First Measurements of the Exclusive Decays of $\Upsilon(5S)$ to $B^{(*)}B^{(*)}(\pi)(\pi)$ Final States and Improved B_s^* Mass Measurement

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Outline

- Part I: $B^{(*)}B^{(*)}(\pi)(\pi)$ final states at the $\Upsilon(5S)$.
  - Introduction and Motivation.
  - B_s CLEO measurements at the $\Upsilon(5S)$.
  - Final states with J/Ψ.
  - Final states with $D^{(*)}$.
  - Summary.
- Part II: BTeV RICH and TestBeam Results.

Υ(5S) Introduction

- The Υ(5S) discovered by CLEO & CUSB in 1985.

  $M(Y(5S) = (10.865 \pm 0.008)$ GeV

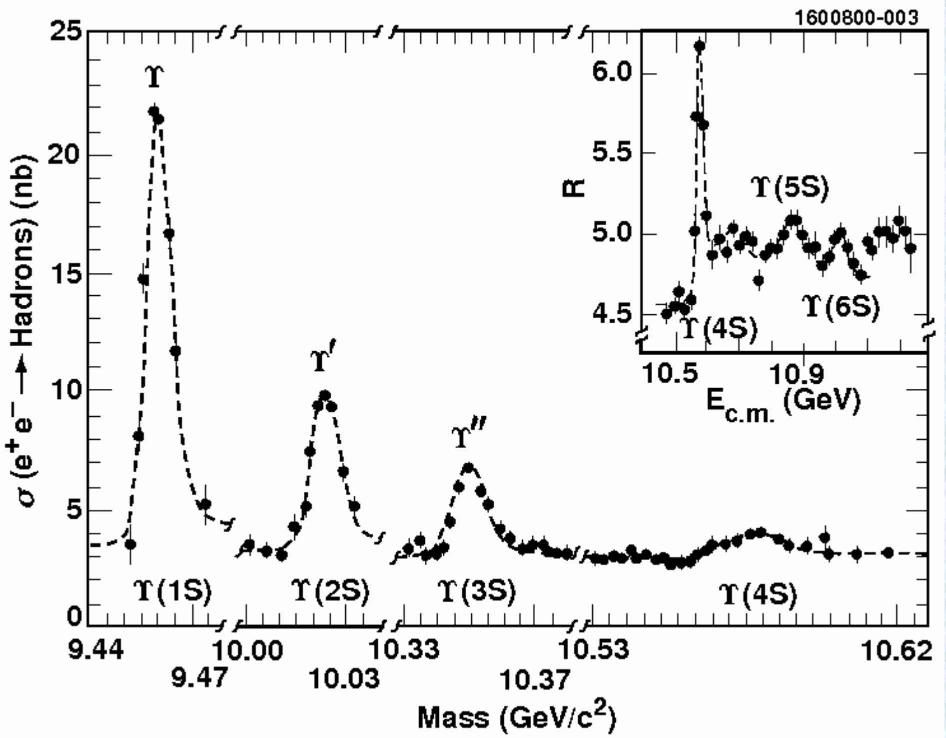
  $\Gamma(110 \pm 13)$ MeV

massive enough to decay into :

$$B\overline{B},\quad B\overline{B^*},\quad B^*\overline{B^*},$$

$$B\overline{B}\pi,\quad B\overline{B^*}\pi, B^*\overline{B^*}\pi, B\overline{B}\pi\pi,$$

$$B_s\overline{B_s},\quad B_s\overline{B_s^*}, B_s^*\overline{B_s^*}$$

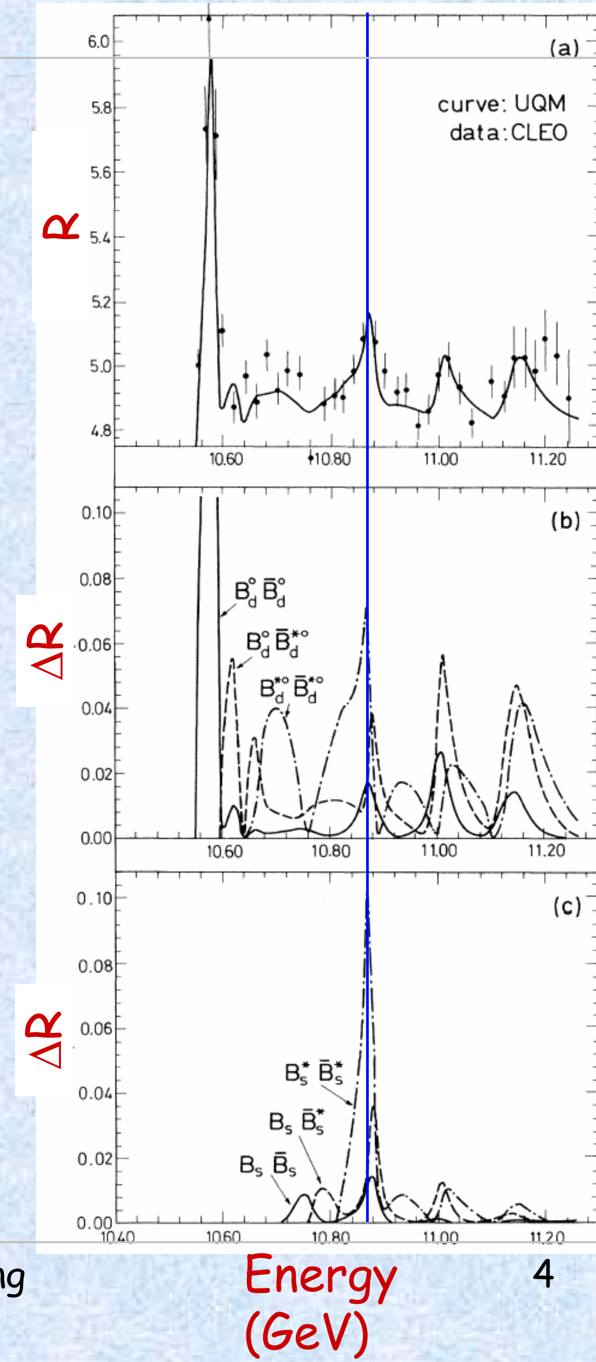


- Knowledge of B_s production at Υ(5S) essential for assessing the potential of B_s physics at a high luminosity e^+e collider (Super-B factory):

  hep-ex/0406071, hep-ph/0503261
- One mystery: M(5S) – M(4S) > M(4S) – M(3S).

Model Predictions

- The hadronic cross section in the Upsilon region is well described by the Unitarized Quark Model (UQM), which is a coupled channel model (ref: S. Ono *et al*, PRL55, 2938(1985)).
- The UQM predicts that the $B_s^{(*)}B_s^{(*)}$ production ~ 1/3 of the total $\Upsilon(5S)$ cross section, the remaining 2/3 from ordinary B. And $\Upsilon(5S)$ decays are dominated by $B^*\bar{B}^*$ and $B_s^*\bar{B}_s^*$.
- Other models predict a smaller $\Upsilon(5S) \rightarrow B_s^*\bar{B}_s^*$ component.



Motivation

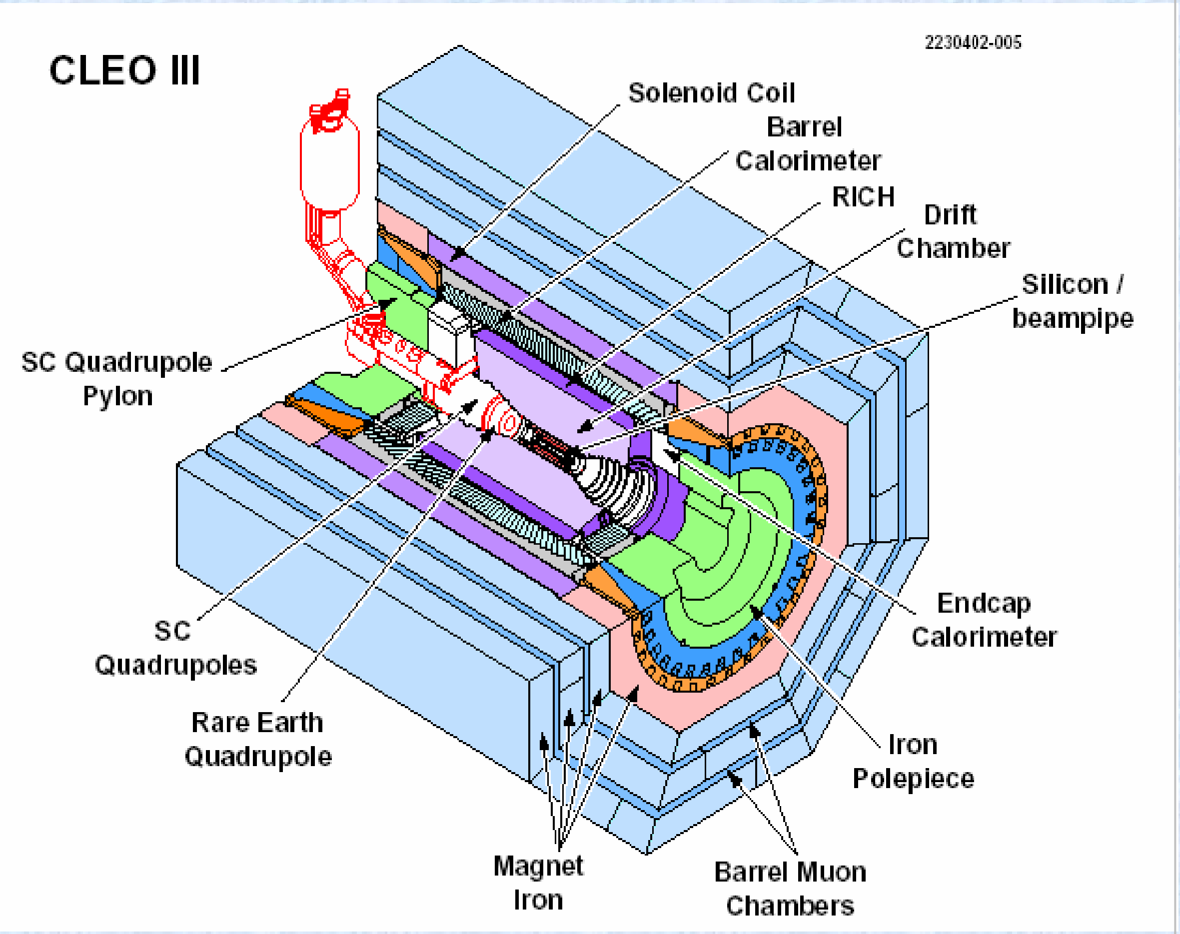
- Further test of UQM at the $\Upsilon(5S)$.
  - Expect ~100K of B_s in CLEO $\Upsilon(5S)$ data sample.
  - And about twice that in ordinary B's (if UQM is correct).

- This talk focuses on $B^{(*)}B^{(*)}(\pi)(\pi)$ states. Aim to measure or set upper limits on all possible $B^{(*)}B^{(*)}(\pi)(\pi)$ final states.

- Along with $M_{bc}(B_s^*)$, can provide precise $M(B_s^*)$. (largest systematic, beam energy shift, cancels)

CLEO III Detector and Data Sample

- Data taken using CLEO III detector at Cornell
- L_{int} = 0.42 fb^{-1}
- $E_{beam} \sim M_{\Upsilon(5S)}/2$ = 5.434 GeV



Inclusive B_s Analysis (CLEO)

- Evidence of B_s in $\Upsilon(5S)$ from inclusive yields of D_s

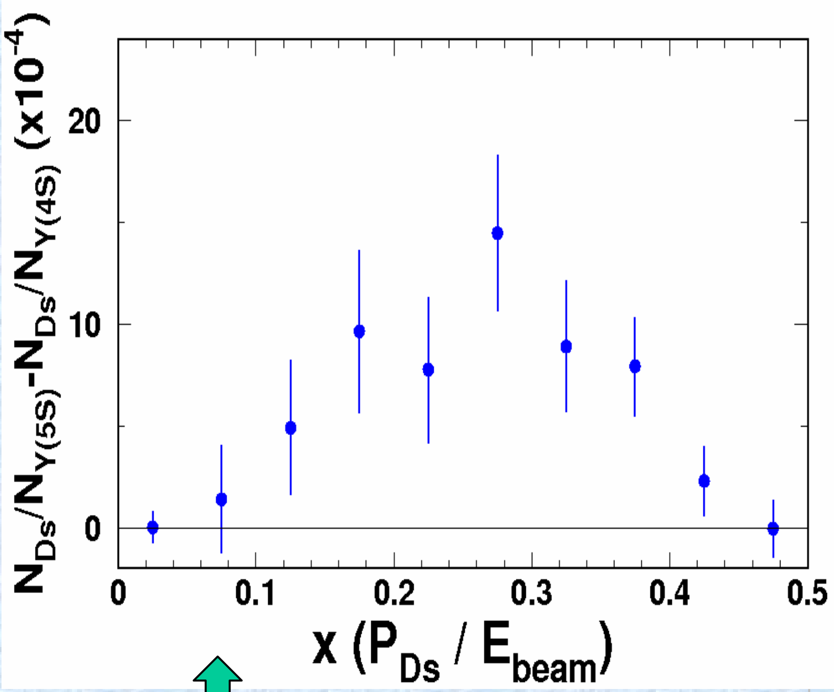
Phys. Rev. Lett **95**, 261801(2005)

- This analysis exploits the difference in D_s inclusive yields in B and B_s decays

✓$B(\Upsilon(5S) \rightarrow D_s X) = (55.0 \pm 5.2 \pm 17.8)\%$
✓$B(\Upsilon(4S) \rightarrow D_s X) = (22.3 \pm 0.7 \pm 5.7)\%$

- $B(\Upsilon(5S) \rightarrow B_s^{(*)} B_s^{(*)})$ $= (16.0 \pm 2.6 \pm 5.8)\%$

- ~ 6 σ away from 0 statistically



•Excess D_s production @$\Upsilon(5S)$, compared to $\Upsilon(4S)$. is evidence for Bs @ $\Upsilon(5S)$.

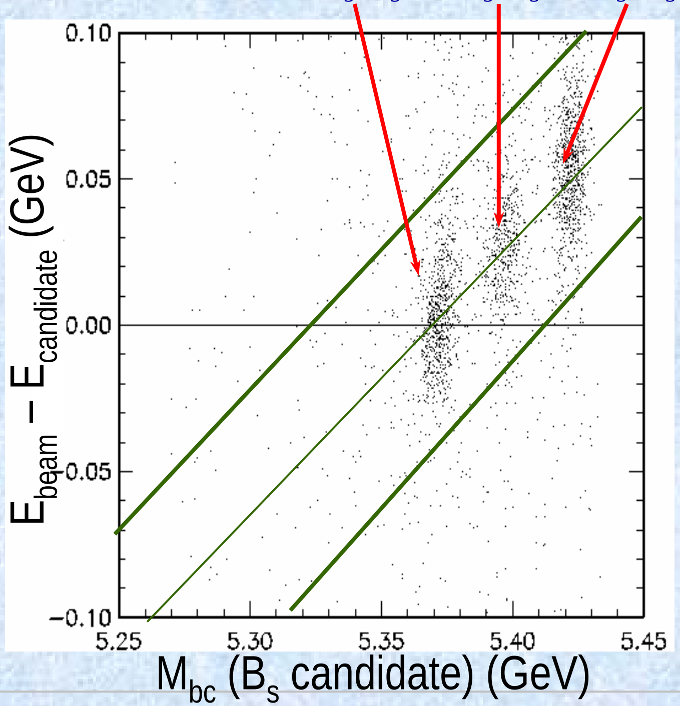
Exclusive B_s Reconstruction

- The B reconstruction techniques used at $\Upsilon(4S)$ are employed to reconstruct B_s from $\Upsilon(5S)$:

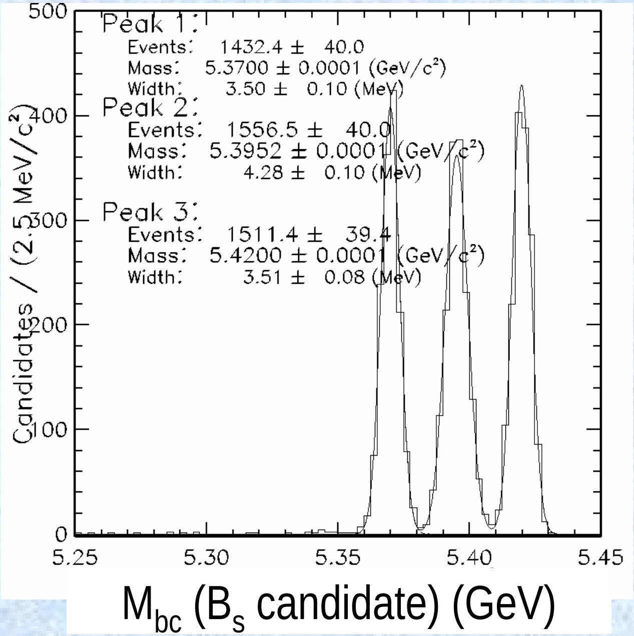
$$M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}, \quad \Delta E = E_{beam} - E_{candidate}$$

- Three sources of B_s produce three distinct distributions.

$\Upsilon(5S) \to B_s\overline{B}_s, \quad B_s\overline{B}_s^*, \quad B_s^*\overline{B}_s^*$ $\quad \mathcal{B}(B_s^* \to B_s\gamma) \sim 100\%$



MC



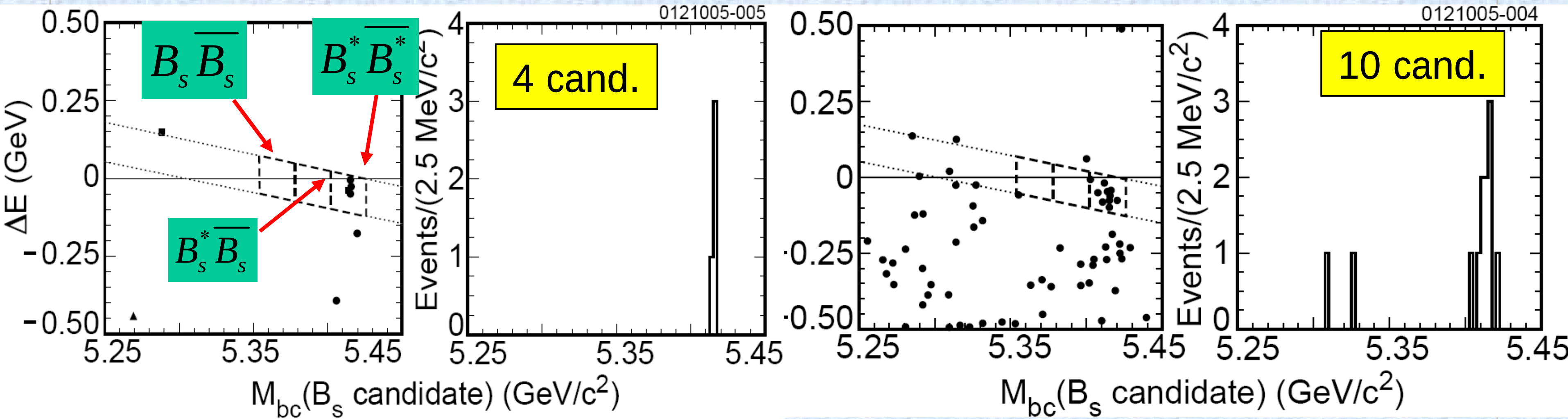
Exclusive B_s Analyses (CLEO)

Phys. Rev. Lett. **96**, 022002 (2006)

$B_s \to J/\psi\,\phi, B_s \to J/\psi\,\eta$

$B_s \to D_s^{(*)}\pi/\rho$

$D_s \to \phi\pi, K^*K, K_sK, \phi\rho$



$$\sigma(e^+e^- \to B_s^*\overline{B_s^*}) = (0.11^{+0.04}_{-0.03} \pm 0.02)\text{nb} \quad (>5\sigma)$$

$B_s^*\overline{B_s^*}$ is dominant

$$\to (31^{+11}_{-9} \pm 6)\% \text{ of the resonant cross section}$$

$$m(B_s^*) = (5413.6 \pm 1.0 \pm 3.0)\text{MeV}$$

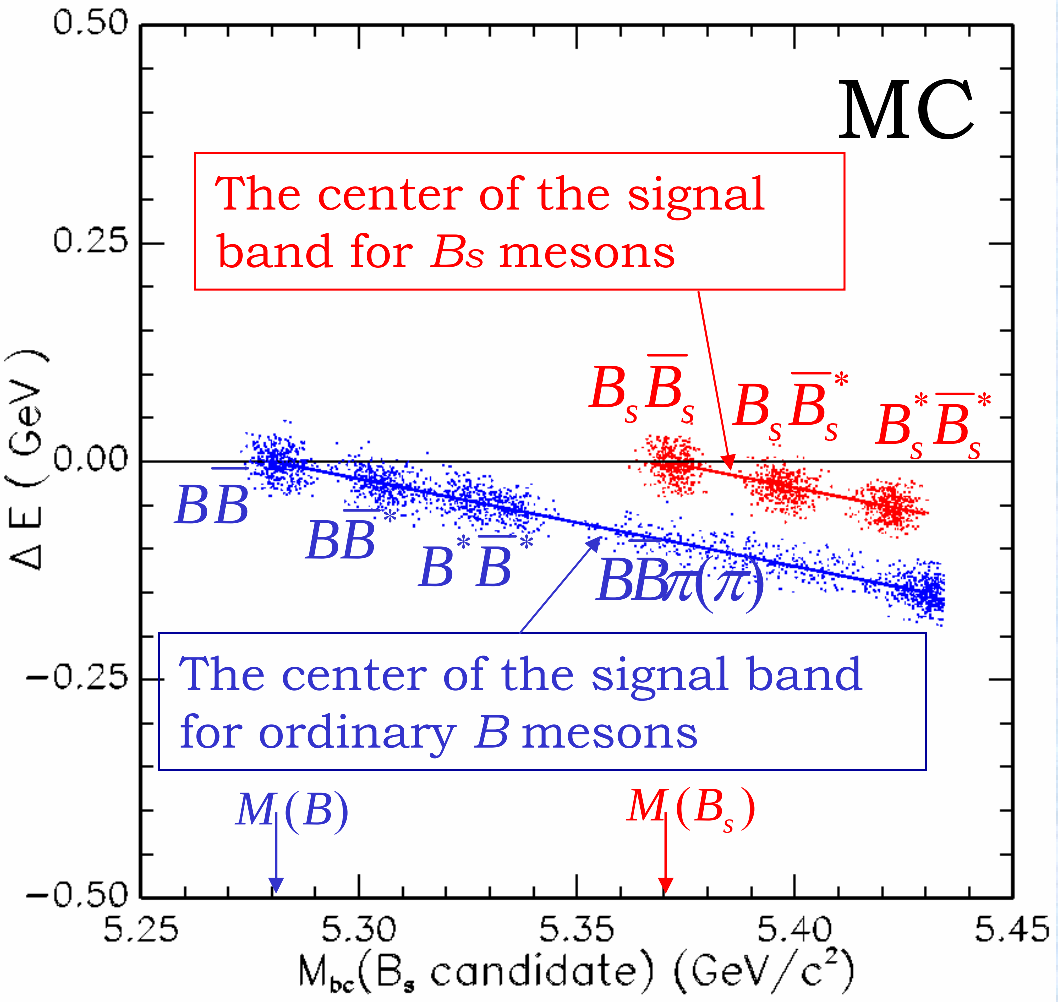
Ordinary B mesons @ Υ(5S)

- The Υ(5S) resonance can decay into 7 possible states with ordinary B mesons:

$B\bar{B},\ \ B\bar{B}^*,\ \ B^*\bar{B}^*,$

$B\bar{B}\pi,\ \ B\bar{B}^*\pi, B^*\bar{B}^*\pi, B\bar{B}\pi\pi$

- No chance of a mix-up. Ordinary B decay modes occupy a different region on the ΔE-Mbc plane & have distinct decay Modes.



Exclusive B Meson Channels (25 in Total)

- $B \rightarrow J/\psi$ decays
  - $B^+ \rightarrow J/\psi\ K^+$
  - $B^0 \rightarrow J/\psi\ K_s$
  - $B^0 \rightarrow J/\psi\ K^+\ \pi^-$

- $B \rightarrow D^{(*)}$ decays
  - $B^+ \rightarrow \overline{D}^0\ \pi^+$
  - $B^+ \rightarrow \overline{D}^0\ \rho^+$
  - $B^+ \rightarrow \overline{D}^{*0}\ \pi^+$
  - $B^+ \rightarrow \overline{D}^{*0}\ \rho^+$
  - $B^0 \rightarrow D^-\ \pi^+$
  - $B^0 \rightarrow D^-\ \rho^+$
  - $B^0 \rightarrow D^{*-}\ \pi^+$
  - $B^0 \rightarrow D^{*-}\ \rho^+$

D decay channels

$D^{*-} \rightarrow D^- \pi^0$

$D^{*-} \rightarrow D^0 \pi^-$

$D^{*0} \rightarrow D^0 \pi^0$

$\overline{D}^0 \rightarrow K^+ \pi^-$

$\overline{D}^0 \rightarrow K^+ \pi^- \pi^0$

$\overline{D}^0 \rightarrow K^+ \pi^+ \pi^- \pi^-$

$D^- \rightarrow K^+ \pi^- \pi^-$

Selection Criteria (1)

Event selection:

1. Using hadron skim
2. $N_{tr} \geq 5$
3. $R_2 < 0.25$ (5S), 0.4 (4S) (suppress continuum)

Track selection:

1. $0.1 < p < 5.3$ GeV
2. $\cos\theta < 0.95$
3. Hit fraction ≥ 0.5
4. $\chi^2/\text{dof} < 10$
5. D0 < 0.005m
6. Z0 < 0.05m

KaonID:

1. using both RICH and dE/dx info
2. $|\sigma_K^2| \leq 3$
3. Combined $\chi^2 < 0$

PionID:

$|\sigma_\pi^2| < 4$ or
RICH $L_\pi - L_K > -5$

Muons for J/ψ :

1. One muon depth$\geq$3
2. The other one E<0.3 GeV

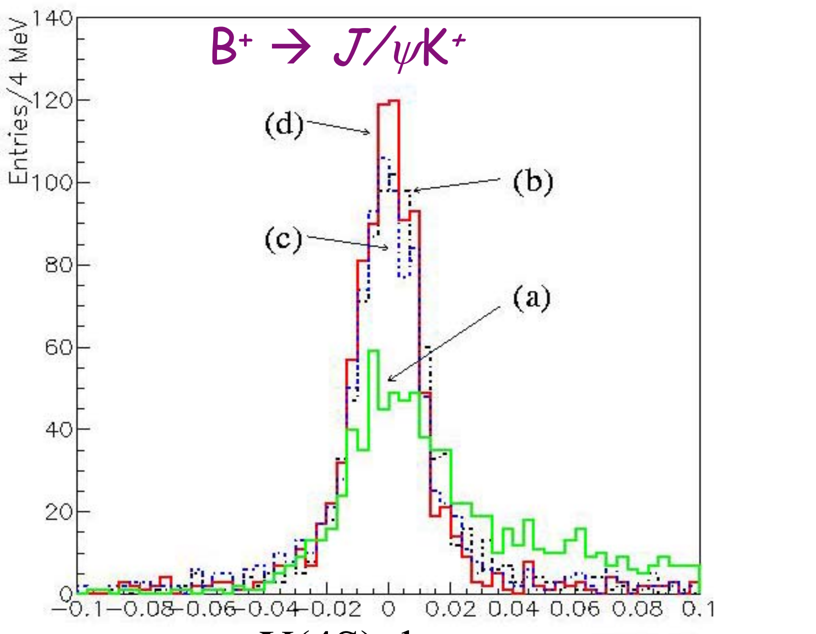
Electrons for J/ψ :

1. E9/E25>0.75
2. $0.5 \leq E/P \leq 1.2$

Selection Criteria (2)

For J/ψ modes:

- $P_{J/\psi}$<2.6 GeV (5S), 2.0 GeV (4S)
- **3.05 ≤ $M_{\mu\mu}$ ≤ 3.14 GeV**
- **1.5 ≤ M_{ee} ≤ 3.14 GeV**
- Radiated photons included for *ee*
- J/ψ mass constraint, fit χ2<100



Y(4S) data

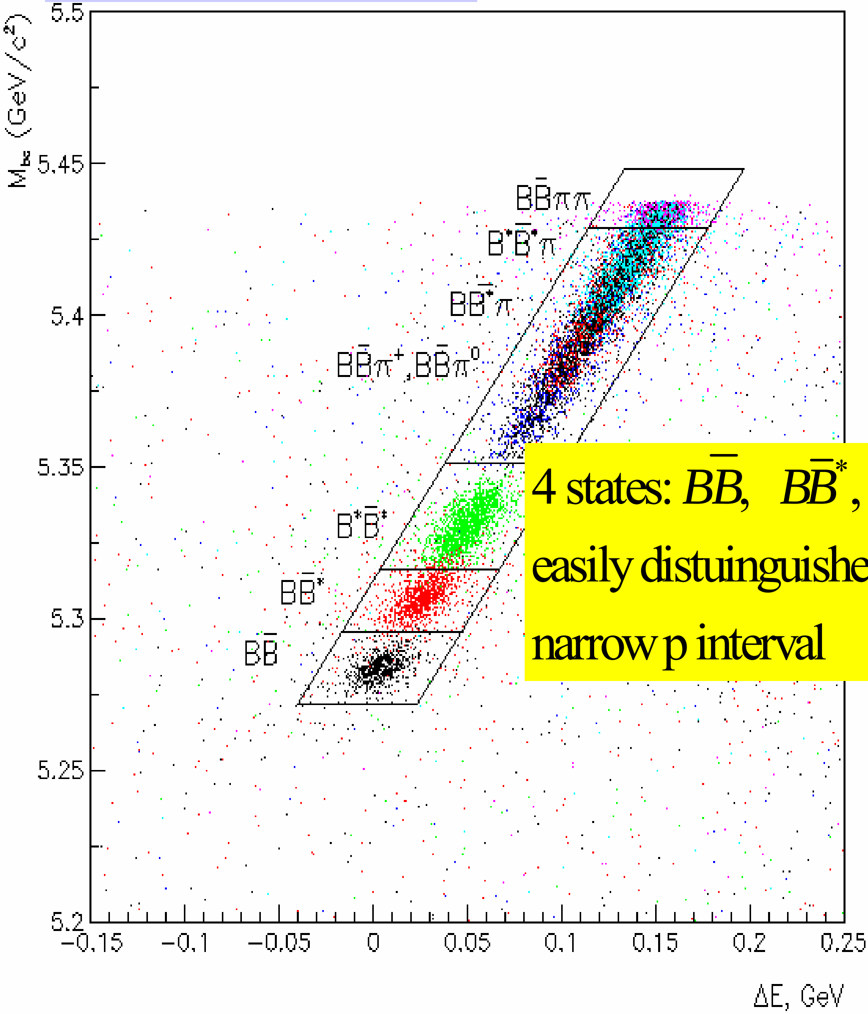
For D modes:

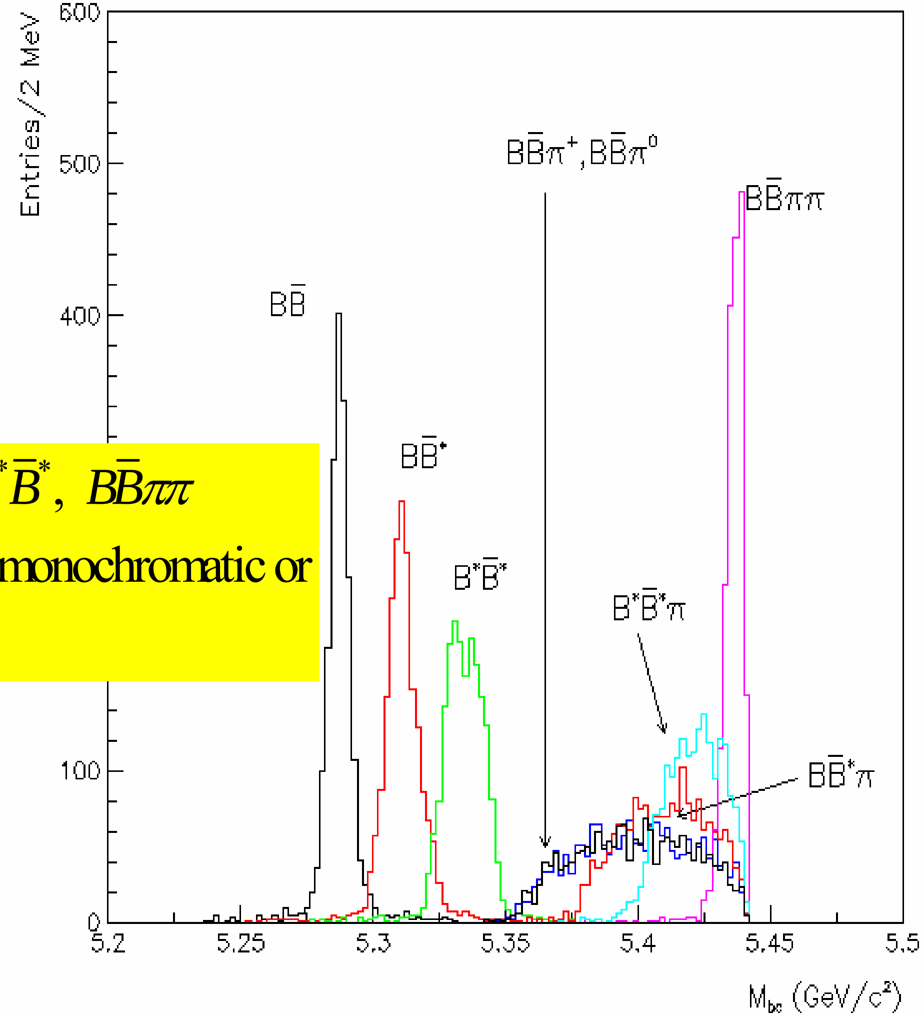
- D^0 and $D^{\pm}$ 2σ mass cut
- $M_{(D^*-D)}$ require 3σ cut
- $|M_\rho-775.8|<150$ MeV
- For ρ, $|\cos\theta_{helicity}|>0.3$ and $\cos\theta_{helicty}>-0.7$
- Require π^0 P>0.4GeV in $D^0 \rightarrow K^- \pi^+ \pi^0$ decay
- $|\cos\theta_{thrust}|<0.75$

$\Upsilon(5S)$ Signal MC M_{bc} vs ΔE ($B^+ \rightarrow J/\psi K^+$)

$$M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$$

$$\Delta E = E_{candidate} - E_{beam}$$





4 states: $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$, $B\bar{B}\pi\pi$

easily distuinguished: monochromatic or narrow p interval

Testing B→ J/ψ X Reconstruction at Υ(4S)

B Branching Fractions on Υ(4S) (~5 fb^{-1})					
Mode	Rec eff (%)	N_{rec}	Product BF PDG (10^{-3})	Source	BF from 4S Data(10^{-3}) statistic error only
$B^+ \to J/\psi\ K^+$	48.4±0.9	314 ±17	1.00 ± 0.04	BELL03	1.18±0.06
$B^0 \to J/\psi\ K_s$	41.9±1.7	65±8	0.29 ± 0.02	BELL03	0.28±0.03
$B^0 \to J/\psi\ K^{*0}$	28.9±0.6	223±15	0.87 ± 0.05	BELL02	0.95±0.08

Measured branching fractions agree with PDG

Number of events expected on Υ(5S)				
channels	**Decay modes**	**Product BF (10^{-3})**	**Rec Eff (%)**	**events expected**
$B^+ \to J/\Psi\ K^+$	$J/\Psi \to ee$ and $\mu\mu$	**1.00 ± 0.04**	**43.4±0.9**	**4.3**
$B^0 \to J/\Psi\ K_s$	$J/\Psi \to ee$ and $\mu\mu$	**0.29 ± 0.02**	**37.2±1.7**	**1.1**
$B^0 \to J/\Psi\ K^{*0}$	$J/\Psi \to ee$ and $\mu\mu$	**0.87 ± 0.05**	**25.6±0.6**	**2.2**
(1.31±0.27)x10^5 resonance events (Phys. Rev. Lett **95**, 261801(2005))				**Total: 8±2**

$B \to D^{(*)} X$ Expectation at $\Upsilon(5S)$

channels	Decay modes	Product BF (10^{-3})	Rec Eff (%)	Events expected
$B^+ \to D^0 \pi^+$	$D^0 \to K^+ \pi^-$	0.19 ± 0.01	34.4±0.5	5.4
	$D^0 \to K^+ \pi^- \pi^0$	0.65 ± 0.05	12.8±0.5	7.0
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	0.37 ± 0.03	20.7±0.7	6.4
$B^+ \to D^0 \rho^+$	$D^0 \to K^+ \pi^-$	0.51 ± 0.07	8.2±0.3	3.5
	$D^0 \to K^+ \pi^- \pi^0$	1.74 ± 0.25	3.0±0.2	4.5
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	1.0 ± 0.14	5.2±0.3	4.4
$B^+ \to D^{*0} \pi^+$	$D^0 \to K^+ \pi^-$	0.11 ± 0.01	11.1±0.5	1.0
	$D^0 \to K^+ \pi^- \pi^0$	0.37 ± 0.04	2.5±0.2	0.8
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	0.21 ± 0.02	6.9±0.4	1.2
$B^+ \to D^{*0} \rho^+$	$D^0 \to K^+ \pi^-$	0.23 ± 0.04	2.1±0.1	0.4
	$D^0 \to K^+ \pi^- \pi^0$	0.79 ± 0.15	0.7±0.1	0.5
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	0.46 ± 0.08	1.5±0.1	0.6
$B^0 \to D^- \pi^+$	$D^- \to K^+ \pi^- \pi^-$	0.25 ± 0.03	30.9±1.5	6.9
$B^0 \to D^- \rho^+$	$D^- \to K^+ \pi^- \pi^-$	0.71 ± 0.12	6.6±0.4	3.9
$B^0 \to D^{*-} \rho^+$	$D^0 \to K^+ \pi^-$	0.17 ± 0.02	4.3±0.2	0.6
	$D^0 \to K^+ \pi^- \pi^0$	0.60 ± 0.09	1.3±0.1	0.7
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	0.34 ± 0.05	2.7±0.2	0.8
	$D^- \to K^+ \pi^- \pi^-$	0.19 ± 0.03	1.7±0.1	0.3
$B^0 \to D^{*-} \pi^+$	$D^0 \to K^+ \pi^-$	0.044 ± 0.003	22.0±0.4	1.3
	$D^0 \to K^+ \pi^- \pi^0$	0.15 ± 0.0	4.0±0.1	0.8
	$D^0 \to K^+ \pi^+ \pi^- \pi^-$	0.09 ± 0.01	12.2±0.4	1.4
	$D^- \to K^+ \pi^- \pi^-$	0.08 ± 0.01	7.3±0.5	0.5
				Total: 53±11

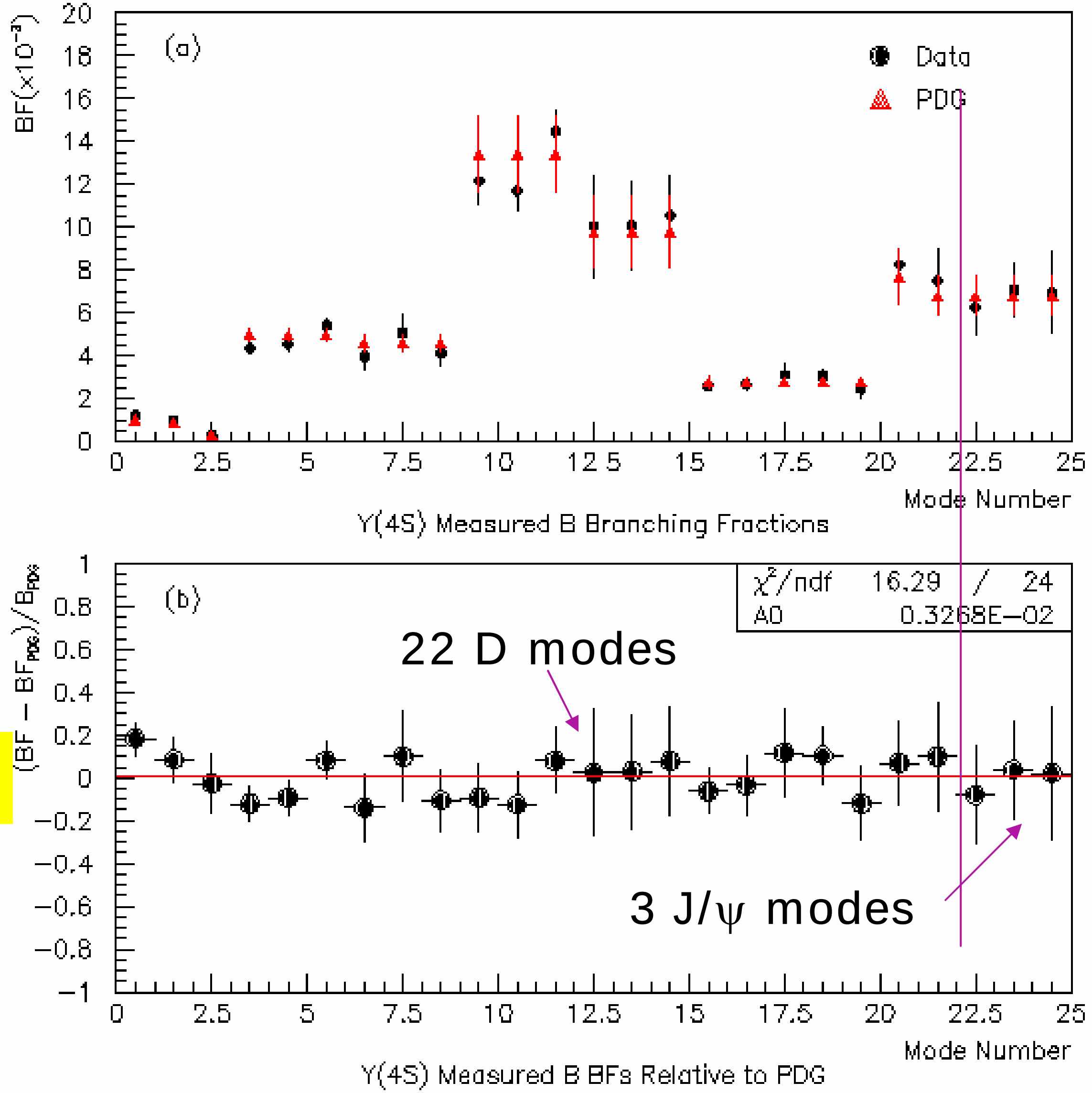
Analysis Validation
B→ J/ψ X & B→ $D^{(*)}$ X in Υ(4S) data

~5 fb^{-1} Υ(4S) data

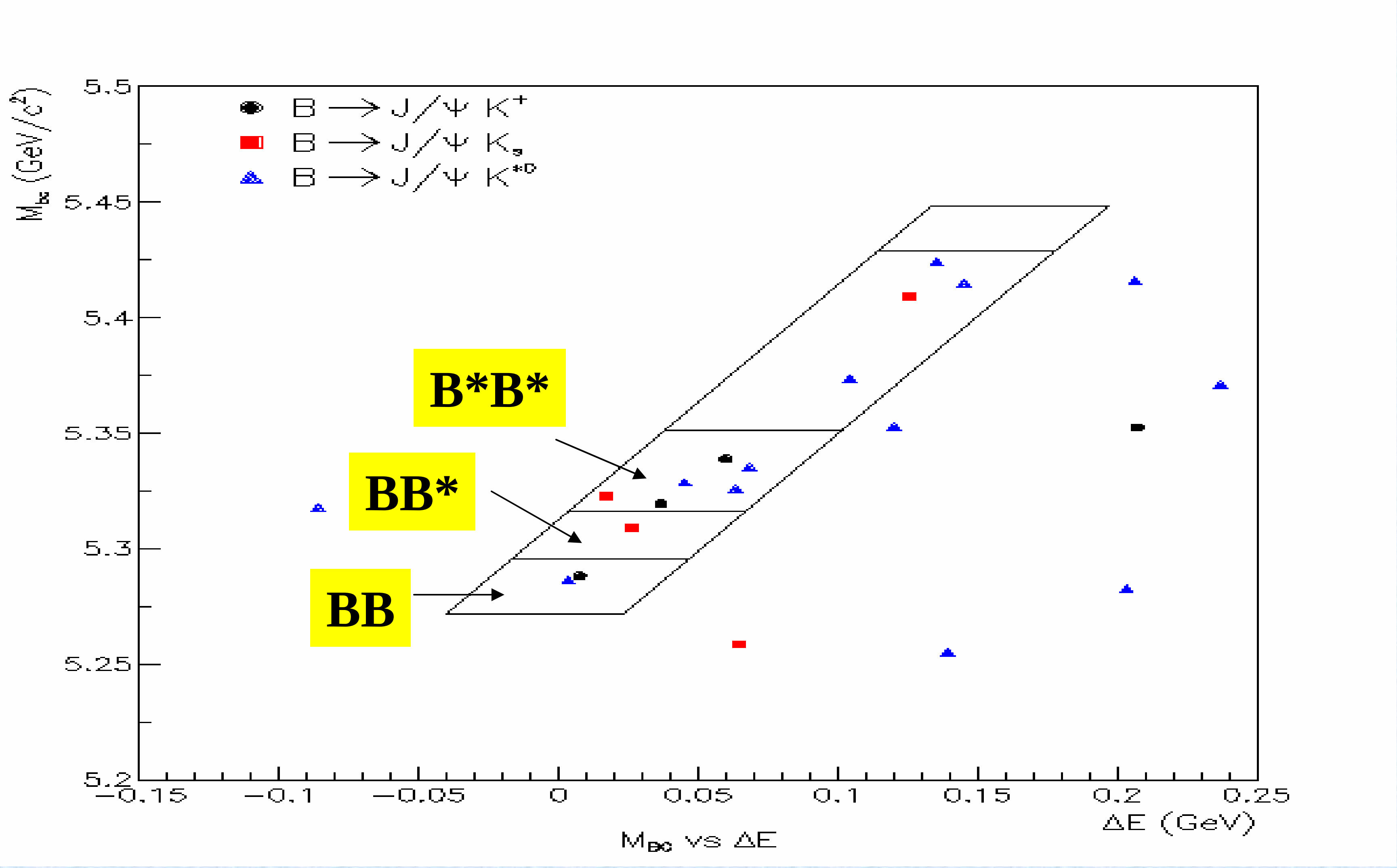
$(4.65 \pm 0.4) \times 10^6 B\overline{B}$

Measured(black)
PDG (red)

(Measured - PDG)



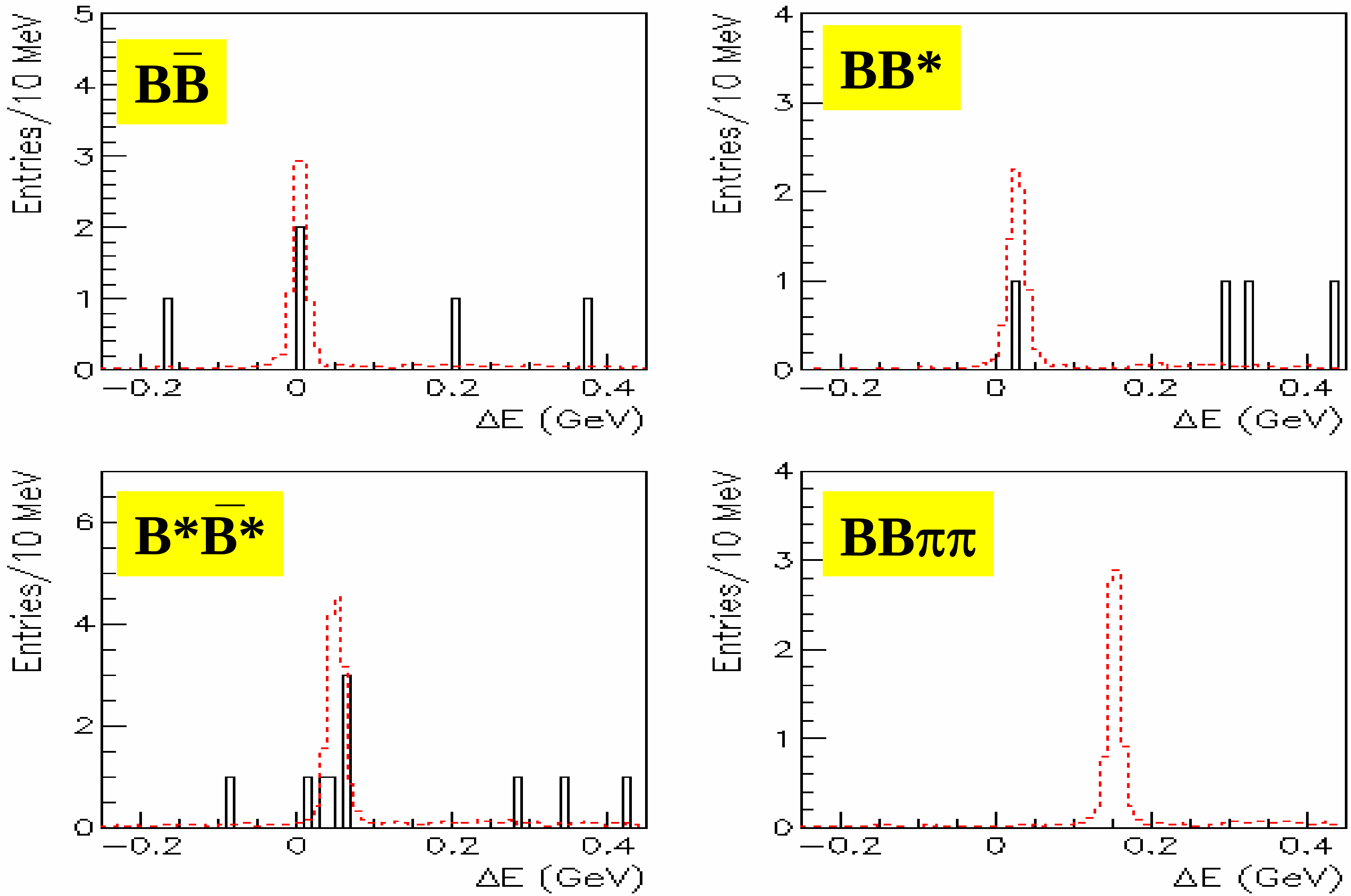
M_{bc} vs ΔE $\Upsilon(5S)$ Data J/ψ Modes



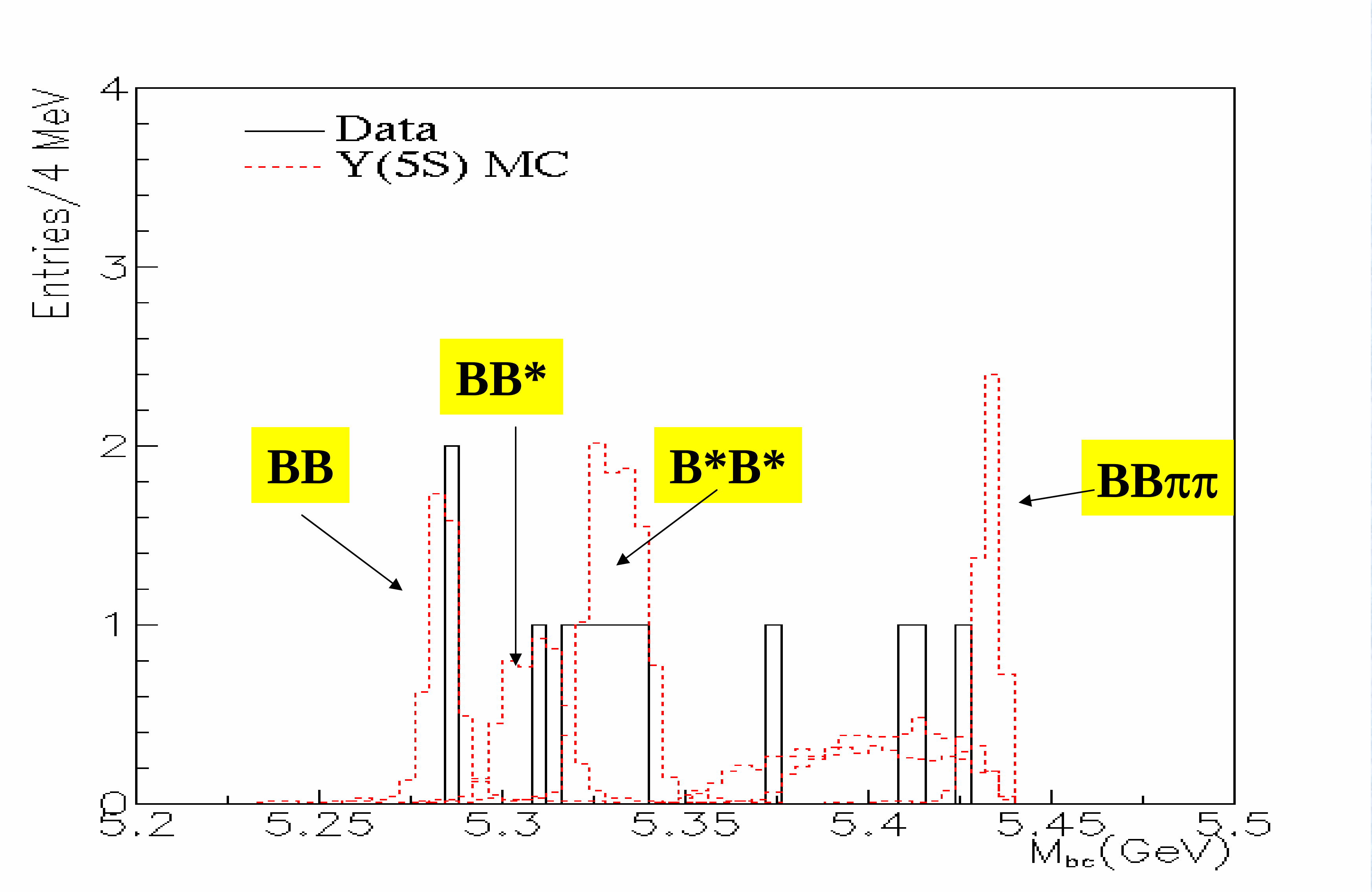
No significant backgrounds from other B decays, B_s decays or the continuum.

ΔE in Slices of M_{bc} J/ψ Modes (data)

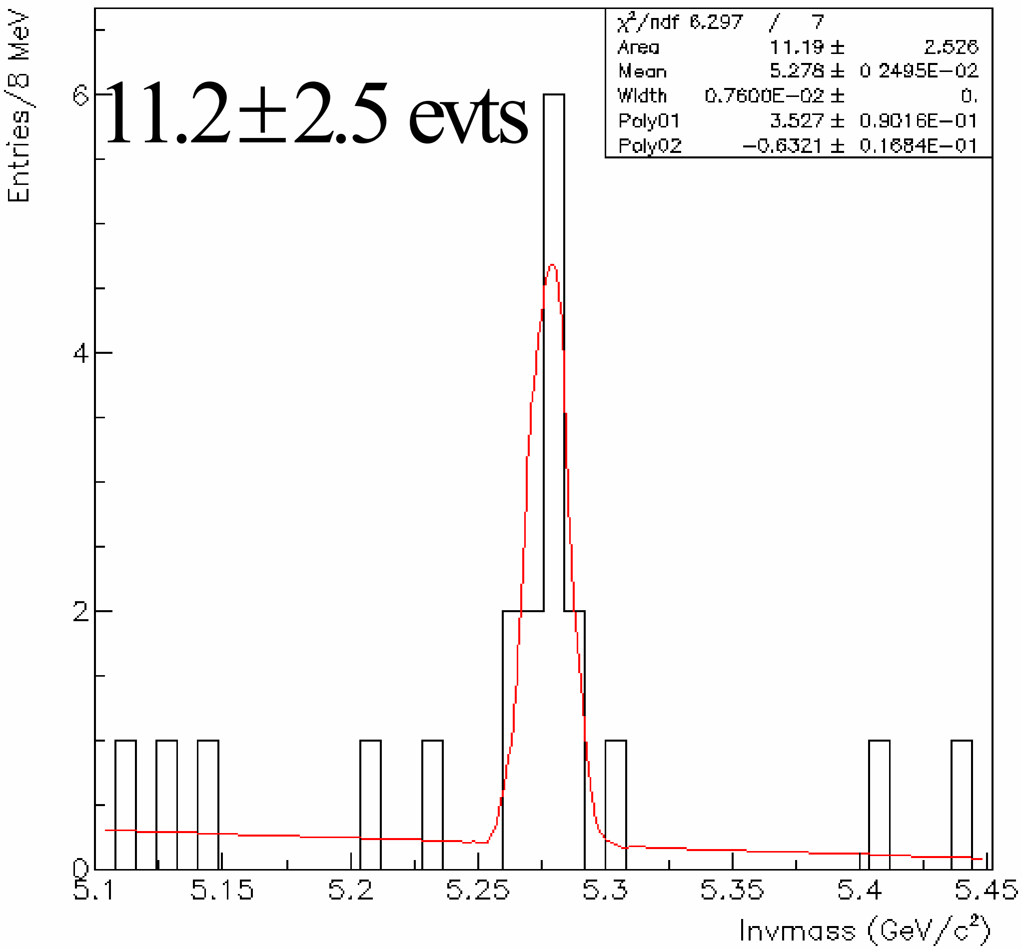
The red dash lines are MC predictions



M_{bc} in Signal Region J/ψ Modes (data)



B Invariant Mass J/ψ Modes (Data)



Recall: we expected

8 ± 2 evts

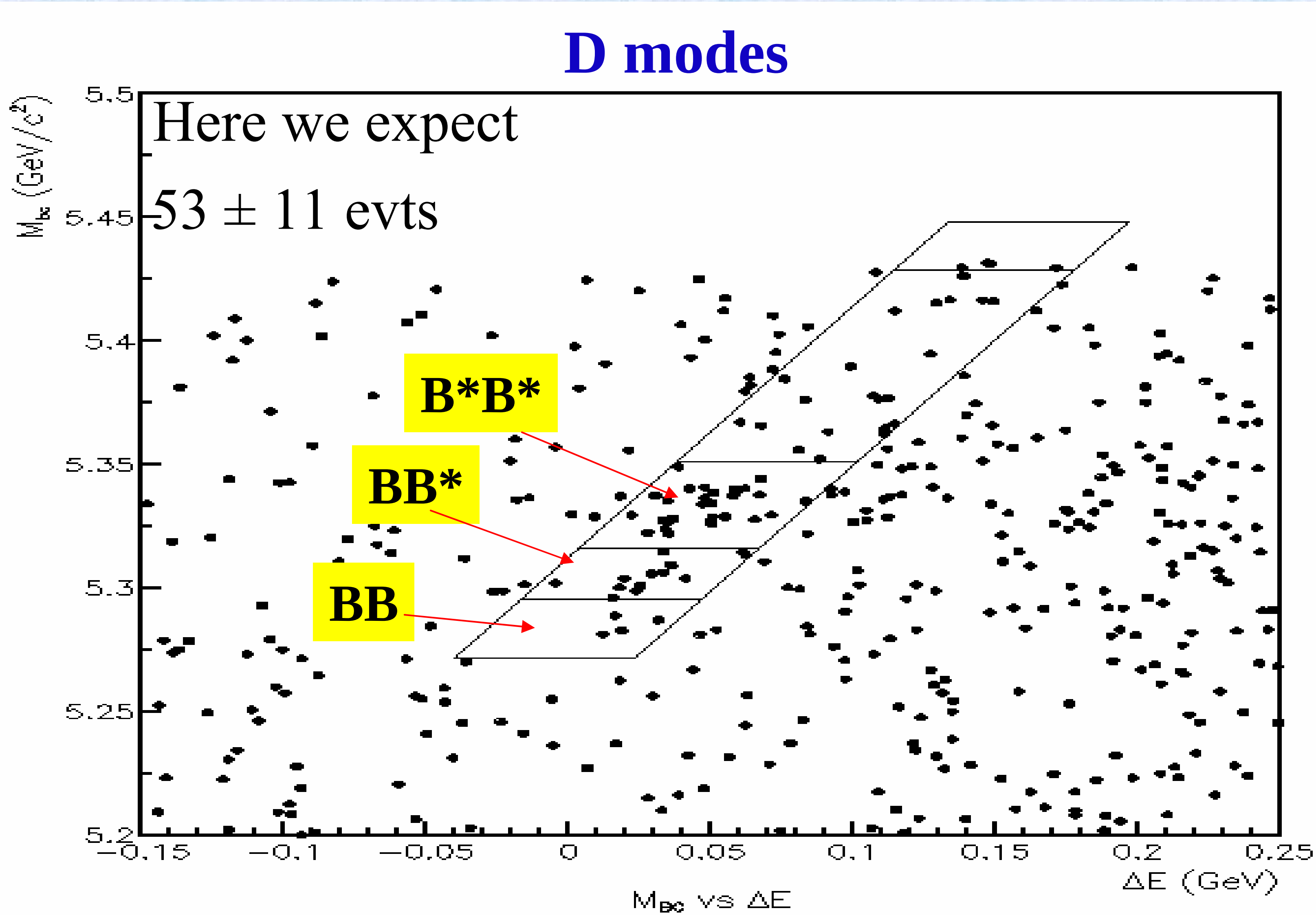
Cross section:

$\sigma(e^+e^- \rightarrow B^{(*)}B^{(*)}(\pi)(\pi))$

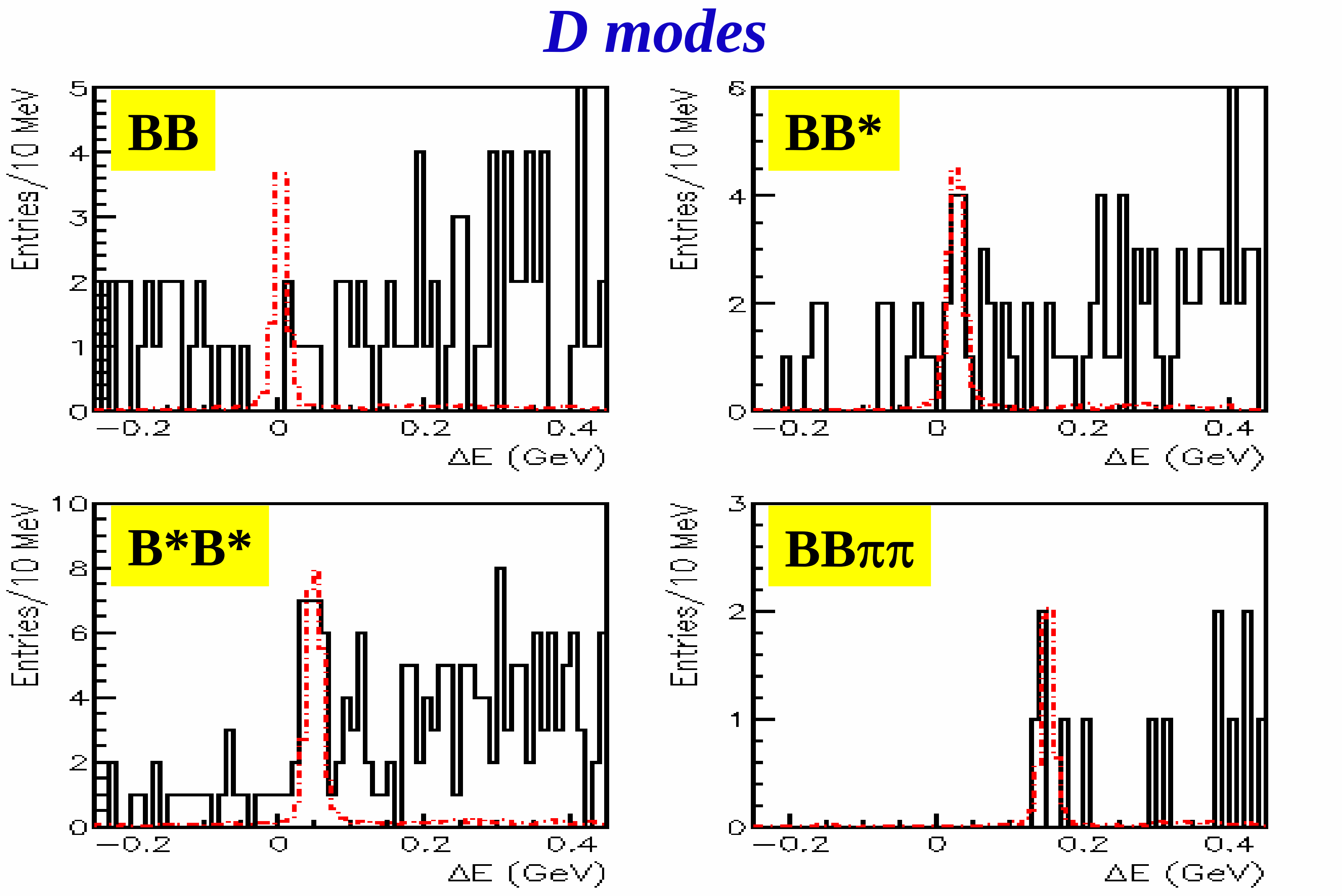
$= (Y-B)/L*\sum(\varepsilon_i*BF_i)$

$$\sigma(e^+e^- \rightarrow B^{(*)}\overline{B^{(*)}}(\pi)(\pi)) = (0.30 \pm 0.10)\text{nb}$$

M_{bc} vs ΔE 5S data

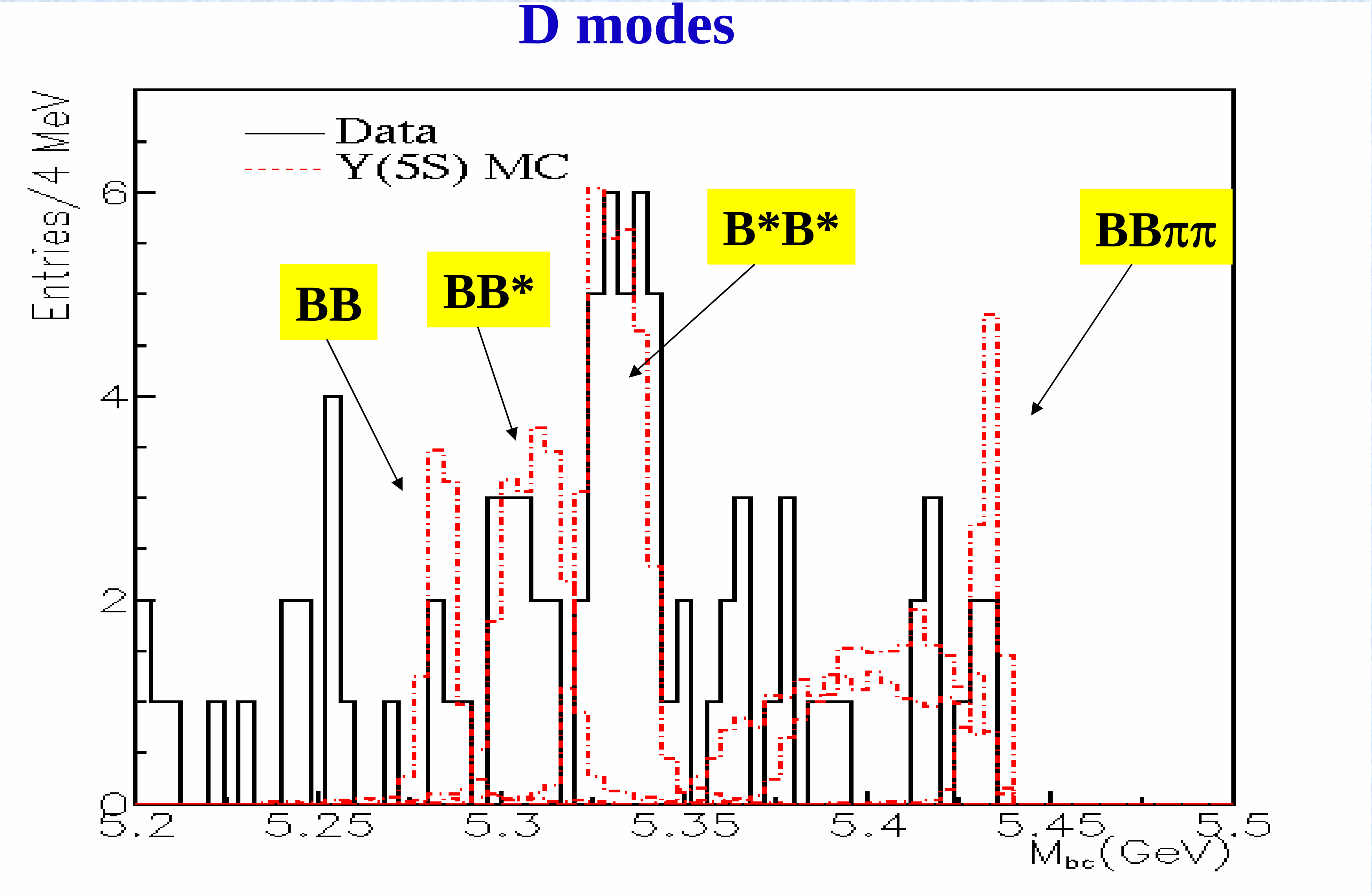


ΔE in Slices of M_{bc}

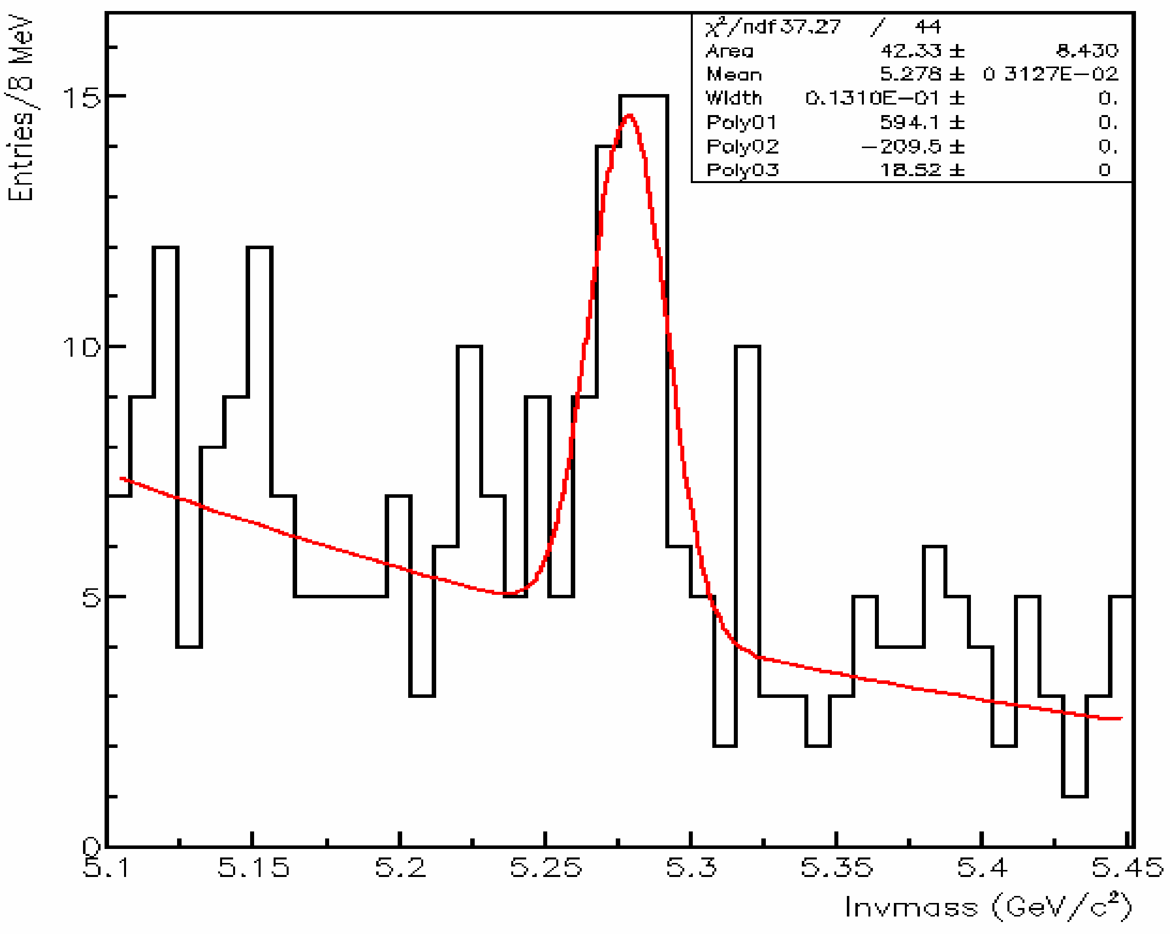


Note different horizontal scales!

M_{bc} in Signal Region



B Invariant Mass D Modes (Υ(5S) Data)



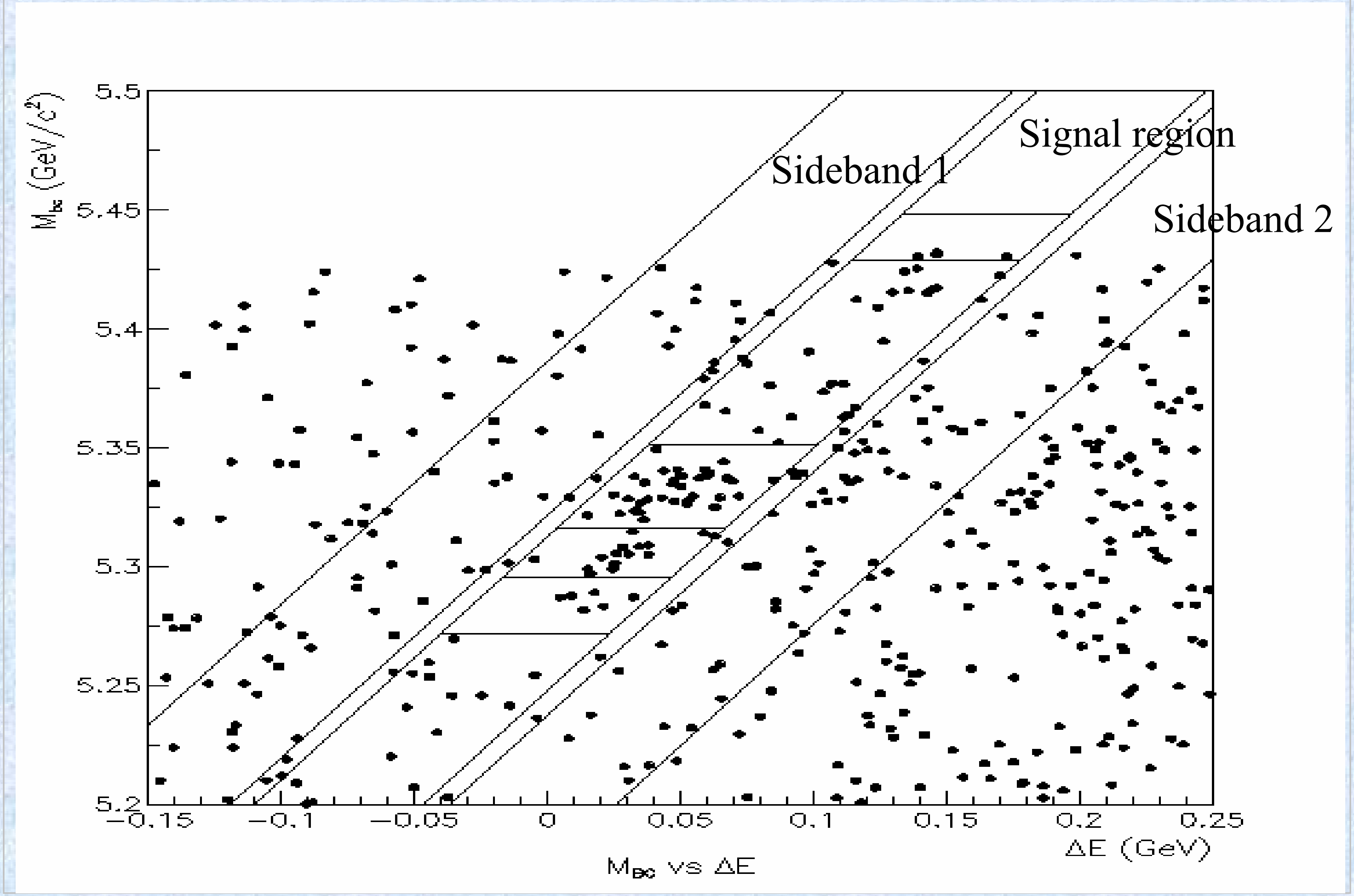
42.3 ± 8.4 evts

Recall: we expected

53 ± 11 evts

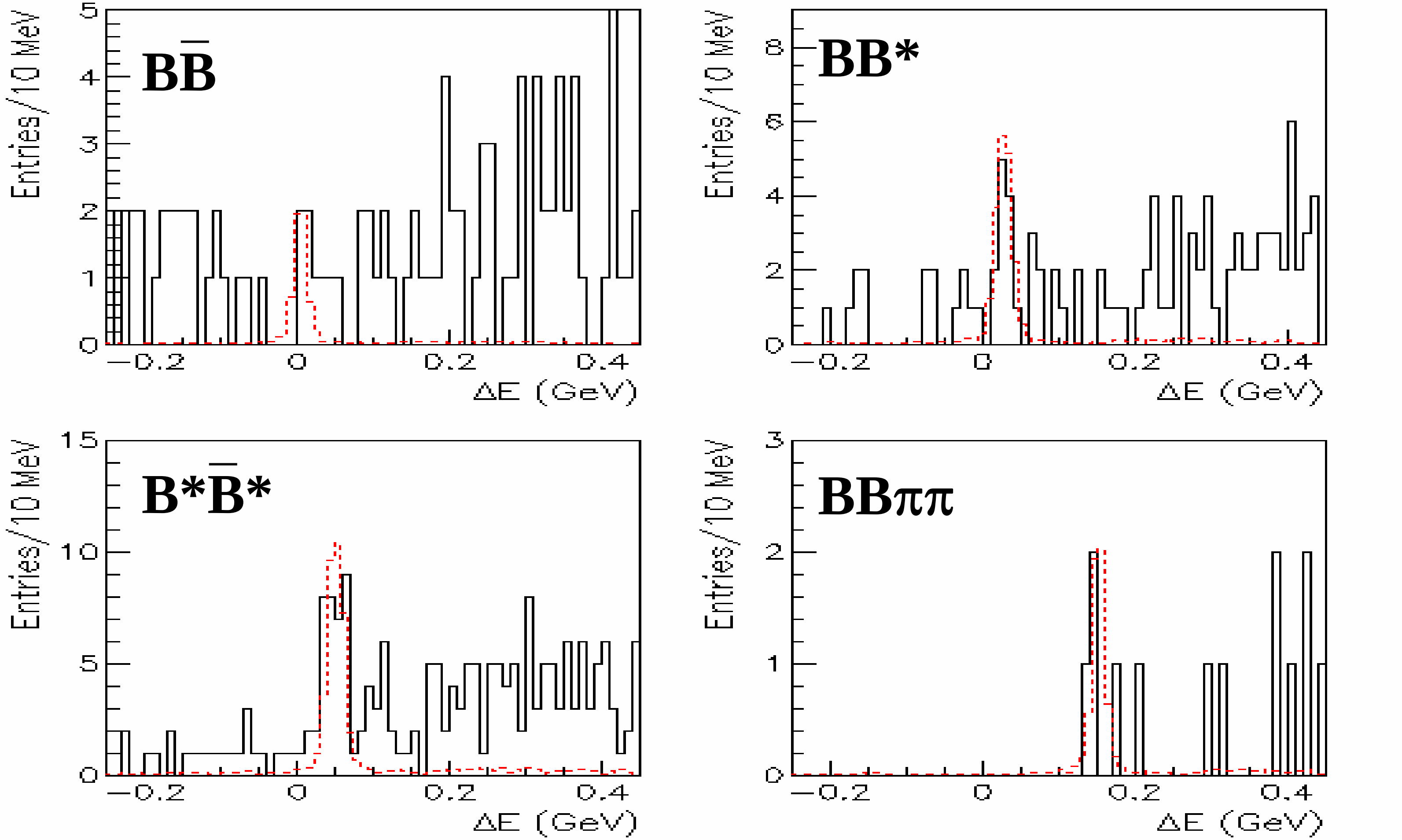
$$\sigma(e^+e^- \to B^{(*)}\overline{B^{(*)}}(\pi)(\pi)) = (0.16 \pm 0.03)\,\text{nb}$$

Data J/ψ and D modes combined



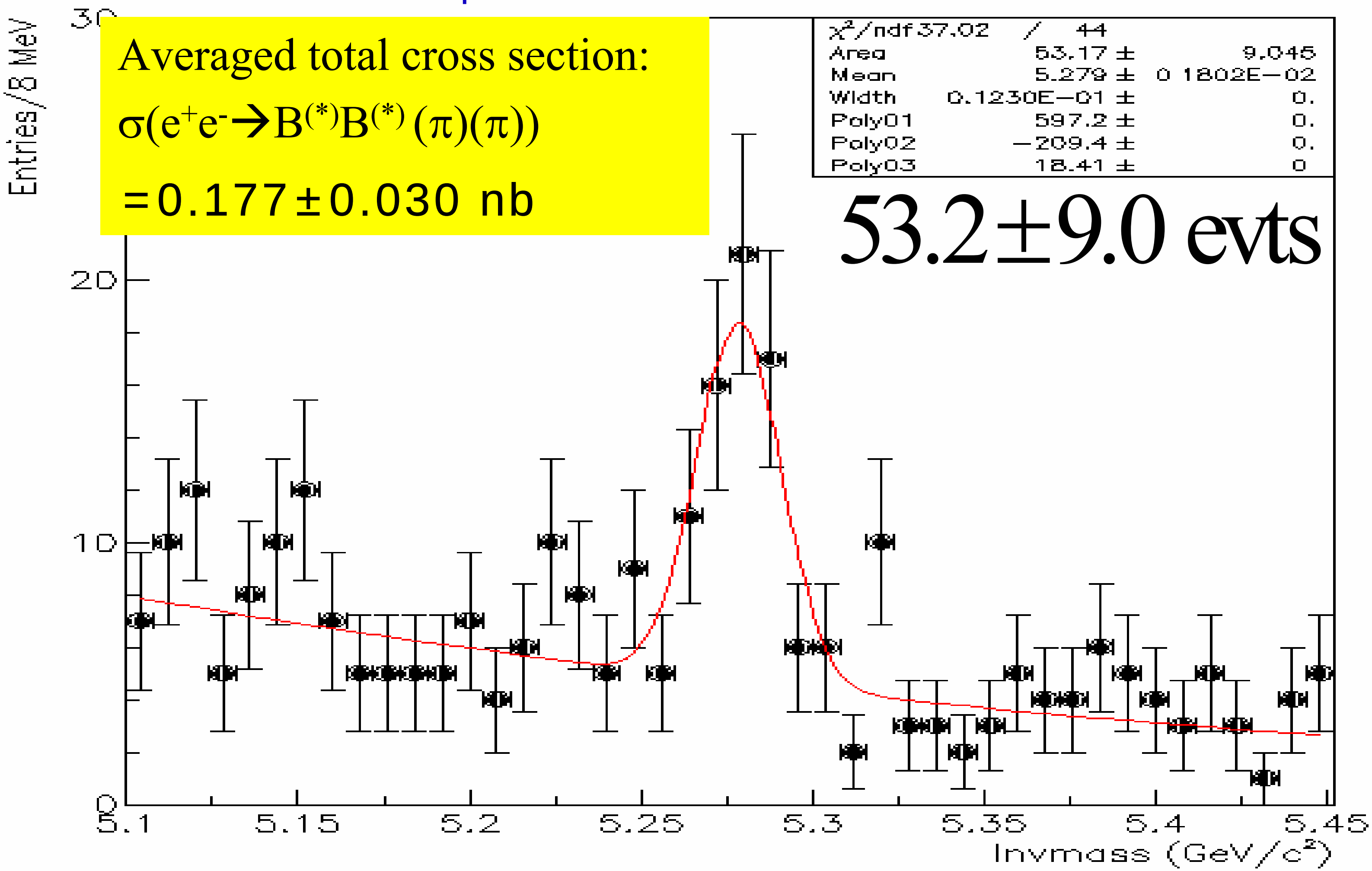
Total ΔE in Slices of M_{bc}

J/ψ and D modes combined



B Invariant Mass

J/ψ and D modes combined



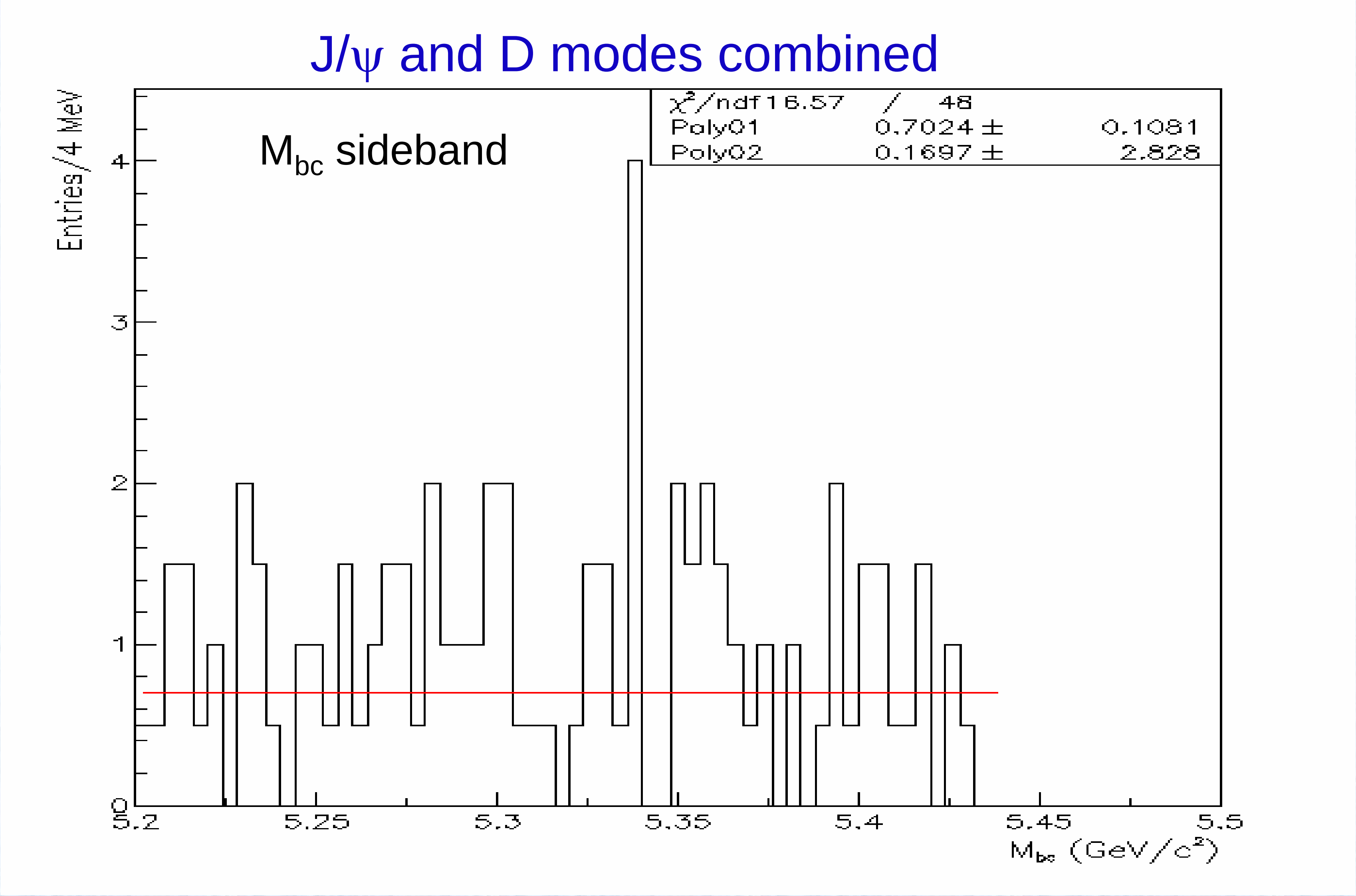
Averaged total cross section:

$\sigma(e^+e^- \rightarrow B^{(*)}B^{(*)}(\pi)(\pi))$

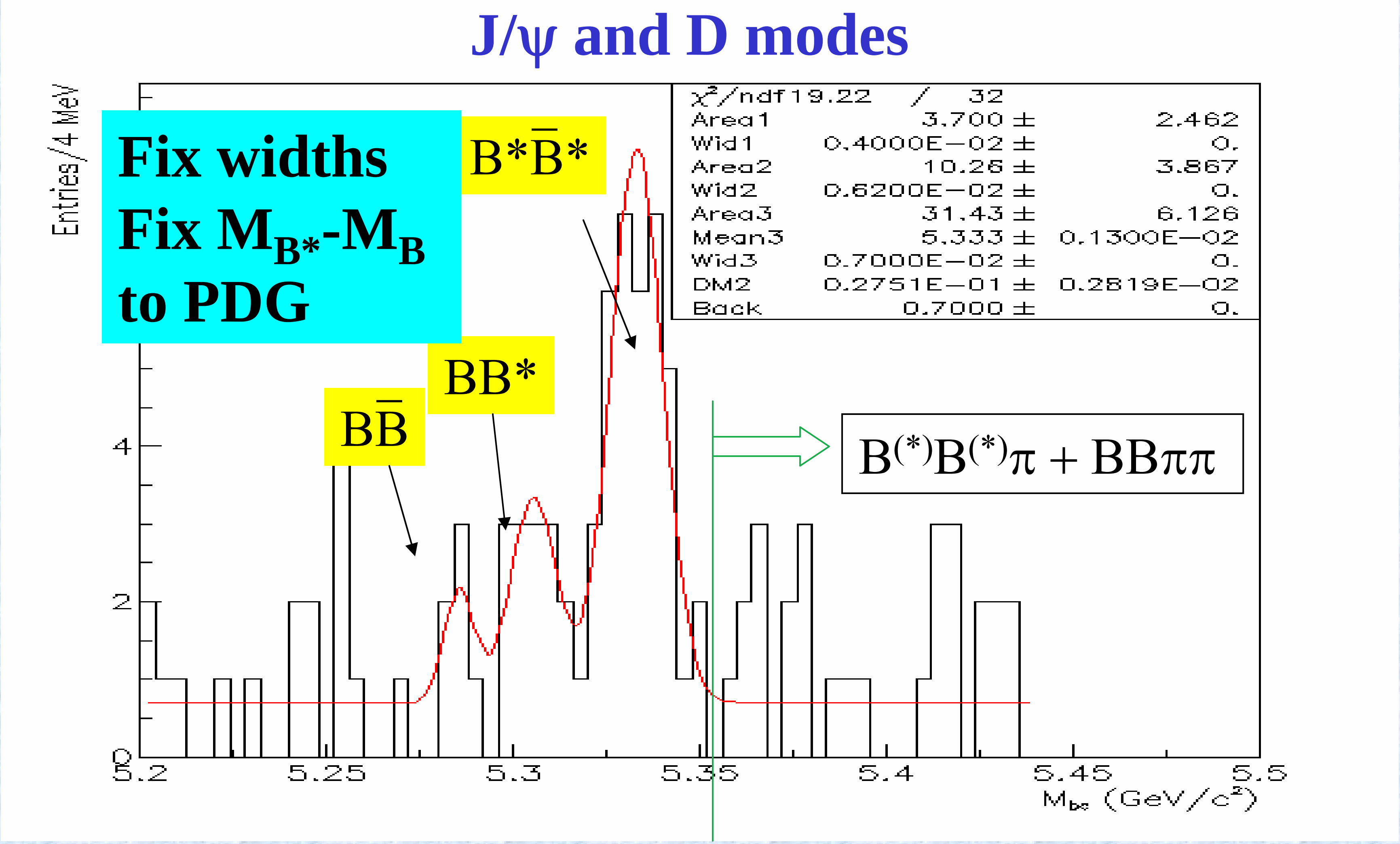
$= 0.177 \pm 0.030$ nb

53.2 ± 9.0 evts

Determination of Contributing Subprocesses

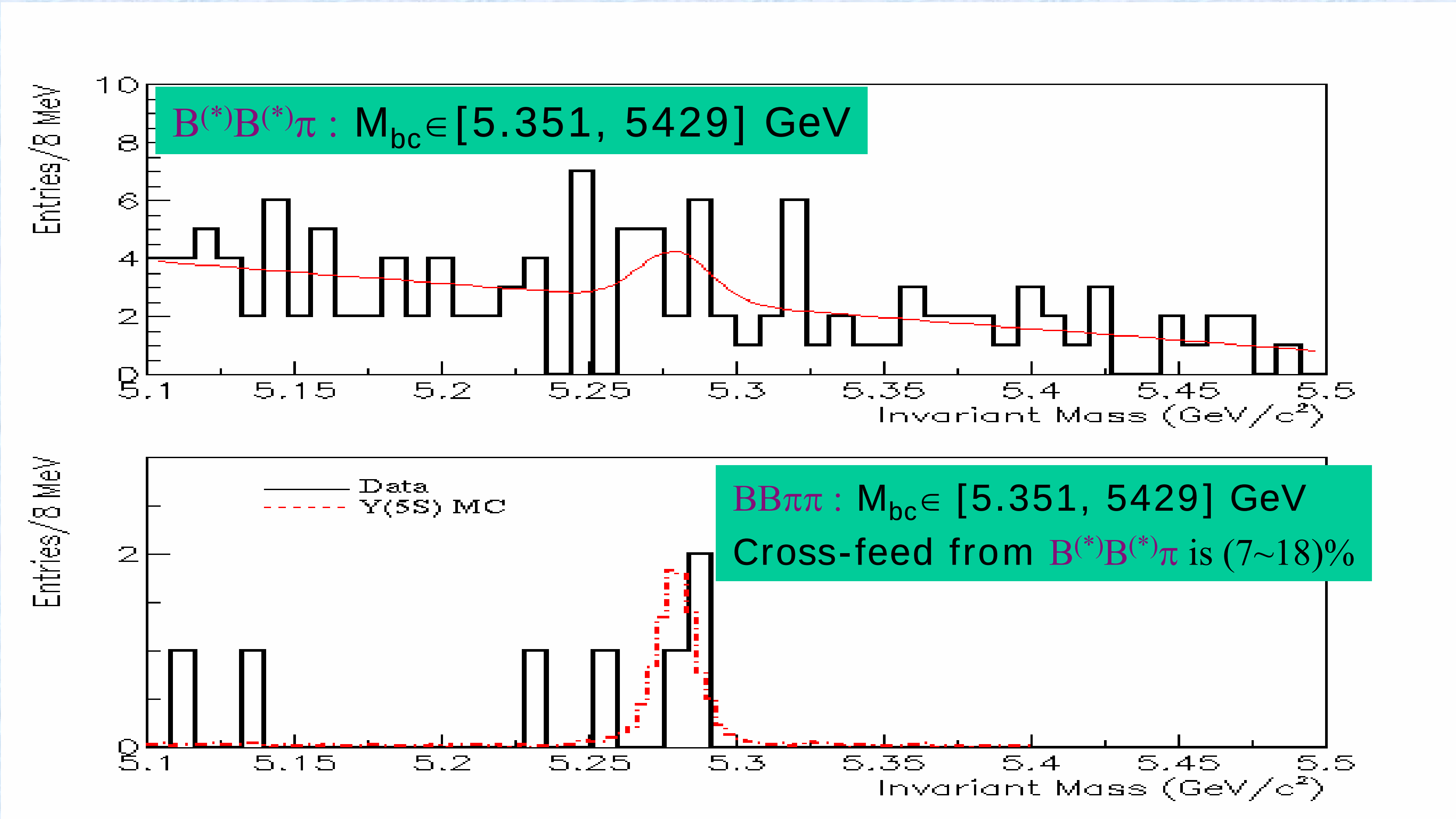


Determination of Contributing Subprocesses



M_{bc} in the signal region

Invariant Mass for $B^{(*)}\overline{B}^{(*)}\pi$ and $BB\pi\pi$



Upper limits are set for $B\overline{B}$, $B^{(*)}\overline{B}^{(*)}\pi$ and $BB\pi\pi$.

Systematics

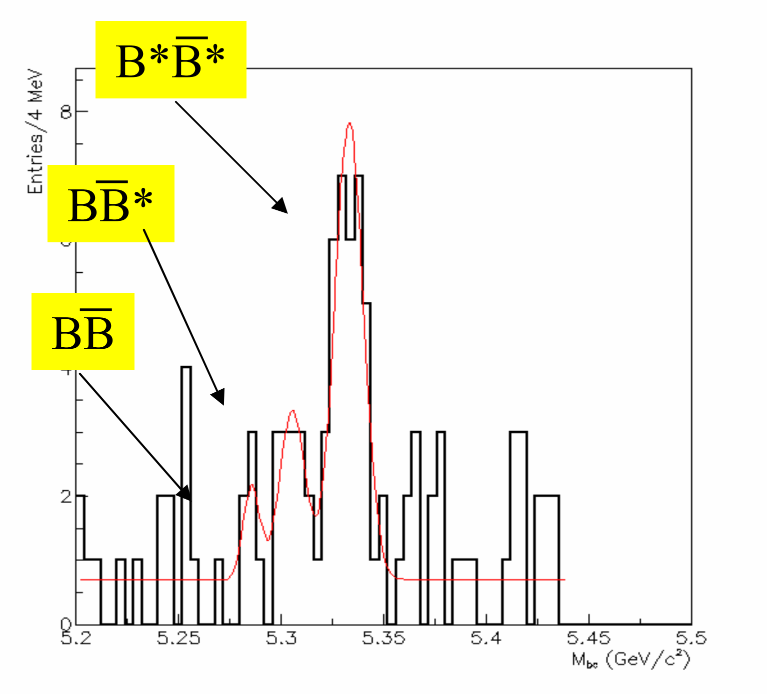
Source	$B^{(*)}B^{(*)}(\pi)(\pi)$ (%)	BB (%)	BB^* (%)	B^*B^* (%)	$B^{(*)}B^{(*)}\pi$ (%)	$BB\pi\pi$ (%)
Recon. Eff.	6.3	6.3	6.3	6.3	6.3	6.3
Input BFs	3.0	3.0	3.0	3.0	3.0	3.0
Background	3.1	16.7	10.4	4.9	3.7	-
Fitting Technique	3.0	12.5	3.3	3.7	4.3	-
Multiple Candidates	3.1	3.1	3.1	3.1	3.1	3.1
Luminosity	2.0	2.0	2.0	2.0	2.0	2.0
total	9.0	22.3	13.5	10.0	9.7	7.0

Cross Section Results

Y(5S)→	Yield	Significance (σ)	Cross-Section (nb)	σ / σ_{tot}
BB	<7.5 at 90% CL	-	<0.038 at 90% CL	<0.22
BB^*	10.3±3.9	4.3	0.039±0.015±0.005	0.22 ±0.09±0.03
B^*B^*	31.4±6.1	7.6	0.119±0.023±0.013	0.67 ±0.13±0.08
$B^{(*)}B^{(*)}\pi$	<13.9 at 90% CL	-	<0.064 at 90% CL	<0.29
$BB\pi\pi$	<6.4 at 90% CL	-	<0.029 at 90% CL	<0.15
Total	53.2±9.0	8.1	0.176±0.030±0.016	

Evidence for B*B,
B*B* is established

B_s* Mass Measurement

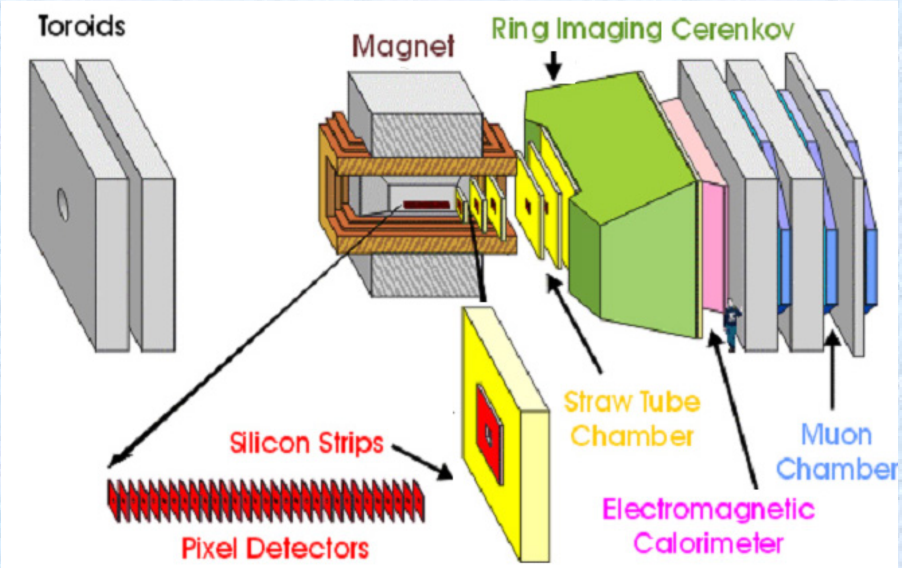


- Combine $M_{bc}(B^*)$ with $M_{bc}(Bs^*)$, measure
  $\Delta M = M(B_s^*) - M(B^*)$
  $M(B_s^*) = M(B^*) + \Delta M$
  - Dominant systematic uncertainty from beam energy calibration, cancels
  - $M(B^*) = (5325 \pm 0.6)$ MeV (PDG)
- <u>This analysis</u>: $M_{bc}(B^*) = (5333.1 \pm 1.3)$ MeV
  (note: beam energy shift of (6.4 ±1.3) MeV)
- CLEO B_s analysis:
  $M_{bc}(B_S^*) = (5413.6 \pm 1.0 \pm 3.0)$ MeV
- From kinematic considerations:
  $\Delta M = \Delta M_{bc} + 1.6$ MeV
- We therefore obtain:
  $M(B_S^*) = \Delta M + M(B^*) = (5411.7 \pm 1.6 \pm 0.6)$ MeV
- Using the CDF measurement
  $M(B_s) = (5366.01 \pm 0.73 \pm 0.33)$ MeV
- M1 Mass splitting
  $M(B_S^*) - M(B_S) = (45.7 \pm 1.7 \pm 0.7)$ MeV
  $M(B^*) - M(B) = (45.78 \pm 0.35)$ MeV

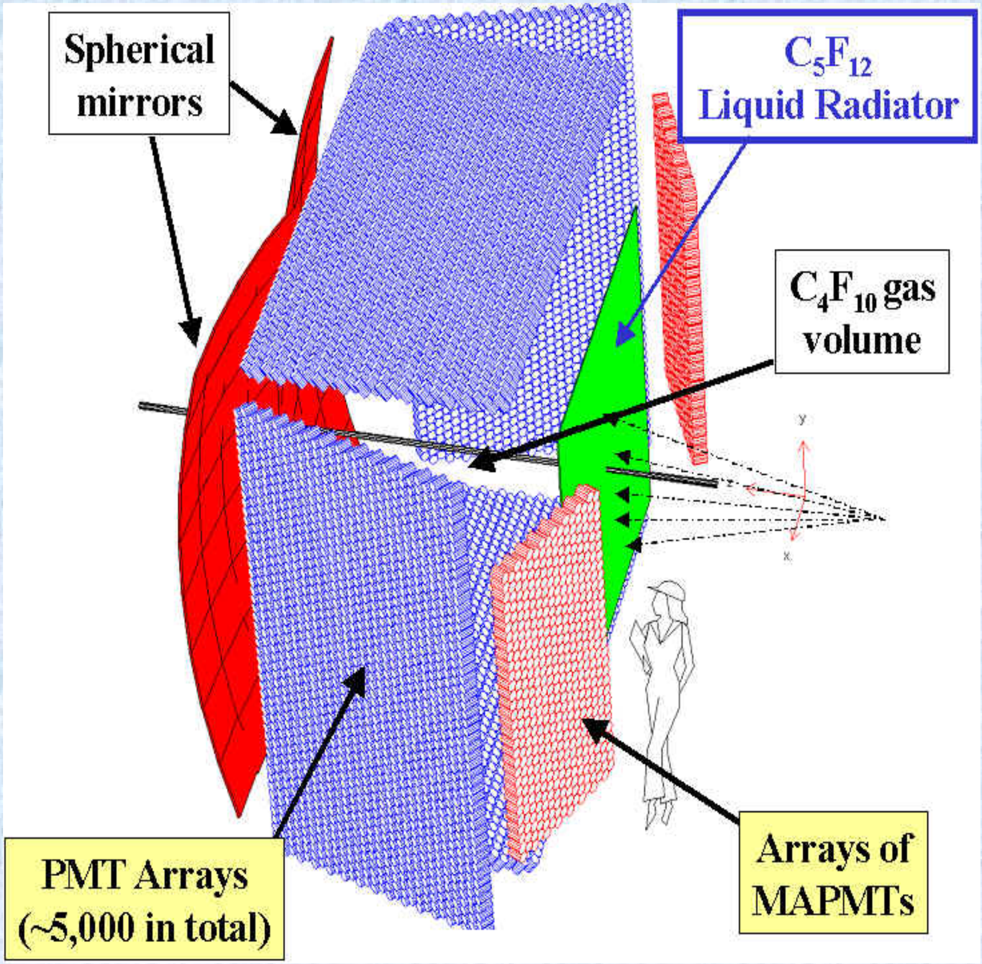
Summary

- First determination of the composition of ordinary BB final states at $\Upsilon(5S)$.
- B*B*:BB*:BB ~ 3:1:<1, consistent with UQM predictions.
- Cross section measurements:
  - $\sigma(\Upsilon(5S)\rightarrow BBX)$ = (0.177 ± 0.030 ± 0.016) nb,
    - ~2/3 of the $\Upsilon(5S)$ resonance cross-section (~rest producing B_s mesons)
  - $\sigma(\Upsilon(5S)\rightarrow B^*B^*)$ = (0.119 ± 0.023 ± 0.013) nb (dominant).
  - $\sigma(\Upsilon(5S)\rightarrow BB^*)$ = (0.039 ± 0.015 ± 0.005) nb.
  - Upper limits for BB, $B^{(*)}B^{(*)}\pi$ and $BB\pi\pi$.
- $M(B_s^*)$=(5411.7 ± 1.6 ± 0.6) MeV is most precise measurement to date.
- M1 Mass splitting: $M(B_S^*) - M(B_S)$ = (45.7 ± 1.7 ± 0.7) MeV

Part II: BTeV RICH and TestBeam Results

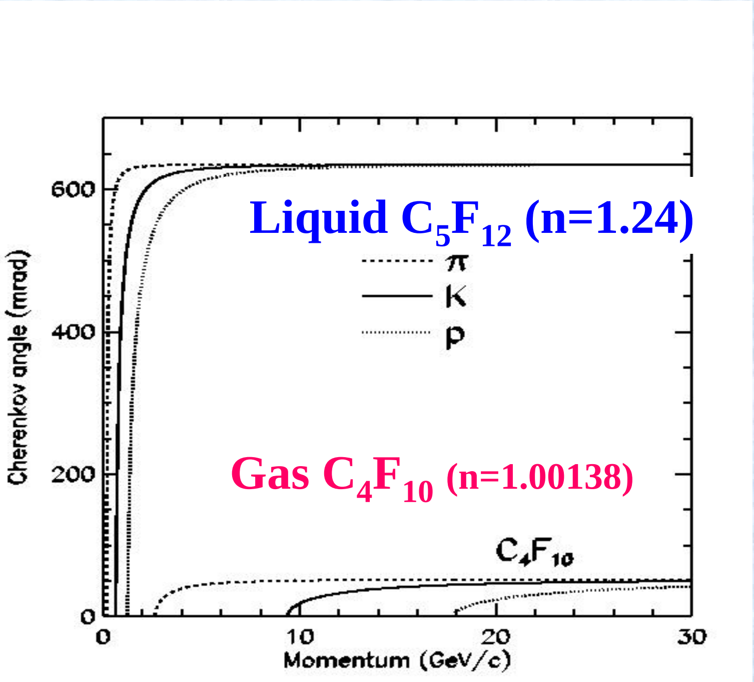


BTeV Rich Overview

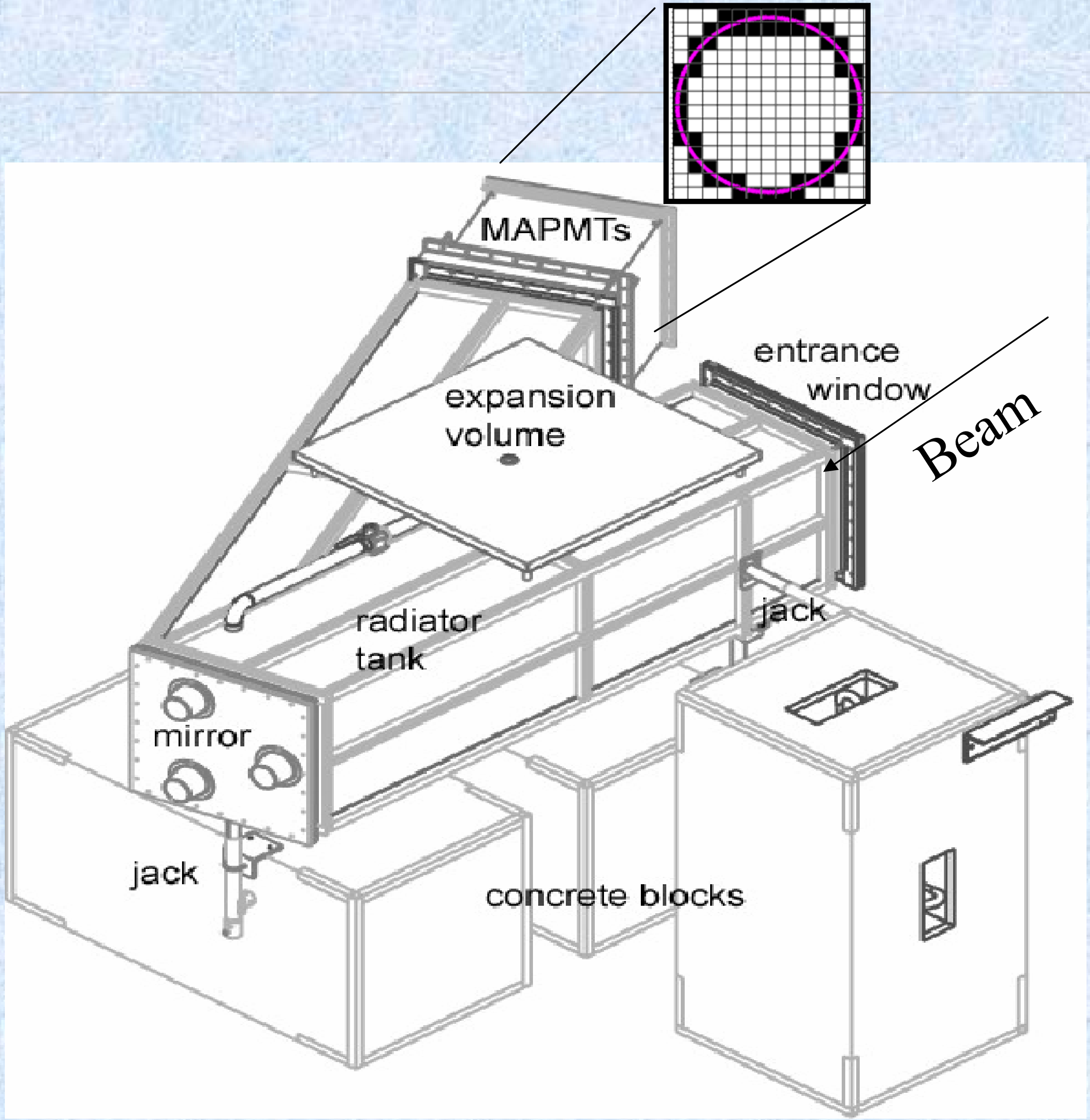


The purpose of the RICH (Ring Imaging Cherenkov detector) is to distinguish π, K, and protons from one another.

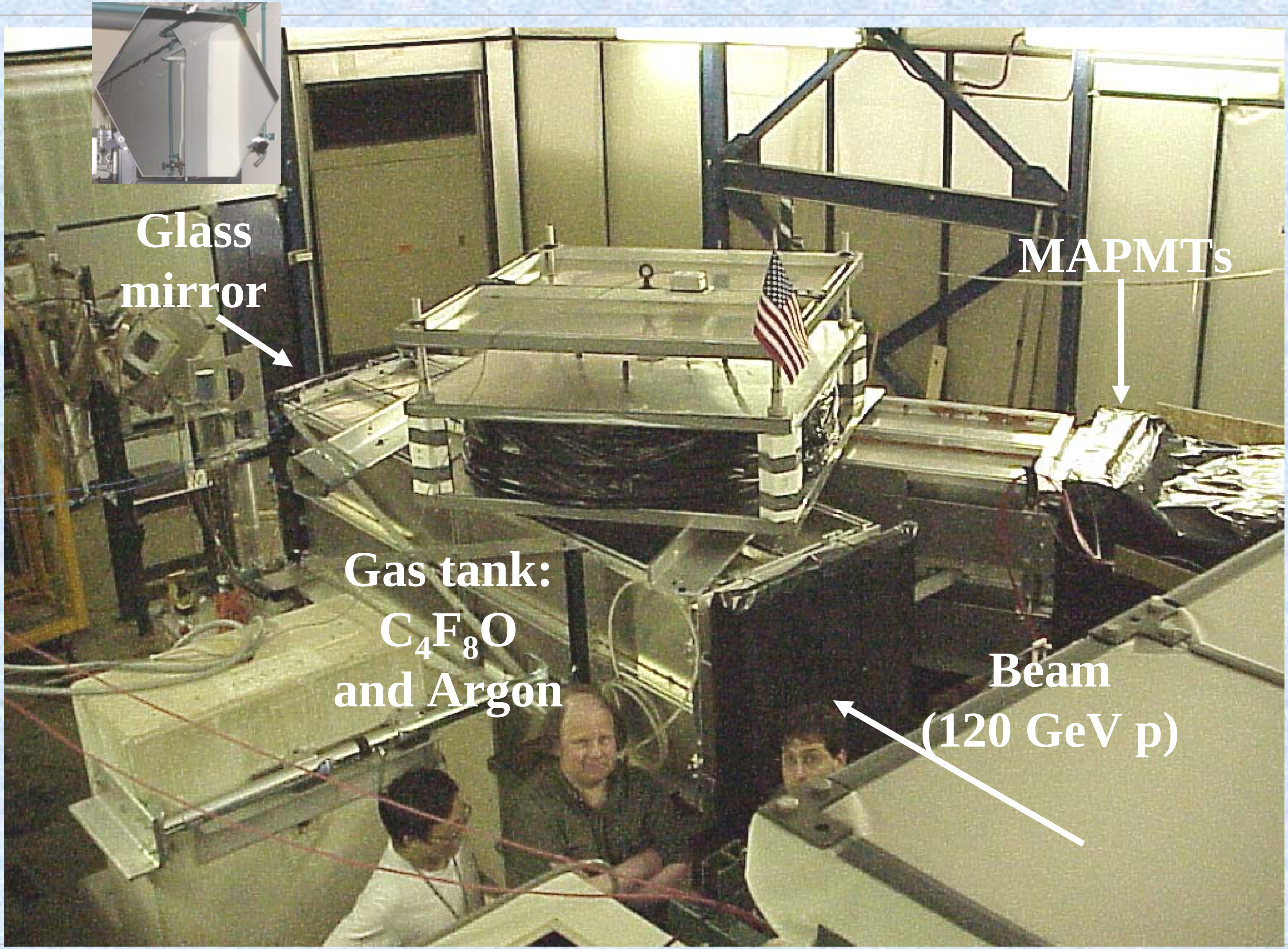
Cherenkov photons are produced at "Cherenkov angle",



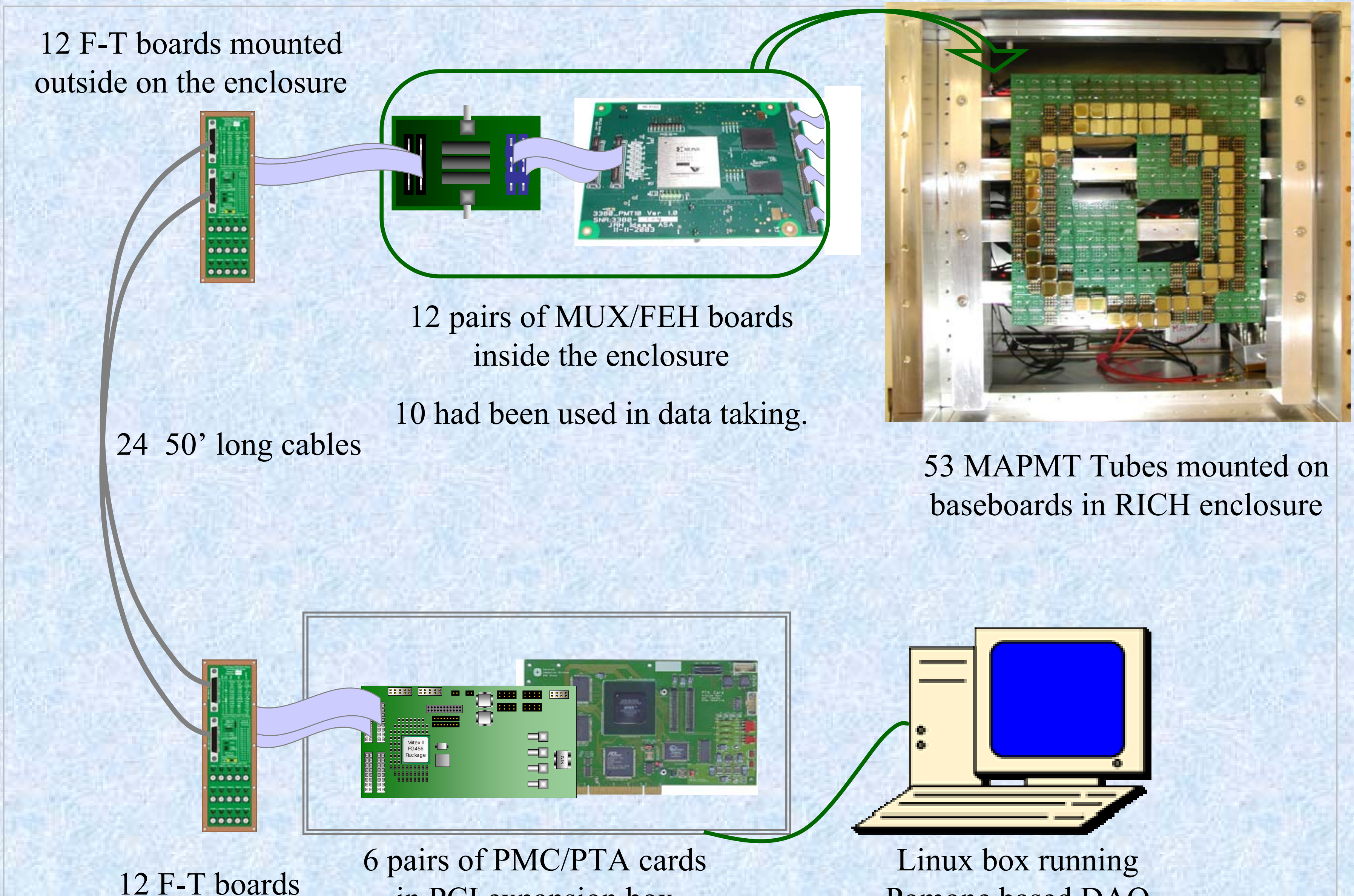
Schematic of the Testbeam Box



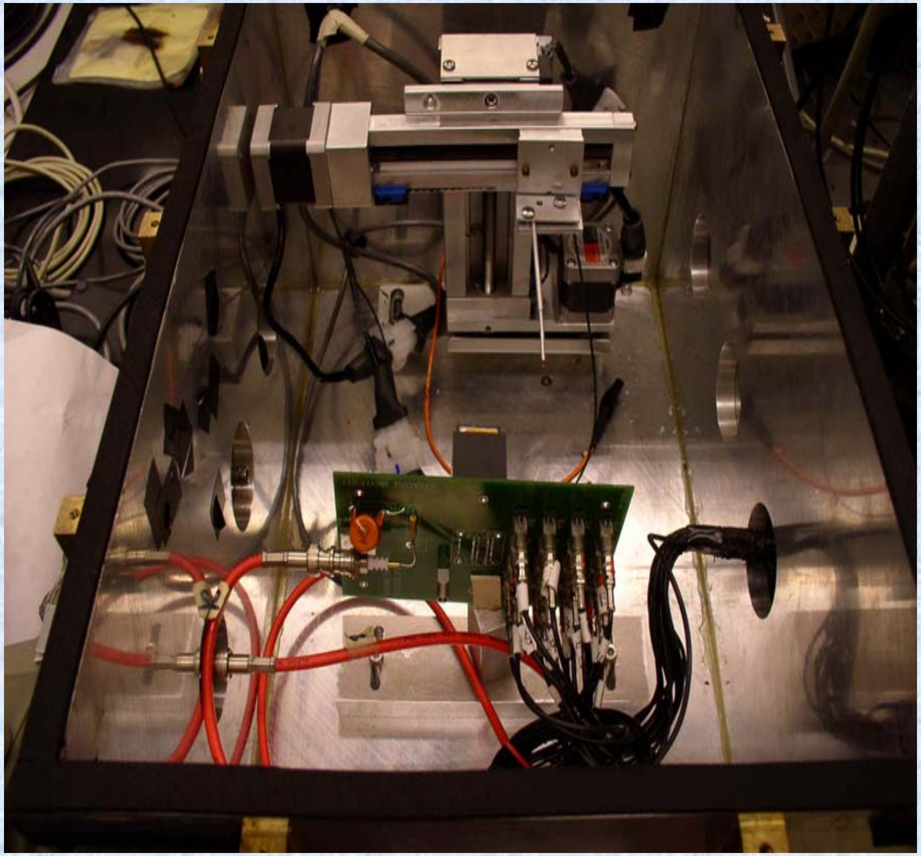
In M-TEST Area



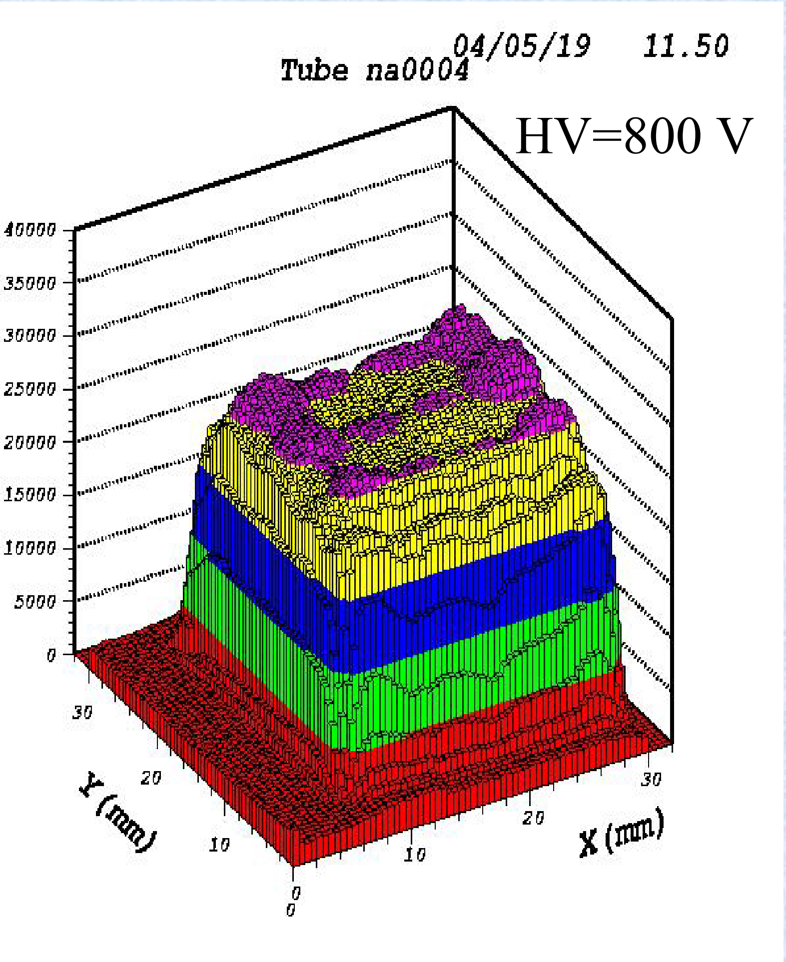
DAQ Overview



MAPMT Electrical Measurements



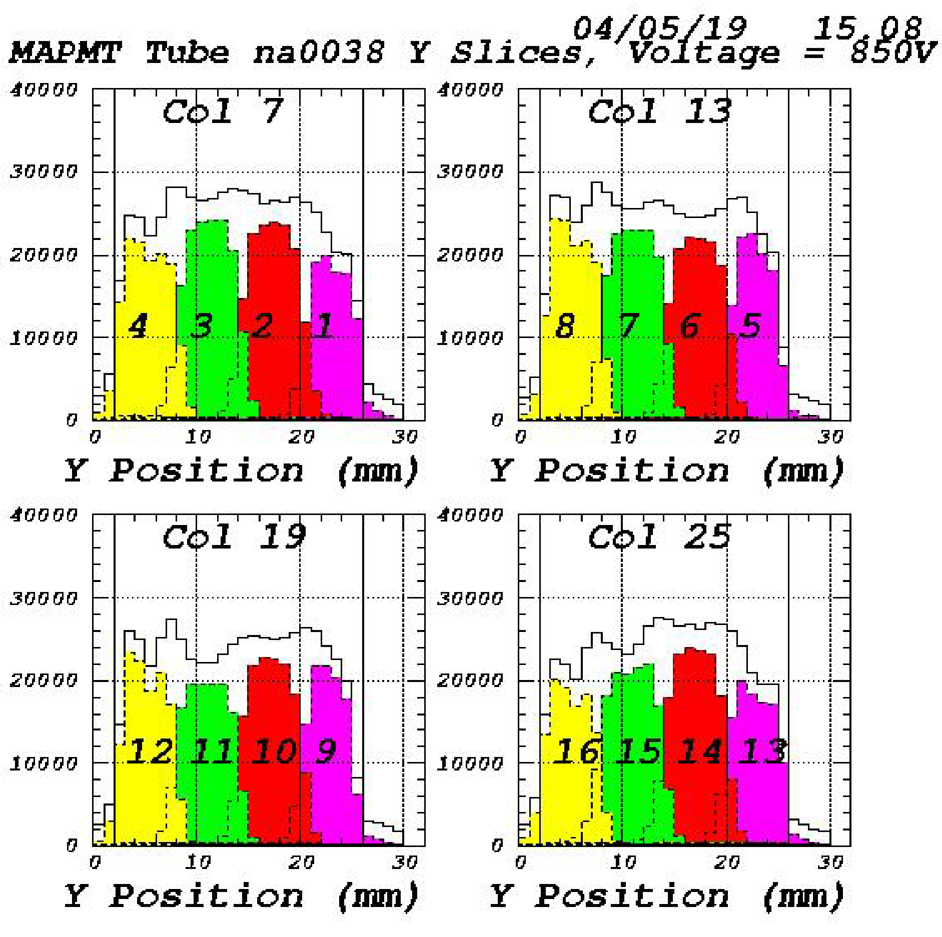
MAPMT Test Box shown with Optical Fiber Connected to XY Stage.



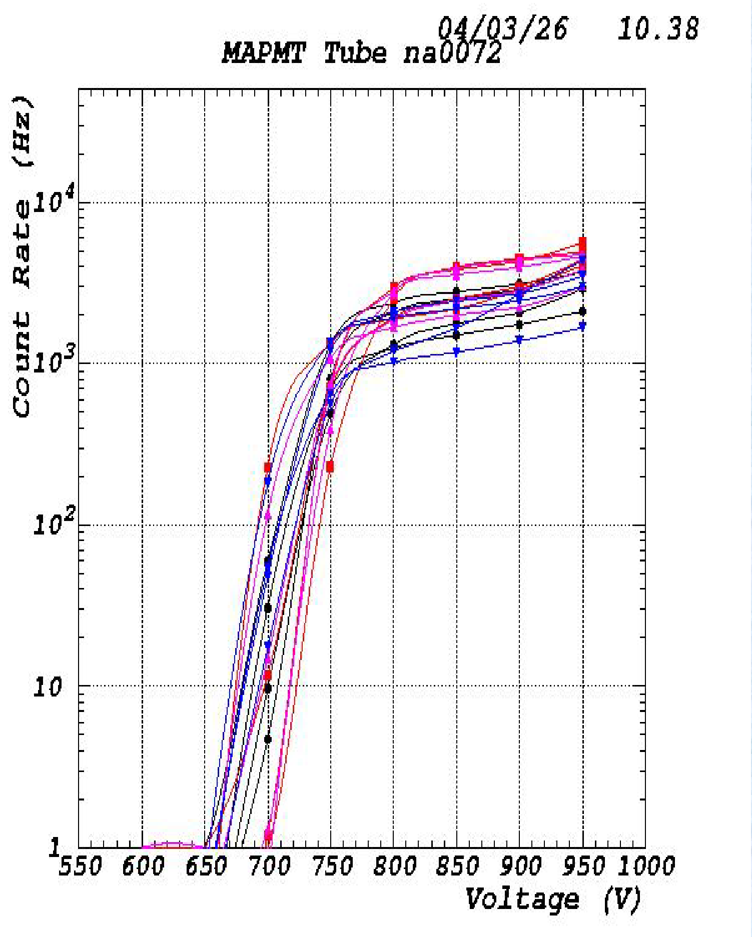
X-Y scan

The MAPMT is middle-center and is connected to a signal distribution PC board.

MAPMT Electrical Measurements (continue)

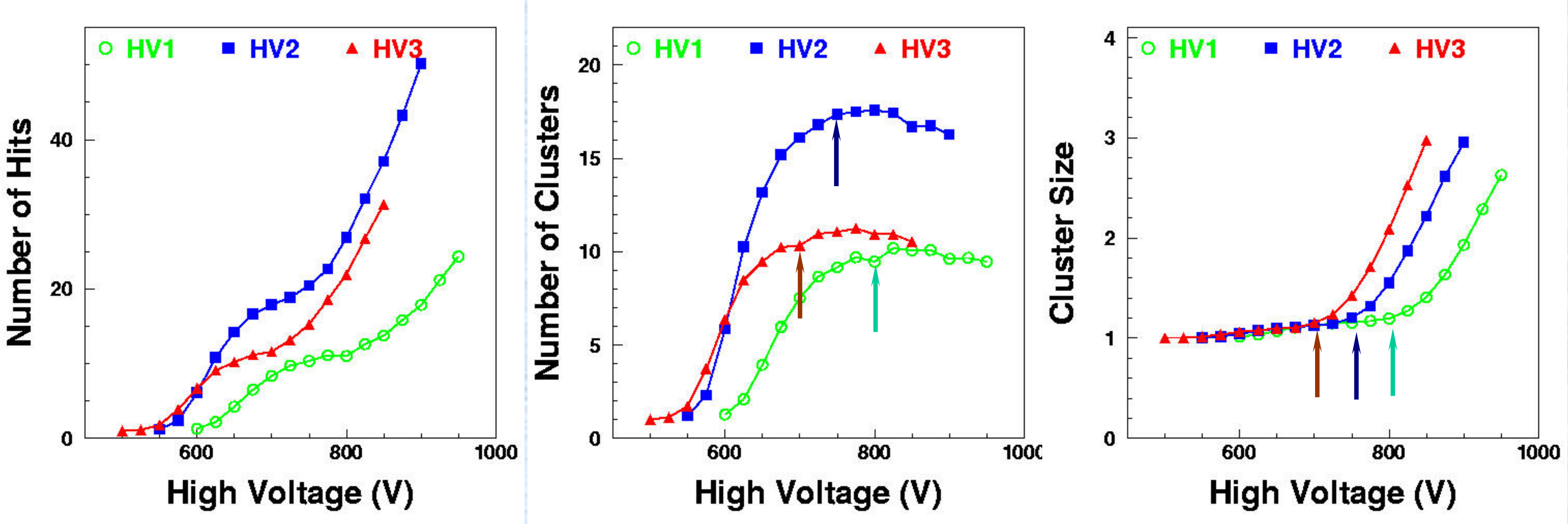


Column Scan results



Plateau Curves

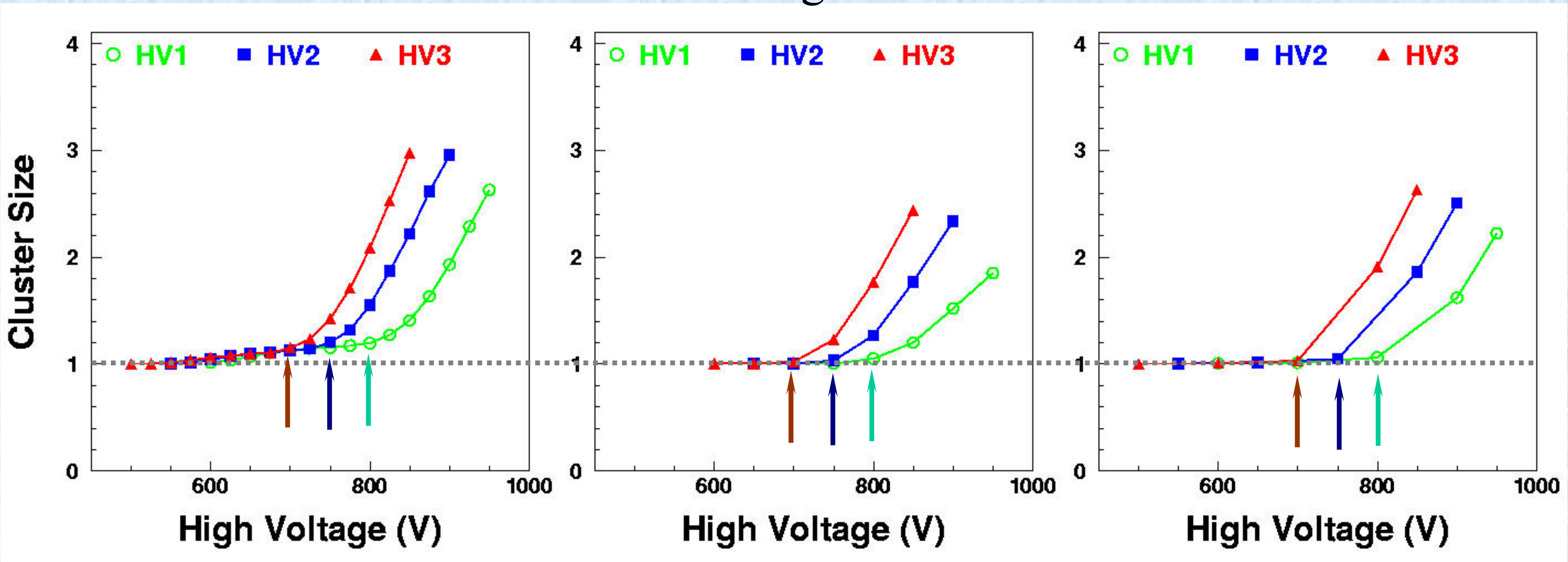
Determination of HV Settings



- MAPMT tubes are divided into 3 groups according to their gain and applied different HV.
- Definition: two or more adjacent channels with hit form a cluster hit.
- The cluster hit may not correspond to only one photon, but with this treatment one can measure plateau.
- We decided to use 800/750/700 V as nominal HV.

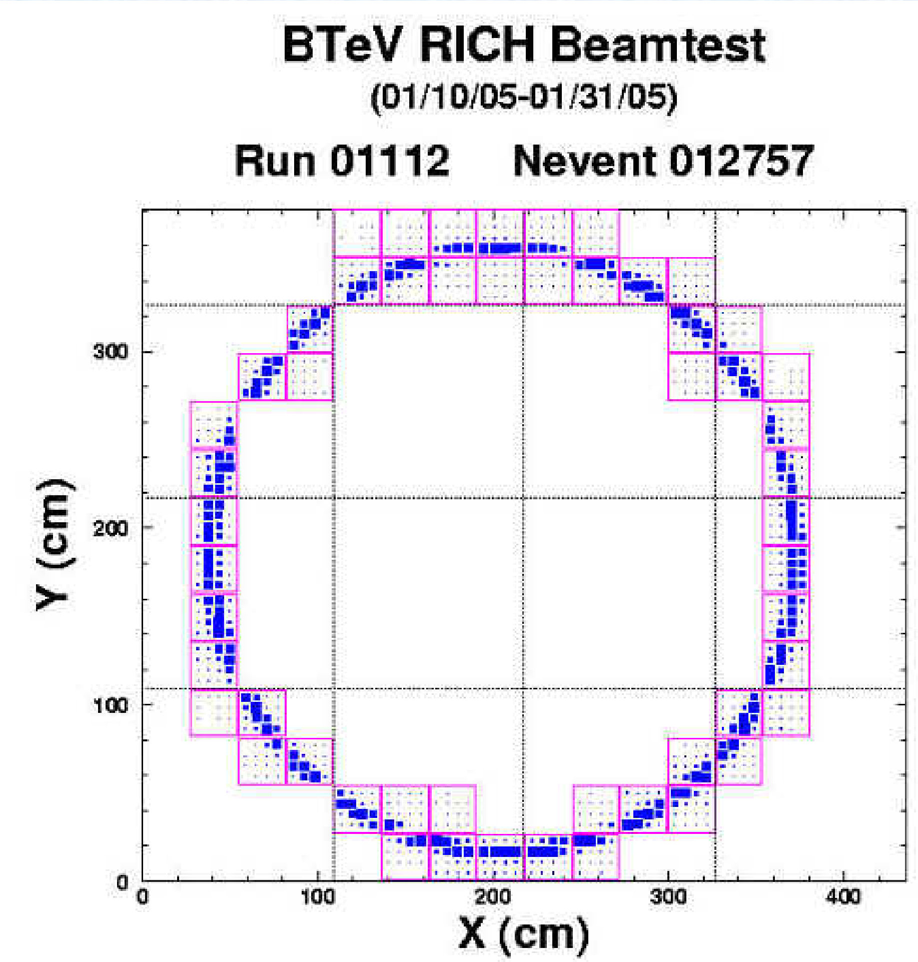
Cluster Size In HV Scan

Beam Background LED Pulser



- There are LEDs inside enclosure to generate light pulses. This is useful to study cross talk effect.
- We also took data with background (pure electronic noise and light leaks).
- With 800/750/700 V setting, most of cluster hits in beam data are due to photons hitting adjacent channels. Only ~5% of total hits are due to cross-talk.

The Beautiful Rings Obtained



- The cumulative distribution of many Cherenkov rings on top of one another. Each square represents a single MAPMT cell.
- The size of the box is proportional to the number of photons detected in that cell.
- The resolution and number of photons per track are in good agreement with the Monte Carlo simulation.
- The results published.
Nucl. Instrum. Meth. A **558**,373(2006) [physics/0505110].