Heavy Flavour Results from DØ

Anthony Ross
Department of Physics
Lancaster University

Fourth Workshop on Theory, Phenomenology and Experiments in Flavour Physics

Capri June 13th 2012

Contents

- $B_s^0 \to J/\psi f_2'(1525)$
- Λ_b lifetime ($\Lambda_b \to J/\psi \Lambda_0$)
- Narrow state decaying to $\Upsilon(1S) + \gamma$
- Time-integrated Semi-leptonic charge asymmetry a_{sl}^s

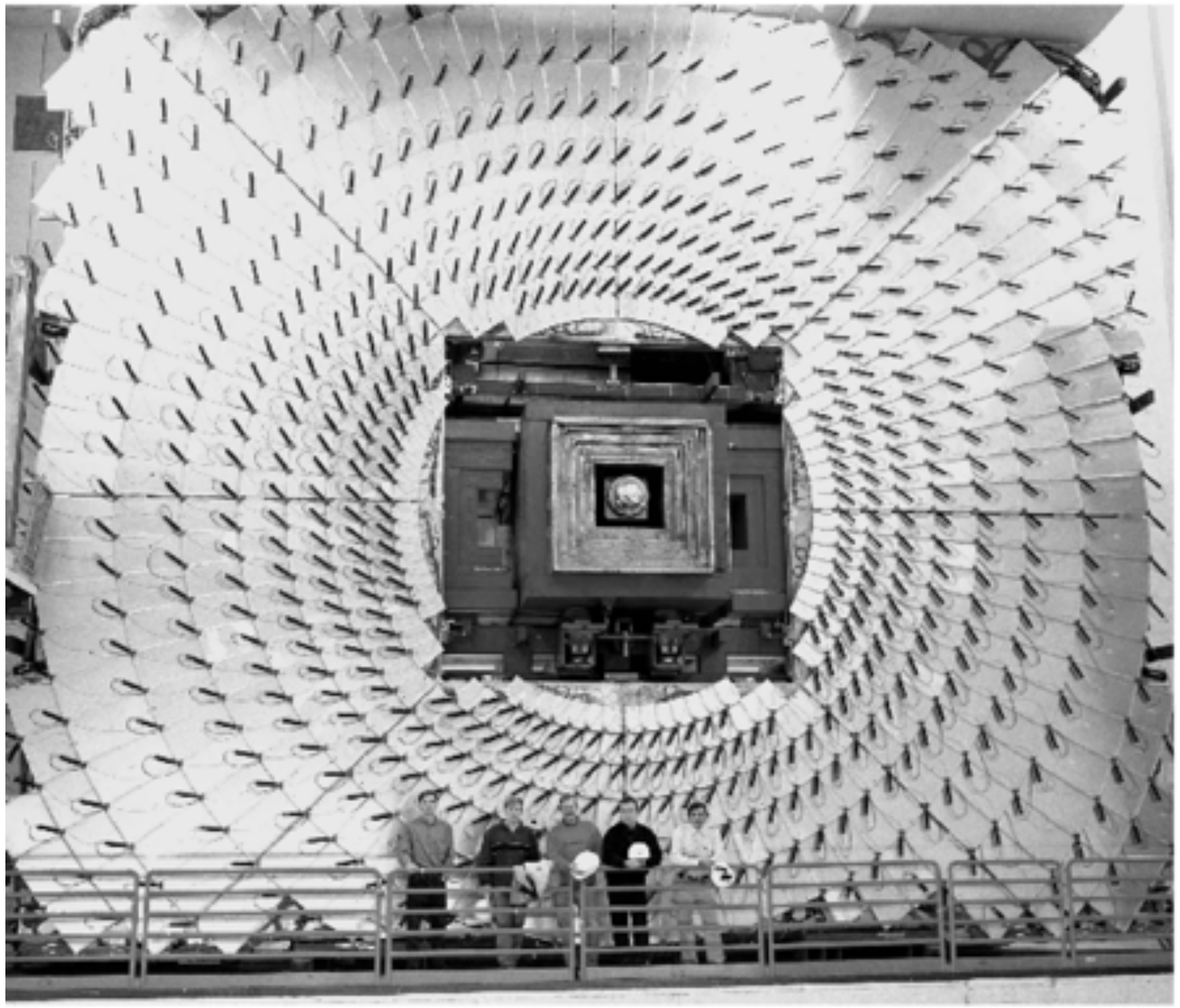
Not covered:

Relative branching ratio of $B_s^0 \to J/\psi f_0(980)$ and $B_s^0 \to J/\psi \phi$

arXiv:1110.4272 (submitted to PRD)

About the DØ Detector

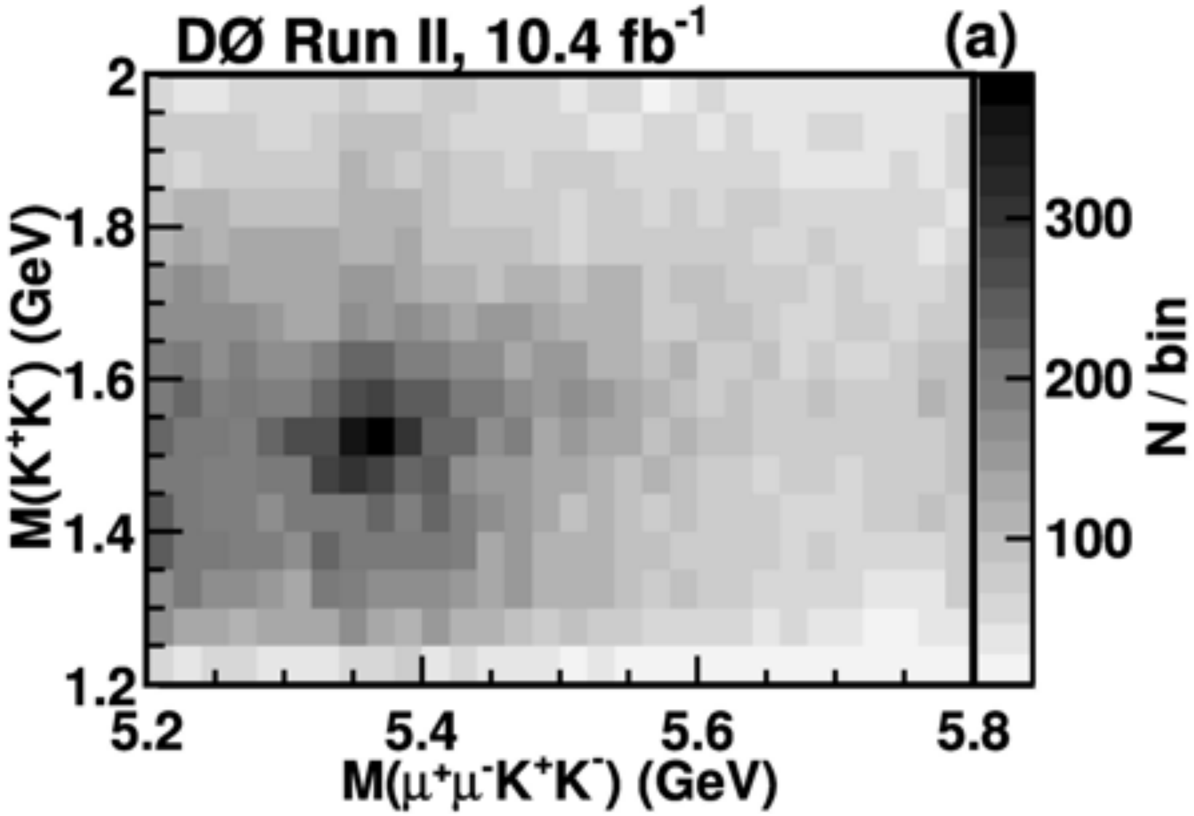
- One of two general purpose detectors on the Tevatron, ppbar collider
- Collected data at 1.96 TeV, 2002 - 2011
- 10.4 fb^{-1} int. lum.
- 700,000 channel silicon microstrip tracker
- 100,000 channel scintilating fibre tracker
- 50,000 channel U/liquid Ar calorimeter
- 70,000 channel muon system



- Fast triggering, good cosmic ray rejection, low punch through, low pt muon detection arxiv.org:1204.5723 (submitted to PRD)

$B_s^0 \to J/\psi f_2'(1525)$

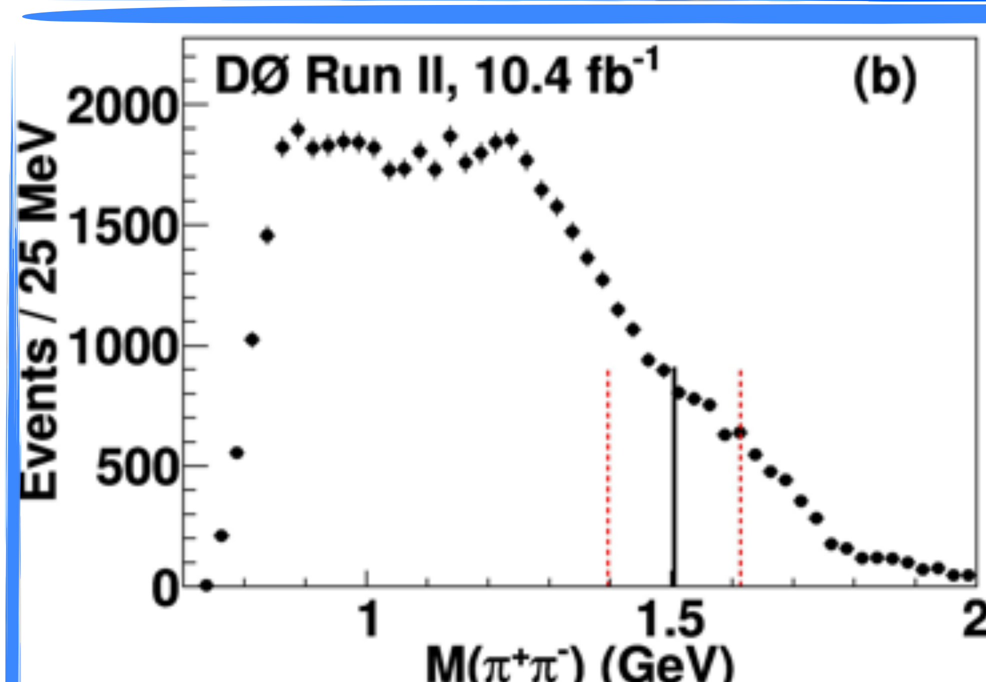
$B_s^0 \to J/\psi K^+K^-,\ J/\psi \to \mu^+\mu^-$



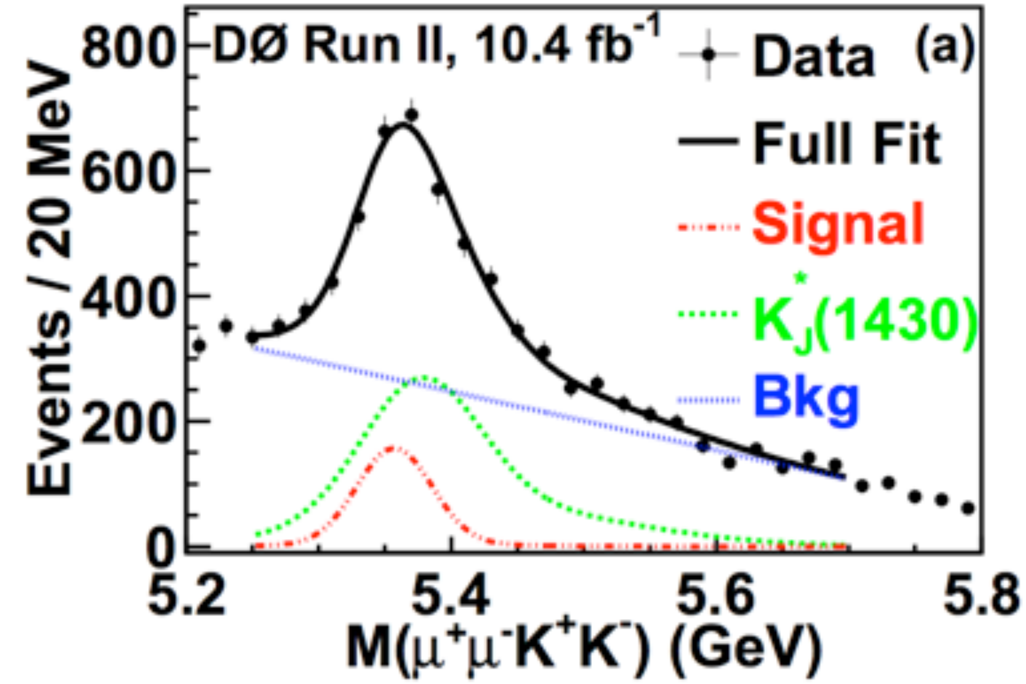
- Using full 10.4 fb^{-1} dataset
- Determination of decay identity
    - $f_0(1500)$ or $f'_2(1525)$?
    - Major peaking background $K^*_{J=0,2}(1430)$
- Investigate spin state
    - J = ?
- Relative branching ratio:
    - requires signal yield and reconstruction efficiencies of two channels with common Br terms
    - Use $B^0_s \to J/\psi\phi$

$B_s^0 \to J/\psi f_2'(1525)$

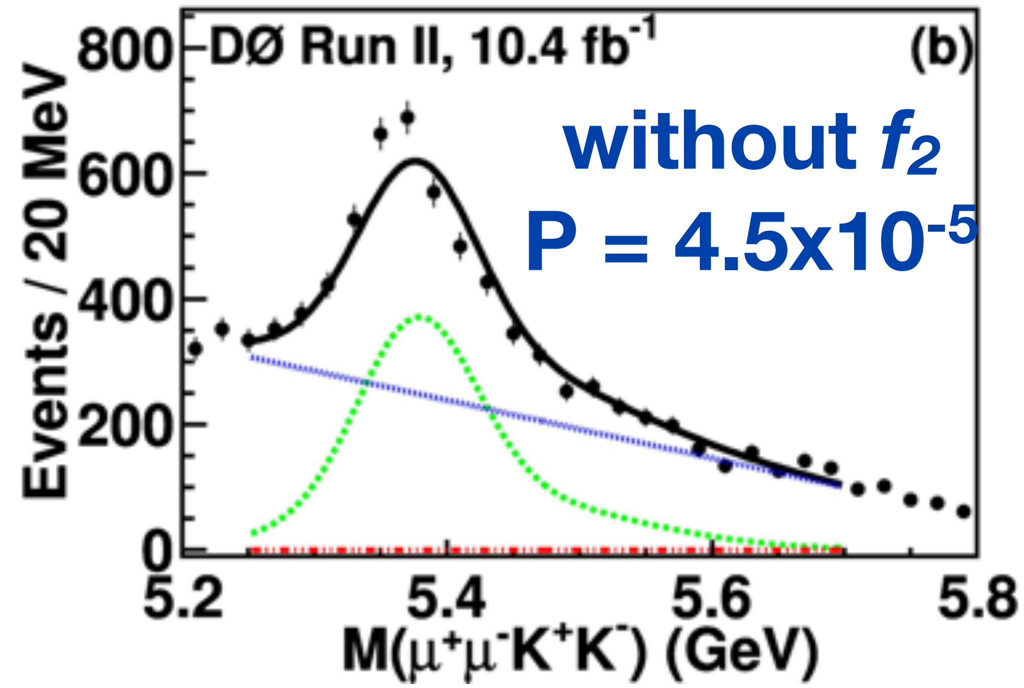
- **Determination of decay identity**
- $K^*_{J=0,2}(1430) \to K^{\pm}\pi^{\mp}$ distribution changes with $M(K^+K^-)$ range
- $f_0(1500)$ and $f_2'(1525)$ have very different Br to K^+K^- (f_2 pref.) and $\pi^+\pi^-$ (f_0 pref.)
- No significant B_s signal in $M(\pi^+\pi^-)$ channel discards f_0 hypothesis



with f_2 signal
P = 0.338

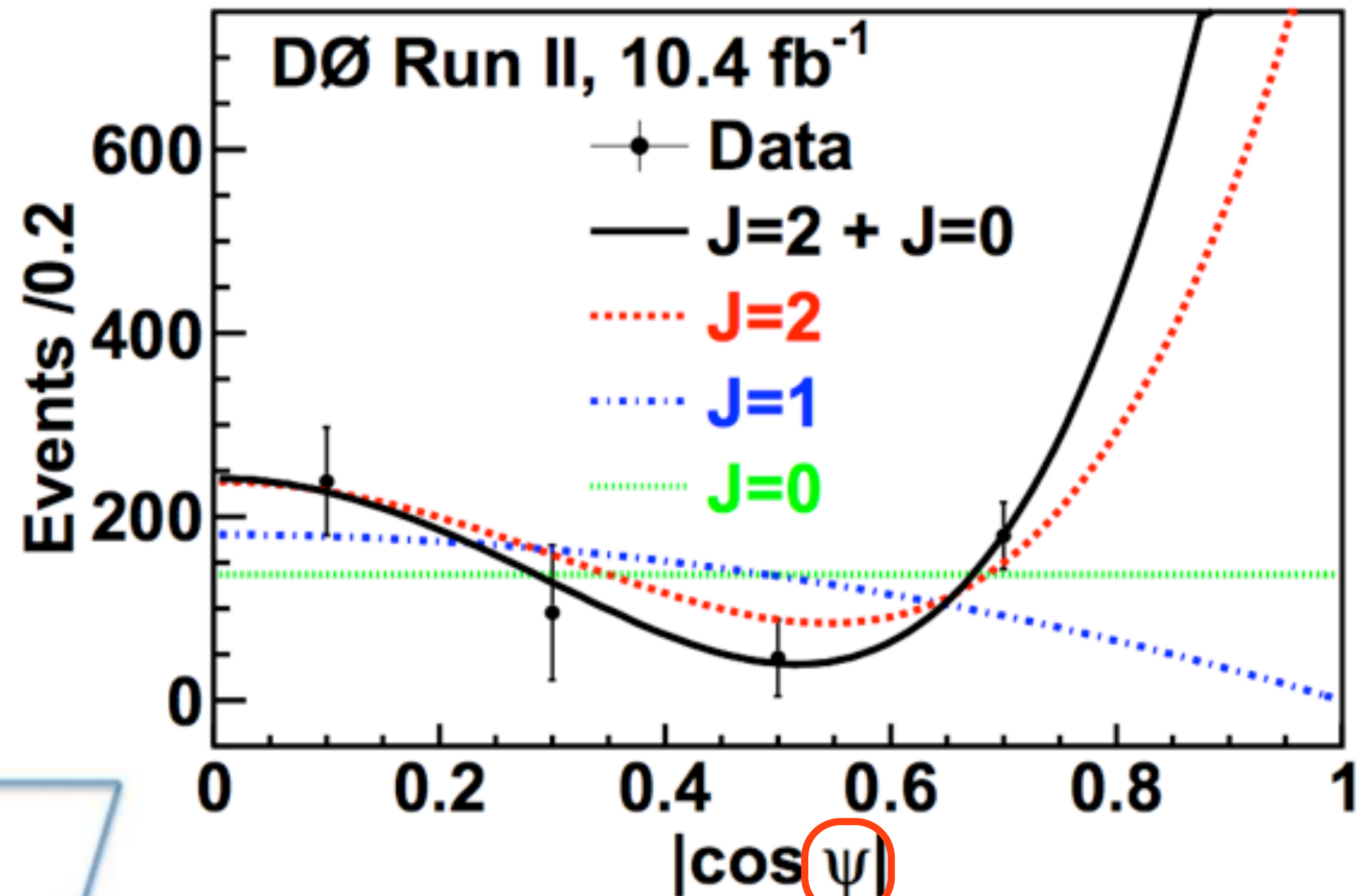


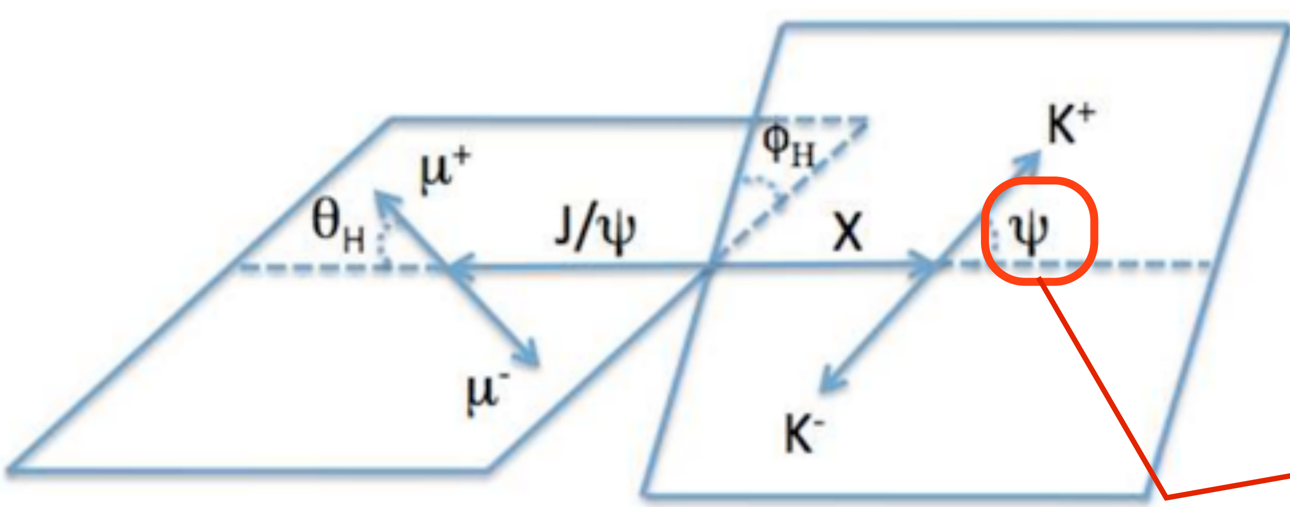
without f_2
P = 4.5x10^{-5}



$B_s^0 \to J/\psi f_2'(1525)$

- **Spin state**
- Find signal yield per ψ region
- Single state pref: J = 2
- Coherent superposition of J=0 and J=2 gives better fit
- J=0 and J=1 disfavored





$$\frac{d\Gamma}{d\Omega} \propto |\Sigma A_{Jm} Y_1^m(\cos\theta_H, \phi_H) Y_J^{-m}(-\cos\psi, 0)|^2 D(\Omega)$$

$$\Omega = \cos\theta_H, \ \ \phi_H, \ \ \text{or} \ \ \cos\phi$$

$B_s^0 \to J/\psi f_2'(1525)$

- **Relative branching ratio** requires signal yield and reconstruction efficiencies of two channels with common Br terms
- Use $B^0_s \to J/\psi\phi$

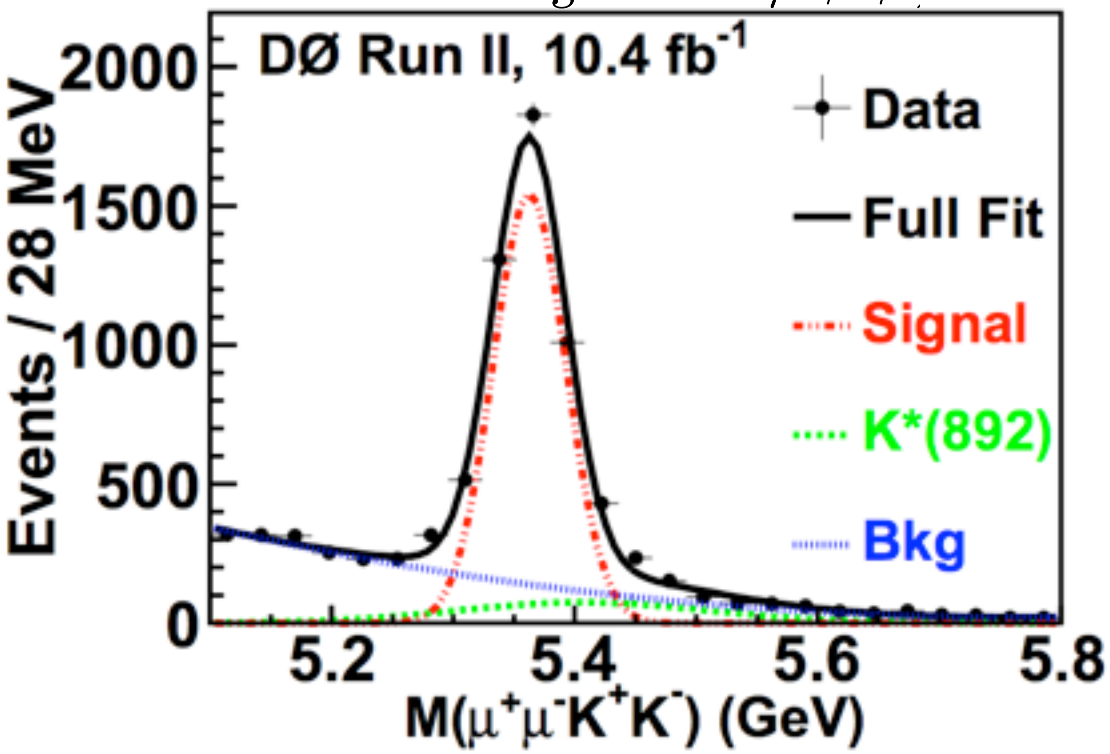
$$N(J/\psi f_2'(1525)) = 578 \pm 100$$
$$N(J/\psi\phi) = 3790 \pm 78$$

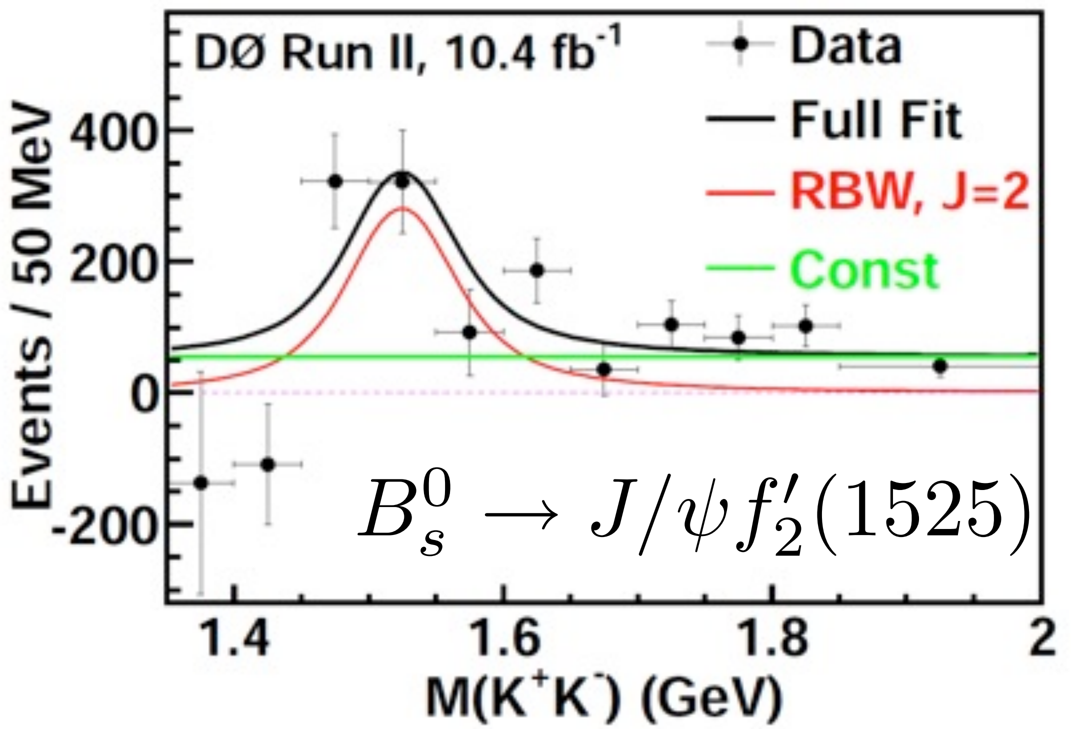
$$R_{f_2'/\phi} = \frac{\mathrm{Br}(B_s^0 \to J/\psi f_2'(1525))}{\mathrm{Br}(B_s^0 \to J/\psi\phi)} = 0.22 \pm 0.05\ (\mathrm{stat}) \pm 0.04\ (\mathrm{syst})$$

Consistent with LHCb result
[PRL **108** 151801 (2012)]

$$R_{f_2'/\phi} = 0.264 \pm 0.027\ (\mathrm{stat}) \pm 0.024\ (\mathrm{syst})$$

$B_s^0 \to J/\psi\phi$





arxiv.org:1204.2340 [PRD **85** 112003 (2012)]

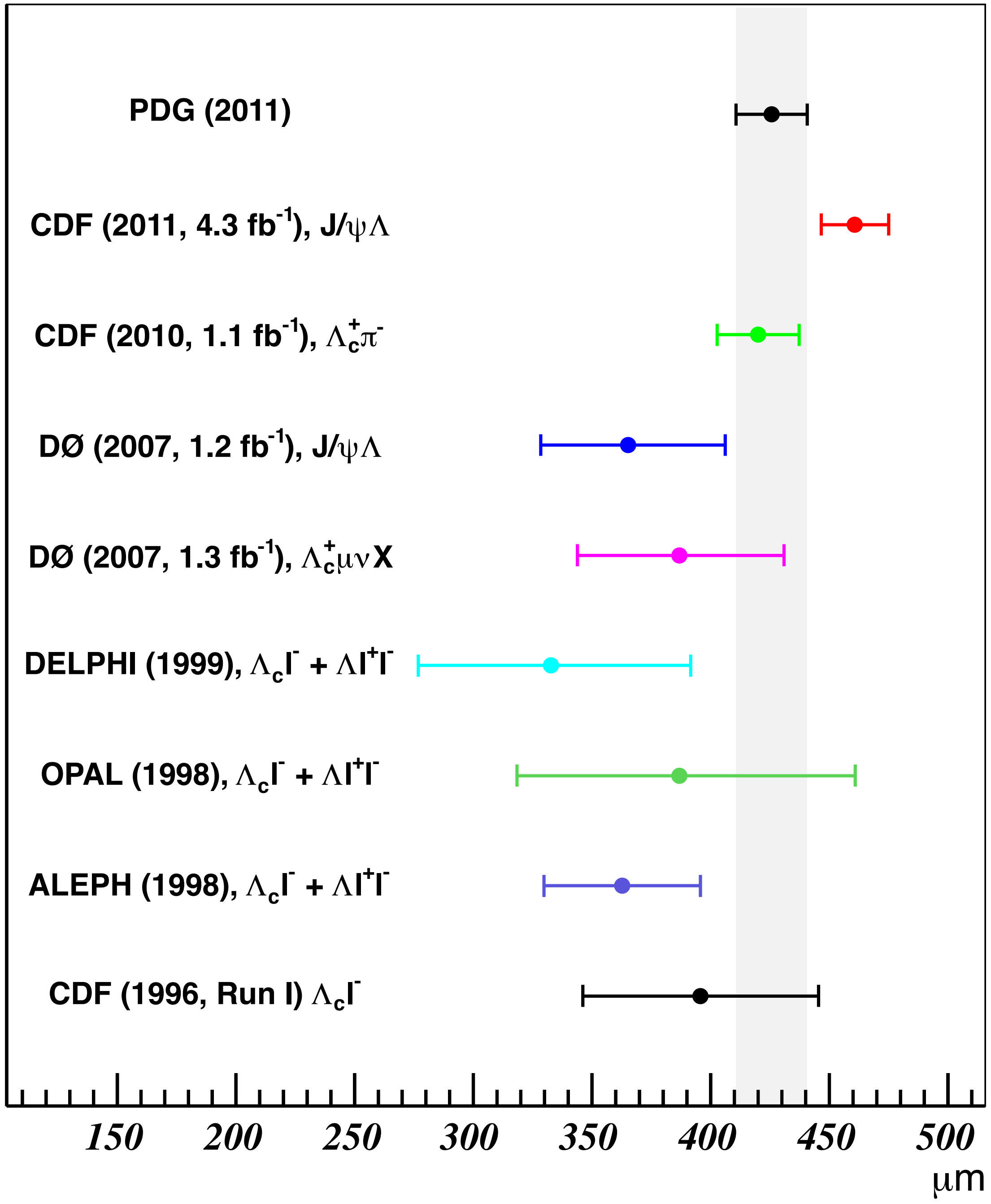
Λ_b lifetime $(\Lambda_b \to J/\psi\Lambda_0)$

- Heavy quark effective theory (HQET) predicts lifetime ratios of strong decays
- NLO HQET prediction: $\tau(\Lambda^0_b)/\tau(B^0) = 0.88 \pm 0.05$ (*)
- CDF: $\tau(\Lambda^0_b)/\tau(B^0) = 1.020 \pm 0.030 \pm 0.008$ (**)
- Previous DØ result:

$$\tau(\Lambda^0_b)/\tau(B^0) = 0.811^{+0.096}_{-0.087} \pm 0.034$$

- CDF result is 2.2σ above W.A.
- This updates DØ measurement from 1.2fb^{-1} to 10.4 fb^{-1}

Λ_b lifetime



* C.Tarantino, Nucl. Phys. B, Proc. Suppl. **156**, 33 (2006)

** T. Aaltonen *et al.* Phys. Rev. Lett. **106**, 121804 (2011)

Λ_b lifetime ($\Lambda_b \rightarrow J/\psi\Lambda_0$)

$$\tau(\Lambda_b^0) \text{ from } \Lambda_b^0 \rightarrow J/\Psi\Lambda_0$$

$$\tau(B^0) \text{ from } B^0 \rightarrow J/\Psi K_s^0$$

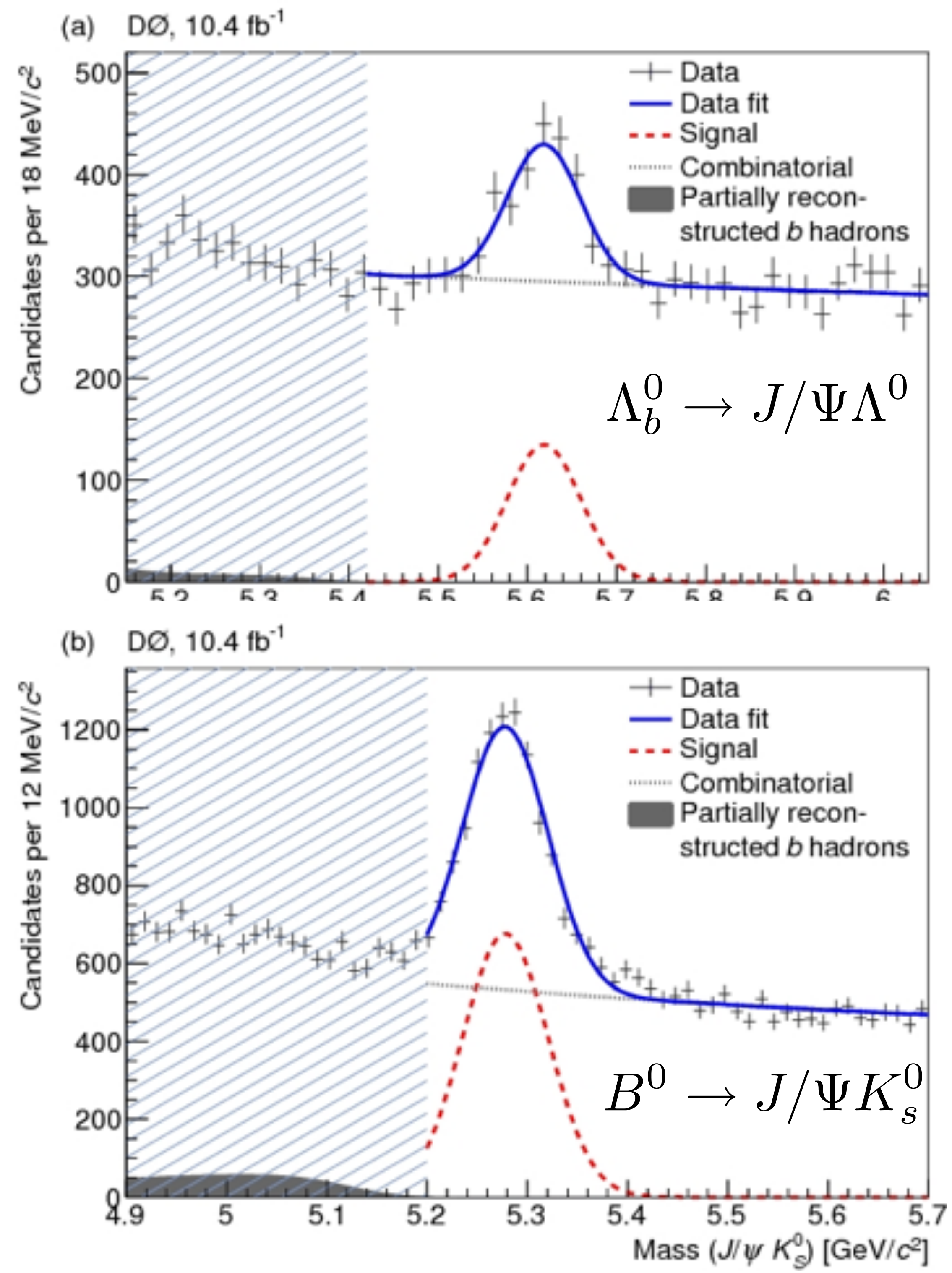
- where

$$J/\Psi \rightarrow \mu^+\mu^-$$

$$\Lambda_0 \rightarrow p\pi^-$$

$$K_s^0 \rightarrow \pi^+\pi^-$$

- B candidate mass cut removes partially reconstructed background region
- Unbinned max likelihood mass and lifetime fit for each channel
- N(Λ^0_b) = 755 ± 49
- N(B^0) = 5671 ± 126

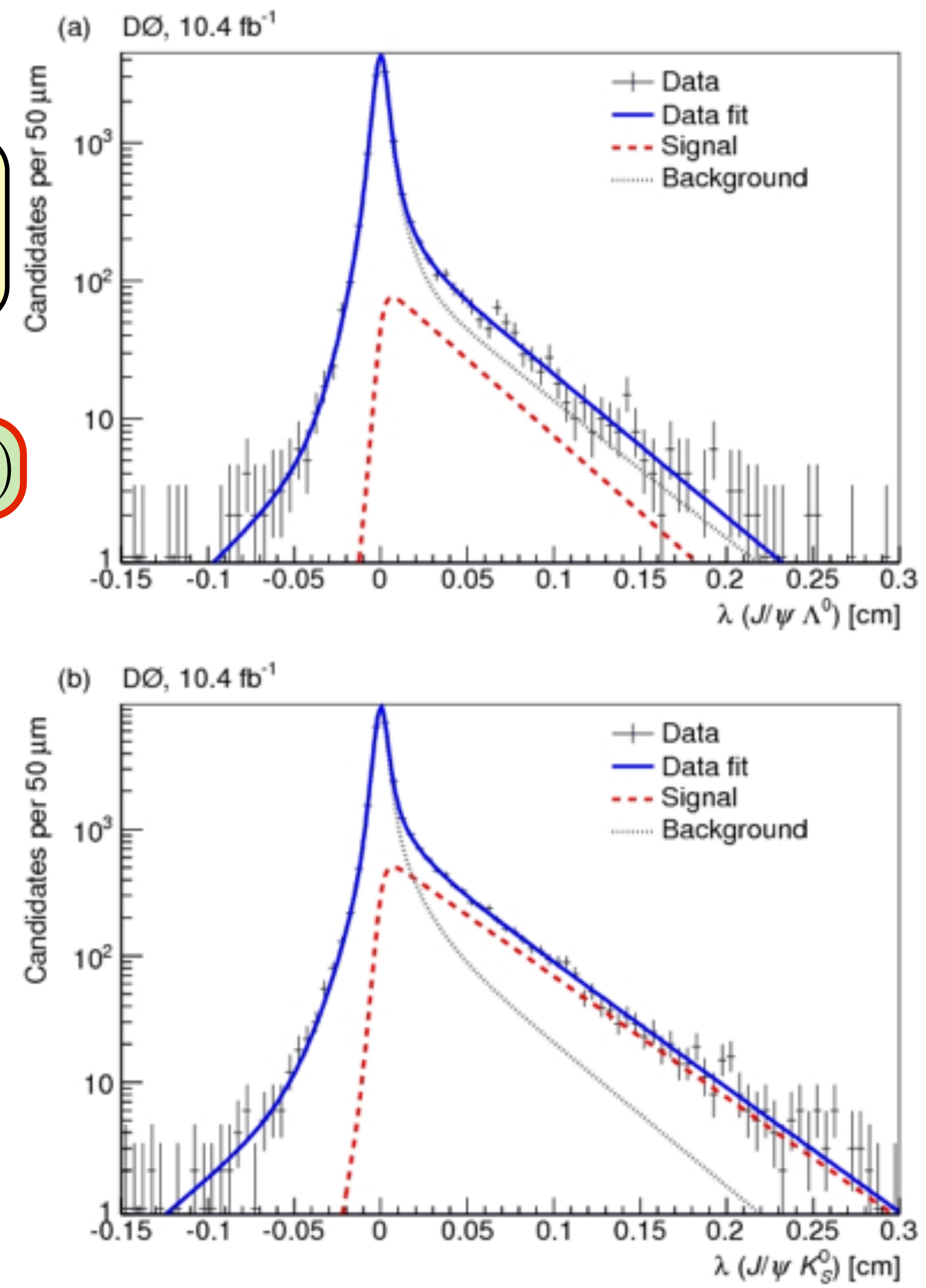


Λ_b lifetime ($\Lambda_b \rightarrow J/\psi\Lambda_0$)

$$\tau(\Lambda_b^0) = 1.303 \pm 0.075\ (\text{stat.}) \pm 0.035\ (\text{syst.})\ \text{ps}$$
$$\tau(B^0) = 1.508 \pm 0.025\ (\text{stat.}) \pm 0.043\ (\text{syst.})\ \text{ps}$$

$$\tau(\Lambda_b^0)/\tau(B^0) = 0.864 \pm 0.052\ (\text{stat.}) \pm 0.033\ (\text{syst.})$$

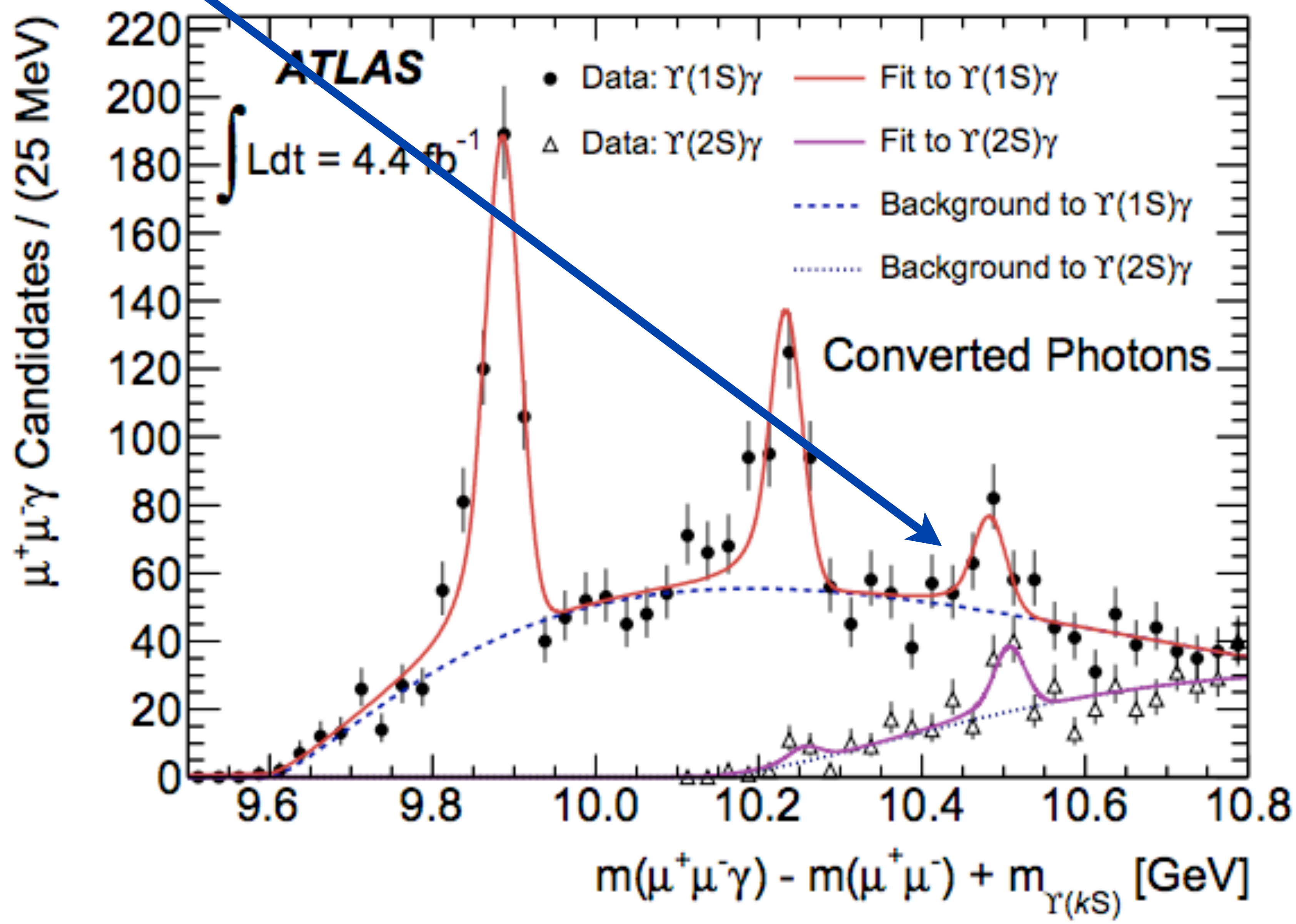
- HQET prediction $\tau(\Lambda^0_b)/\tau(B^0)$ = 0.88 ± 0.05
- CDF result $\tau(\Lambda^0_b)/\tau(B^0)$ = 1.02 ± 0.03
- World Average $\tau(\Lambda^0_b)/\tau(B^0)$ = 1.00 ± 0.06 (*)
- DØ result agrees with HQE, is compatible with W.A., but is 2.2σ from CDF



* K. Nakamura *et al.* (PDG), J. Phys. G **37**, 075021 (2010)

Narrow state decaying to $\Upsilon(1S) + \gamma$

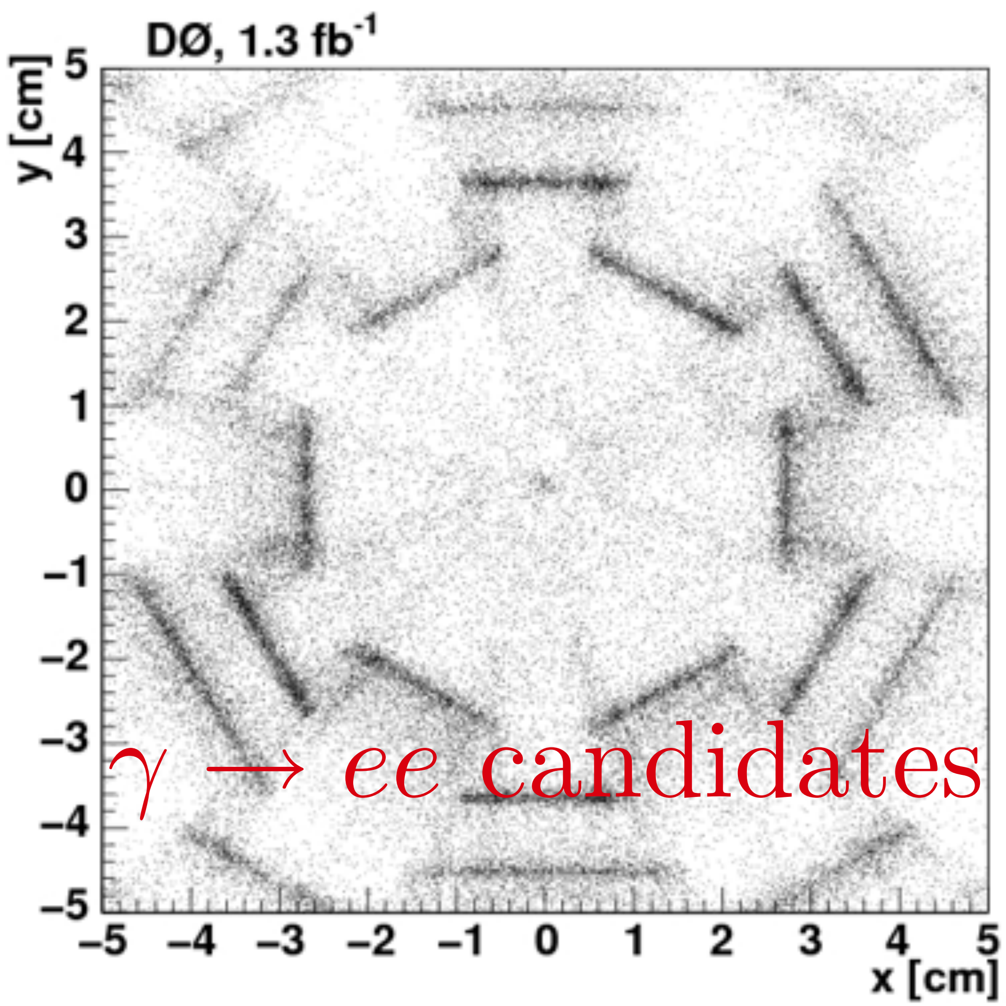
- Investigation of the observation by ATLAS [PRL **108** 152001 (2012) , arXiv.org:1112.5154]

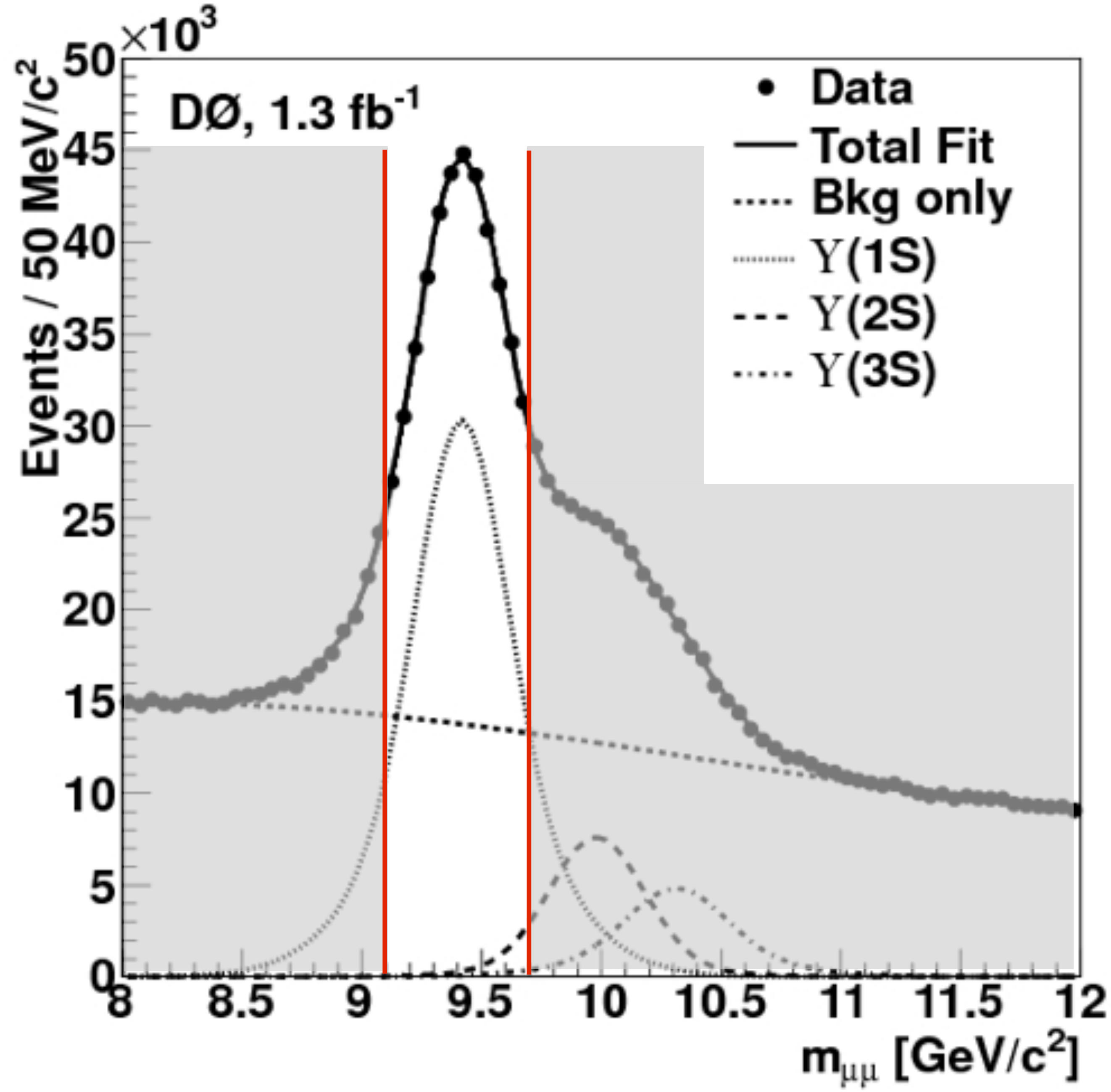


arxiv.org:1203.6034 (Submitted to PRD)

Narrow state decaying to $\Upsilon(1S) + \gamma$

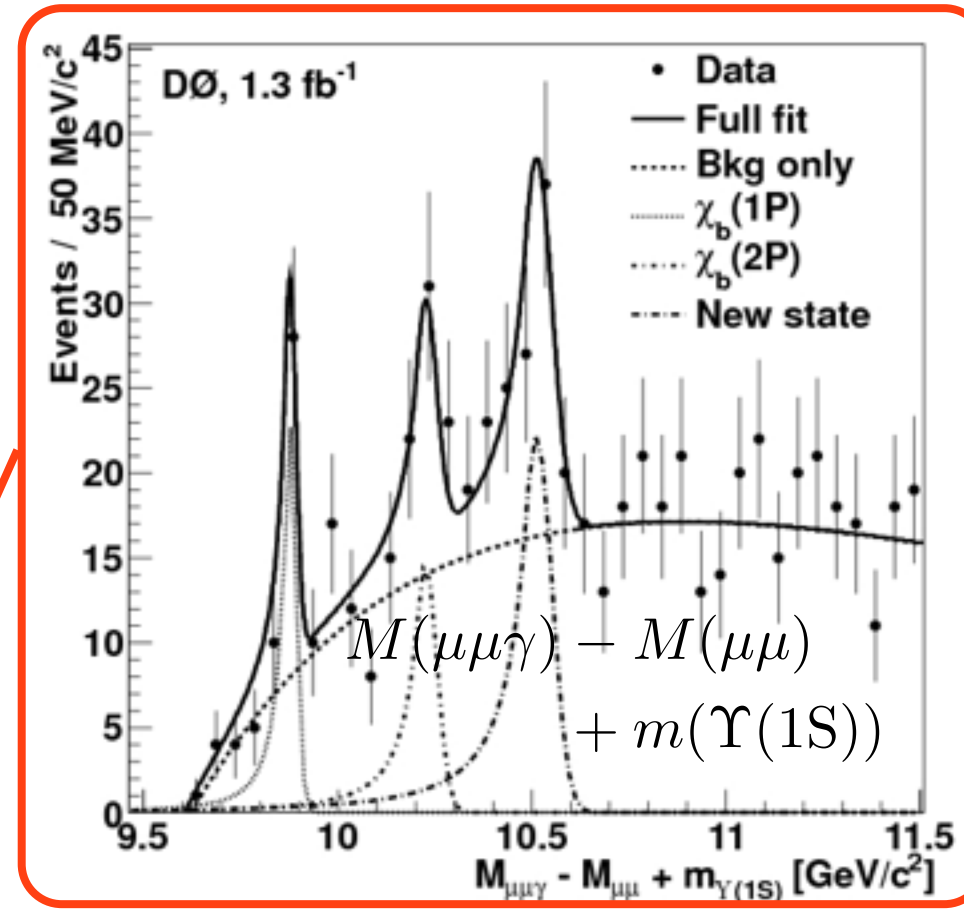
- Investigation of the observation by ATLAS [PRL **108** 152001 (2012) , arXiv.org:1112.5154]
- We reconstruct ϒ to dimuon + gamma to ee using 1.3 fb^{-1}

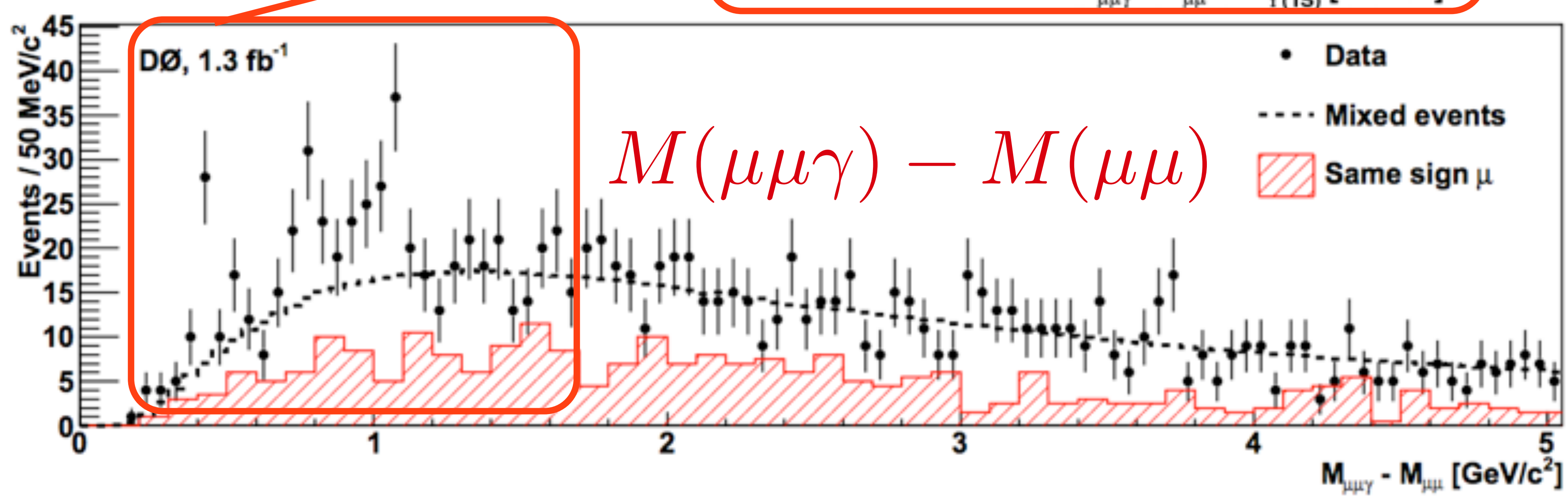




Narrow state decaying to $\Upsilon(1S) + \gamma$

- χ_b(1P,2P) observed consisted with W.A.
- BG modelled by event mixing
- A third state can be fitted
- This analysis can not determine if it is a new χ_b state or an exotic *b* state
- 65 ± 11 events in third peak





Narrow state decaying to $\Upsilon(1S) + \gamma$

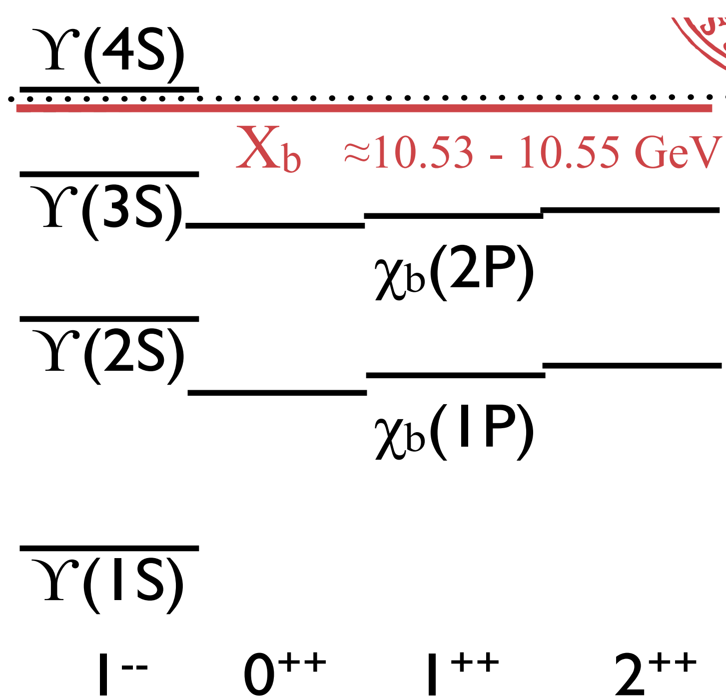
$$\text{DØ}\ M(X) = 10.551 \pm 0.014(\text{stat}) \pm 0.016(\text{syst})\text{GeV}/c^2$$

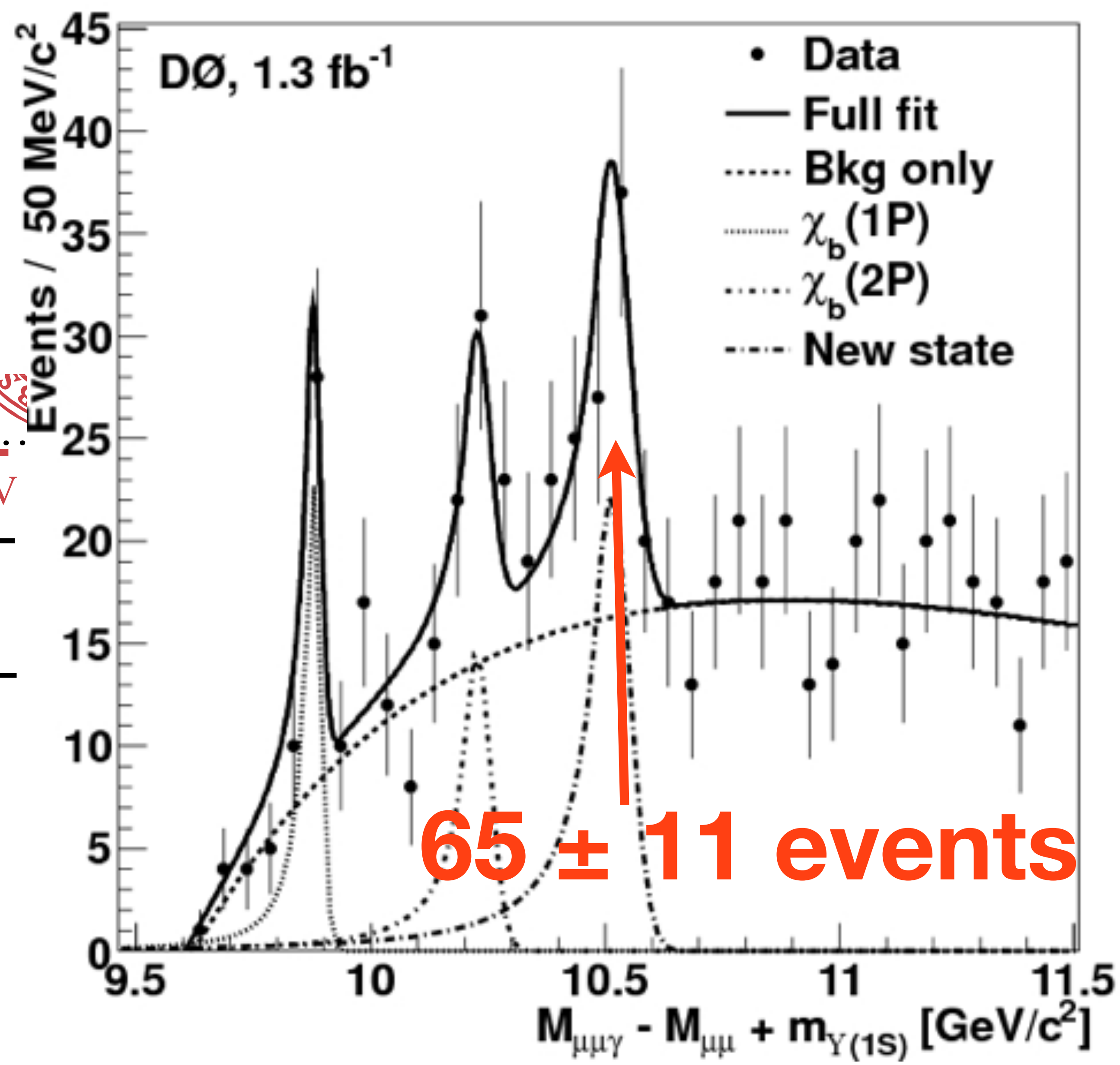
$$\text{ATLAS}\ M(X) = 10.530 \pm 0.005(\text{stat}) \pm 0.009(\text{syst})\text{GeV}/c^2$$

- Further studies are being performed
- More data to be used
- Branching ratios?
- Spin structure?
- # states?

Kwong, Rosner
Phys.Rev.D38:279,1988
$m(\chi_b(3P)) \approx 10.520$ GeV

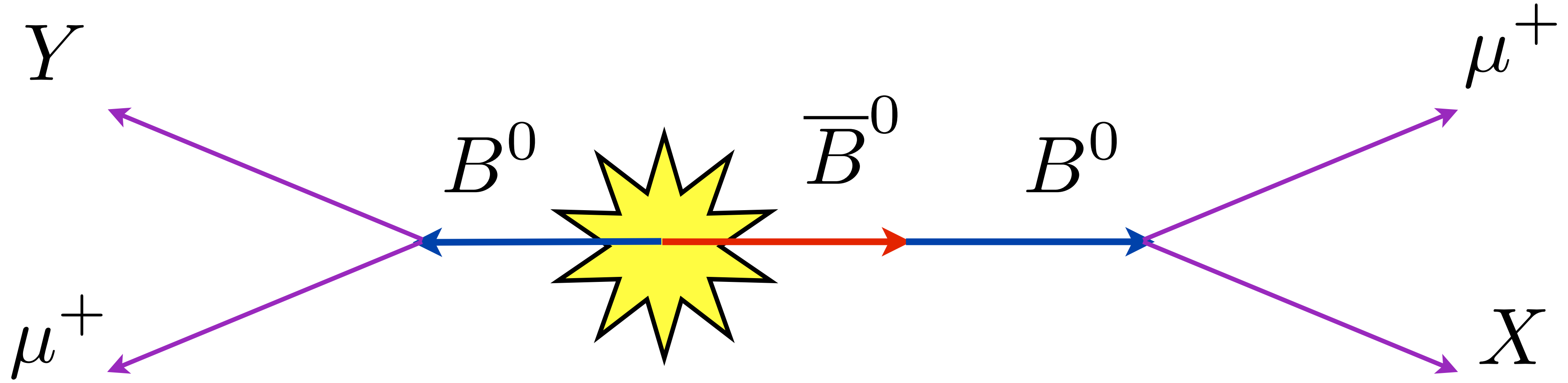
Törnqvist
Phys.Lett.B590:209-215,2004
$m(B\bar{B}^*) \approx 10.545$ GeV





arxiv.org:1106.6308 PRD **84** 052007 (2011)

Anomalous like-sign dimuon asymmetry



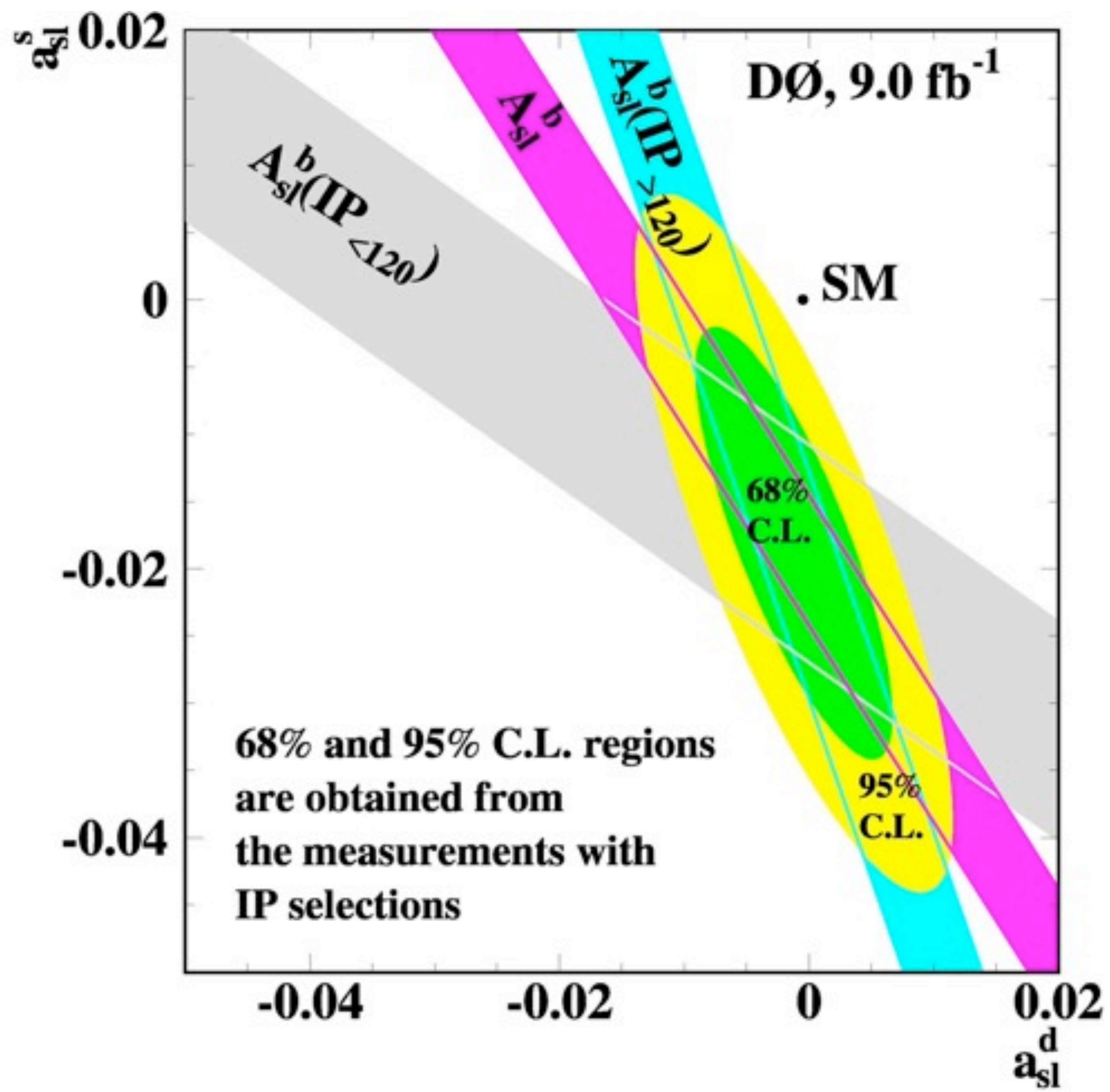
$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$
$$= C_d a^d_{sl} + C_s a^s_{sl}$$

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

Anomalous like-sign dimuon asymmetry

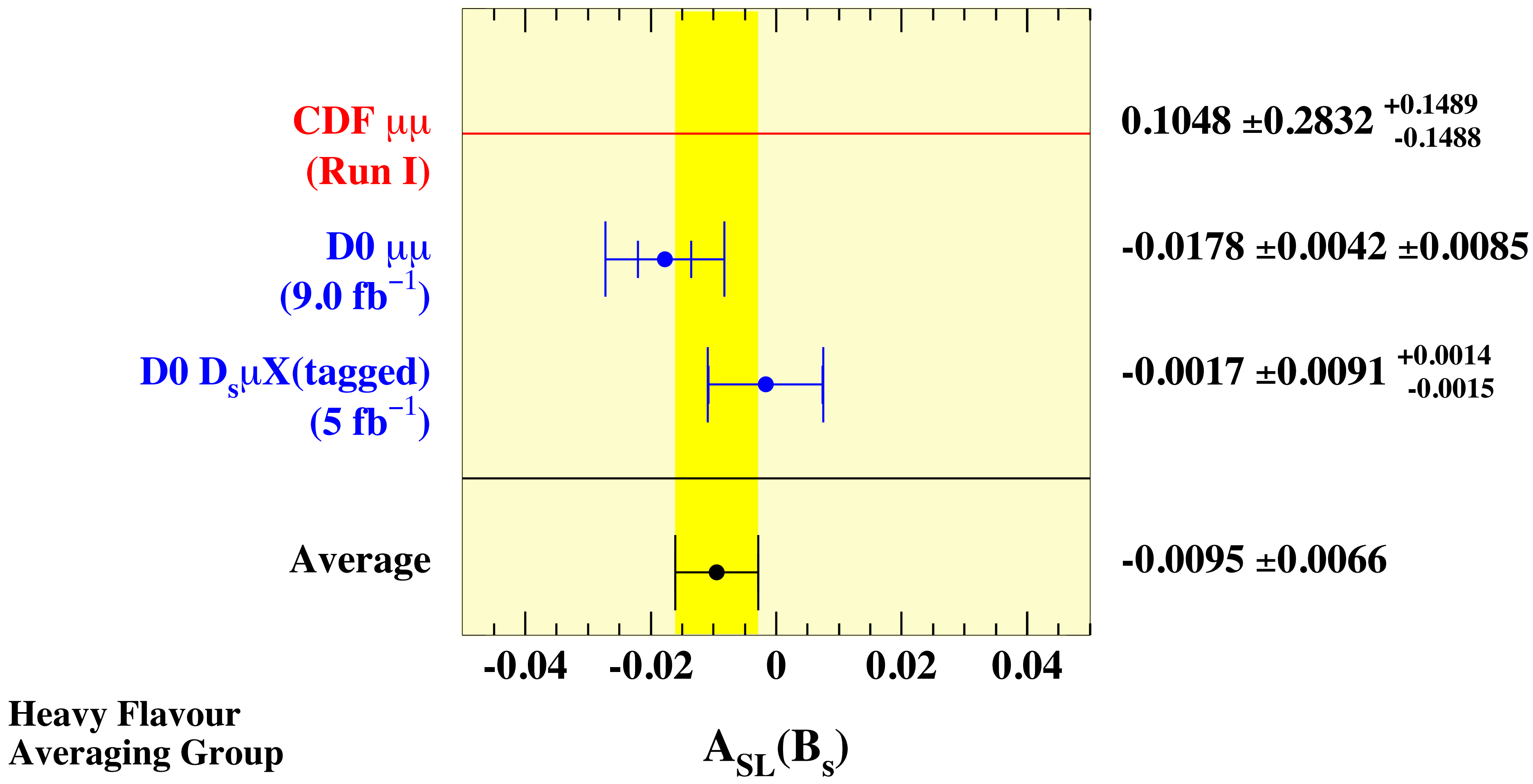
$$A^b_{sl} = (-0.787 \pm 0.172(\mathrm{stat}) \pm 0.093(\mathrm{syst}))\,\%$$
$$a^d_{\mathrm{sl}} = (-0.12 \pm 0.52)\%,$$
$$a^s_{\mathrm{sl}} = (-1.81 \pm 1.06)\%.$$

- 3.9σ deviation from SM expectations
- Two time-integrated flavour specific studies are being conducted to extract a^s_{sl} and a^d_{sl}
- Independent and complimentary to A^b_{sl} + IP studies



Semi-leptonic charge asymmetry a^s_{sl}

a^s_{sl} is the time-integrated semi-leptonic charge asymmetry



$$a^s_{sl}(\text{S.M.}) = (2.06 \pm 0.57) \times 10^{-5}$$

(arXiv:1102.4274)
A. Lenz & U. Nierste, JHEP06 072 (2007)

$$a^s_{sl}(\text{DØ prev.}) = [-1.7 \pm 9.1^{+1.2}_{-2.3}] \times 10^{-3}$$

Semi-leptonic charge asymmetry a^s_{sl}

$$a^s_{sl} = \frac{\Gamma(\overline{B}^0_s \to B^0_s \to \mu^+ X) - \Gamma(B^0_s \to \overline{B}^0_s \to \mu^- X)}{\Gamma(\overline{B}^0_s \to B^0_s \to \mu^+ X) + \Gamma(B^0_s \to \overline{B}^0_s \to \mu^- X)}$$

$$a^s_{sl} = \frac{A_{\text{raw}} - A_{\text{background}}}{f_{B^0_q(\text{osc})}}$$

$$A_{\text{raw}} = \frac{N(\mu^+) - N(\mu^-)}{N(\mu^+) + N(\mu^-)}$$

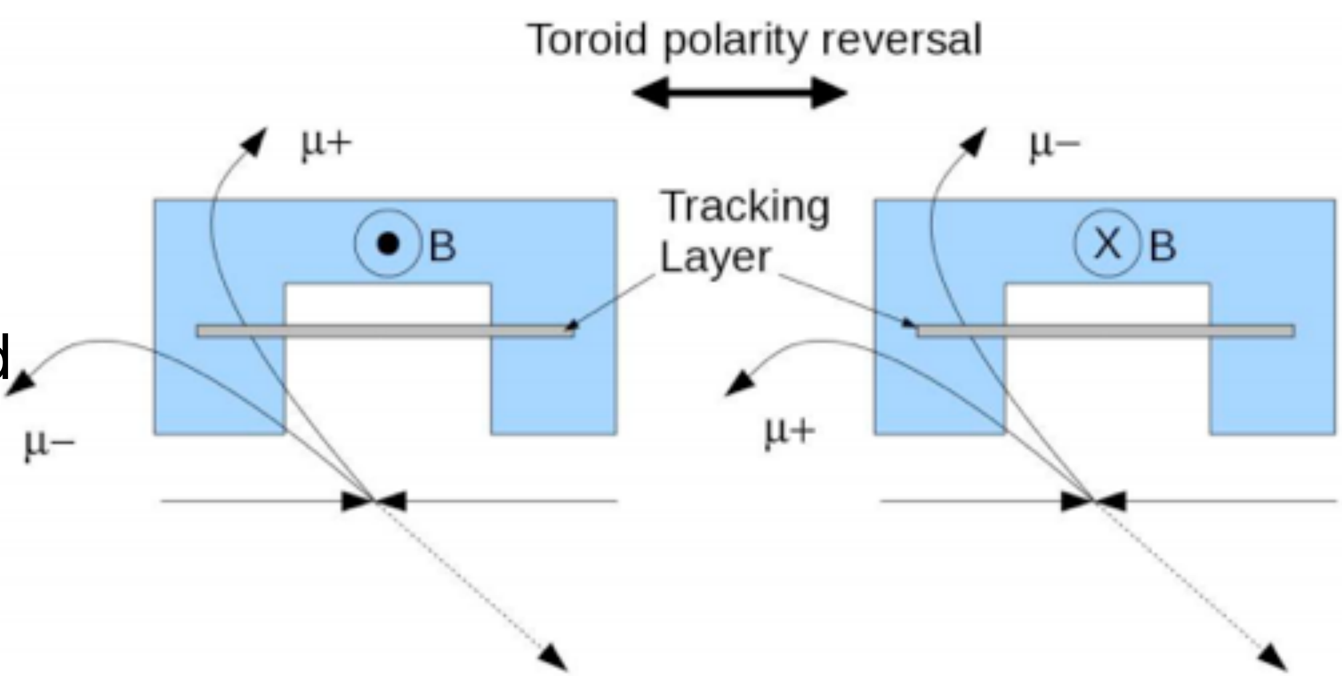
- Use the lepton charge to tell between B^0_s and anti-B^0_s at decay
- $A_{\text{background}}$ is comprised of A_μ and A_{track}: muon and charged track reconstruction efficiency asymmetries.
- $f_{B0s}(\text{osc})$, the fraction of candidates that originated from an oscillated B^0_s, is a dilution factor.

Semi-leptonic charge asymmetry a^s_{sl}

- Residual first order detector asymmetries:
    - reco efficiency may be asymmetric between positive and negative tracks
    - The DØ detector's solenoidal and toroidal magnet systems regularly had their polarities independently reversed
    - Weight each event per toroid-solenoid polarity combination - contribution from each combination equal
    - acceptance becomes equal

$$w_{\pm,\pm} = \frac{N_{\min}}{N_{\pm,\pm}}$$

- $w_{\pm,\pm}$ is the weight for toroid,solenoid polarity
- N from event counting or fitting



Preliminary

Semi-leptonic charge asymmetry a^s_{sl}

$$a^s_{sl} = \frac{A_{\text{raw}} - A_{\text{background}}}{f_{B^0_q(\text{osc})}}$$

$$A_{\text{raw}} = \frac{N(\mu^+) - N(\mu^-)}{N(\mu^+) + N(\mu^-)}$$

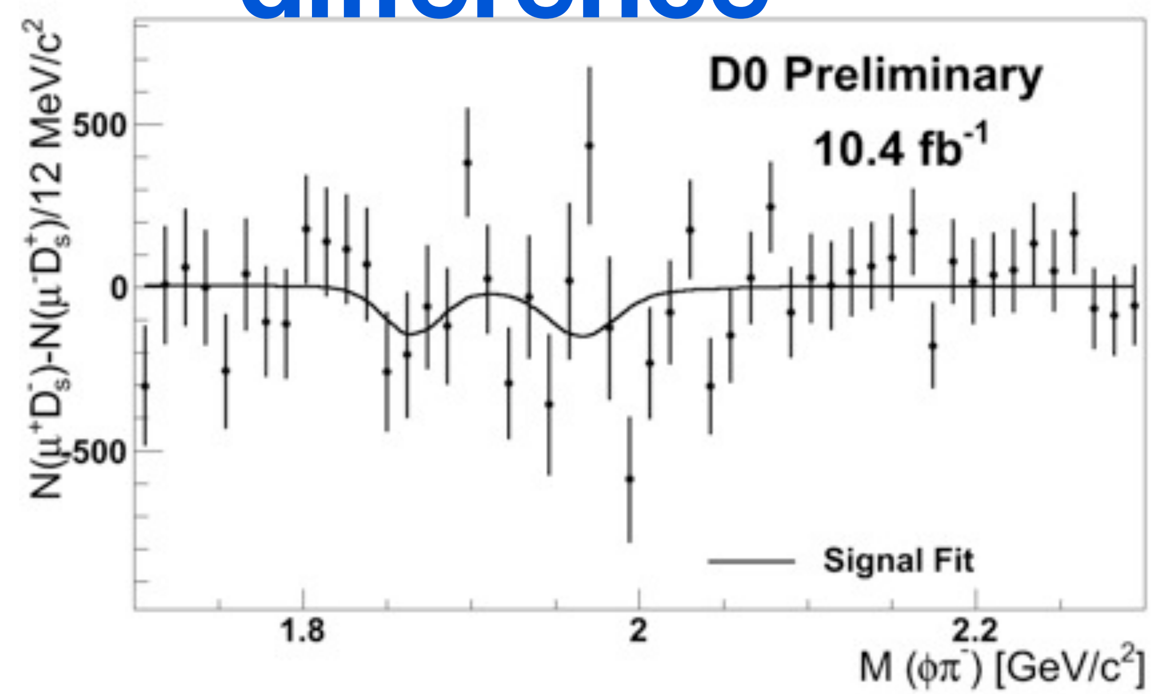
$$B^0_s \to D^-_s \mu^+ X$$

$$D^-_s \to \phi\pi^-$$

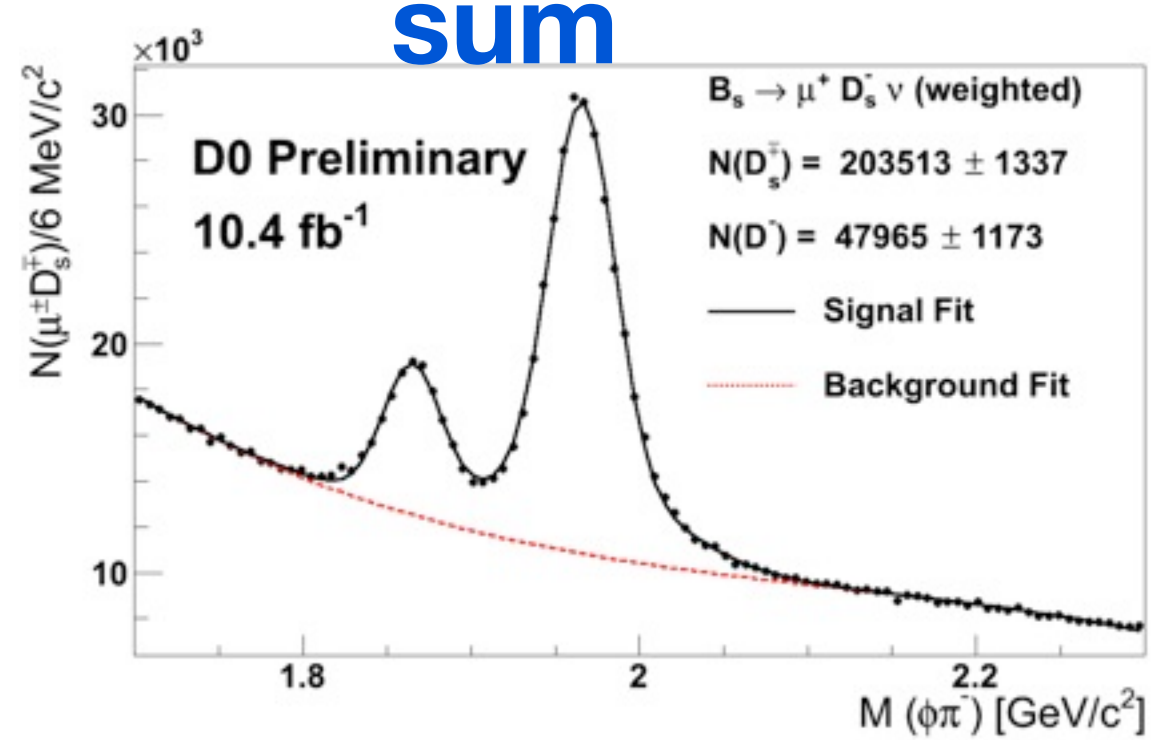
$$\phi \to K^+ K^-$$

- Non-lifetime biasing cuts + LLR determinant
- Blinded sensitivity tests performed
- Sum and difference fitted simultaneously
- F(sum) = $F^{sig}(D^+_s) + F^{sig}(D^+) + F^{bck}$
- F(diff) = $A_{raw}F^{sig}(D^+_s) + A_{D+}F^{sig}(D^+) + A_{bck}F^{bck}$

difference



sum



Semi-leptonic charge asymmetry a^s_{sl}

$$a^s_{sl} = \frac{A_{\text{raw}} + A_{\text{background}}}{f_{B^0_q}(\text{osc})}$$

- $A_{\text{background}}$ from muon, pion/additional track reconstruction efficiencies
- These were extracted by data driven dedicated studies
- A_{muon} extracted from data using tag and probe study, J/ψ
- Convolute A_{muon} with muon p_T
- From MC study of detector - pion track reco asymmetry found to be very small and positive, to effect of < 0.05%
- This is accounted as systematic uncertainty (0.05%)
- q(pi) = -q(mu), any remaining tracking asymmetry cancelled to first order
- Background correction. $A_{\text{background}}$ = [0.11 ± 0.03(stat) ± 0.05(syst)] %.

Semi-leptonic charge asymmetry a_{sl}^{s}

- Only oscillated B_s contribute to a^s_{sl}
- Determine fraction of muD_s events that come from B_s using simulated events
- Used latest oscillation frequency from LHCb and world averages
- ($\Delta M_s = 17.69 \pm 0.08\ \mathrm{ps}^{-1}$, $\Delta M_d = 0.507 \pm 0.004\ \mathrm{ps}^{-1}$)
- Correct for fraction of prompt D_s production
- Contamination from B_d negligible
  - ($\Delta a^s_{sl} = 0.005\%$ effect if $a^d_{sl} \sim 1\%$)
  - $fB^0_s = 0.465 \pm 0.017$

$$a_{sl}^{s} = \frac{A_{\mathrm{raw}} - A_{\mathrm{background}}}{f_{B_q^0(\mathrm{osc})}}$$

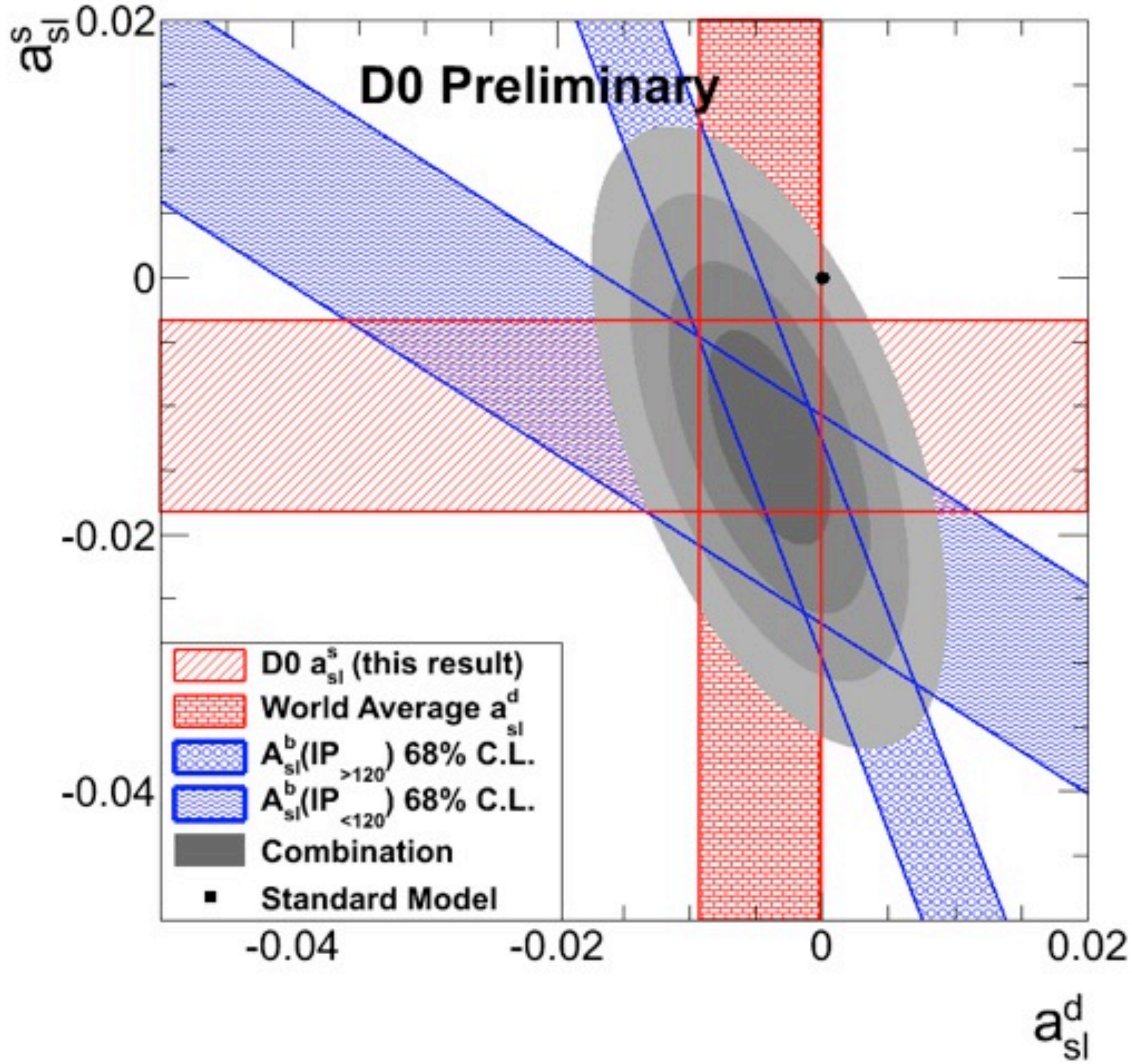
$$P(B_s^0 \to \overline{B}_s^0) = \frac{1}{2}\left[1 - \frac{\cos(\Delta M_s \cdot t)}{\cosh(\Delta\Gamma_s \cdot t)}\right]$$

$$P(B_d^0 \to \overline{B}_d^0) = \frac{1}{2}\left[1 - \frac{\cos(\Delta M_d \cdot t)}{\cosh(\Delta\Gamma_d \cdot t)}\right]$$

Semi-leptonic charge asymmetry a^s_{sl}

$$a^s_{sl} = [-1.08 \pm 0.72 \text{ (stat.)} \pm 0.16 \text{ (syst.)}] \ \%$$

- Consistent with both SM prediction and anomalous dimuon results
- Most precise single measurement of a^s_{sl} to date
- Combination with anomalous dimuon asymmetry:
  - $a^s_{sl} = (-1.25 \pm 0.55)$ %
  - $a^d_{sl} = (-0.40 \pm 0.31)$ %
  - 3.4 standard deviation from SM



Summary

$B_s^0 \to J/\psi f_2'(1525)$

- DØ confirms channel, measured relative Br, investigates spin state

Λ_b lifetime $(\Lambda_b \to J/\psi \Lambda_0)$

- Updated lifetime measurement, agrees with HQE, disagrees with CDF

Narrow state decaying to $\Upsilon(1S) + \gamma$

- Decay confirmed, mass consistent with LHCb results

Time-integrated Semi-leptonic charge asymmetry a_{sl}^s

- Updated measurement, single most precise extraction of this value

and there is still much more to come from DØ!

BACKUP

CP – violating phase $\phi_s^{J/\psi\phi}$

- Standard model predication (M. Bona et al., JHEP **10** 081 2006)

$$\begin{aligned}\phi_s^{J/\psi\phi} &= -2\beta_s^{SM} \\ &= 2\arg[-V_{tb}V_{ts}^*/V_{cb}V_{cs}^*] \\ &= -0.038 \pm 0.002\end{aligned}$$

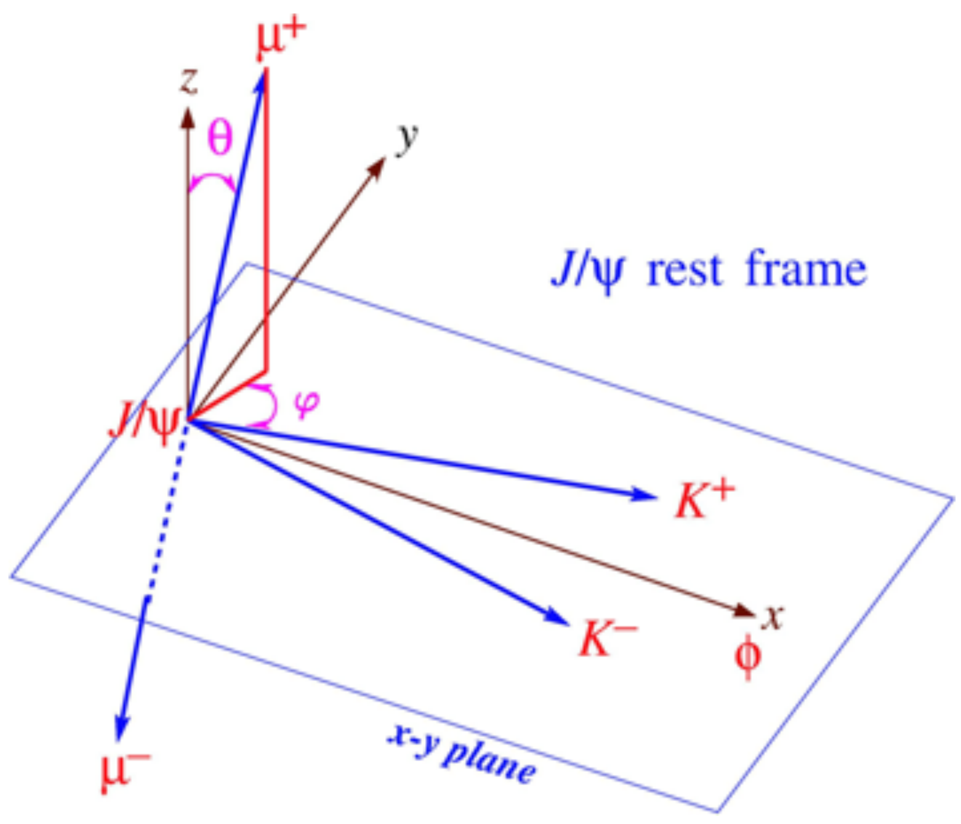
- CP violating phase in $b \to c\bar{c}s$
- New phenomena may alter phase
- Extract phase from time dependant amplitudes

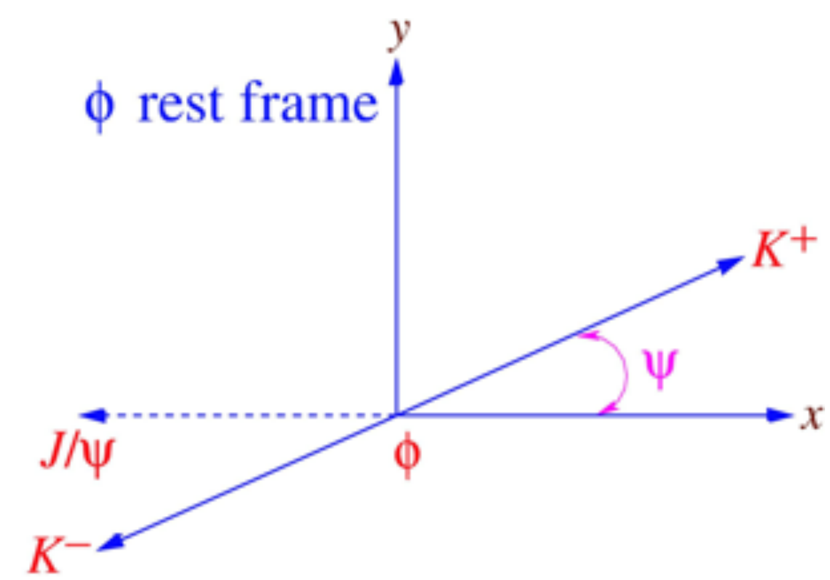
$$\mathcal{A}_i = F(t)[E_+(t) \pm e^{2i\beta_s} E_-(t)]a_i$$

$$\overline{\mathcal{A}}_i = F(t)[\pm E_+(t) + e^{-2i\beta_s} E_-(t)]a_i$$

$$F(t) = \frac{e^{-\Gamma_s t/2}}{\sqrt{\tau_H + \tau_L \pm \cos 2\beta_s(\tau_L - \tau_H)}}$$

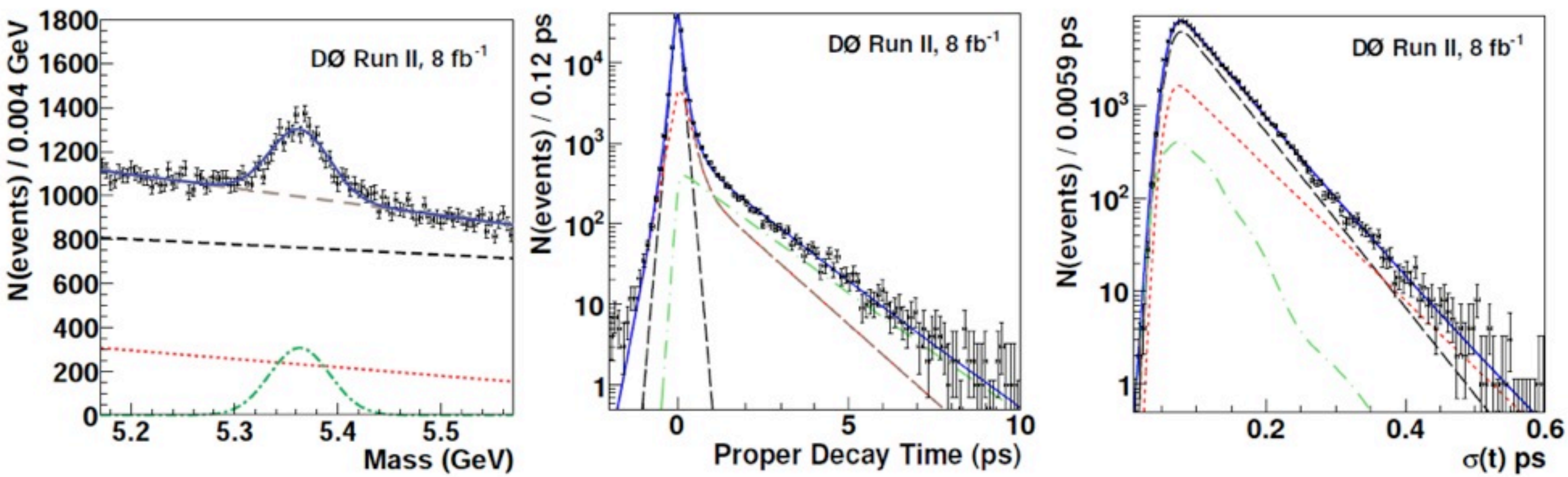
$$E_\pm \equiv \frac{1}{2}[e^{(\frac{-\Delta\Gamma_s}{4}+i\frac{\Delta M_s}{2})t} \pm e^{-(\frac{-\Delta\Gamma_s}{4}+i\frac{\Delta M_s}{2})t}]$$





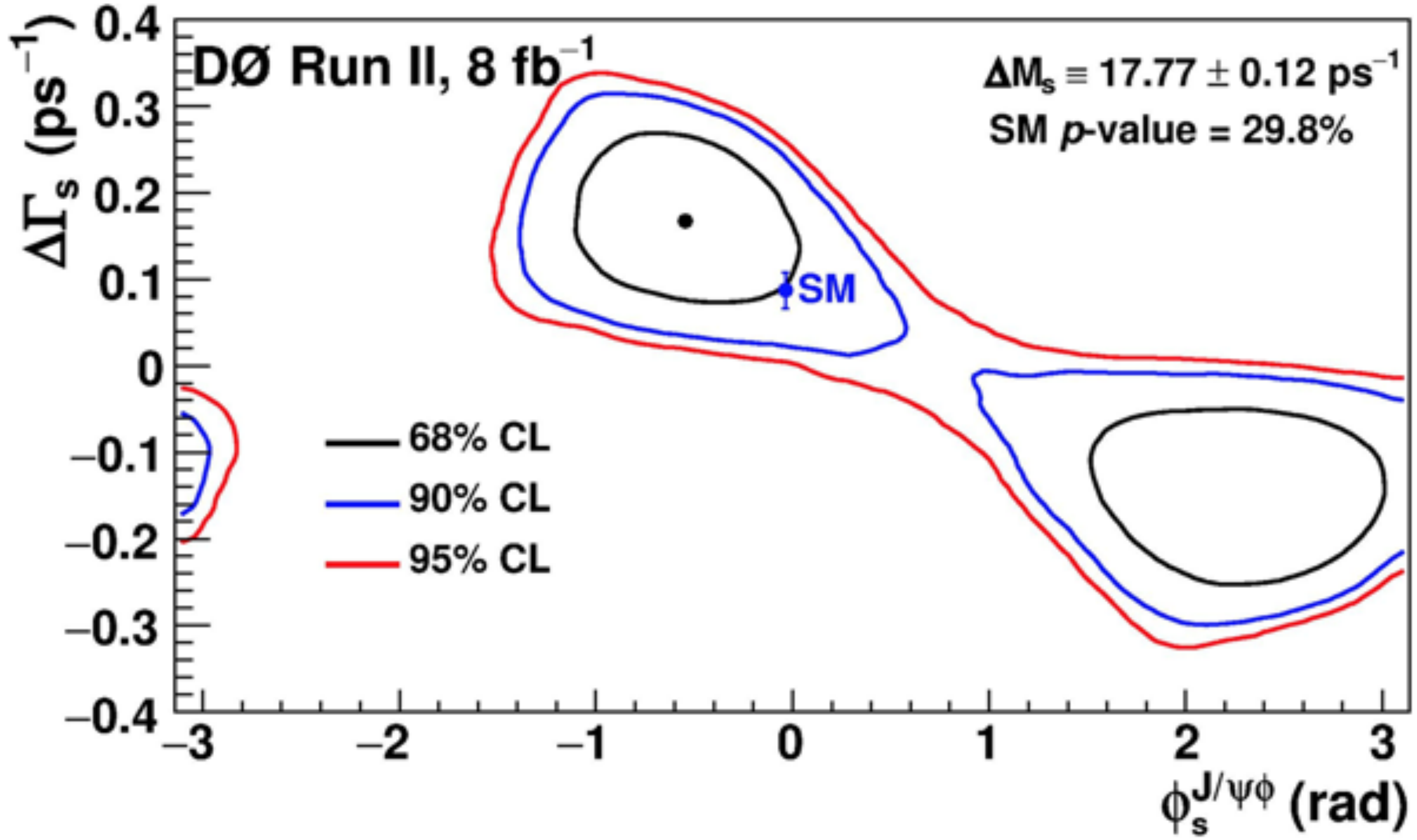
$CP-$violating phase $\phi_s^{J/\psi\phi}$

- Using 8 fb^{-1} of $B^0_s \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$
- Boosted Decision Tree for background suppression (simple cuts method also used)
- Opposite sign flavour tagging
- Oscillation frequency $\Delta M_s = 17.77 \pm 0.12$ ps^{-1} fixed
- 5598 ± 113 events from BDT sample, 5050 ± 105 from simple cuts



CP – violating phase $\phi_s^{J/\psi\phi}$

$$\overline{\tau}_s = 1.443^{+0.038}_{-0.035}\ \text{ps},$$
$$\Delta\Gamma_s = 0.163^{+0.065}_{-0.064}\ \text{ps}^{-1},$$
$$\phi_s^{J/\psi\phi} = -0.55^{+0.38}_{-0.36},$$
$$|A_0|^2 = 0.558^{+0.017}_{-0.019},$$
$$|A_{\|}|^2 = 0.231^{+0.024}_{-0.030},$$
$$\delta_{\|} = 3.15 \pm 0.22,$$
$$\cos(\delta_{\perp} - \delta_s) = -0.11^{+0.27}_{-0.25}.$$
$$F_S = 0.173 \pm 0.036,$$



- p-value for Standard Model ($\phi_s^{J/\psi\phi}$, $\Delta\Gamma_s$) = (-0.038,0.087ps^{-1}) = 29.8 %

$B_s^0 \to J/\psi f_2'(1525)$

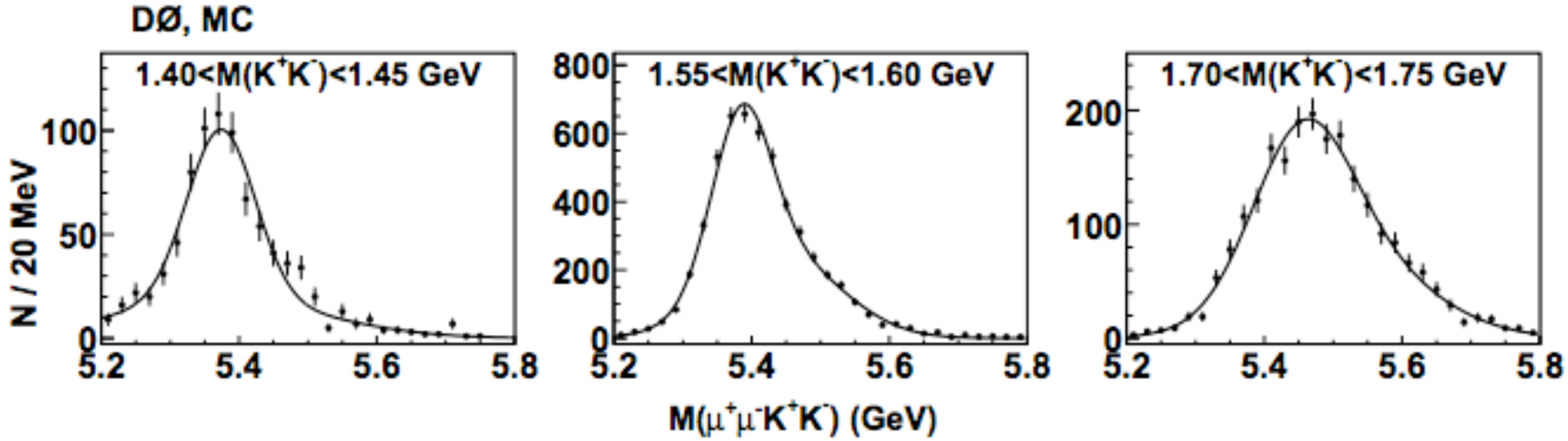


FIG. 4: Invariant mass of B^0 mesons from the simulated decay $B^0 \to J/\psi K_2^*(1430), K_2^*(1430) \to K^\pm\pi^\mp$, where the pion is assigned the kaon mass, for a sampling of different $M(K^+K^-)$ ranges. The distributions are fitted with a sum of two Gaussian functions with free masses, widths, and normalizations.

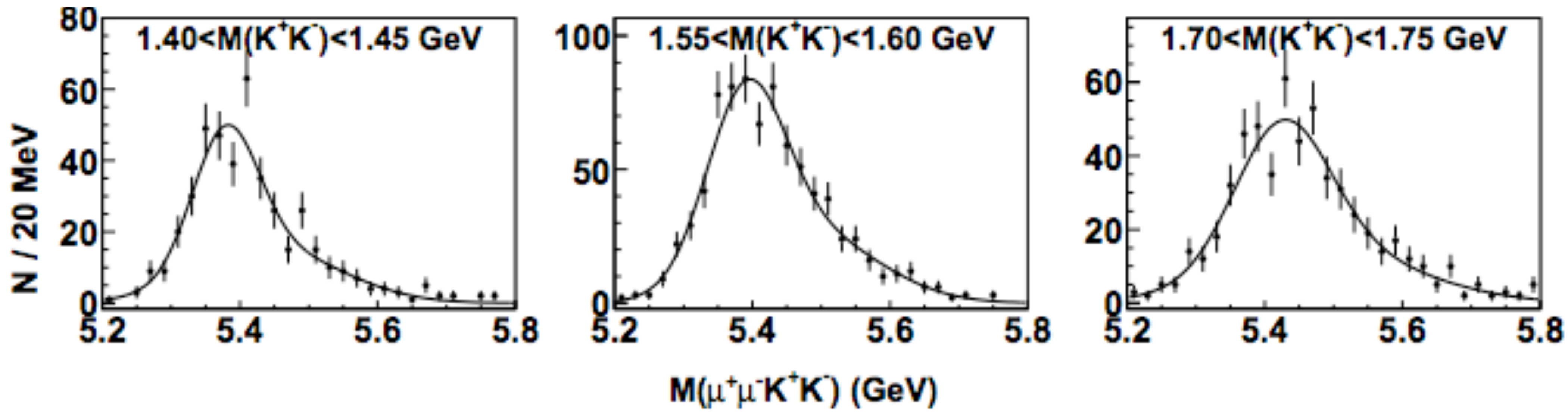
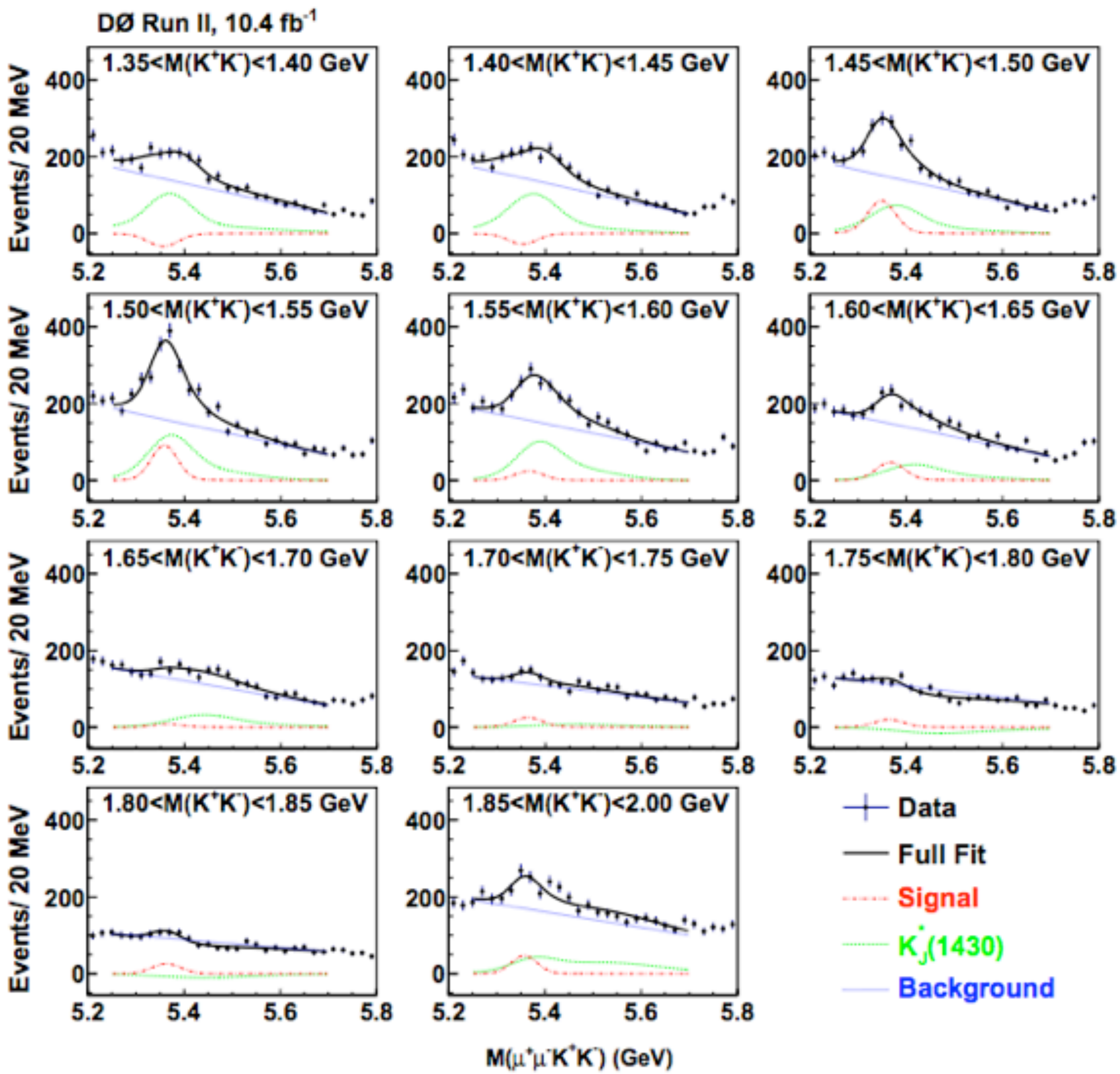
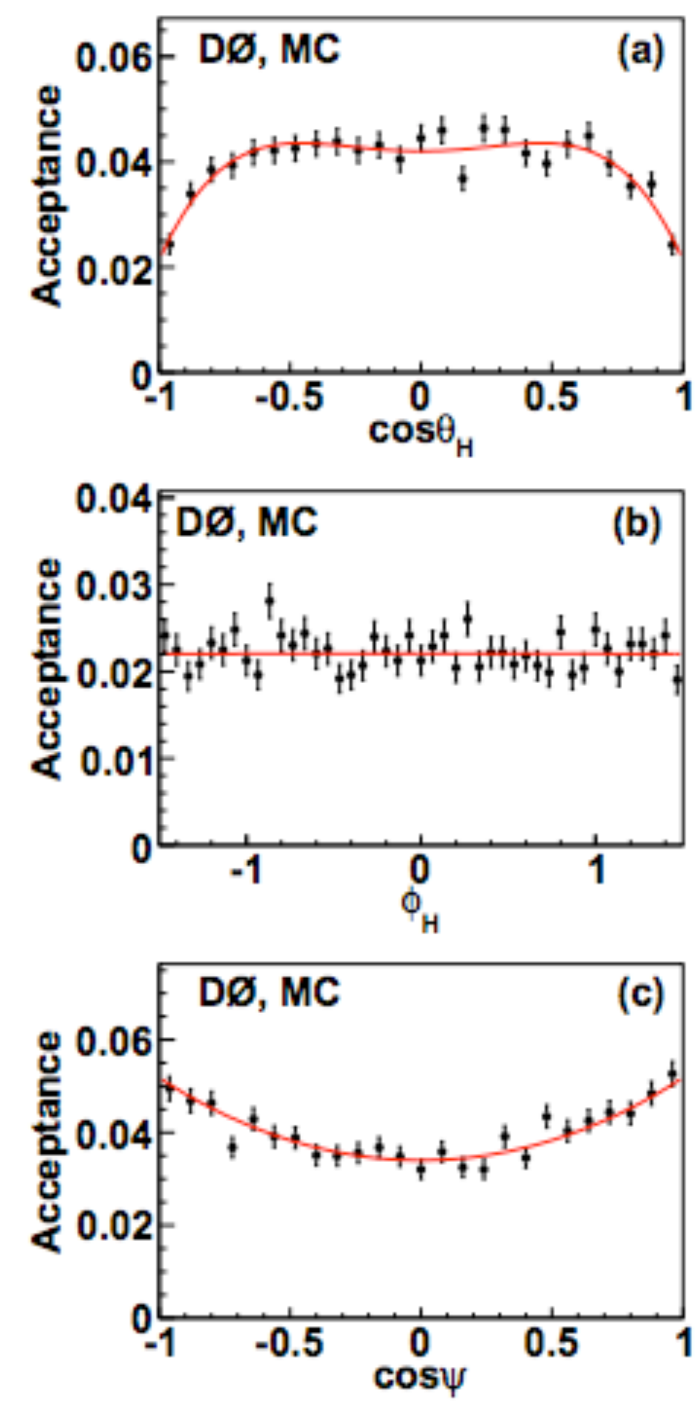


FIG. 5: Invariant mass of B^0 mesons from the simulated decay $B^0 \to J/\psi K_0^*(1430), K_0^*(1430) \to K^\pm\pi^\mp$, where the pion is assigned the kaon mass, for a sampling of different $M(K^+K^-)$ ranges. The distributions are fitted with a sum of two Gaussian functions with free masses, widths, and relative normalizations.

$$B_s^0 \to J/\psi f_2'(1525)$$





$B_s^0 \to J/\psi f_2'(1525)$

TABLE I: Sources of systematic relative uncertainty on $R_{f_2'/\phi}$.

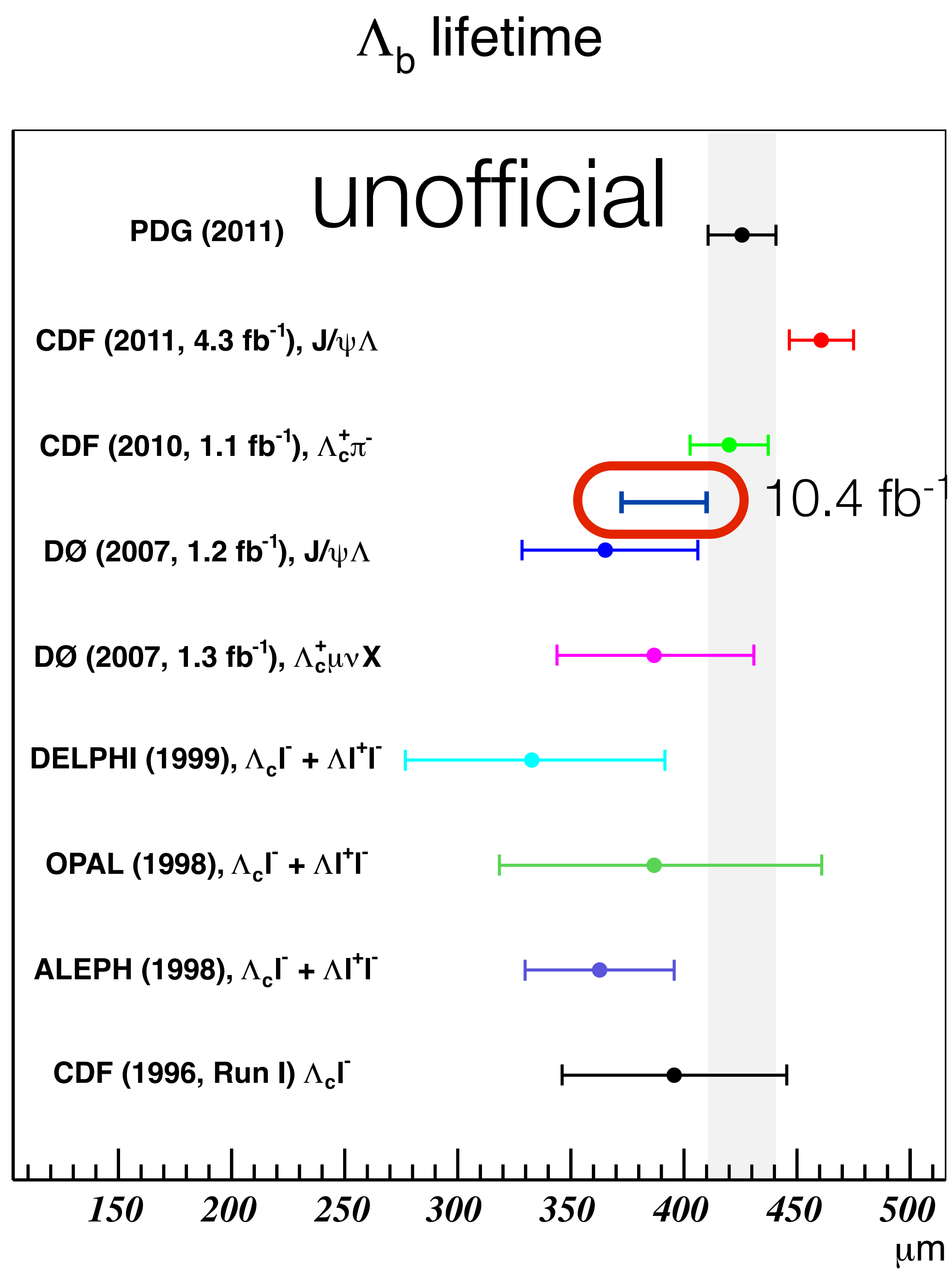
Source	Uncertainty (%)
$K_0^*(1430)$ width	5
$K_0^*(1430)$ template	7
Combinatorial background shape	10
Signal shape	12
Trigger efficiency	3
$M(K^+K^-)$ dependence of efficiency	2
Helicity dependence of efficiency	3
$f_2'(1525)$ mass	3
$f_2'(1525)$ natural width	1
Total	18

Λ_b lifetime ($\Lambda_b \rightarrow J/\psi\Lambda_0$)

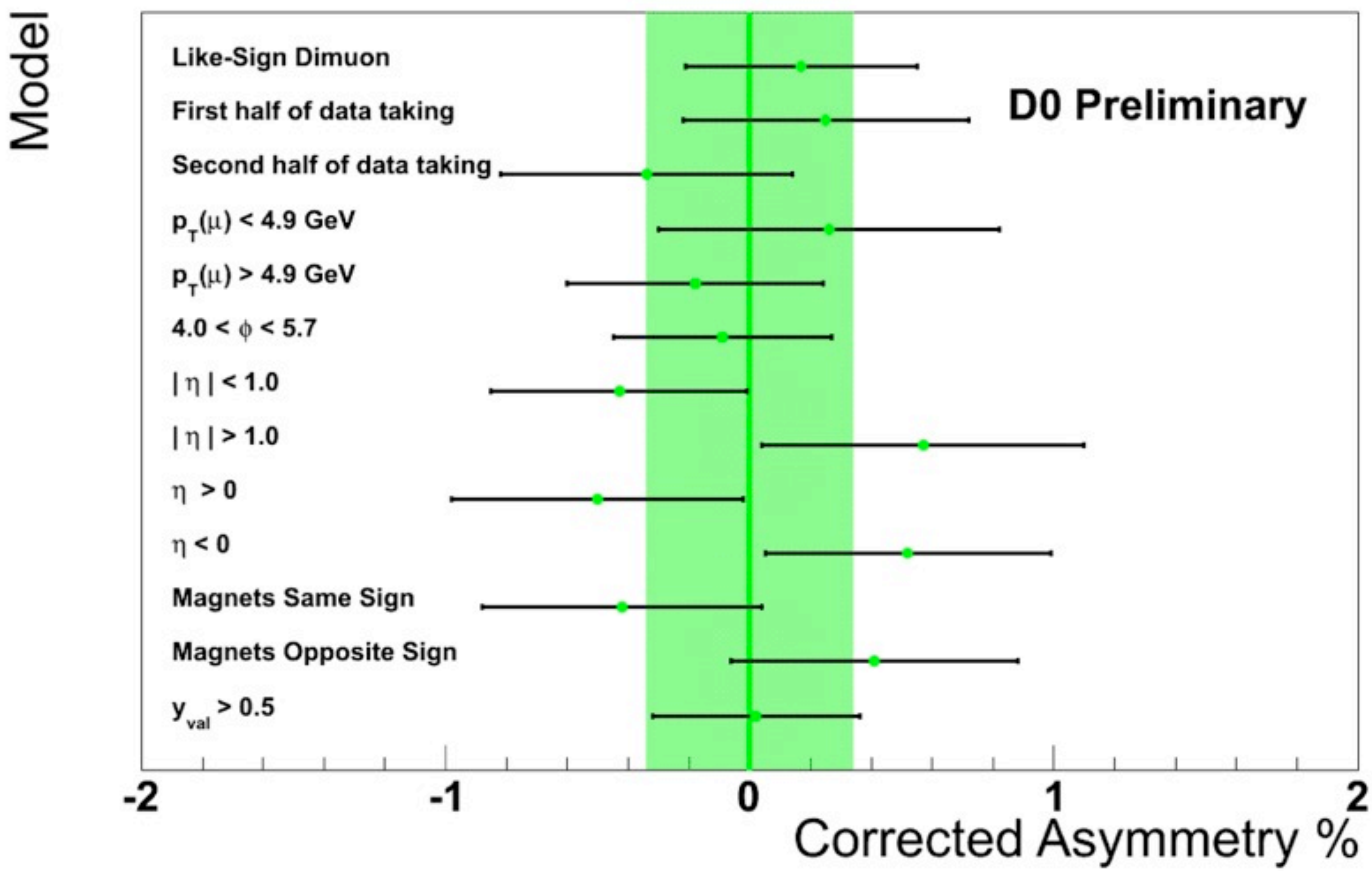
TABLE I: Summary of systematic uncertainties on the measurements of $c\tau(\Lambda_b^0)$ and $c\tau(B^0)$, and on their ratio. Individual uncertainties are combined in quadrature to obtain the total uncertainties.

Source	Λ_b^0 (μm)	B^0 (μm)	Ratio
Mass model	2.2	6.4	0.008
Proper decay length model	7.8	3.7	0.024
Proper decay length uncertainty	2.5	8.9	0.020
Partially reconstructed b hadrons	2.7	1.3	0.008
$B_s^0 \rightarrow J/\psi K_S^0$	–	0.4	0.001
Alignment	5.4	5.4	0.002
Total	10.4	12.9	0.033

Λ_b lifetime ($\Lambda_b \rightarrow J/\psi\Lambda_0$)

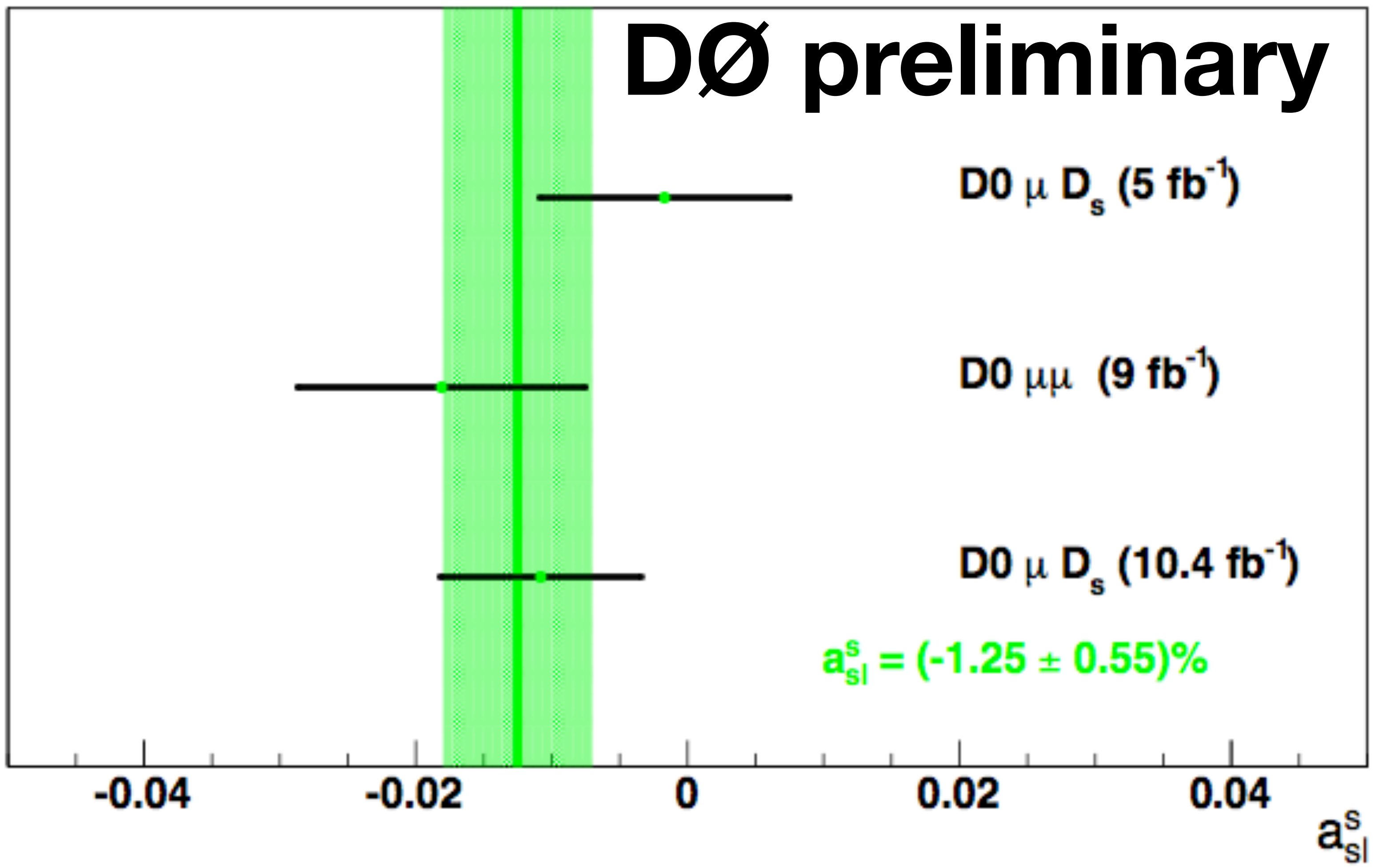


Semi-leptonic charge asymmetry a_{sl}^{s}

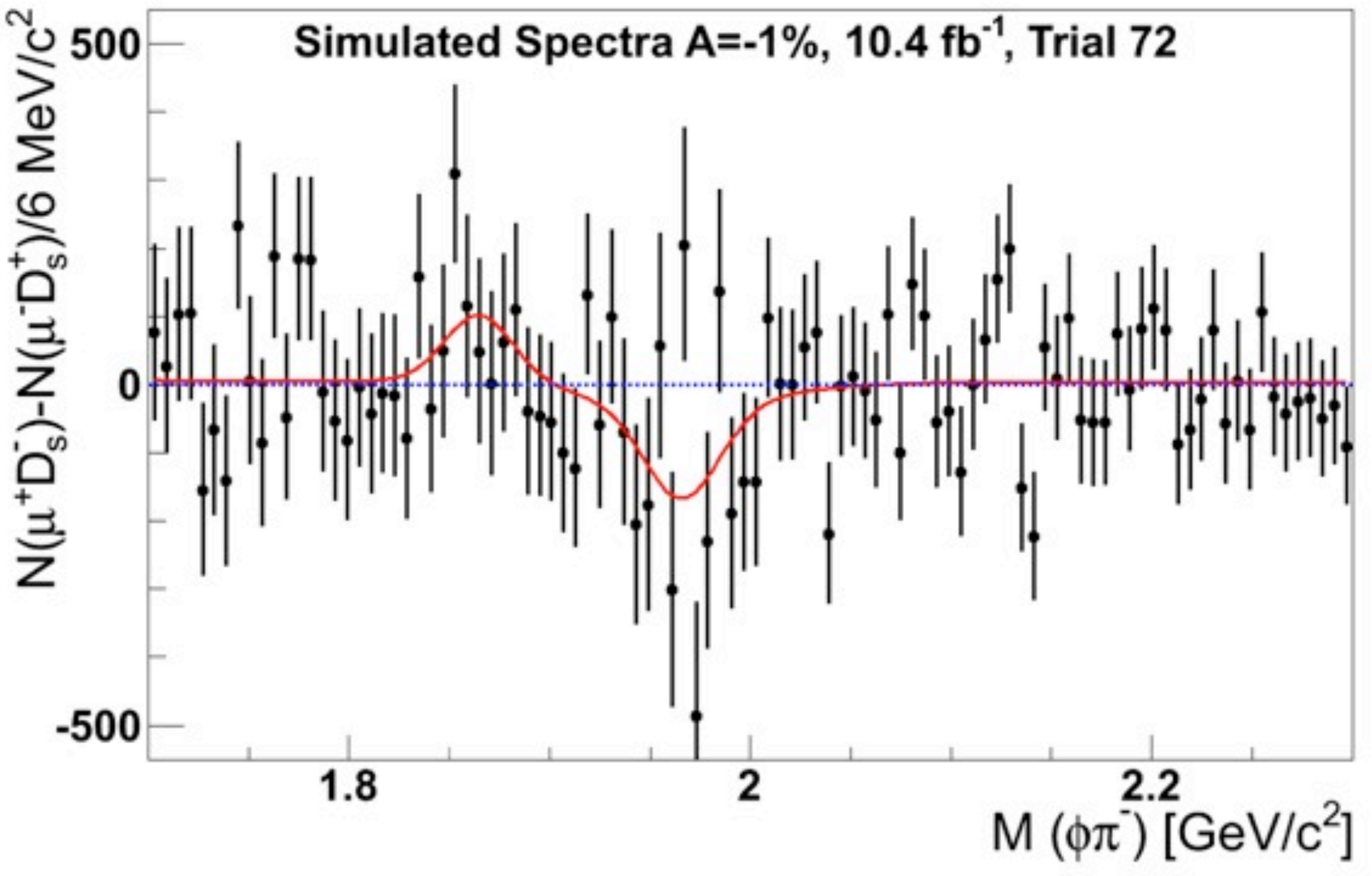


Cross checks

Semi-leptonic charge asymmetry a^s_{sl}



Semi-leptonic charge asymmetry a_{sl}^{s}



Simulated input from $A_{\mathrm{raw}} = -1\%$

Fitting functions:

$$F^{\mathrm{sig}}(D^+) = \frac{1}{\sqrt{2\pi}}\left(f_{D1}\frac{1}{\sigma_3}\exp\left[\frac{-(x-M_D)^2}{2\sigma_3^2}\right] + (1-f_{D1})\frac{1}{\sigma_4}\exp\left[\frac{-(x-M_D)^2}{2\sigma_4^2}\right]\right)$$

$$F^{\mathrm{sig}}(D_s^+) = \frac{1}{\sqrt{2\pi}}\left(f_{G1}\frac{1}{\sigma_1}\exp\left[\frac{-(x-M_{D_s})^2}{2\sigma_1^2}\right] + (1-f_{G1})\frac{1}{\sigma_2}\exp\left[\frac{-(x-M_{D_s})^2}{2\sigma_2^2}\right]\right)$$