Anomalous like-sign dimuon charge asymmetry

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Last year result

- DØ Collaboration reported last year the evidence of anomalous like-sign dimuon charge asymmetry using 6.1 fb^{-1} of data

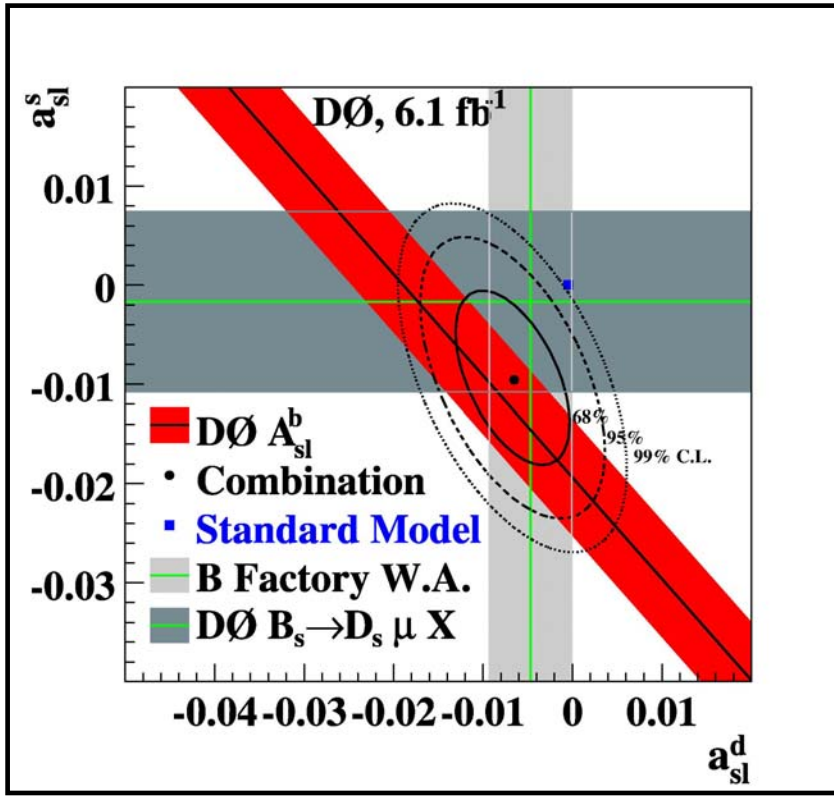
$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

  - N_b^{++}, N_b^{--} – number of events with two b hadrons decaying semileptonically and producing two muons of the same charge

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

$$A_{sl}^{b}(SM) = (-0.023^{+0.005}_{-0.006})\%$$

- Differs from SM prediction by 3.2σ



- Result can also be presented in terms of semileptonic charge asymmetries of B^0 and B^0_s mesons: a^d_{sl} and a^s_{sl}

Main features of measurement

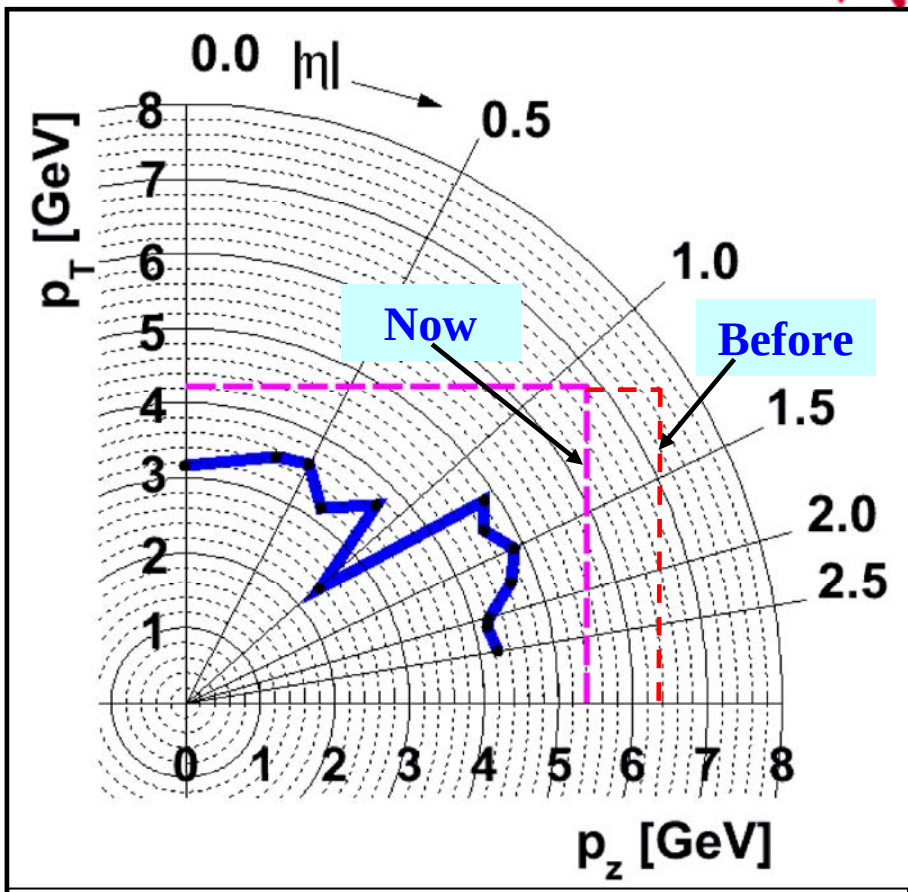
- Measure raw like-sign dimuon charge asymmetry A and raw inclusive muon charge asymmetry a :

$$A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \qquad a \equiv \frac{n^{+} - n^{-}}{n^{+} + n^{-}}$$

  - N^{++}, N^{--} – the number of events with two like-sign dimuons
  - n^{+}, n^{-} – the number of muons with given charge
- Background (i.e., non-CP violating charge asymmetry, mainly produced by $\pi \rightarrow \mu$ and $K \rightarrow \mu$ decays) is measured directly in data
- Raw asymmetry a is determined mainly by the background contribution and is used to constraint the background and reduce systematic uncertainties
- Raw asymmetry A contains both the background and possible signal contribution and is used to measure A^{b}_{sl}

Updated measurement

- In this updated measurement:
  - Increased statistics 6.1fb^{-1} → 9.0 fb^{-1}
  - Improved muon selection
    - 13% increase of statistics for the same integrated luminosity
    - 20% reduction of background from K→μ, π→μ decays
  - Improved analysis technique
  - Study dependence of asymmetry on muon impact parameter



Cut on muon $|p_z|$ changed from 6.4 to 5.4 GeV (shown as a dashed lines). Smallest muon momentum required for detection by the muon system (solid line).

New result

- We get for 9.0 fb^{-1}:

$$A_{sl}^{b} = (-0.787 \pm 0.172\,(\text{stat}) \pm 0.093\,(\text{syst}))\%$$

- Consistent with our previous measurement with 6.1 fb^{-1}
- Deviates from the SM prediction by 3.9 σ

a^d_{sl} and a^s_{sl} contributions

- Asymmetry A^b_{sl} is a linear combination of a^d_{sl} and a^s_{sl} – semileptonic charge asymmetries of B^0 and B^0_s

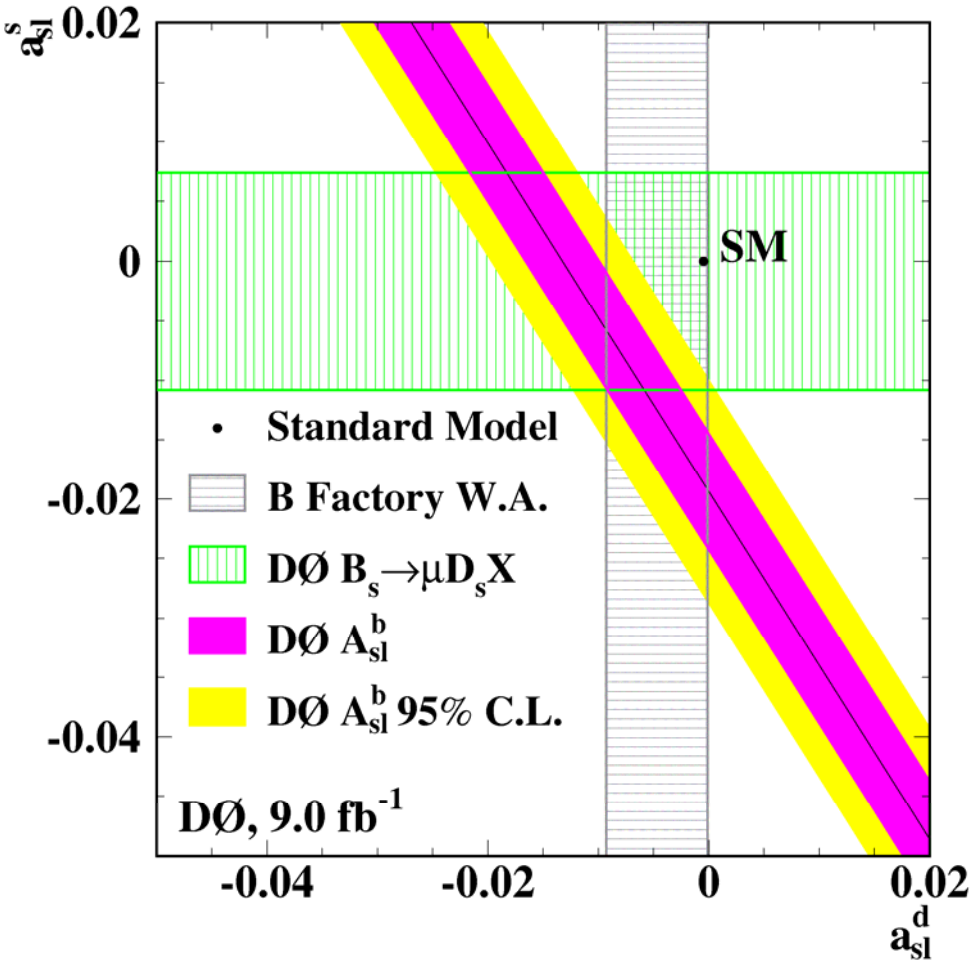
$$A^b_{sl} = C_d a^d_{sl} + C_s a^s_{sl}$$

- Coefficients C_d and C_s depend on mean mixing probability and the production fractions of B^0 and B^0_s mesons, respectively
- We use the values of B^0 and B^0_s fractions measured at LEP and averaged by HFAG
  - Measurements of production fractions at LEP are consistent with the values obtained at LHCb

$$C_d = 0.594 \pm 0.022$$
$$C_s = 0.406 \pm 0.022$$

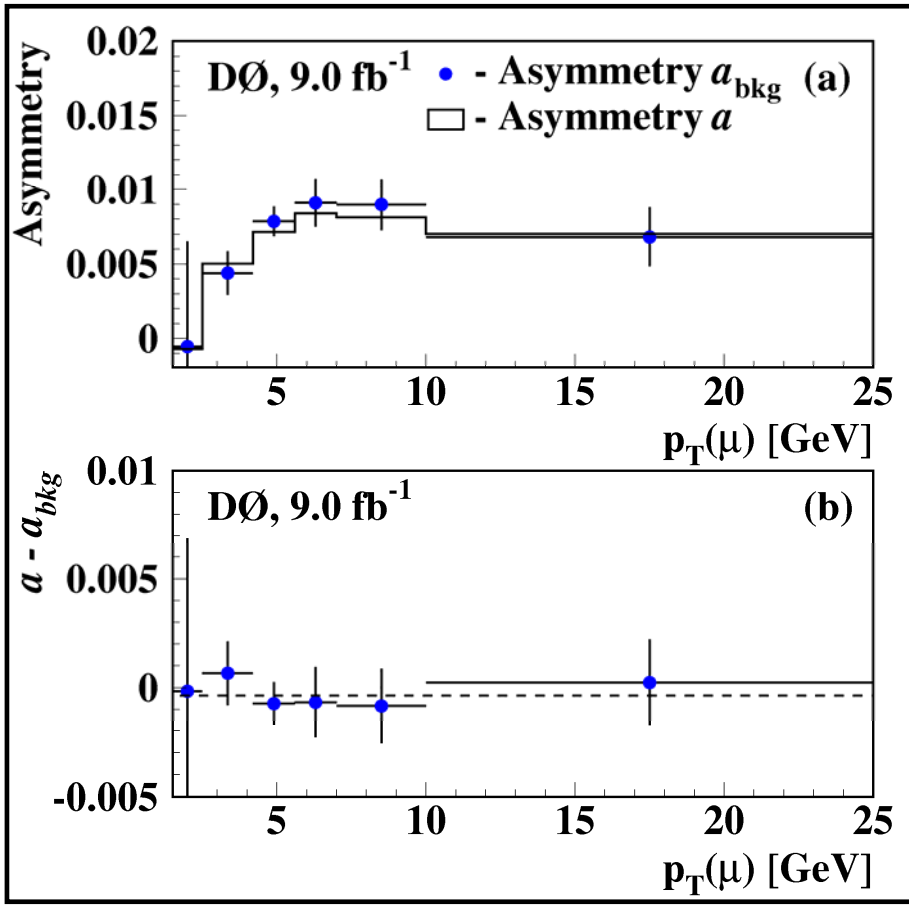
a^d_{sl} and a^s_{sl} contributions

- New constraint in a^d_{sl} versus a^s_{sl} plane
- Result is consistent with other measurements of a^d_{sl} and a^s_{sl}



Closure test

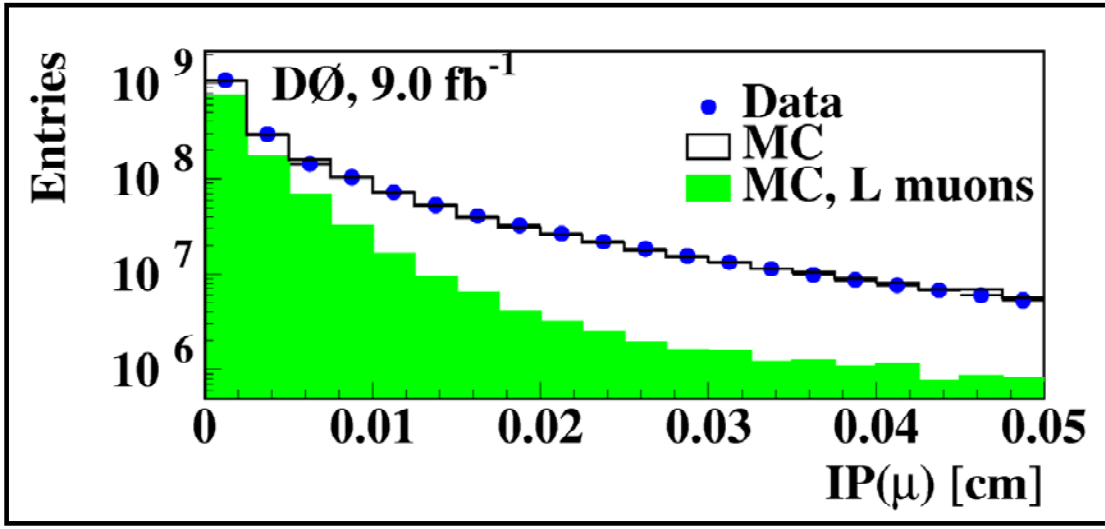
- The raw inclusive muon charge asymmetry a is mainly determined by the background asymmetry a_{bkg}
- The contribution of A^b_{sl} in a is suppressed by factor $k = 0.031 \pm 0.003$
- We measure a_{bkg} in data, and we can verify how does it describe the observed raw asymmetry a
- We compare a and a_{bkg} as a function of muon p_T
- We get $\chi^2/\text{dof} = 0.8/6$ for the difference between these two distributions



Excellent agreement between the expected and observed values of a , including a p_T dependence

Dependence on muon impact parameter

- Muons from $\pi \rightarrow \mu$ and $K \rightarrow \mu$ have small impact parameter (IP)
  - When the decay is outside the tracking volume
  - Hadrons mainly come from primary interaction



- Muons from B decays have large impact parameter
- To test the origin of dimuon charge asymmetry we perform two complimentary measurements requiring
  - IP > 120 μm for both muons
  - IP < 120 μm for both muons

a^d_{sl} and a^s_{sl} contributions

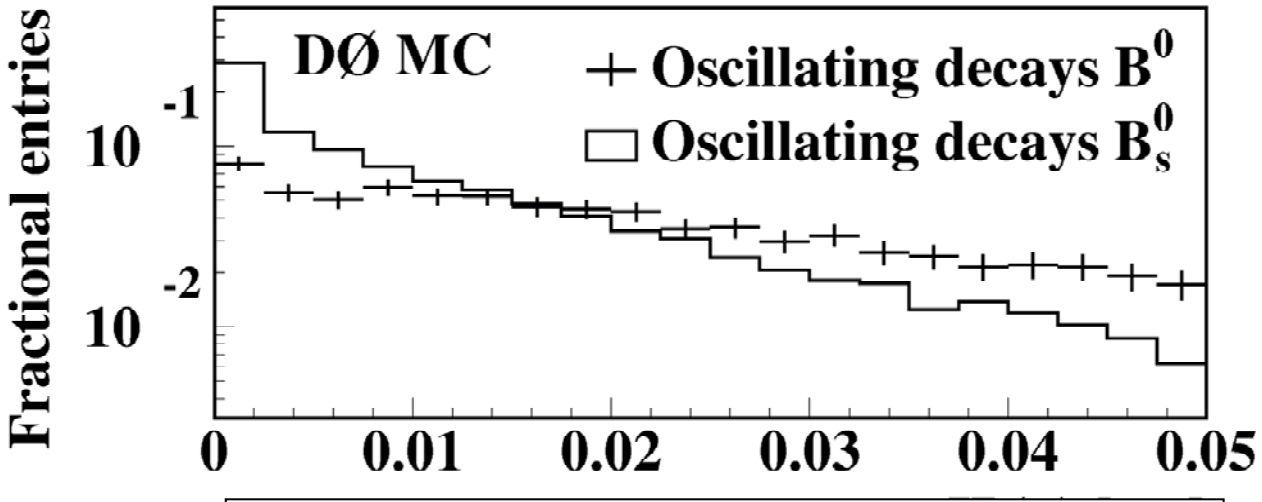
- The contributions of a^d_{sl} and a^s_{sl} in A^b_{sl} changes significantly when we select muons with IP above or below given threshold:

$$\text{for IP} > 120\ \mu\text{m} \quad A^b_{sl} = (0.728 \pm 0.018) a^d_{sl} + (0.272 \pm 0.018) a^s_{sl}$$
$$\text{for IP} < 120\ \mu\text{m} \quad A^b_{sl} = (0.397 \pm 0.022) a^d_{sl} + (0.603 \pm 0.022) a^s_{sl}$$

- These contributions are determined by the mean mixing probability of B^0 and B^0_s in the selected sample

a^d_{sl} and a^s_{sl} contributions

- Mean mixing probability of B^0 increases in the subsample of events with IP > 120 μm
  - Period of B^0 oscillation $2\pi/\Delta M_d$ is much larger than its lifetime, therefore muons with small impact parameter (IP < 120 μm) are dominantly produced by non-oscillating decays of B^0
  - Selecting events with IP>120 μm we increase the fraction of oscillating B^0
  - Fraction of oscillating B^0_s mesons does not change for IP>120 μm because of small period of B^0_s oscillation



Normalized IP distribution for muons produced in oscillating decays of B^0 and B^0_s

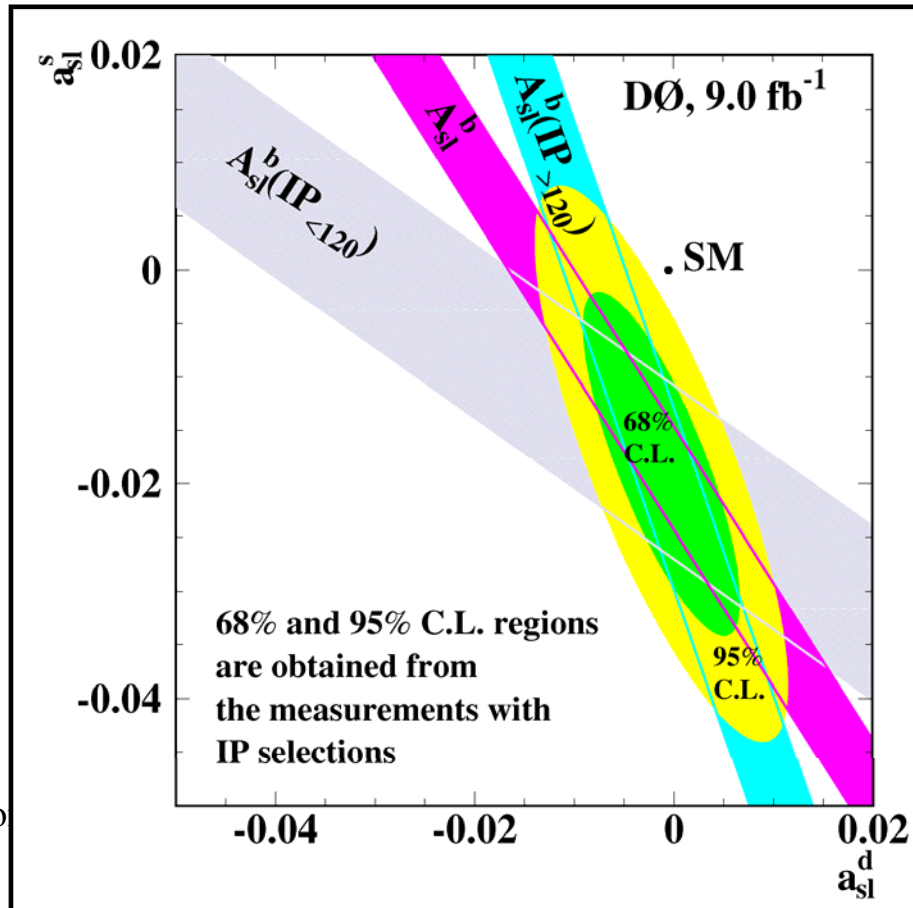
Results with IP cuts

- We obtain:

$$\text{for IP} > 120\ \mu\text{m} \quad A_{sl}^{b} = (-0.579 \pm 0.210 \pm 0.094)\%$$
$$\text{for IP} < 120\ \mu\text{m} \quad A_{sl}^{b} = (-1.14\ \pm 0.37\ \ \pm 0.32\ \ )\%$$

- From these results we get the separate values of a^{d}_{sl} and a^{s}_{sl}:

$$a_{sl}^{d} = (-0.12 \pm 0.52)\%$$
$$a_{sl}^{s} = (-1.81 \pm 1.06)\%$$



Conclusions

- New measurement of dimuon charge asymmetry is performed

$$A_{sl}^{b} = (-0.787 \pm 0.172\,(\text{stat}) \pm 0.093\,(\text{syst}))\%$$

- This result deviates from the SM prediction by 3.9σ
- Dependence of charge asymmetry on muon impact parameter tested

$$\text{for IP} > 120\ \mu\text{m} \quad A_{sl}^{b} = (-0.579 \pm 0.210 \pm 0.094)\%$$
$$\text{for IP} < 120\ \mu\text{m} \quad A_{sl}^{b} = (-1.14 \pm 0.37 \pm 0.32)\%$$

- From IP study we obtain the measurement of a^{d}_{sl} and a^{s}_{sl} :

$$a_{sl}^{d} = (-0.12 \pm 0.52)\%$$
$$a_{sl}^{s} = (-1.81 \pm 1.06)\%$$

- Result is consistent with the hypothesis that the dimuon charge asymmetry is produced in semileptonic B decays

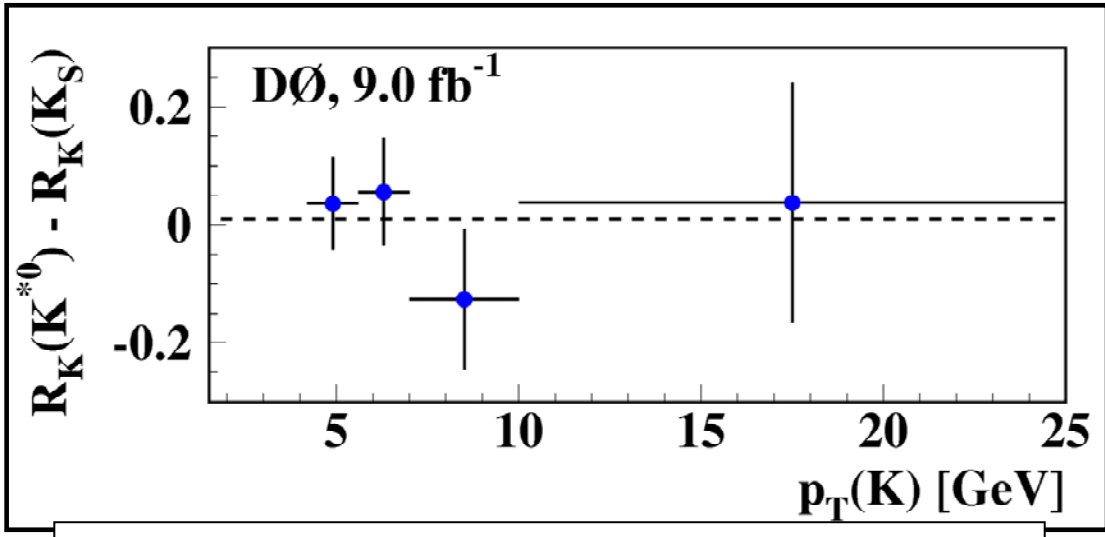
Backup slides

Improved analysis technique

- Main background comes from K→μ decays
- The most important quantity is $R_K=F_K/f_K$ – ratio of the fractions of $K\to\mu$ in the like-sign dimuon and inclusive muon samples
- Previously determined by measuring production of $K^{*0}\to K^+\pi^-$ decays with $K\to\mu$ in the like-sign dimuon and inclusive muon samples
- Perform a complementary measurement using the production of $K_S\to\pi^+\pi^-$ with $\pi\to\mu$
- Results in both channels are consistent

$$\Delta R_K = 0.01 \pm 0.05$$

- Important confirmation of the validity of F_K/f_K measurement



Difference between R_K values measured using K^{*0} and K_S events

Consistency checks

- Repeat closure test in bins of $|\eta|$
  - $\chi^2/\text{dof} = 2.8/4$
- Dependence of the dimuon asymmetry on the dimuon mass
  - Good consistency of predicted and observed asymmetry for measured A^b_{sl}
  - Significant disagreement for $A^b_{sl}=A^b_{sl}(SM)$