Measurement of $B \to X_s\gamma$ at Belle

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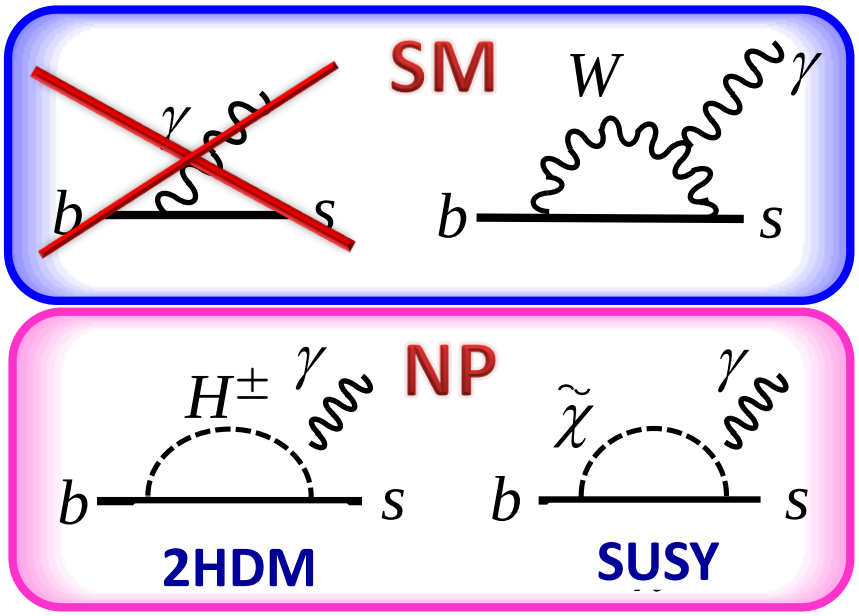
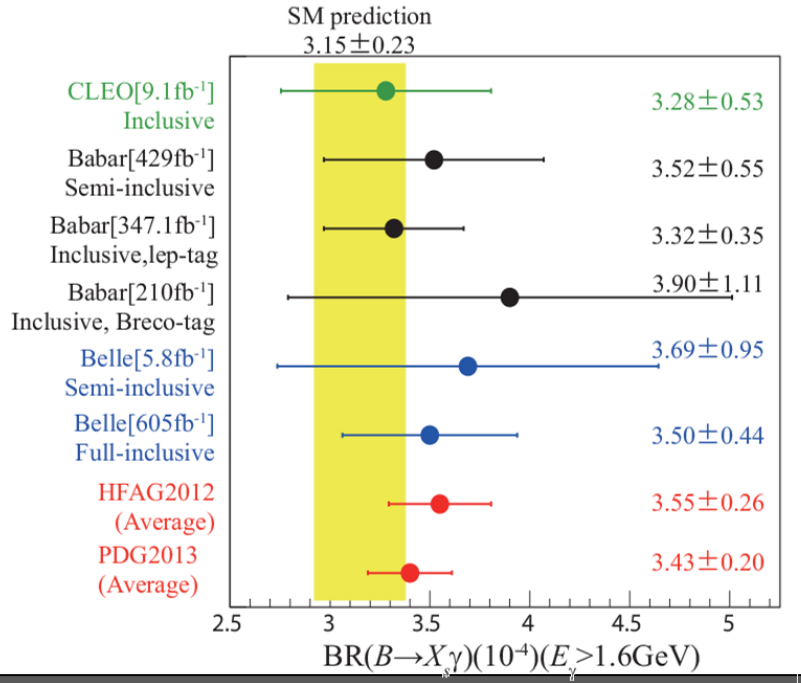
On the behalf of the Belle collaboration

Moriond EW, La Thuile, 17/03/2014

Introduction

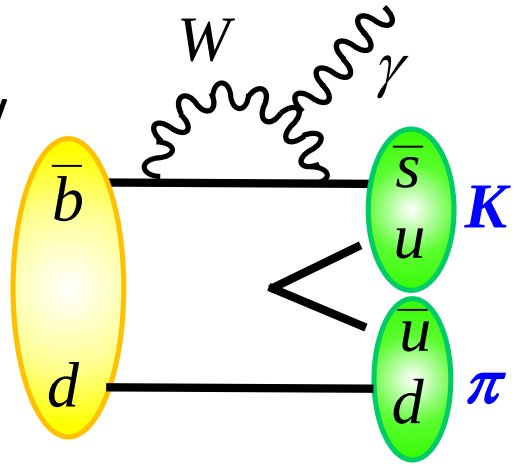
- **$b \to s\gamma$ transition :** Flavor Changing Neutral Current (FCNC)
  - Forbidden at tree level in the SM, and proceeds only at low rate via loop diagrams.
  - The inclusive branching fraction is sensitive to new particles within the loop. --> One of the best probe to search for new physics





Analysis Method

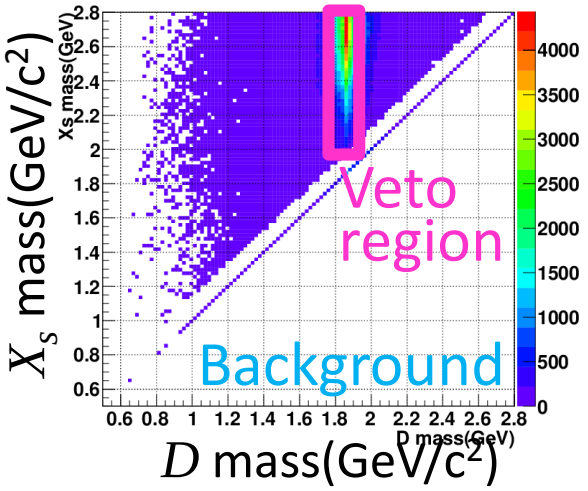
- **Signal**
  - Quark-level process of $b \to s\gamma$ can not be directly measured.
  - The measured process is a B meson decay into a photon plus an inclusive hadronic system(X_s).



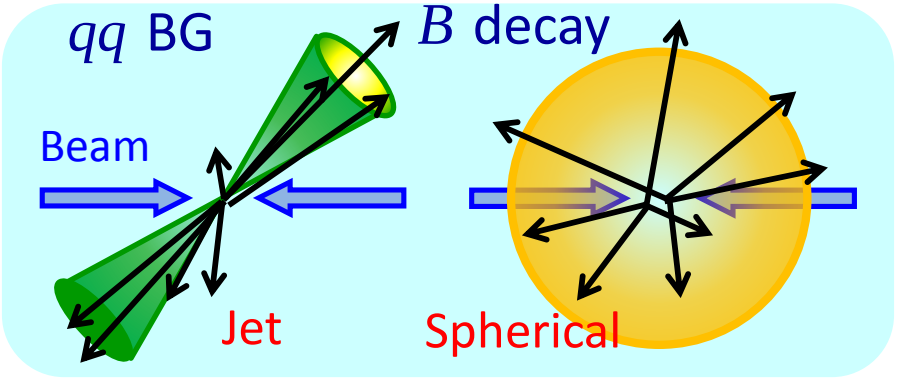
- X_s reconstruction : sum-of-exclusives approach
  - As many X_s final states as possible are reconstructed and summed to get the inclusive branching fraction.
  - 38 final states
    - Consist of 1 or 3 kaons(with at most 1 K_S), at most 1 η, and at most 4π (with at most 2π^0s)
    - Cover ~70% of X_s final state.
  - Unmeasured modes are estimated by Pythia.

Background

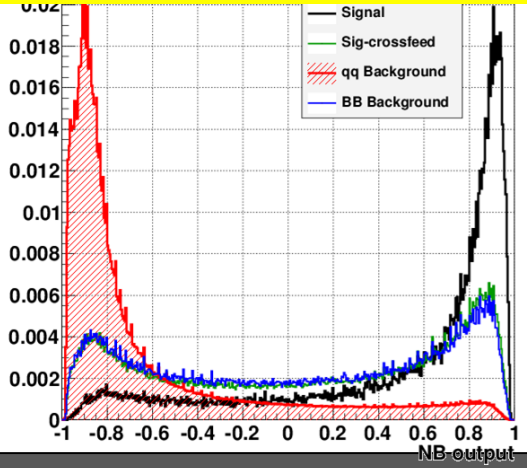
- **Event with D meson decay :**
  - $B \to D^{(*)}\rho$, etc.
  - vetoed by partially reconstructed D meson mass



- **$e^+e^- \to qq$ (q=u, d, c, s) event**
  - The largest background
  - Multivate analysis with Neural network(NeuroBayes)
  - 12 inputs(event shape variables, etc)



Output of Neural network

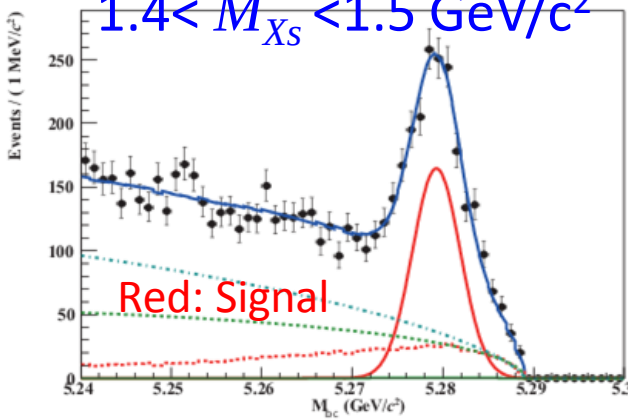


Signal Yield

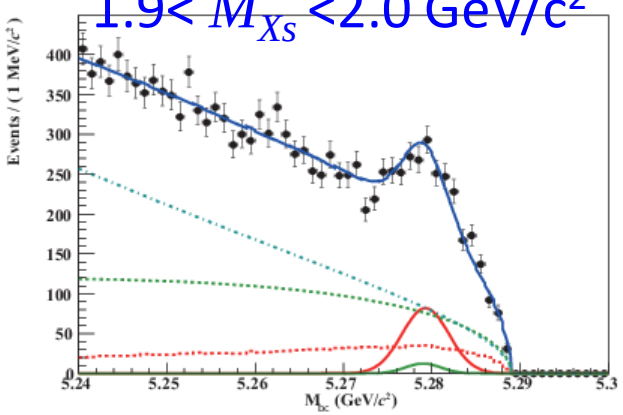
- **M_{bc} fit** to extract signal yield
  - $M_{bc} \equiv \sqrt{E_{beam}^{2} - |\vec{p}_B|^2}$
  - Fits in 19 X_s mass bins from 0.6 to 2.8 GeV/c² (=1.9 GeV of E_γ) to reduce uncertainty from M_{Xs} shape.

M_{bc} distributions

1.4< M_{Xs} <1.5 GeV/c²



1.9< M_{Xs} <2.0 GeV/c²



M_{X_s} bin(GeV/c²)	Yield
0.6-0.7	-6±10
0.7-0.8	36±14
0.8-0.9	2032±54
0.9-1.0	1689±49
1.0-1.1	301±27
1.1-1.2	310±31
1.2-1.3	1019±46
1.3-1.4	1117±50
1.4-1.5	1090±52
1.5-1.6	806±50
1.6-1.7	723±37
1.7-1.8	664±37
1.8-1.9	652±54
1.9-2.0	542±60
2.0-2.1	403±54
2.1-2.2	285±35
2.2-2.4	449±80
2.4-2.6	273±84
2.6-2.8	87±82

Results with Belle's full data

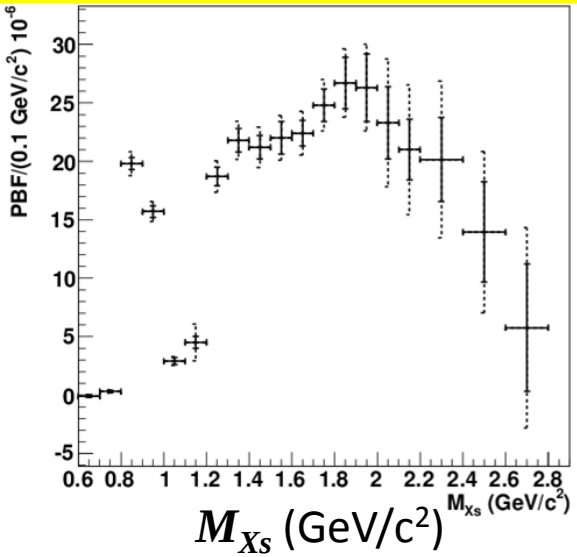
- $B(B \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}$ (M_{Xs}<2.8 GeV/c^2)
- Extrapolated BF to E_γ> 1.6 GeV to compare with the SM prediction

-->$B(B \to X_s\gamma) = (3.74 \pm 0.18 \pm 0.35) \times 10^{-4}$ (E_γ> 1.6 GeV)

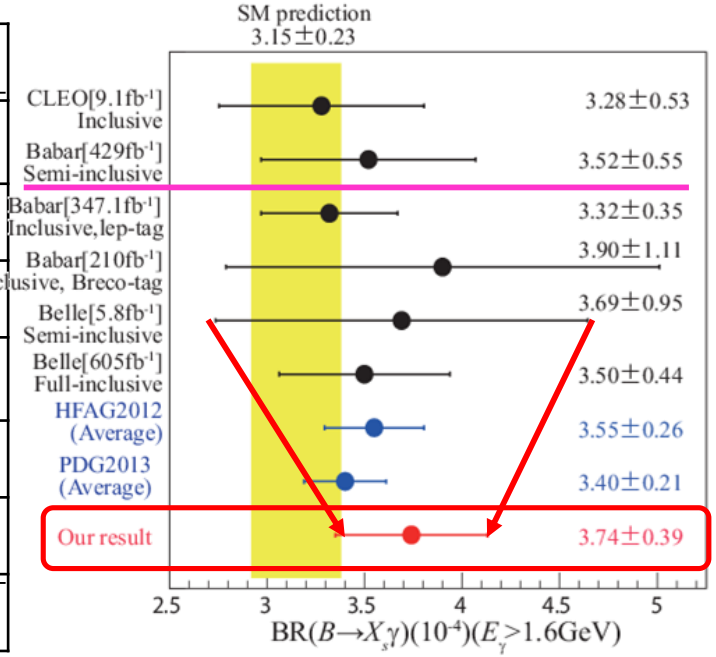
(Preliminary)

- Consistent with the SM prediction within 1.3σ.

Partial branching fraction



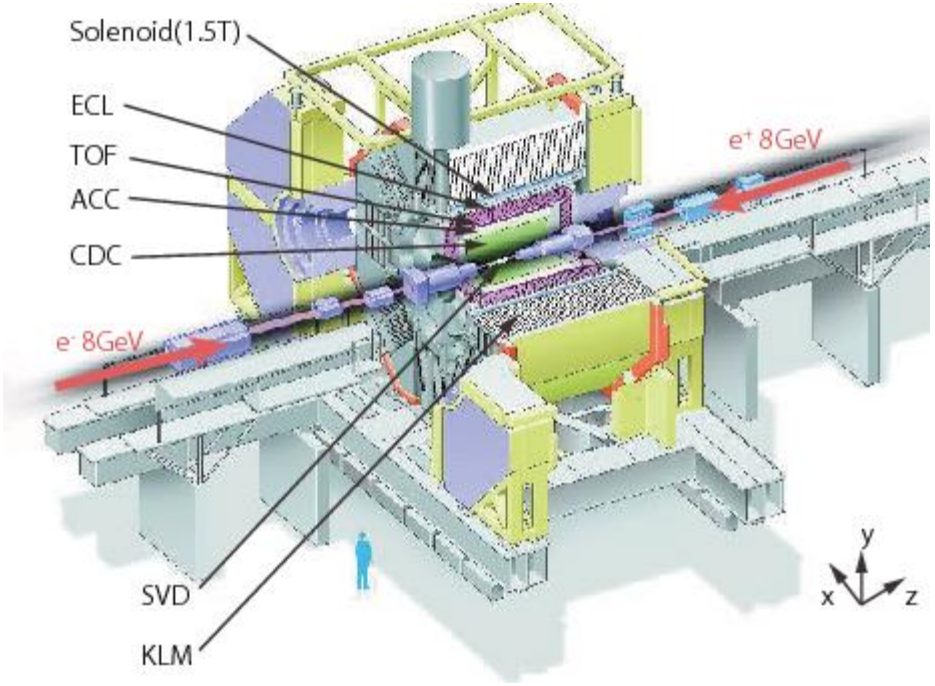
Systematic Uncertainties(%)	
B counting	1.4
Detector Response	3.0
Background Rejection	3.4
M_{bc} PDF	5.1
Fragmentation model	6.7
Missing mode	1.6
Total	**9.3**



Backup

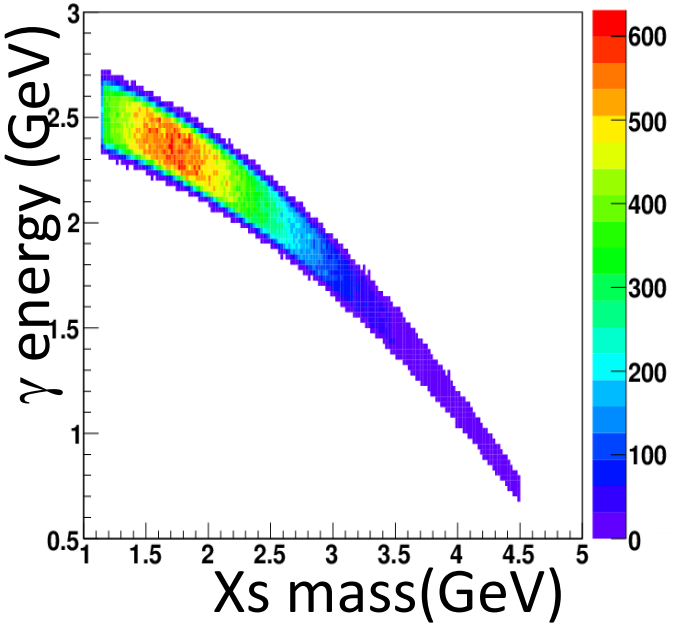
Belle Detector

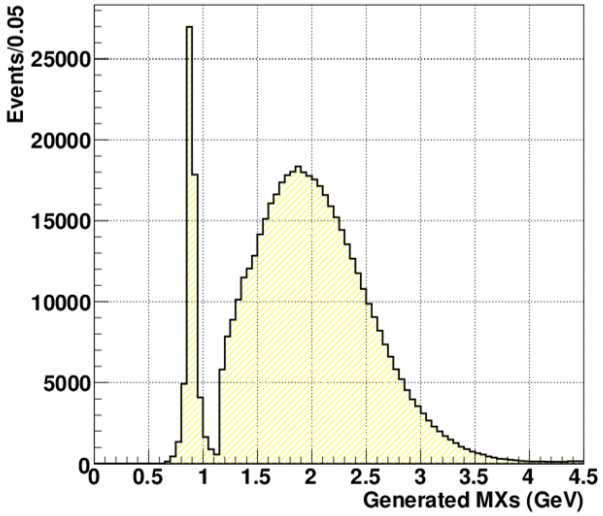
- **Vertex Detector** ($\sigma \sim 75\ \mu m$)
  - Silicon-strip Detector
- **Tracker** ($\sigma/p_t \sim 0.5\ \%$)
  - Central Drift Chamber
  - Silicon-strip Detector
- **Calorimeter** ($\sigma/E \sim 1.6\ \%$)
  - CsI Electromagnetic Calorimeter

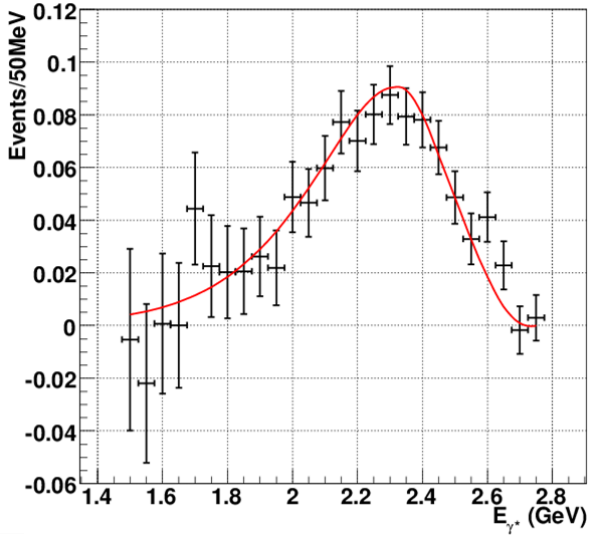


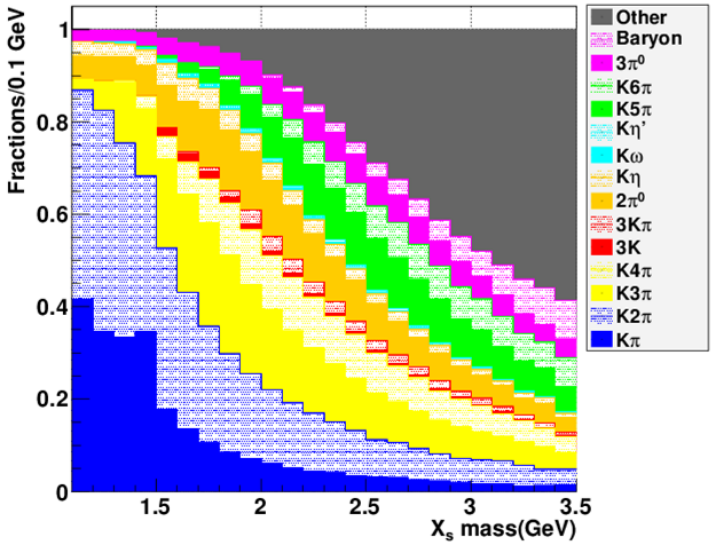
- **Paritle Identification**
  - $K^{\pm}/\pi^{\pm}$: CDC(dE/dx), Cherenkov counter, Time-of-Flight
    -> K ID 88 %、 π fake ID 8.5 %
  - Electron : E/p measured by CDC and calorimeter -> 92 % ID
  - K_L/μ : μ detector(RPC) -> 90 % μ ID

X_s mass vs γ energy









$b \to s\gamma$

$$\Gamma(b \to s\gamma) = \frac{G_F^2 \alpha_{em} m_b^5 \left| V_{ts}^* V_{tb} \right|^2}{32\pi^3} \left| C_7^{\text{eff}} \right|^2$$

Effective Hamiltonian of inclusive radiative B decay

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$$

C_i : Wilson coefficient

$O_{1,2}$: current current operator

$O_{3\text{-}6}$: QCD penguin operator

$O_{7,8}$: electro- and chromo operator

$O_{9,10}$: semi-leptonic operator

$B \to X_s \gamma$ asymmetries

- **Direct CPV** : Amplitude difference and between B and B

$$A_{CP} = \frac{\Gamma(B \to X_s\gamma) - \overline{\Gamma}(\overline{B} \to X_s\gamma)}{\Gamma(B \to X_s\gamma) + \overline{\Gamma}(\overline{B} \to X_s\gamma)}$$

  - Theoretical and experimental error are canceled.(Exclusive is also sensitive to NP)
  - SM = ~0.5 %

- **Isospin violation** : Amplitude difference and between B and B

$$\Delta_{0+} = \frac{\Gamma(B^+ \to X_s\gamma) - \Gamma(B^0 \to X_s\gamma)}{\Gamma(B^+ \to X_s\gamma) + \Gamma(B^0 \to X_s\gamma)}$$

  - SM = +5~10%

	Belle	**Babar**
A_{CP}	$0.002 \pm 0.050 \pm 0.030$ (140 fb^{-1})	$-0.011 \pm 0.030 \pm 0.014$ (350fb^{-1})
Δ_{0+}	No	$-0.006 \pm 0.058 \pm 0.009 \pm 0.024$ (350fb^{-1})

Reconstructed final states

Reconstructed final states				
$K\pi$	$K\pi$	$K_s\pi$	$K\pi^0$	$K_s\pi^0$
$K2\pi$	$K\pi\pi$	$K_s\pi\pi$	$K\pi\pi^0$	$K_s\pi\pi^0$
$K3\pi$	$K\pi\pi\pi$	$K_s\pi\pi\pi$	$K\pi\pi\pi^0$	$K_s\pi\pi\pi^0$
$K4\pi$	$K\pi\pi\pi\pi$	$K_s\pi\pi\pi\pi$	$K\pi\pi\pi\pi^0$	$K_s\pi\pi\pi\pi^0$
$3K$	KKK	KKK_s		
	$KKK\pi$	$KKK_s\pi$	$KKK\pi^0$	$KKK_s\pi^0$
$K\eta$	$K\eta$	$K_s\eta$	$K\eta\pi$	$K_s\eta\pi$
	$K\eta\pi^0$	$K_s\eta\pi^0$	$K\eta 2\pi$	$K_s\eta 2\pi$
	$K\eta\pi\pi^0$	$K_s\eta\pi\pi^0$		
$2\pi^0$	$K\pi^0\pi^0$	$K_s\pi^0\pi^0$	$K\pi\pi^0\pi^0$	$K_s\pi\pi^0\pi^0$
	$K\pi\pi\pi^0\pi^0$	$K_s\pi\pi\pi^0\pi^0$		

Systematic Uncertainties(%) in M_{Xs} bins

M_{X_s} bin (GeV/c^2)	$B\overline{B}$ counting	Detector response	Background rejection	Signal PDF	Scf PDF	Peaking BG PDF	$q\overline{q}$ BG PDF	Frag.	Missing fraction	Total
0.6-0.7	1.4	2.7	3.4	0.0	0.0	0.0	0.0	-	-	4.5
0.7-0.8	1.4	2.6	3.4	0.1	12.2	7.8	0.0	-	-	15.3
0.8-0.9	1.4	2.6	3.4	0.2	0.4	0.5	0.0	-	-	4.5
0.9-1.0	1.4	2.6	3.4	0.1	0.5	0.4	0.0	-	-	4.5
1.0-1.1	1.4	2.6	3.4	0.1	2.9	1.1	0.3	-	-	5.4
1.1-1.2	1.4	3.0	3.4	0.4	3.1	1.7	0.2	32.1	1.2	32.1
1.2-1.3	1.4	3.2	3.4	0.2	1.6	0.9	0.0	2.1	1.0	5.6
1.3-1.4	1.4	3.2	3.4	0.2	1.6	0.2	0.0	2.6	1.9	6.0
1.4-1.5	1.4	3.1	3.4	0.2	2.0	0.1	0.0	4.0	1.3	6.7
1.5-1.6	1.4	3.3	3.4	0.6	2.2	0.1	0.0	2.4	1.3	6.1
1.6-1.7	1.4	3.5	3.4	0.1	1.7	2.1	0.2	2.8	1.9	6.7
1.7-1.8	1.4	3.6	3.4	0.1	2.2	1.7	0.2	3.4	1.0	6.8
1.8-1.9	1.4	3.7	3.4	0.1	1.9	2.0	0.1	3.6	2.1	7.2
1.9-2.0	1.4	3.7	3.4	0.1	4.2	4.0	0.1	3.7	1.6	8.8
2.0-2.1	1.4	3.8	3.4	0.1	5.6	0.6	0.2	17.8	2.2	19.5
2.1-2.2	1.4	3.8	3.4	0.3	3.7	2.5	0.4	21.9	1.9	23.1
2.2-2.4	1.4	3.8	3.4	0.1	7.4	7.1	0.0	25.5	1.6	28.0
2.4-2.6	1.4	3.8	3.4	0.1	11.5	21.8	0.3	29.6	1.0	38.9
2.6-2.8	1.4	3.8	3.4	0.1	44.7	101.0	0.9	29.4	2.0	114

Fragmentation model study

1	$K\pi$ without π^0
2	$K\pi$ with π^0
3	$K2\pi$ without π^0
4	$K2\pi$ with π^0
5	$K3\pi$ without π^0
6	$K3\pi$ with π^0
7	$K4\pi$
8	$2\pi^0$
9	$K\eta$
10	$3K$

$1.15< M_{X_s} <1.5$ GeV/c^2			$1.5< M_{X_s} <2.0$ GeV/c^2		
Mode	Data	MC	Mode	Data	MC
1	10.7±0.62	14.5 (+6.4)	1	2.39±0.35	2.91 (+1.5)
2	5.32±0.31	7.50 (+7.1)	2	1.19±0.18	1.49 (+1.7)
3	25.7±0.82	21.6 (-5.0)	3	13.6±0.76	15.0 (+1.9)
4	44.8±1.51	36.5 (-5.5)	4	19.7±1.06	22.0 (+2.2)
5	0.91±0.52	0.95 (+0.1)	5	11.3±0.94	6.58 (-5.0)
6	8.06±2.17	14.9 (+3.1)	6	21.7±2.39	23.7 (+0.8)
7	0.30±0.50	0.52 (+0.5)	7	8.80±2.70	8.35 (-1.7)
8	2.52±2.52	1.85 (-0.3)	8	14.7±2.08	8.20 (-3.1)
9	1.71±0.43	0.93 (-1.8)	9	5.00±1.27	5.78 (+0.6)
10	0.00±0.00	0.01 (+0.0)	10	1.64±0.24	1.29 (-1.5)
$2.0< M_{X_s} <2.4$ GeV/c^2			$2.4< M_{X_s} <2.8$ GeV/c^2		
Mode	Data	MC	Mode	Data	MC
1	1.21±0.64	2.91 (-0.1)	1	0.46±0.65	0.90 (+0.7)
2	0.60±0.32	1.49 (+0.0)	2	0.23±0.32	0.49 (+0.8)
3	7.06±1.37	15.0 (+1.9)	3	3.84±2.15	8.20 (+2.0)
4	8.93±2.63	22.0 (+1.9)	4	8.49±4.03	11.8 (+0.8)
5	12.1±2.53	6.58 (-1.5)	5	12.7±5.20	8.18 (-0.9)
6	16.1±5.65	23.7 (+1.1)	6	3.27±12.8	21.2 (+1.4)
7	28.0±9.10	8.35 (-1.3)	7	3.10±26.7	20.4 (-0.7)
8	15.5±15.5	8.20 (-0.4)	8	53.1±28.7	7.69 (-1.6)
9	6.82±3.69	5.78 (-0.2)	9	10.6±8.19	5.89 (-0.6)
10	3.61±1.10	1.29 (-2.0)	10	4.13±2.84	1.04 (-1.1)

Systematics

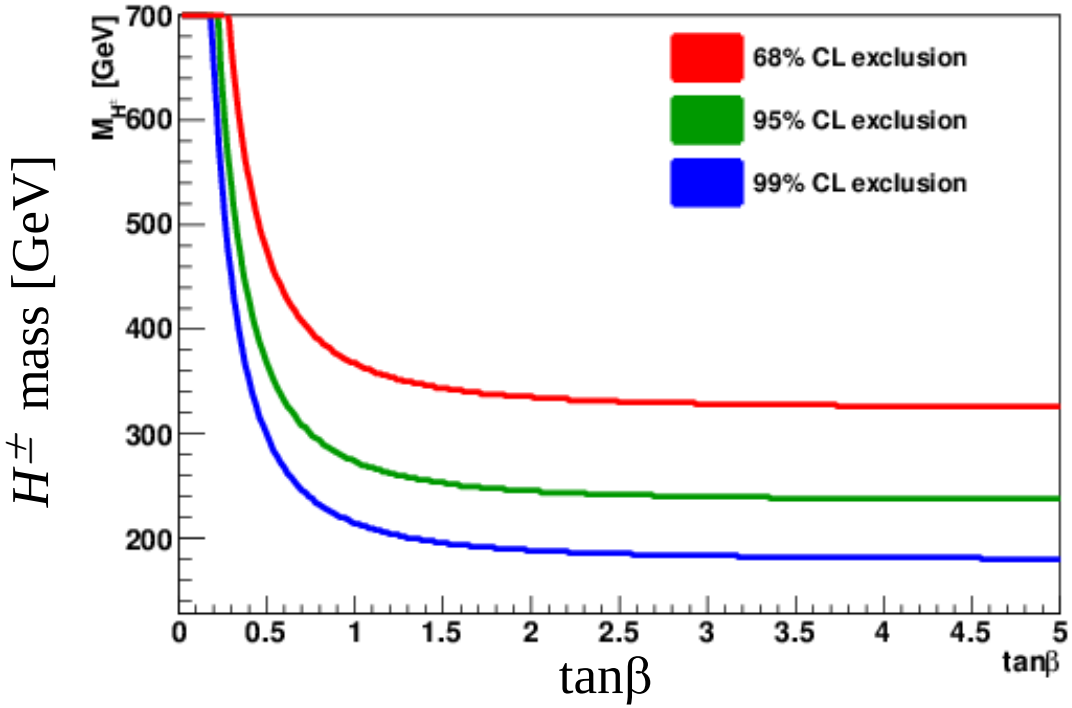
- Fragmentation Model Uncertainty
  - The fractions in total M_{Xs} region are fluctuated by $\pm 1\sigma$ to evaluate the uncertainty.

    → Systematics : 6.7 %

- Missing Mode Uncertainty
  - Reconstructed mode = 76.6 % ($1.15 < M_{Xs} < 2.8$ GeV/c^2)
  - Parameters in Pythia are shifted within parameter region which is consistent with the model of the data.

    → Systematics : 1.6 %

Constraint to 2HDM



- Consistent with the SM prediction, $(3.15 \pm 0.23) \times 10^{-4}$, within 1.3σ.
- $M_{H\pm}$ >238 GeV/c^2(95%CL) in 2HDM.