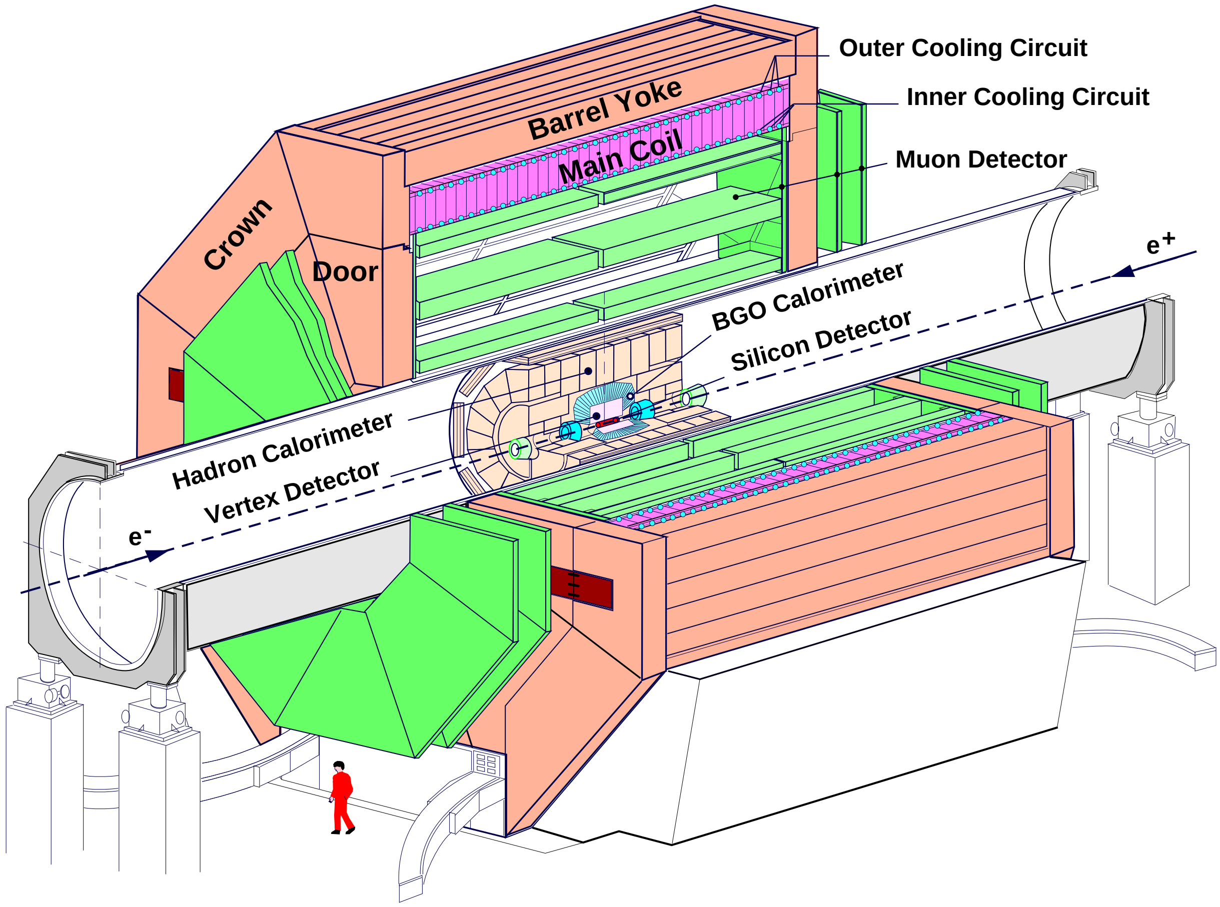
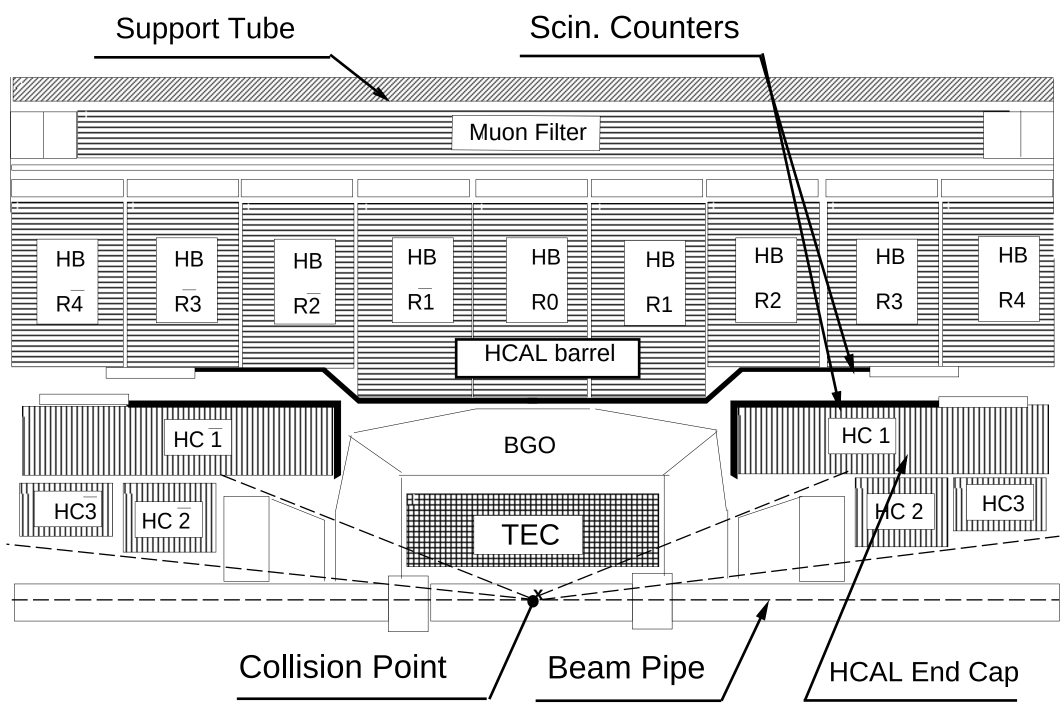
Indian Participation in e^+e^- Experiments

- Participation in the L3 Collaboration Experiment
- Participation in the Belle Collaboration Experiment

Tariq Aziz
TIFR, Mumbai

DST Interaction Meeting, November 10-12, 2003


Outer Cooling Circuit
Inner Cooling Circuit
Muon Detector
Barrel Yoke
Main Coil
Crown
Door
e^+
BGO Calorimeter
Silicon Detector
Hadron Calorimeter
Vertex Detector
e^-


Support Tube
Scin. Counters
Muon Filter
HB R4
HB R3
HB R2
HB R1
HB R0
HB R1
HB R2
HB R3
HB R4
HCAL barrel
HC 1
BGO
HC 1
HC3
HC 2
TEC
HC 2
HC3
Collision Point
Beam Pipe
HCAL End Cap

4 HCAL modules (HC2+HC3)×2 Made by TIFR Group

Each Layer is Proportional Chamber(sensor) + Depleted Uranium (absorber) Sandwich
Each Chamber is 19-25 wire sensor packed in one sub-module. 1100 Such Chambers made.

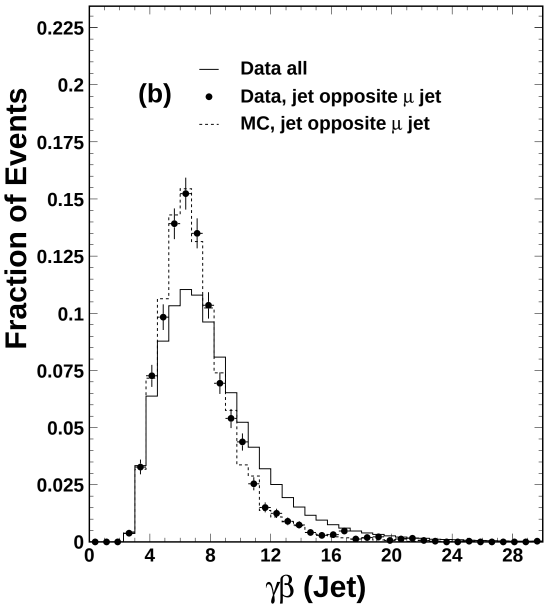
Parts for Forward-Backward Muon Chambers
3000 HV & Readout Cards and
7500 Wire Crimping Support Blocks

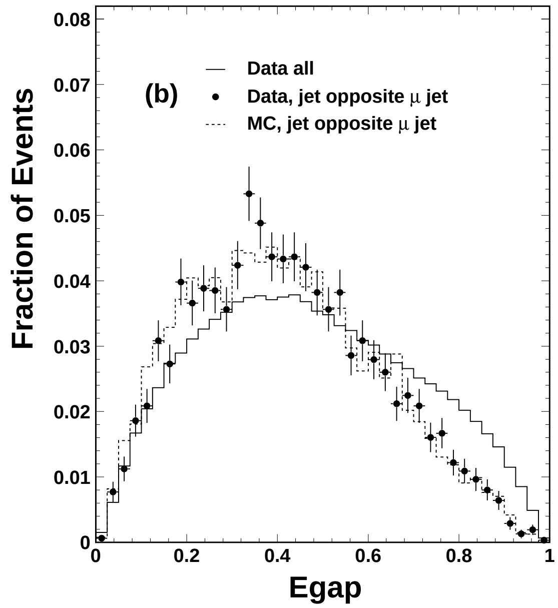
Contributions in Data taking, Data filtering, Core Software Tools, Physics Analysis

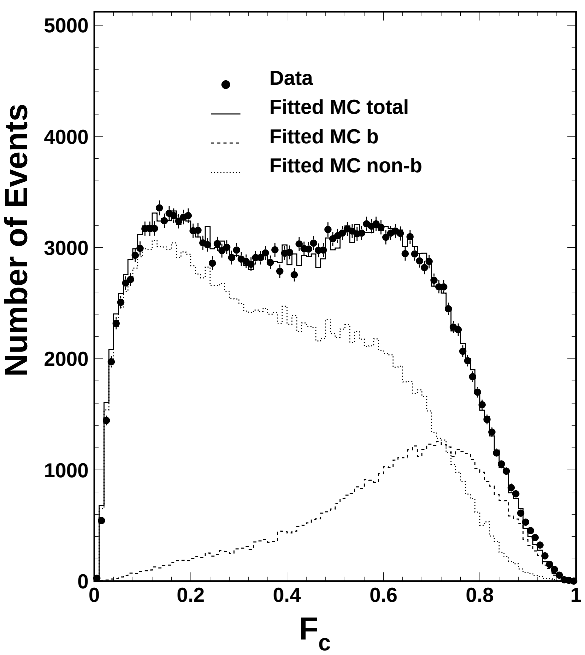
- Z-Lineshape and EW Parameters: M_Z, Γ_Z, N_ν ...
- Z → b$\bar{\text{b}}$ tagging, b-asymmetry, R_b, $B^0 \Leftrightarrow \bar{B}^0$
- QCD studies, α_s from eventshape, Colour reconnection
- Higgs Search
- SUSY Searches
- WW and ZZ production Studies, W-mass and Width

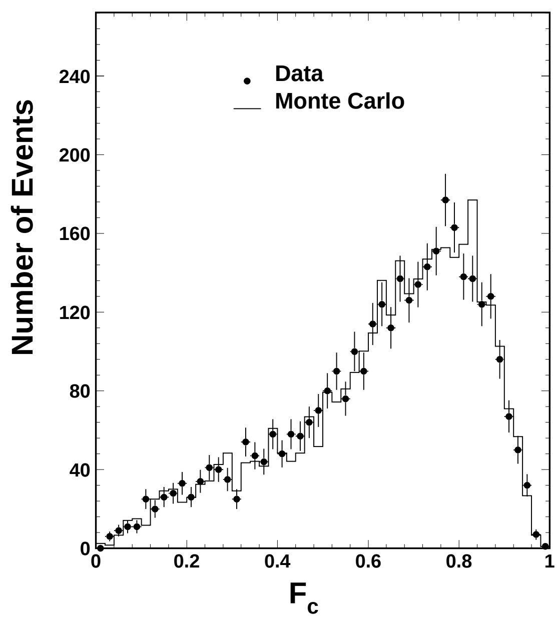
Tagging b-flavour events and R_b measurement

- Secondary Vertexing did not exist
- Tagging b-falvour events using only Calorimetry   a challenge
- Never done before   Design sophisticated physics variables that maximize the sensitivity and minimize the systematics
- Design a transparent NEURAL NETWORK and prove the concept for physics analysis





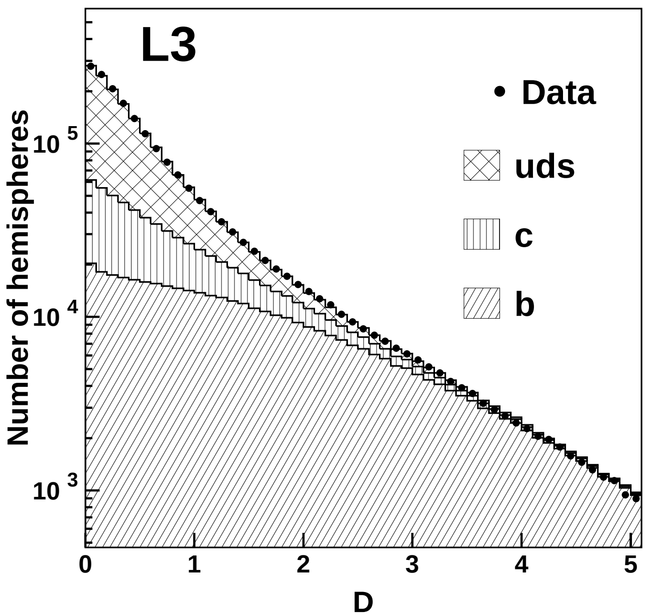


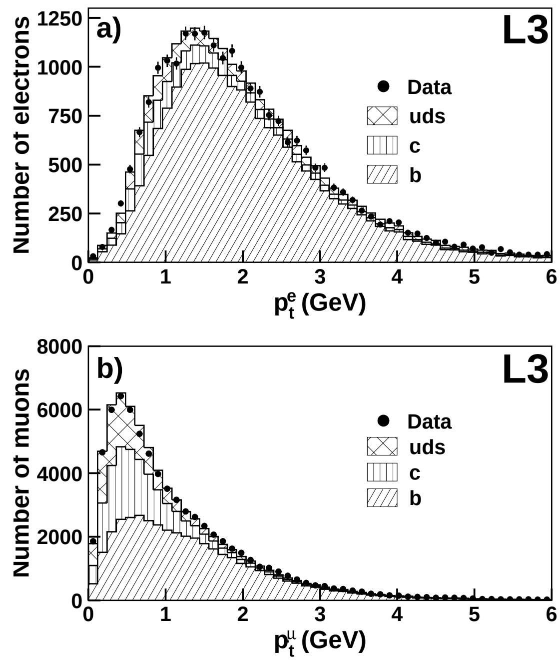


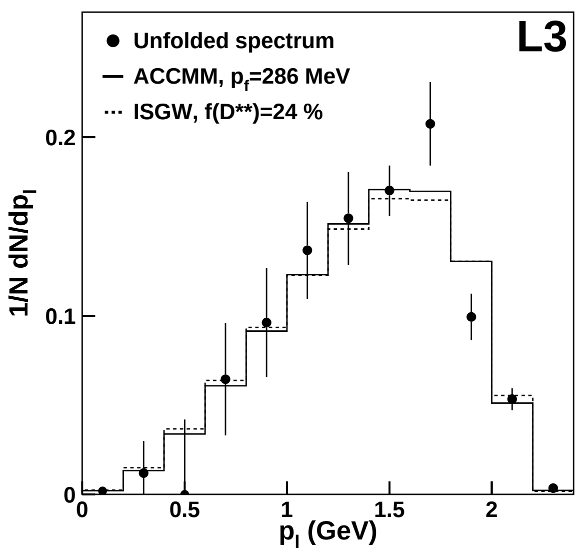
$$R_b = \frac{Z \to b\bar{b}}{Z \to hadrons} = 0.222 \pm 0.003 \pm 0.006$$

R_b using Double Tag

Tag each hemisphere using High P_t leptons and secondary vertexing
Minimize MC dependence in R_b as well as B semileptonic Br using single tagged and double tagged events







$R_b = 0.2174 \pm 0.0015 \pm 0.0028$

Single Largest Sensitivity to Top Mass Free from Higgs

Br $(b \to \ell \nu X) = (10.16 \pm 0.13 \pm 0.30)\%$

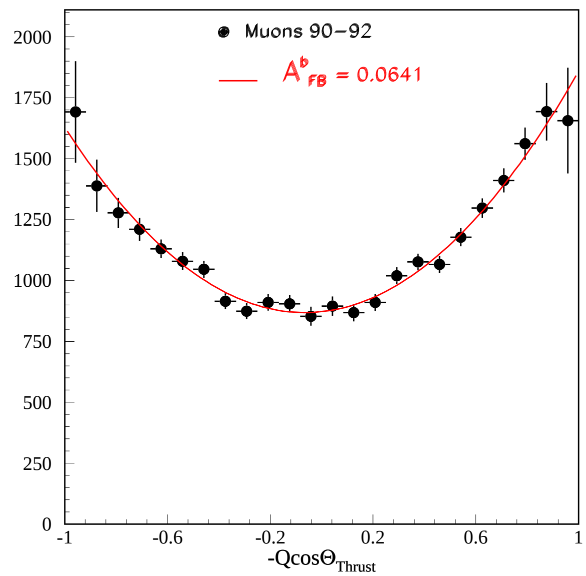
Resolved controversy on Br ratio measured at $\Upsilon(4S)$ and at LEP

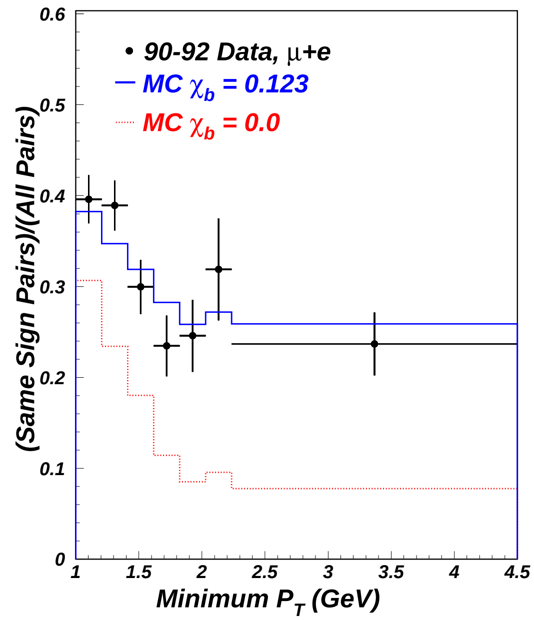
$e^+e^- \rightarrow Z \rightarrow b\bar{b}$

$\frac{d\sigma}{d\cos\theta_b} \propto \frac{3}{8}(1+\cos^2\theta_b) + A^b_{FB}\cos\theta_b$

A^b_{FB} a measure of vector coupling and thus $\sin^2\theta_{eff}$

Mixing/Oscillation dilutes asymmetry

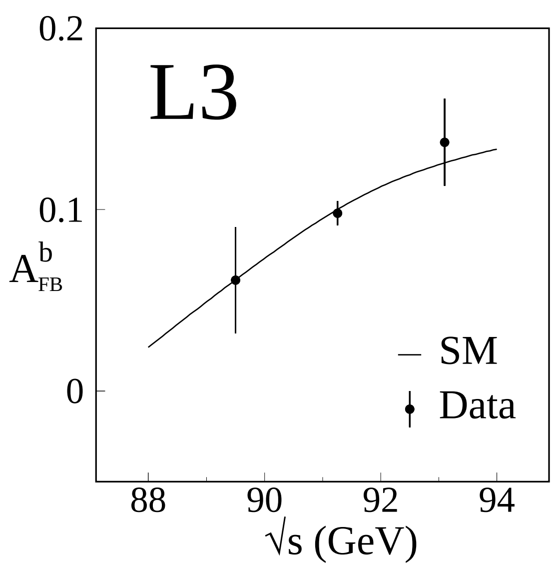


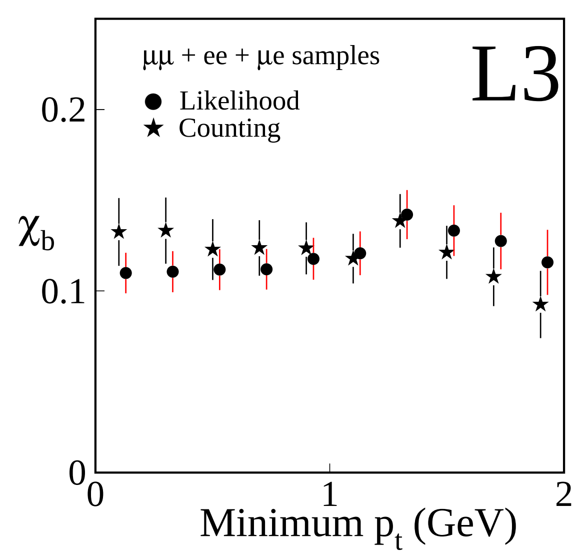


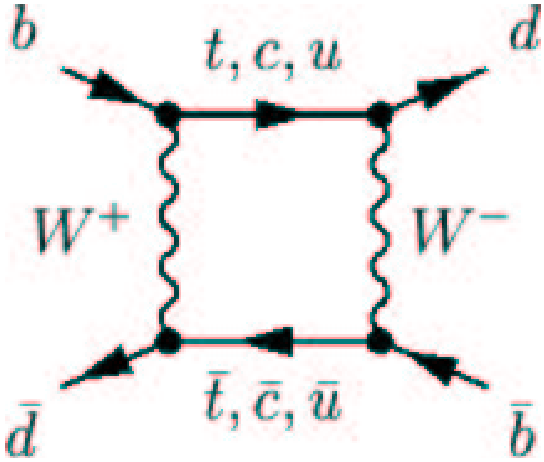
For entire LEP-I data

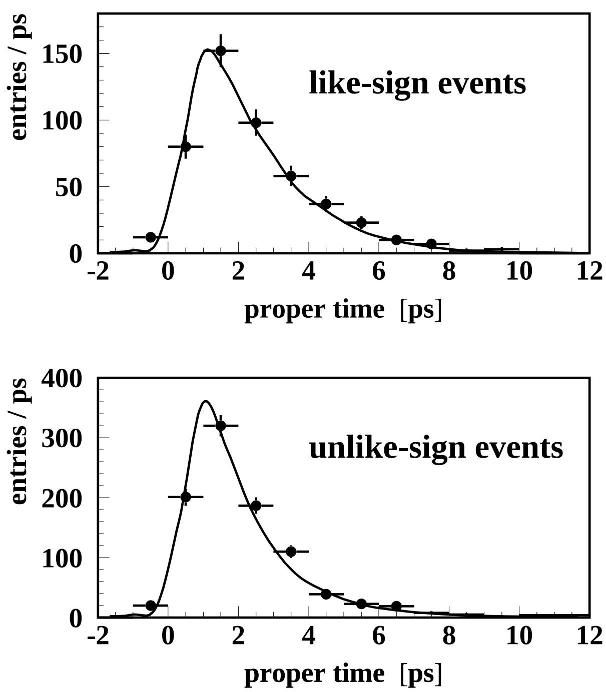
$\chi_b = 0.1192 \pm 0.0068 \pm 0.0051$

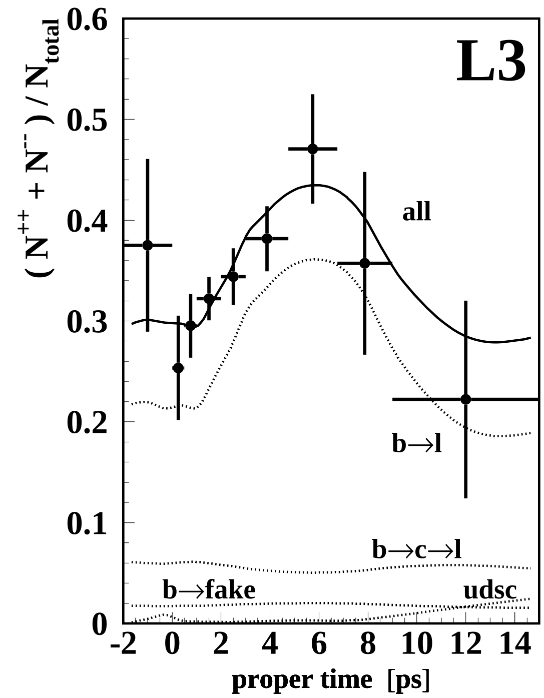
$A^{0,b}_{FB} = 0.1015 \pm 0.0064 \pm 0.0035 \quad \sin^2\theta_{eff} = 0.2318 \pm 0.0013$





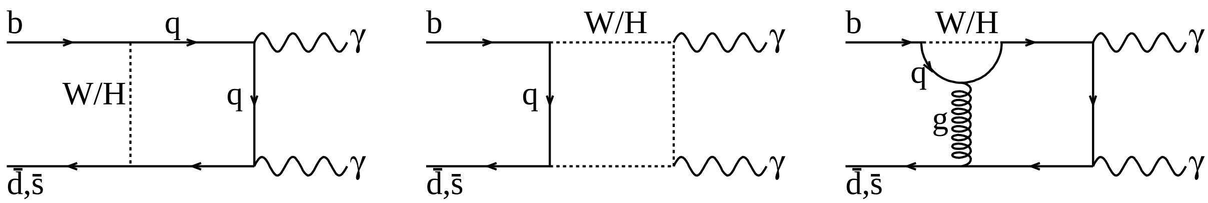


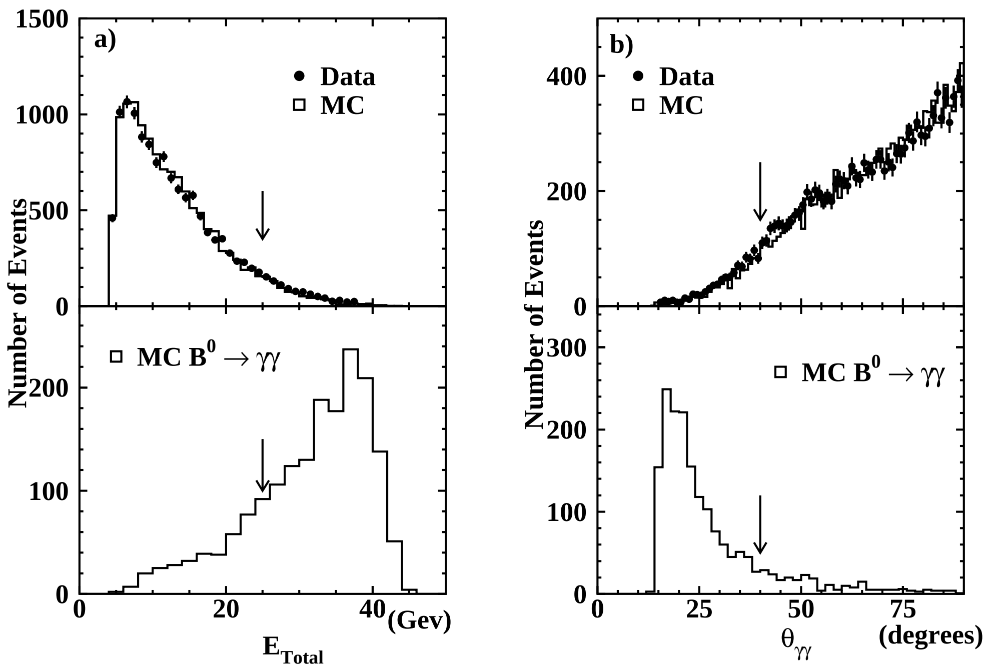




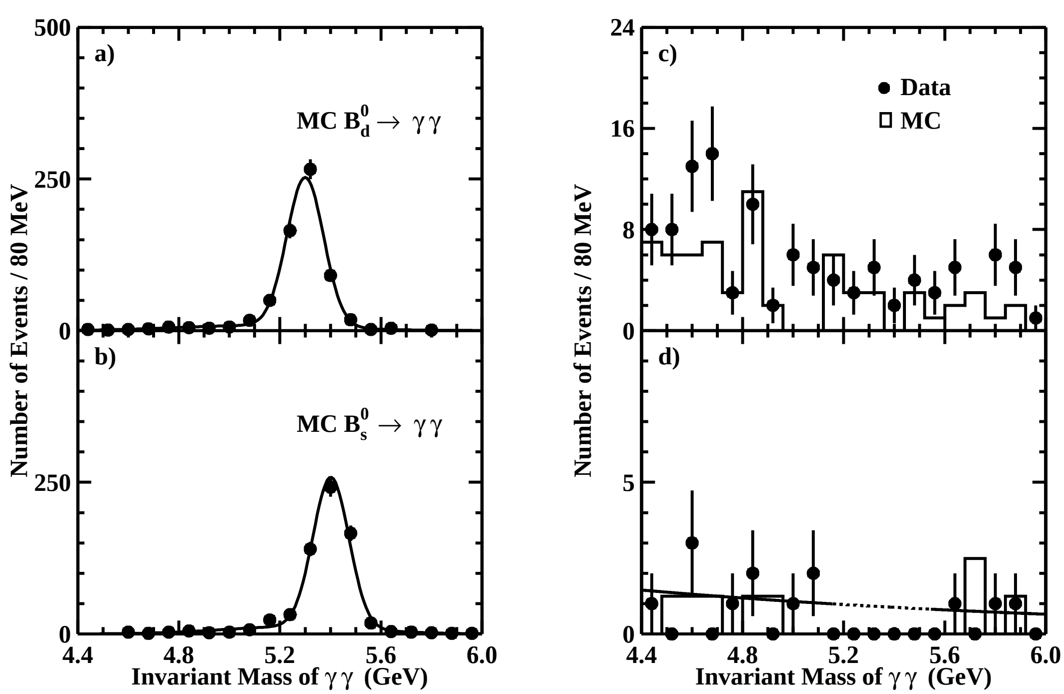
$$\Delta m_d = (0.496^{+0.055}_{-0.051} \pm 0.043) ps^{-1}$$

Search for $B_d^0 \to \gamma\gamma$ and $B_s^0 \to \gamma\gamma$



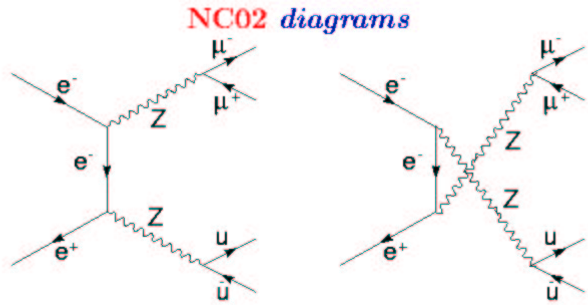


Use NN-Tag for $Z \to b\bar{b}$



$Br(B_d^0 \to \gamma\gamma) < 3.9 \times 10^{-5}$ at 90% CL.
$Br(B_s^0 \to \gamma\gamma) < 1.48 \times 10^{-4}$ at 90% CL.

Triggered a large number of theoretical papers on the subject



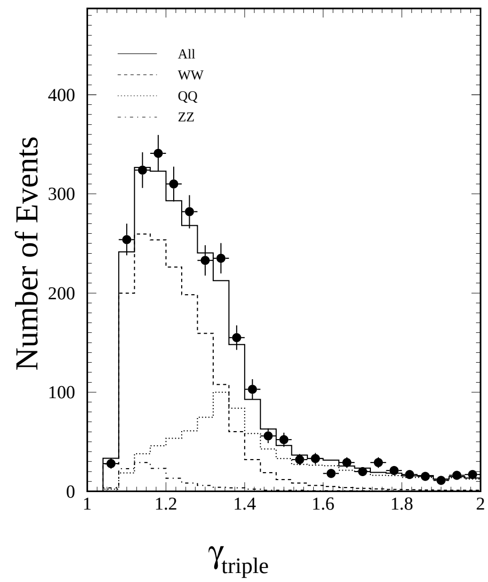
$e^+e^- \rightarrow ZZ$ a low cross-section process

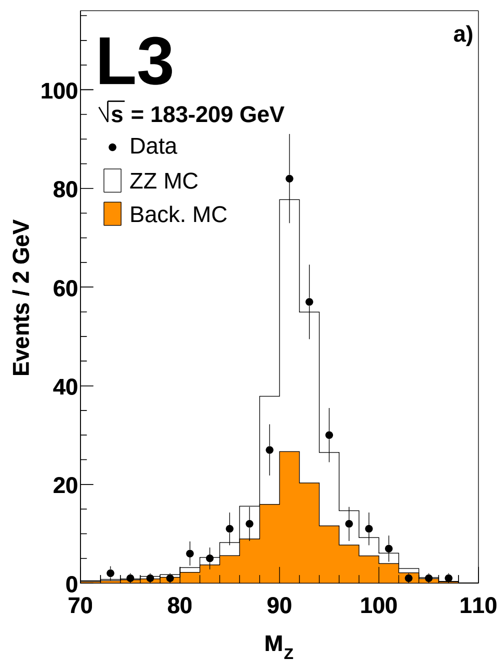
Difficult in the presence of huge backgrounds from QCD and WW

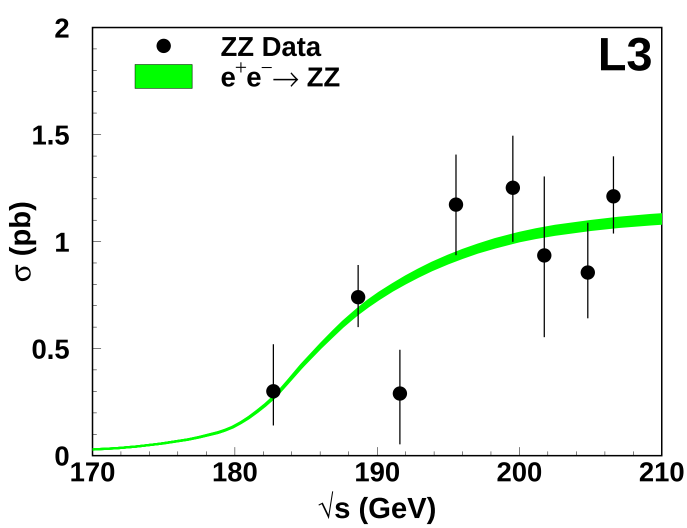
Need sophisticated physics variables to disentangle signal from background

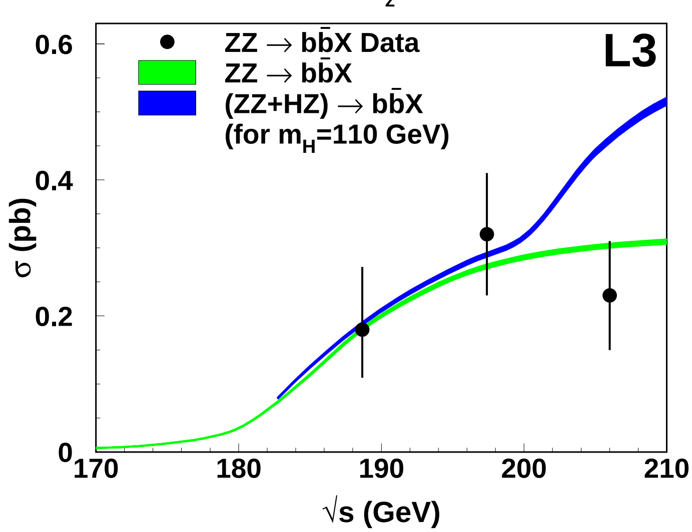
Important to test SM couplings and beyond such as Extra-Dimensions

Irreducible background to Higgs search like ZH when one Z decays to $b\bar{b}$







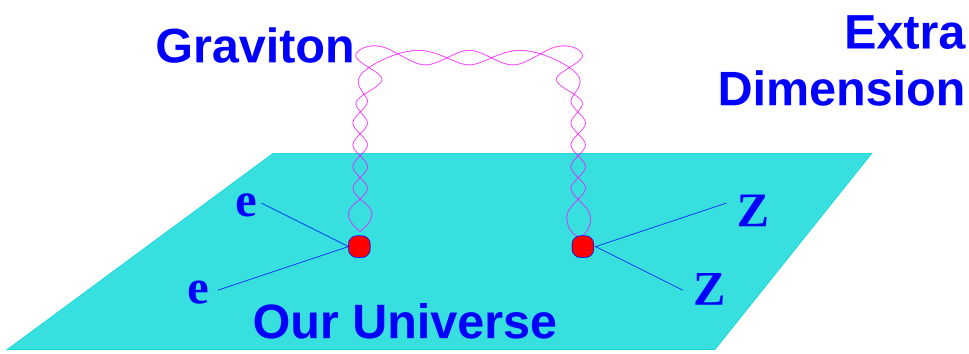


In Particle Interactions Gravitational Effects Relevant at Planck Mass

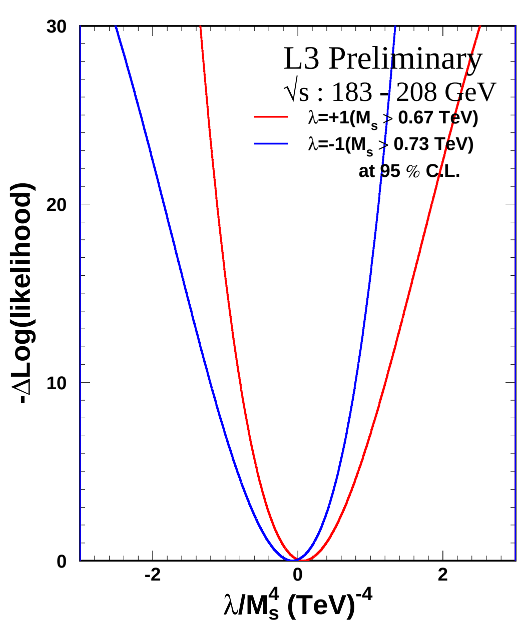
Mass Scale could be lowered to ElectroWeak Scale
Provided Gravity remains restricted to Extra Dimensions

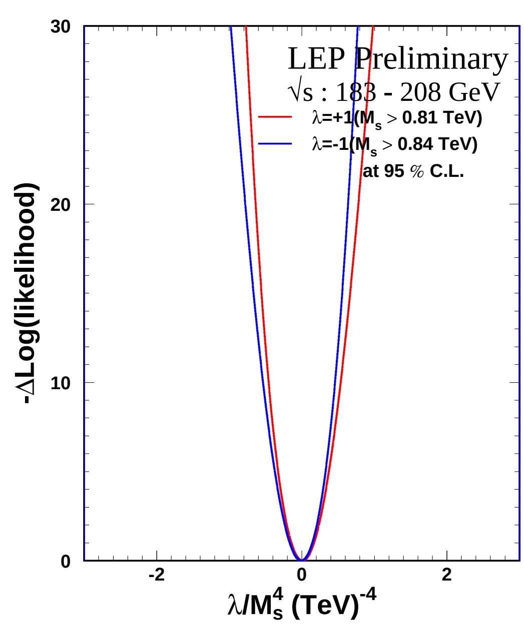
$$M_{Pl}^2 \approx R^n M_S^{n+2},$$

M_S is effective Planck Mass Scale or String Scale



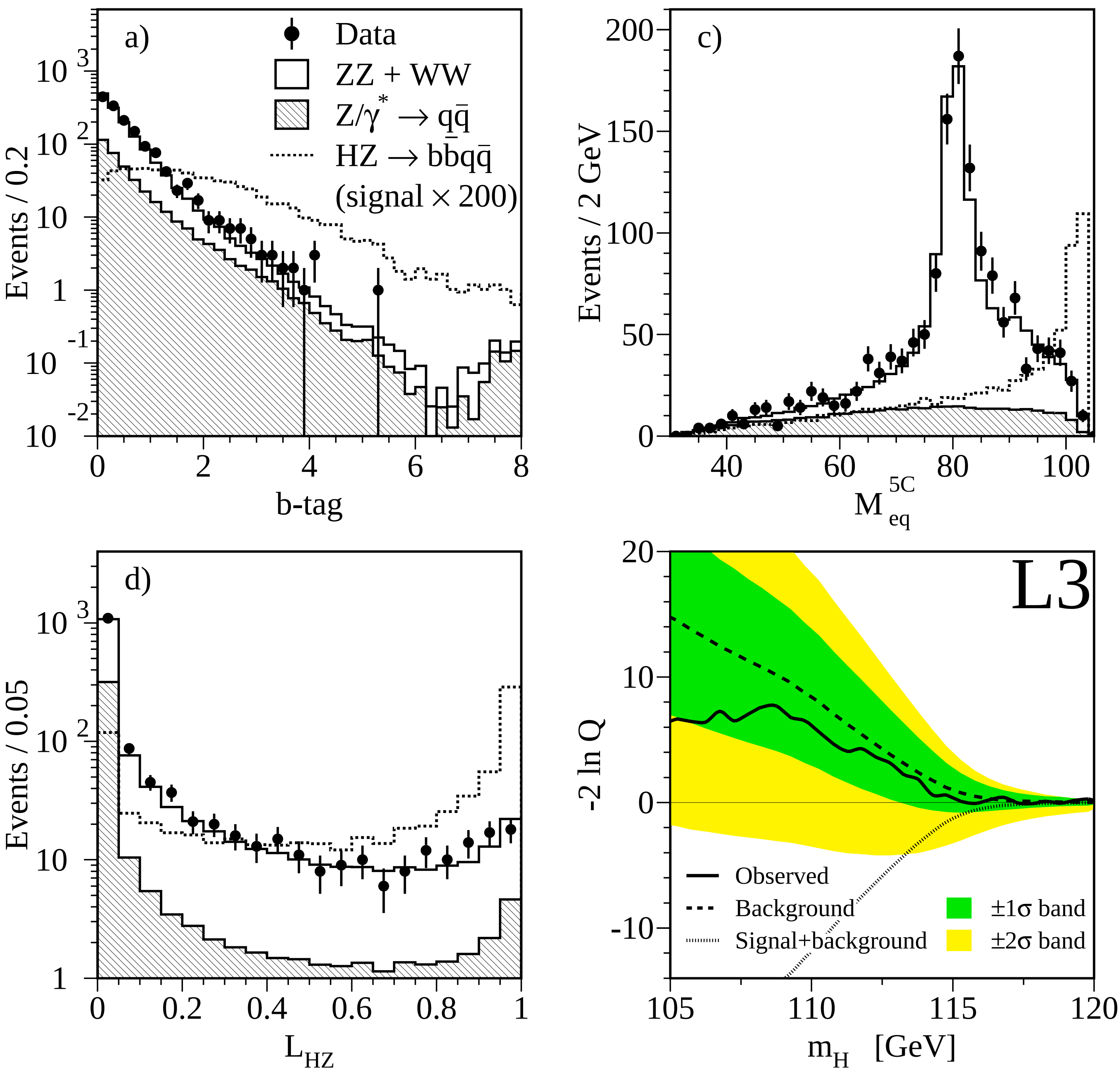
ZZ cross-sections and Angular distributions altered due additional coupling and interference with SM couplings





For $M_S \approx 0.7\ TeV$ only $n \geq 3$ relevant
Else M_S should be much higher than ElectroWeak Scale

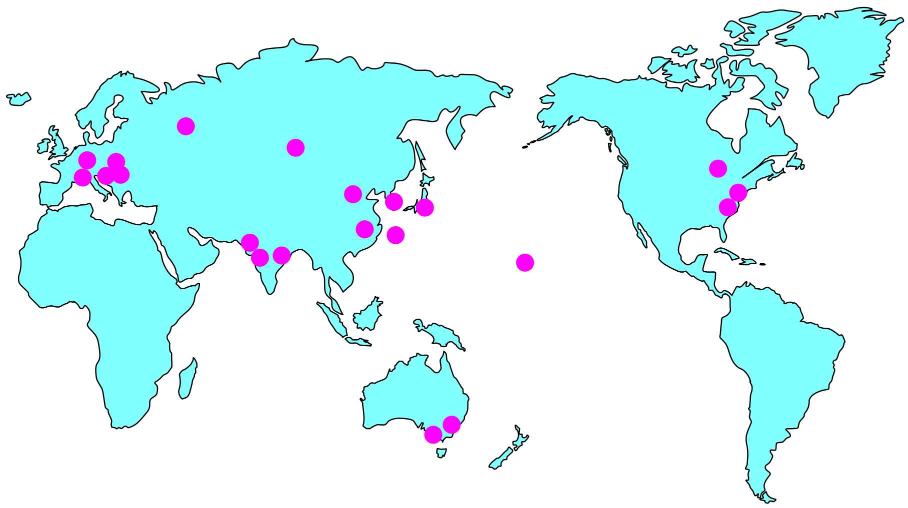
Combine several discriminating variables to construct Single Likelihood Discriminant



$M_H > 112$ GeV at 95% CL.

$M_H > 114$ GeV at 95% CL For Entire LEP

Participation in BELLE Collaboration Experiment



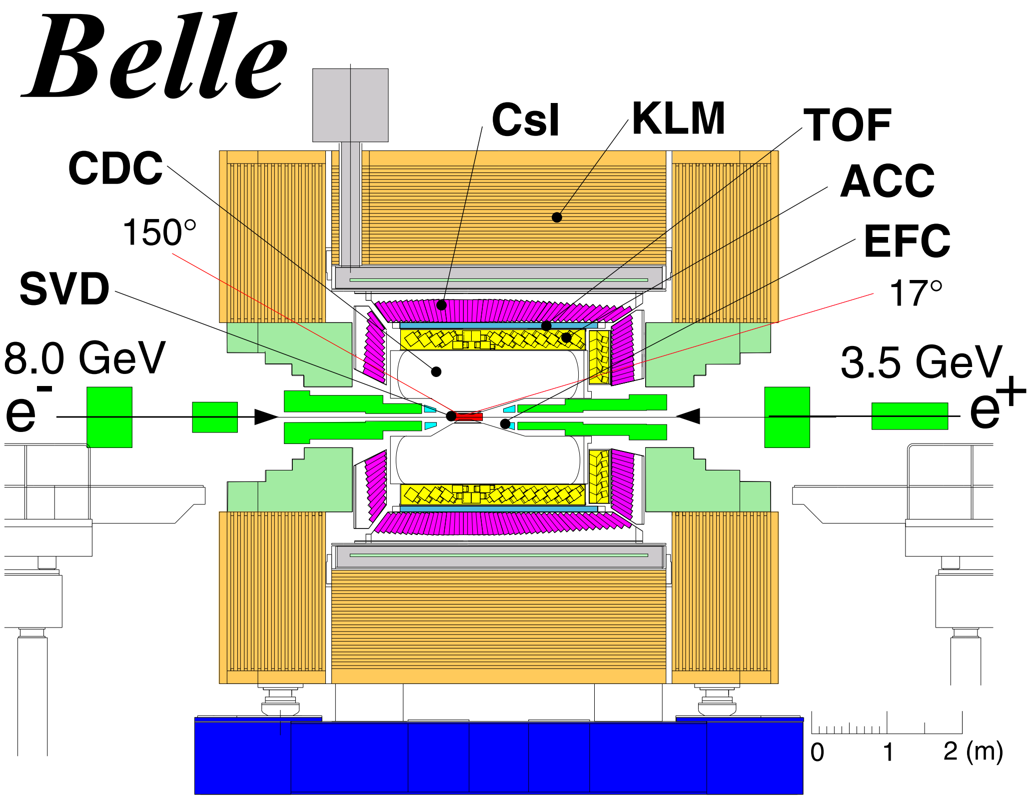
Aomori, Japan	Novosibirsk, Russia	Chiba, Japan
Chuo, Japan	Cincinnati, USA	Frankfurt, Germany
Gyeongsang, Korea	Hawaii, USA	Hiroshima, Japan
IHEP, China	ITEP, Russia	Kanagawa, Japan
KEK, Japan	Seoul, Korea	Krakow, Poland
Kyoto, Japan	Kyungpook, Korea	Lausanne, Switzerland
Ljubljana, Slovenia	Melbourne, Australia	Nagoya, Japan
Nara, Japan	Chungli, Taiwan	Kaohsiung, Taiwan
Miao Li, Taiwan	Taipei Taiwan	Niigata, Japan
Osaka, Japan	Osaka City, Japan	Panjab, India
Peking, China	Princeton, USA	Saga, Japan
Hefei, China	Seoul, Korea	Sungkyunkwan, Korea
Sydney, Australia	Tata, India	Toho, Japan
Tohoku, Japan	Tohoku Gakuin, Japan	Tokyo, Japan
TIT, Japan	TUAT, Japan	Toyama, Japan
Tsukuba, Japan	Utkal, India	Vienna, Austria
Yokkaichi, Japan	Virginia, USA	Yonsei Japan

Utkal University, Bhubaneswar
S.Jena, M.Satpathy

Panjab University, Chandigarh
S.Kumar, J.B.Singh, N.Soni

Tata Institute, Mumbai
T.Aziz, S.Banerjee, G.Gokharoo, A.Gurtu, G.Majumdar, K.Mazumdar, K.Sudhakar

- $8 GeV\ (e^-)\ \times\ 3.5\ GeV\ (e^+)$
- Crossing angle $= \pm 11\ \ mrad$
- Lorentz boost, $\gamma\beta = 0.425 = \frac{E_{e^-} - E_{e^+}}{\sqrt{4E_{e^-}.E_{e^+}}}$
- Luminosity $L = 10^{34} cm^{-2} s^{-1}$
- $\int Ldt = 158 fb^{-1}$,
  On-Resonance $140 fb^{-1}$, 152×10^6 $B\bar{B}$ Pairs



- SVD : 3 DSSD lyr $\sigma \sim 55\mu m$
- CDC : 50 layers $\sigma_p/p \sim 0.35\%$, σ_π(dE/dx) $\sim 7\%$
- ACC : (n=1.01 - 1.03) K/π $\sim$ 3.5 GeV
- TOF : $\sigma \sim 95$ ps
- CsI : $16X_0$, $\sigma_E/E_\gamma \sim 1.9\%$
- KLM : RPC+Fe 14/15 lyr μ and K_L detection

- Contributions to Detector Monitoring and Calibration, Data Taking, Reconstruction Algorithms and Physics Analysis

  - Calibration of ECL Crystals using beam test data and test of non-linearity along the crystal length
  - Calibration of low energy photon using D^* events
  - Maintenance of KLM detector and efficiency calculation for RPC chambers using MUON tracks
  - Algorithms for the reconstruction of missing momentum (neutrino)
  - Uncertainty on track finding efficiency
  - Use Radiative Mupair events to calibrate high energy photons (2-3 GeV)
  - Using informations of TOF and ACC to improve energy resolution of ECL

- Plan to Participate in Belle Detector Upgrade High Luminosity Option, Facilities for Silicon Strip Detector Activity being setup

Mixing in 6 Quarks (Kobayashi and Maskawa 1973) far reaching

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

4 Fundamental Parameters to be determined by experiment

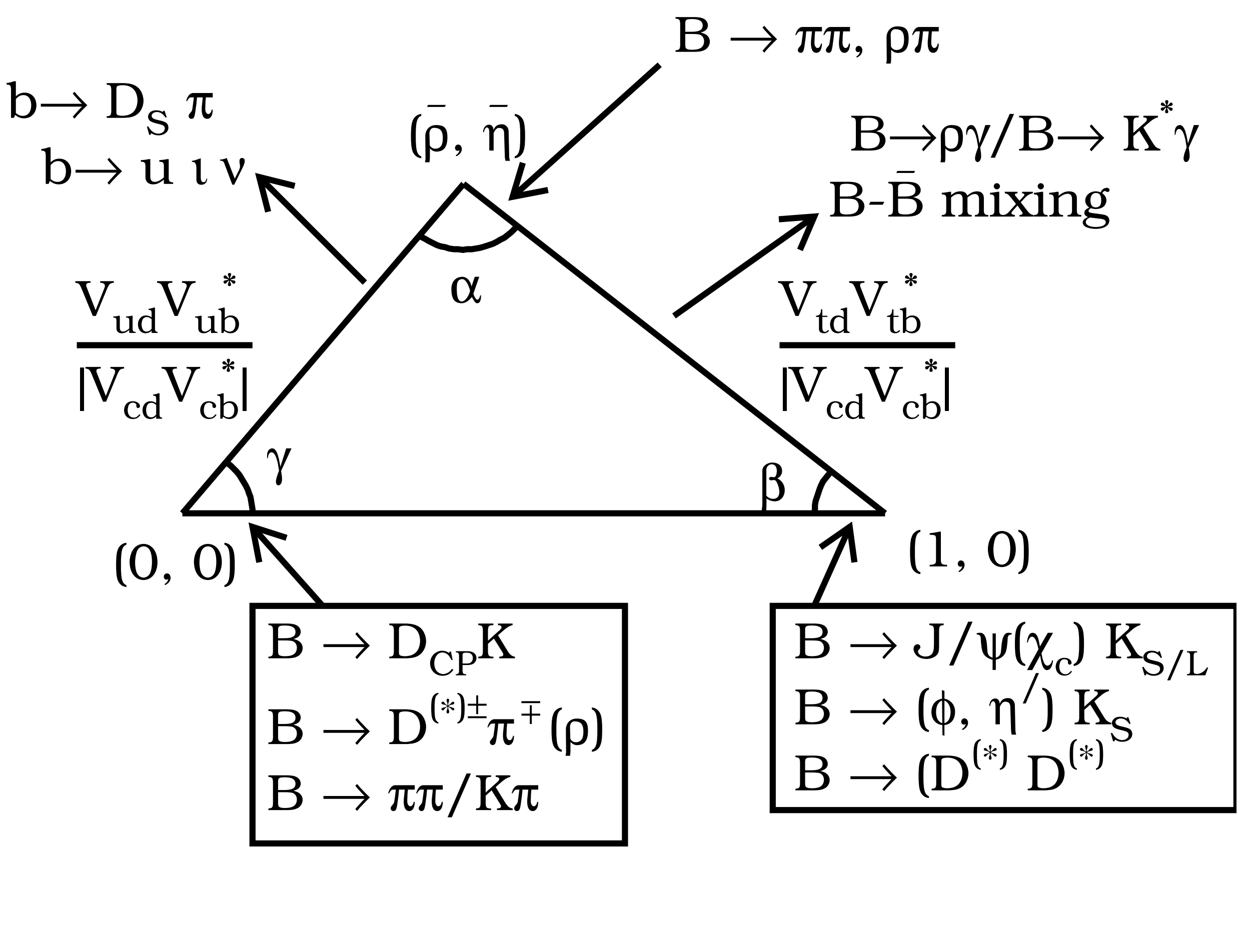
Simple parametrization by Wolfenstein in $A,\ \lambda,\ \rho,\ \eta$

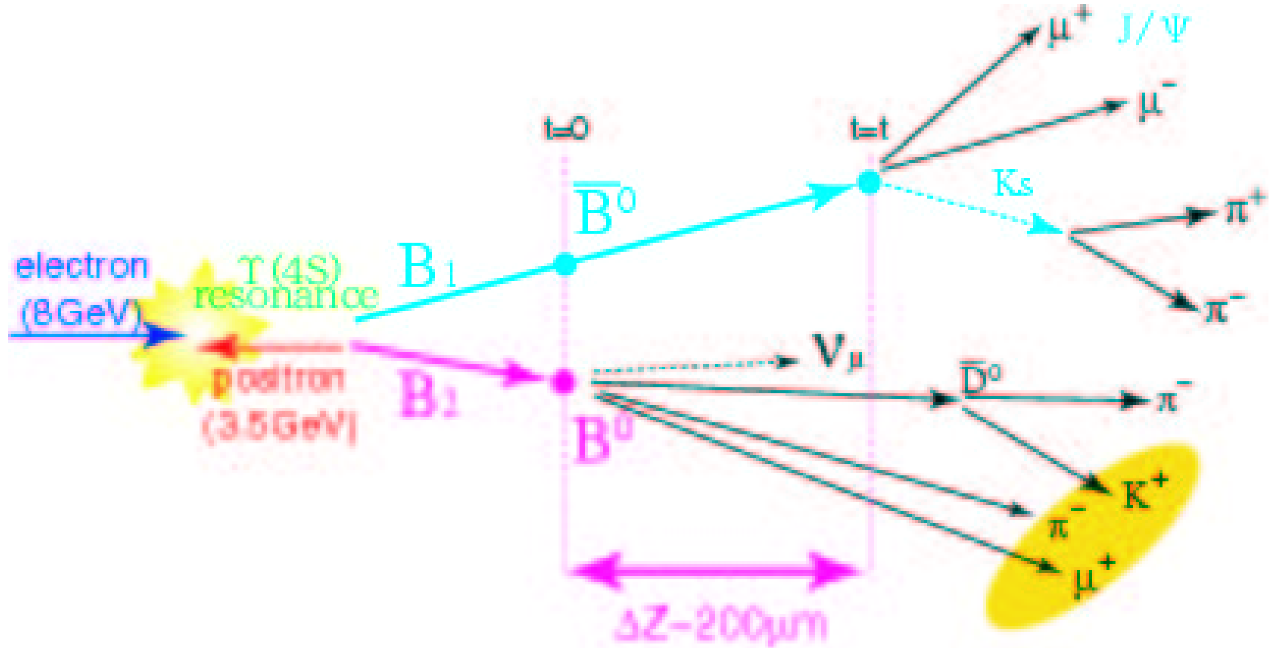
$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

For CP Violation $\eta \neq 0$

Unitarity $(\sum V_{ij}.V^*_{ik} = \delta_{jk})$ implies two relevant triangles for CP violating B decays. The most accessible one involves V_{ub} and V_{td}

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$





♦ Both B_d^0 or $\bar{B}_d^0$ can lead to same CP eigen states, f_{cp} (=$\pi^+\pi^-$, or $J/\psi K^0$)

♦ Tagged by e^+, μ^+, K^+ as B_d^0 Tagged by e^-, μ^-, K^- as $\bar{B}_d^0$

♦ CP-dependent Oscillation in decay time

$$P(B_d^0(t) \to f_{cp}) \propto e^{-t/\tau}(1 + \gamma_{cp} \sin(\Delta m.t))$$
$$P(\bar{B}_d^0(t) \to f_{cp}) \propto e^{-t/\tau}(1 - \gamma_{cp} \sin(\Delta m.t))$$

♦ Observe asymmetry amplitude as a function of time

$$A(t) = \frac{N(B_d^0(t) \to f_{cp}) - N(\bar{B}_d^0(t) \to f_{cp})}{N(B_d^0(t) \to f_{cp}) + N(\bar{B}_d^0(t) \to f_{cp})} = \gamma_{cp} \sin(\Delta m.t)$$

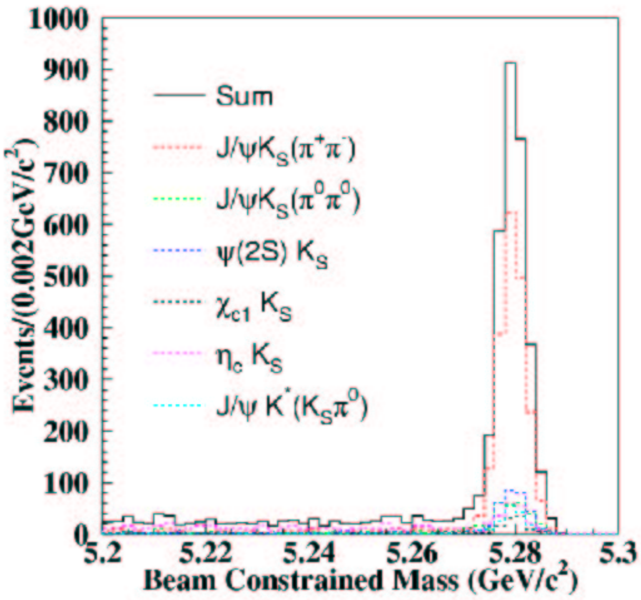
♦ For CP violation to manifest $\gamma_{cp} \neq 0$

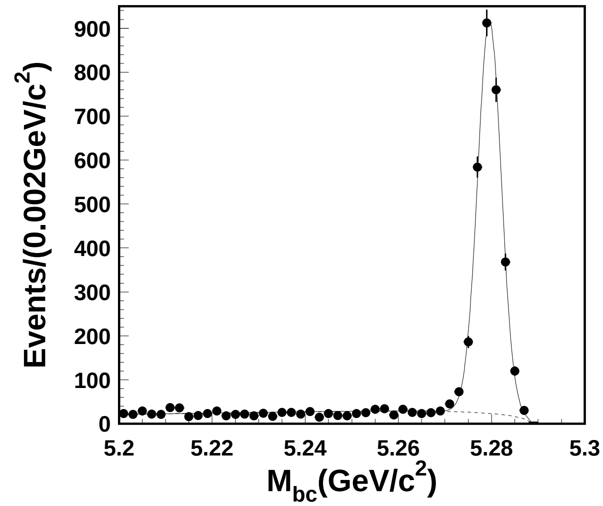
♦ For $B_d^0 \to J/\psi K_s^0$ $\gamma_{cp} = -\sin 2\beta$ and for $B_d^0 \to \pi^+\pi^-$ $\gamma_{cp} = \sin 2\alpha$

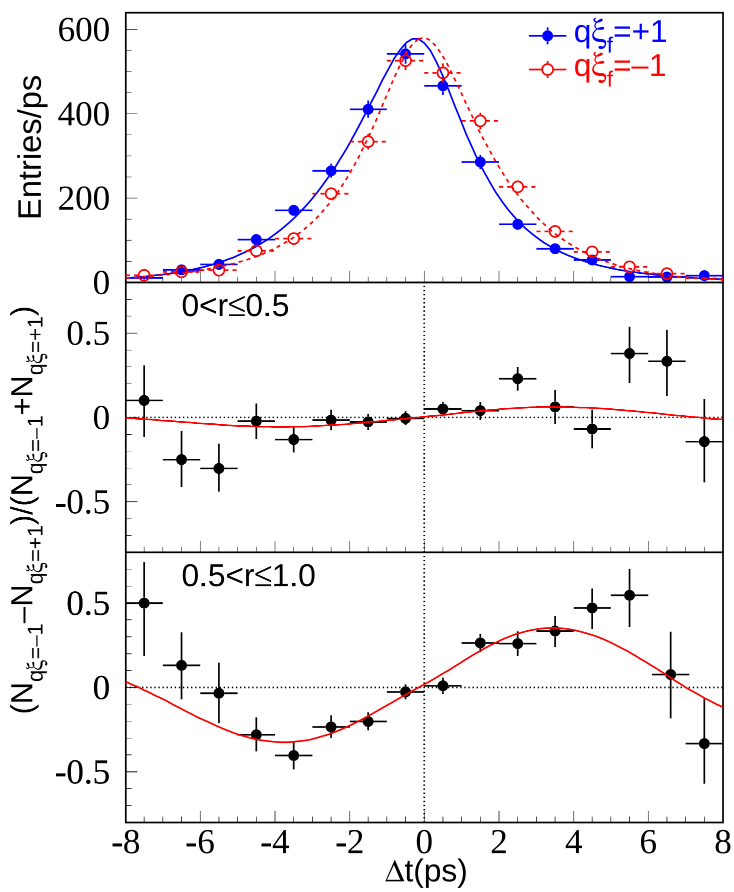
♦ For Asymmetric B factory environment t replaced by $\Delta t = (t_{cp} - t_{tag})$

♦ Wrong Flavour tag and Wrong f_{cp} dilute asymmetry

Physics Potential

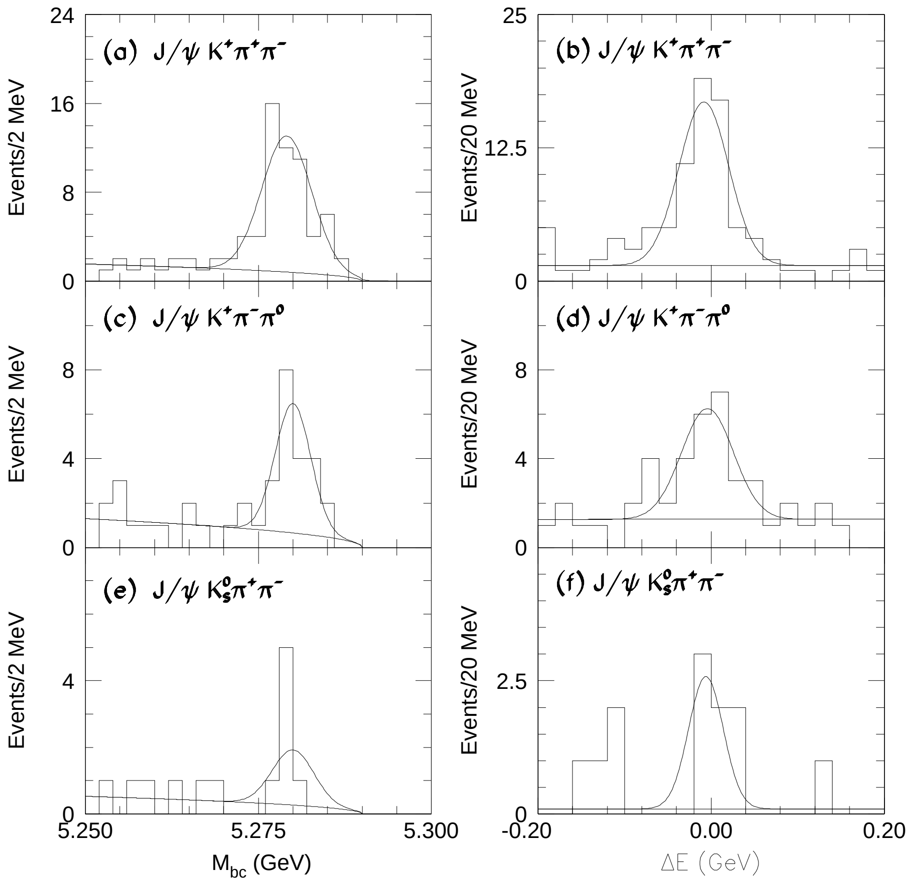






$$\sin(2\beta) = 0.733 \pm 0.057 \pm 0.028$$

$\mathcal{B}(B \to J/\psi X) \sim 1\%$,
Little known about explicit decay modes



$$\mathcal{B}(B^+ \to J/\psi K_1^+(1270)) = (1.80 \pm 0.34 \pm 0.39) \times 10^{-3}$$
$$\mathcal{B}(B^0 \to J/\psi K_1^0(1270)) = (1.30 \pm 0.34 \pm 0.32) \times 10^{-3}$$

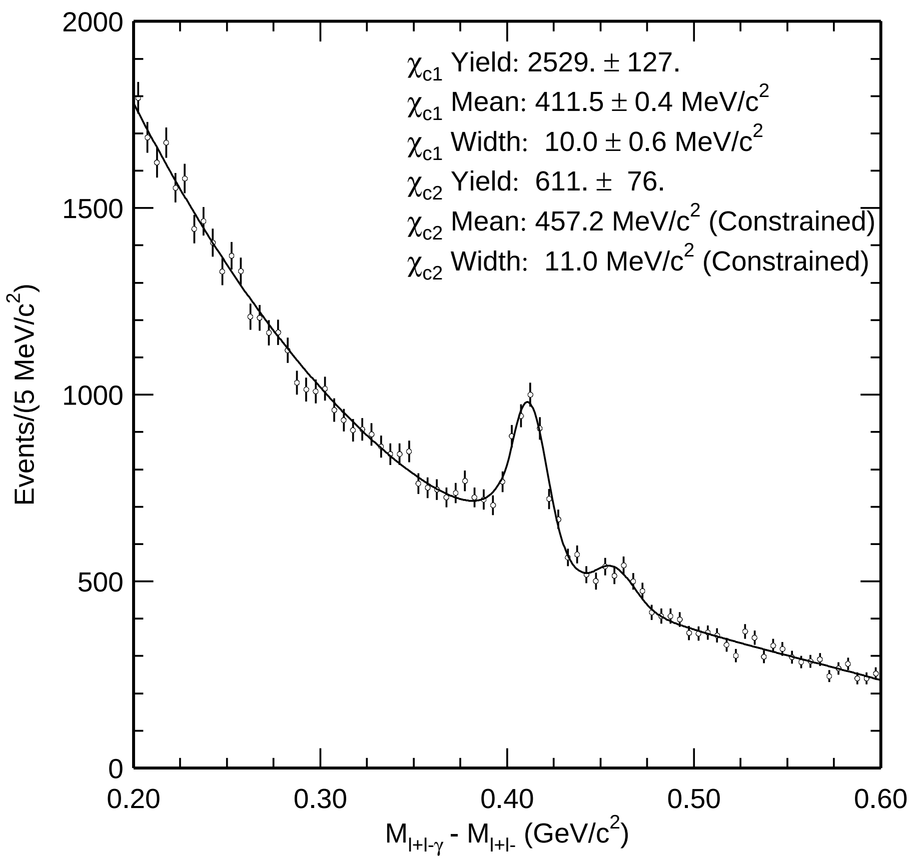
Observation of $B \to \chi_{c2} X$

Within factorization limit
$B \to \chi_{c0} X$ and $B \to \chi_{c2} X$ not expected

Study based on 29.4fb^{-1} data at $\Upsilon(4S) \approx 10.6\ GeV$

χ_{c1} and χ_{c2} reconstructed using $J/\psi(\to \ell^+\ell^-)\gamma$

Clear Signal seen for χ_{c2} in addition to χ_{c1}

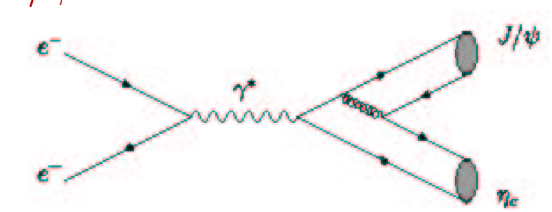


$$\mathcal{B}(B \to \chi_{c1} X) = (3.32 \pm 0.22) \times 10^{-3}$$
$$\mathcal{B}(B \to \chi_{c2} X) = (1.53^{+0.23}_{-0.28}) \times 10^{-3}$$

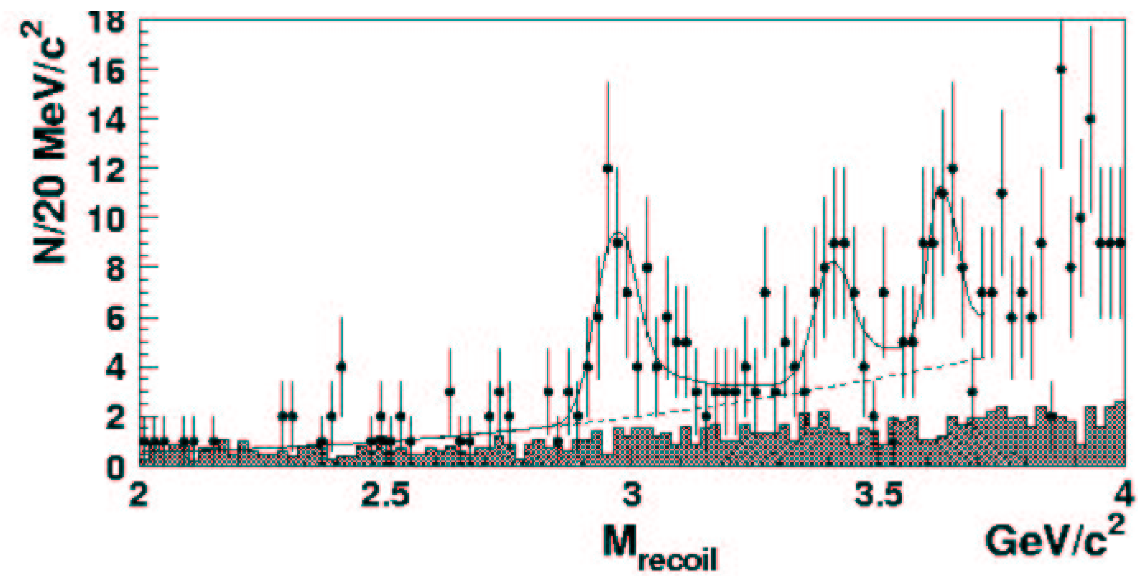
Double cc Production

Based on 41.8 fb^{-1} Data at $\Upsilon(4S)$ and 4.4 fb^{-1} below resonance

Reconstruct $J/\psi \rightarrow \ell^+\ell^-$, Look for the system recoiling against J/ψ



$$M_{recoil} = \sqrt{(\sqrt{S} - E^*_{J/\psi})^2 - {p^*_{J/\psi}}^2}$$



❑ Clear signals seen for
$J/\psi\ \eta_c$ $J/\psi\ \chi_{c0}$ $J/\psi\ \eta_c(2S)$

❑ $\sigma(e^+e^- \rightarrow J/\psi c\bar{c}) = 0.87^{+0.21}_{-0.19} \pm 0.17\ pb$

❑ $\sigma(e^+e^- \rightarrow J/\psi\eta_c) \times \mathcal{B}(\eta_c \rightarrow \geq 4charged) = 0.033^{+0.007}_{-0.006} \pm 0.009\ pb$

❑ These cross-sections are Order of Magnitude larger than the current QCD estimate

❑ Generating lot of theoretical activity to understand these observations including possible scenarios like Light Higgs.

- ❑ $B \to \chi_{c1(2)}\ K(K^*)$
- ❑ $B \to \rho\,\gamma$ and $B \to \omega\,\gamma$
- ❑ $B \to D\ (n)\pi$ and $B \to D^*\ (n)\pi$
- ❑ $B \to D_s^+\ D_s^-$ and $B \to D_s^{*+}\ D_s^{*-}$

- ✧ A beginning of CP violation and Rare B decays
- ✧ Plenty of Data to be analyzed
- ✧ Super B-Factory Option Luminosity: $10^{36}/cm^2/sec$
- ✧ Many excitements ahead

Anyone who keeps the ability to see beauty newer grows old

Franz Kafka