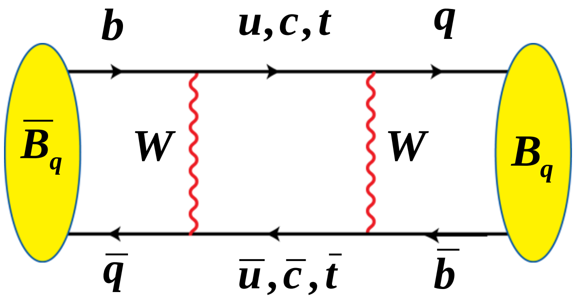
Measurement of ϕ_s at DØ experiment

G.Borissov, Lancaster University, UK

on behalf of DØ collaboration

CP violation in mixing

- CP violation in mixing is described by a complex phase ϕ_q of B_q ($q=d,s$) mass matrix



$$\Delta M_q = M_H - M_L \approx 2|M_q^{12}|$$

$$\Delta \Gamma_q = \Gamma_L - \Gamma_H \approx 2|\Gamma_q^{12}|\cos\phi_q$$

$$\phi_q = \arg\left(-\frac{M_q^{12}}{\Gamma_q^{12}}\right)$$

$$\|\mathbf{M}_q\| = \begin{bmatrix} M_q & M_q^{12} \\ (M_q^{12})^* & M_q \end{bmatrix} - \frac{i}{2}\begin{bmatrix} \Gamma_q & \Gamma_q^{12} \\ (\Gamma_q^{12})^* & \Gamma_q \end{bmatrix}$$

SM prediction

- SM predicts very small values of ϕ_q:

$$\phi_d^{SM} = -0.091^{+0.026}_{-0.038}$$
$$\phi_s^{SM} = 0.0042 \pm 0.0014$$

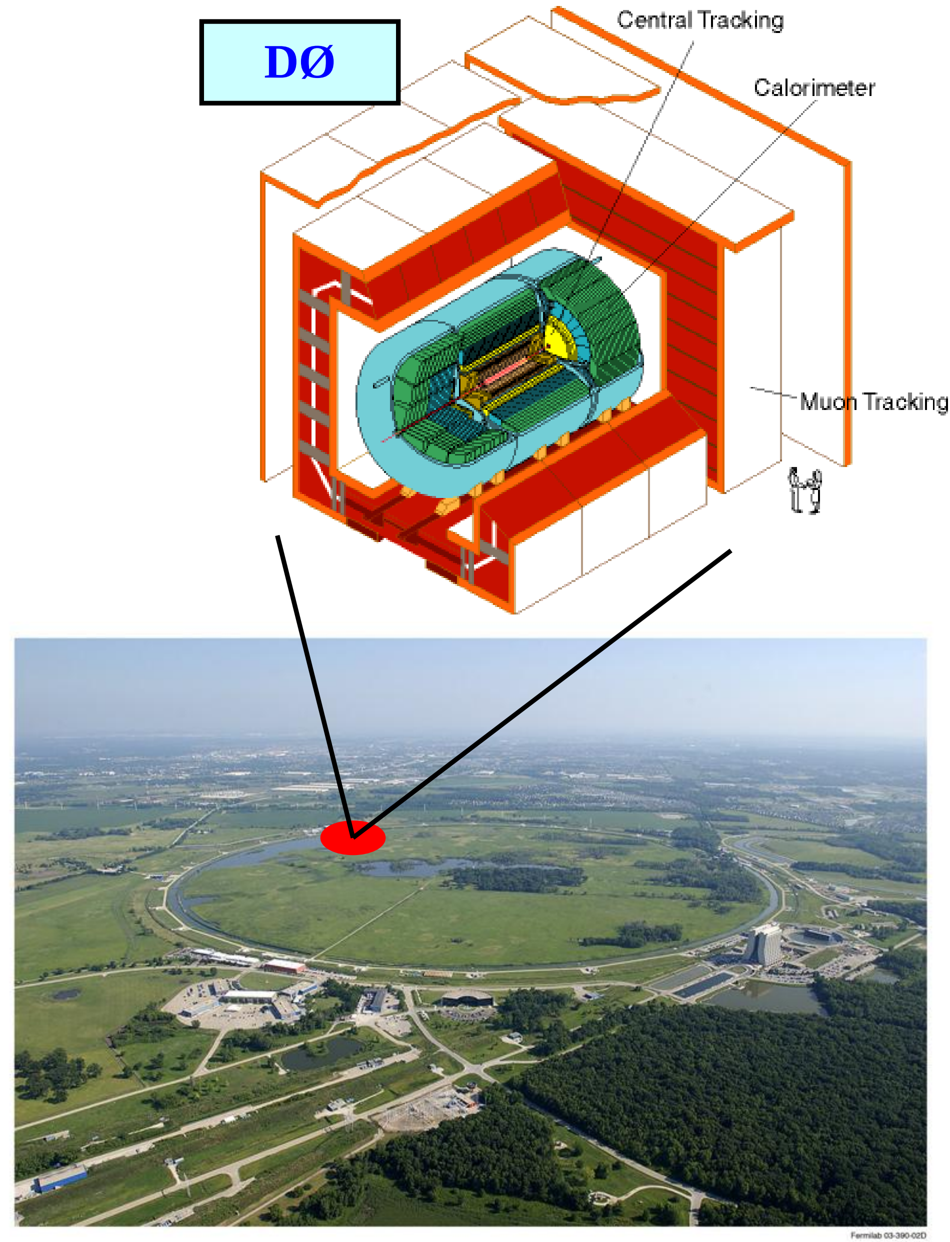
  - A. Lenz, U. Nierste, J. High Energy Phys. 0706, 072 (2007)
  - These values are below current experimental sensitivity
- New physics contribution can significantly change these values

$$\phi_d = \phi_d^{SM} + \phi_d^{NP}$$
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

Large non-zero value of ϕ_q would indicate the presence of new physics

Measurement of ϕ_q

- The phase ϕ_q can be measured in several independent ways:
  - Charge asymmetry of semileptonic B_q decays;
  - Dimuon charge asymmetry;
  - Decay $B_s \to J/\psi\varphi$;
- DØ experiment at Fermilab performs all these measurements



Semileptonic charge asymmetry

- The charge asymmetry a^q_{sl} of "wrong sign" semileptonic B^0_q ($q = d,s$) decays:

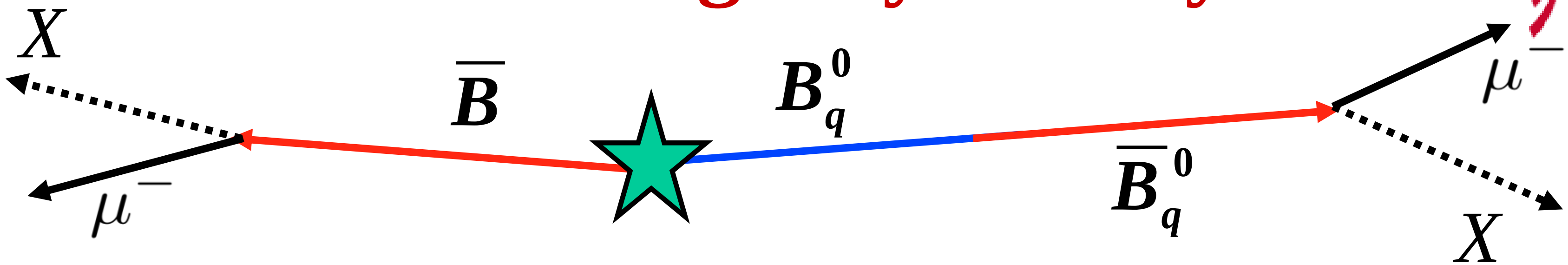
$$a^q_{sl} \equiv \frac{\Gamma(\overline{B}^0_q \to \mu^+ X) - \Gamma(B^0_q \to \mu^- X)}{\Gamma(\overline{B}^0_q \to \mu^+ X) + \Gamma(B^0_q \to \mu^- X)}; \quad q = d, s$$

- This asymmetry is related with the phase ϕ_q as:

$$a^q_{sl} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan(\phi_q)$$

- a^d_{sl} is measured by B factories : $a^d_{sl} = -0.0047 \pm 0.0046$
- a^s_{sl} is measured by DØ experiment

Dimuon charge asymmetry



- Charge asymmetry of same sign dimuon pairs produced in a $p\overline{p}$ collision

$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

N_b^{++} (N_b^{--}) – number of same-sign $\mu^+\mu^+$ ($\mu^-\mu^-$) events from $B \rightarrow \mu X$ decay

- Both B_d and B_s contribute in A^b_{sl} at Tevatron :

$$A_{sl}^b = (0.506 \pm 0.043) a_{sl}^d + (0.494 \pm 0.043) a_{sl}^s$$

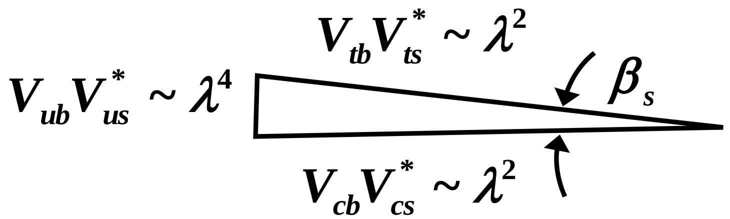
B_d contribution

B_s contribution

Decay $B_s \to J/\psi\ \varphi$

- CP violation in $B_s \to J/\psi\varphi$ decay is described by the phase $\phi^{J/\psi\varphi}$
- Within the SM $\phi^{J/\psi\varphi}$ is related to the angle β_s of the (bs) unitarity triangle:

$$\phi^{J/\psi\varphi,SM} = -2\beta_s = 2\arg\left(-\frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*}\right) = -0.038 \pm 0.002$$



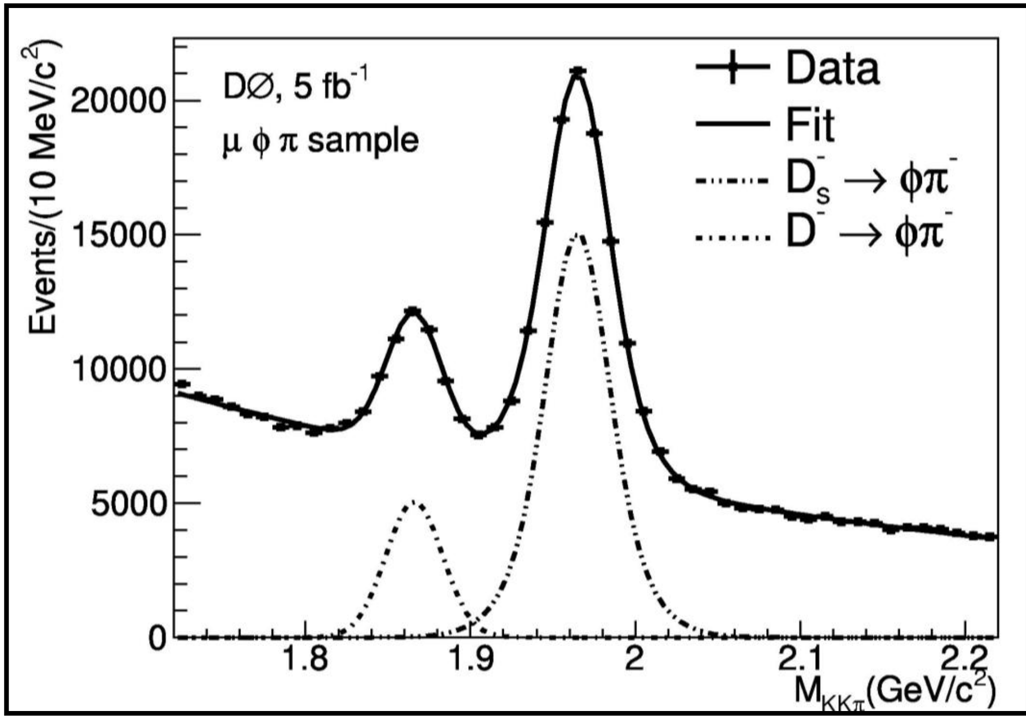
- It can be significantly modified by the new physics contribution:

$$\phi^{J/\psi\varphi} = \phi^{J/\psi\varphi,SM} + \phi_s^{NP}$$

ϕ_s^{NP} is the same for $\phi^{J/\psi\varphi}$ and ϕ_s

Semileptonic charge asymmetry

- Select decay $B_s \to \mu\nu D_s$ with $D_s \to \varphi\pi$ or $D_s \to K^*K$ events;
  - 81400 $D_s \to \varphi\pi$ events;
  - 33600 $D_s \to K^*K$ events;
- Use flavour tagging to determine the initial state of B_s
  - Events without flavour tagging are also used
- Result obtained (5 fb^{-1}) is consistent with the SM prediction:



$$a_{sl}^s = -0.0017 \pm 0.0091^{+0.0014}_{-0.0015}$$

$$a_{sl}^s(SM) = (2.1 \pm 0.6) \times 10^{-5}$$

Measuring the dimuon charge asymmetry

- Measure two raw asymmetries (include muons from all sources):

raw dimuon charge asymmetry

$$A \equiv \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%$$

raw inclusive muon charge asymmetry

$$a \equiv \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%$$

- Both asymmetries contain contributions from A^b_{sl} and detector-related background asymmetries

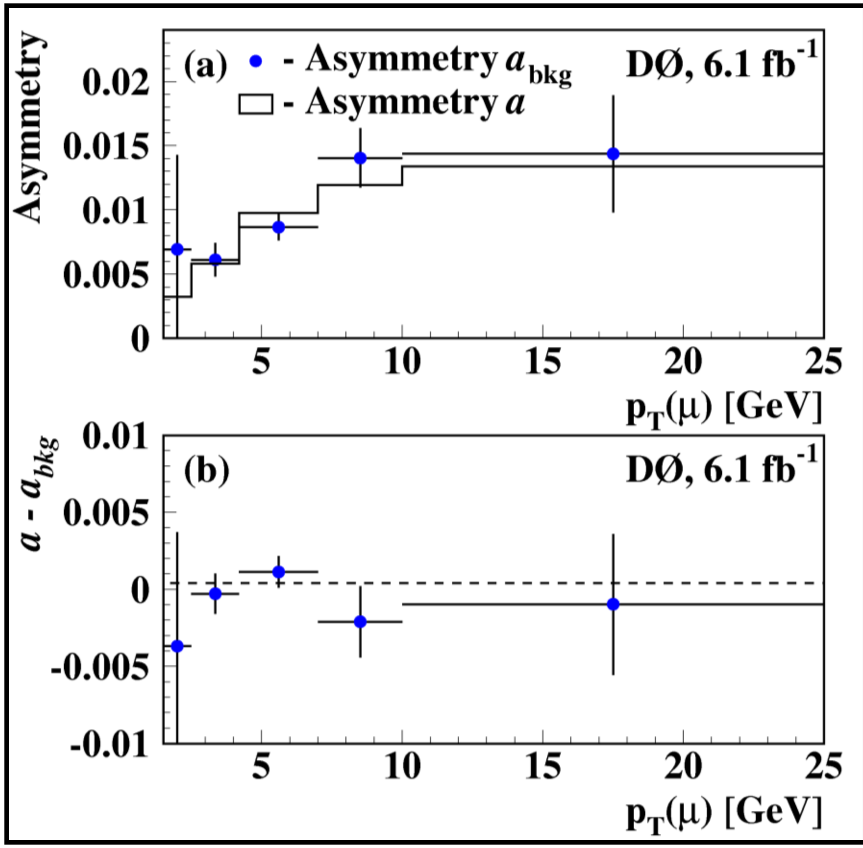
$$A = K\, A^b_{sl} + A_{bkg}$$

$$a = k\, A^b_{sl} + a_{bkg}$$

  - contribution from A^b_{sl} to a is strongly suppressed by k=0.041 0.003
- Determine background contributions A_{bkg} and a_{bkg} using data with minimal input from simulation
- Exploit the correlation of background content in raw asymmetries to reduce the uncertainty on A^b_{sl}

Test of background description

- Raw inclusive muon asymmetry a is dominated by the background asymmetry a_{bkg}
- a_{bkg} is measured in data
- Compare a and a_{bkg} to verify the background description
- This comparison is done as a function of muon p_T
- Good consistency between observed and expected asymmetries
  - χ^2/dof = 2.4/5 for the difference between these two distributions



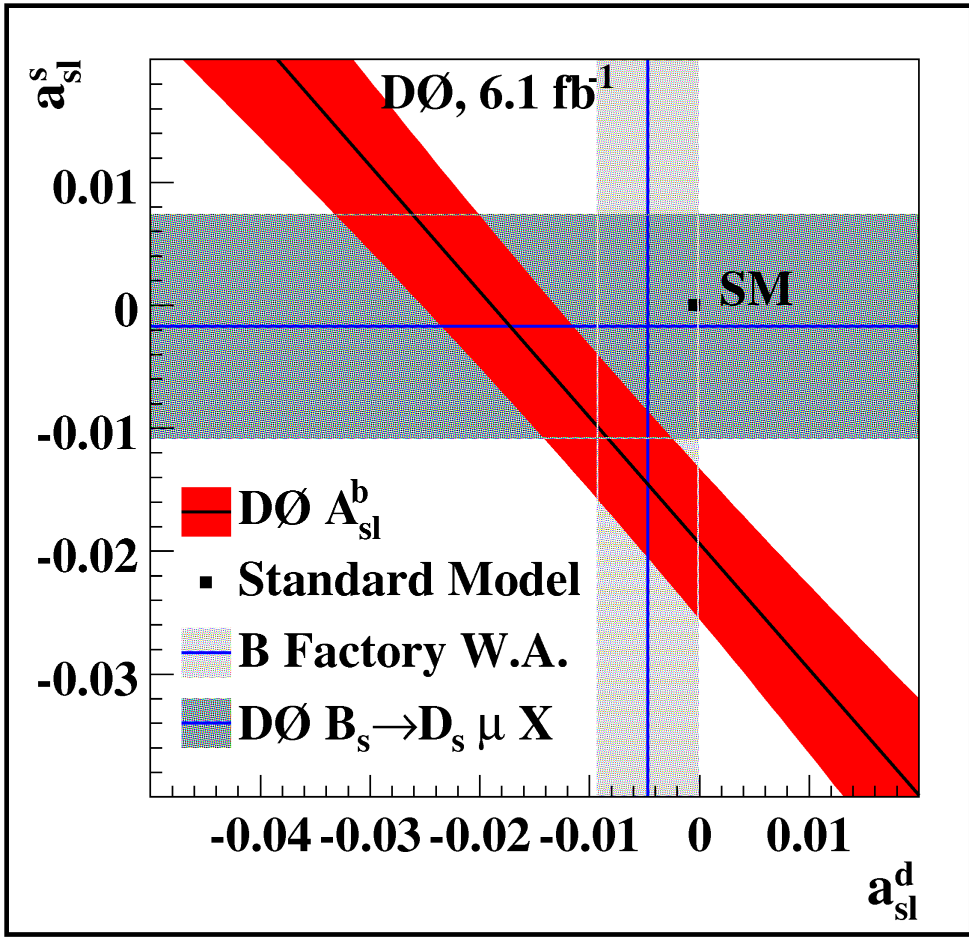
Evidence for an anomalous like-sign charge asymmetry

$$A^b_{sl} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\,\%$$

- This result differs from the SM prediction by ~3.2 σ
- A^b_{sl} produces a band in a^d_{sl} v.s. a^s_{sl} plane:

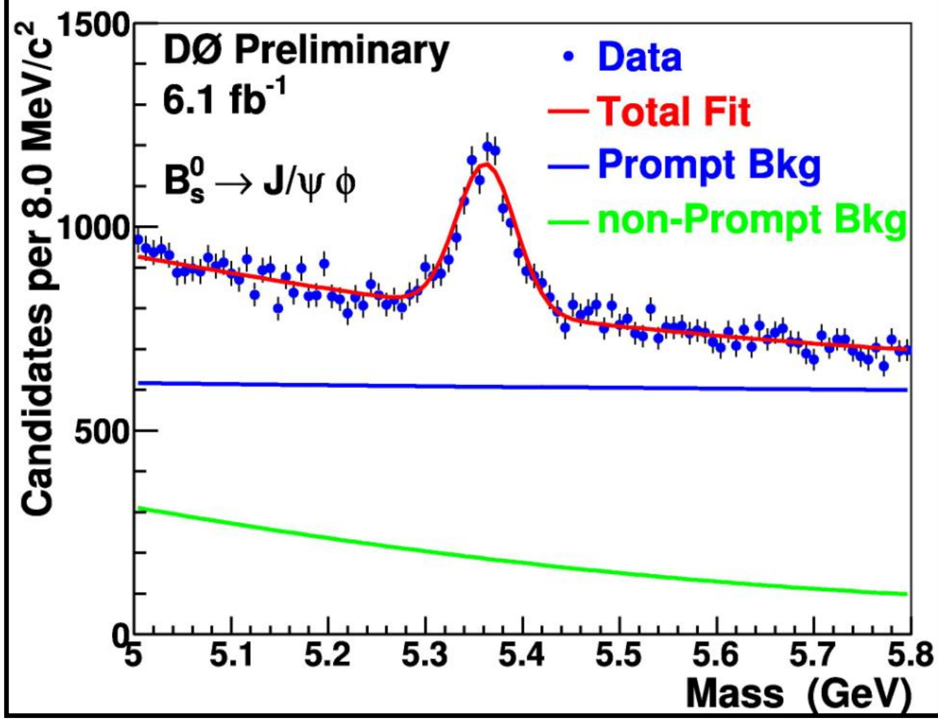
$$A^b_{sl} = (0.506 \pm 0.043) a^d_{sl} + (0.494 \pm 0.043) a^s_{sl}$$

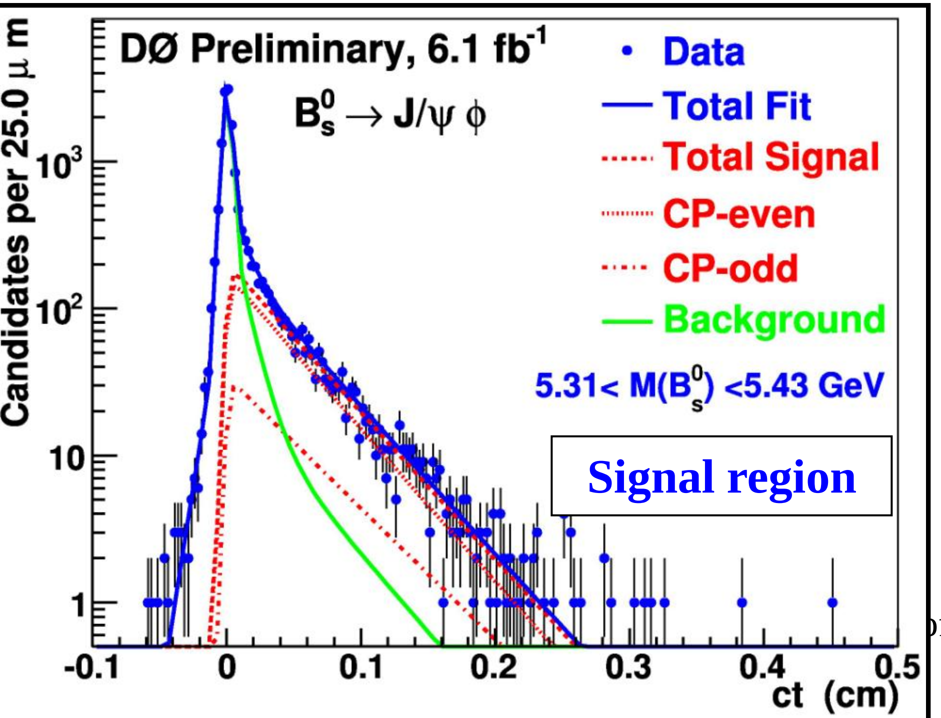
- Obtained result agrees well with other measurements of a^d_{sl} and a^s_{sl}

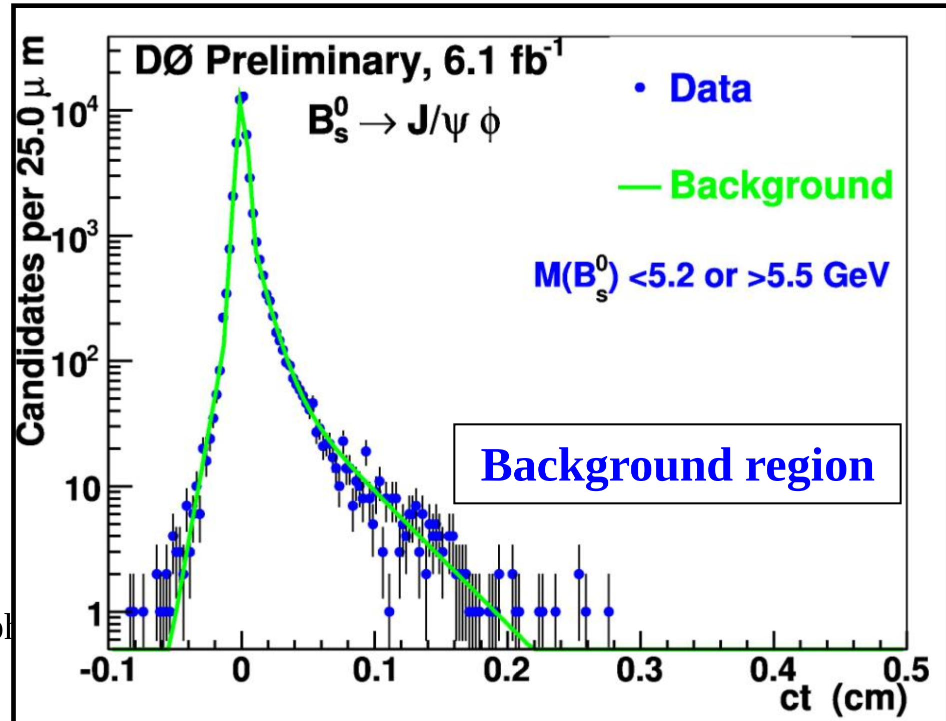


$B_s \to J/\psi\ \varphi$

- 6.1 fb^{-1} of data analyzed
- ~3400 signal $B_s \to J/\psi\ \varphi$ events
- Both $\Delta\Gamma$ and $\phi^{J/\psi\varphi}$ are extracted from the time evolution of angular distributions of decay products



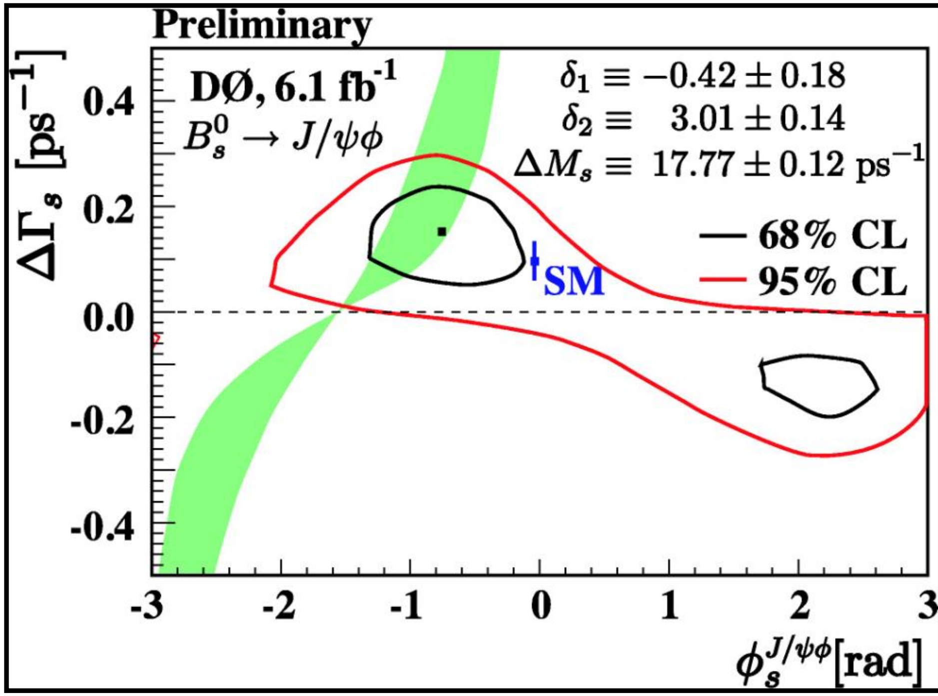




$B_s \to J/\psi\ \varphi$

- S-wave is found to be non-significant, not included
- Only the opposite flavour tagging is used
- Strong phases are constrained to the values from $B^0 \to J/\psi K^{*0}$
- $\tau(B_s)$ and $\Delta\Gamma_s$ are consistent with other measurements

$$\tau_s = 1.47 \pm 0.04 \pm 0.01 \text{ ps}$$
$$\Delta\Gamma_s = 0.15 \pm 0.06 \pm 0.01 \text{ ps}^{-1}$$
$$\phi_s = -0.76^{+0.38}_{-0.36} \pm 0.02$$



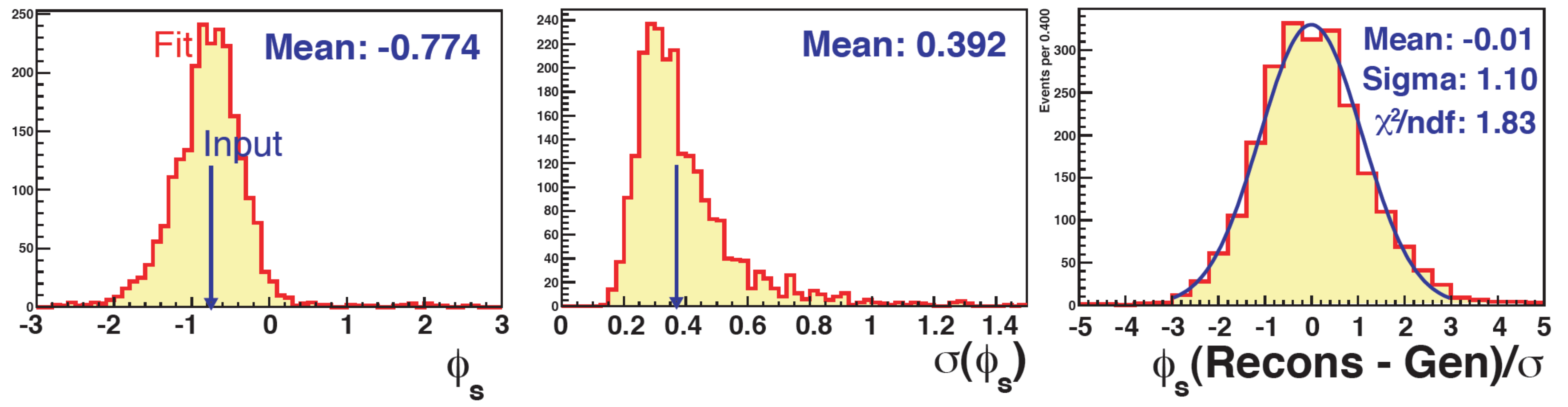
$$0.014 < \Delta\Gamma_s < 0.263 \text{ ps}^{-1} \quad (95\% \text{ C.L.})$$
$$-1.65 < \phi^{J/\psi\varphi} < 0.24 \quad (95\% \text{ C.L.})$$

and

$$-0.235 < \Delta\Gamma_s < -0.040 \text{ ps}^{-1} \quad (95\% \text{ C.L.})$$
$$1.14 < \phi^{J/\psi\varphi} < 2.93 \quad (95\% \text{ C.L.})$$

$B_s \to J/\psi\ \varphi$ checks

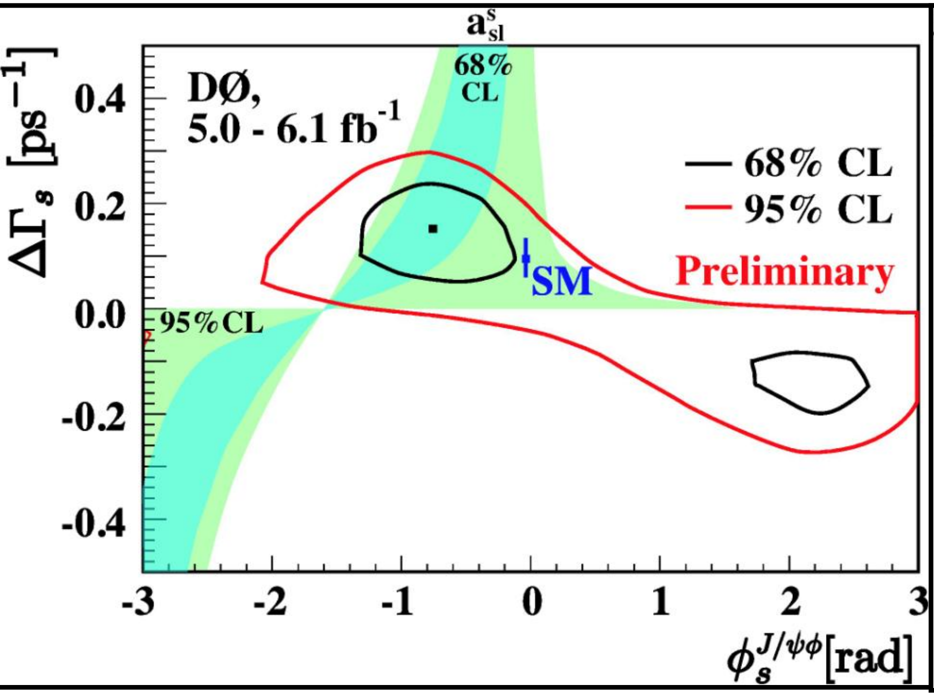
- Ensemble of toy MC samples generated
  - Check of biases due to the fitting procedure
  - Check of uncertainties
  - Determine adjustment for correct statistical coverage of CL regions
  - Impact of external systematic uncertainties

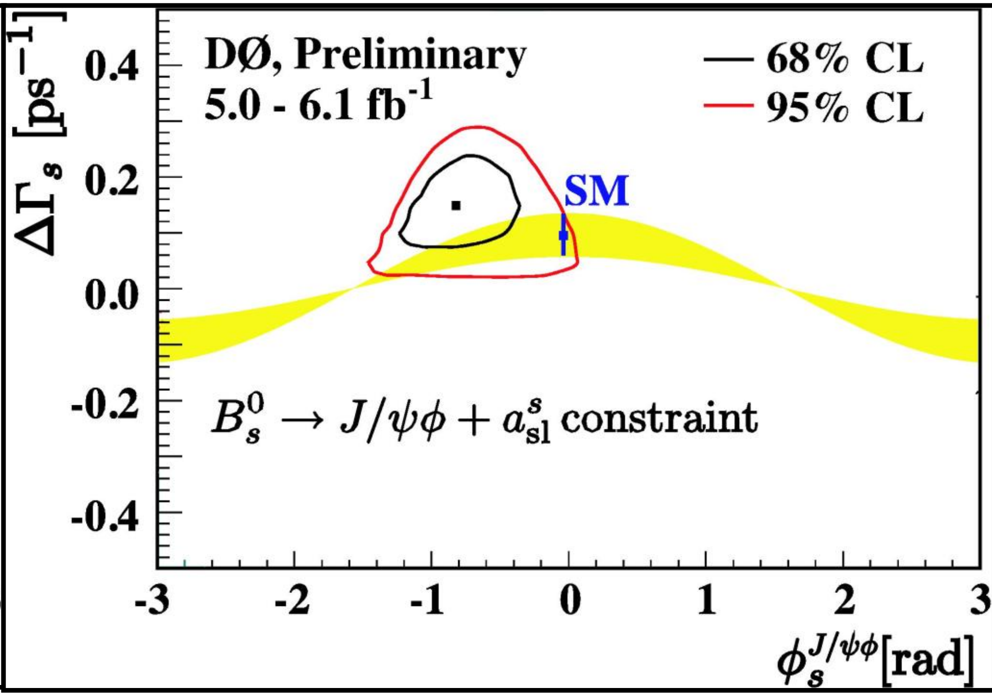


Combination of DØ results

- $B_s \to J/\psi\ \varphi$
- A^b_{sl}
- a^s_{sl} from $B_s \to D_s \mu \nu$
- p-value at SM point is 7.5%

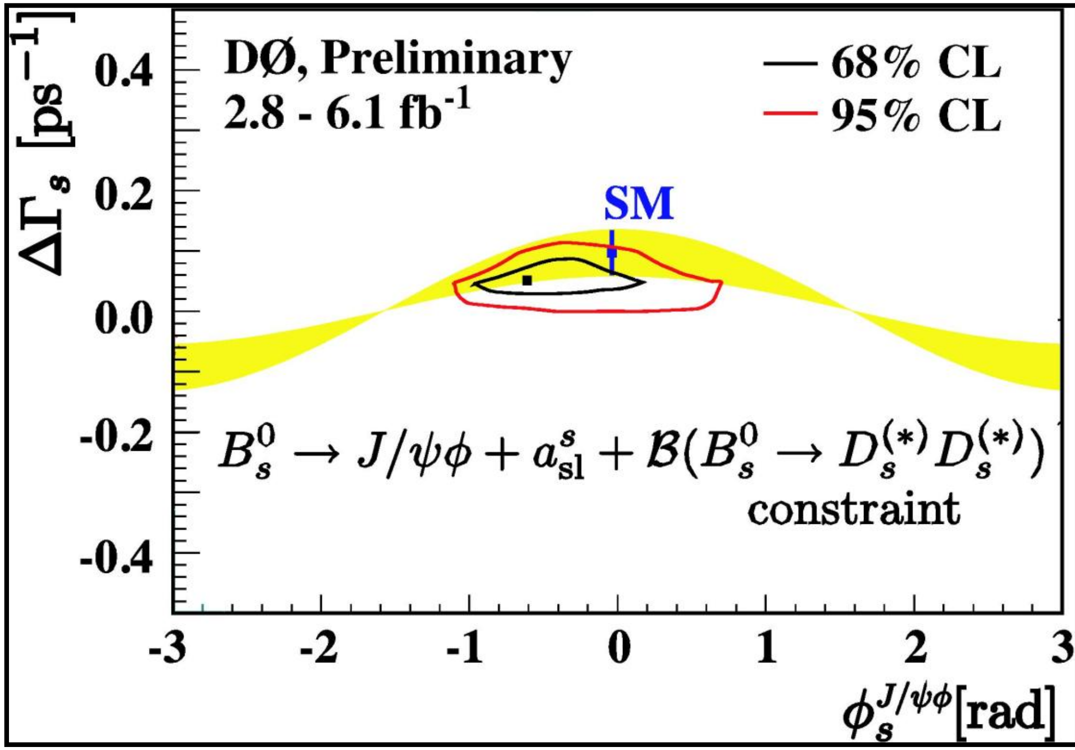
$$a^s_{sl} = (-1.00 \pm 0.59)\%\ \ (D0)$$





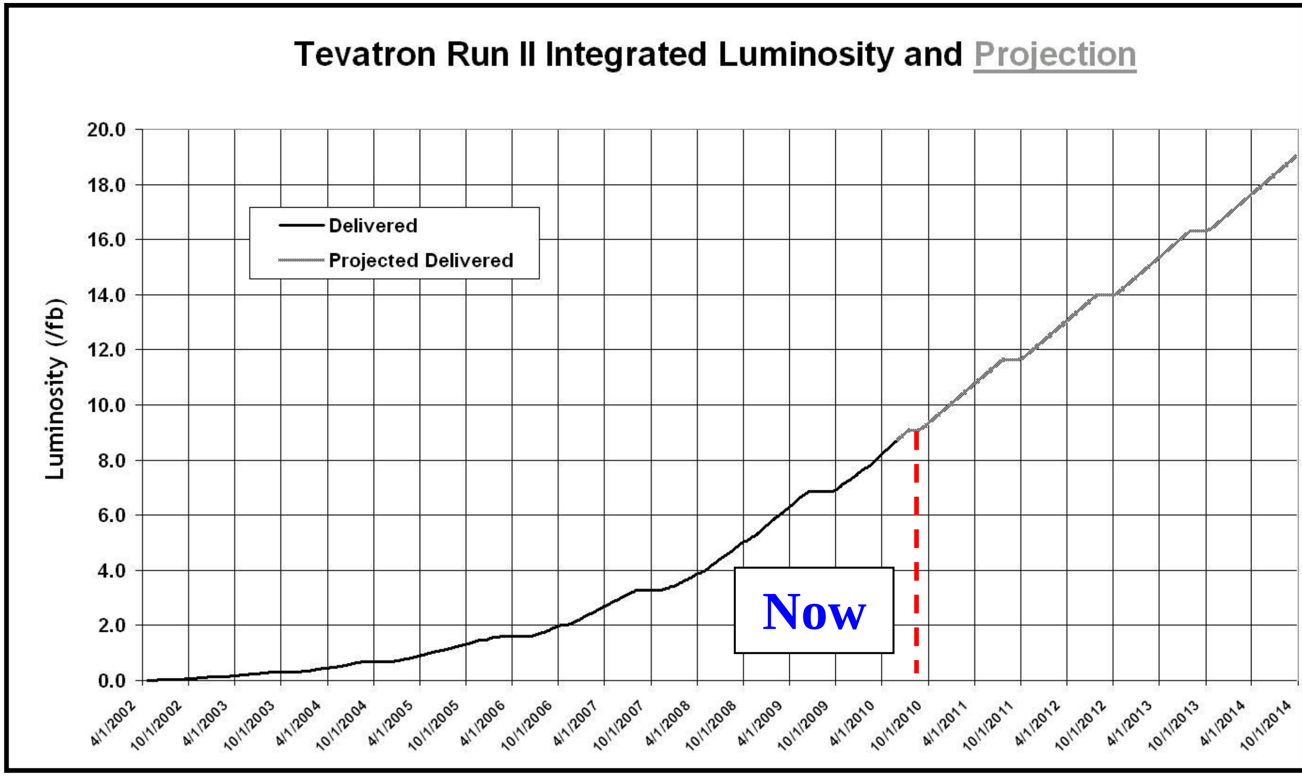
Combination of DØ results

- $B_s \to J/\psi\ \varphi$
- A^b_{sl}
- a^s_{sl} from $B_s \to D_s \mu \nu$
- $\Delta\Gamma_s^{CP}$ from $B_s \to D_s^{(*)+} D_s^{(*)-}$
  - $D_s^{(*)+} D_s^{(*)-}$ is mainly CP-even and $\mathrm{Br}(B_s \to D_s^{(*)+} D_s^{(*)-})$ is proportional to $\Delta\Gamma_s^{CP}$
- p-value of SM point is 6%



Not the final word yet

- Tevatron experiments now collect >2 fb^{-1} / year
- By the end of 2011 run, the statistics of all measurements will be almost doubled
- Uncertainties of all measurements are statistically dominated



Tevatron experiments have excellent prospects to make a strong statement on the contribution of new physics in *B* decays

DØ plans and prospects

- More statistics is already available
  - 8 fb^{-1} already collected
  - 10 fb^{-1} expected by the end of 2011 run
- Update of all measurements with increased statistics
- Improvement of analysis in $B_s \to J/\psi\ \varphi$ and A^b_{sl}
- Study of lifetime dependence of A^b_{sl}
- Measure semileptonic charge asymmetry of B_d

Conclusions

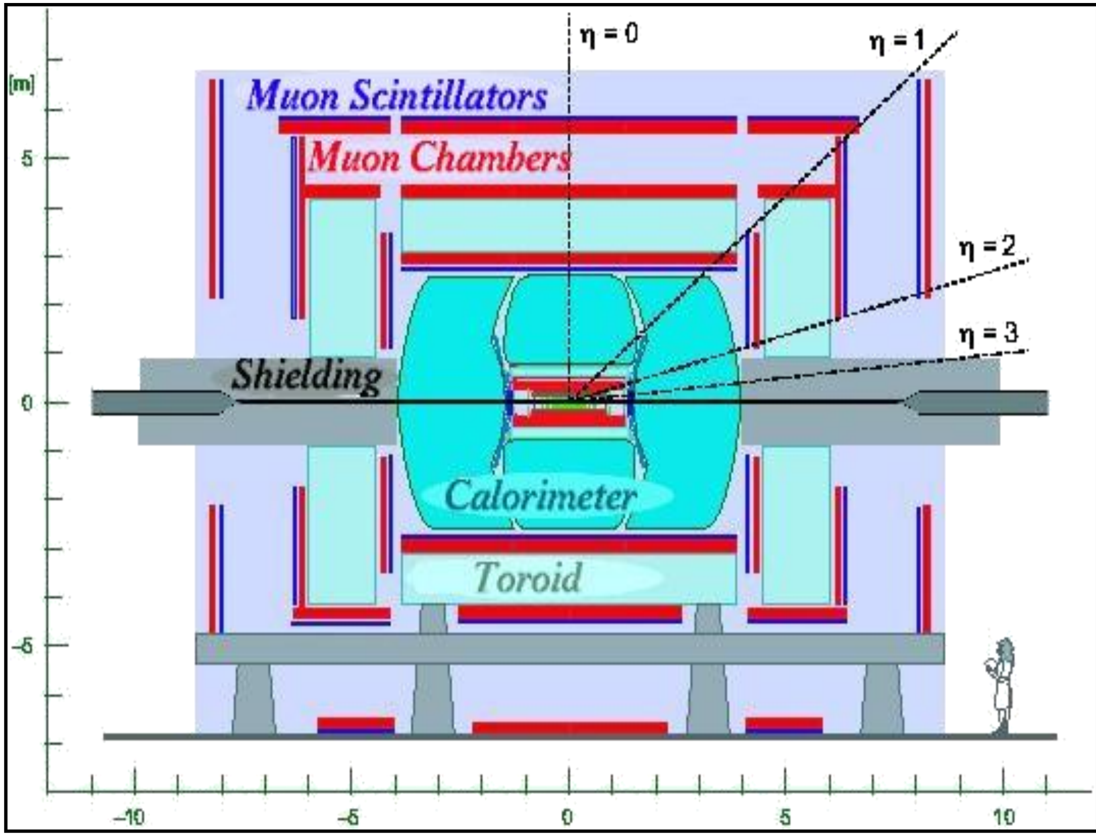
- DØ collaboration performs extensive study of CP violation in B_s system;
- Unique measurement of the B_s semileptonic charge asymmetry a^s_{sl} consistent with the SM;
- Evidence for an anomalous dimuon charge asymmetry asymmetry A^b_{sl} at 3.2σ
- New results in $B_s \to J/\psi\ \varphi$ demonstrate a better consistency with the SM
- All results are consistent with A^b_{sl} measurement
- Combination of all DØ results for B_s system gives *p*-value = 6.0% of the SM
- Excellent prospects for the future improvement of precision

Backup slides

DØ Detector

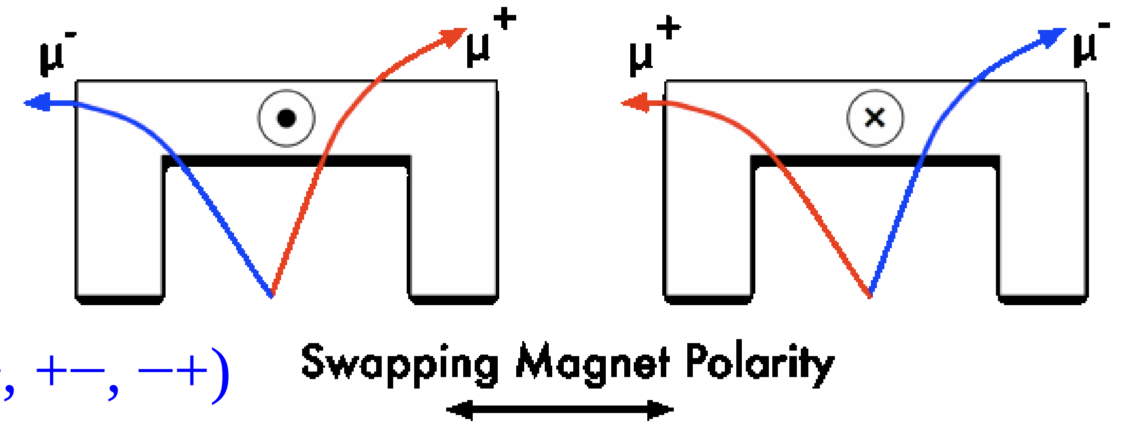
Key elements for B-physics:

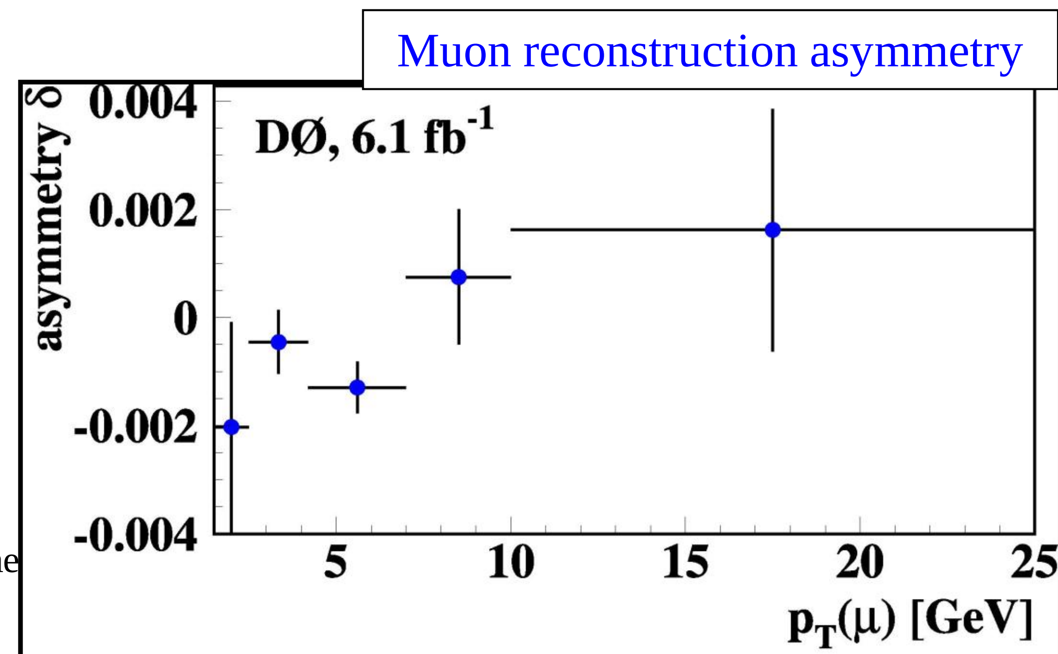
- Muon system;
- Muon trigger;
- Solenoid + Toroid;
- Polarities of magnets are regularly reversed;
- Tracking with precise vertex detector;
- Wide acceptance up to $|\eta|<2$;



Original experimental technique

- Polarities of DØ solenoid and toroid are reversed every ~2 weeks
- 4 equal sized samples with different polarities (++, −−, +−, −+)
- difference in reconstruction efficiency between positive and negative particles minimized
- Reconstruction asymmetries reduced from ~1% to <0.1%
  - To be compared with raw dimuon asymmetry A= (0.564 0.053)%



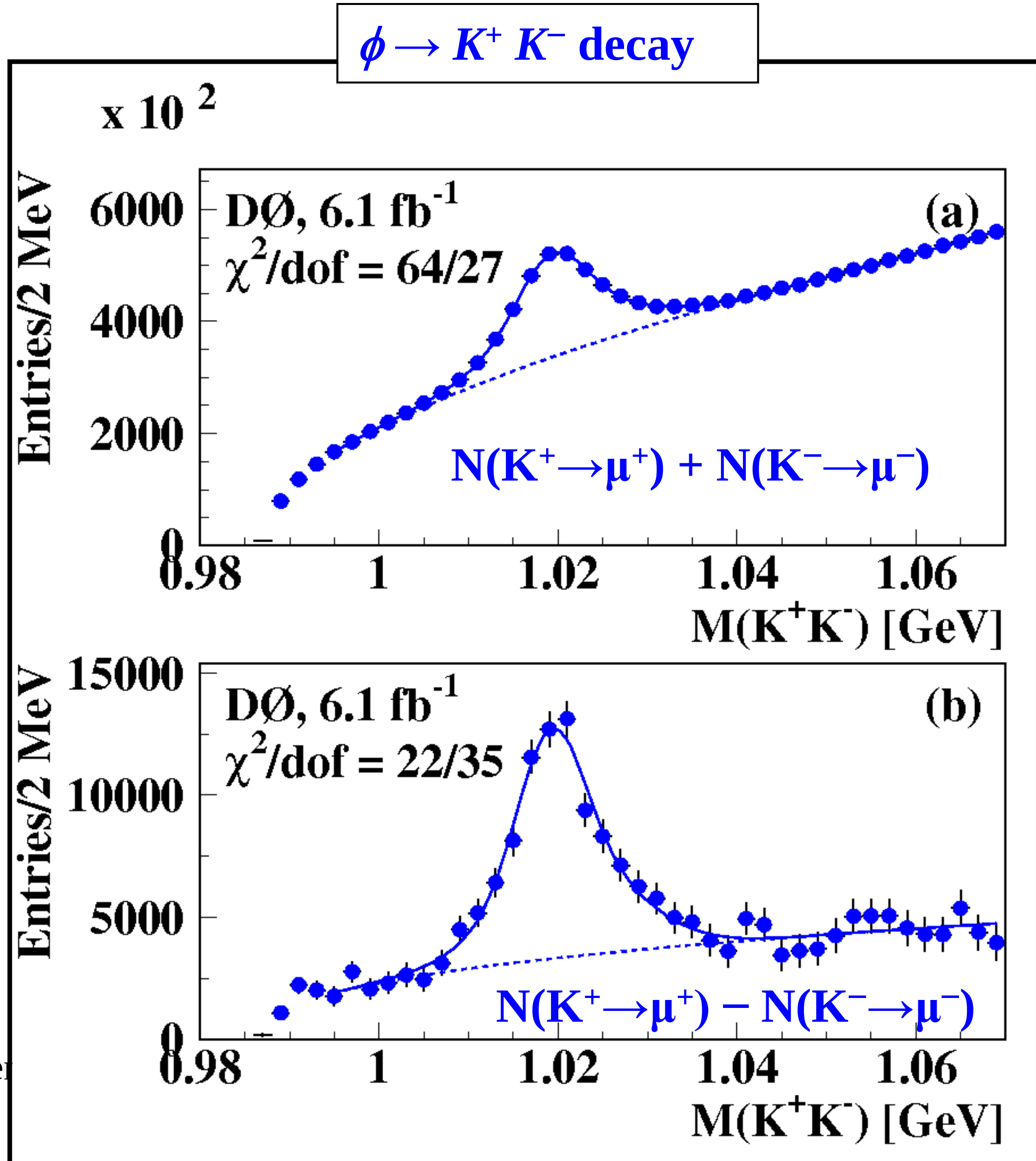


Measurement of kaon asymmetry

- Define sources of kaons:

$$K^{*0} \rightarrow K^+ \pi^-$$
$$\phi(1020) \rightarrow K^+ K^-$$

- Require that the kaon is identified as a muon
- Build the mass distribution separately for positive and negative kaons
- Compute asymmetry in the number of observed events



Measurement of kaon asymmetry

$$a_{bkg} = f_k a_k + f_\pi a_\pi + f_p a_p + (1 - f_{bkg})\delta$$

$$A_{bkg} = F_k A_k + F_\pi A_\pi + F_p A_p + (2 - F_{bkg})\Delta$$

- Results from $K^{*0} \to K^+\pi^-$ and $\phi(1020) \to K^+K^-$ agree well
  - For the difference between two channels: $\chi^2/\mathrm{dof} = 5.4 / 5$
- We combine the two channels together: