YongPyong-High1 2015

Joint Winter Conference on Particle Physics, String and Cosmology

Search for $B^+ \rightarrow l^+ X^0$ with hadronic tagging method at Belle

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2015-01-30

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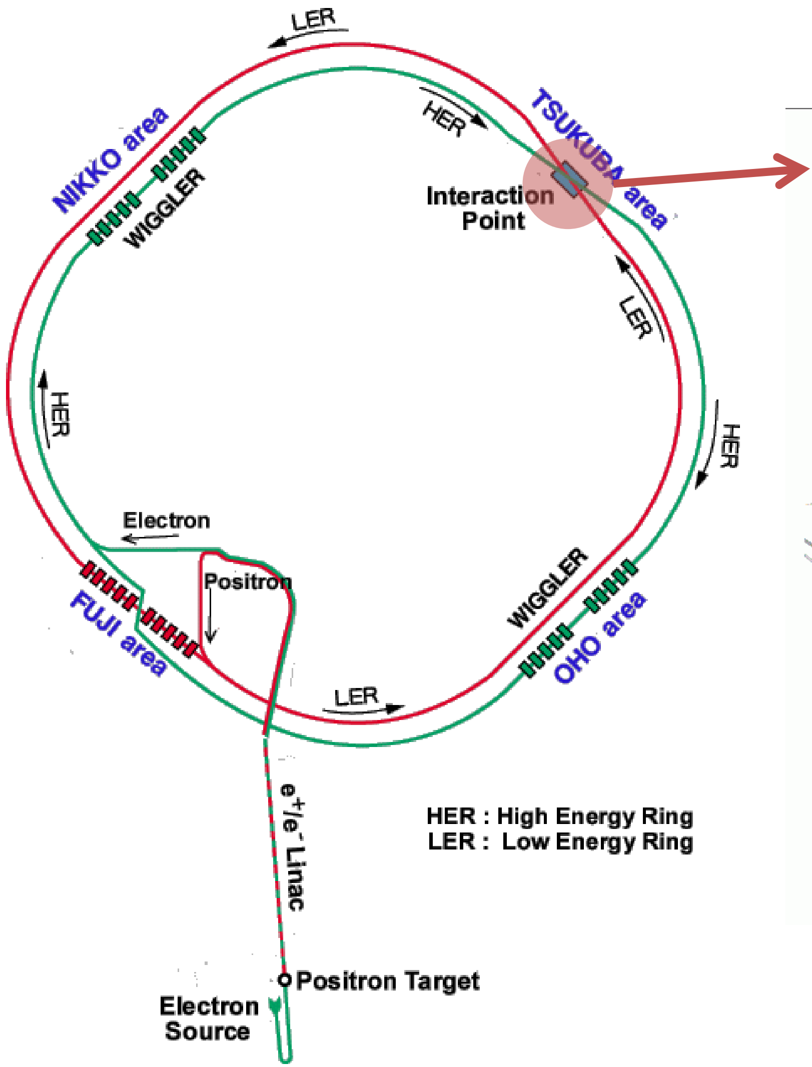
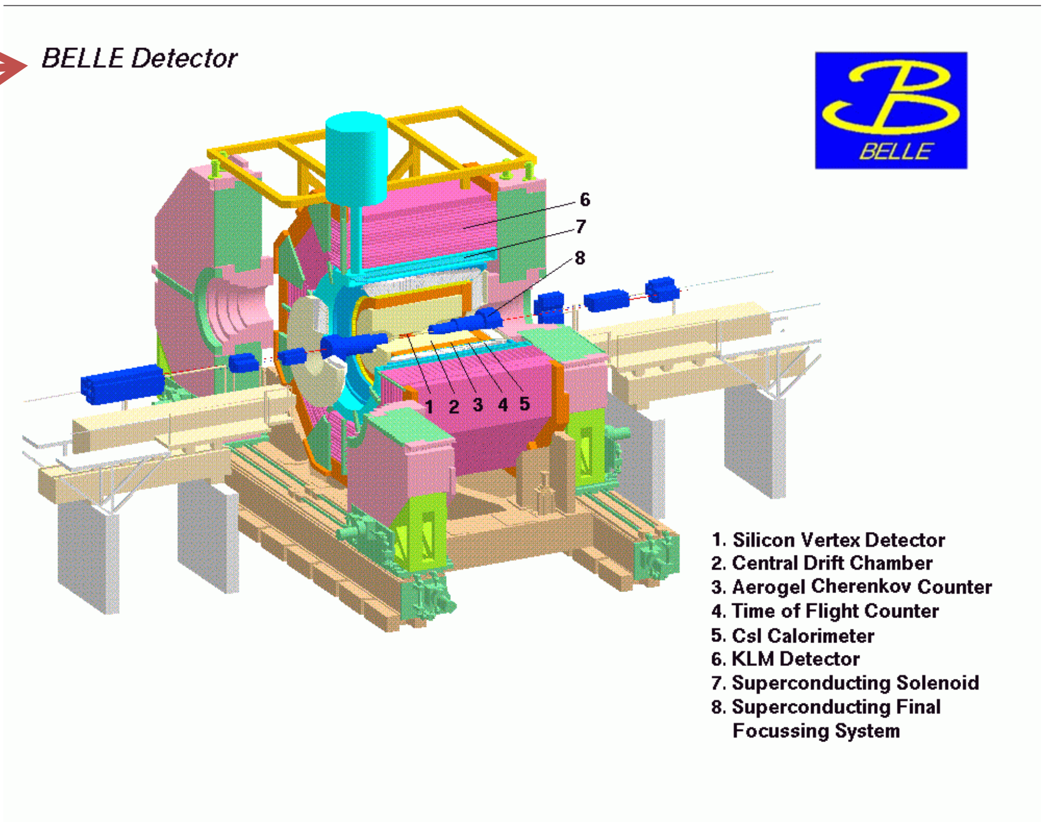
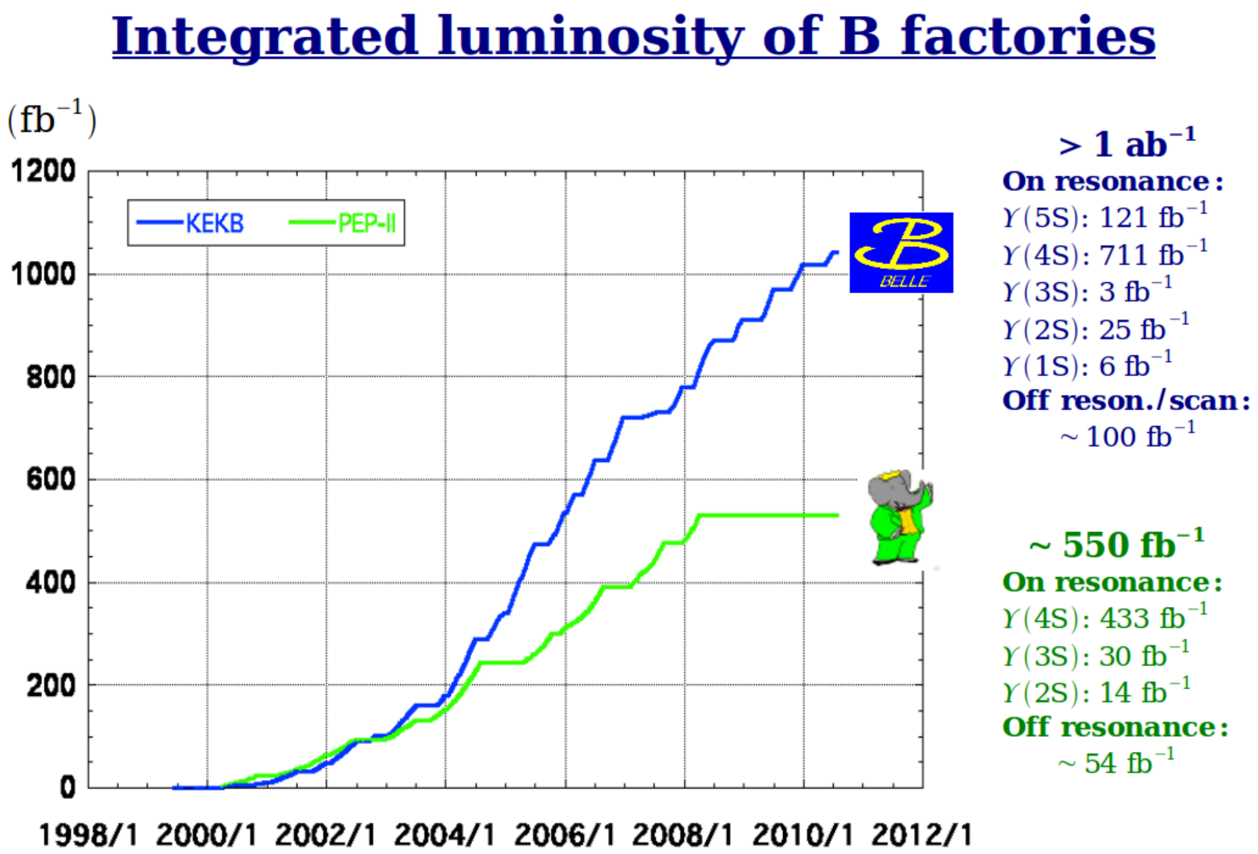
Belle Experiment





Belle Experiment



772 Million $B\bar{B}$ pairs created from Υ(4S) decays.

We use the full Belle Υ(4S) data set.

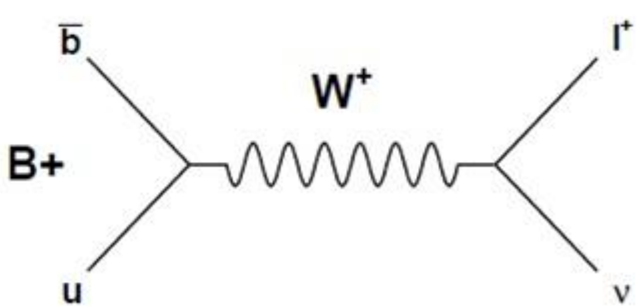
Motivation

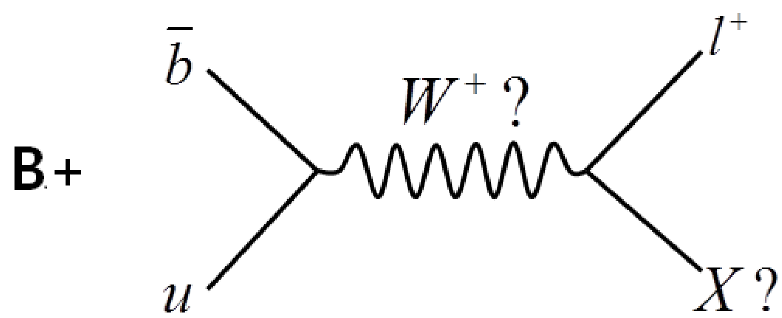
At Belle, there are searches that have invisible particle in the final states.

eg) $B^+ \rightarrow l\,\nu$, $B^0 \rightarrow \nu\,\bar{\nu}$, $B \rightarrow K\,\nu\,\bar{\nu}$, $B \rightarrow D(*)\,\tau\,\nu$

Neutrino is not detected at Belle detector, from this we have interesting assumption → What if massive particle can substitute neutrino?

From now, we call it **X^0**





Possible mass range that X^0 can have

$$0 \leq m(X^0) \leq m(B^+) - m(l^+)$$

Why $B^+ \rightarrow l^+ X^0$?

$B^+ \rightarrow \overline{D}^0 \, l^+ \, X^0$

* We don't consider 3body decay (moment is not clear)

$B^+ \rightarrow \tau^+ X^0$

* additional neutrino produced

→ **Hard to search**

We consider $B^+ \rightarrow l^+ X^0$ ($l = e, \mu$)

For $m(X^0)$: 0.1 – 1.8 GeV/c^2

X^0 candidate : LSP (RPV)

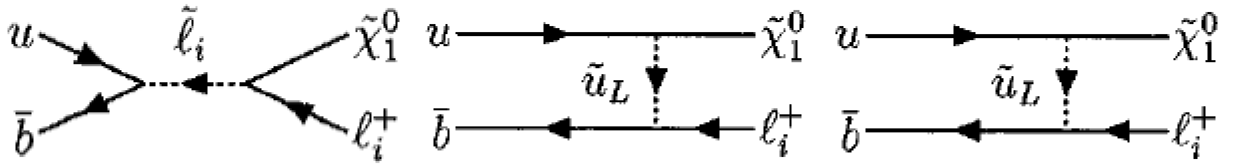


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Figure 3: Some Feymann diagrams to produce lightest neutralino from B meson decays in SUSY

$$\Gamma\left(B^+ \rightarrow l_i^+ \tilde{\chi}_1^0\right) = \frac{\lambda_{i13}'^2 g'^2 f_B^2 m_{B^+}^2 p_l^B}{8\pi(m_u + m_b)^2} \left(\frac{1}{2M_{\tilde{l}_i}^2} + \frac{1}{12M_{\tilde{u}_L}^2} + \frac{1}{6M_{\tilde{b}_R}^2} \right)^2 \left(M_{B^+}^2 - M_{l_i}^2 - M_{X^0}^2\right)^2$$

When we assuming r-parity violation, one lightest neutralino can be produced from B meson decay via slepton or squark.

We can give bounds for unknown parameters

X^0 candidate : Large Extra Dimension

$$\Gamma_H\left(B^- \to l_L\psi\right) \sim \frac{1}{8\pi} m_B^3 \left(\frac{m\, m_b}{m_H^2}\right)^2 f_B^2\, |V_{ub}|^2 G_F^2 \left(\frac{m_B}{M_*}\right)^\delta \left(\frac{M_{Pl}}{M_*}\right)^2, \quad (34)$$

$$\begin{aligned}\Gamma_W\left(B^- \to \mu_L\psi\right) &\approx \frac{1}{8\pi} G_F^2 m_B f_B^2 |V_{ub}|^2 \sum_n \left(\frac{n}{R}\right)^2 \left(\frac{mR}{n}\right)^2 \frac{1}{N^2}\left(1 - \frac{n^2/R^2}{m_B^2}\right)^2 \\ &\approx \frac{1}{8\pi} G_F^2 m_B f_B^2 |V_{ub}|^2 m_\nu^2 \left(\frac{m_B}{M_*}\right)^\delta \left(\frac{M_{Pl}}{M_*}\right)^2 x_\delta, \quad (35)\end{aligned}$$

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* RH-neutrino in large extra dimension might candidate of X^0.

* When there are δ additional dimensions, decay width via H or W. ($\Gamma_W >> \Gamma_H$)

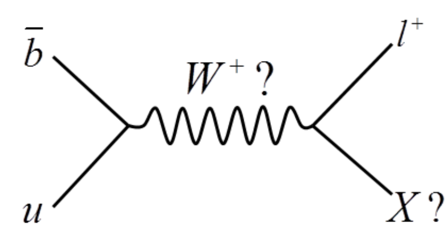
* Decay width is proportional to $\mathbf{R}^\delta$.

M_{Pl} : 4D Planck scale

M_* : (4+δ)D fundamental Planck scale

R : size of additional dimension

B+



$B^+ \to l^+ X^0$ – Sample for analysis

Signal MC

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

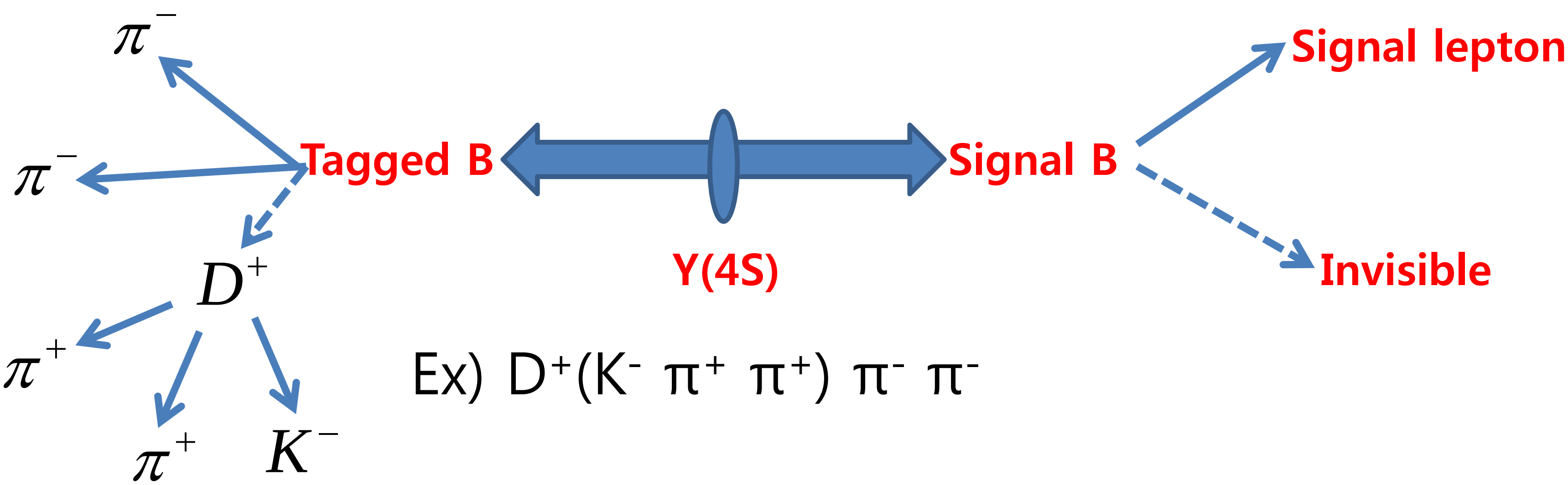
We have 18 kinds of X for different mass

Background MC

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

Separately generated! (last five modes: $e\nu\gamma$, $\mu\nu\gamma$, π^+K^0, $\pi^0 e\nu$, $\pi^0\mu\nu$)

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

* 615 B^+ channels are used for reconstruction.

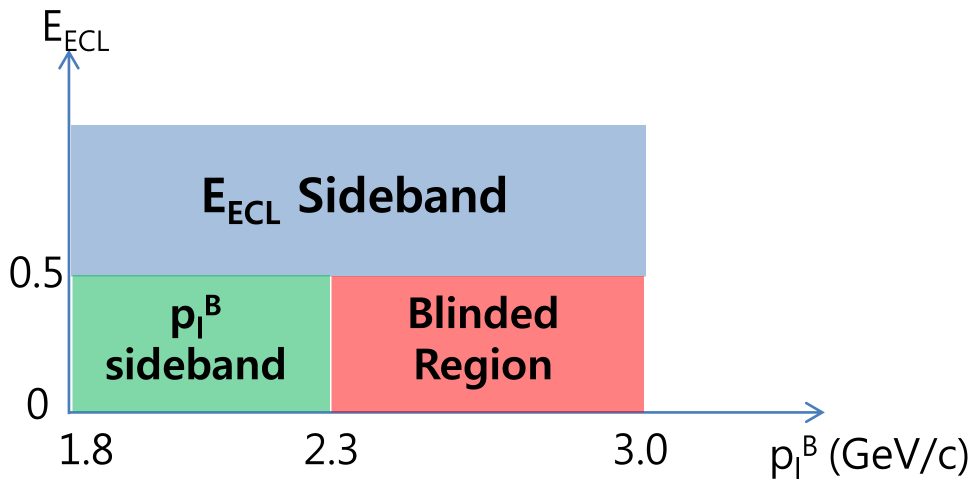
* Low efficiency, high purity

Good way to reconstruct modes with invisible particle

$B^+ \rightarrow l^+ X^0$ - event selection

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

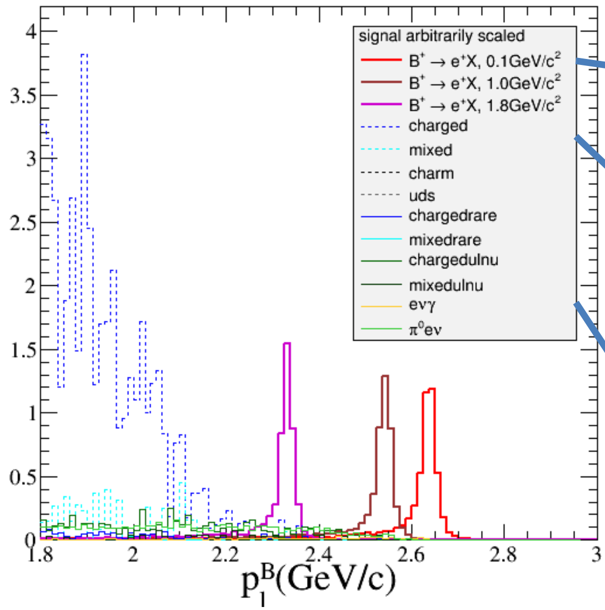
Quality of tagged-B meson
$\|\Delta E\| < 0.05$ GeV
$M_{bc} > 5.27$ GeV/c^2
$O_{NB} > e^{-6}$



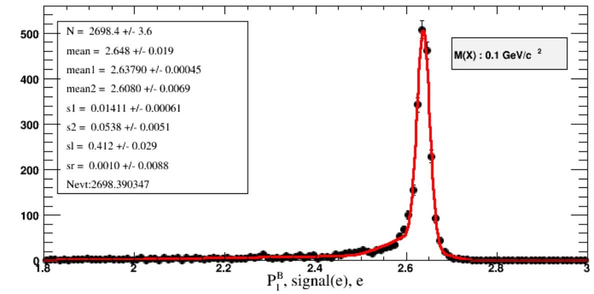
E_{ECL} : Remaining energy of ECL calorimeter (tagged-B & signal lepton)

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

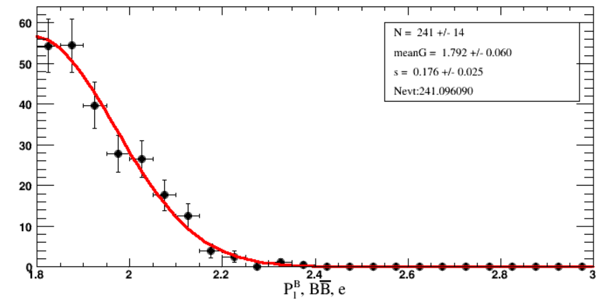
$B^+ \rightarrow l^+ X^0$ – PDF modeling



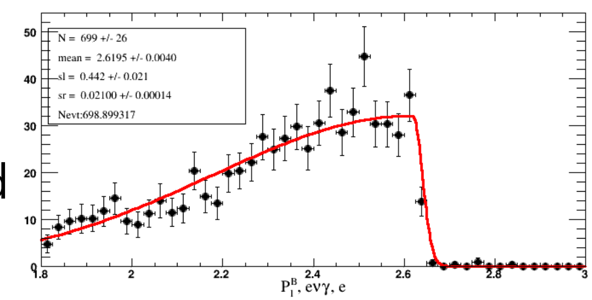
Fitting Signal



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

$B^+ \to l^+ X^0$ – obtain U.L. of B.F.

$$B.F. = \frac{N_{obs} - BG_{est}}{\varepsilon_{sig} N(B\bar{B})}$$

* B.F. is obtained by Feldman-Cousins method

* Signal region is optimized.

N_{obs} : Number of Data in the signal region (counting)

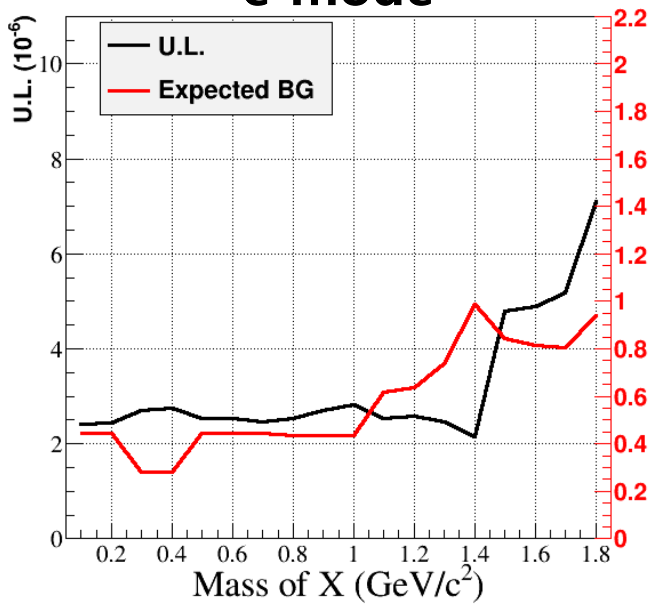
BG_{est} : expected background in the signal region,

decided by background PDF, data distribution in the p_l^B sideband

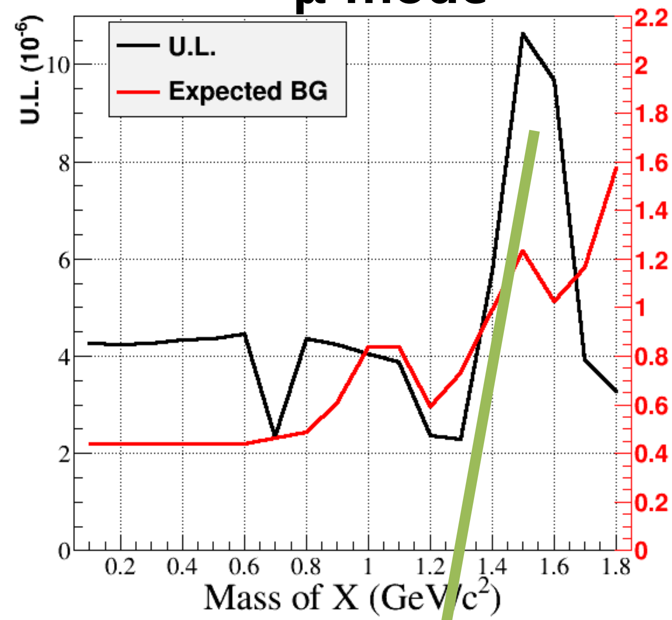
ε_{sig} : decided by signal PDF.

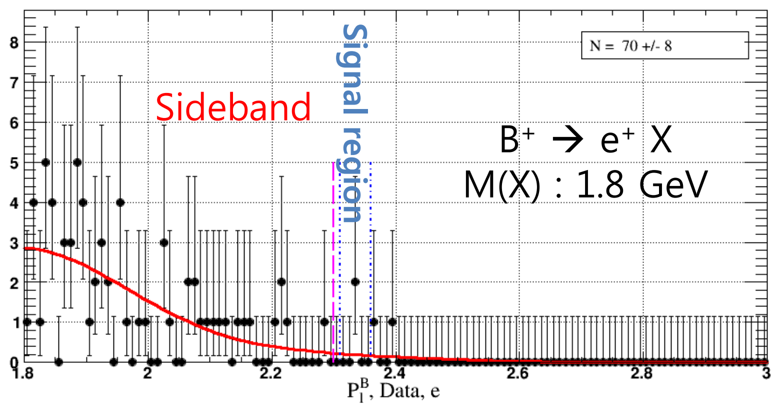
$B^+ \to l^+ X^0$ - preliminary result

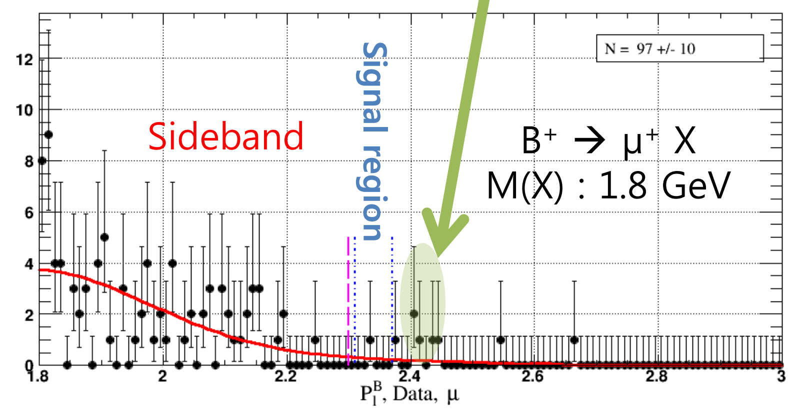
e mode



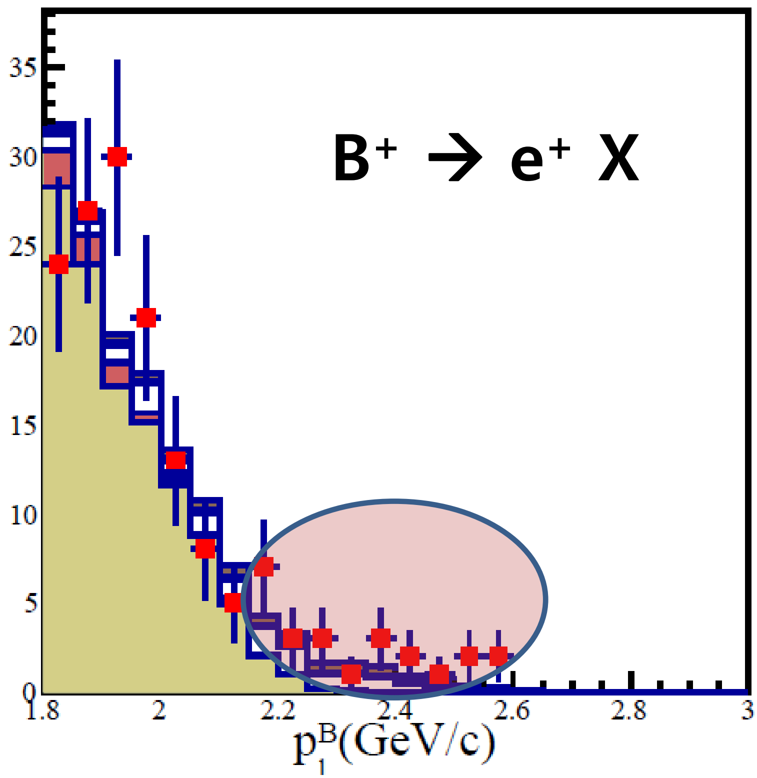
μ mode

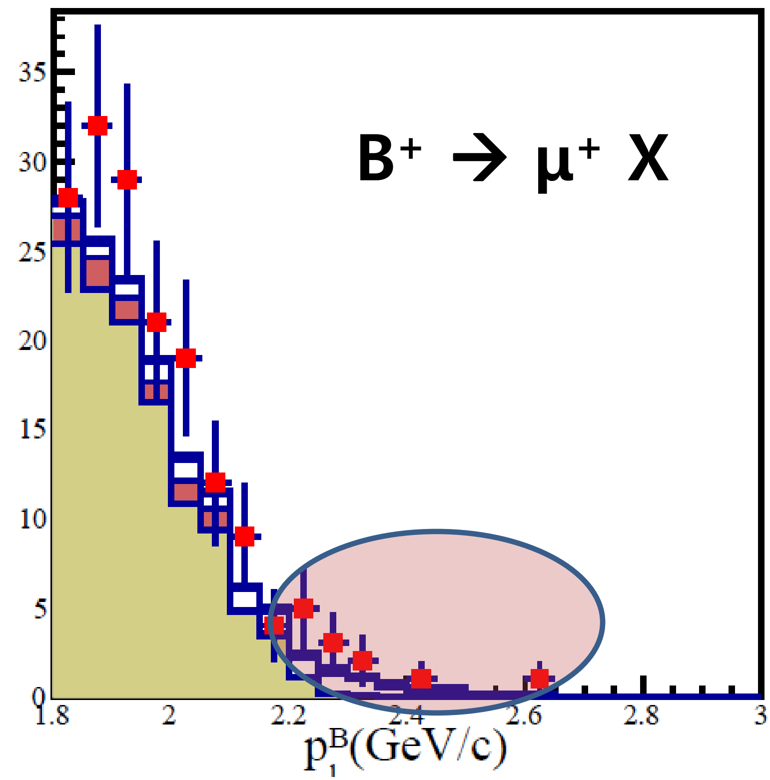






$B^+ \rightarrow l^+ X^0$ – E_{ECL} sideband calibration





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 !!

$B^+ \rightarrow l^+ X^0$ – Bounds for parameters

$$\Gamma\left(B^+ \rightarrow l_i^+ \tilde{\chi}_1^0\right) = \frac{\lambda'^2_{i13} g'^2 f_B^2 m_{B^+}^2 p_l^B}{8\pi(m_u + m_b)^2} \left(\frac{1}{2M^2_{\tilde{l}_i}} + \frac{1}{12M^2_{\tilde{u}_L}} + \frac{1}{6M^2_{\tilde{b}_R}} \right)^2$$

$$\lambda'^2_{i13} \left(\frac{1}{2M^2_{\tilde{l}_i}} + \frac{1}{12M^2_{\tilde{u}_L}} + \frac{1}{6M^2_{\tilde{b}_R}} \right)^2 < \frac{8\pi(m_u + m_b)^2 U.L.(B \rightarrow l_i X^0)}{\tau_{B^+} g'^2 f_B^2 m_{B^+}^2 p_{l_i}^B (m_{B^+}^2 - m_{l_i}^2 - m_{X^0}^2)}$$

This is parameter we give bounds !

Summary

* We search for $B^+ \rightarrow l^+ + X^0$, where X^0 have 0.1 ~ 1.8 GeV mass range

* Hadronic tagging method enables effective background suppression

* $B^+ \rightarrow l^+ X^0$ has preliminary results, and analysis enters the final steps

* e^+e^- B-factory experiments has an advantage for this study.

BACKUP

$B^+ \rightarrow l^+ X^0$ - skim procedure

SKIM PATH

Hadronic Tagging → LX_SKIM → ANALYSIS_CODE

LX_SKIM

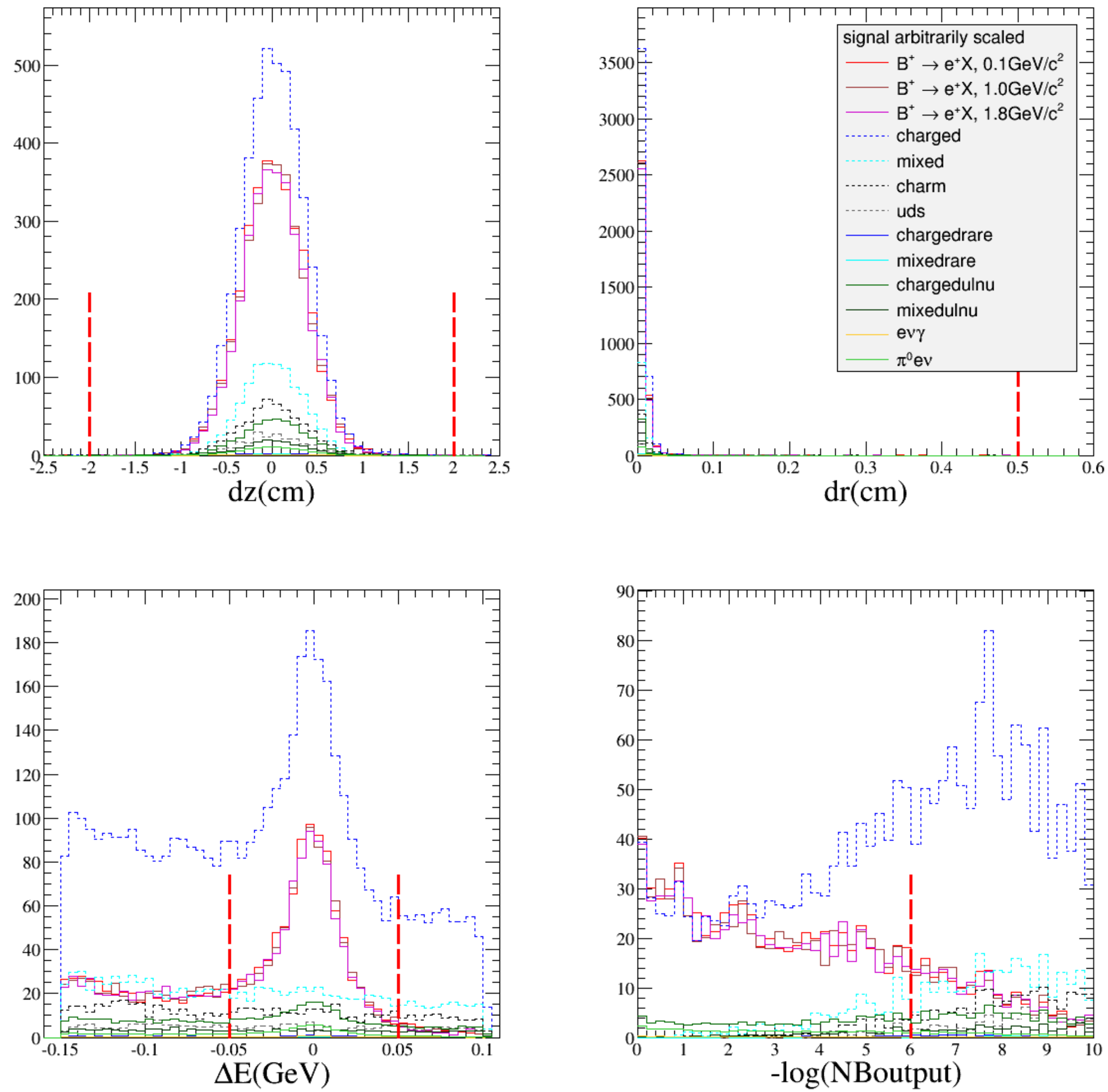
- 1 charged particle not used in Full_recon →call it 'c'
- (Charge of c) x (Charge of tagged B) = -1
- Momentum of c(LAB frame) >1.0 GeV

e mode

dz, dr, deltaE

-log(Nboutput)

distributions



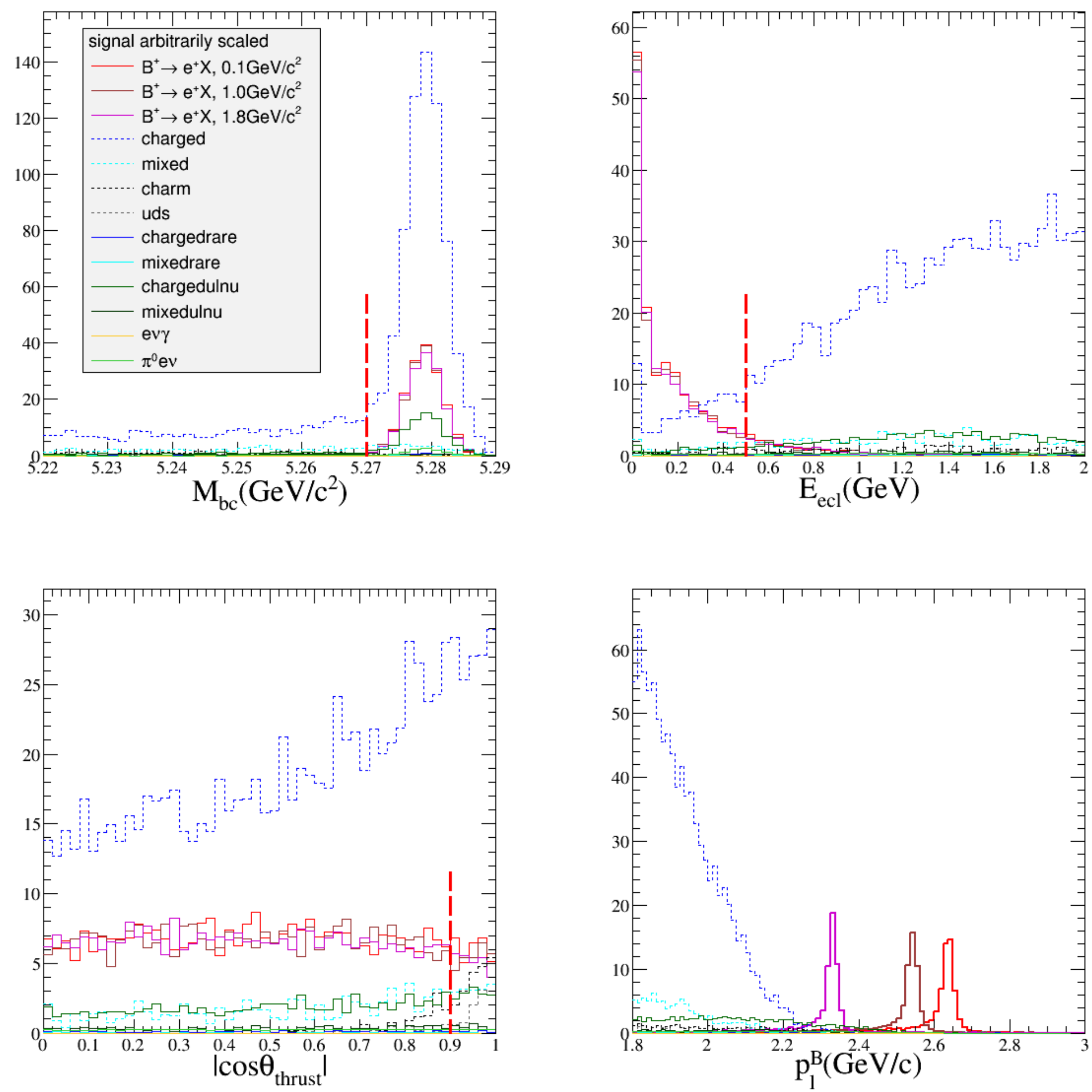
e mode

Mbc, Eecl,

cos(thrust), plB

distributions

with basic cut

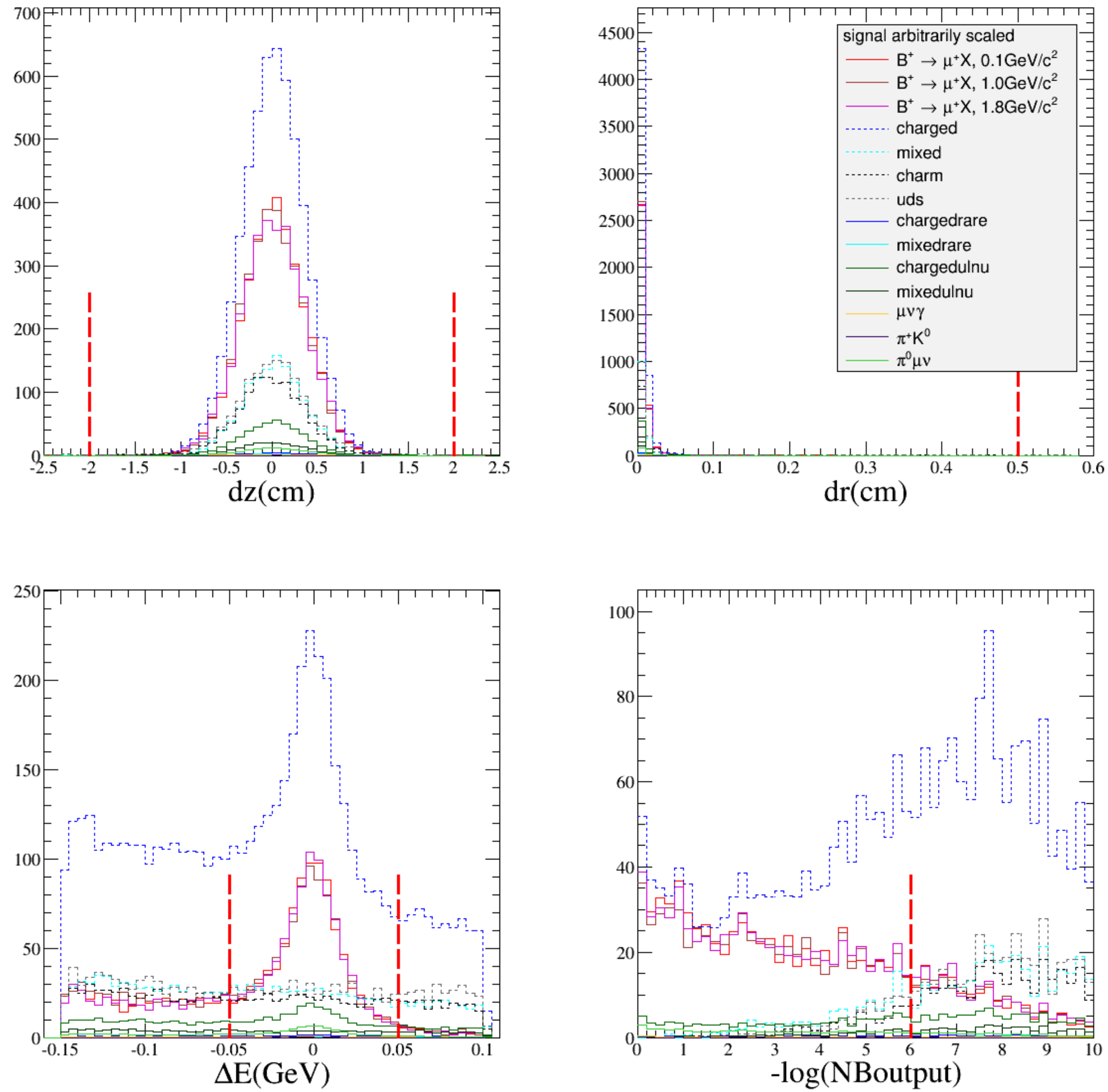


μ mode

dz, dr, deltaE

-log(Nboutput)

distributions



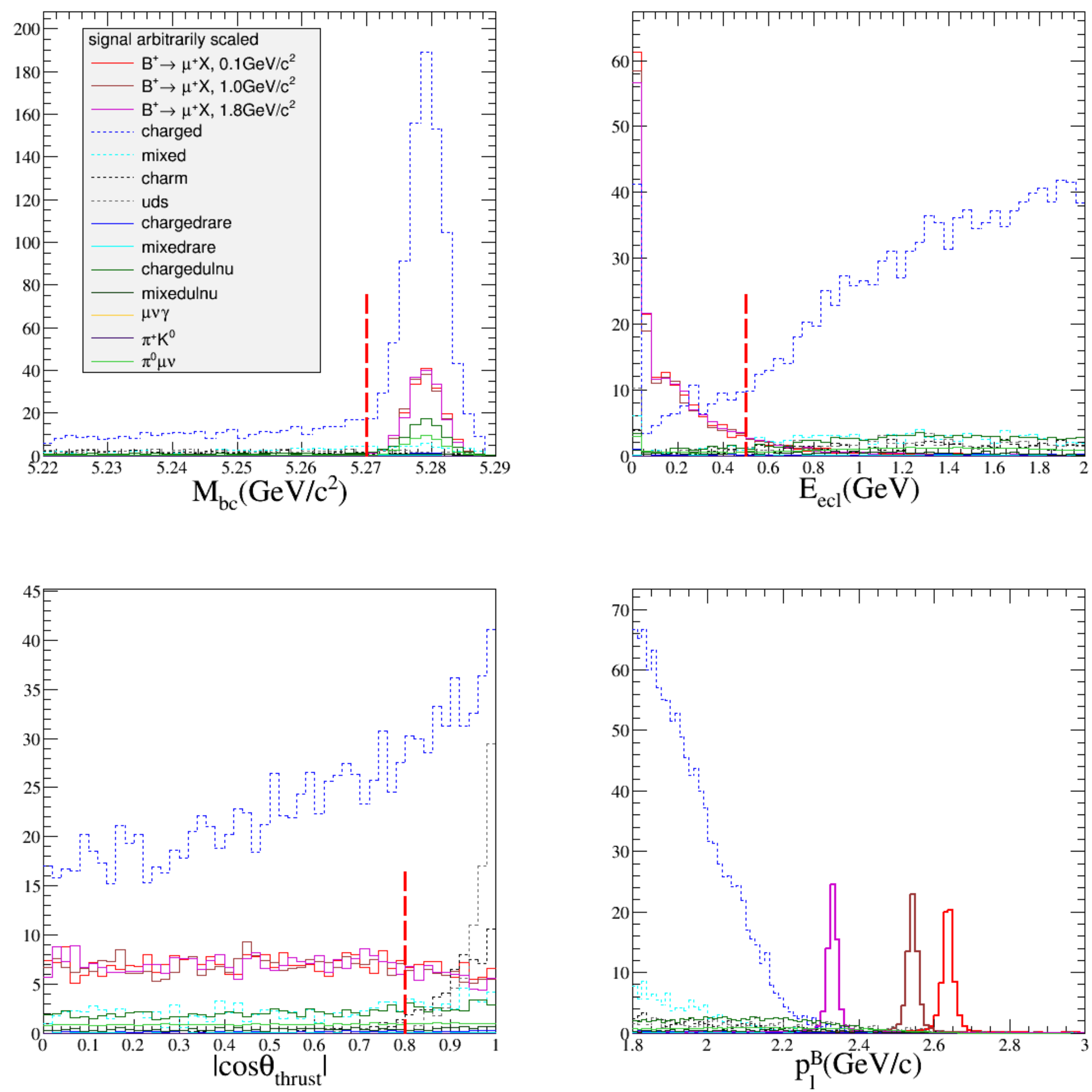
μ mode

Mbc, Eecl,

cos(thrust), plB

distributions

with basic cut



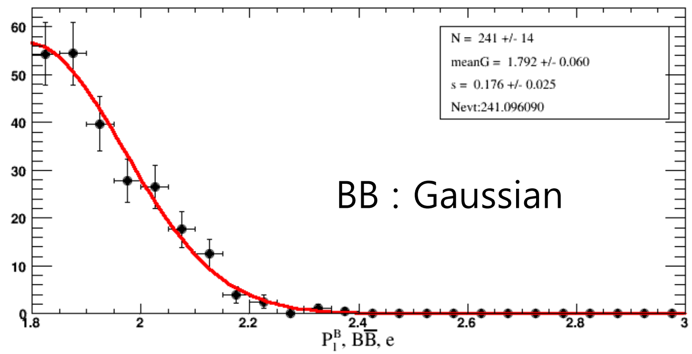
Fitting to obtain PDFs (MC samples)

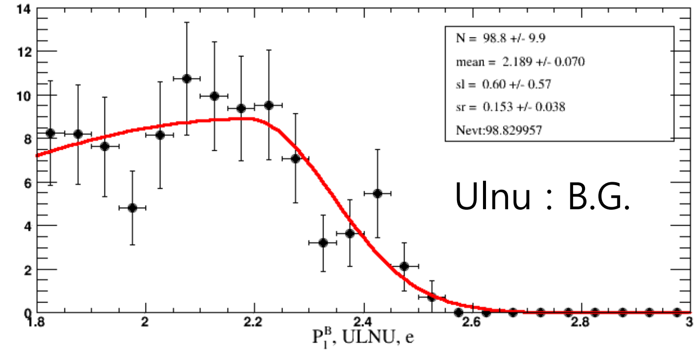
- 1D ML fit for p_l^B was done (1.8~3.0 GeV/c)
- Cuts for all remaining variables are same
- Using simple function as much as possible

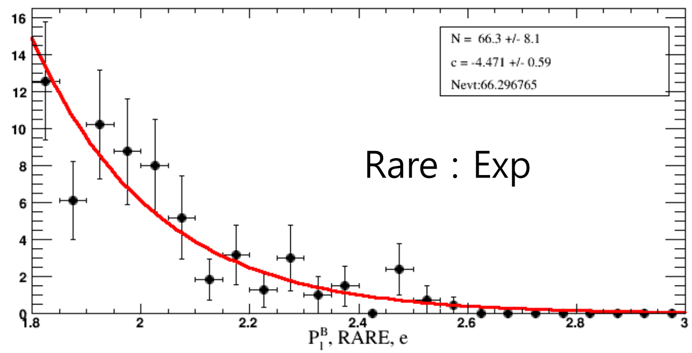
Some modes in Ulnu are scaled

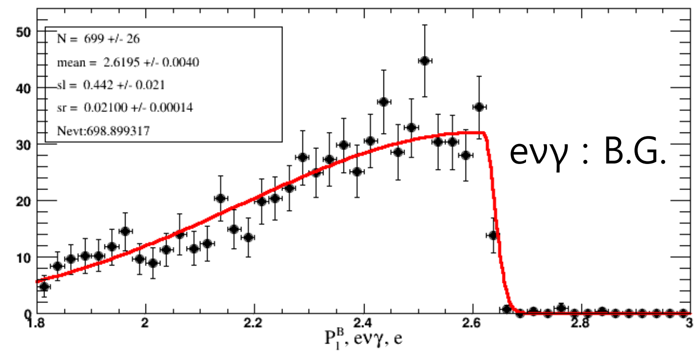
Mode	Branching Fraction		Scale factor
	Belle MC	PDG	
$\rho l \nu$	1.49×10^{-4}	1.07×10^{-4}	0.7181
$\eta l \nu$	8.4×10^{-5}	3.9×10^{-5}	0.4643
$\eta' l \nu$	3.3×10^{-5}	2.3×10^{-5}	0.6970

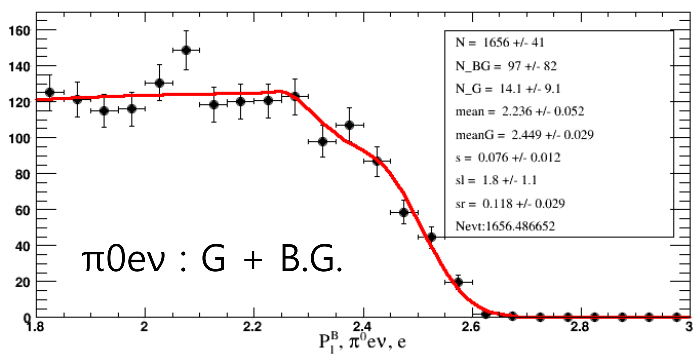
e-mode signal region(E_{ecl}<0.5 GeV)
All Other cuts are applied to signal region



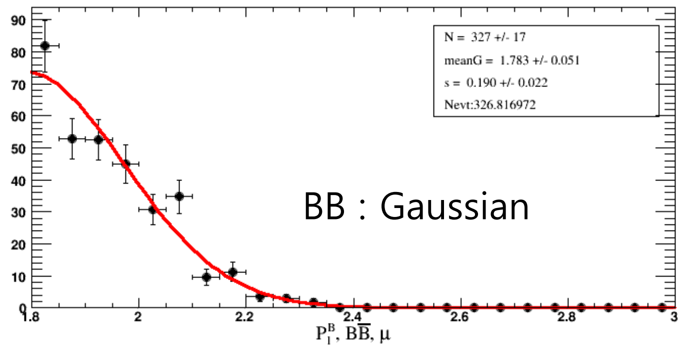


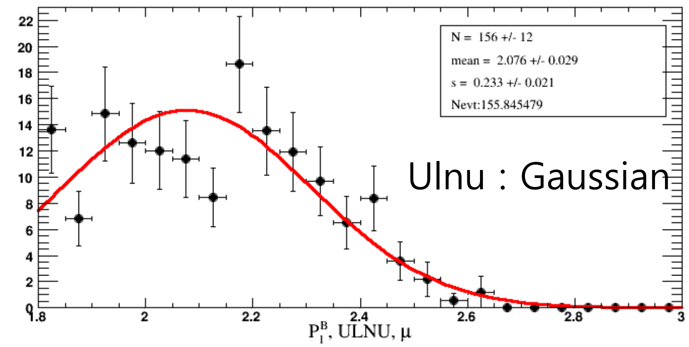


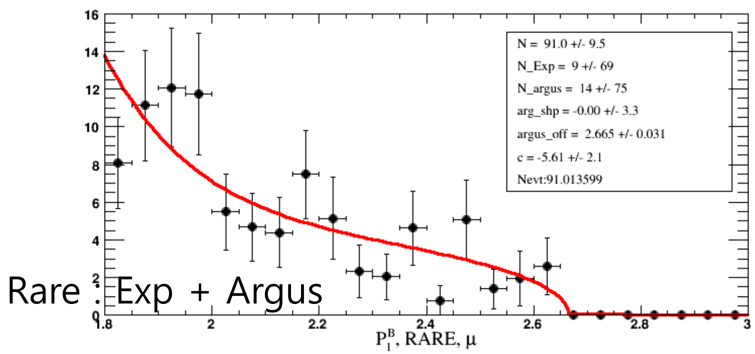


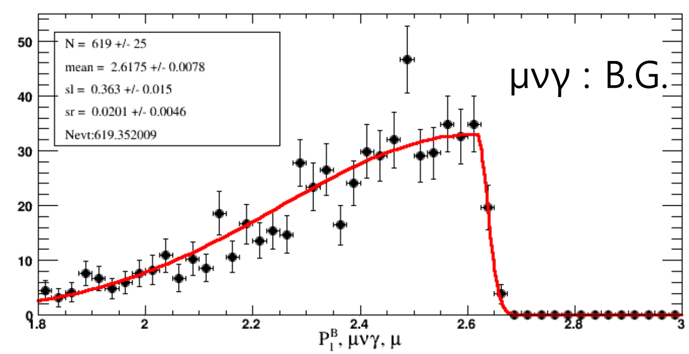


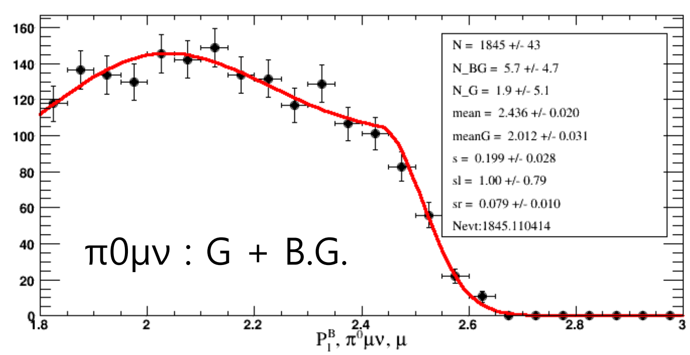
μ-mode signal region(E_{ecl}<0.5 GeV)
All Other cuts are applied to signal region

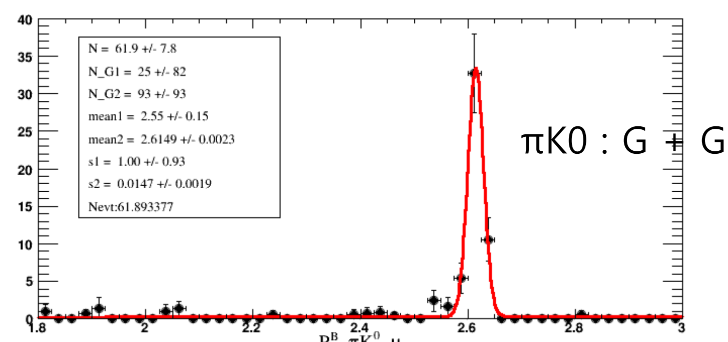












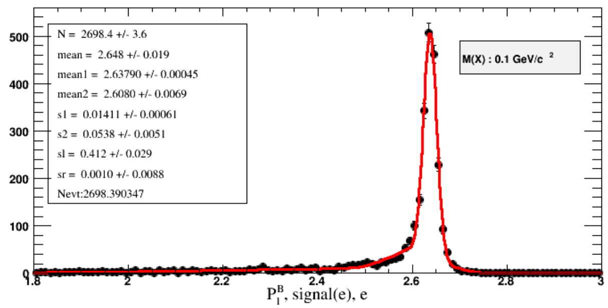
Signal (left : e mode, right : μ mode)

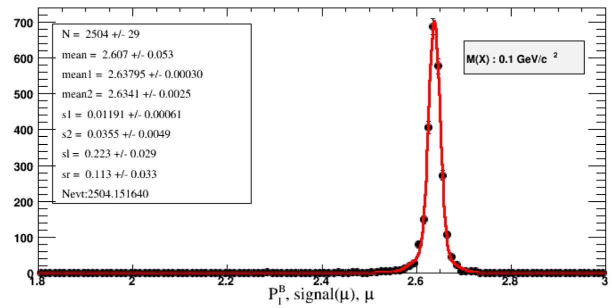
For E_{ecl}<0.5 & 1.8< p_l^B <3.0

Signal is fitted with

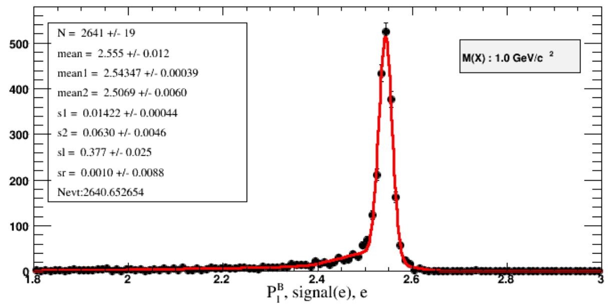
Gauss+Gauss+B.G

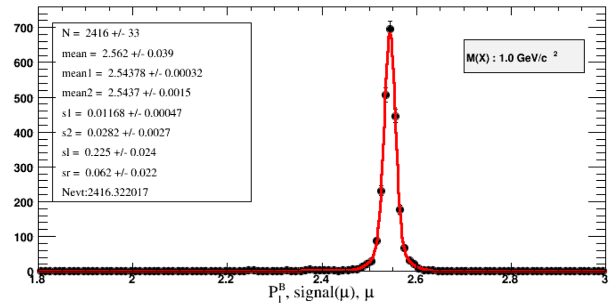
M_X : 0.1 GeV



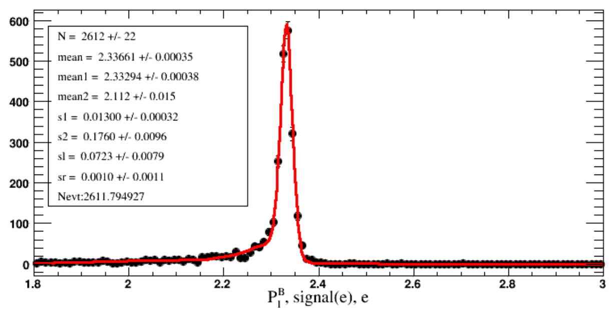


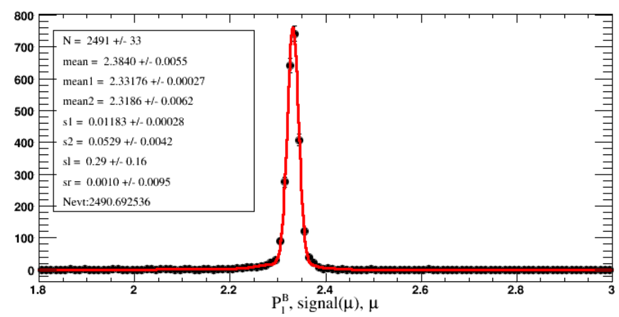
M_X : 1.0 GeV



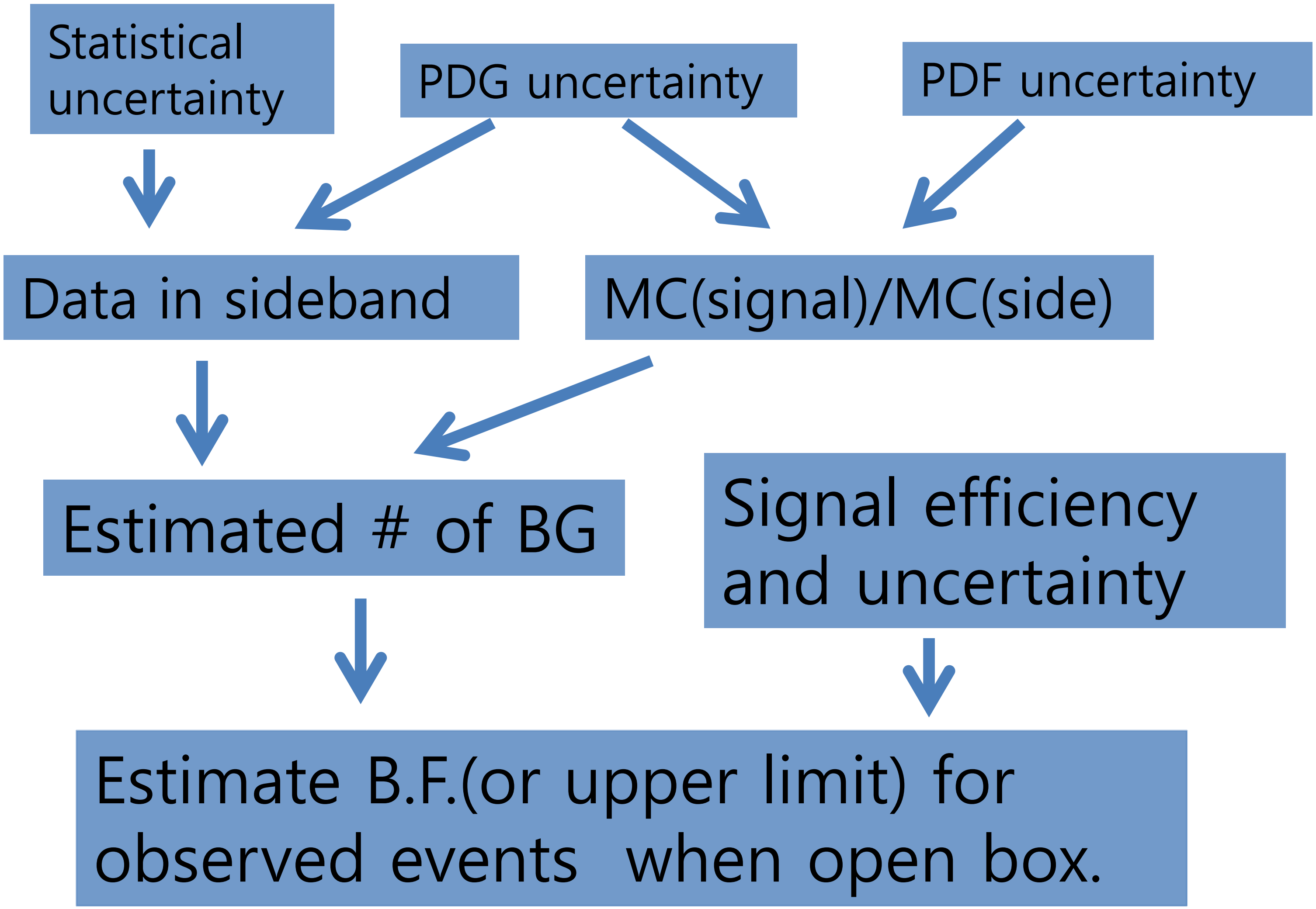


M_X : 1.8 GeV





Expectation of Branching Fraction



Expected Upper Limit

$$B.F. < \frac{U.L.(Yield)}{\varepsilon_{sig} N(B\bar{B})}$$

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

POLE → U.L.

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

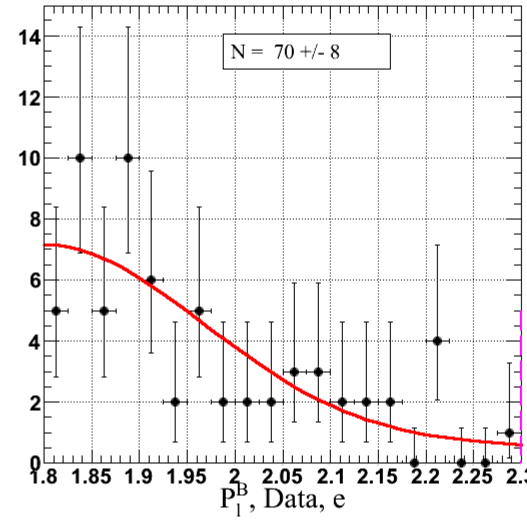
Optimization Study using the criterion of 'Best Upper Limit'

$$\text{Mean of U.L.} = \frac{\sum_{n=0}^{6} Yield_{U.L.}(BG_{est};n) \cdot Poisson(BG_{est};n;1000)}{\sum_{n=0}^{6} Poisson(BG_{est};n;1000) \cdot N(B\overline{B}) \cdot \varepsilon_{sig}}$$

- **n : # of observed events in signal region.**
- **Yield_{U.L.} : U.L. of Yields using POLE program**
- **Poisson : # of values of 1,000 events have Poisson dist**

$B^+ \rightarrow l^+ X^0$ - Optimization

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



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

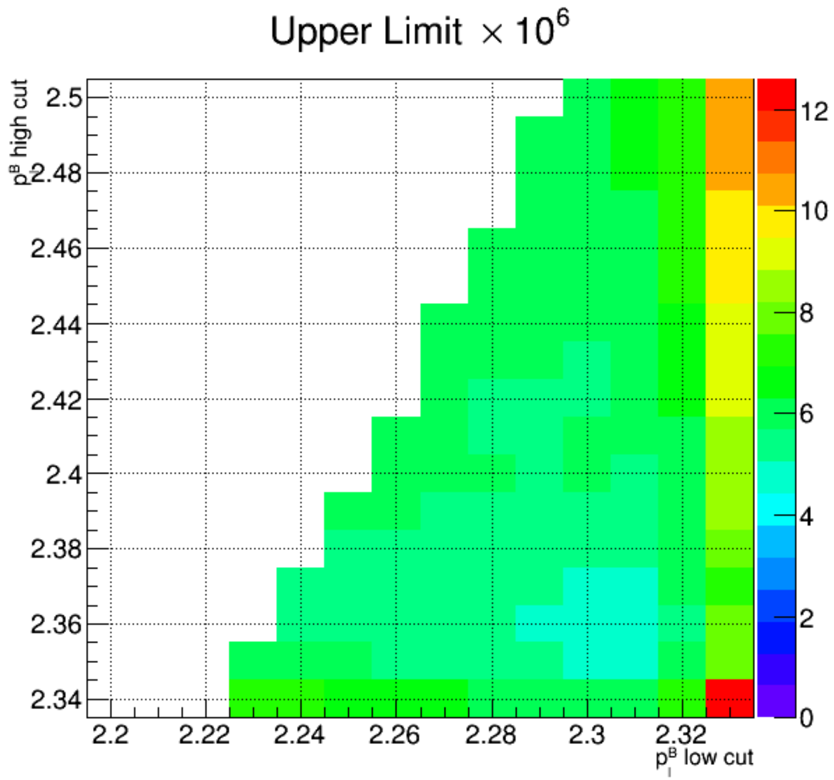
Feldman-Cousins method

POLE → U.L.

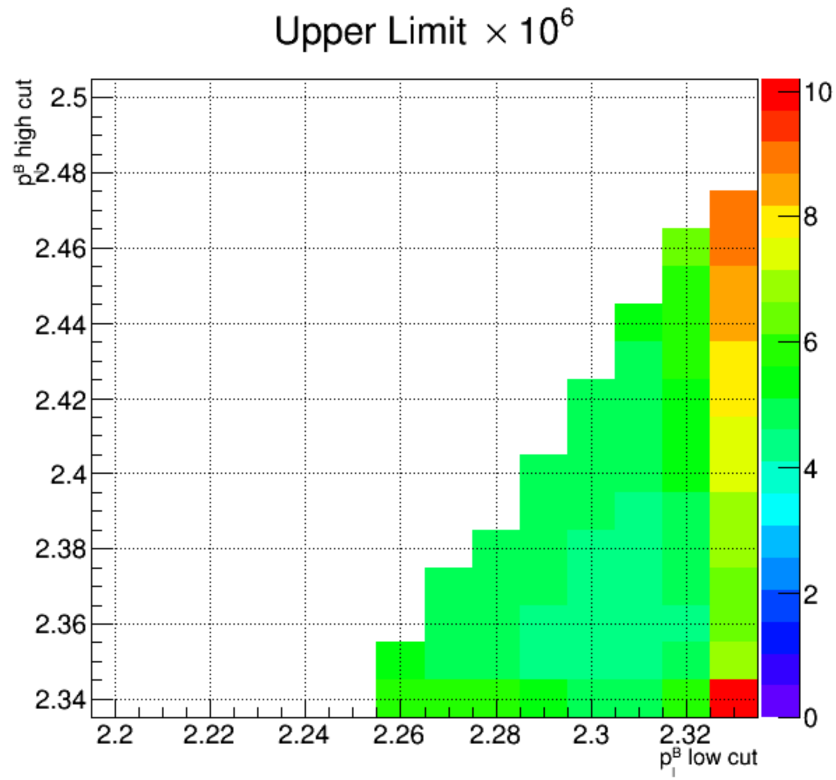
Uncertainty from PDG(BF), PDF, systematic, etc……

$B^+ \rightarrow l^+ X^0$ - Optimization

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



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



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

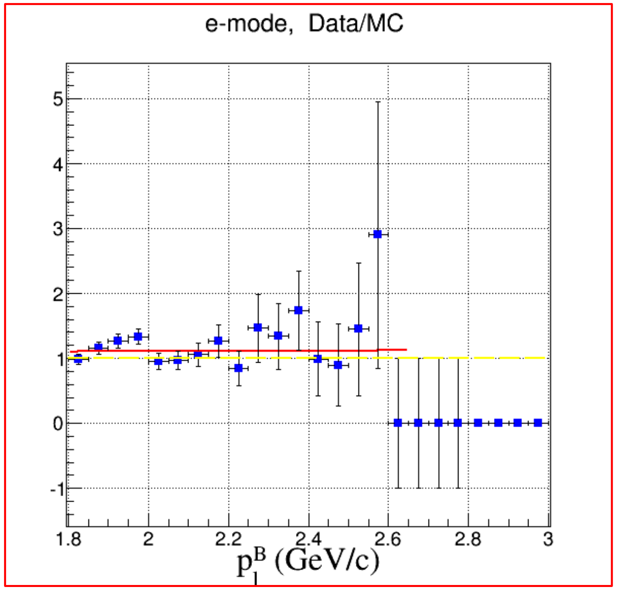
Summary Table (e-mode)

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

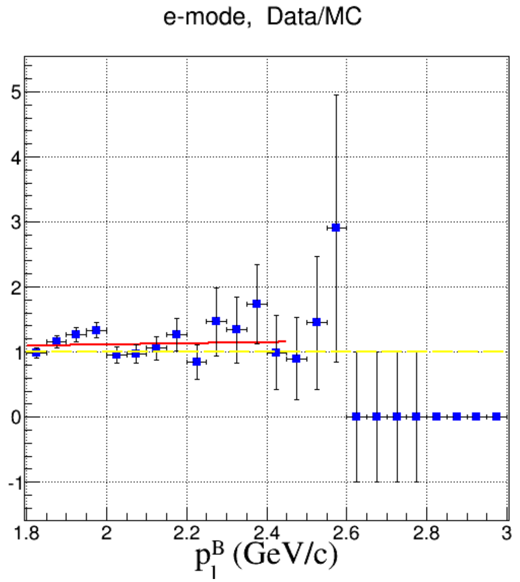
Summary Table (μ-mode)

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

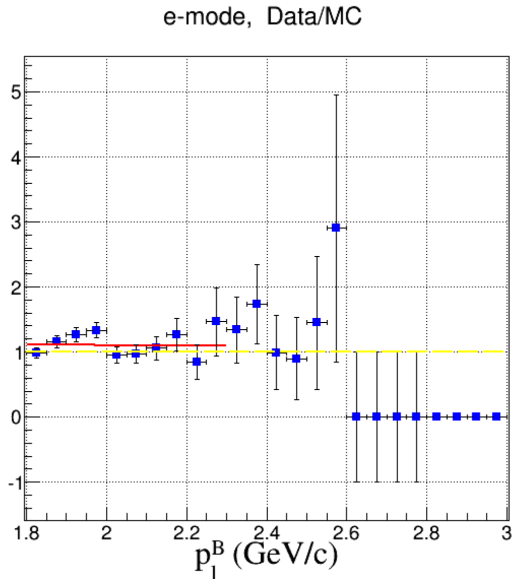
$B^+ \rightarrow l^+ X^0$ – E_{ECL} sideband calibration



$1.8 < p_l^B < 2.65$



$1.8 < p_l^B < 2.45$



$1.8 < p_l^B < 2.3$

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)

$B^+ \to l^+ X^0$ – E_{ECL} sideband calibration

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