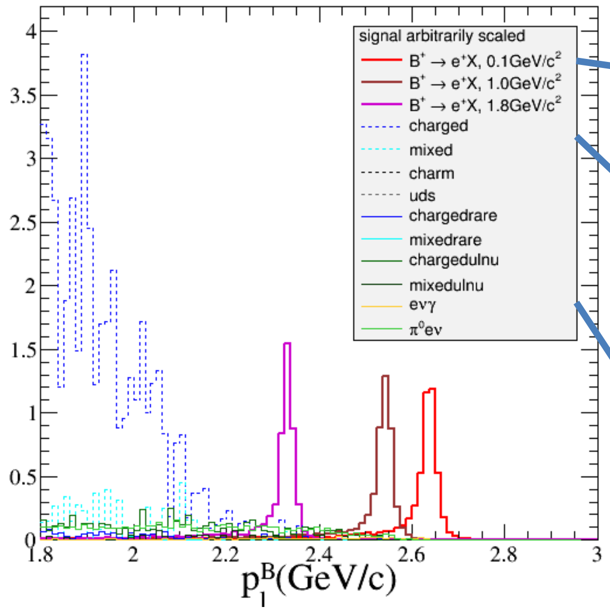
$O_{NB} > e^{-6}$



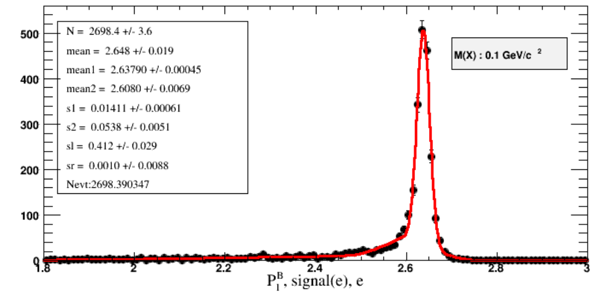
E_{ECL} : Remaining energy of ECL calorimeter (tagged-B & signal lepton)

p_l^B : signal lepton's momentum in the signal B rest frame

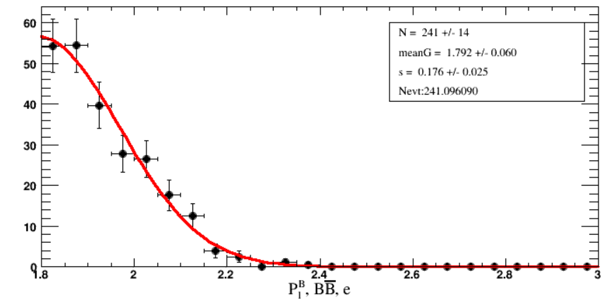
Event selection



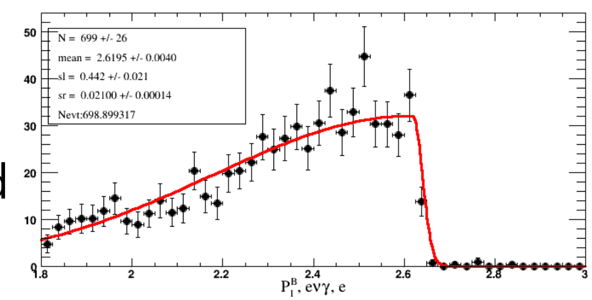
Fitting Signal



Fitting Background



Fitting Peaking Background

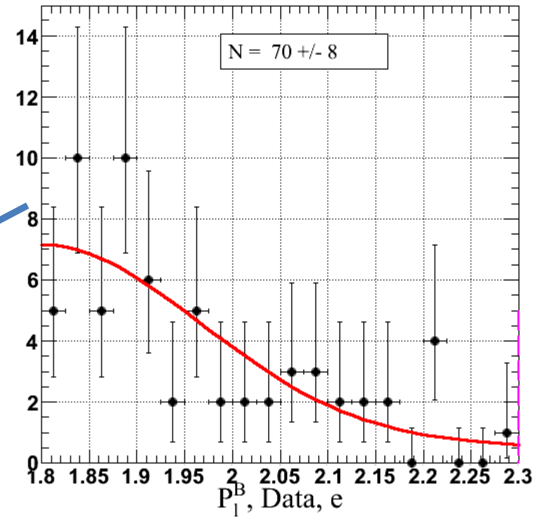


p_l^B peak changes by mass of X

→ p_l^B cut should be optimized for each mass of X

Optimization (obtaining Yield)

$$U.L. = \frac{U.L.(Yield)}{\epsilon_{signal} N(B\overline{B})}$$



BG : Fit p_l^B sideband extrapolate PDF

$$BG_{est} = Data_{side} \times \frac{S(MC)_{sig}}{S(MC)_{side}}$$

1. Relative uncertainty of ε_{sig}
2. Estimated BG and uncertainty
3. # of observed events

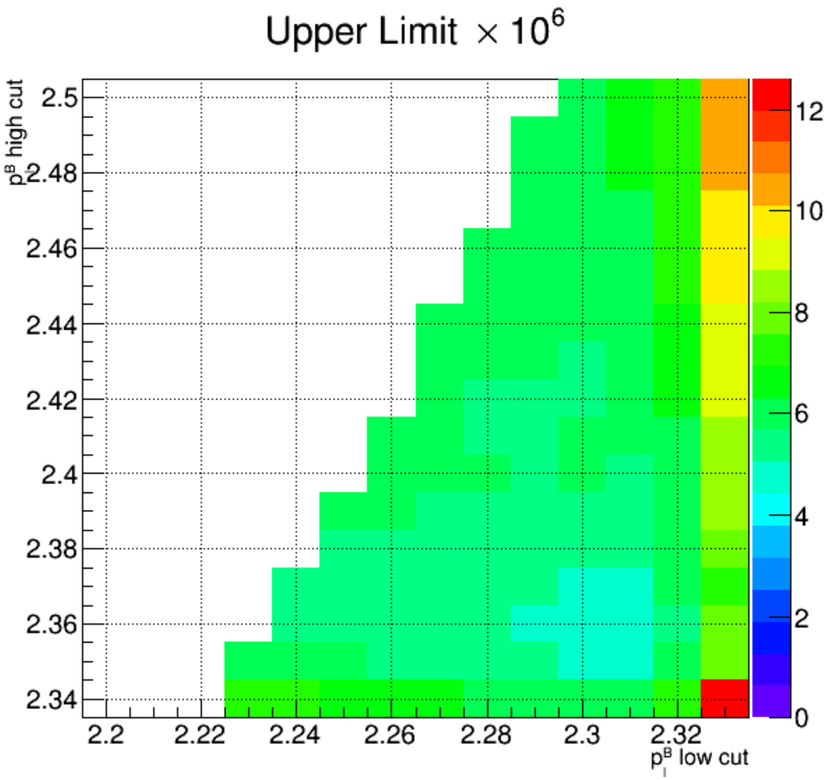
Feldman-Cousins method

POLE → U.L.

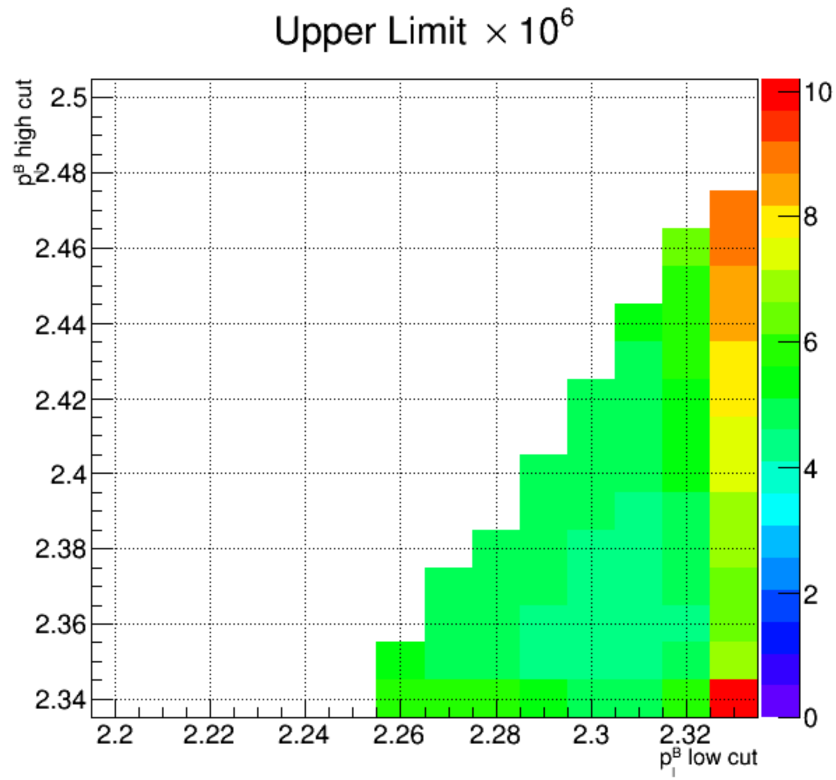
Uncertainty from PDG(BF), PDF, systematic, etc……

Optimization

Mean of upper limit of branching fraction based on MC for each p_l^B creteria



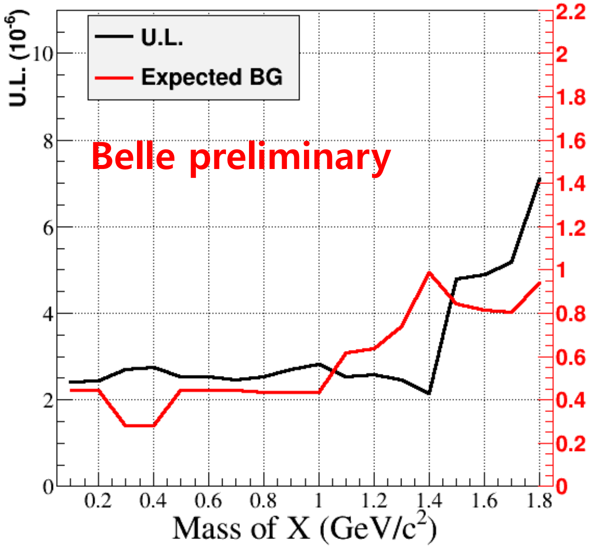
$B^+ \rightarrow e^+ X$
M(X) : 1.8 GeV/c²



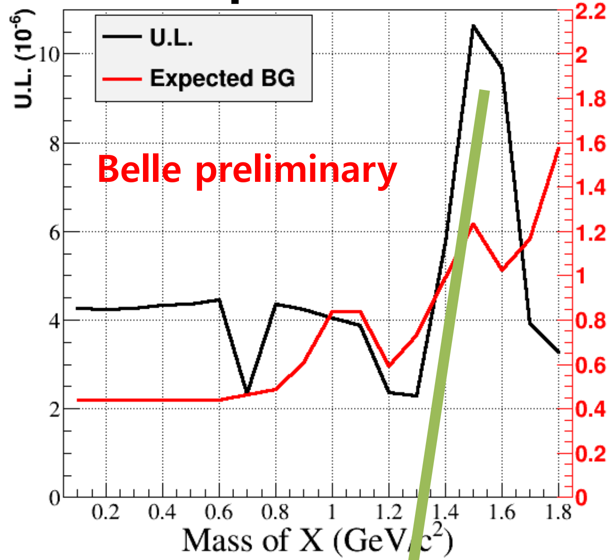
$B^+ \rightarrow \mu^+ X$
M(X) : 1.8 GeV/c²

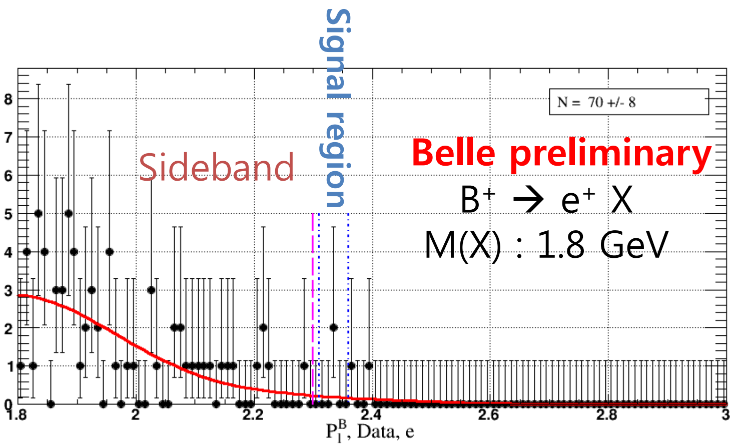
Preliminary result

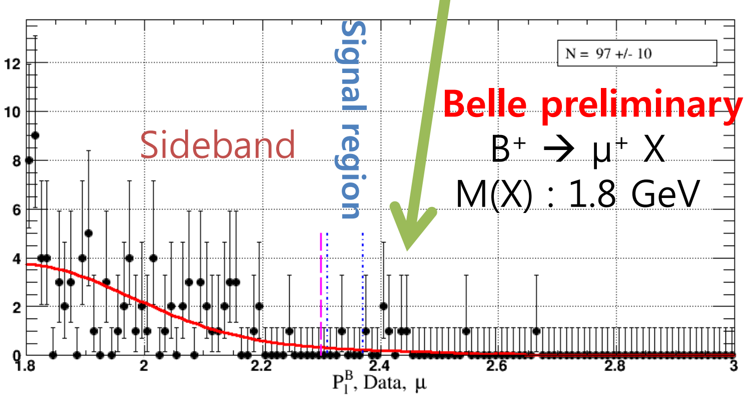
e mode



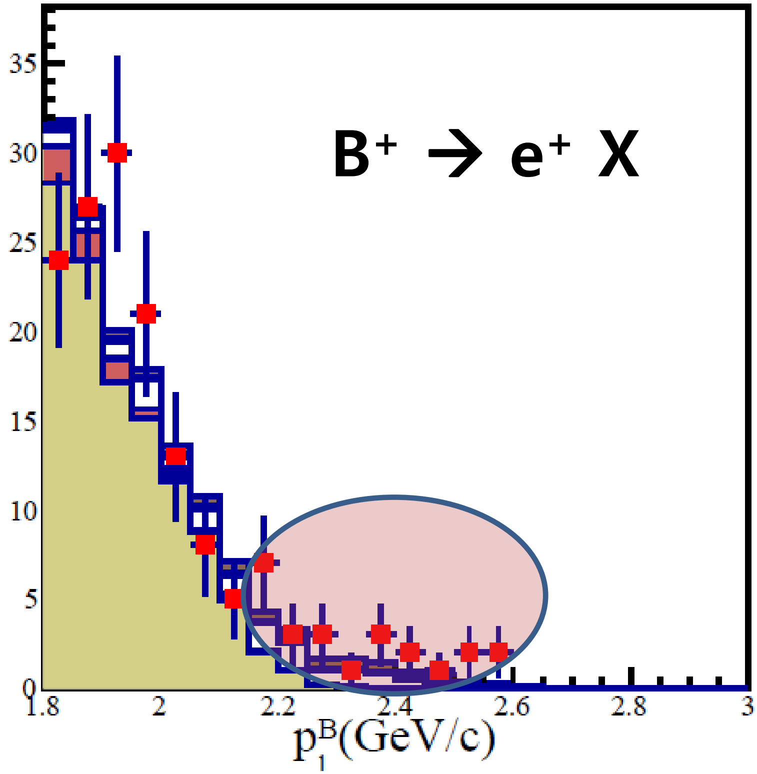
μ mode

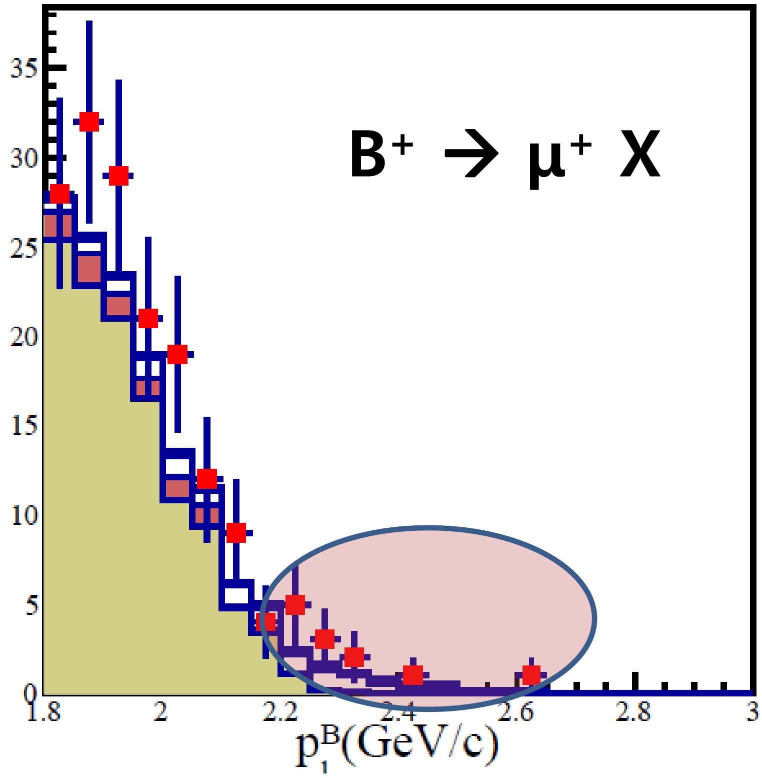






Calibration in E_{ECL} sideband

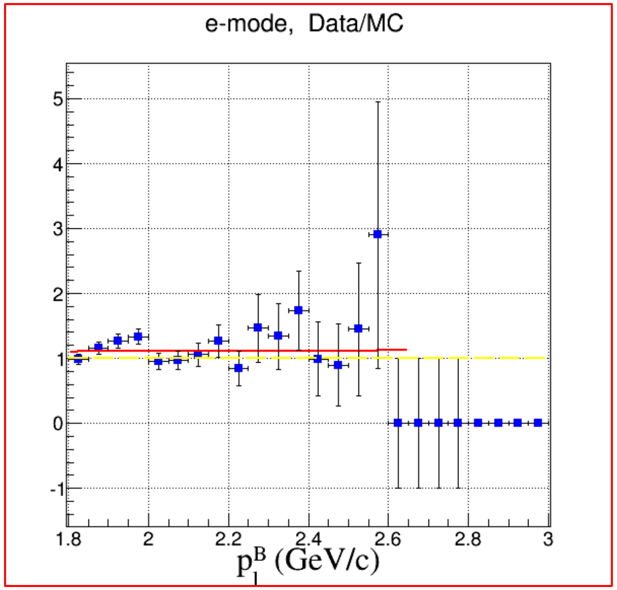




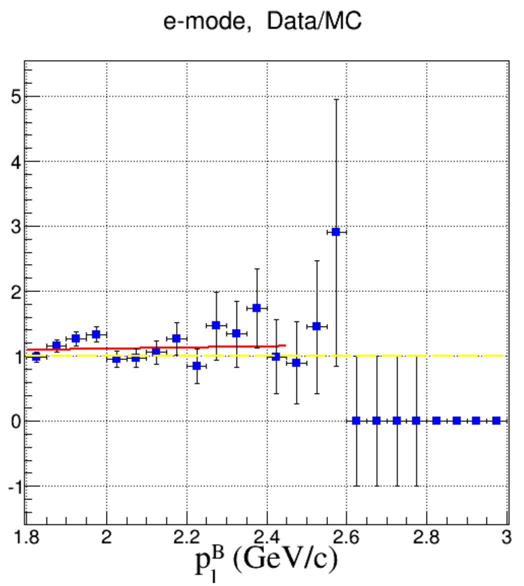
There are some disagreement between Data and MC, about $p_l^B > 2.2$ GeV/c for E_{ECL} sideband region($0.5 < E_{ECL} < 1.0$ GeV).

→ Get Calibration Factor !!

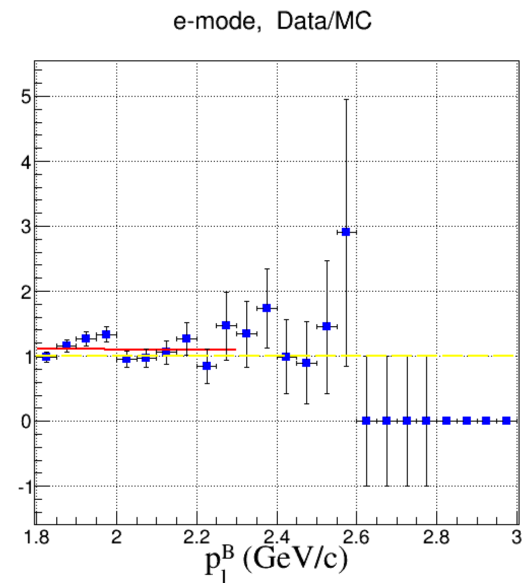
Calibration in E_{ECL} sideband



$1.8 < p_l^B < 2.65$



$1.8 < p_l^B < 2.45$



$1.8 < p_l^B < 2.3$

E_{ECL} cut : $0.5 < E_{ECL} < 2.0$ GeV (Because we want more statistics)

Data/MC ratio is fitted to linear function

Ratio function : $R(p_l^B) = p_0 + p_1 \times (p_l^B - 1.8)$

when p_0 and p_1 is parameter

To fit well, we apply error to bins where no events (but MC exist)

Calibration in E_{ECL} sideband

Originally we use Data & MC ratio in p_l^B sideband region to scale expectation of BG

So we use this ratio fitting function to scale BG expectation.

Calibration factor R* is used for scaling.

We use ratio fitting function when fitting range $1.8 < p_l^B < 2.65$ GeV/c

Old :

$$BG_{est} = Data_{side} \times \frac{S(MC)_{sig}}{S(MC)_{side}}$$

New :

$$BG_{est} = R^* \times Data_{side} \times \frac{S(MC)_{sig}}{S(MC)_{side}}$$

Summary

* We search for $B^+ \rightarrow l^+ X$, where X can be any invisible (and possibly massive) spin-1/2 particle.

* We successfully suppressed background by help of hadronic tagging method.

* In preliminary results, the upper limits are $O(10^{-6})$

* Recently, estimated background is calibrated by difference between Data and MC in E_{ECL} sideband.

Thank you for listening!

BACK UP

Skim procedure

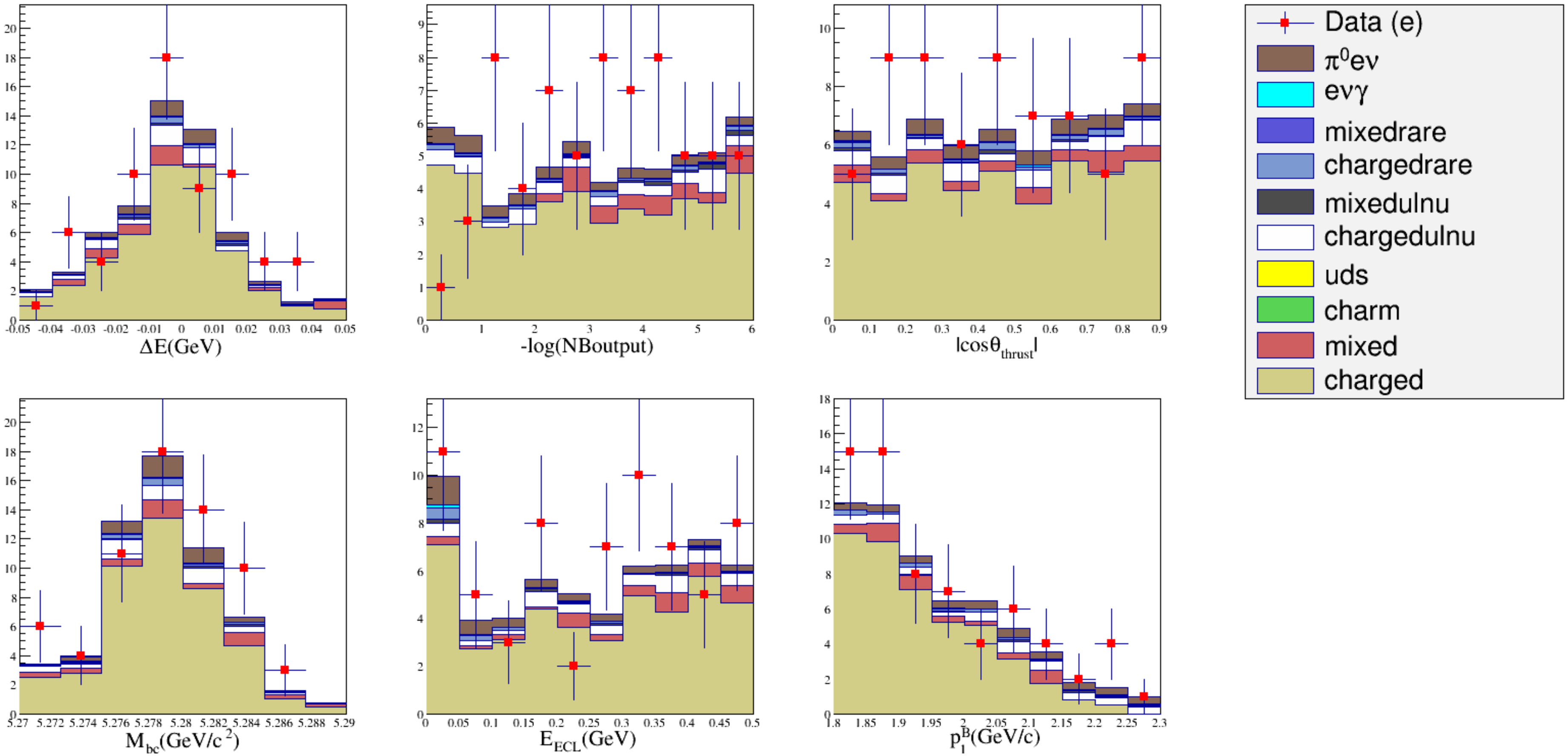
SKIM PATH

Hadronic Tagging → LX_SKIM → ANALYSIS_CODE

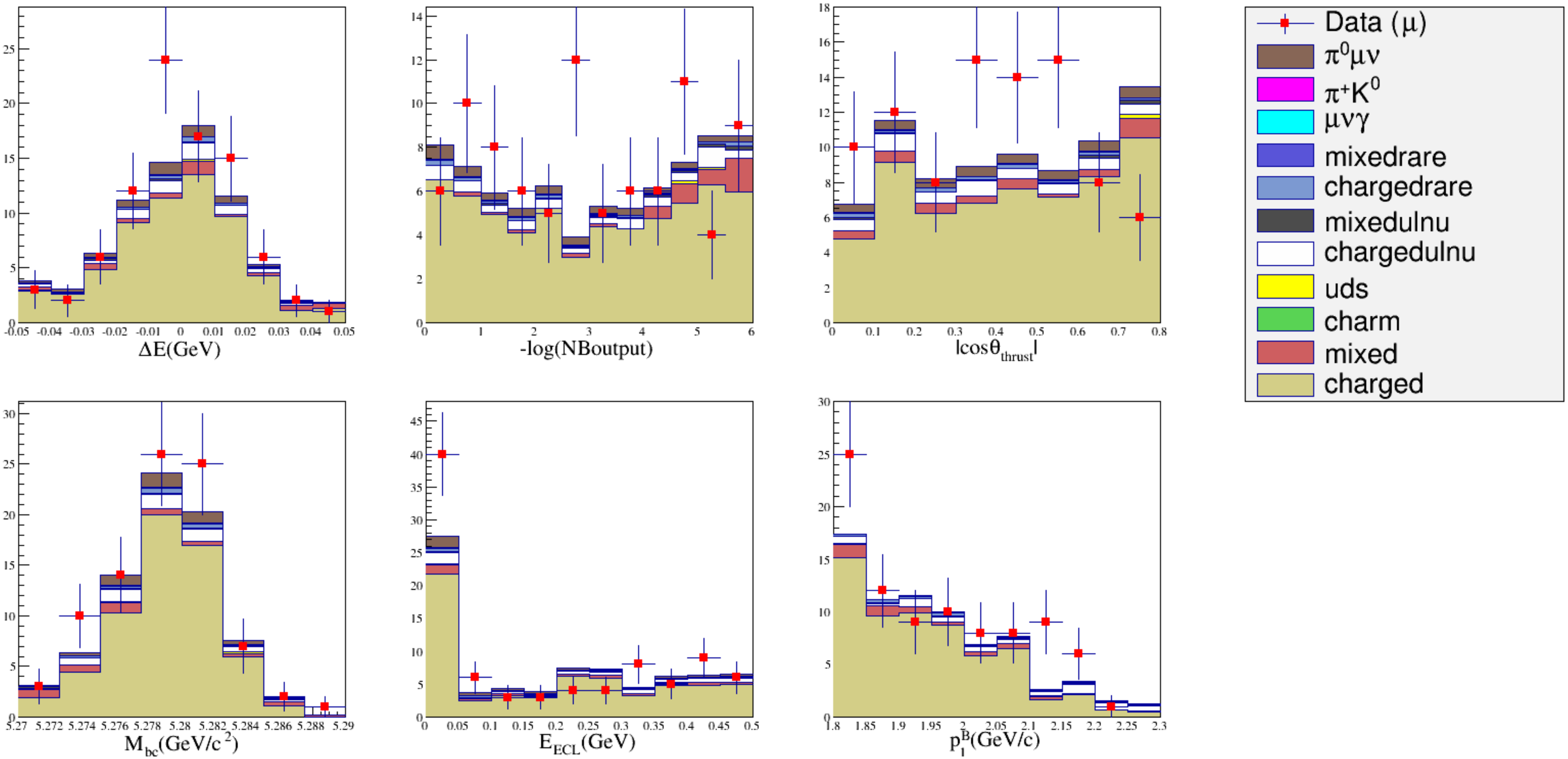
LX_SKIM

- 1 charged particle not used in Full_recon →call it 'c'
- (Charge of c) x (Charge of tagged B) = -1
- Momentum of c(LAB frame) >1.0 GeV

p_l^B sideband ($B^+ \rightarrow e^+ X$)



p_l^B sideband ($B^+ \to \mu^+ X$)



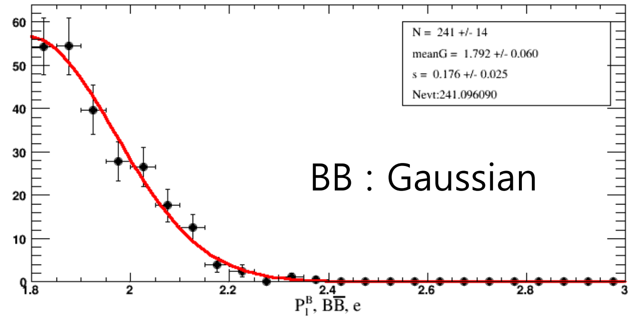
Fitting PDFs (MC)

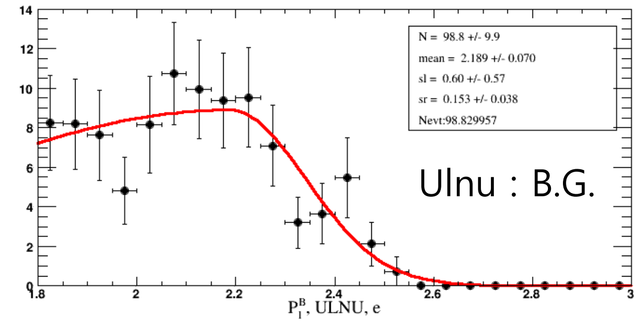
- 1D ML fit for p_l^B was done (1.8~3.0 GeV/c)
- Cuts for all remaining variables are same
- Using simple function as much as possible

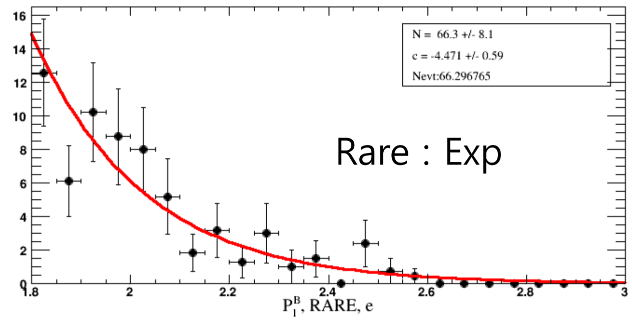
Some modes in Ulnu are scaled

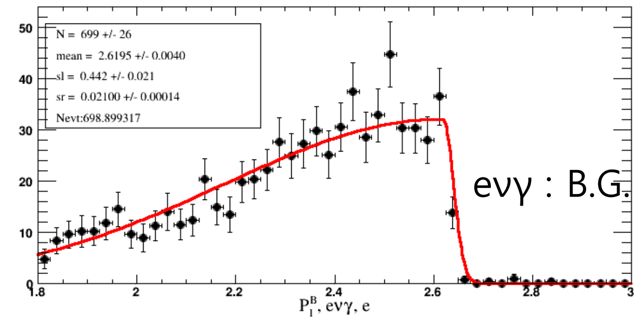
Mode	Branching Fraction		Scale factor
	Belle MC	PDG	
$\rho l \nu$	1.49×10^{-4}	1.07×10^{-4}	0.7181
$\eta l \nu$	8.4×10^{-5}	3.9×10^{-5}	0.4643
$\eta' l \nu$	3.3×10^{-5}	2.3×10^{-5}	0.6970

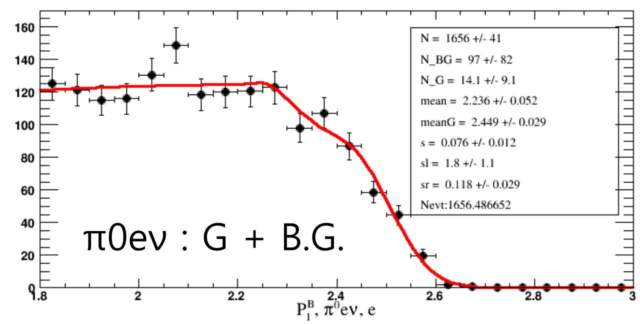
$B^+ \rightarrow e^+ X$ Background PDF



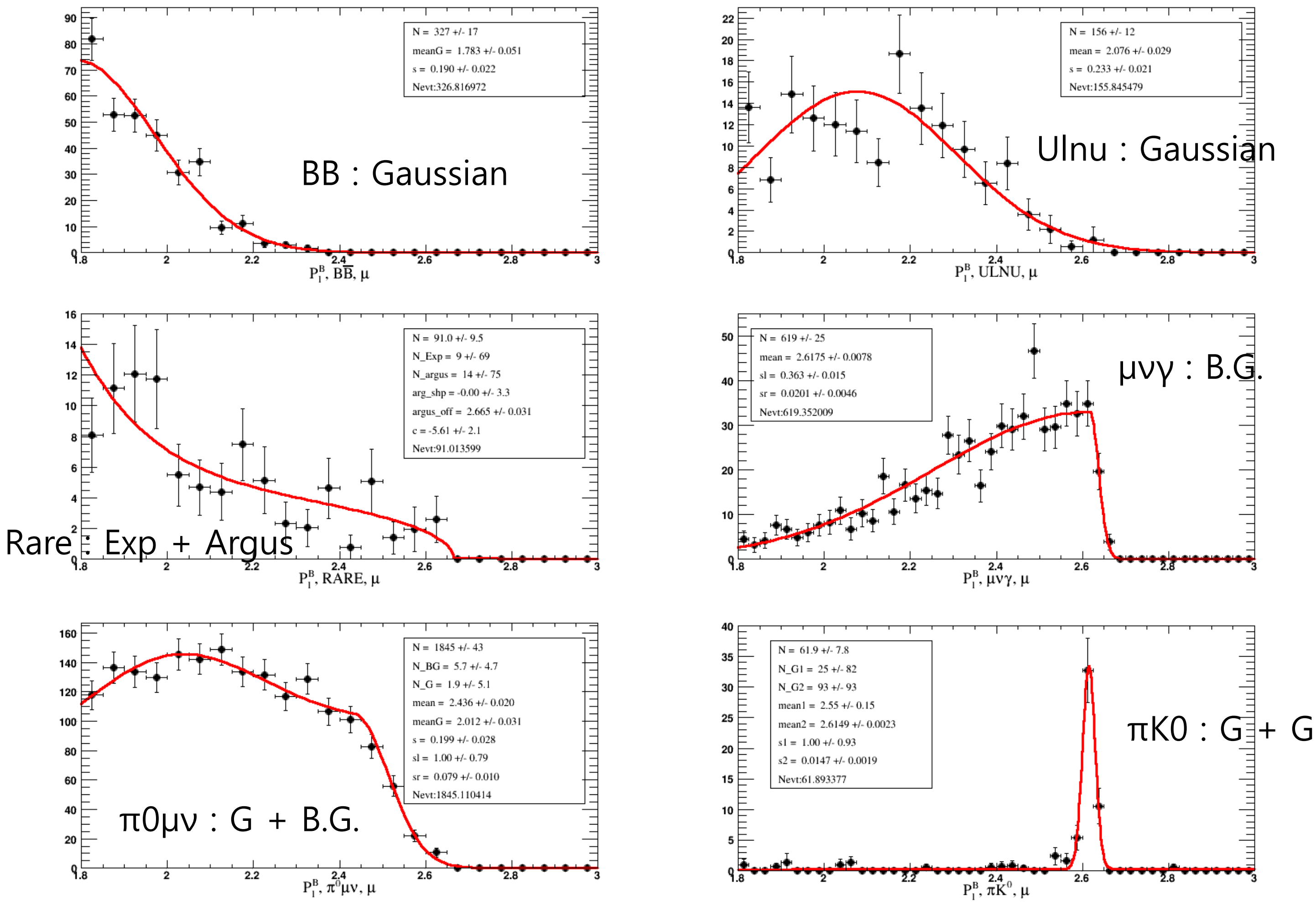






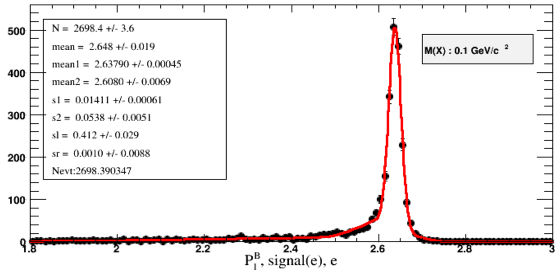
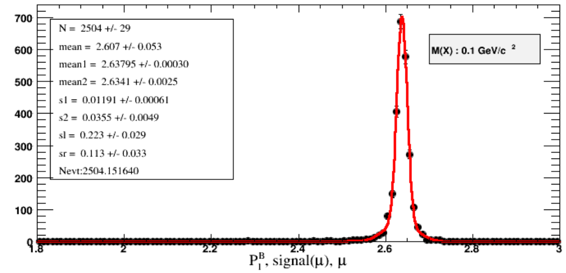
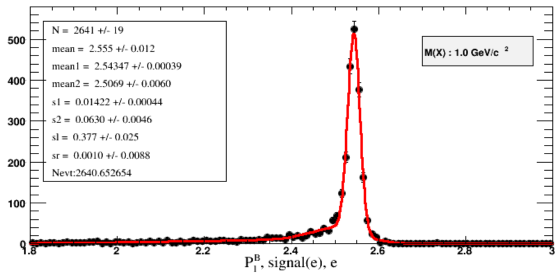
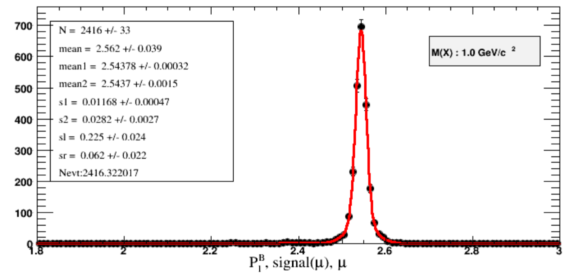
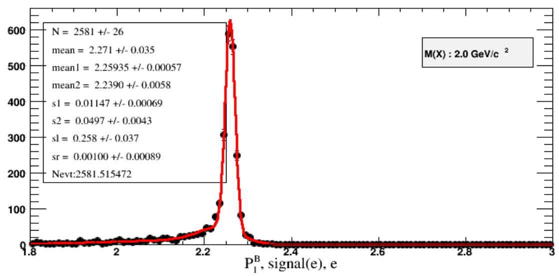
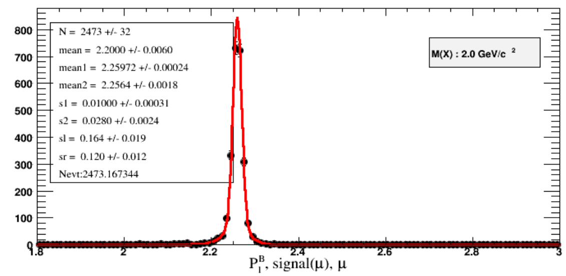


$B^+ \rightarrow \mu^+ X$ Background PDF



Signal PDF

Signal PDF :
G + G + B.G

	$B^+ \rightarrow e^+ X$	$B^+ \rightarrow \mu^+ X$
M(X) : 0.1 GeV/c^2		
M(X) : 1.0 GeV/c^2		
M(X) : 1.8 GeV/c^2		

Optimization

Control of variables to be optimized

p_l^B high cut → move(0.01 GeV level)

p_l^B low cut → move(0.01 GeV level)

Remain cut → fixed

We give 1,000 values have Poisson distribution for estimated BG

These values are chosen for Yields

Yield > 6 cases are ignored (too high U.L. can disturb mean)

16.0% uncertainty of signal efficiency assumed

We don't need to consider E_{ECL} contribution to p_l^B distribution

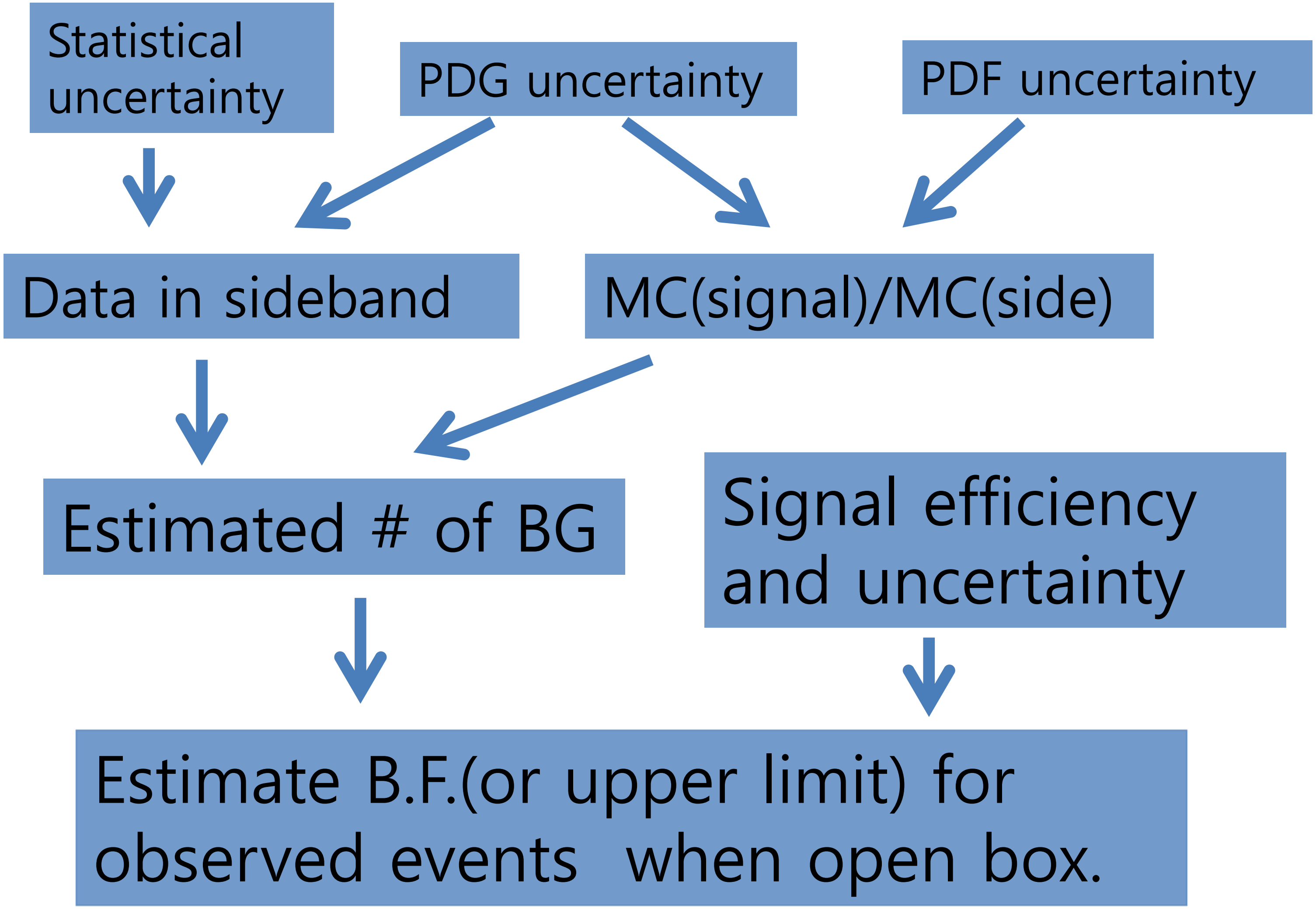
BG_{est} > 3.0 case not considered

Optimization

e mode	plB cut(GeV/c)	BG_est
0.1(GeV)	2.52<plB<2.70	0.442
0.2	2.52<plB<2.70	0.442
0.3	2.55<plB<2.68	0.282
0.4	2.55<plB<2.68	0.282
0.5	2.52<plB<2.70	0.442
0.6	2.52<plB<2.70	0.442
0.7	2.52<plB<2.70	0.442
0.8	2.51<plB<2.62	0.436
0.9	2.51<plB<2.62	0.436
1.0	2.51<plB<2.62	0.436
1.1	2.47<plB<2.57	0.615
1.2	2.45<plB<2.53	0.636
1.3	2.43<plB<2.51	0.738
1.4	2.41<plB<2.51	0.985
1.5	2.39<plB<2.46	0.843
1.6	2.37<plB<2.43	0.816
1.7	2.34<plB<2.39	0.805
1.8	2.31<plB<2.36	0.941

μ mode	plB cut(GeV/c)	BG_est
0.1(GeV)	2.58<plB<2.68	0.439
0.2	2.58<plB<2.68	0.439
0.3	2.58<plB<2.68	0.439
0.4	2.58<plB<2.68	0.439
0.5	2.58<plB<2.68	0.439
0.6	2.58<plB<2.68	0.439
0.7	2.56<plB<2.63	0.462
0.8	2.54<plB<2.61	0.485
0.9	2.52<plB<2.60	0.605
1.0	2.49<plB<2.58	0.838
1.1	2.49<plB<2.58	0.838
1.2	2.48<plB<2.53	0.594
1.3	2.45<plB<2.50	0.731
1.4	2.42<plB<2.48	0.994
1.5	2.40<plB<2.47	1.233
1.6	2.37<plB<2.42	1.025
1.7	2.34<plB<2.39	1.164
1.8	2.31<plB<2.37	1.574

Expectation of Branching Fraction



Summary Table ($B^+ \rightarrow e^+ X$)

M(X)	plB cut	BG_est	Efficiency(‰)	Observed event	U.L. (10^{-6})
0.1 (GeV)	2.52 < plB < 2.70	0.442±0.201	1.13±0.14	0	2.41
0.2	2.52 < plB < 2.70	0.442±0.201	1.12±0.14	0	2.43
0.3	2.55 < plB < 2.68	0.282±0.134	1.08±0.13	0	2.70
0.4	2.55 < plB < 2.68	0.282±0.134	1.06±0.13	0	2.75
0.5	2.52 < plB < 2.70	0.442±0.201	1.08±0.13	0	2.52
0.6	2.52 < plB < 2.70	0.442±0.201	1.07±0.13	0	2.54
0.7	2.52 < plB < 2.70	0.442±0.201	1.11±0.14	0	2.45
0.8	2.51 < plB < 2.62	0.436±0.190	1.07±0.13	0	2.54
0.9	2.51 < plB < 2.62	0.436±0.190	1.01±0.13	0	2.69
1.0	2.51 < plB < 2.62	0.436±0.190	0.97±0.12	0	2.81
1.1	2.47 < plB < 2.57	0.615±0.251	0.99±0.12	0	2.54
1.2	2.45 < plB < 2.53	0.636±0.257	0.97±0.12	0	2.57
1.3	2.43 < plB < 2.51	0.738±0.303	0.98±0.12	0	2.45
1.4	2.41 < plB < 2.51	0.985±0.410	1.02±0.12	0	2.15
1.5	2.39 < plB < 2.46	0.843±0.374	0.95±0.12	1	4.80
1.6	2.37 < plB < 2.43	0.816±0.380	0.94±0.11	1	4.88
1.7	2.34 < plB < 2.39	0.805±0.389	0.89±0.11	1	5.17
1.8	2.31 < plB < 2.36	0.941±0.455	0.90±0.11	2	7.10

Summary Table ($B^+ \rightarrow \mu^+ X$)

M(X)	pIB cut	BG_est	Efficiency(‰)	Observed event	U.L. (10^{-6})
0.1 (GeV)	2.58 < pIB < 2.68	0.439±0.111	1.18±0.14	1	4.26
0.2	2.58 < pIB < 2.68	0.439±0.111	1.19±0.15	1	4.23
0.3	2.58 < pIB < 2.68	0.439±0.111	1.18±0.14	1	4.26
0.4	2.58 < pIB < 2.68	0.439±0.111	1.19±0.15	1	4.34
0.5	2.58 < pIB < 2.68	0.439±0.111	1.15±0.14	1	4.37
0.6	2.58 < pIB < 2.68	0.439±0.111	1.13±0.14	1	4.45
0.7	2.56 < pIB < 2.63	0.462±0.116	1.13±0.14	0	2.35
0.8	2.54 < pIB < 2.61	0.485±0.140	1.14±0.14	1	4.37
0.9	2.52 < pIB < 2.60	0.605±0.187	1.14±0.14	1	4.23
1.0	2.49 < pIB < 2.58	0.838±0.270	1.13±0.14	1	4.04
1.1	2.49 < pIB < 2.58	0.838±0.270	1.18±0.14	1	3.87
1.2	2.48 < pIB < 2.53	0.594±0.194	1.06±0.13	0	2.37
1.3	2.45 < pIB < 2.50	0.731±0.233	1.03±0.13	0	2.28
1.4	2.42 < pIB < 2.48	0.994±0.307	1.10±0.13	2	5.75
1.5	2.40 < pIB < 2.47	1.233±0.371	1.11±0.14	5	10.64
1.6	2.37 < pIB < 2.42	1.025±0.287	1.05±0.13	4	9.66
1.7	2.34 < pIB < 2.39	1.164±0.308	1.05±0.13	1	3.93
1.8	2.31 < pIB < 2.37	1.574±0.402	1.12±0.14	1	3.27

Recent progress

Lifetime acceptance of X

We suppose that X have no experimental signature. Also, we set X is not decaying particle.

X should pass ECL(CsI) calorimeter with no decay.

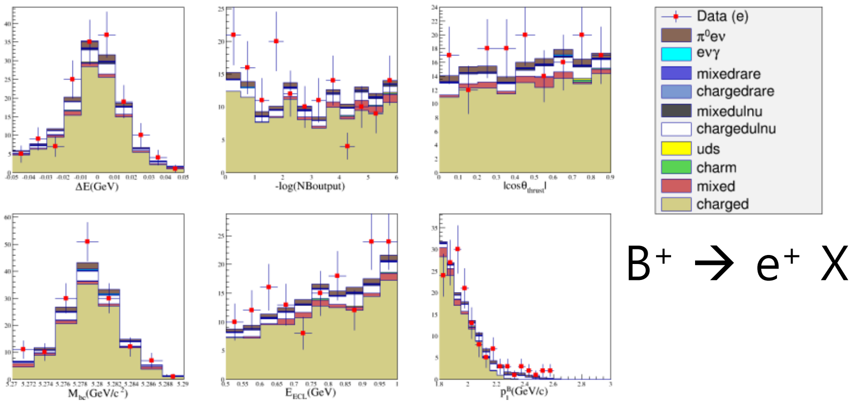
$\gamma\beta ct = (p/m)ct > 2716$mm (in Lab frame)

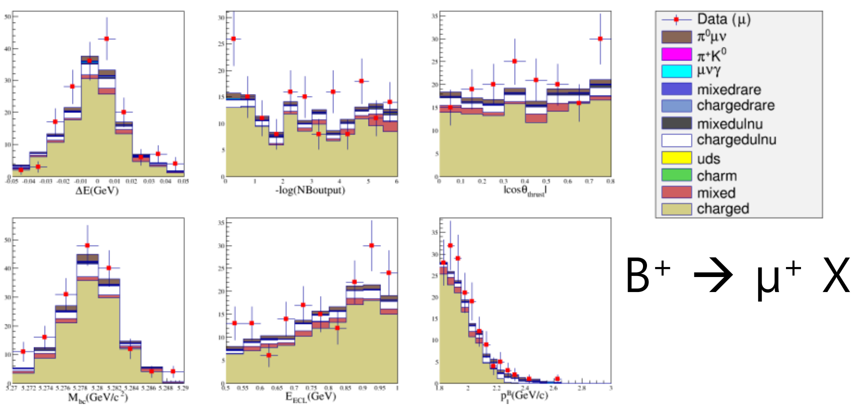
So, we study for X to have lifetime more than 1.43×10^{-8} sec case.

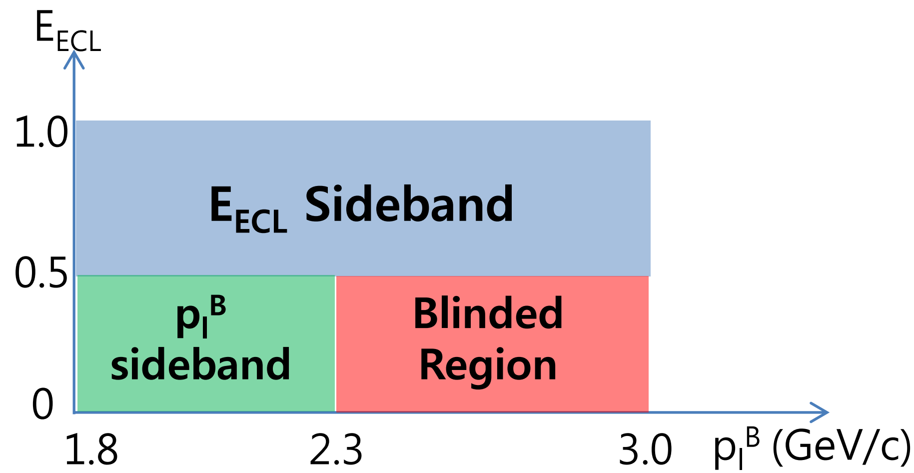
M(X)	p_{X}^{Lab}	Lifetime
0.1	1.633	5.55×10^{-10}
0.2	1.629	1.11×10^{-9}
0.3	1.621	1.68×10^{-9}
0.4	1.610	2.25×10^{-9}
0.5	1.597	2.84×10^{-9}
0.6	1.580	3.44×10^{-9}
0.7	1.560	4.07×10^{-9}
0.8	1.537	4.72×10^{-9}
0.9	1.511	5.40×10^{-9}
1.0	1.482	6.11×10^{-9}
1.1	1.450	6.87×10^{-9}
1.2	1.415	7.68×10^{-9}
1.3	1.376	8.56×10^{-9}
1.4	1.335	9.50×10^{-9}
1.5	1.291	1.05×10^{-8}
1.6	1.243	1.17×10^{-8}
1.7	1.193	1.29×10^{-8}
1.8	1.139	1.43×10^{-8}

Recent progress

Compare Data & MC in E_{ECL} sideband region







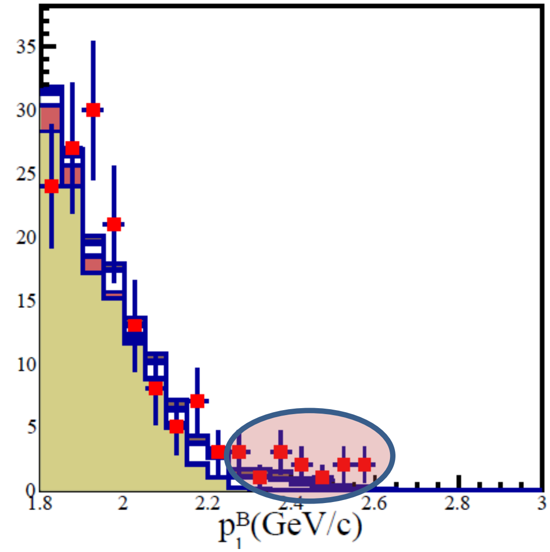
Trial for understanding E_{ECL} sideband

From last BAM,

we try 3 kinds of approaching method

to understand data events for E_{ecl}

Sideband region with high p_l^B.



1 : We use lepton's momentum in LAB frame. And draw their Phi & Theta value.

2 : We suppose they are from QED background like $e^+e^- \rightarrow \tau^+\tau^-$

3 : We give off-timing cut for data & 911-veto for MC, and look whether there are any better agreement.