CP Violation Parameter sin(2β) Measurement Using Opposite Side Jet Charge Tagging algorithm

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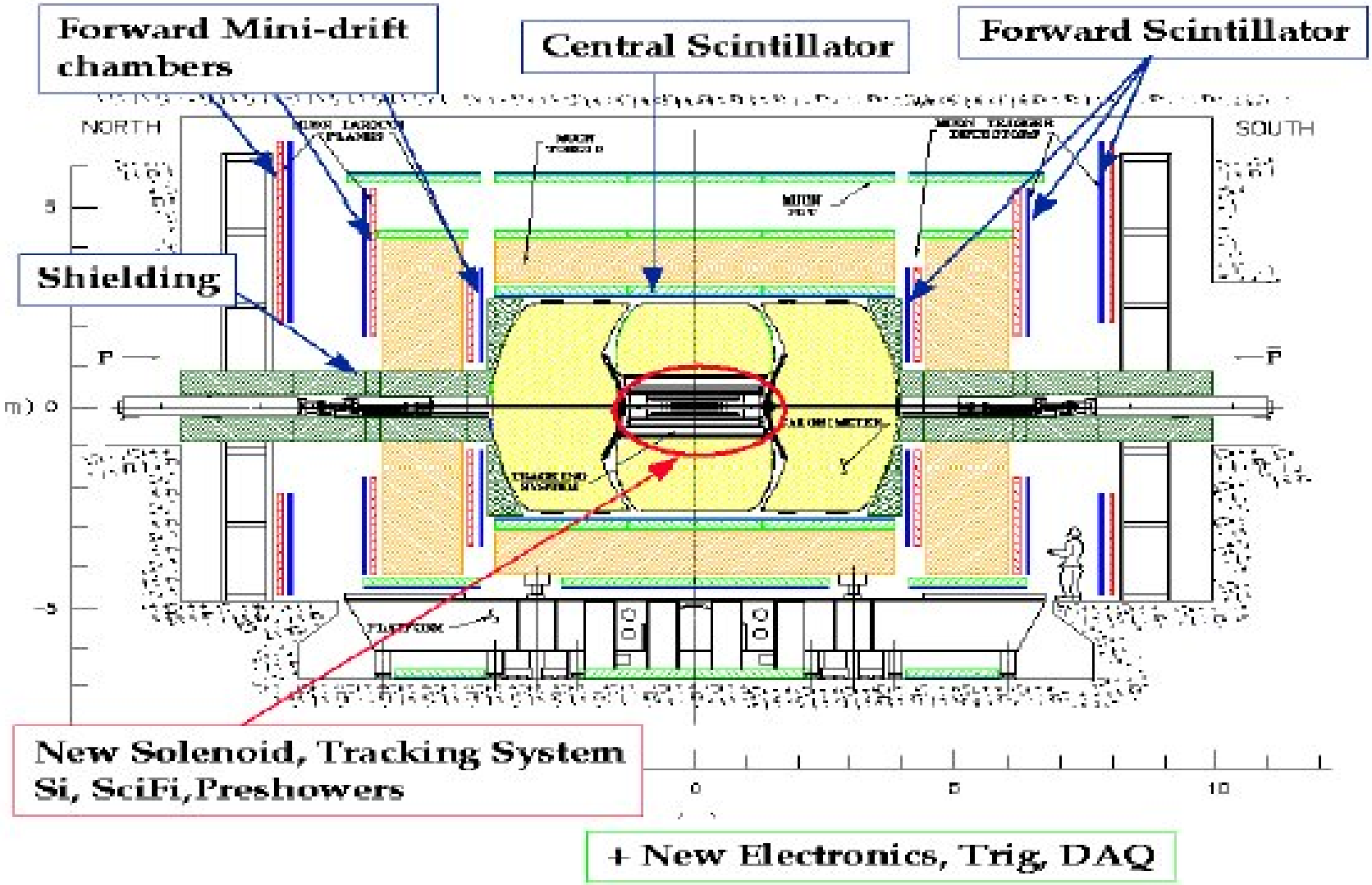
Outline:

1. Opposite Side Jet Charge Tagging Algorithm (JETQ)

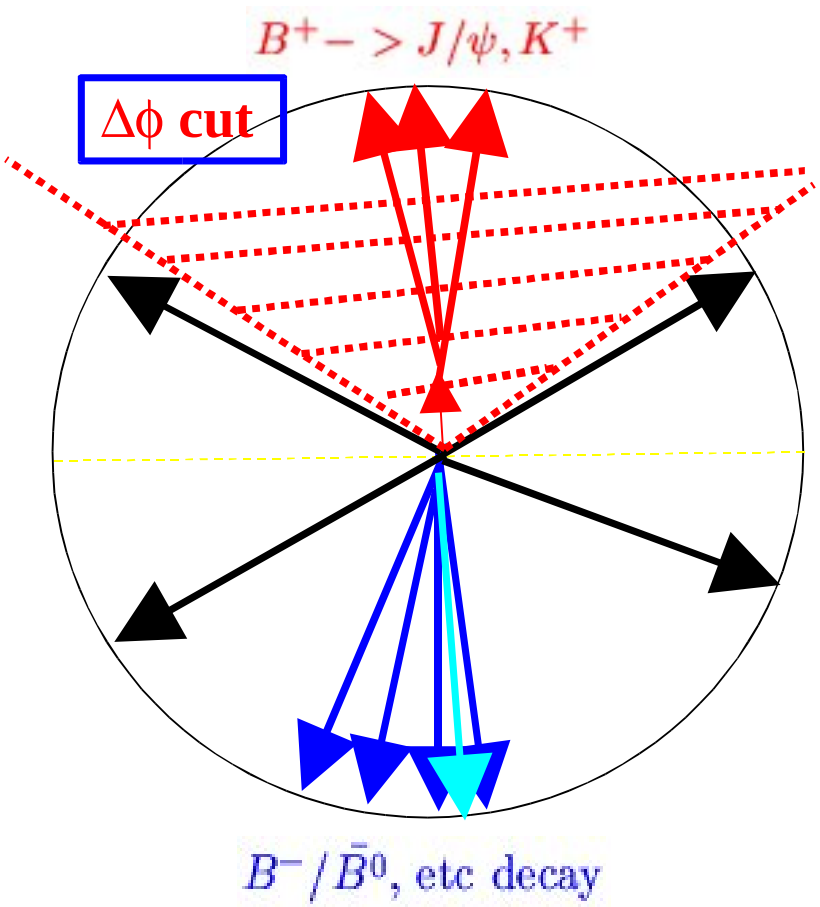
2. Verification of JETQ tagging algorithm

3. sin(2β) measurement with $B_d \rightarrow J/\psi$ Ks data sample (225 pb^{-1})

Overview of Detector



Opposite Side Jet Charge Tagging Algorithm



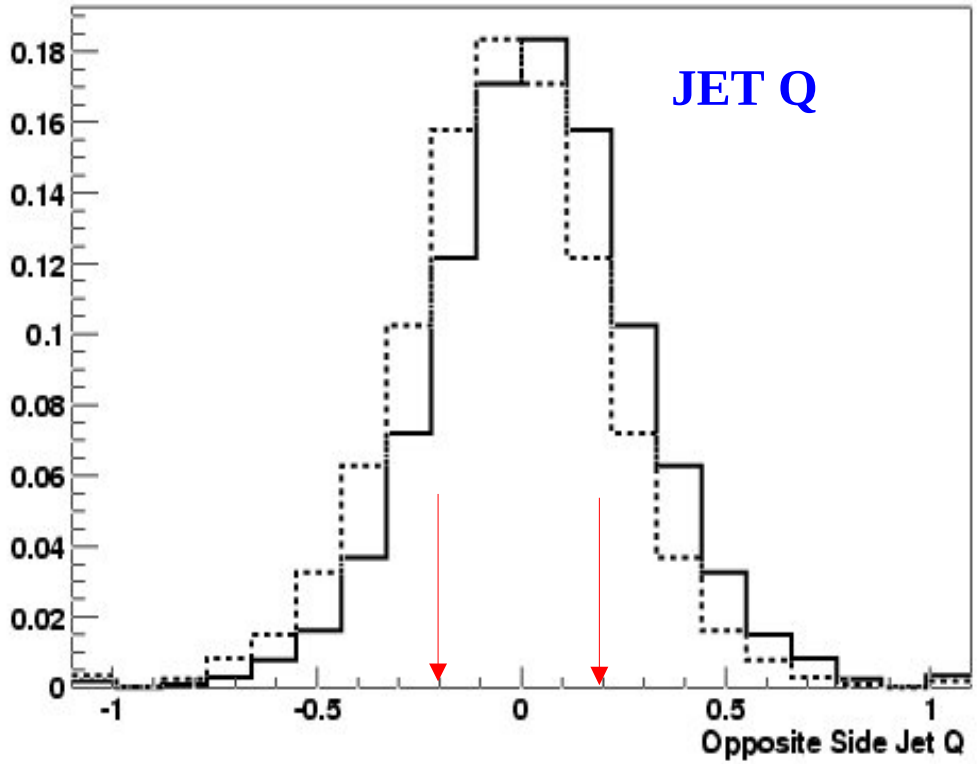
See the drawing on the left, taking all the tracks

- Remove decay products from the reconstructed *B*
- Remove tracks in the red shaded area(i.e. Δϕ cut)
- Remove tracks with pt < 0.25 GeV/c.
- Remove tracks w/ |TrkVtx_z − PVtx_z| > 2 cm
- Remove tracks w/ 2D_dca > 0.2 cm
- Use the remaining tracks, calculate the jet charge

$$Q = \frac{\sum P_T^{\,i} * q^i}{\sum P_T^{\,i}}$$

- Q > 0.2 tags $\bar{b}$ −hadron,
  Q < −0.2 tags b −hadron,
  |Q| < 0.2: event is untagged.

Jet charge distribution and the tagging performance



The jet charge distribution for a MC B^- sample

The Tagging dilution and efficiency

$$D = \frac{N_{correct} - N_{incorrect}}{N_{correct} + N_{incorrect}}$$

$$\epsilon = \frac{N_{correct} + N_{incorrect}}{N_{correct} + N_{incorrect} + N_{untag}}$$

Goal: maximize εD^2

Verification of JETQ tagging algorithm

Integrated luminosity: ~225 pb^{-1}

1) Calibration sample $B^{+/-} \rightarrow J/\psi\ K^{+/-}$

The tagging dilutions of data $B^{+/-}$ sample agree well with MC results.

$\Delta\phi$ cut	MC	Data
0.7	17.6% ± 0.6%	15.2% ± 4.0%
1.2	14.7% ± 0.6%	13.7% ± 3.9%
2.0	12.0% ± 0.5%	8.1% ± 3.7%

2) Further verification with B_d mixing results using data sample

Expected from MC B^0 / $\bar{B}^0$ sample ($\Delta\phi$=1.2):

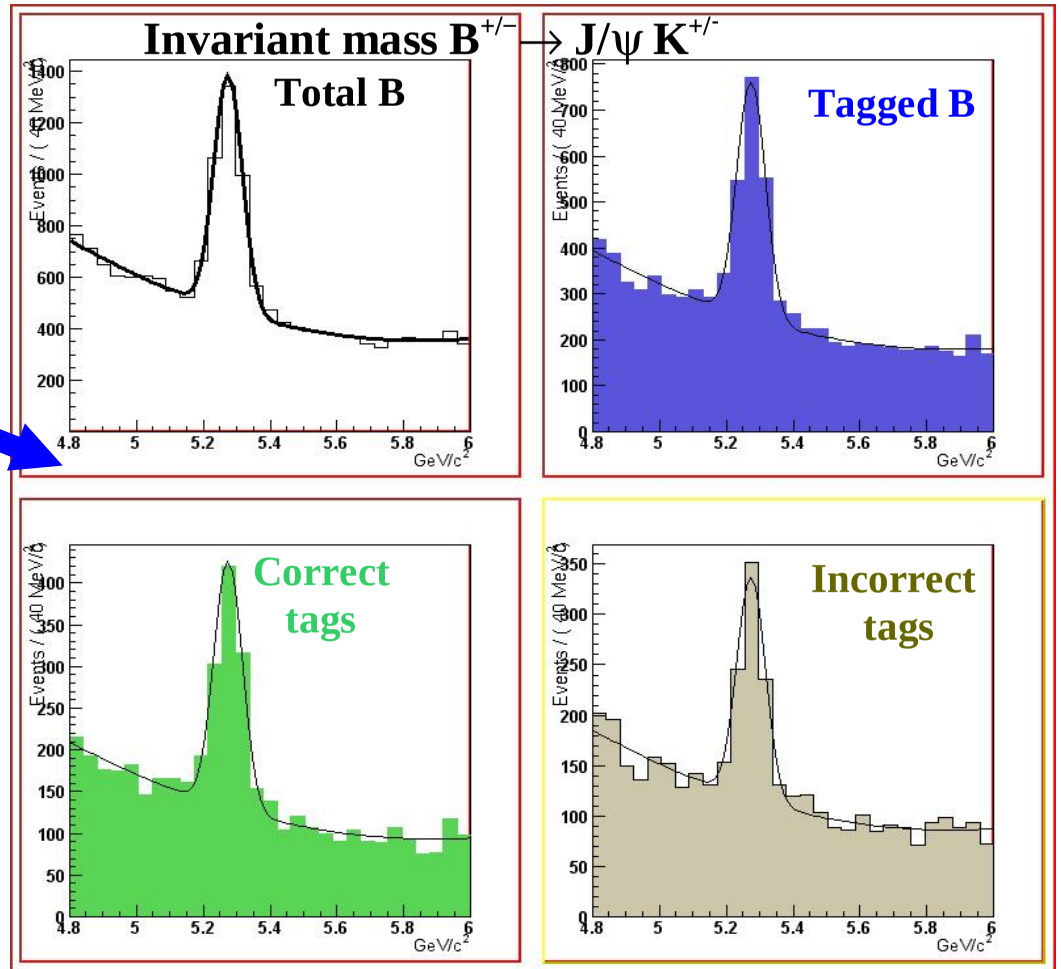
D_{MCexp} = 11.4%

Good agreement

B mixing study with data sample:

D_{mix_data} = **11.5%±1.3%**

Total / tags / correct tags: 2379/1348/774



Fit: signal: Gaussian; background: p0+p1×mass+p2×mass^2

CP violation parameter sin(2β) measurement

CP violation is described by the standard model of electroweak interactions

- **a consequence of a complex phase in the CKM matrix**
- $$\frac{dN}{dt}(B^0 \to J/\psi K_s^0) \neq \frac{dN}{dt}(\bar{B}^0 \to J/\psi K_s^0)$$

$$J/\psi \to \mu^+\mu^- \quad K_s^0 \to \pi^+\pi^-$$

- **Time dependent measurement**

$$A_{CP}(t) = \frac{\bar{\Gamma}(t) - \Gamma(t)}{\bar{\Gamma}(t) + \Gamma(t)} = \sin 2\beta \times \sin \Delta m t$$

$$\beta = arg[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}]$$

- **Standard Model predicts sin(2β) ≈ 0.75.**

- **Time integrated measurement:**

$$\sin 2\beta = \frac{1 + x_d^2}{x_d} A_{int}$$

$$\delta[\sin 2\beta] = \frac{1 + x_d^2}{x_d} \frac{1}{\sqrt{N\epsilon D^2}}$$

$$A_{tag} = \frac{\bar{N}_t - N_t}{\bar{N}_t + N_t} \qquad A_{int} = \frac{A_{tag}}{D}$$

N_t: tagged B^0, $\bar{N}_t$: tagged $\bar{B}^0$

N: input B , D: tagging dilution

x_d: mixing parameter

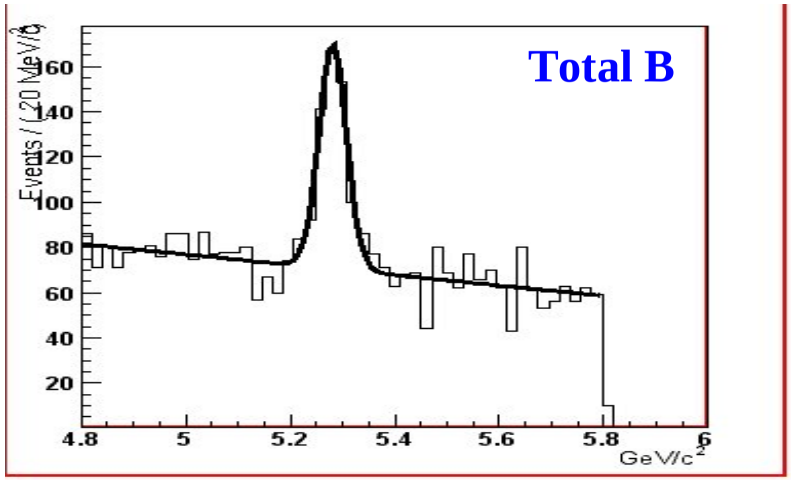
Dilution is drawn from the MC prediction, which has been verified in B_d mixing study with data sample.

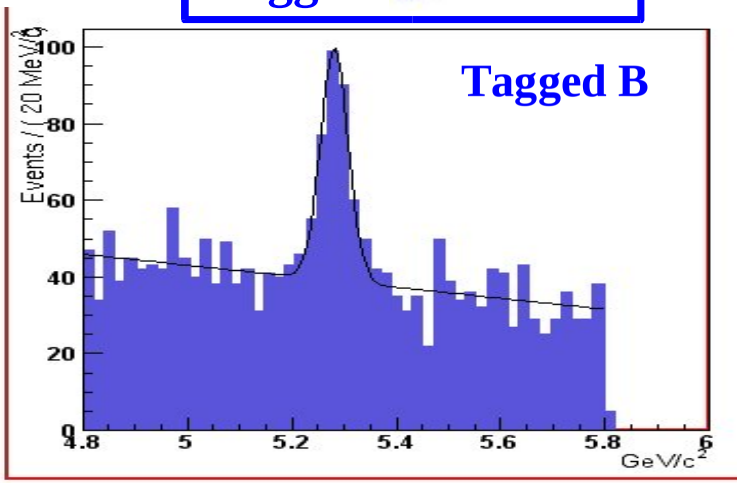
Tagging results for neutral B sample (time integrated)

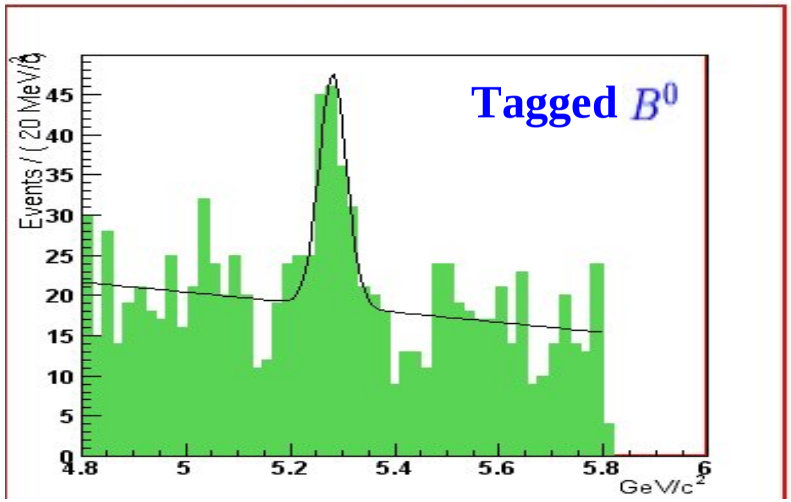
1) Input data sample: 225 pb^{-1}

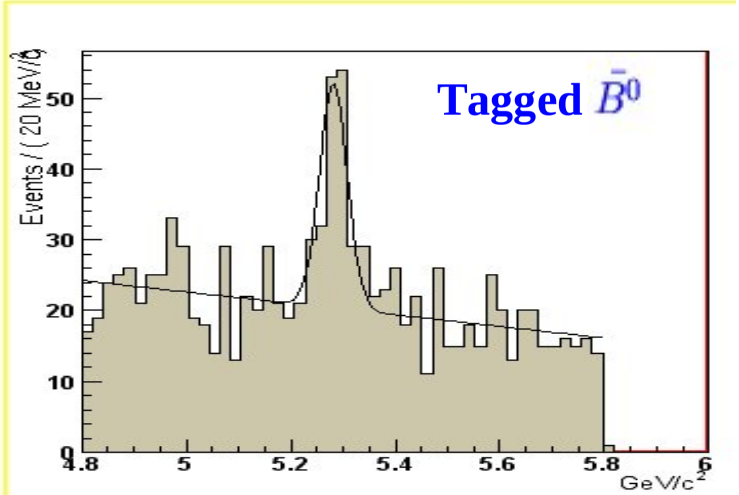
2) reconstruct $B_d \rightarrow J/\psi$ Ks

Tagging results
Tagged $\bar{B}^0$ = 106.6
Tagged B^0 = 96.8



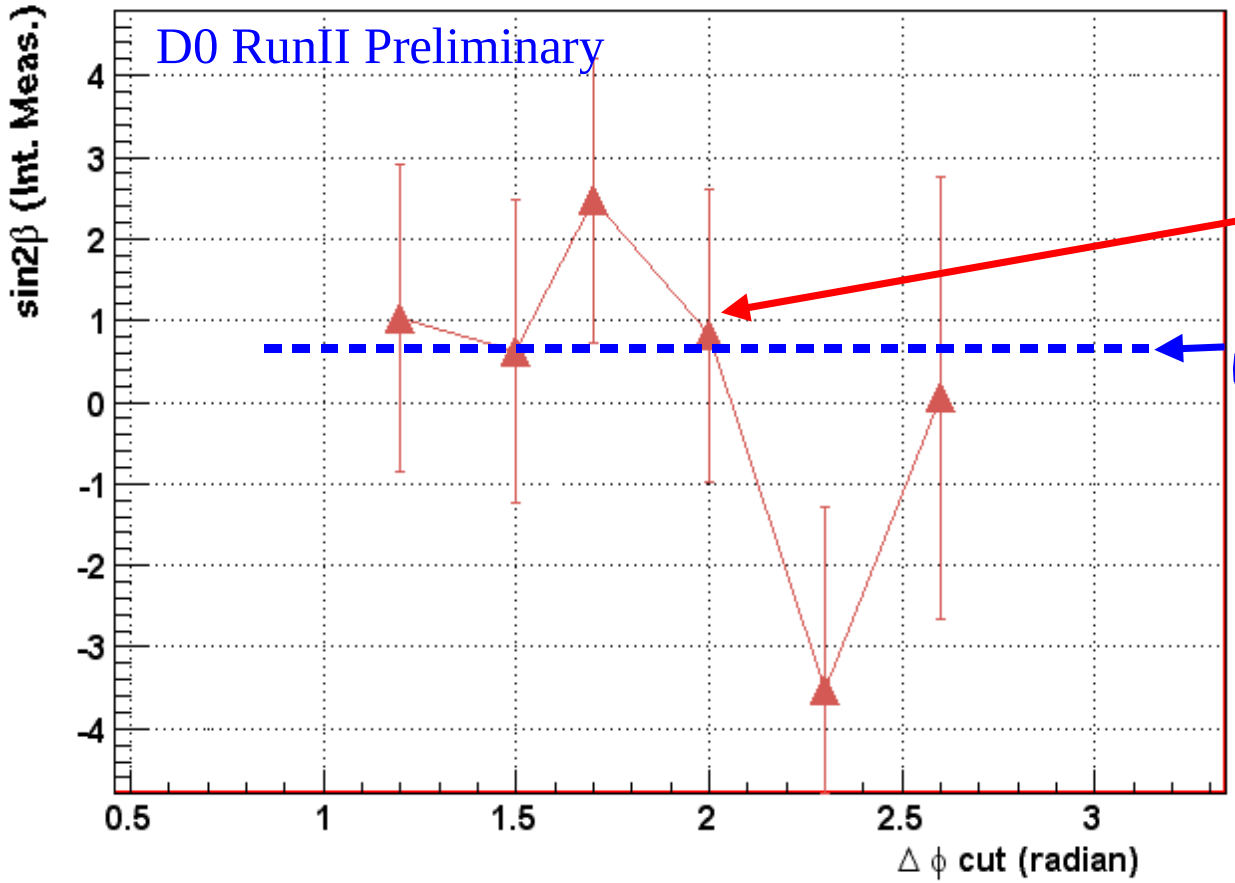






Time integrated sin(2β) measurement

Measured sin(2β) with different Δϕ cuts



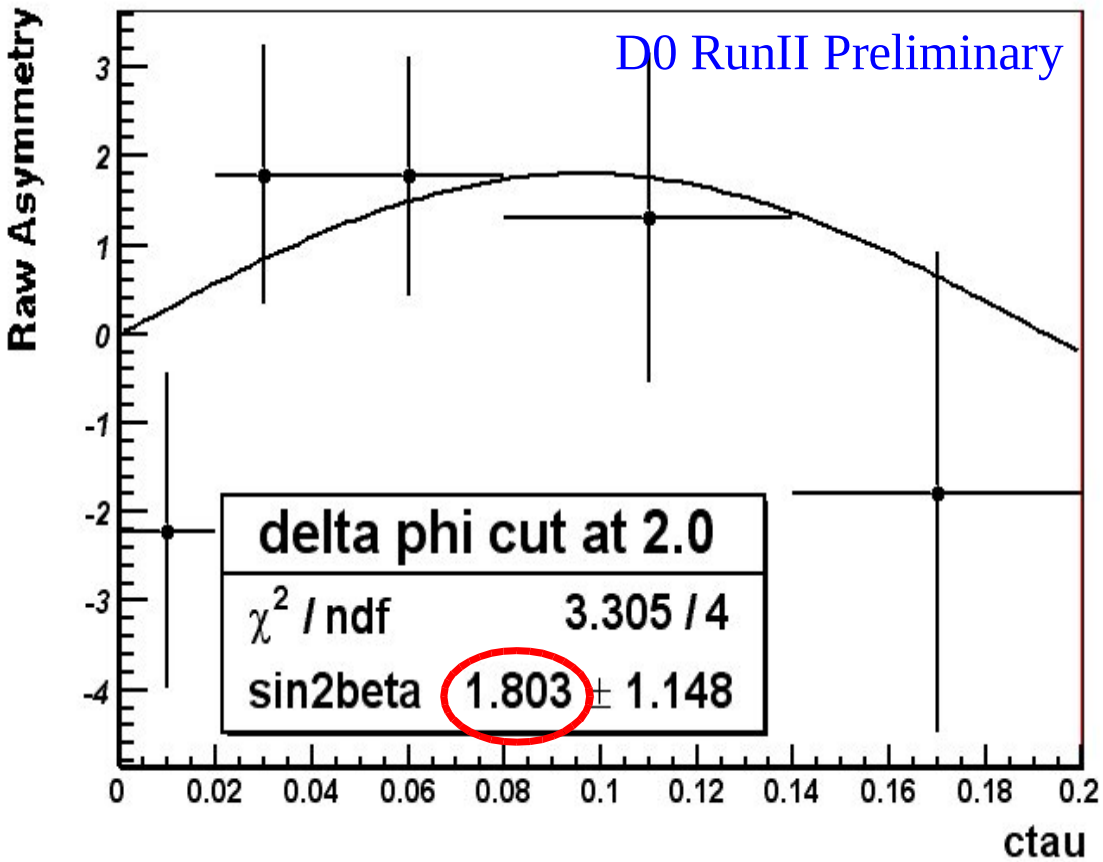
sin(2β) = 0.82 ± 1.80
(statistic error only)

BaBar: 0.76 ± 0.07
Belle: 0.73 ± 0.06

Robustness check has been done by varying associated cuts in both small (1%) and large scale (e.g. PT → 0.5, 1), no change is found to be larger than the statistical error.

Time dependent sin(2β) measurement

$$A_{raw}(t) = \frac{\bar{\Gamma}(t) - \Gamma(t)}{\bar{\Gamma}(t) + \Gamma(t)} = \sin 2\beta \times \sin \Delta m t$$



Divide the proper decay length into 5 bins:

0 – 200 μm
200 – 400 μm
400 – 800 μm
800 – 1400 μm
1400 – 2000 μm

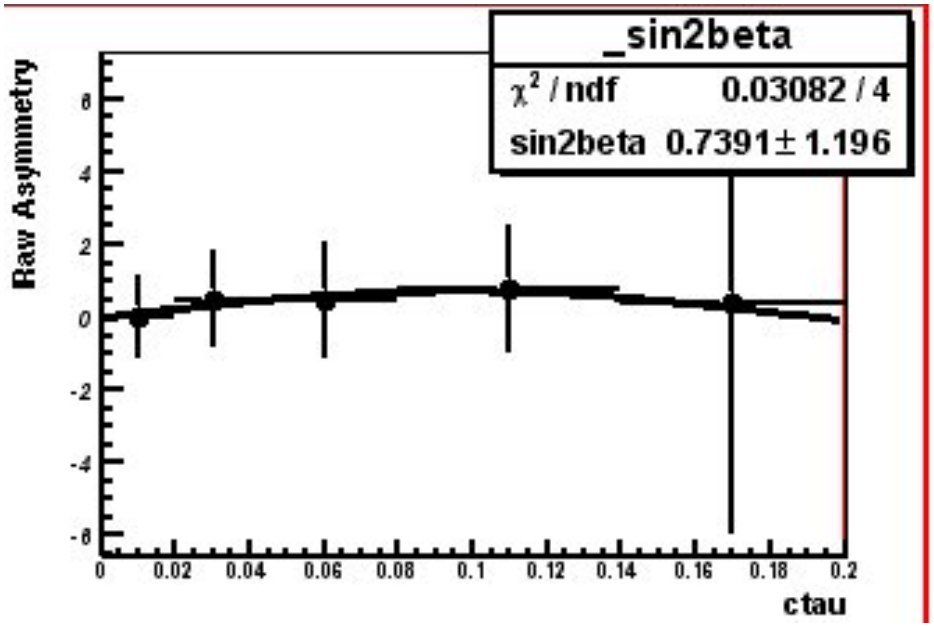
Next ...

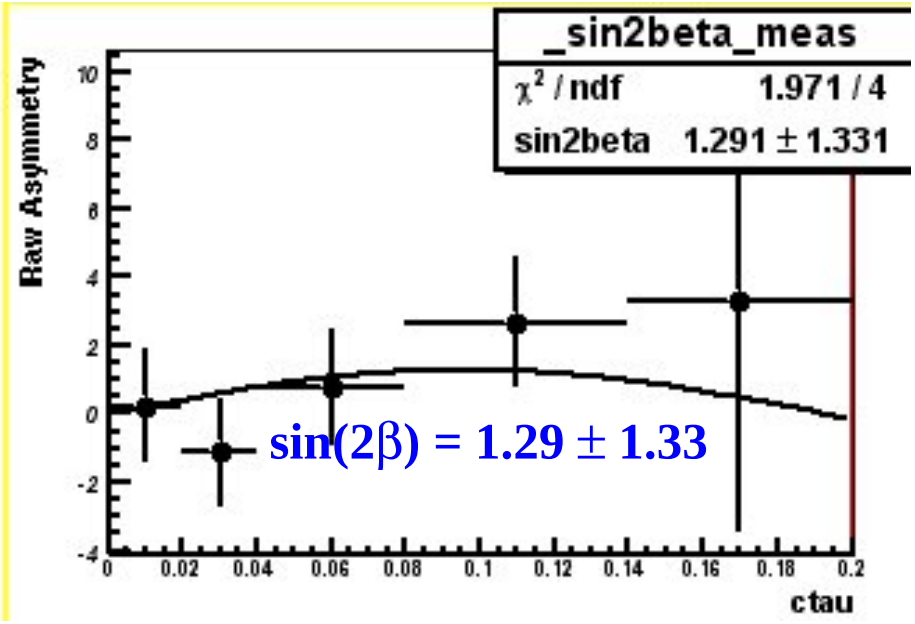
- **Unbinned likelihood fit**
- **More statistics**

MC studies I: 200 tagged events

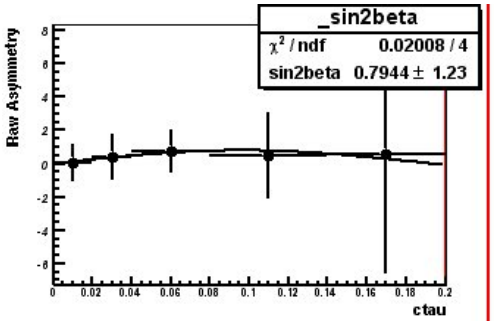
$$N \sim \Gamma_f(t) = e^{-\Gamma t} \times (1 - sin2\beta \times sin\Delta mt) \qquad N^i_{tag} = Binomial(N^i, (1.+D)/2) + Binomial(\bar{N}^i, (1.-\bar{D})/2)$$

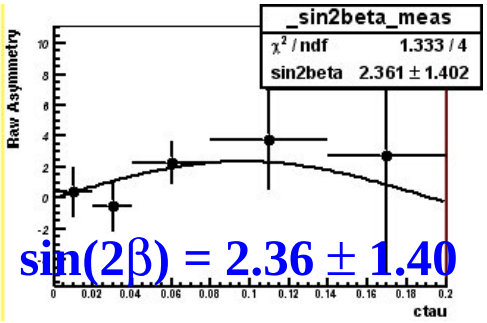
$$\bar{N} \sim \bar{\Gamma}_f(t) = e^{-\Gamma t} \times (1 + sin2\beta \times sin\Delta mt) \qquad \bar{N}^i_{tag} = Binomial(N^i, (1.-D)/2) + Binomial(\bar{N}^i, (1.+\bar{D})/2)$$

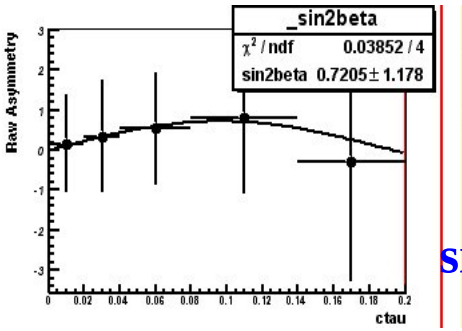


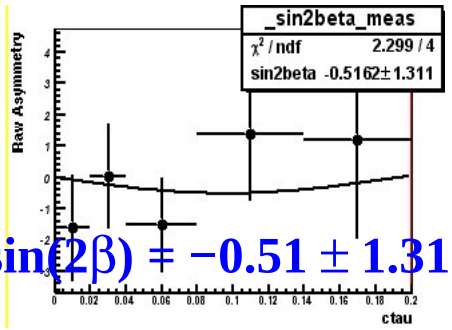


More MC fits:

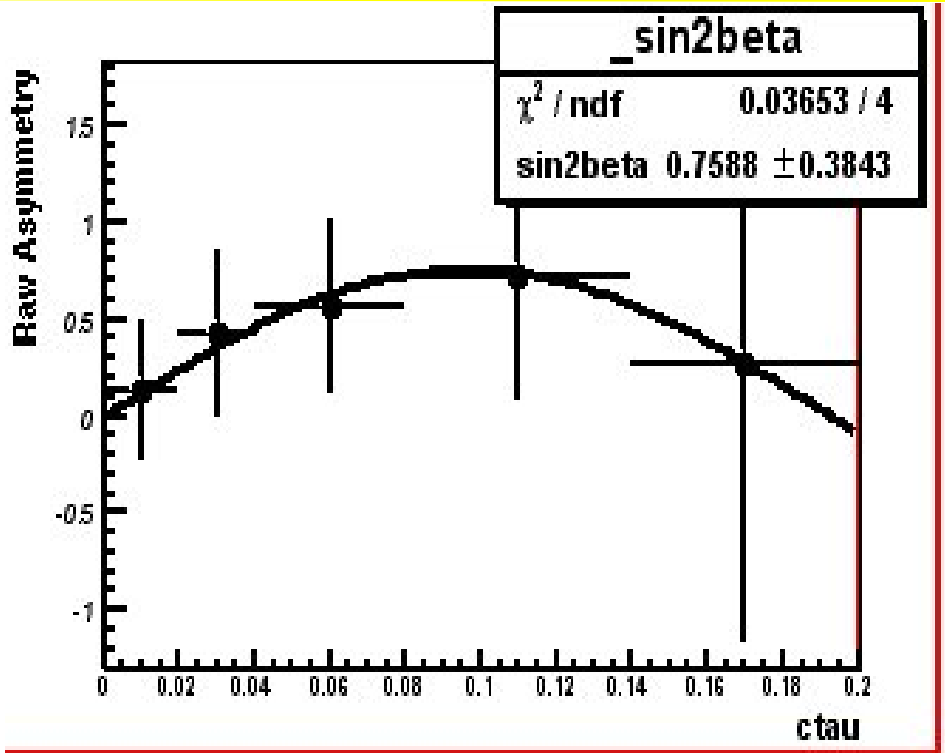


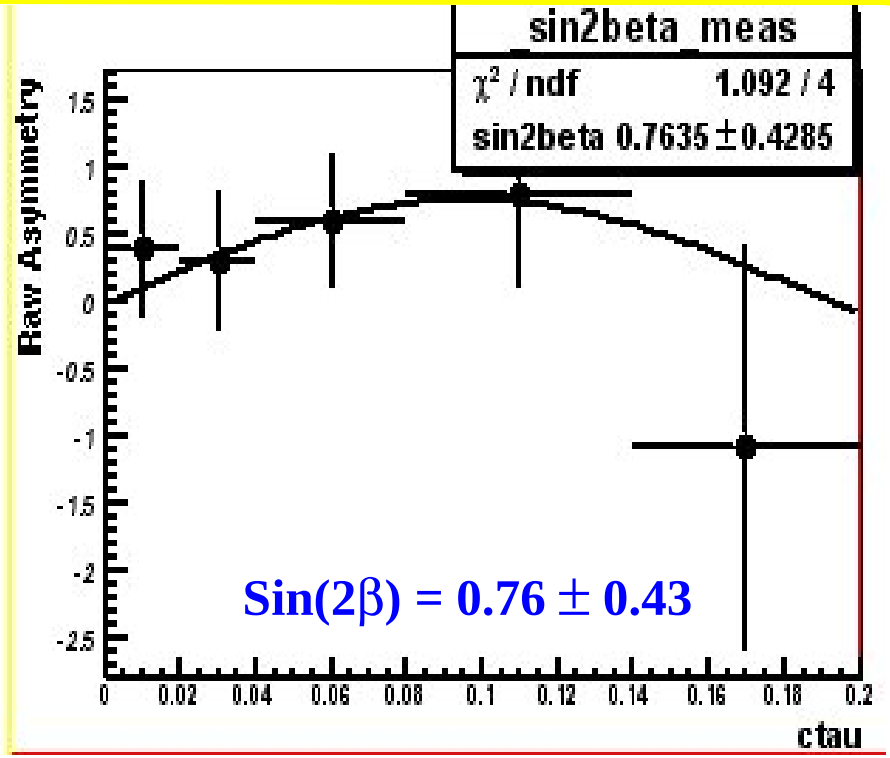






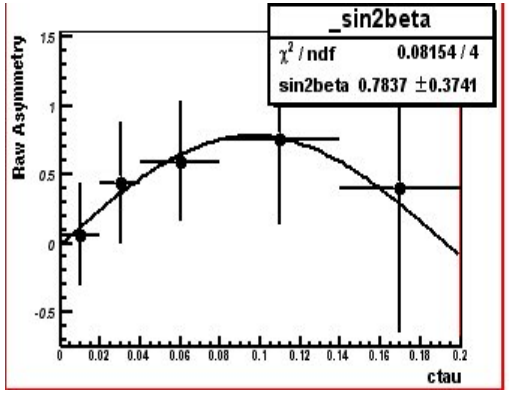
MC studies II: 2000 tagged events

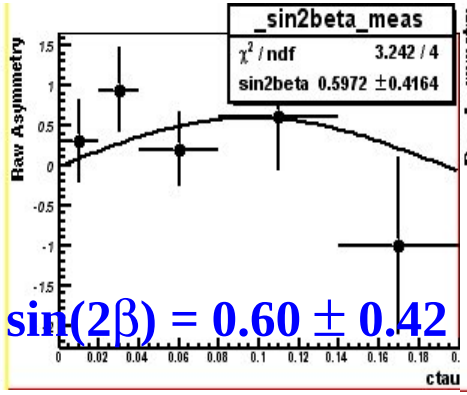




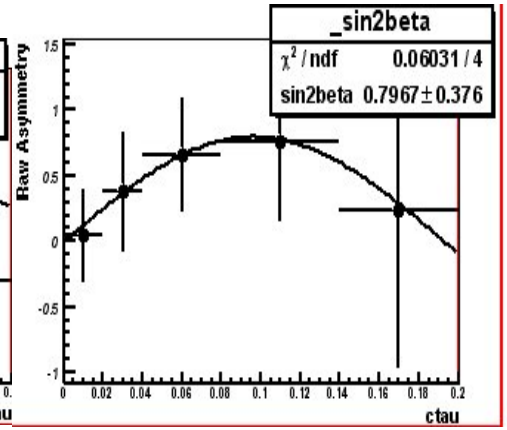
Sin(2β) = 0.76 ± 0.43

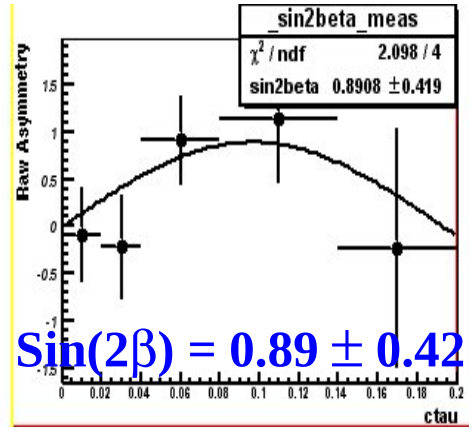
More MC fits:





sin(2β) = 0.60 ± 0.42





Sin(2β) = 0.89 ± 0.42

Summary

- **Have developed a jet charge tagging (JETQ) algorithm for *b* flavor tagging and tested it on both $B^{+/-}$ data sample and B_d sample**

  The results of data agree with the predictions from the MC results.

- **Have applied the JETQ algorithm to B^0 data sample where we expect CP violation and find:**
  - **time integrated, $\Delta\phi = 2.0$, $\sin(2\beta) = 0.82 \pm 1.80$**
  - **time dependent, $\Delta\phi = 2.0$, $\sin(2\beta) = 1.80 \pm 1.15$**