Analysis of $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ at Belle

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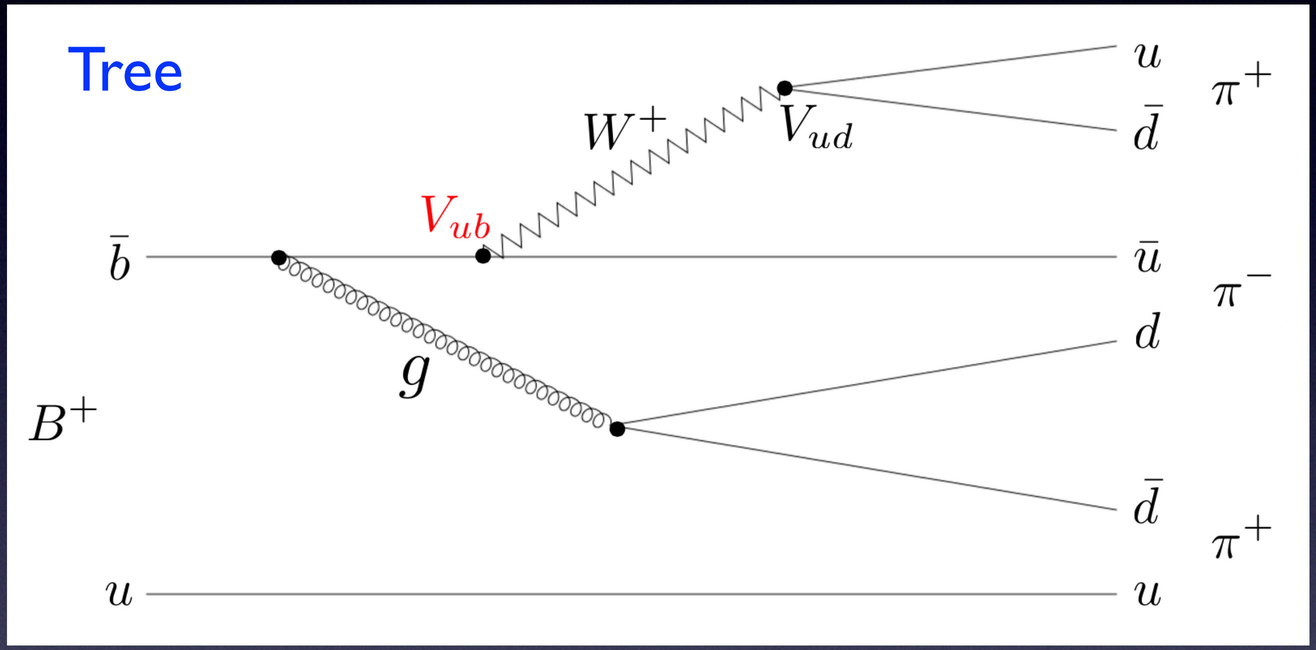
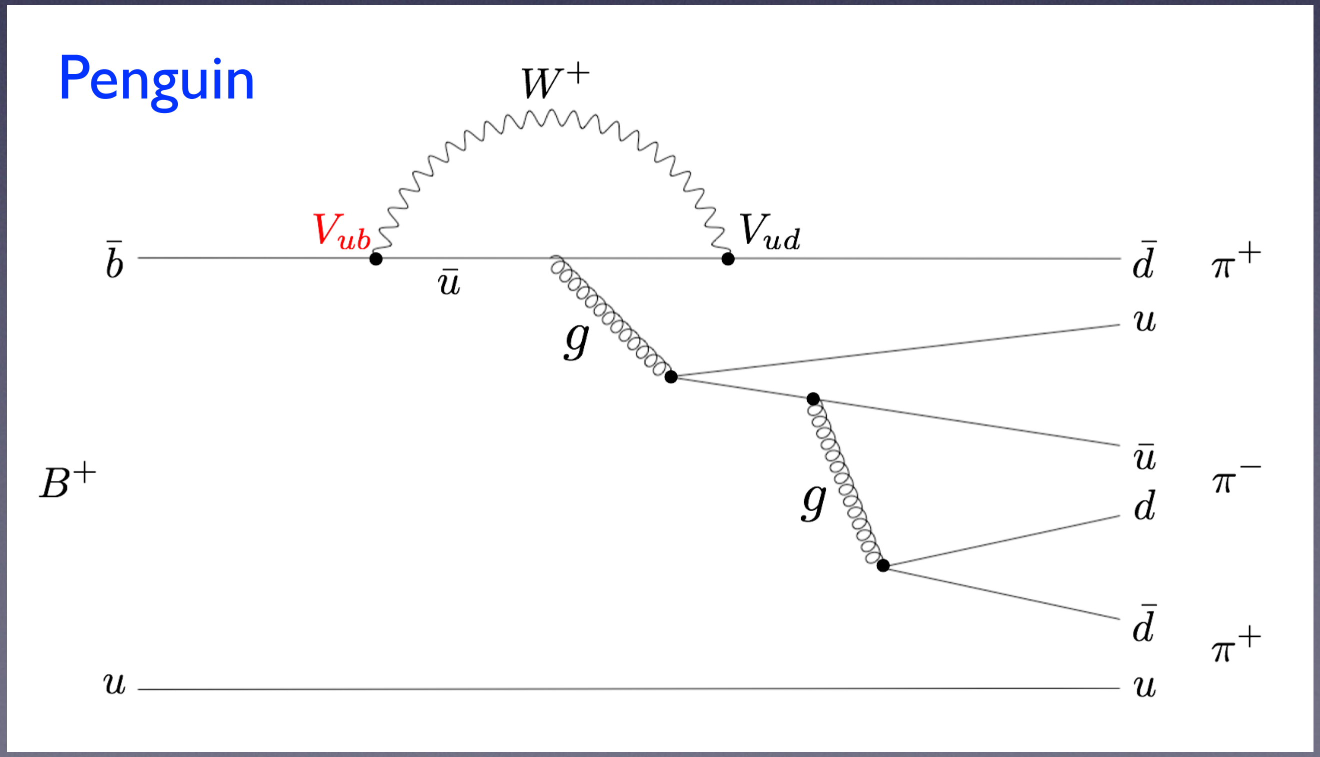
Outline

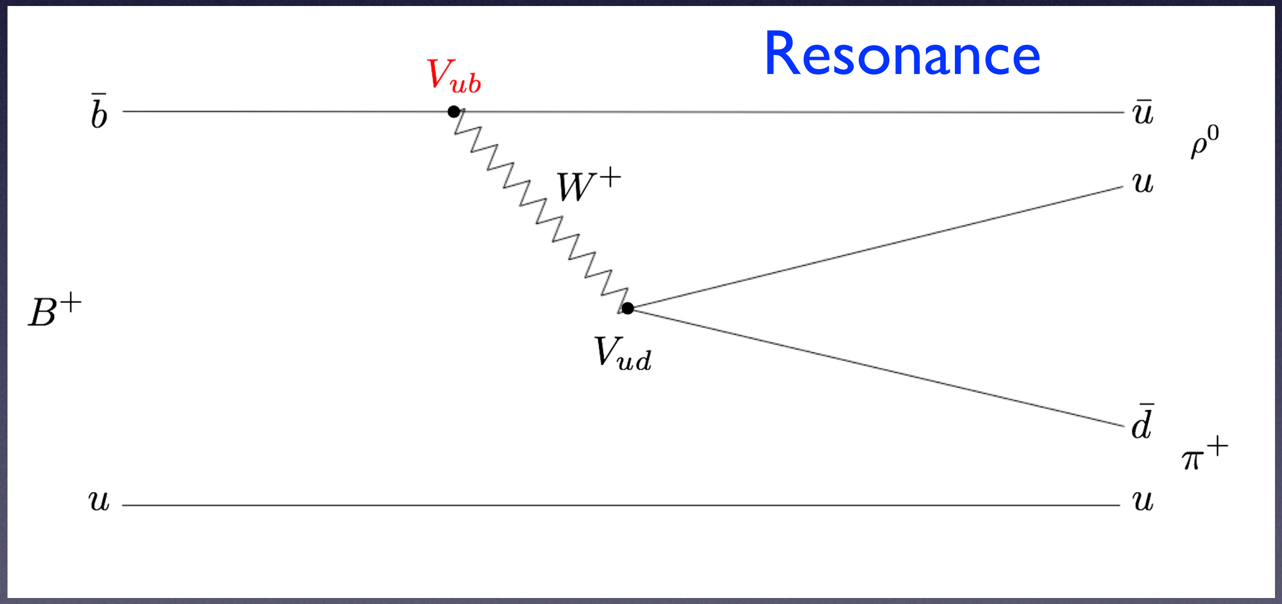
- Motivation
- Belle detector
- Data skim and MC simulation
- Continuum background suppression
- $B\bar{B}$ background suppression
- Other backgrounds from rare B decays

1. Motivation

- Probe the properties of the weak interaction through their dependence on the <u>complex quark couplings</u> in CKM matrix (V_{ub})
- Measure <u>direct CP asymmetry</u> via rate difference between B^+ and B^- decay





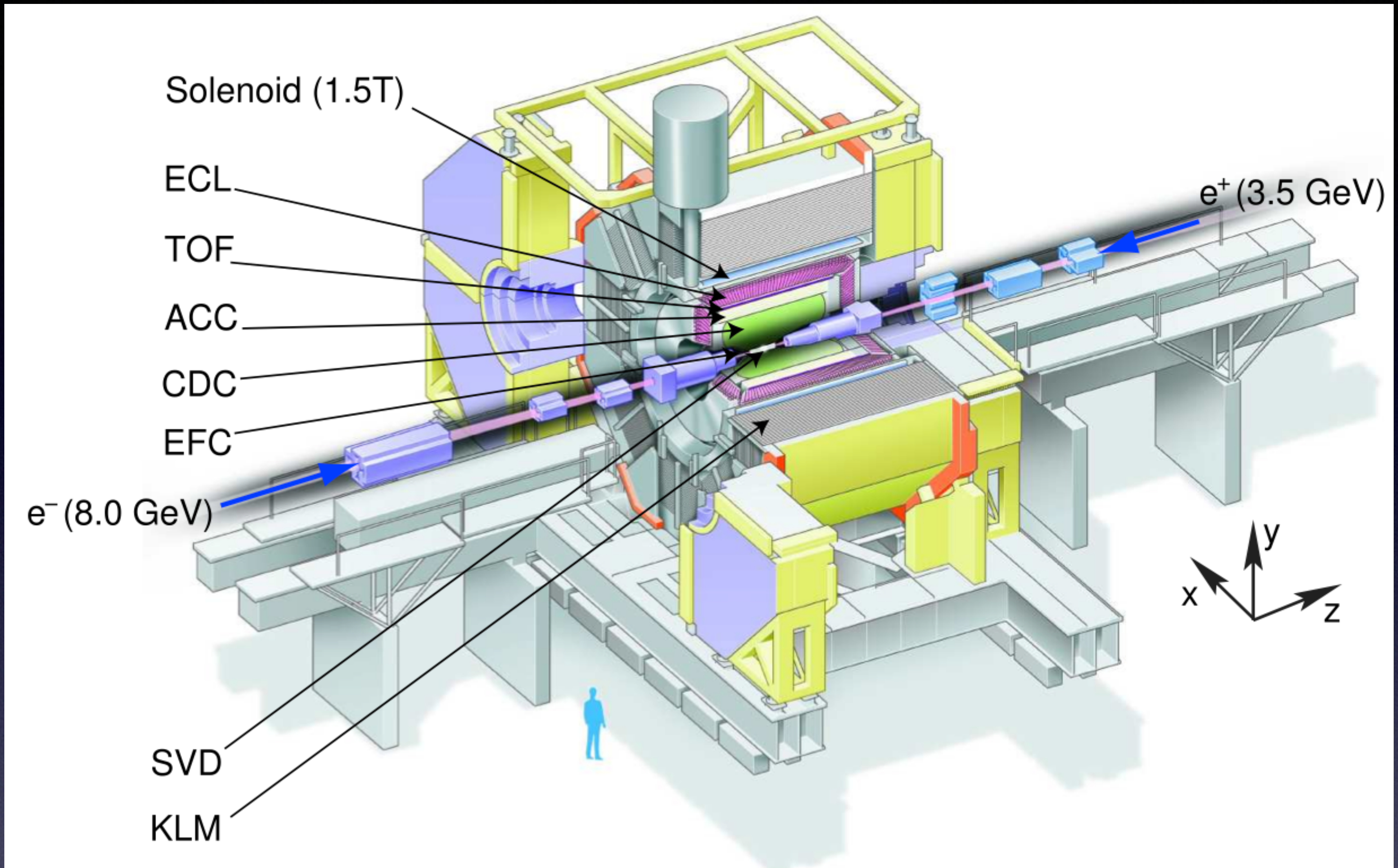


Previous Results of Branching Fractions

Year Reported	Collaboration	Number of $B\overline{B}$ Pairs (x10^6)	Branching Fraction (x10^{-6})
2002	Belle	32	$8.0^{+2.3}_{-2.0} \pm 0.7$
2003	BaBar	89	$10.9 \pm 3.3 \pm 1.6$
2005	BaBar	232	$16.2 \pm 1.2 \pm 0.9$
2009	BaBar	465	$15.2 \pm 0.6^{+1.3}_{-1.2}$

- The previous similar analysis at Belle in 2002 is $B^+ \to \rho^0 \pi^+$.
- Number of $B\overline{B}$ pairs from Belle in this analysis: 772 x 10^6.

2. Belle Detector



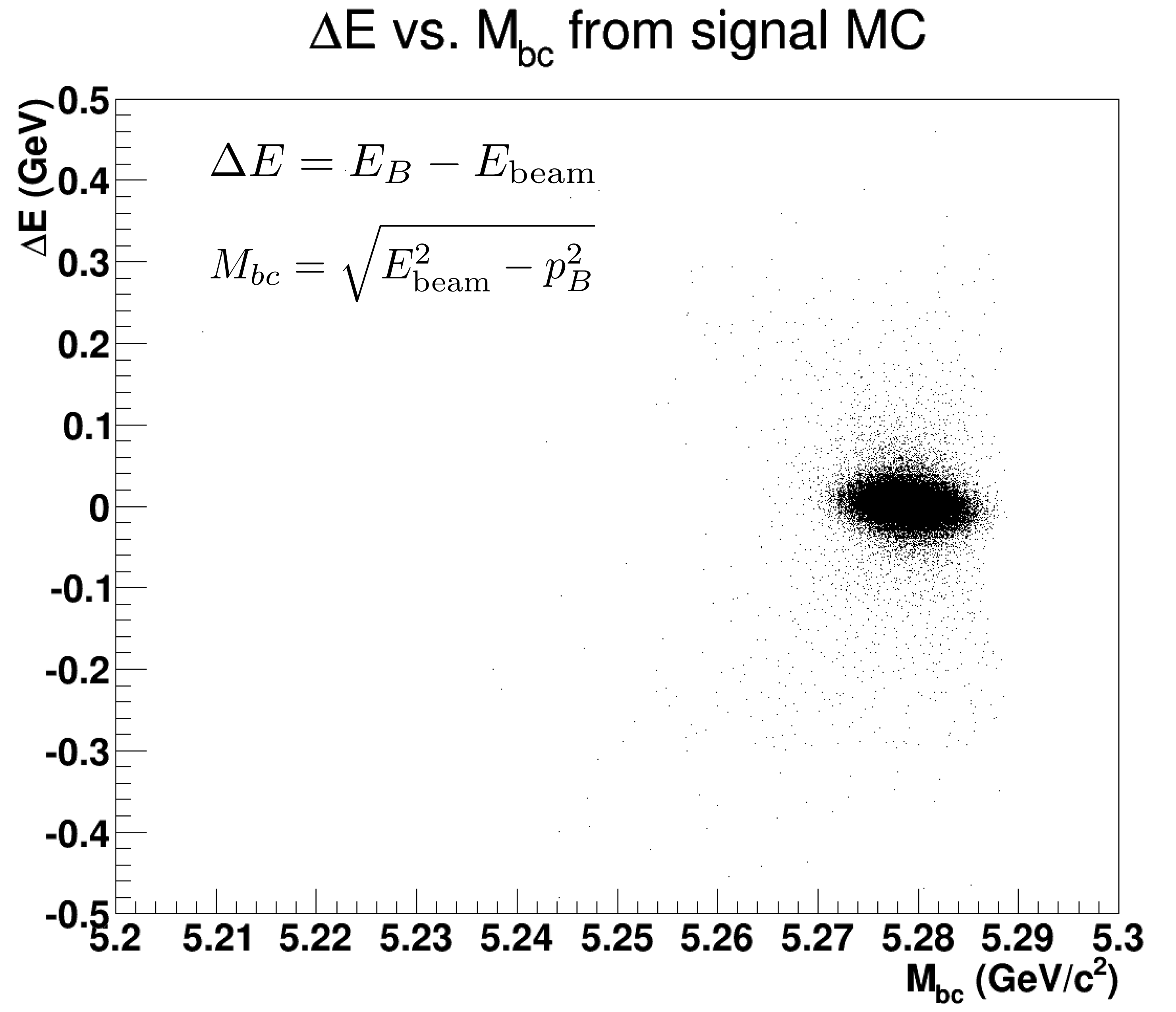
Functions of sub-detectors:

- *B* decay vertices: SVD (Silicon Vertex Detector)
- Charged particle tracking: CDC (Central Drift Chamber)
- π/K identification: CDC, ACC (Aerogel Cherenkov Counter), TOF (Time of Flight Counter)
- Electron identification: ECL (Electromagnetic Calorimeter)
- Muon and K_L identification: KLM (K_L and μ Detector)

3. Event Reconstruction and Data Skim

1. Event reconstruction: three charged pions (±+-) to form a *B* meson candidate.

2. Real data skimmed to save the events related to this analysis only.
   - Skim condition applied on real data: M_{bc}(5.2 - 5.3 GeV/c^2) and ΔE(-0.5 – 0.5 GeV), in Upsilon(4S) center of mass frame.
   - Passing ratio ~ 4%



3. Extra cuts for skimming on generic MC samples (continuum and $B\bar{B}$ events).
   - Track vertex |dr| < 1 cm;
   - Track vertex |dz| < 5 cm;
   - Particle ID likelihood π/K > 0.1;

Passing ratio ~ 1.13%

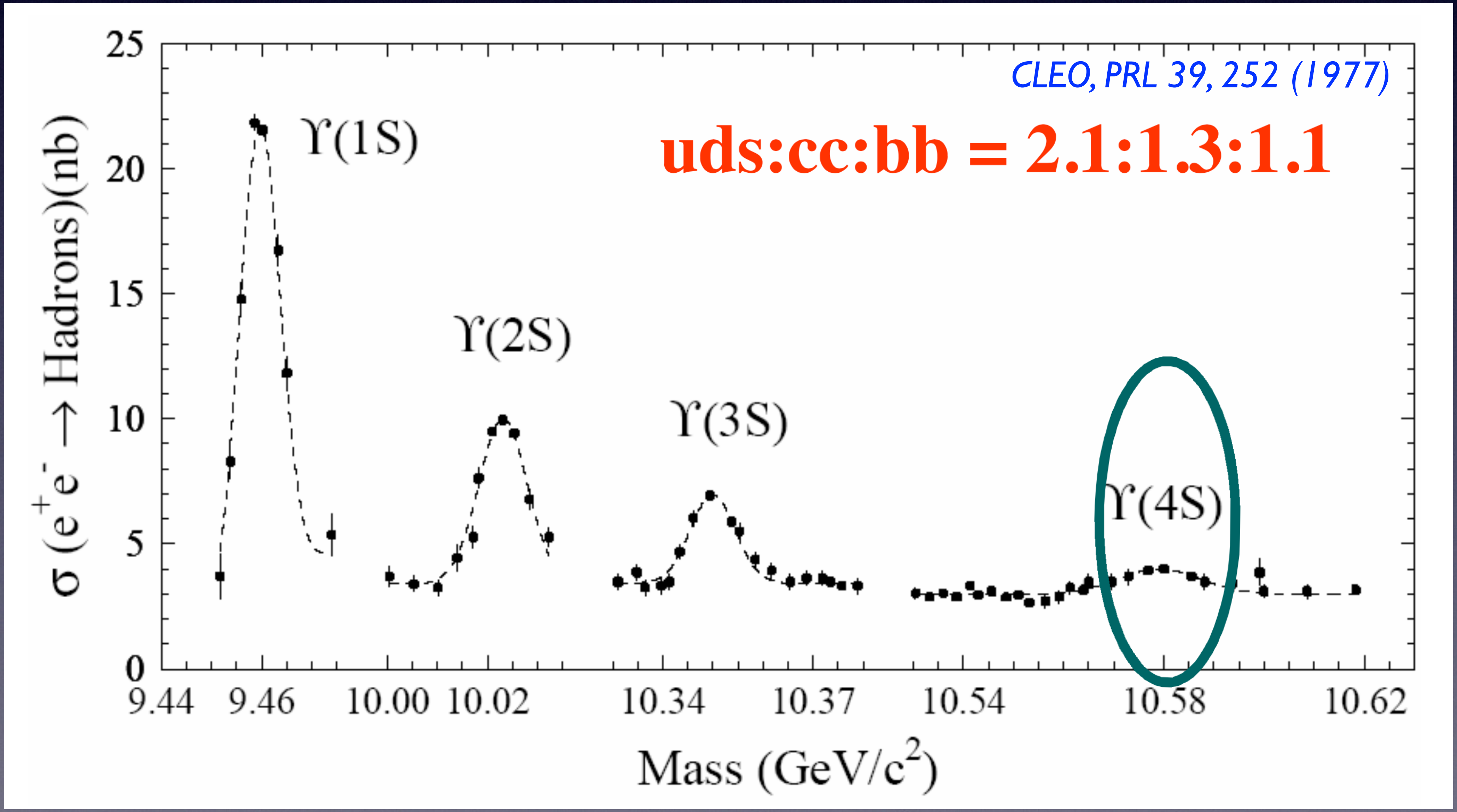
Data Sample from MC Simulation

Type of MC Simulation	Number of Events
Signal	658 streams
Each type of $B\bar{B}$ background	44-971 streams
Generic $B\bar{B}$	10 streams
Generic $q\bar{q}$	6 streams
Rare B	50 streams

- One stream equals the same amount of events in the real data.

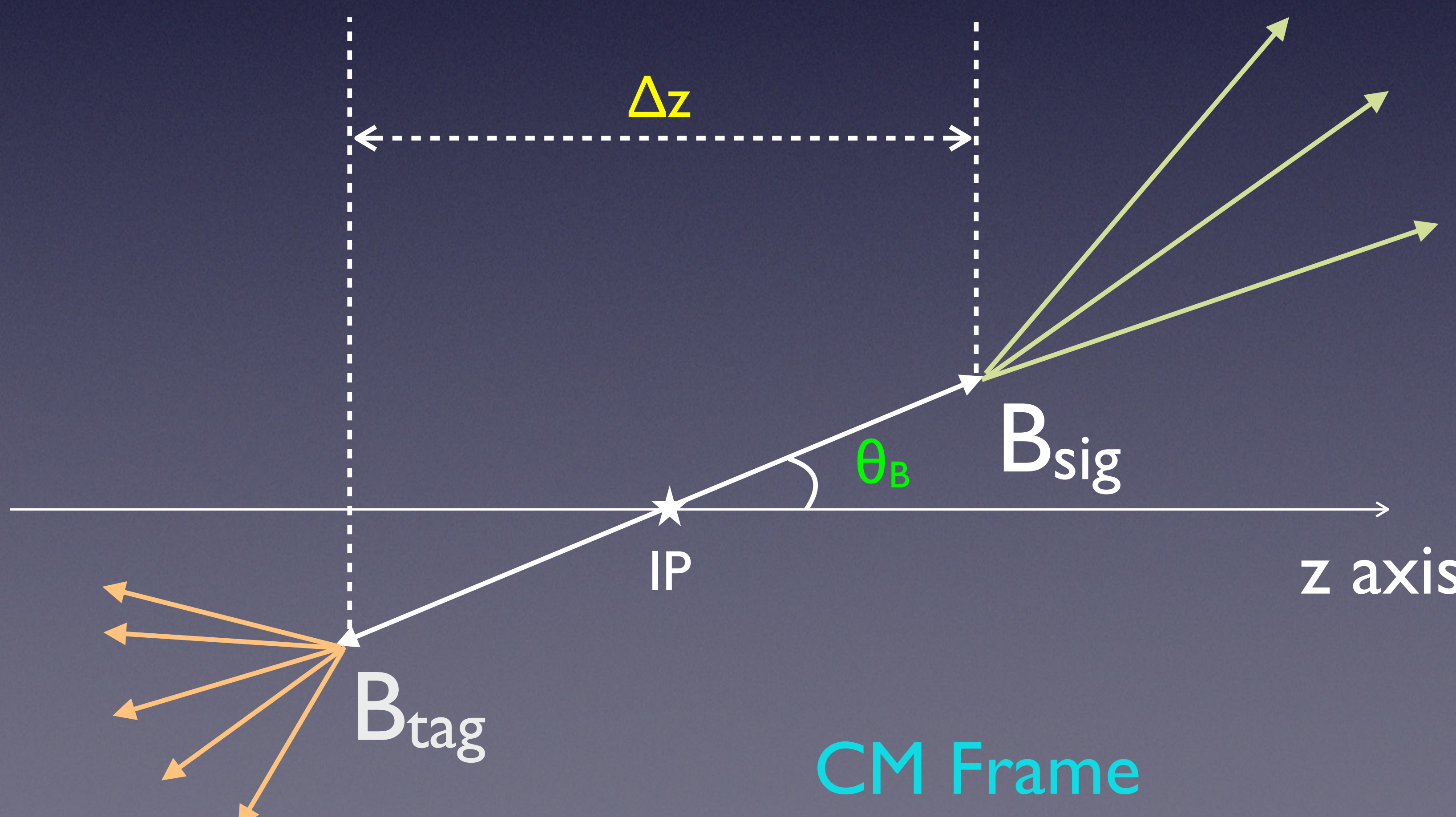
4. Continuum Background Suppression

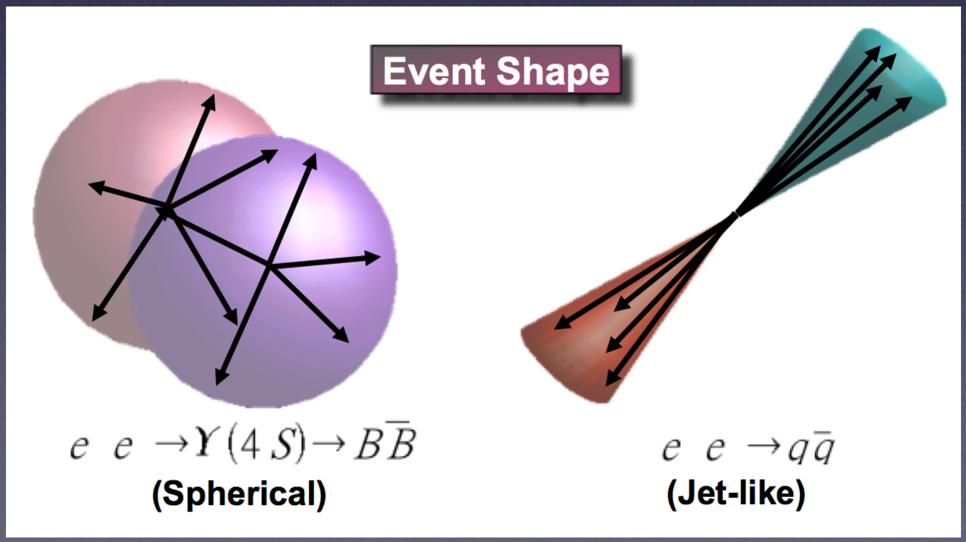
1. Continuum $e^+e^- \to q\bar{q}\ (q = u, d, s, c)$ events are the most dominant background
2. Method to suppress the continuum background: exploit the difference in event topology by signal MC and continuum MC data.



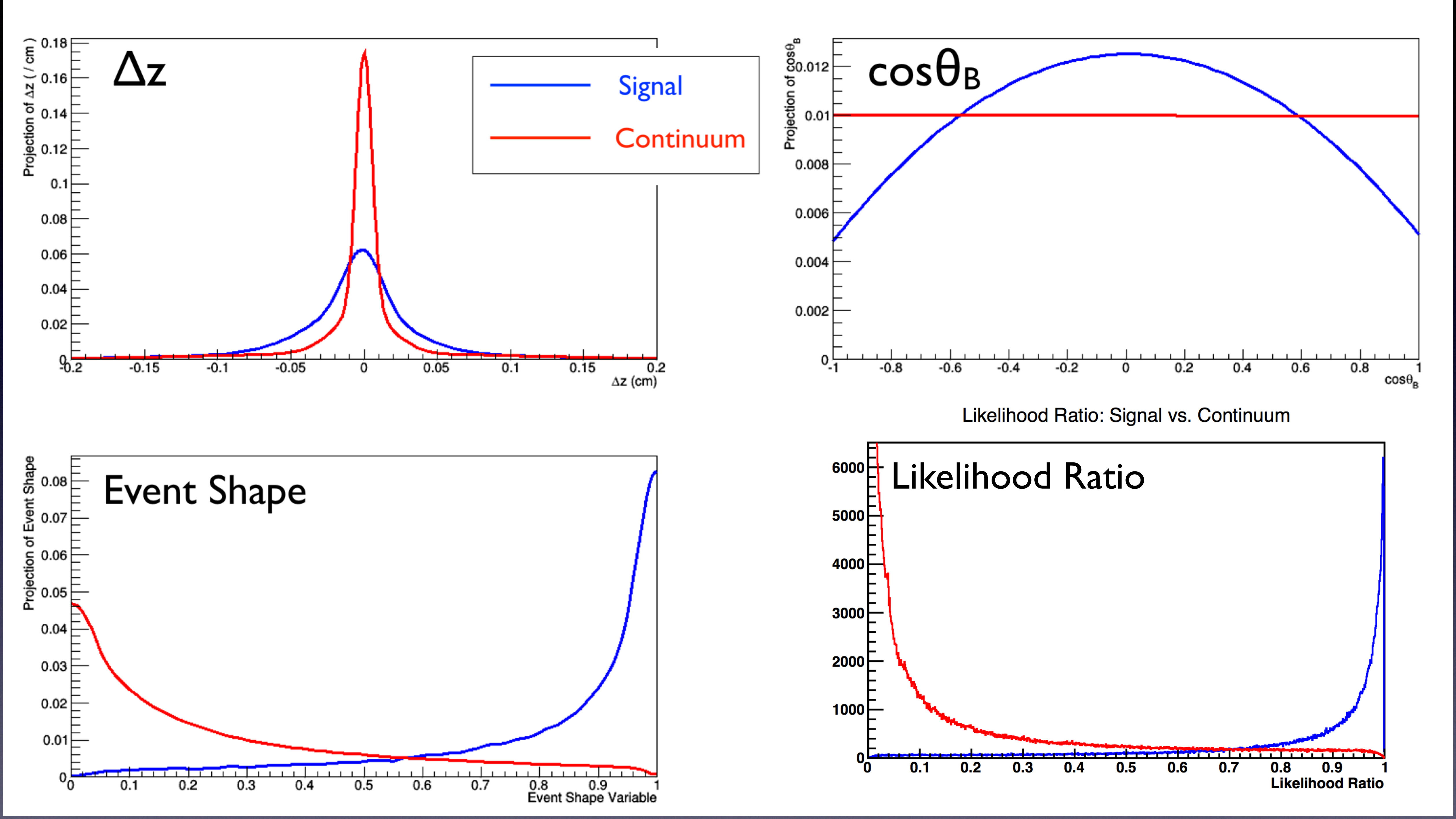
Variables to Separate $B\bar{B}$ and Continuum Events

- Δz : the distance along the z axis between signal and tag B in the CM
- $\cos\theta_B$: cosine of the angle between the B momentum and the z axis in the CM
- Event shape: spherical for signal vs. jet-like for continuum.





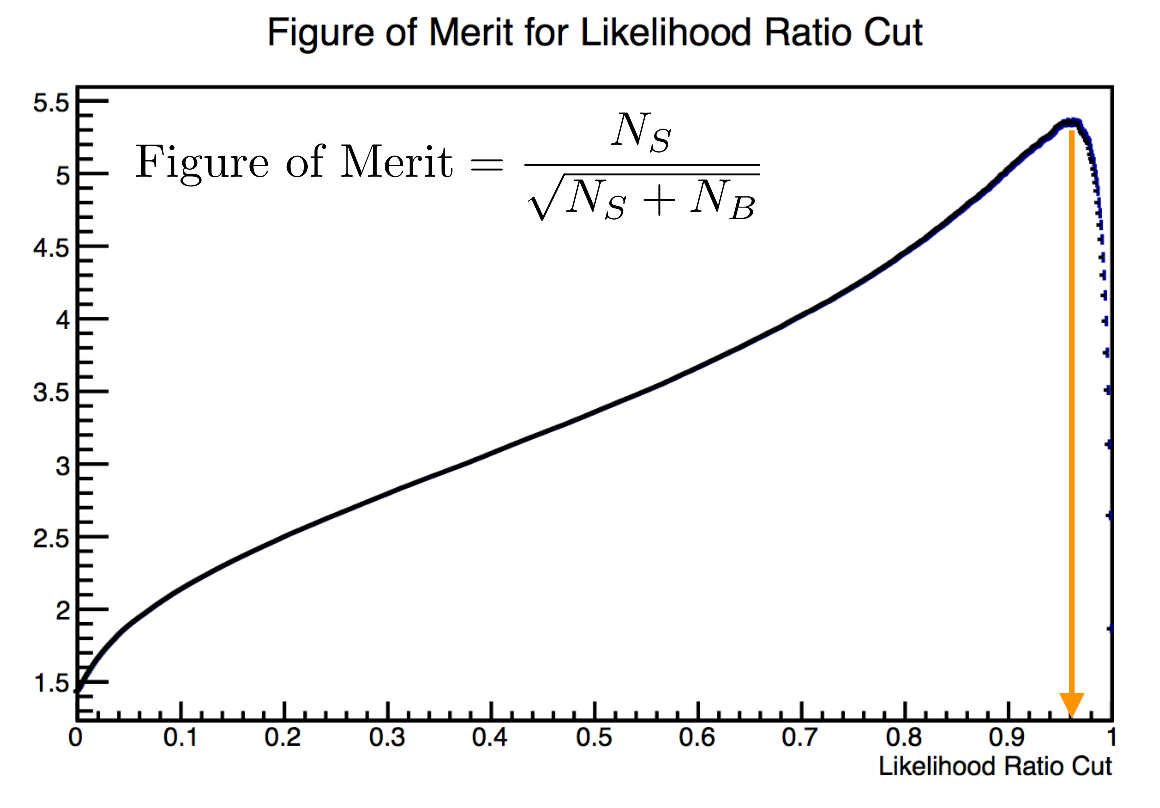
Distinguish Signal from Continuum



$$L_S = P_S(\Delta z) \times Q_S(\cos\theta_B) \times R_S(klr)$$
$$L_B = P_B(\Delta z) \times Q_B(\cos\theta_B) \times R_B(klr)$$
$$LR = \frac{L_S}{L_S + L_B}$$

Figure of Merit for Likelihood Ratio

- For smallest statistical error on the asymmetry, we need to maximize $N_S/\mathrm{sqrt}(N_S+N_B)$
- For a given LR minimum cut, calculate passed event number for signal (N_S) and continuum (N_B)
- Get the LR cut which corresponds to the peak of figure of merit (FOM).

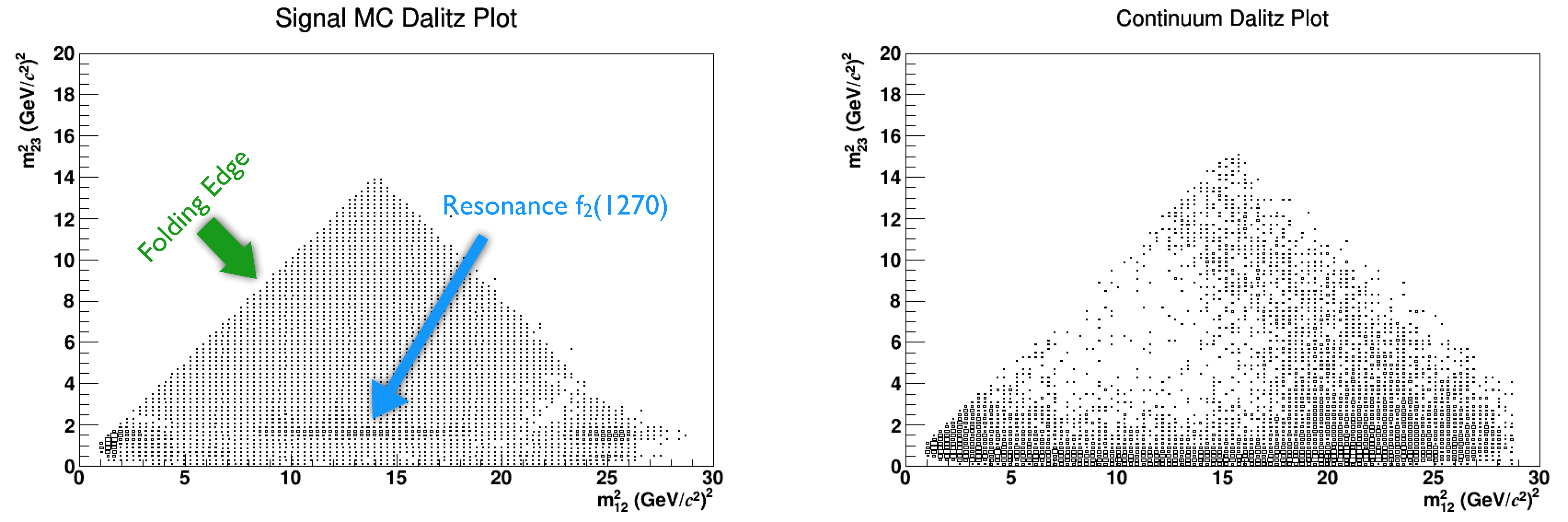


Selected likelihood ratio cut (LR_{cut}) to suppress continuum background

- Result: the selected LR_{cut} remove 99% of continuum background while keeping 40% of signal .

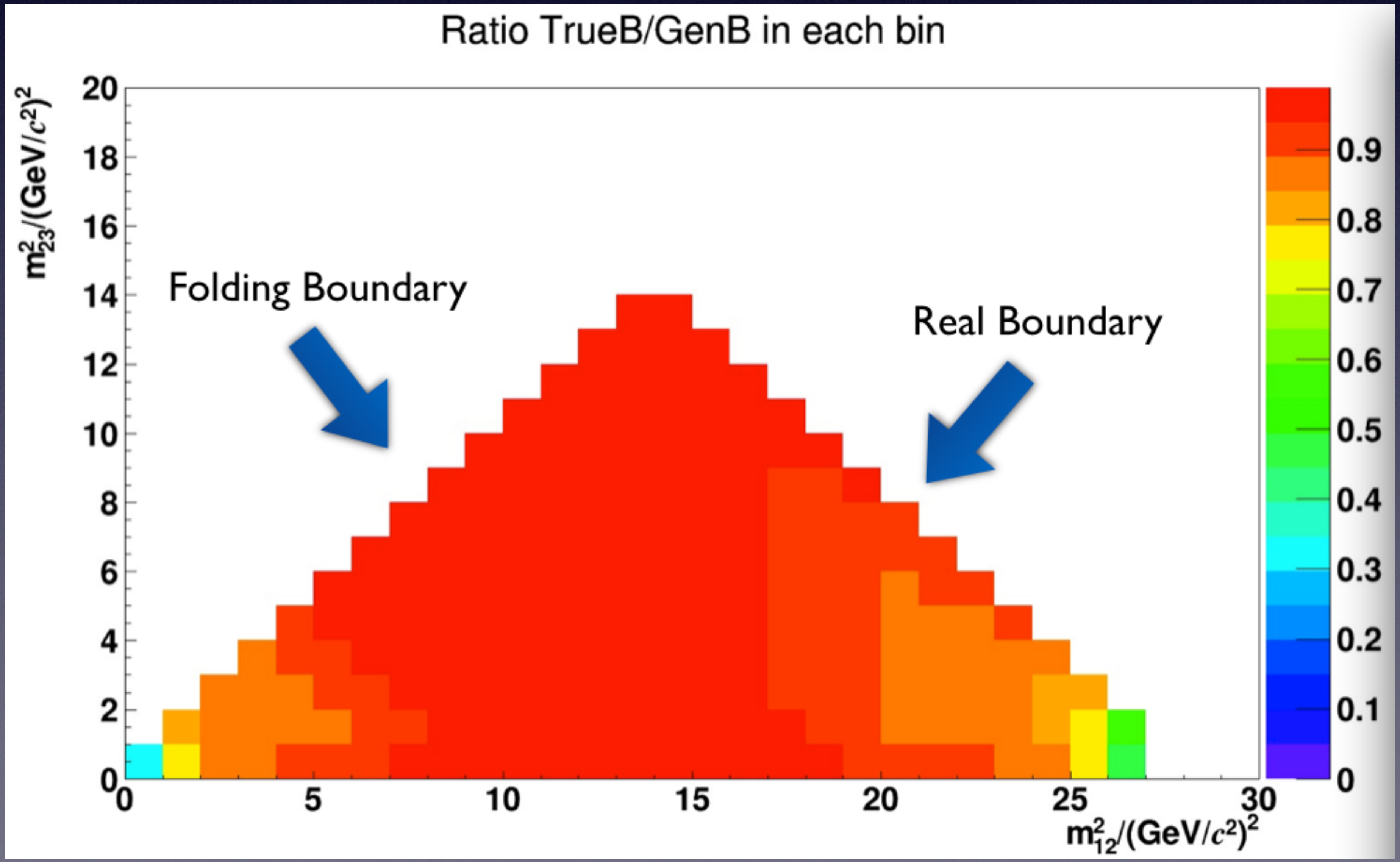
5. Dalitz Plot

- Three tracks (1,2,3) forms a candidate, then $m_{12}^2 = (p_1^\mu + p_2^\mu)^2$
- Define Dalitz plot variables in the way that we always have $m_{12}^2 \geq m_{23}^2$, then the Dalitz plots are *folded* along the axis of symmetry.
- Resonances show up as bands on Dalitz plot.



Dalitz Plot Efficiency

- We generated MC samples on phase space to evaluate the efficiency of reconstruction (reconstructed *B* vs. generated *B*).
- In most region, the efficiency is over 95%. But it is low in some boundary region as shown in the figure.



6. $B\bar{B}$ Background Suppression

Major $B\bar{B}$ backgrounds:

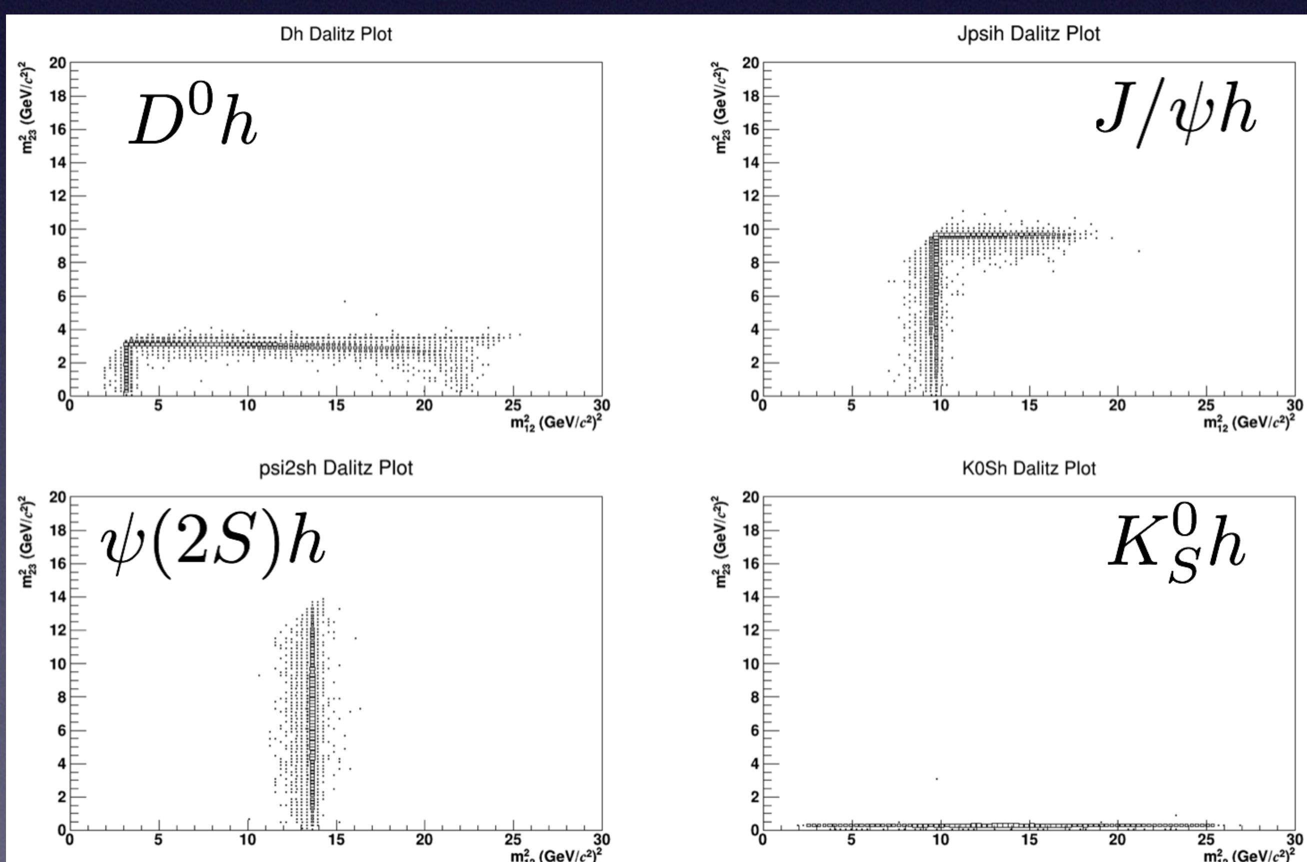
(1) $B^{\pm} \to D^0 h^{\pm}, D^0 \to h'^{+} h''^{-}$

(2) $B^{\pm} \to J/\psi\, h^{\pm}, J/\psi \to l^{+} l^{-}$

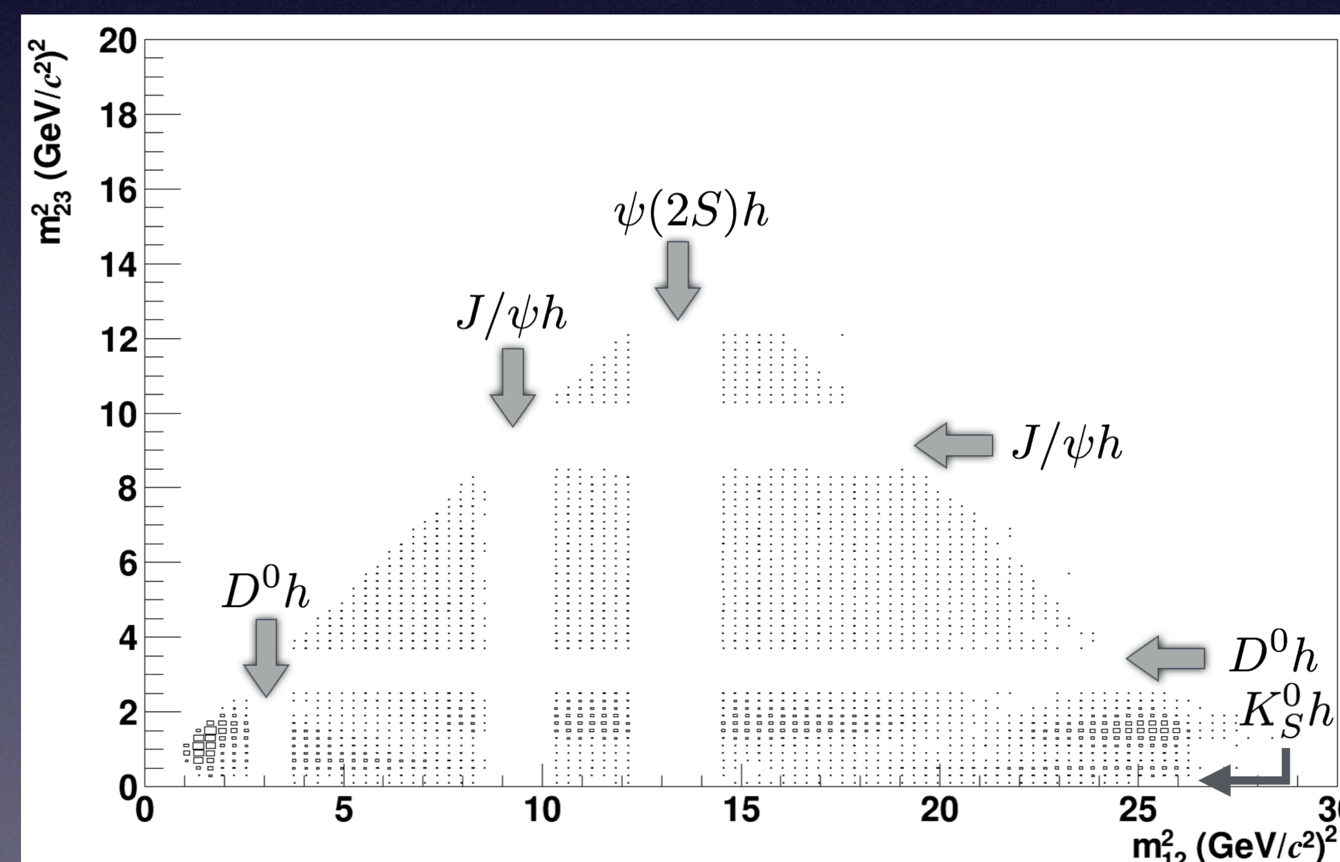
(3) $B^{\pm} \to \psi(2S)\, h^{\pm}, \psi(2S) \to l^{+} l^{-}$

(4) $B^{\pm} \to K^0_S h^{\pm}, K^0_S \to \pi^{+}\pi^{-}$

- *h means π or K;*
- *A kaon or lepton could be misidentified as a pion.*



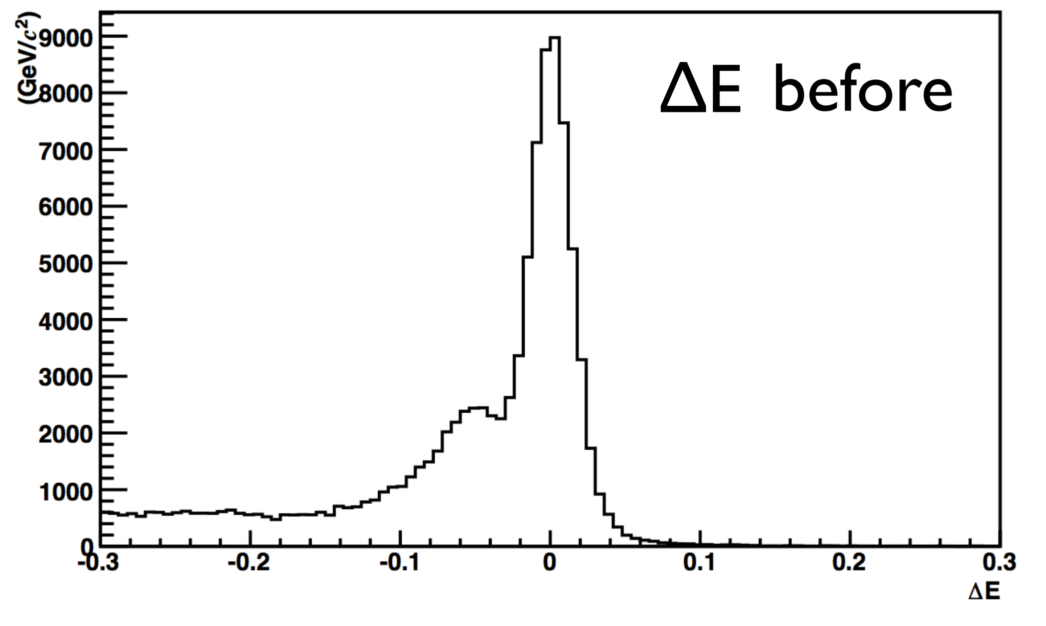
Dalitz plot for each mode (from MC)



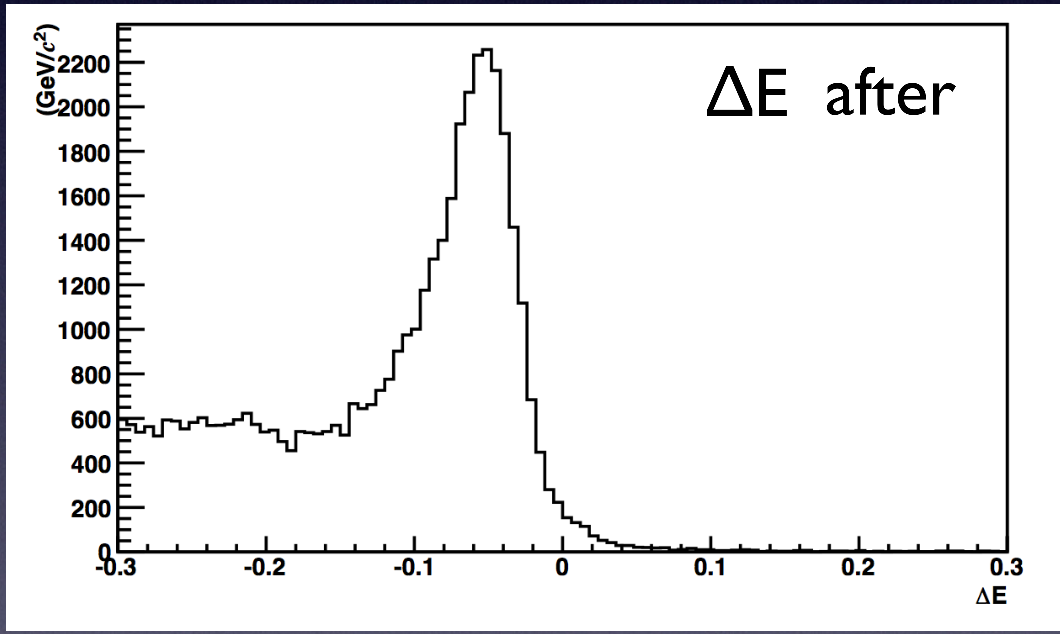
Veto ranges: 99% $B\bar{B}$ background events in each band

7. Rare *B* Background

- Rare *B* backgrounds include all the non-signal rare *B* decay modes.
- Study on rare *B* MC sample prepared in Belle (50 streams).
- We need the non-signal distribution for ΔE, therefore the peak at ΔE=0 should be removed.



Remove peak at ΔE = 0

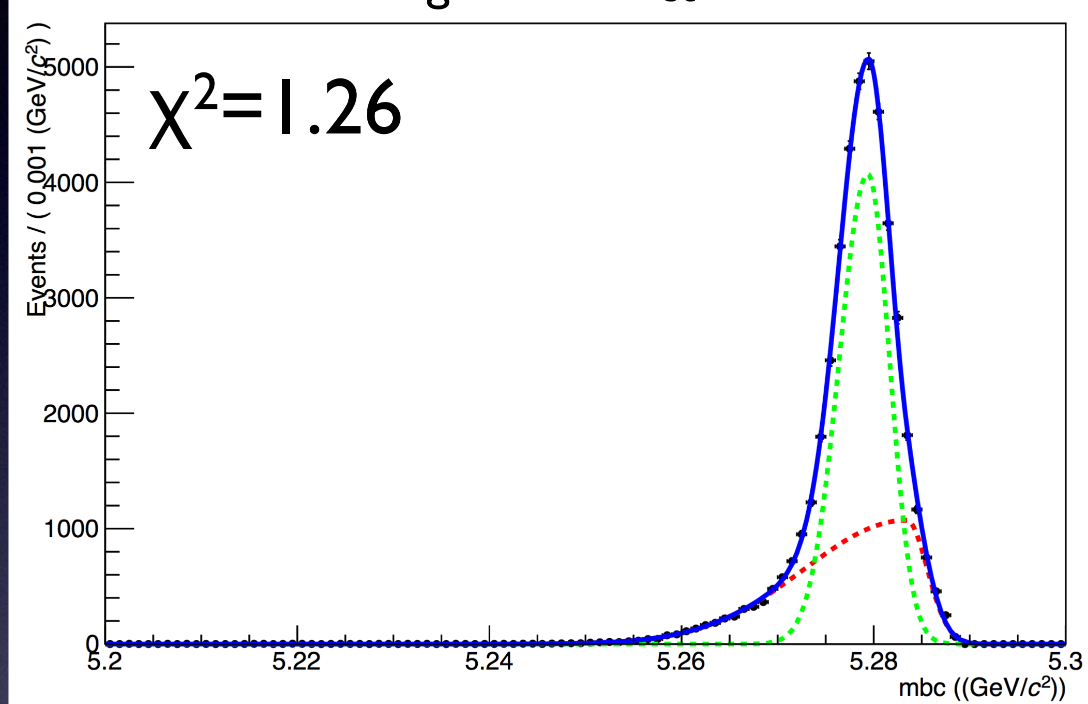


- Method to remove signal-like modes in charged rare modes: review all the decay modes in the charged rare B decay table and find the modes which would looks like signal: B→Xh, with X→h'h".

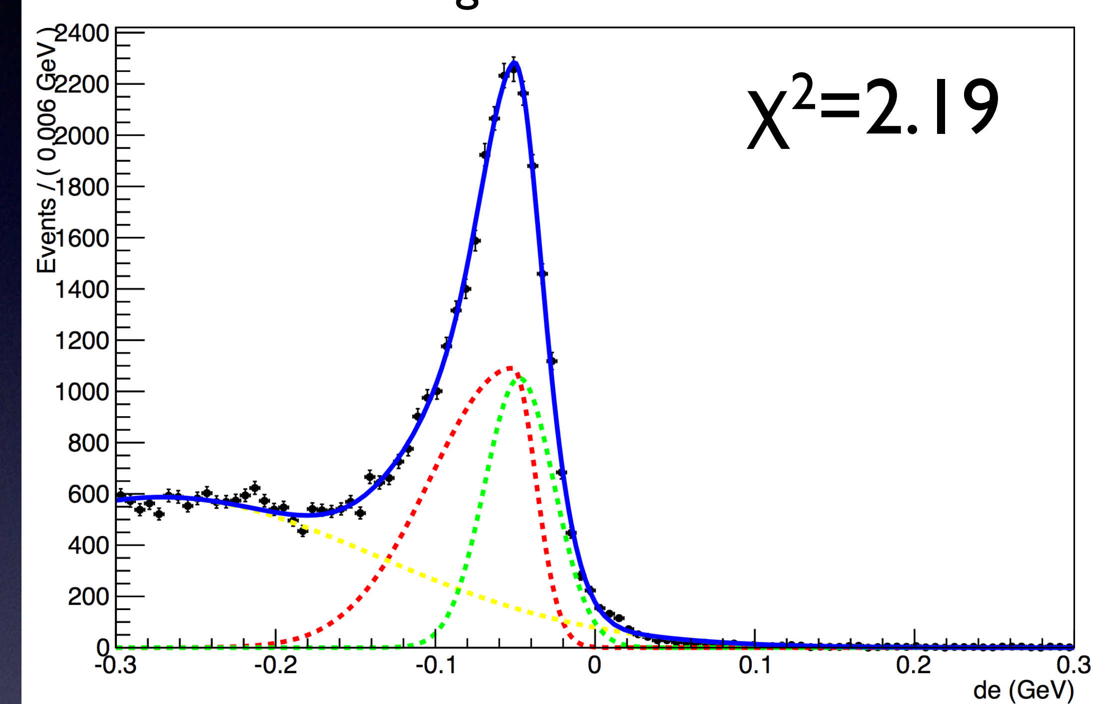
Model the M_{bc}, ΔE, and Dalitz plot of rare B

- Find analytical function to describe the PDFs of M_{bc} and ΔE
- For Dalitz plot, use 2-D RooHistPdf (PDF sampled from histogram)

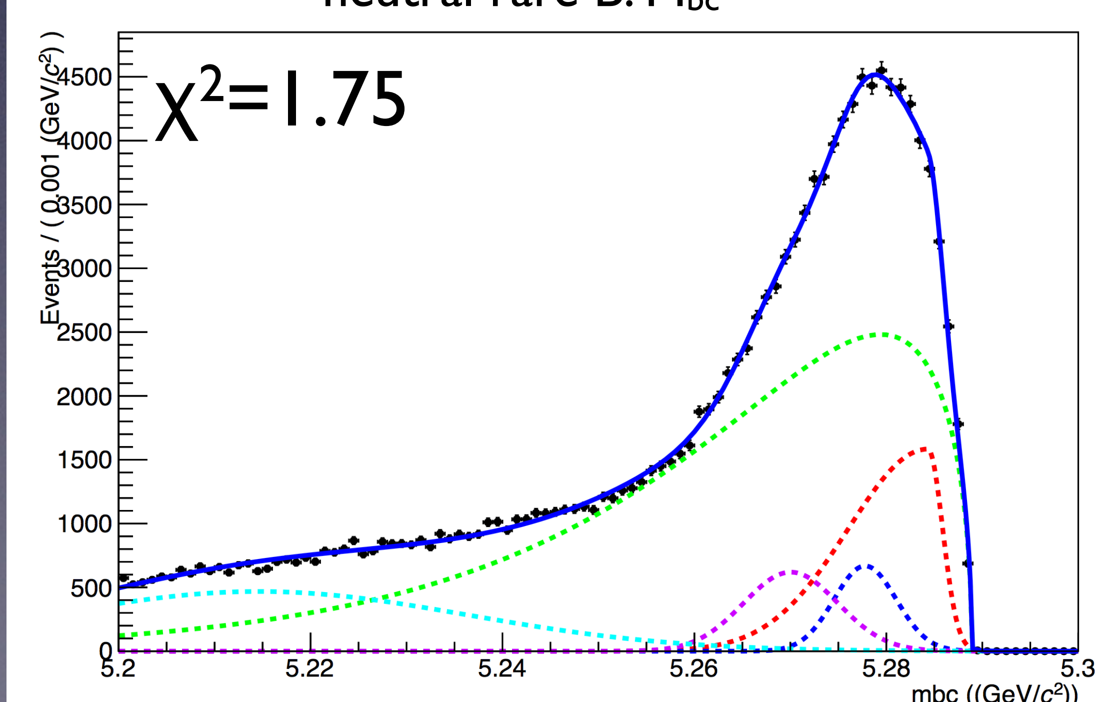
charged rare M_{bc}



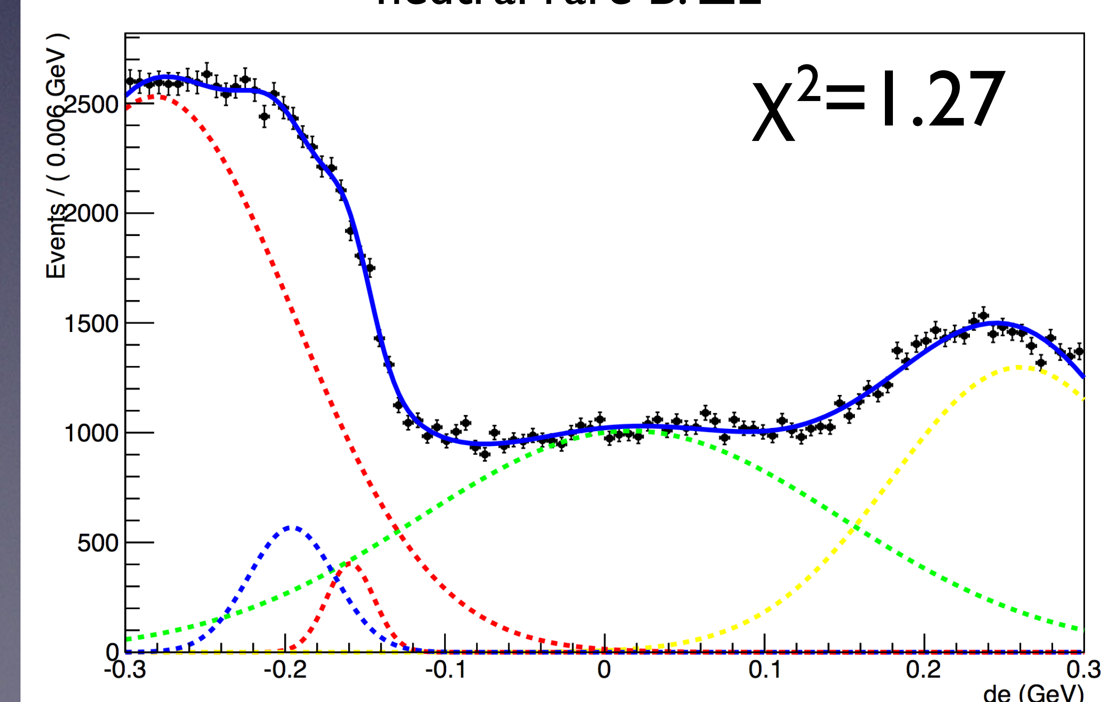
charged rare B: ΔE



neutral rare B: M_{bc}



neutral rare B: ΔE



Summary

Study $B^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$ using Belle data ($772\text{x}10^{6}$ $B\bar{B}$ paris):

- Skim real data and generic MC.
- Suppress continuum and $B\bar{B}$ background.
- Study the background from rare B decays.
- Next: study on systematic error study; unblind the real data and extract physical results.

Thanks !

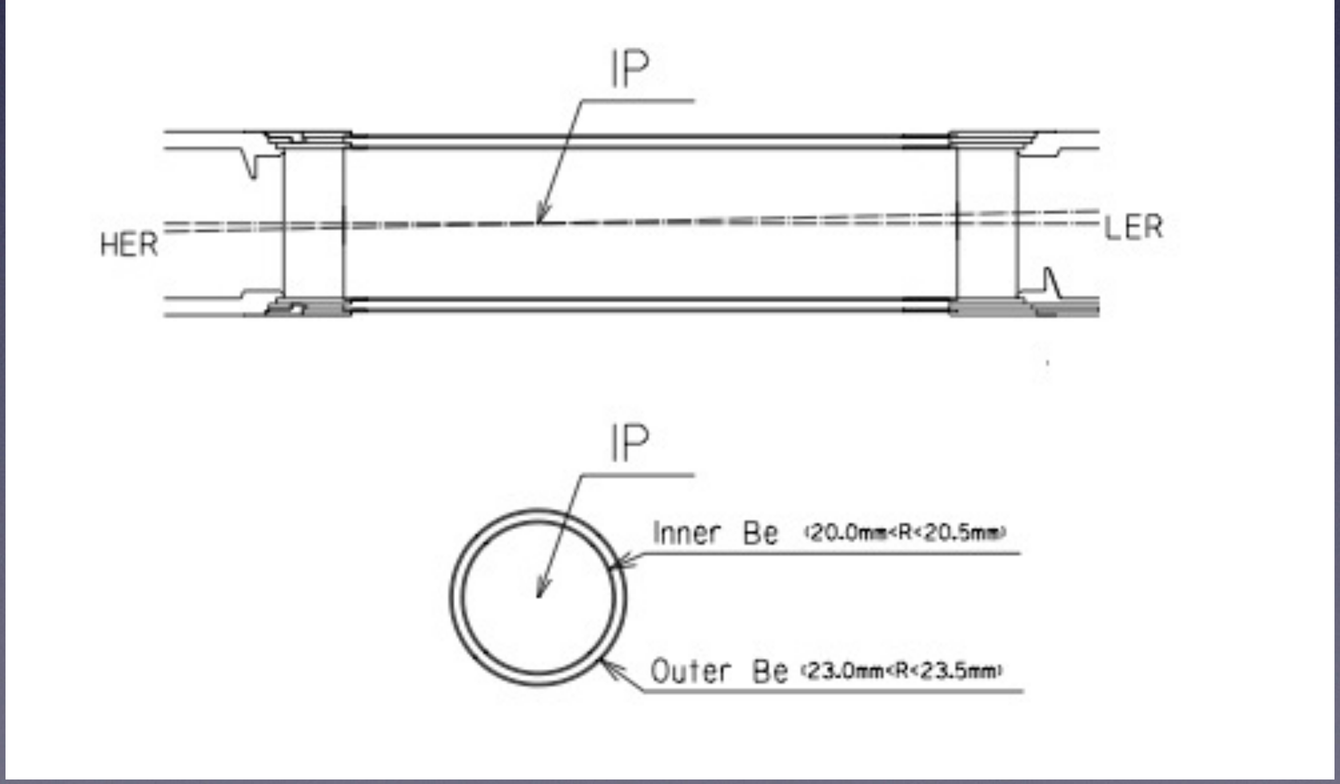
Backup Slides

1. Overview

- KEKB circumference: 3 km
- e^+: 3.5 GeV, e^-: 8.0 GeV
- Collide angle: 22 mrad (1.26°)(reason: reduce bkg synchrotron radiation)
- z+ direction: magnetic field; opposite direction of e^+ beam.
- B decay vertices: SVD
- Charged particle tracking: CDC
- PID: dE/dx in CDC, ACC, TOF
- EM showers: ECL
- Muons and KL identification: KLM
- Whole θ region: 17° to 150°.

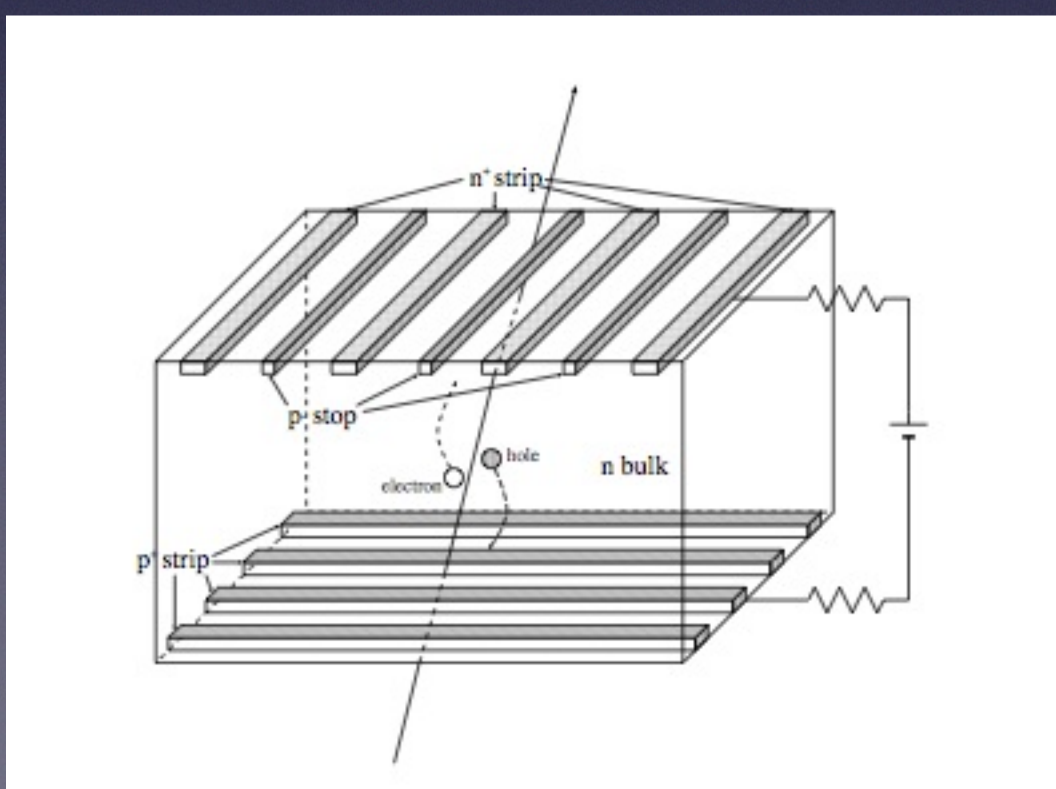
2. Beam Pipe

- SVD should be close to the IP, but 2 constrains:
    - beam-included heating of the beam pipe;
    - large beam bkg due to multiple Coulomb scattering in the beam pipe wall
- extending from z = -4.6 to 10.1 cm
- inner r = 20 mm (SVD1); 15 mm (SVD2)



3. Silicon Vertex Detector (SVD)

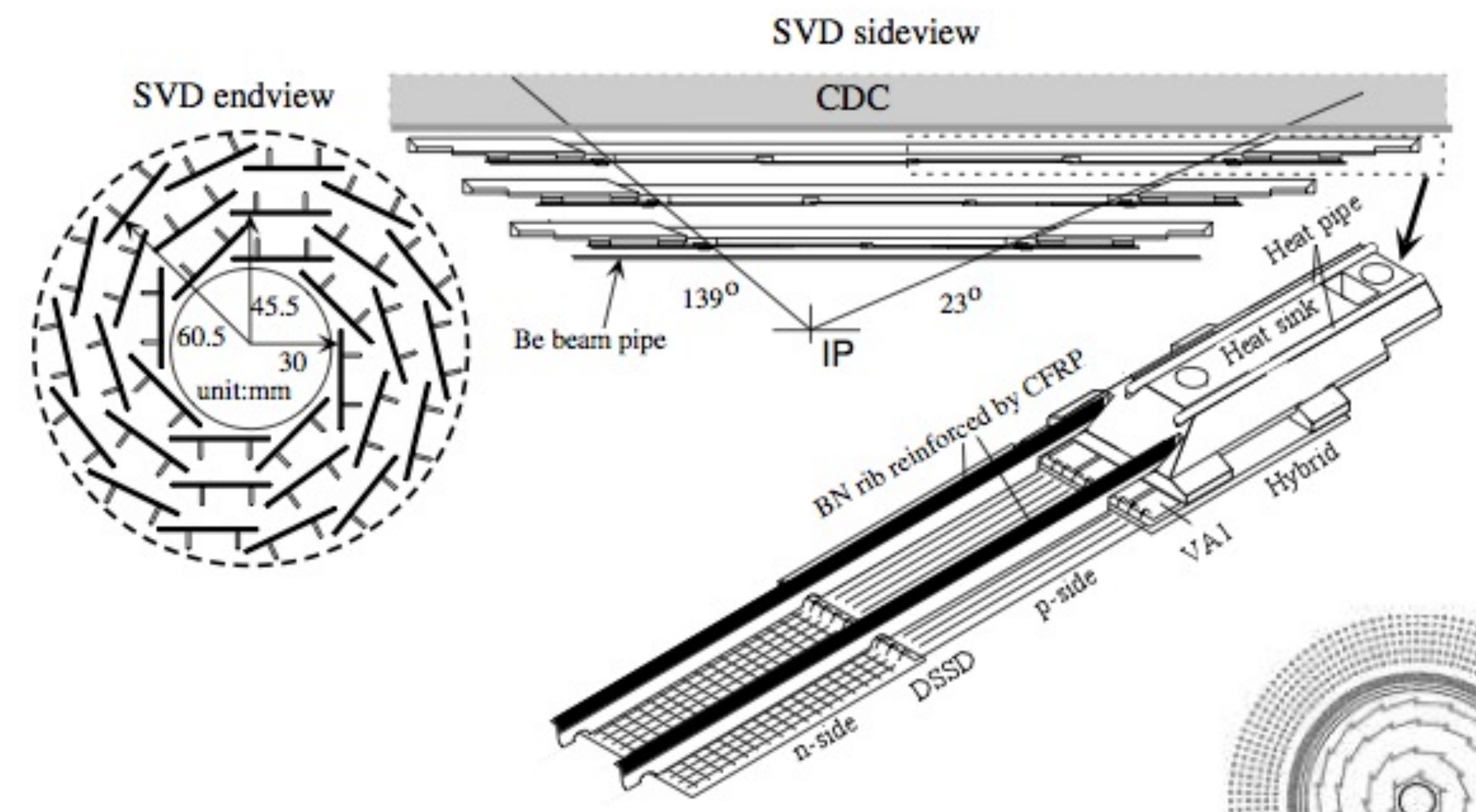
- Separate 2 B meson decay vertices
- Average Δz of 2 B mesons: 200 μm
- SVD precision: within 100 μm
- SVD detects particles passing through a Double Sided Silicon Detector (DSSD), by observing the charge collected by sense-strips on both sides of the DSSD.
- DSSD is a semiconductor with a pn junction.
- SVD1: 1998-2003; SVD2(2003-end)



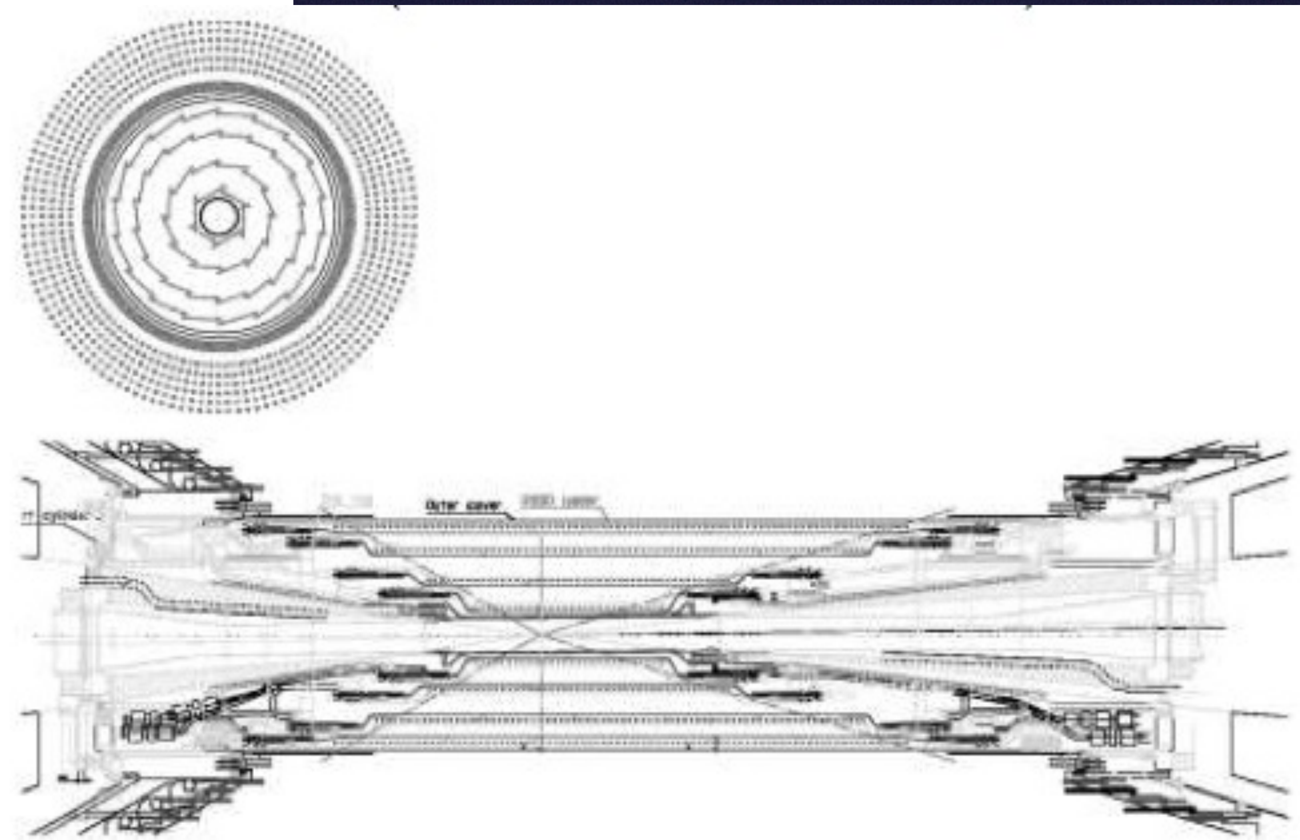
	SVD1	SVD2
Beam-pipe radius (mm)	20	15
Number of layers	3	4
Number of DSSD ladders in layers 1/2/3/4	8/10/14/N.A.	6/12/18/18
Number of DSSDs in ladder in layers 1/2/3/4	2/3/4/N.A.	2/3/5/6
Radii of layers 1/2/3/4 (mm)	30.0/45.5/60.5/N.A.	
Angular coverage	$23° \leq \theta \leq 140°$	$23° \leq \theta \leq 140°$
Angular acceptance	0.86	0.86
Total number of channels	81920	110592
Strip pitch(μm) for z	84	75(73 for layer 4)

Table 3.1: Characteristics of the SVD1 and the SVD2

3. Silicon Vertex Detector (SVD)



SVD1 (SVD1 end-view and SVD1 side-view)

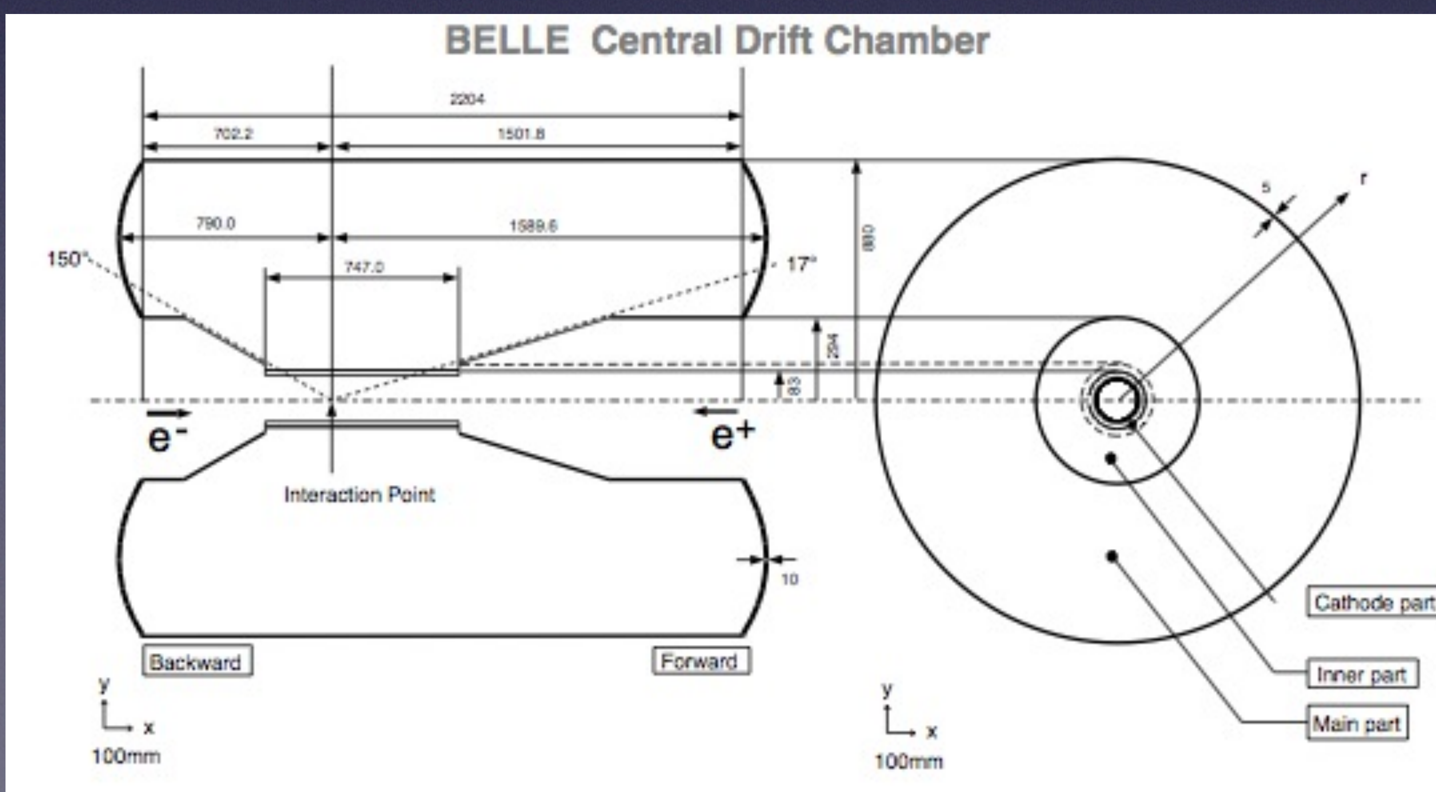


SVD2 (SVD2 end-view and SVD2 side-view)

Figure 3.6: Silicon vertex detector configurations for the SVD1 and the SVD2.

4. Central Drift Chamber (CDC)

- Reconstruct trajectories of charge particles(then $p_{perp} = qBr$)
- measure dE/dx for PID
- Info on the hits in CDC is used in triggering
- Length: 2.4m; Radius: 83 to 874 mm
- polar angel: 17° to 150°
- Spatial resolution: 10 μm in r-φ, 2 mm in z
- distinguish π/K of momentum < 0.8 GeV/c



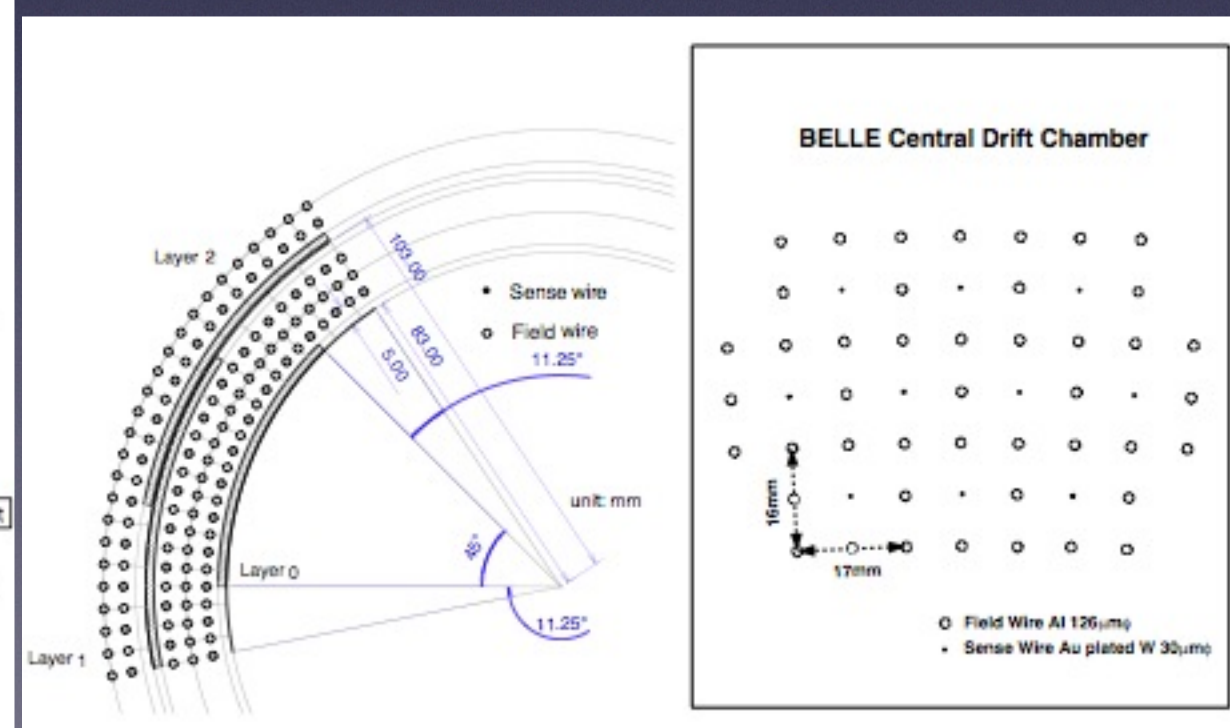
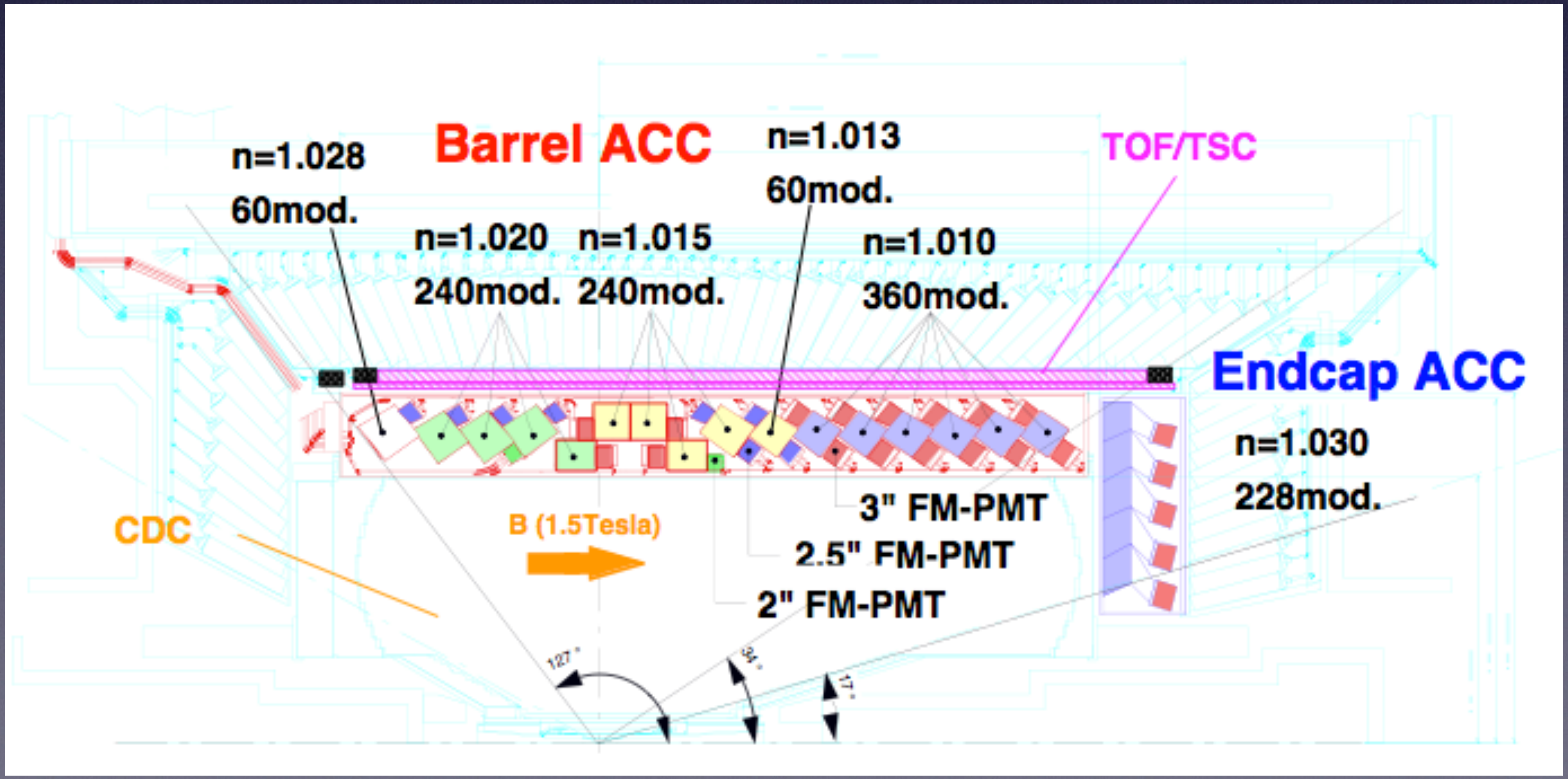


Figure 3.7: The Central Drift Chamber (CDC): side-view (left) and end-view (right).

5. Aerogel Cherenkov Counter

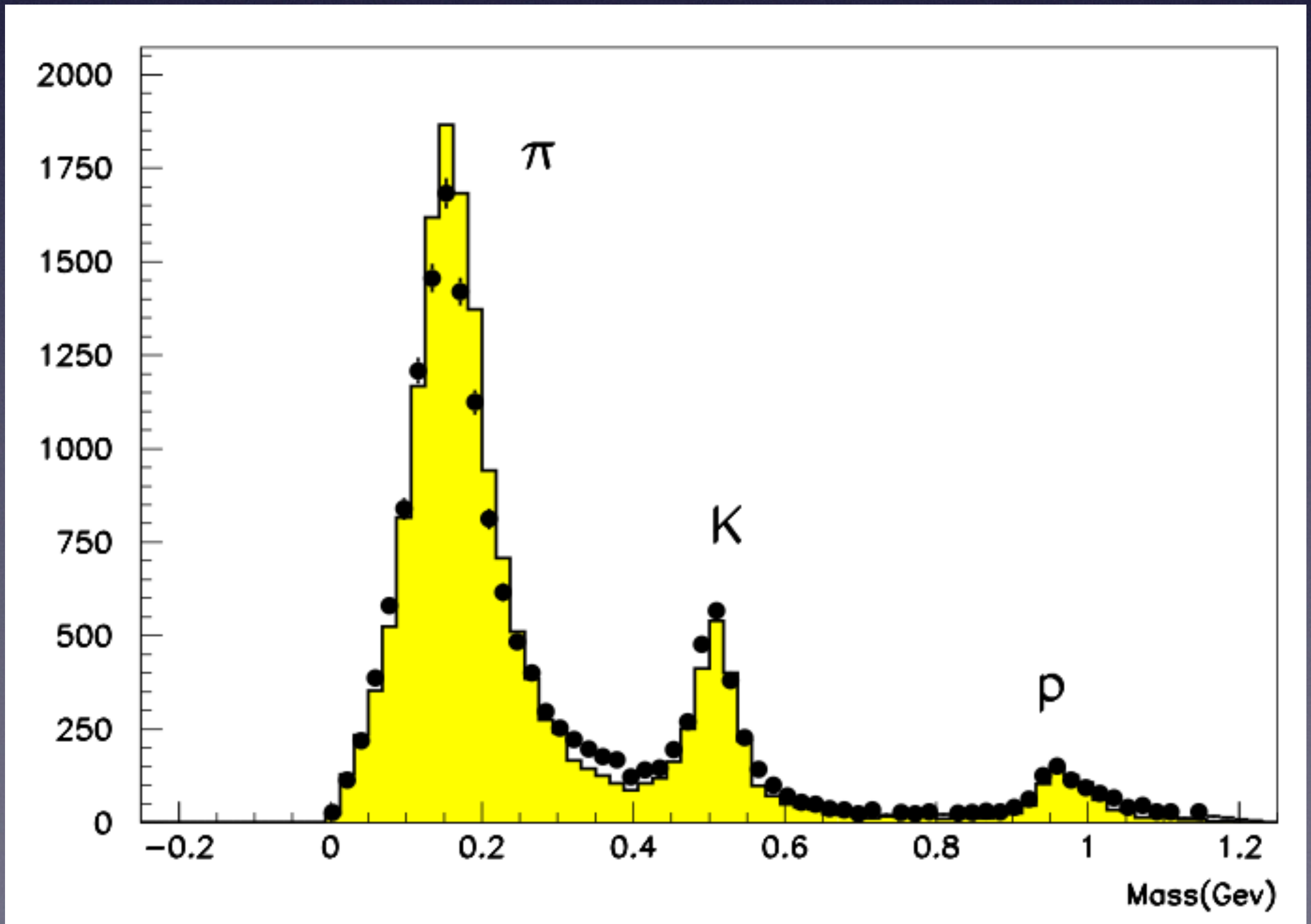
- For K/π separation with momentum between 1.2 and 3.4 GeV/c
- In this momentum range, π emits Cherenkov light, but K not
- Angle range: 17° to 127°



6. Time of Flight Counter (TOF)

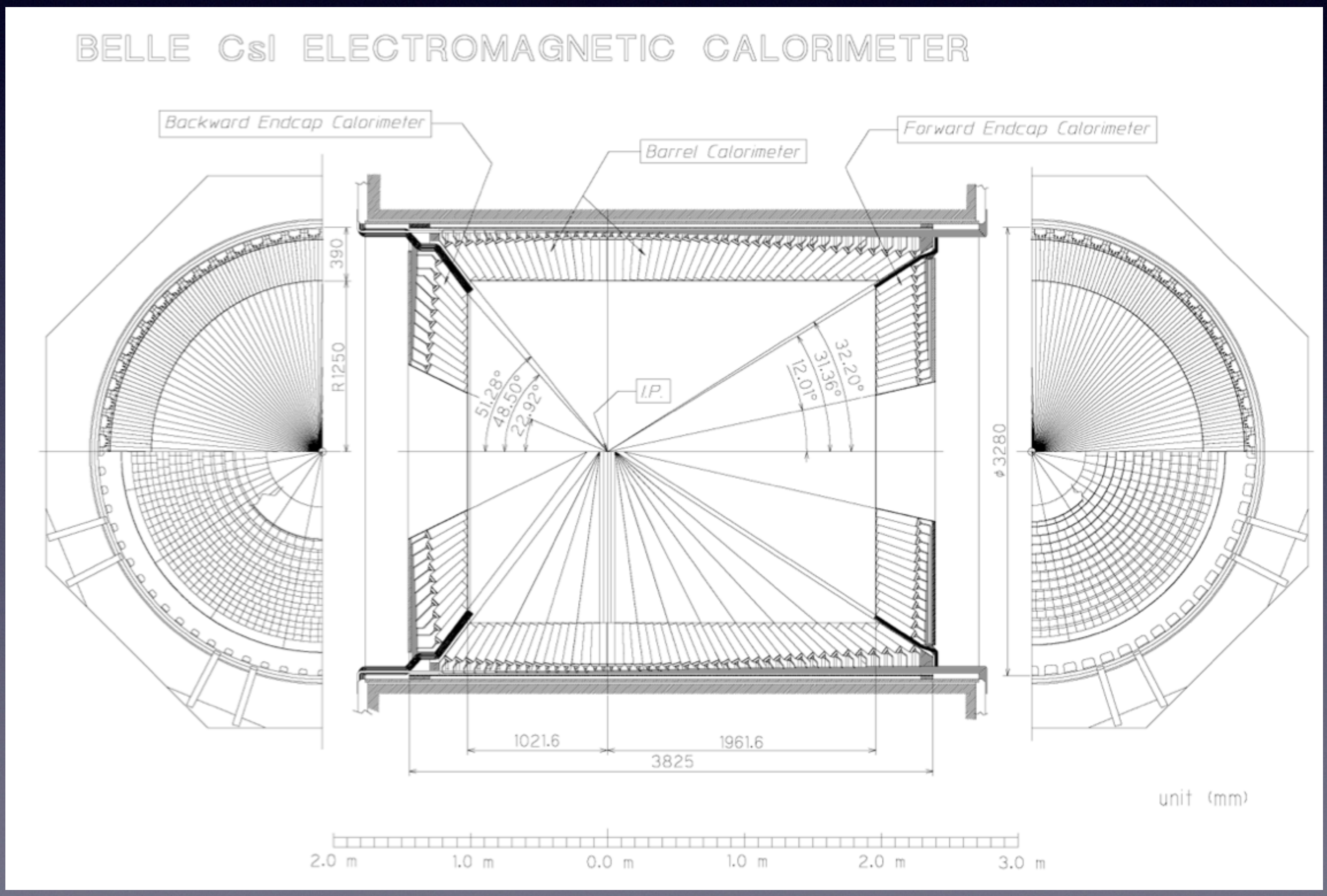
- Distinguish π/K with momentum (0.8, 1.2) GeV/c
- Measure the time elapsed between the collision at the IP and its passage through the TOF barrel
- Provide fast timing signals for the trigger system, which requires a timing resolution 100ps
- Since we know T, L, p, we can calculate m by:

$$T = \frac{L}{c}\sqrt{1 + \left(\frac{mc}{p}\right)^2}$$



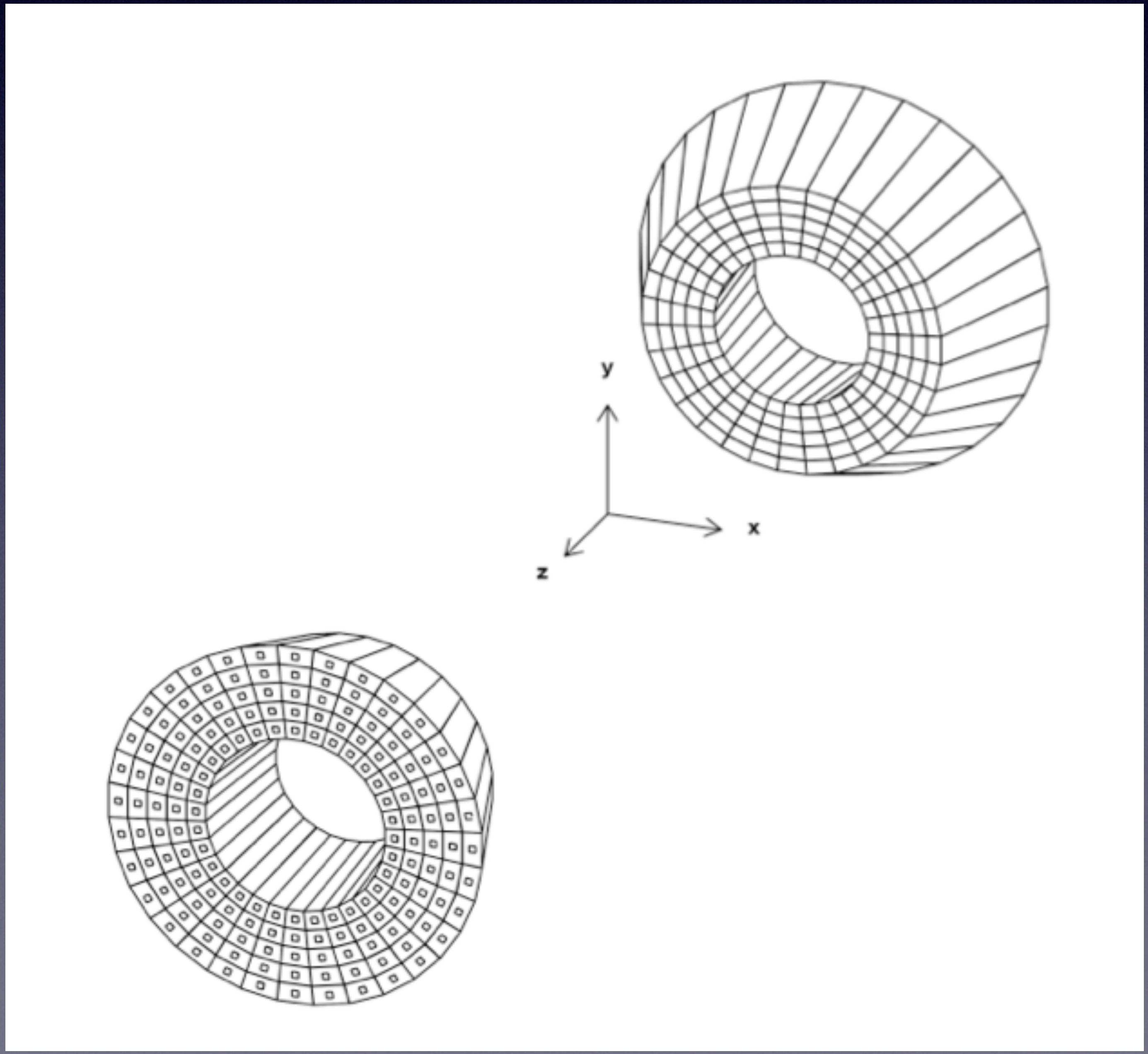
7. Electromagnetic Calorimeter

- Measures the energy and position of photons with high efficiency and good resolution.
- Electron identification

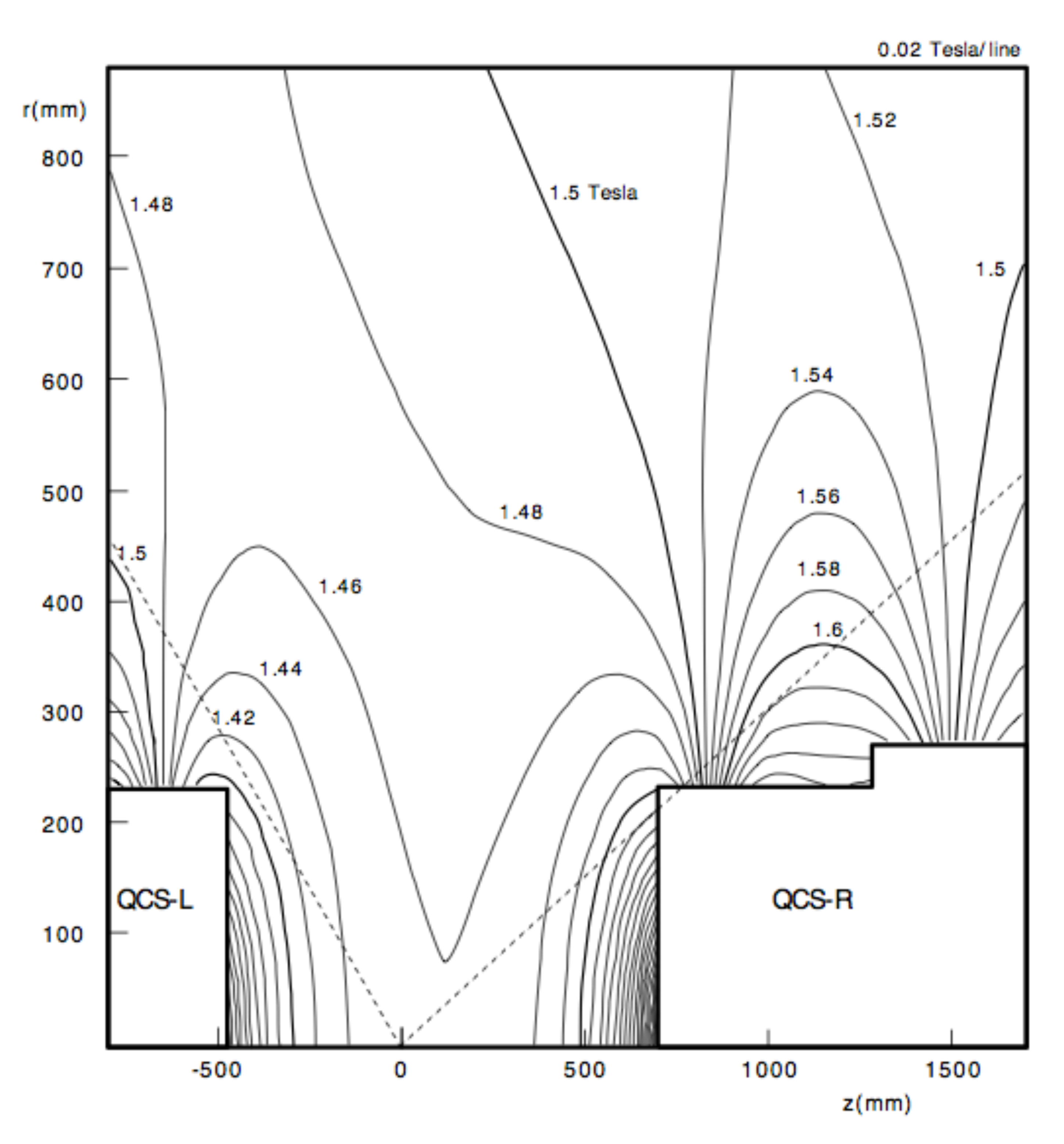


8. Extreme Forward Calorimeter (EFC)

- Extend the polar angle coverage of ECL
- Around the beam pipe close the the IP
- Mask the beam background of the CDC detector



9. Solenoid Magnet



General	Central field	1.5 T
	Length	4.41 m
	Weight	23 t
	Cool-down time	≤ 6 days
	Quench-recovery time	≤ 1 day
Cryostat	Inner/Outer Radius	1.70/2.00 m
Coil	Effective radius	1.8 m
	Length	3.92 m
	Superconductor	NbTi/Cu
	Nominal current	4400 A
	Inductance	3.6 H
	Stored energy	35 MJ
	Typical charging time	0.5 h

Table 3.2: Main parameters of the solenoid magnet.

10. K_L and μ Detector (KLM)

- Identify K_L and μ for momenta greater than 0.6 GeV/c

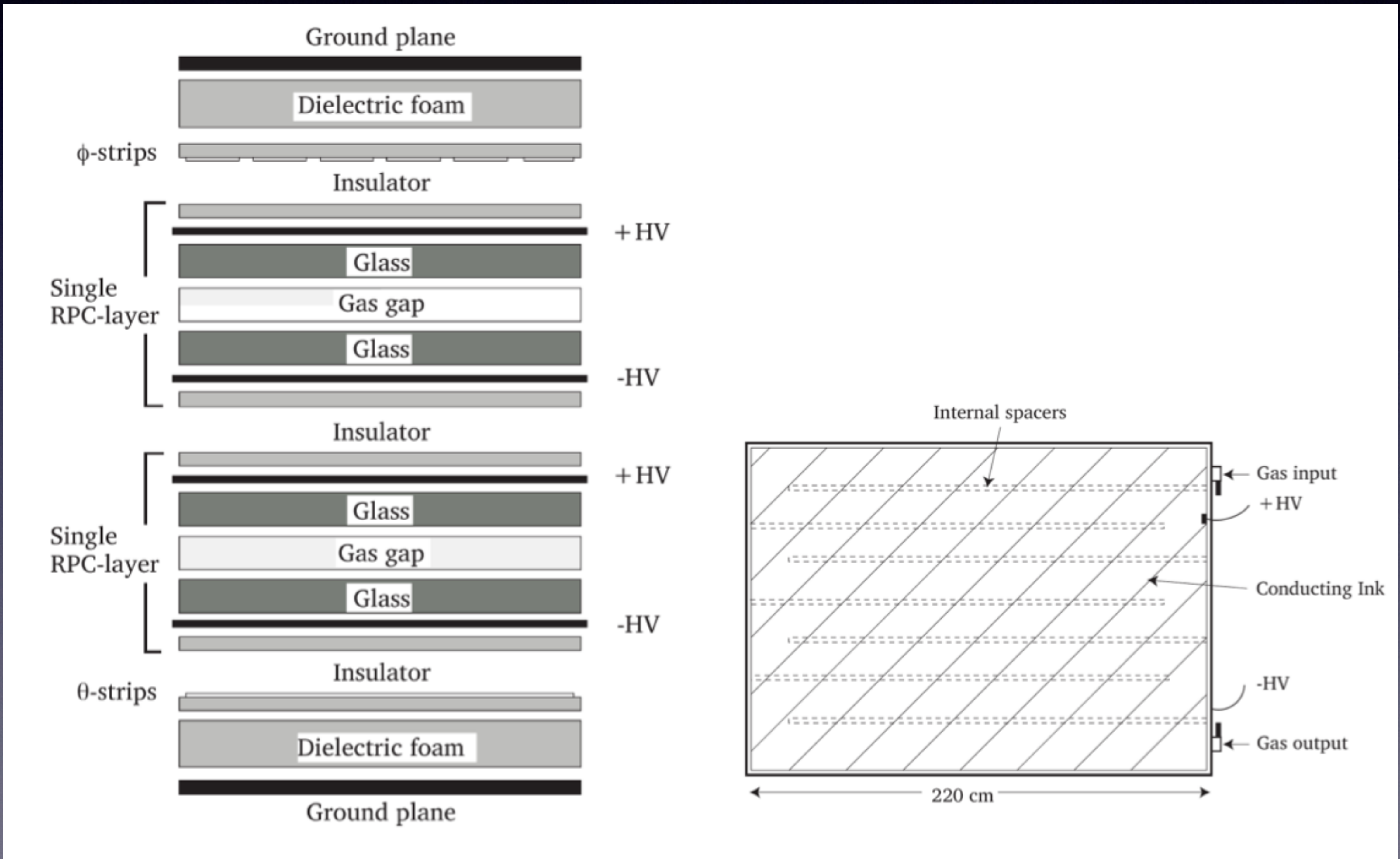
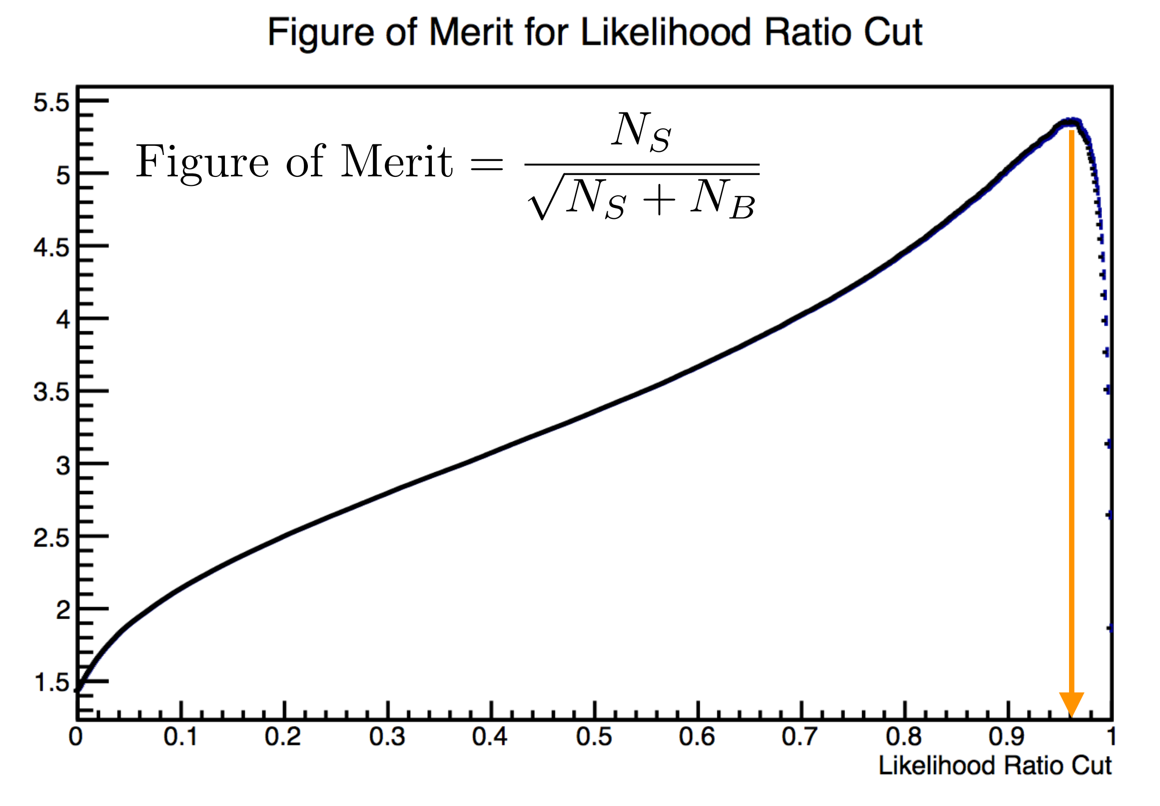


Figure of Merit for Likelihood Ratio

- For smallest statistical error on the asymmetry, we need to maximize $N_S/\mathrm{sqrt}(N_S+N_B)$
- For a given LR minimum cut, calculate passed event number for signal (N_S) and continuum (N_B)
- Get the LR cut which corresponds to the peak of figure of merit (FOM).



Selected likelihood ratio cut (LR_{cut}) to suppress continuum background

Summary of Continuum Suppresion

	LR_{cut}	Efficiency for signal	Efficiency for background
SVD1 with Δz	0.9524	39.1%	0.781%
SVD1 w/o Δz	0.9103	43.0%	1.66%
SVD2 with Δz	0.9610	38.0%	0.660%
SVD2 w/o Δz	0.9189	40.4%	1.42%

Decay Modes

B+ to X0 h+	Spin	X0	X0 life length	m width(MeV)	h+-	*10^3	X0 to	*10^3	ratio *10^6	misID	final ratio
1.865	0	D0bar	1.229E-02		pi	4.81	KK	3.96	19.0476	2	0.190476
1.865		D0bar	1.229E-02		pi	4.81	pipi	1.401	6.73881		6.73881
1.865		D0bar	1.229E-02		pi	4.81	K+pi-	38.8	186.628	1	18.6628
1.865		D0bar	1.23E-02		pi	4.81	pi+K-	0.147	0.70707	1	0.070707
1.865		D0bar	1.229E-02		K	0.365	KK	3.96	1.4454	3	0.0014454
1.865		D0bar	1.229E-02		K	0.365	pipi	1.401	0.511365	1	0.0511365
1.865		D0bar	1.229E-02		K	0.365	K+pi-	38.8	14.162	2	0.14162
1.865		D0bar	1.229E-02		K	0.365	pi+K-	0.147	0.053655	2	0.00053655
									229.2939		
3.097	1	J/psi		9.29E-02	pi	0.049	ee	59.4	2.9106	2	0.029106
3.097		J/psi		9.29E-02	pi	0.049	mumu	59.3	2.9057	2	0.029057
3.097		J/psi		9.29E-02	pi	0.049	pipi	0.147	0.007203		0.007203
3.097		J/psi		9.29E-02	K	1.016	ee	59.4	60.3504	3	0.0603504
3.097		J/psi		9.29E-02	K	1.016	mumu	59.3	60.2488	3	0.0602488
3.097		J/psi		9.29E-02	K	1.016	pipi	0.147	0.149352	1	0.0149352
									126.572055		
3.686	1	psi(2S)		3.04E-01	pi	0.0244	ee	7.73	0.188612	2	0.00188612
3.686		psi(2S)		3.04E-01	pi	0.0244	mumu	7.7	0.18788	2	0.0018788
3.686		psi(2S)		3.04E-01	pi	0.0244	pipi	0.08	0.001952		
3.686		psi(2S)		3.04E-01	K	0.639	ee	7.73	4.93947	3	0.00493947
3.686		psi(2S)		3.04E-01	K	0.639	mumu	7.7	4.9203	3	0.0049203
3.686		psi(2S)		3.04E-01	K	0.639	pipi	0.08	0.05112	1	0.005112
									10.289334		
3.415	2	chi_c0(1P)		10.4	K	0.134	pipi	8.5	1.139	1	0.1139
3.415		chi_c0(1P)		10.4	K	0.134	KK	6.06	0.81204	3	0.00081204
0.498	0	K0S	2.68		pi	0.0231	pipi	692	15.9852		15.9852
0.498		K0S	2.68		K	0.00136	pipi	692	0.94112	1	0.094112
									16.92632		16.92632
0.783	1	omega		84.9	K	0.0067	pipi	15.3	0.10251	1	0.010251
0.896	1	K*(892)		46.2	pi	0.0101	Kpi	999	10.0899	1	1.00899
		KKK				0.0337		1000	33.7	3	0.0337
signal		pipipi							15.2		15.2
0.775	1	rho0		149	pi	0.0083	pipi	1000	8.3		8.3
1.275	2	f2(1270)		185	pi	0.0016	pipi	848	1.3568		1.3568
1.465	1	rho(1450)		400	pi	0.0014	pipi	seen			0
		pipipi nonres				0.0053		1000	5.3		5.3
0.783	1	omega		84.9	pi	0.0069	pipi	15.3	0.10557		0.10557