Evidence for Anomalous Dimuon Charge Asymmetry at D-Zero

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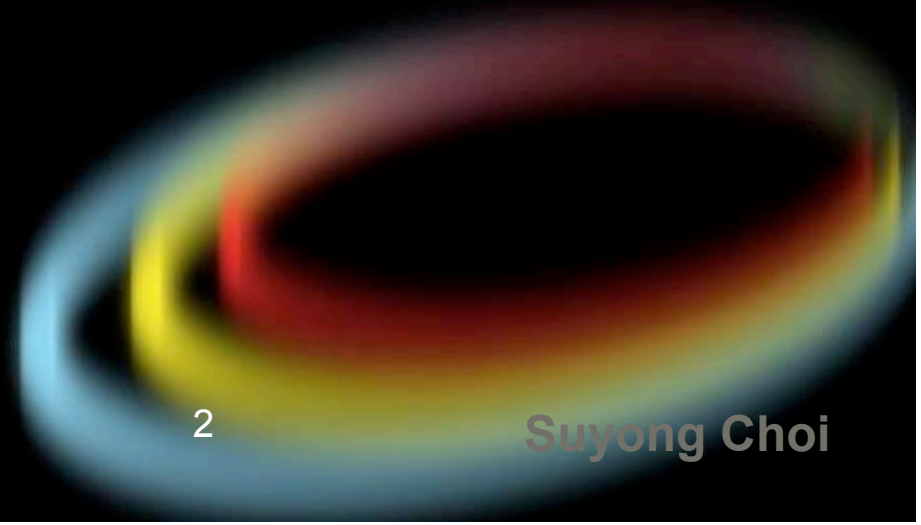
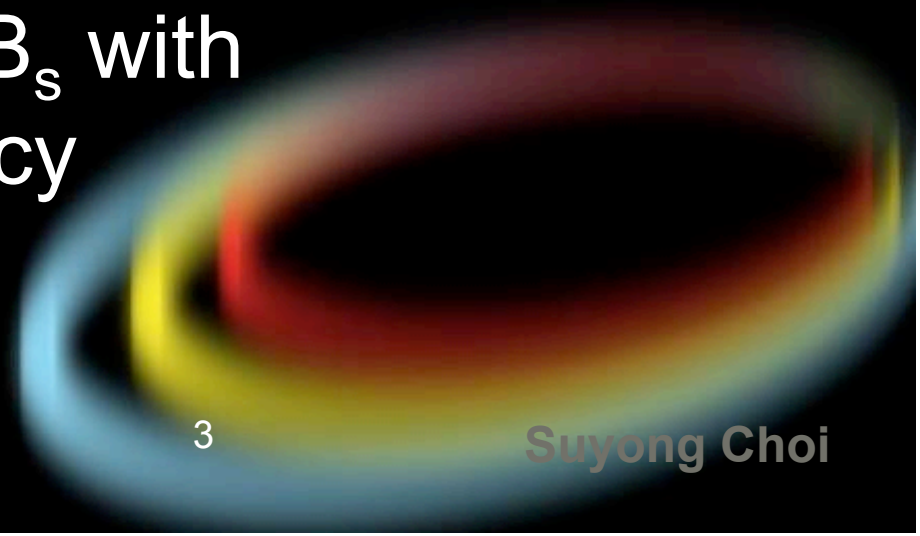


Introduction

- CP violation in B_s is sensitive to new physics
  - SM contribution is suppressed
  - Hadronic uncertainties under control
- Tevatron data probes B_s with unprecedented accuracy



Relationship Between Parameters in B_s System

$$\Delta M_s = M_H - M_L = 2\left|M_{12}\right|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H = 2\left|\Gamma_{12}\right|\cos\left(\phi_s\right)$$

$$\phi_s = \arg\left[-\frac{M_{12}}{\Gamma_{12}}\right] = 0.0042 \pm 0.0014 \quad \text{(in SM)}$$

- With new physics contributions:

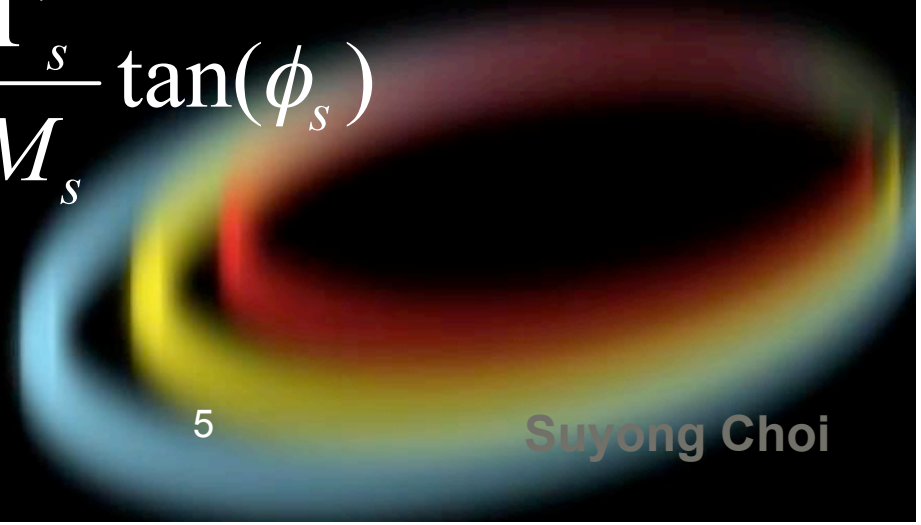
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

Semilepton Asymmetry

- Wrong-sign semileptonic decay

$$a_{sl}^{s} = \frac{N\left(\bar{B}_s^0 \to \ell^+ + X\right) - N\left(B_s^0 \to \ell^- + X\right)}{N\left(\bar{B}_s^0 \to \ell^+ + X\right) + N\left(B_s^0 \to \ell^- + X\right)}$$

$$= \frac{|\Gamma_{12}|}{|M_{12}|}\sin(\phi_s) = \frac{\Delta\Gamma_s}{\Delta M_s}\tan(\phi_s)$$



2008 HFAG Averages

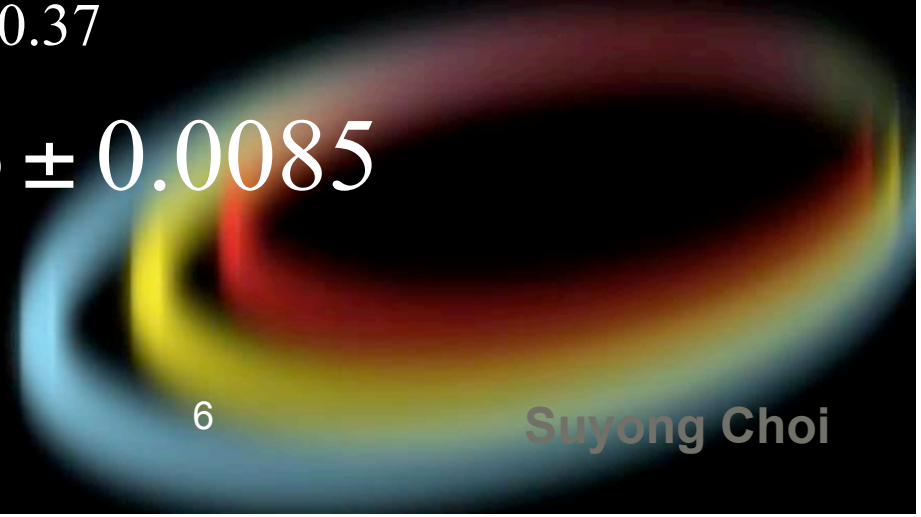
- arXiv:0808.1297

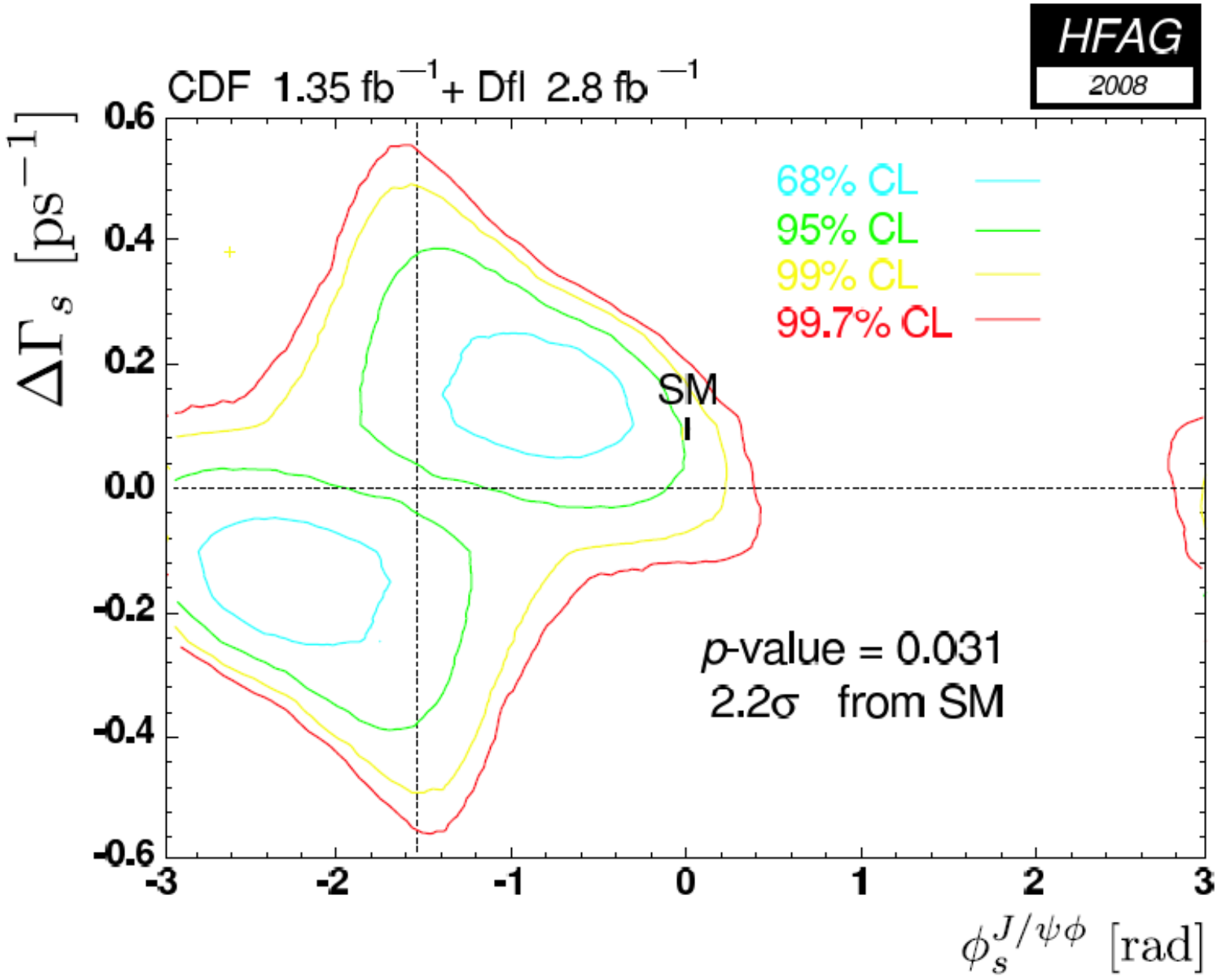
$$\Delta M_s = 17.78 \pm 0.12\ ps^{-1}$$

$$\Delta\Gamma_s = 0.154^{+0.054}_{-0.070}\ ps^{-1}$$

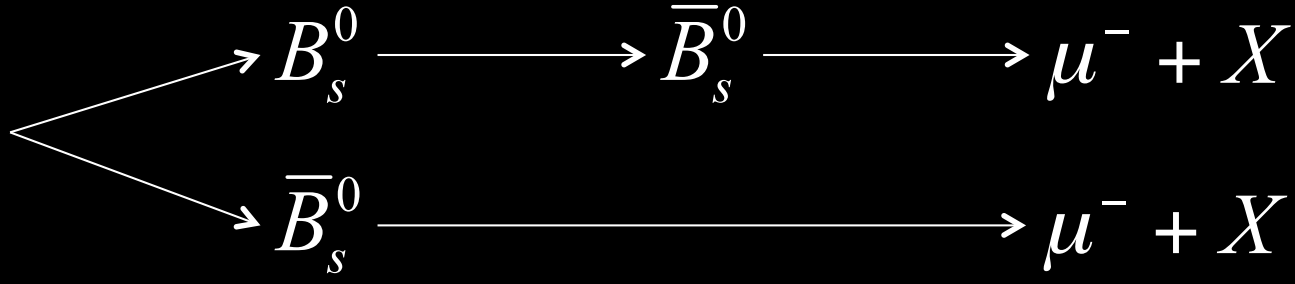
$$\phi_s = -0.77^{+0.29}_{-0.37}$$

$$a^s_{sl} = 0.0016 \pm 0.0085$$




HFAG
2008
CDF 1.35 fb^{-1} + DfI 2.8 fb^{-1}
68% CL
95% CL
99% CL
99.7% CL
SM
p-value = 0.031
2.2σ from SM
$\Delta\Gamma_s$ [ps^{-1}]
$\phi_s^{J/\psi\phi}$ [rad]
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-3
-2
-1
0
1
2
3

Dimuon Asymmetry



- Source of like-sign leptons Flavor oscillation
  - Non-zero value of charge asymmetry indicates CP violation

Dimuon Asymmetry

- Dimuon asymmetry $A_{sl}^{b} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$

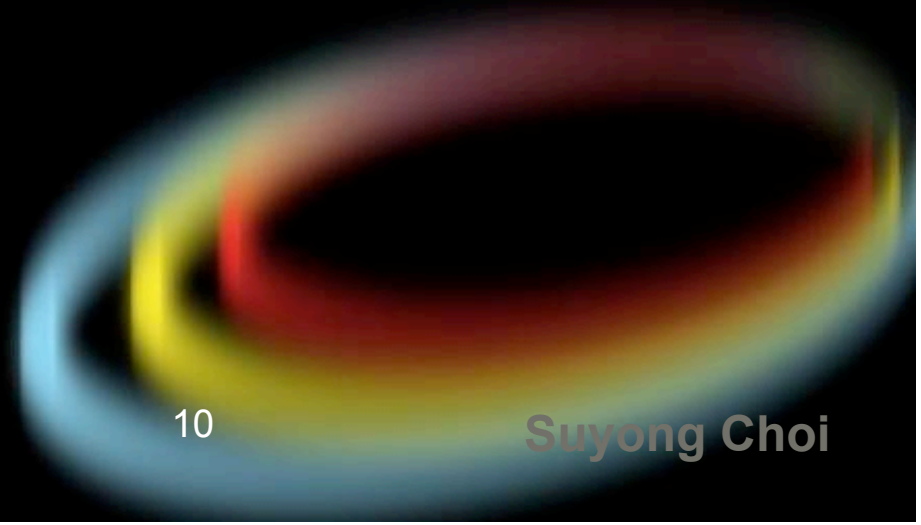
- At the Tevatron, prediction

$$A_{sl}^{b} = \beta_d a_{sl}^{d} + \beta_s a_{sl}^{s}$$

$$= \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4}$$

Dimuon Asymmetry and wrong sign decay asymmetry

$$a_{sl}^{s} = \frac{\Gamma(\overline{B}_s^0 \to \mu^+ X) - \Gamma(B_s^0 \to \mu^- X)}{\Gamma(\overline{B}_s^0 \to \mu^+ X) + \Gamma(B_s^0 \to \mu^- X)} = A_{sl}^{s}$$

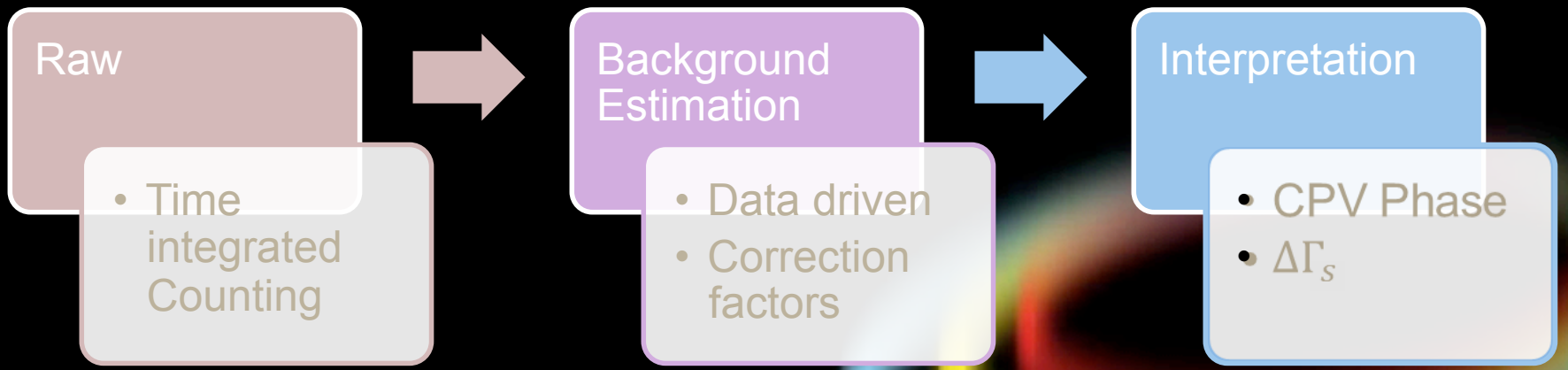


MEASUREMENT OF DIMUON ASYMMETRY AT D-ZERO

Measurement Strategy

- Asymmetries

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

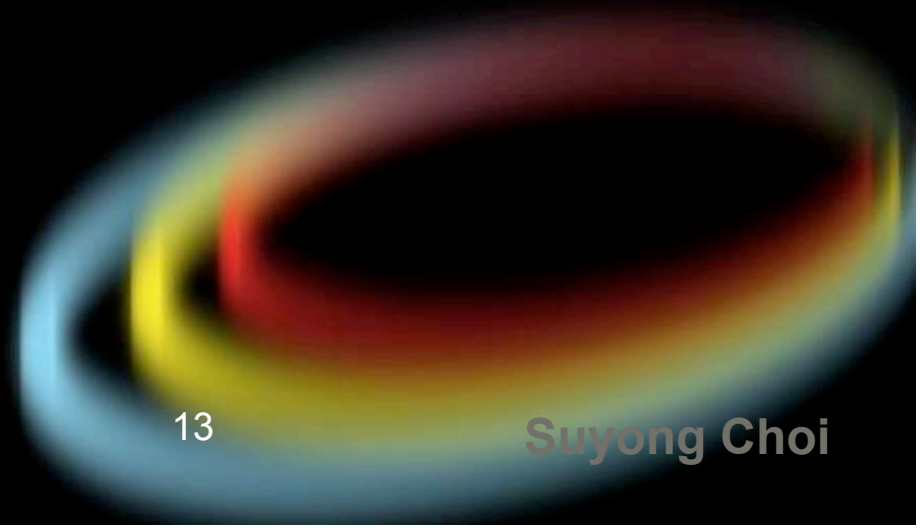


Muons

- Inclusive muons vs same-sign dimuon

	Inclusive sample	Dimuon sample
Sample size	Large	Small
Backgrounds	Large	Small
Dilution	Large	Small

  - Biases
  - Correction



Asymmetry Observables

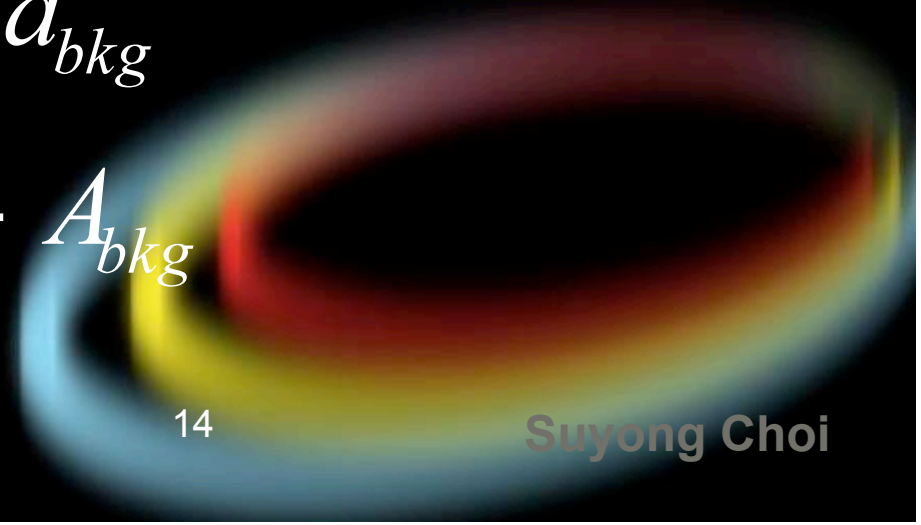
- In the absence of backgrounds

$$a = A = A_{sl}^{b}$$

- With backgrounds

$$a = kA_{sl}^{b} + a_{bkg}$$

$$A = KA_{sl}^{b} + A_{bkg}$$

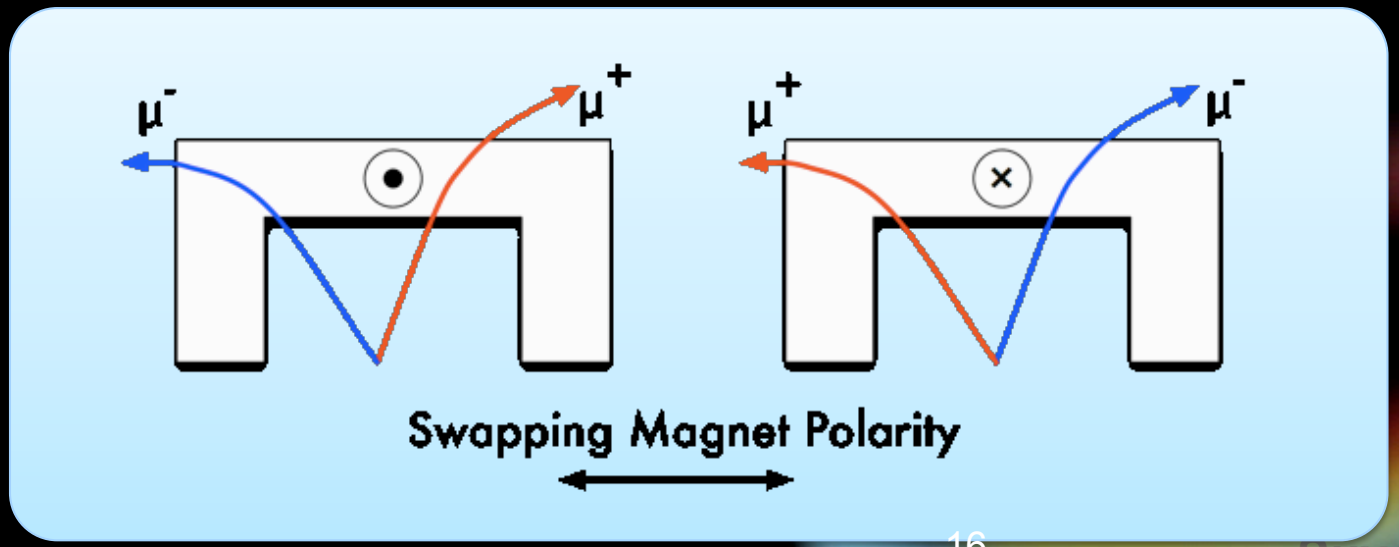


Backgrounds

- Asymmetry of μ+ and μ- reconstruction
- Muons from $K^{\pm} \rightarrow \mu^{\pm} + X$, $\pi^{\pm} \rightarrow \mu^{\pm} + X$
- Punchthroughs of p,K,π can look like muons
  - Different interactions between + and – charged particles
- False association of charged track to muon system hits
- Backgrounds contribute to both A and a
  - A and a have correlated systematic errors

Data

- 6.1 fb-1 of D-Zero detector
  - Solenoid and Toroid magnetic field reversed regularly
  - Difference in reconstruction between μ+ and μ- minimized



Raw Asymmetries

- Sample size
  - 1.4 x 10^9 inclusive muon events
  - 3.7 x 10^6 like-sign dimuon events

- Raw asymmetries

$$a_{raw} = (+0.955 \pm 0.003)\%$$

$$A_{raw} = (+0.564 \pm 0.053)\%$$

Background Contribution a_{bkg}

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

- a_i – charge asymmetry of particle i
- f_i – fraction of particle i mis-ided as muon in inclusive muon sample
- δ - charge asymmetry of μ reconstruction

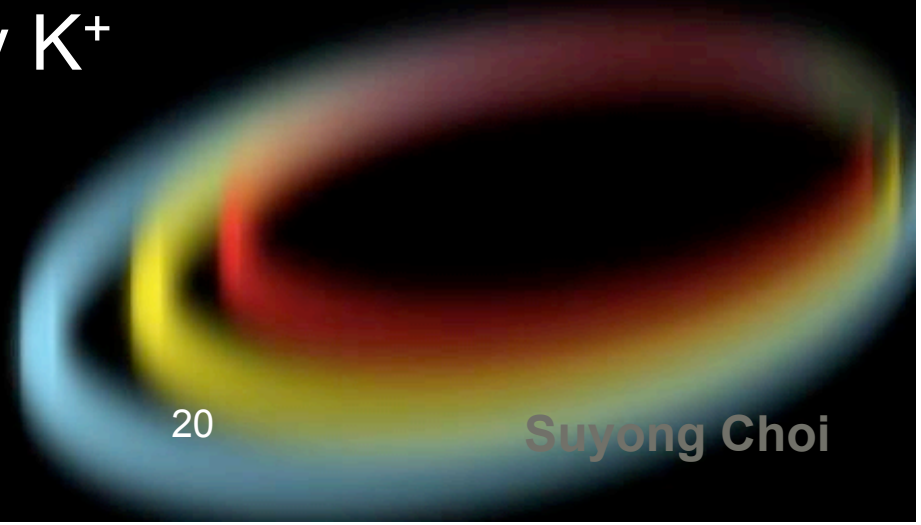
Background Contribution A_{bkg}

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

- $f_i \neq F_i$
- $a_i \neq A_i$

Kaon Charge Asymmetry

- Most of the background contribution comes from Kaons
- K^+ travels further than K^- :
  - K^- can interact to produce strange baryons
  - more punchthroughs by K^+
- We expect A_k, $a_k > 0$



Measuring A_K and a_K

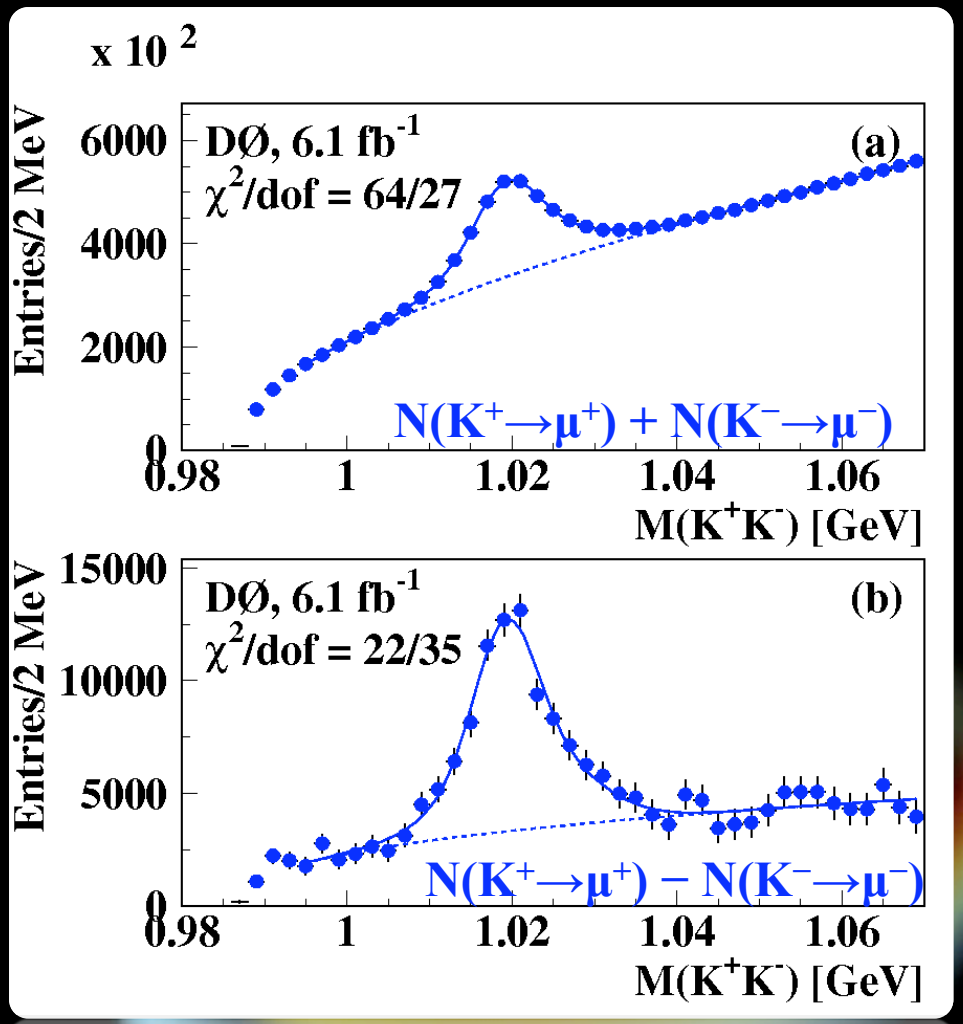
- Use Kaons from

$$K^{*0} \rightarrow K^{+}\pi^{-}$$

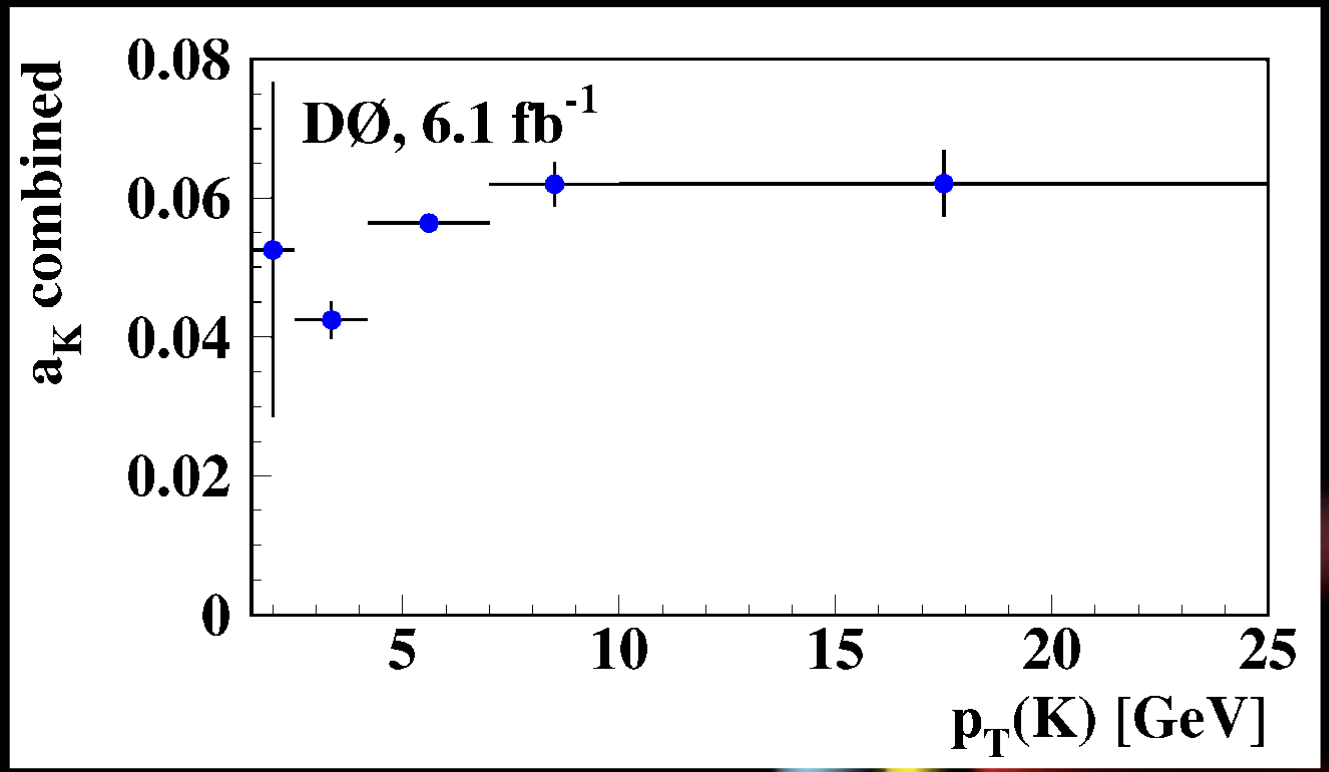
$$\varphi(1020) \rightarrow K^{+}K^{-}$$

  - Require that K is identified as a muon

- a_k from both samples agree

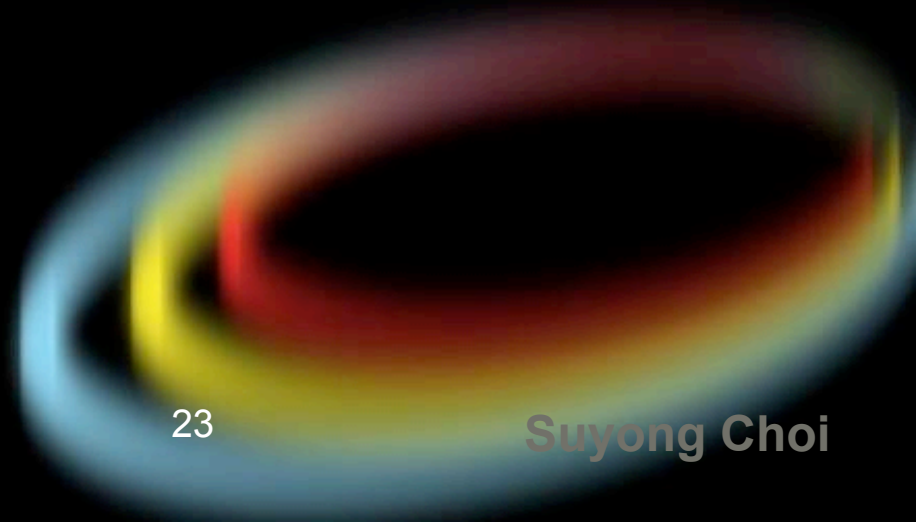


Kaon charge asymmetry



Asymmetry due to Backgrounds

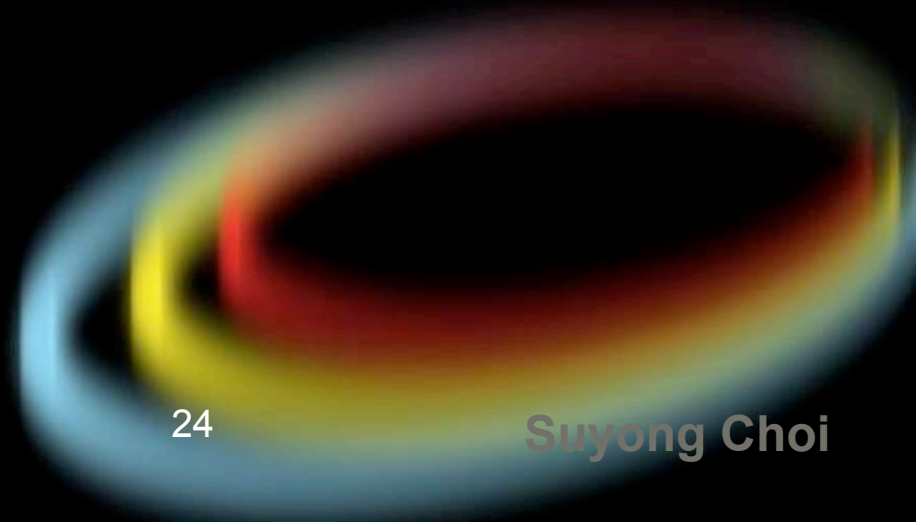
	a_K	a_π	a_p
Data	(+5.51 ± 0.11)%	(+0.25 ± 0.10)%	(+2.3 ± 2.8)%



Background Rates

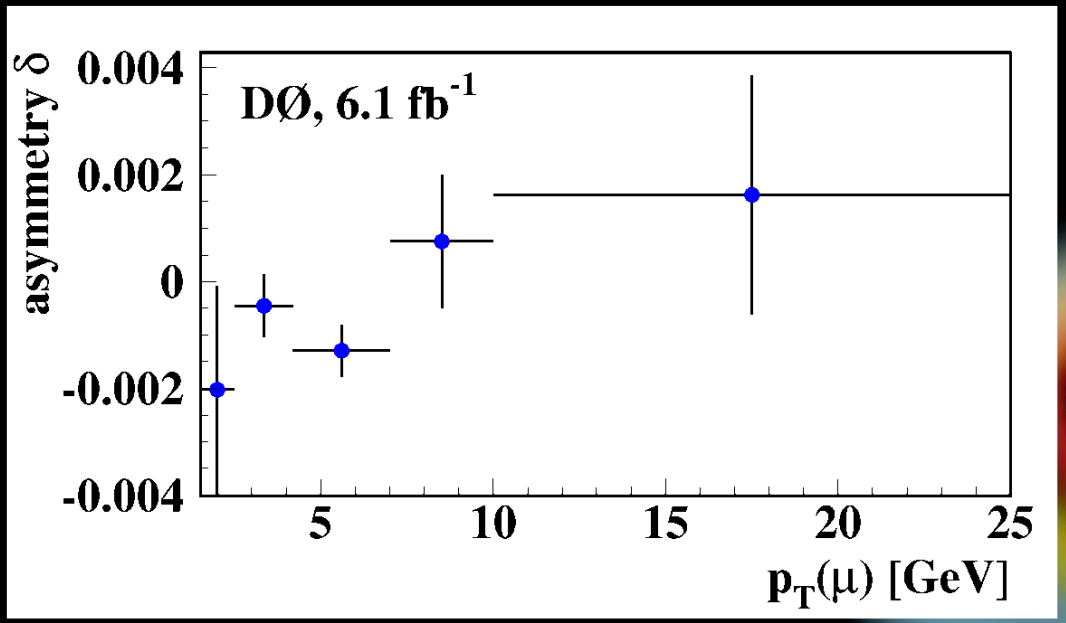
- Data and MC agree
  - MC values are used only for systematics

	$(1-f_{bkg})$	f_K	f_π	f_p
MC	(59.0±0.3)%	(14.5±0.2)%	(25.7±0.3)%	(0.8±0.1)%
Data	(58.1±1.4)%	(15.5±0.2)%	(25.9±1.4)%	(0.7±0.2)%



Muon Reconstruction Asymmetry

- Reversal of magnet polarities cancel software bias on μ^+ and μ^-
  - Detector asymmetries for a given polarity ~1%
  - Residual reconstruction asym. ~ 0.01%
  - Measured using $J/\Psi \rightarrow \mu^+\mu^-$



$\delta = (-0.076 \pm 0.028)\%$

$\Delta = (-0.068 \pm 0.023)\%$

Summary of Backgrounds to Asymmetry

	$f_K a_K$ (%) or $F_K A_K$ (%)	$f_\pi a_\pi$ (%) or $F_\pi A_\pi$ (%)	$f_p a_p$ (%) or $F_p A_p$ (%)	$(1-f_{bkg})\delta$ (%) or $(2-F_{bkg})\Delta$ (%)	a_{bkg} or A_{bkg}
Inclusive	0.854±0.018	0.095±0.027	0.012±0.022	−0.044±0.016	0.917±0.045
Dimuon	0.828±0.035	0.095±0.025	0.000±0.021	−0.108±0.037	0.815±0.070

$$a_{raw} = (+0.955 \pm 0.003)\%$$

$$A_{raw} = (+0.564 \pm 0.053)\%$$

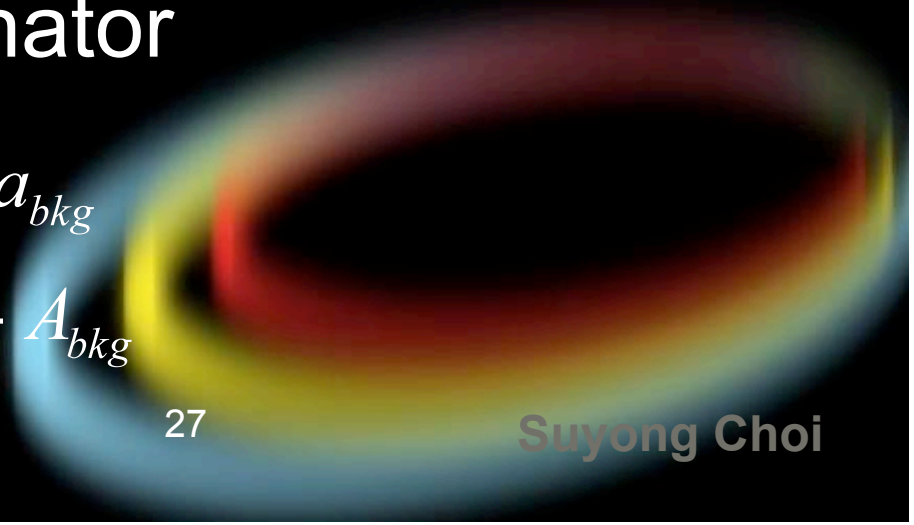
Other Signals

- Other decays of b- and c-quark contribute

- These decays do not produce any asymmetry, but dilutes asymmetry by contributing to denominator

$$k\, A_{sl}^{b} = a_{raw} - a_{bkg}$$

$$K\, A_{sl}^{b} = A_{raw} - A_{bkg}$$



Dilution

- From simulations of b,c decays

$$k = 0.041 \pm 0.003$$

$$K = 0.342 \pm 0.023$$

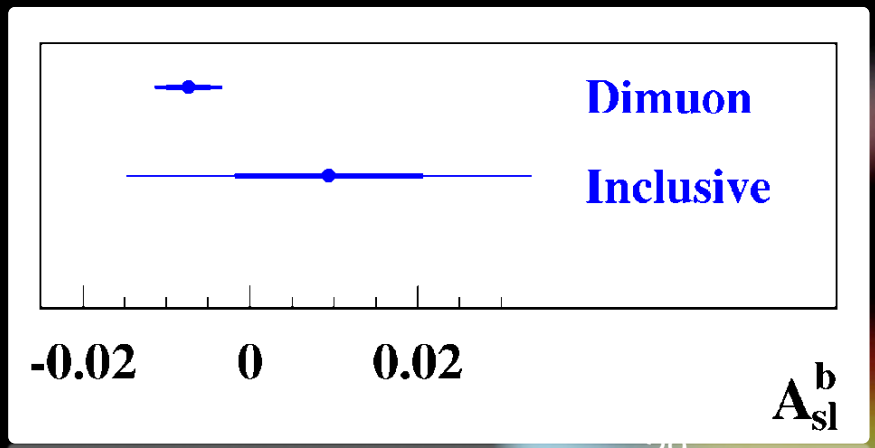
  - Inclusive sample has much more non-oscillating b,c dcays

Results

- After correcting for backgrounds and dilution

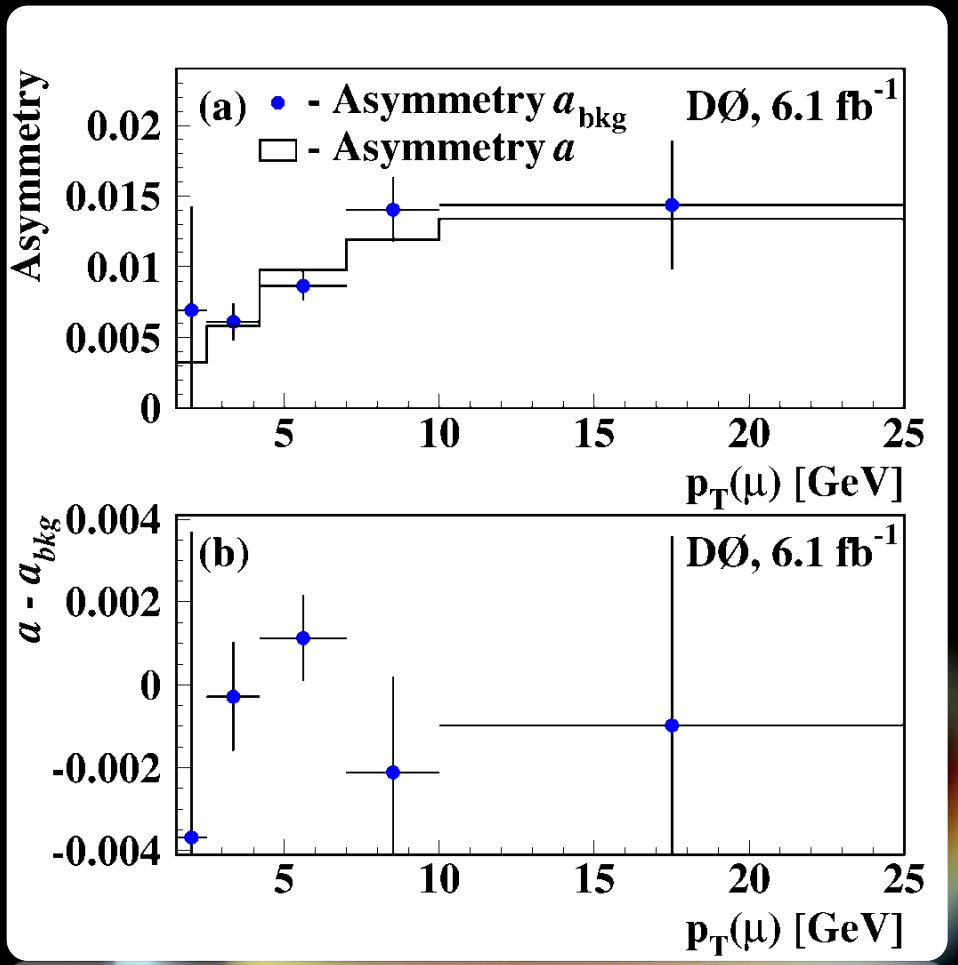
$$a_{sl}^{b} = (+0.94 \pm 1.12\ (\text{stat}) \pm 2.14\ (\text{syst}))\% \quad (\text{inclusive})$$

$$A_{sl}^{b} = (-0.736 \pm 0.266\ (\text{stat}) \pm 0.305\ (\text{syst}))\% \quad (\text{dimuon})$$



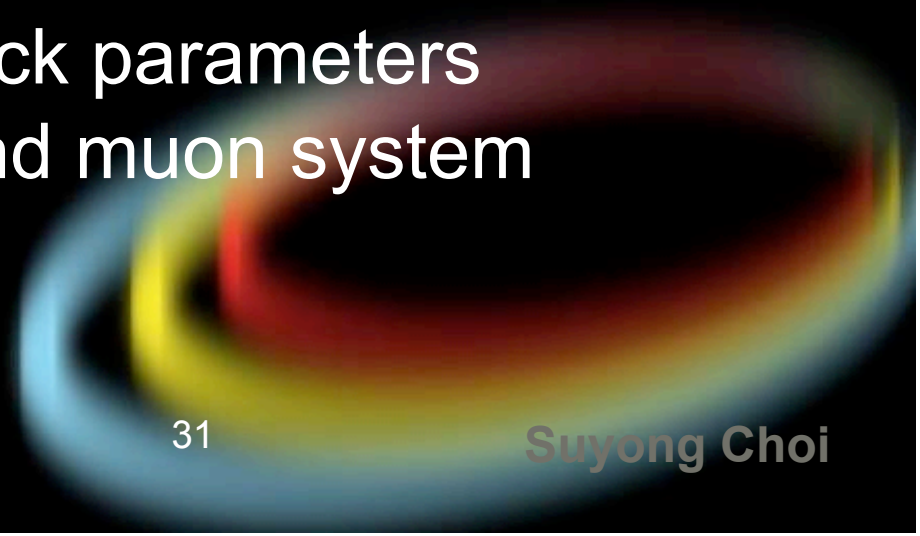
Closure Test

- a value is mostly due to background
- A_{sl}^{b} contribution to a is only 4%



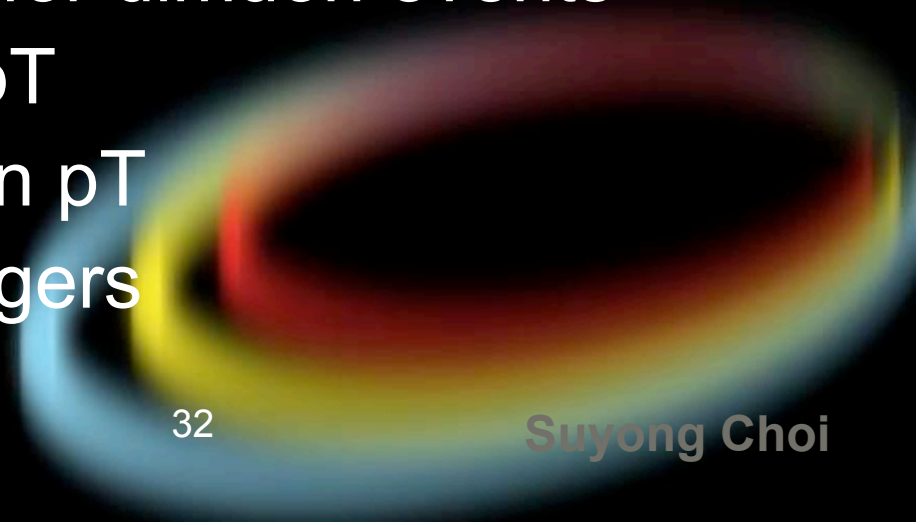
Consistency Checks I

- Partition data
  - First half, second half
  - High-luminosity, low luminosity
- Tracks
  - Better agreement of track parameters measured by tracker and muon system
  - Impact parameter



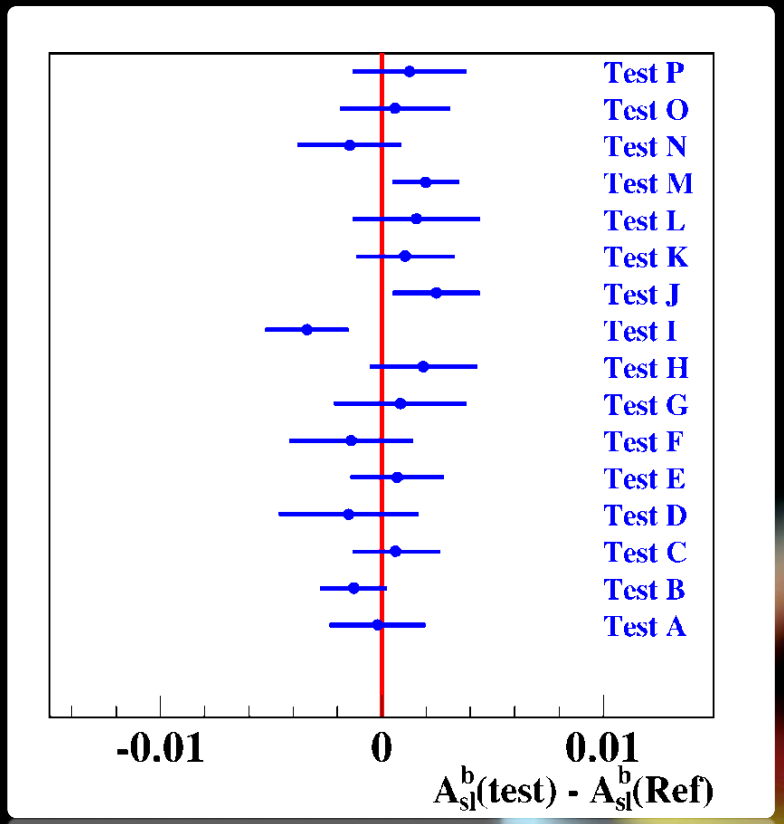
Consistency Checks II

- Muon selection
  - Tighter muon selection - # of stations
  - Avoid region for poor identification
  - Reject forward muons
  - Avoid cracks
  - Greater invariant mass for dimuon events
  - Raise minimum muon pT
  - Reduce maximum muon pT
  - Single and dimuon Triggers



Consistency Checks

- Variations for A_{raw} of up to 140% seen



Combination

- Combine results from inclusive and dimuon samples to minimize uncertainty

$$A' \equiv A - \alpha\, a$$

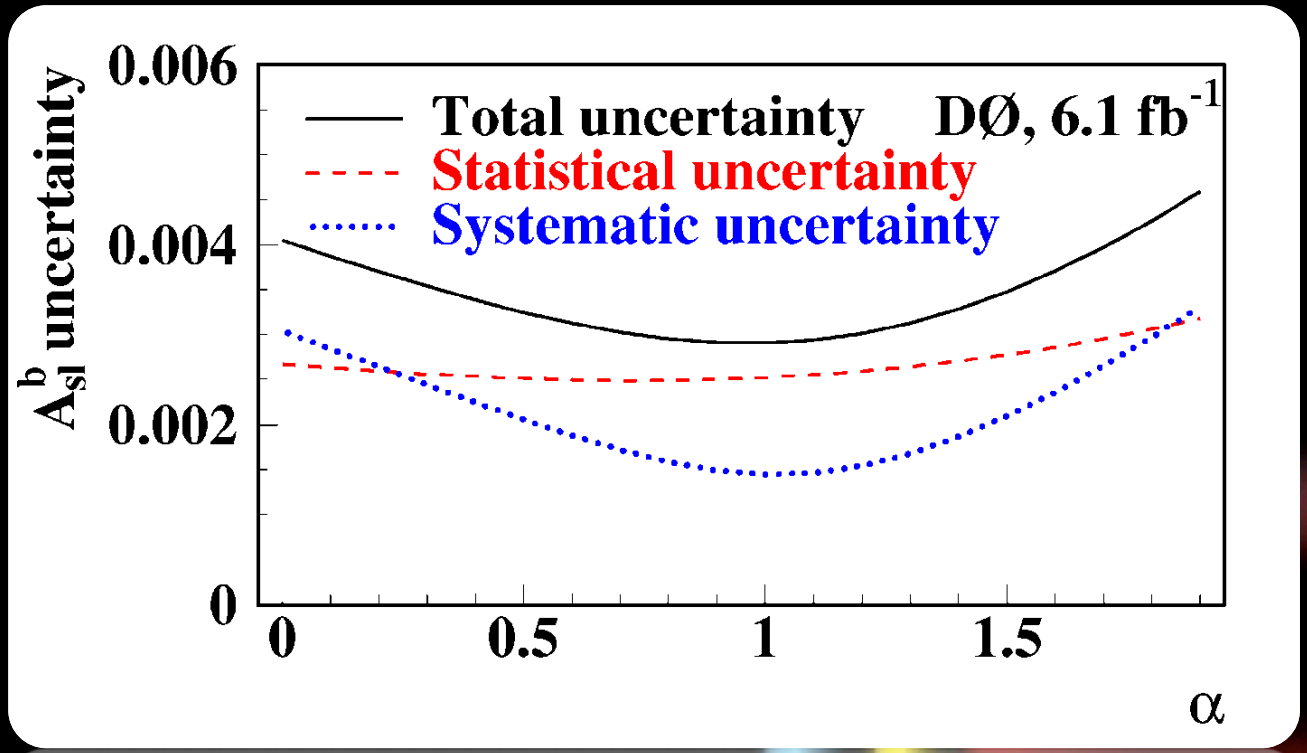
$$= (K - \alpha\, k) A_{sl}^{b} + (A_{bkg} - \alpha\, a_{bkg})$$

  - Background contributions cancel
  - Signal contributions do not cancel

Result

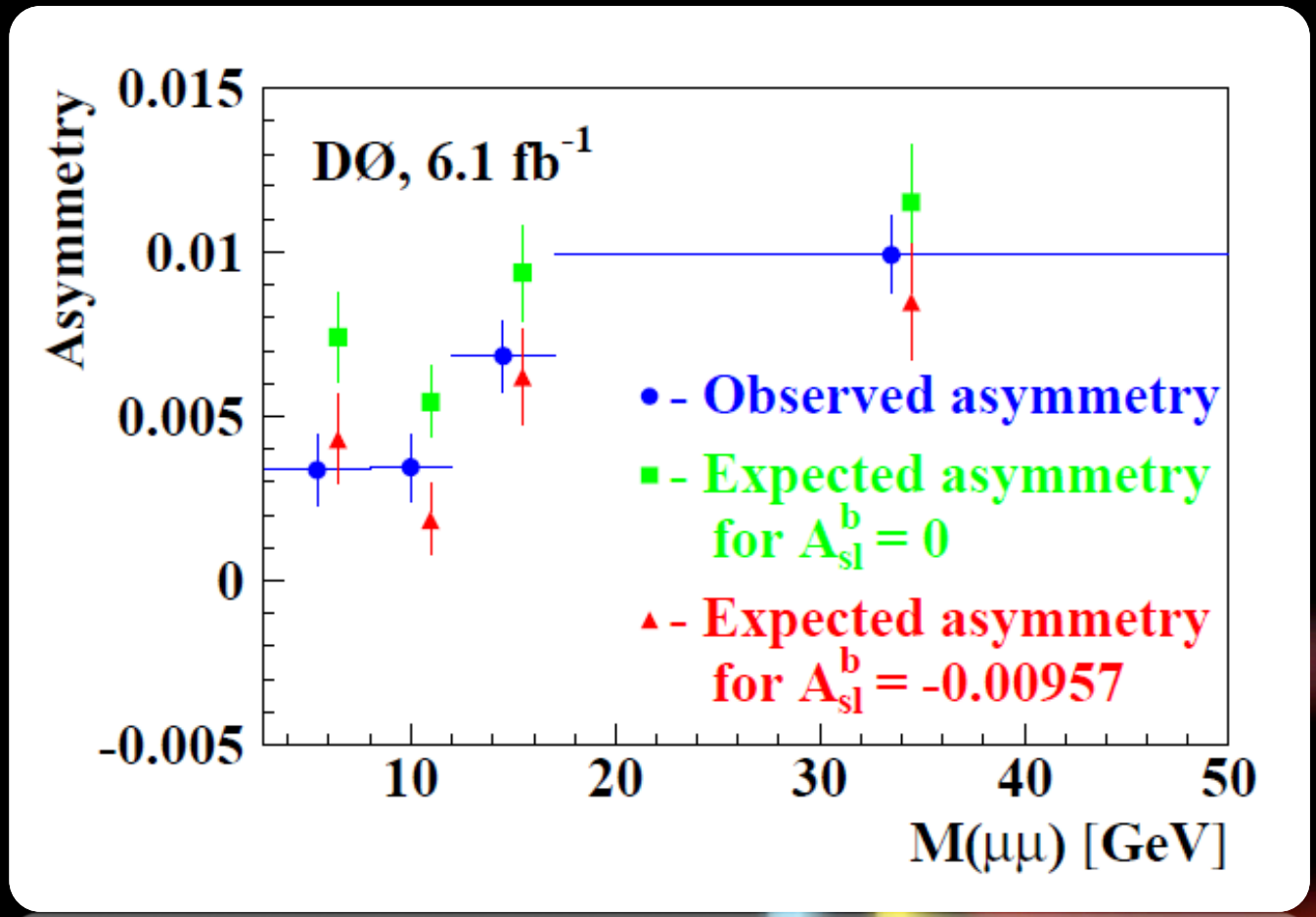
$A_{sl}^{b} = (-0.957 \pm 0.251\ (\text{stat}) \pm 0.146\ (\text{syst})\ )\%$

3.2σ deviation



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

Mass Dependence

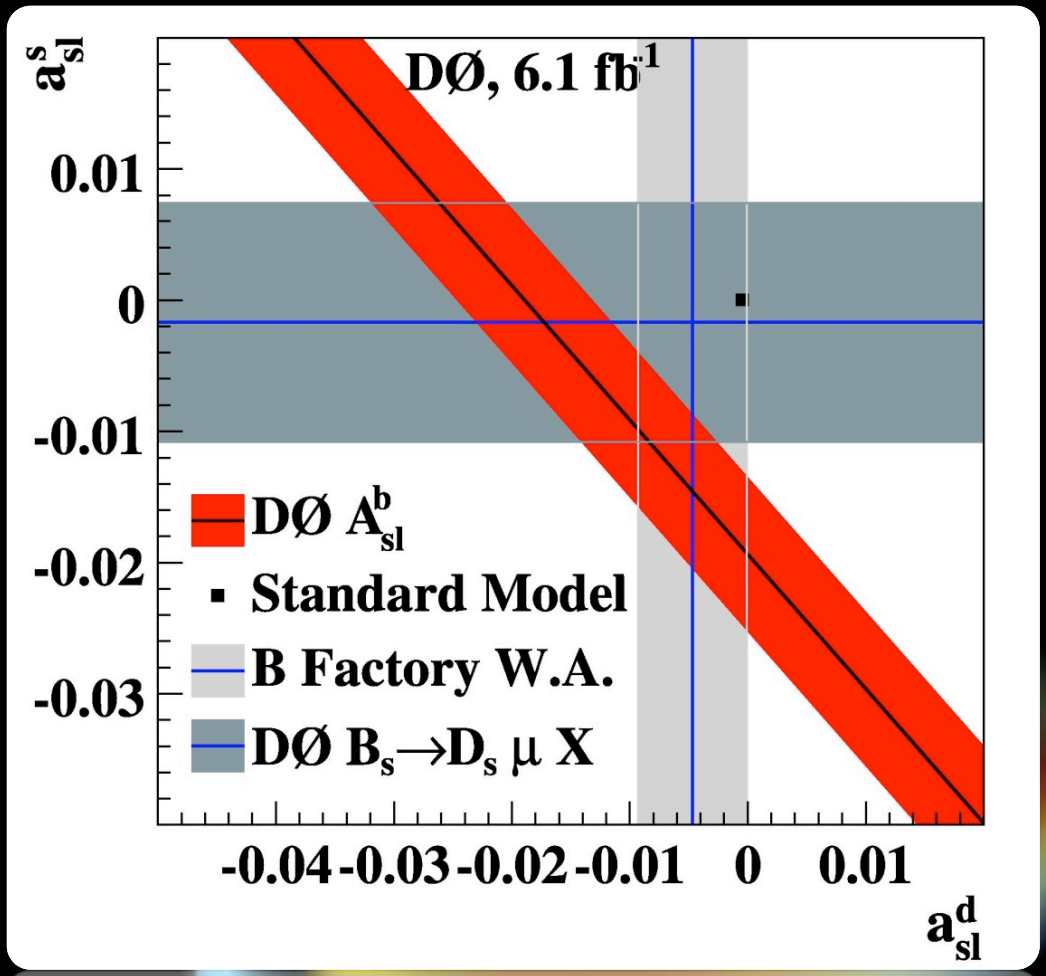


Comparison with Other Measurements

- We measure combination

$$A_{sl}^{b} = 0.506\, a_{sl}^{d} + 0.494\, a_{sl}^{s}$$

- In agreement with existing results



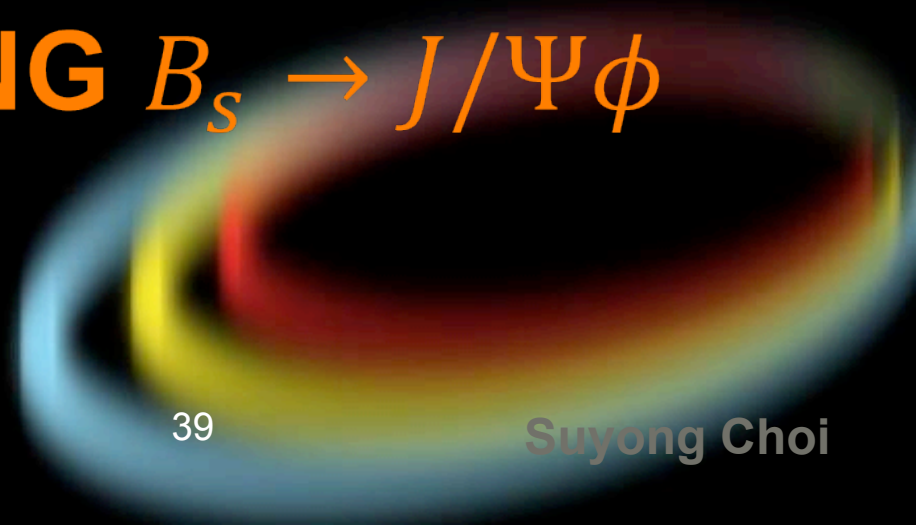
Bs asymmetry

- Obtained A^b_{sl} value can be translated to the semileptonic charge asymmetry of B_s meson
  - a^d_{sl} = −0.0047±0.0046 from B factories

- We obtain: $a^s_{sl} = (-1.46 \pm 0.75)\%$

$$a^s_{sl}(SM) = (+0.0021 \pm 0.0006)\%$$

CPV PHASE USING $B_s \rightarrow J/\Psi\phi$ AT D-ZERO



$B_s \to J/\psi\phi$

- Both B_s and B_s-bar can decay
  - Interference of direct decay and that through mixing

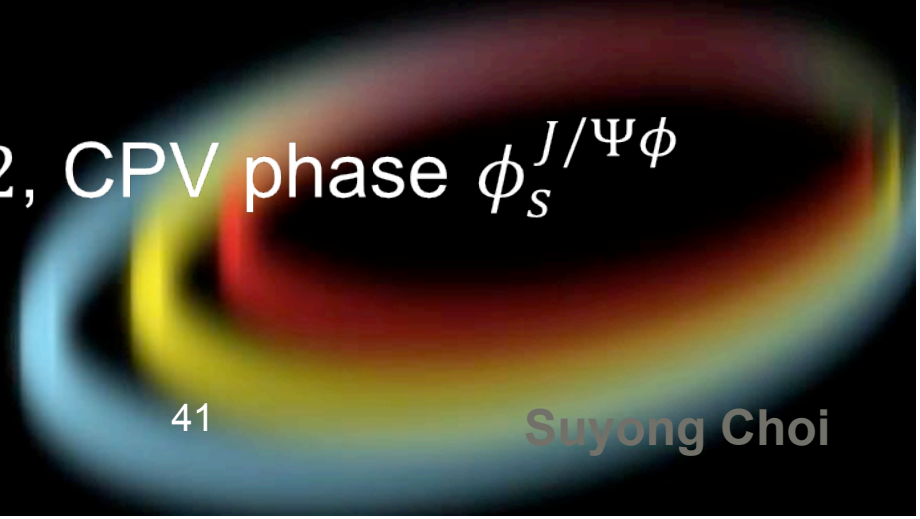
- Reltative phase difference between mixing and $b \to ccs$

$$2\beta_s^{SM} = 2\arg\left[-\frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*}\right] = 0.038 \pm 0.002$$

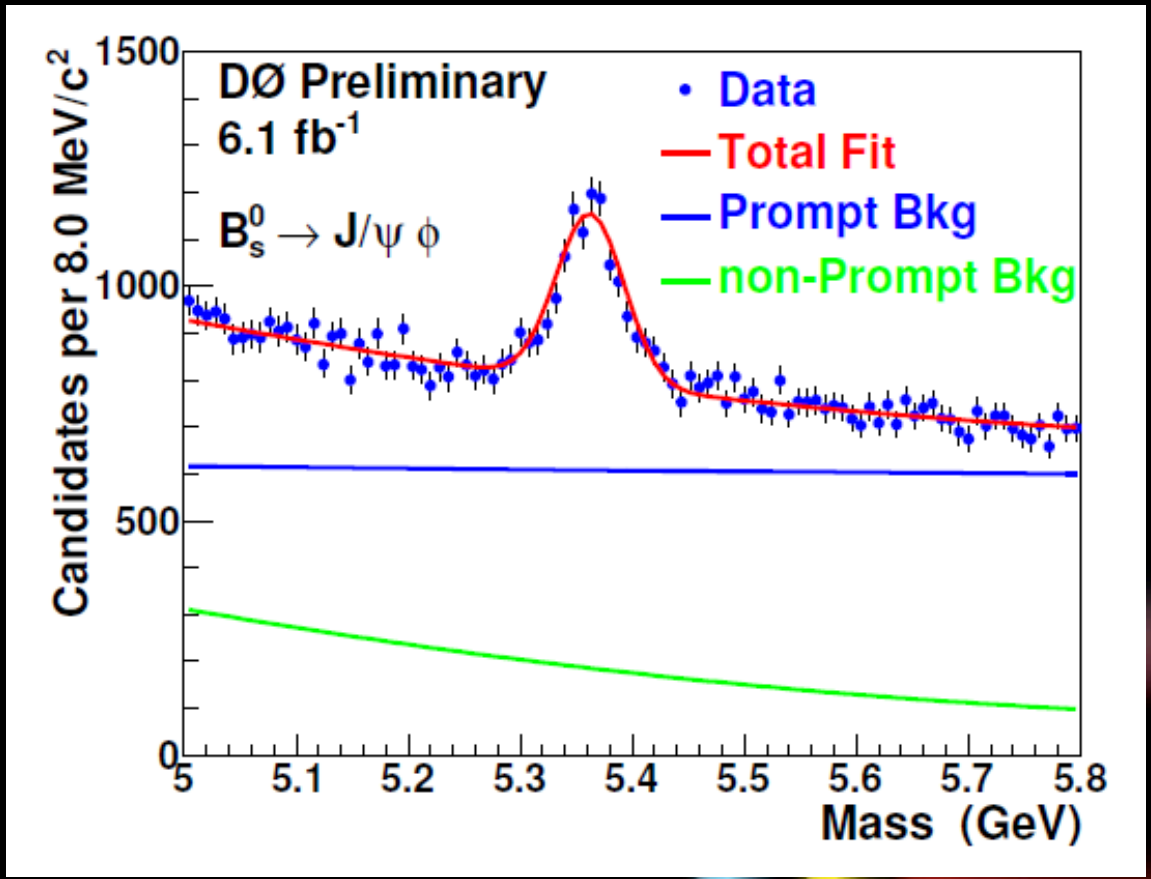
Time Dependent Analysis of $B_s \to J/\Psi\phi$

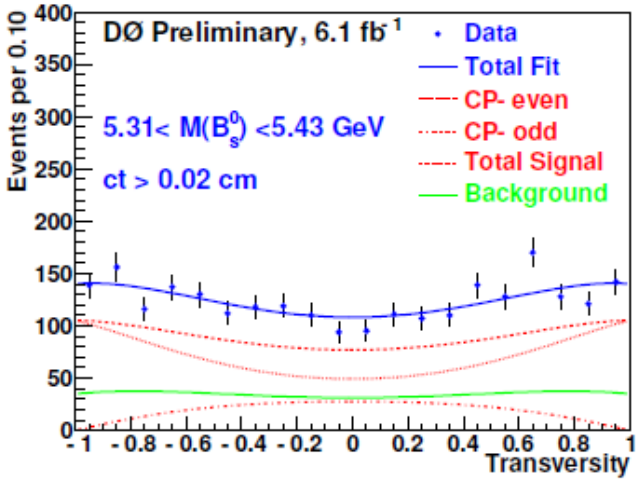
- Using angular analysis separate
  - CP even
  - CP odd

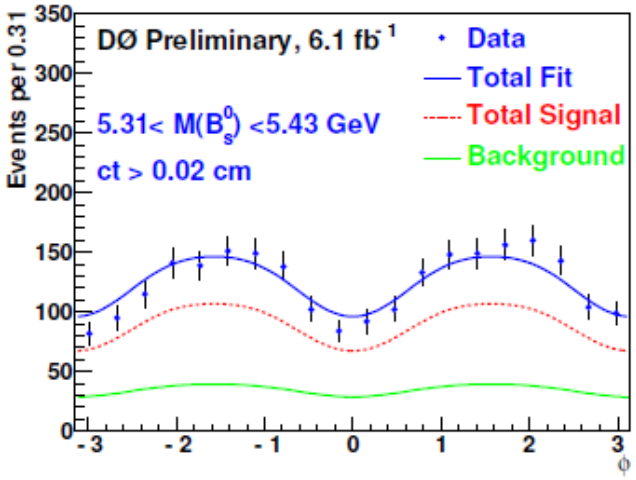
- Update to PRL 101, 241801 (2008)
  - Larger statistics 6.1 fb^{-1}
  - Extract: $\Delta\Gamma_s$, $(\Gamma_H + \Gamma_L)/2$, CPV phase $\phi_s^{J/\Psi\phi}$

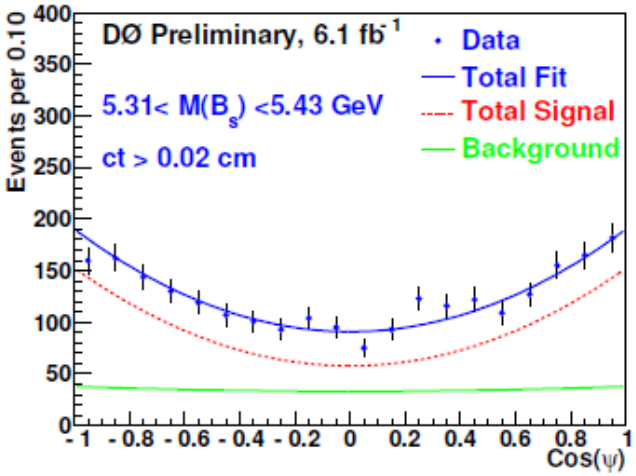


$M(J/\Psi + \phi)$


DØ Preliminary
6.1 fb-1
B0s → J/ψ φ
Data
Total Fit
Prompt Bkg
non-Prompt Bkg
Candidates per 8.0 MeV/c2
Mass (GeV)
0
500
1000
1500
5
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8


DØ Preliminary, 6.1 fb-1
5.31< M(B0s) <5.43 GeV
ct > 0.02 cm
Data
Total Fit
CP- even
CP- odd
Total Signal
Background
Events per 0.10
Transversity

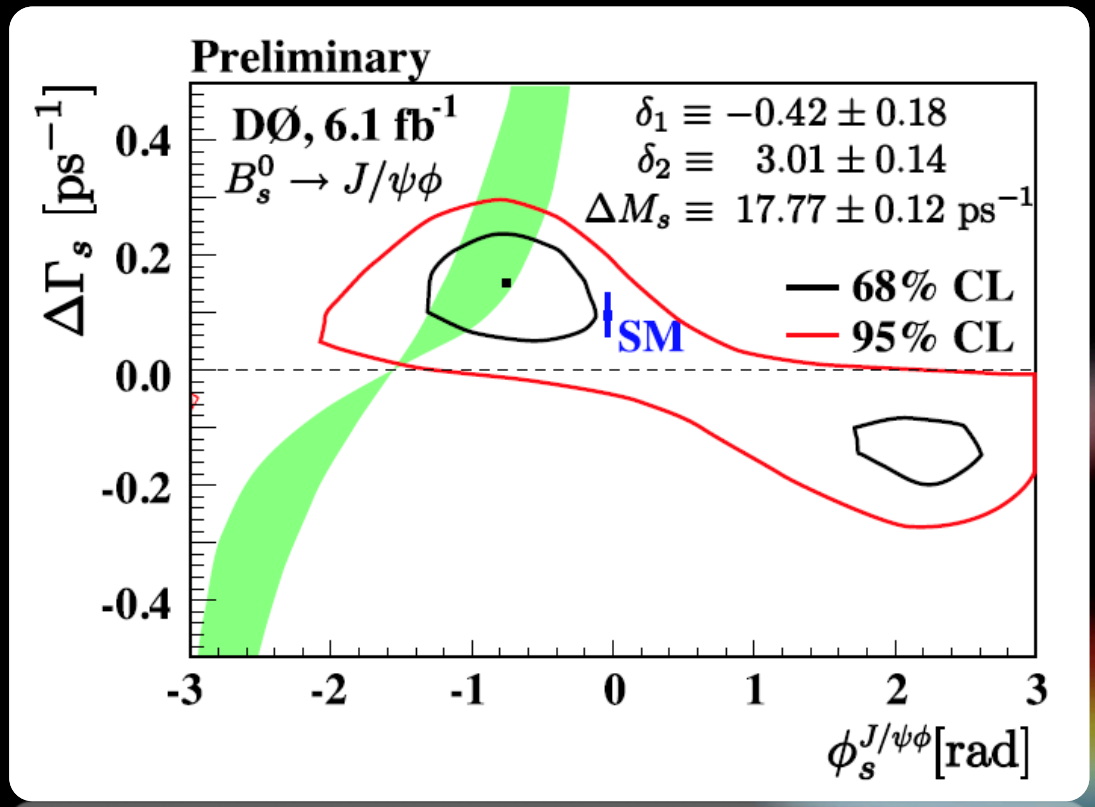

DØ Preliminary, 6.1 fb-1
5.31< M(B0s) <5.43 GeV
ct > 0.02 cm
Data
Total Fit
Total Signal
Background
Events per 0.31
ϕ


DØ Preliminary, 6.1 fb-1
5.31< M(Bs) <5.43 GeV
ct > 0.02 cm
Data
Total Fit
Total Signal
Background
Events per 0.10
Cos(ψ)

Result

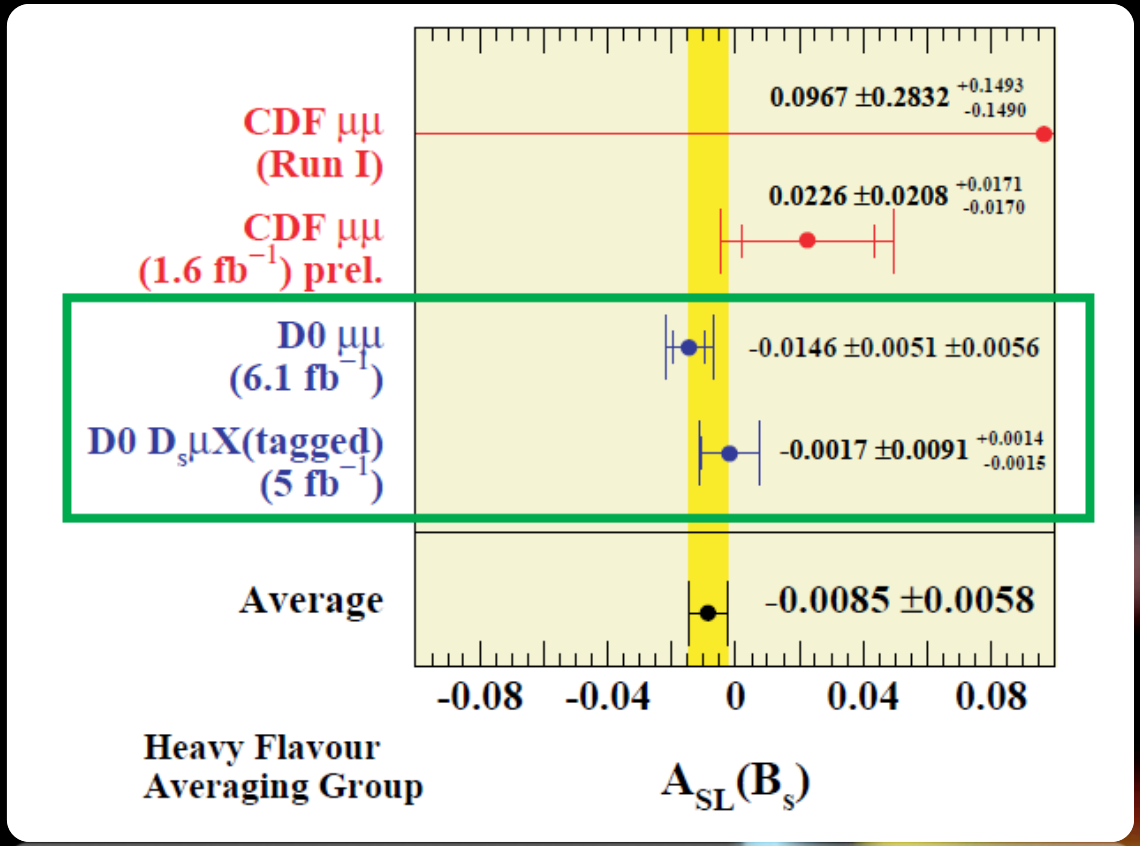
$$\Delta\Gamma_s = 0.15 \pm 0.06(stat) \pm 0.01(syst)$$

$$\phi_s^{J/\psi\phi} = -0.76^{+0.38}_{-0.36}(stat) \pm 0.02(syst)$$



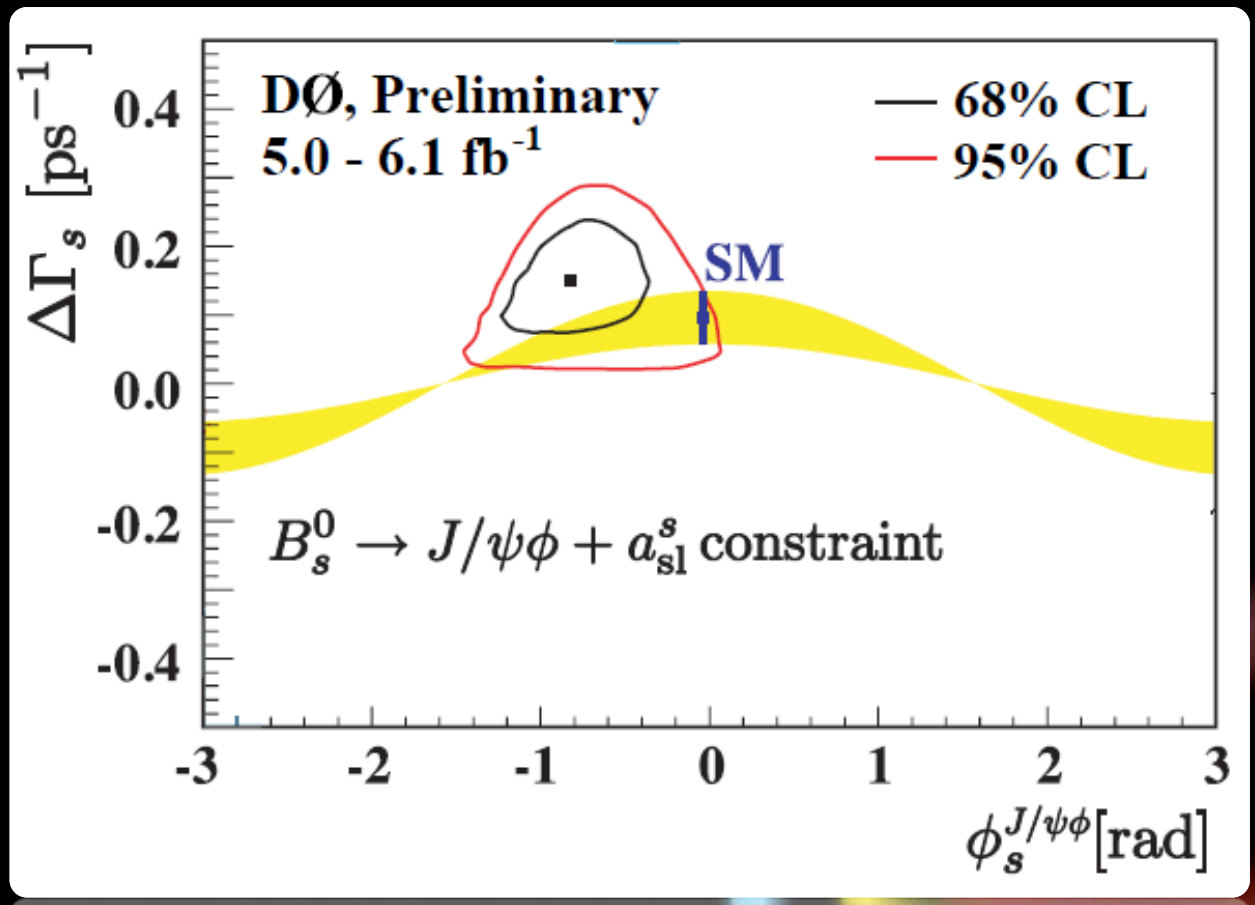
Combination with Other Results

- D-Zero's combination on -0.0100±0.059



Dimuon asymmetry

0904.3907


DØ, Preliminary
5.0 - 6.1 fb^{-1}
68% CL
95% CL
SM
$B_s^0 \to J/\psi\phi + a_{sl}^s$ constraint
$\Delta\Gamma_s$ [ps^{-1}]
0.4
0.2
0.0
-0.2
-0.4
-3
-2
-1
0
1
2
3
$\phi_s^{J/\psi\phi}$[rad]

Bs to Ds Ds

- Phys. Rev. Lett. 102, 091801 (2009) [arXiv.org:0811.2173]

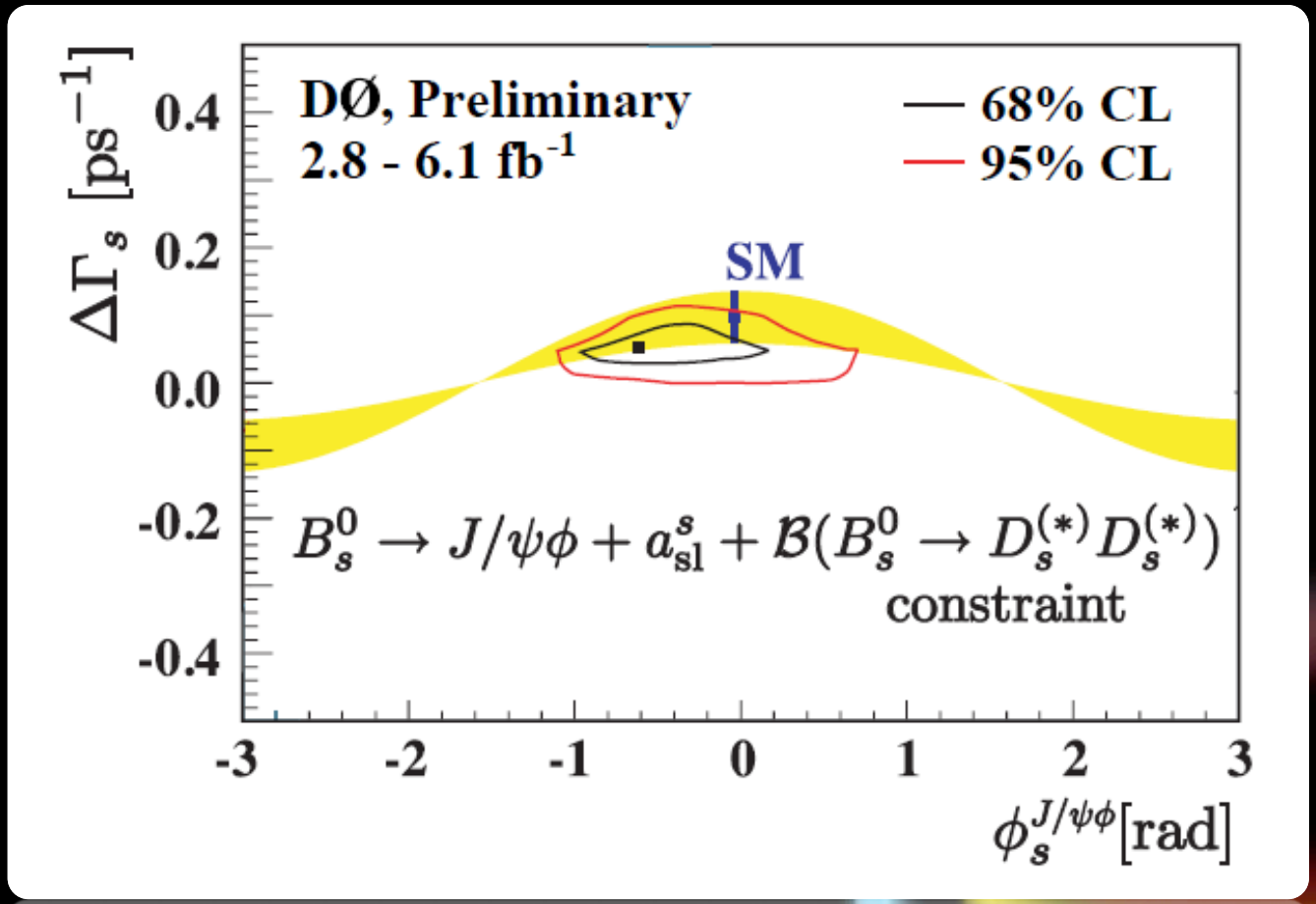
$$2\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) \simeq \frac{\Delta\Gamma_s}{\Gamma_s \cos\phi_s}\left[\frac{1}{1-2x_f} - \frac{\Delta\Gamma_s \cos\phi_s}{2\Gamma_s}\right]$$

$$\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = 0.035 \pm 0.015.$$

tion where $\phi_s = 0$, this mostly limits the value of $\Delta\Gamma_s$, i.e.,

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.072 \pm 0.030.$$

Combined Result



p-value: 6%

Summary

- Dimuon charge asymmetry while shows evidence of deviating from SM
- It is consistent with other results from D-Zero and other experiments
  - p-value of 6% in combination