Charge Asymmetries in Semi-Leptonic B Decays

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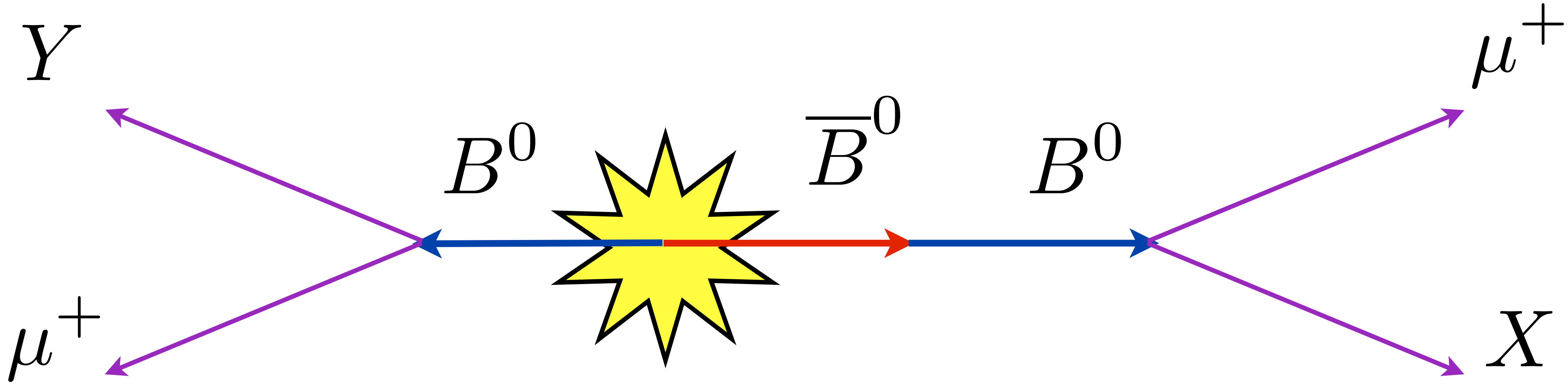
for the D0 Collaboration

ICHEP 2012 - Melbourne

7 July 2012

Anomalous like-sign dimuon asymmetry



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$
$$= C_d a_{sl}^d + C_s a_{sl}^s$$

where $a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q$

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

$C_{d(s)}$ is the fraction of $B_d(B_s)$ events in the data sample.

D0 - Dimuon Charge Asymmetry

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

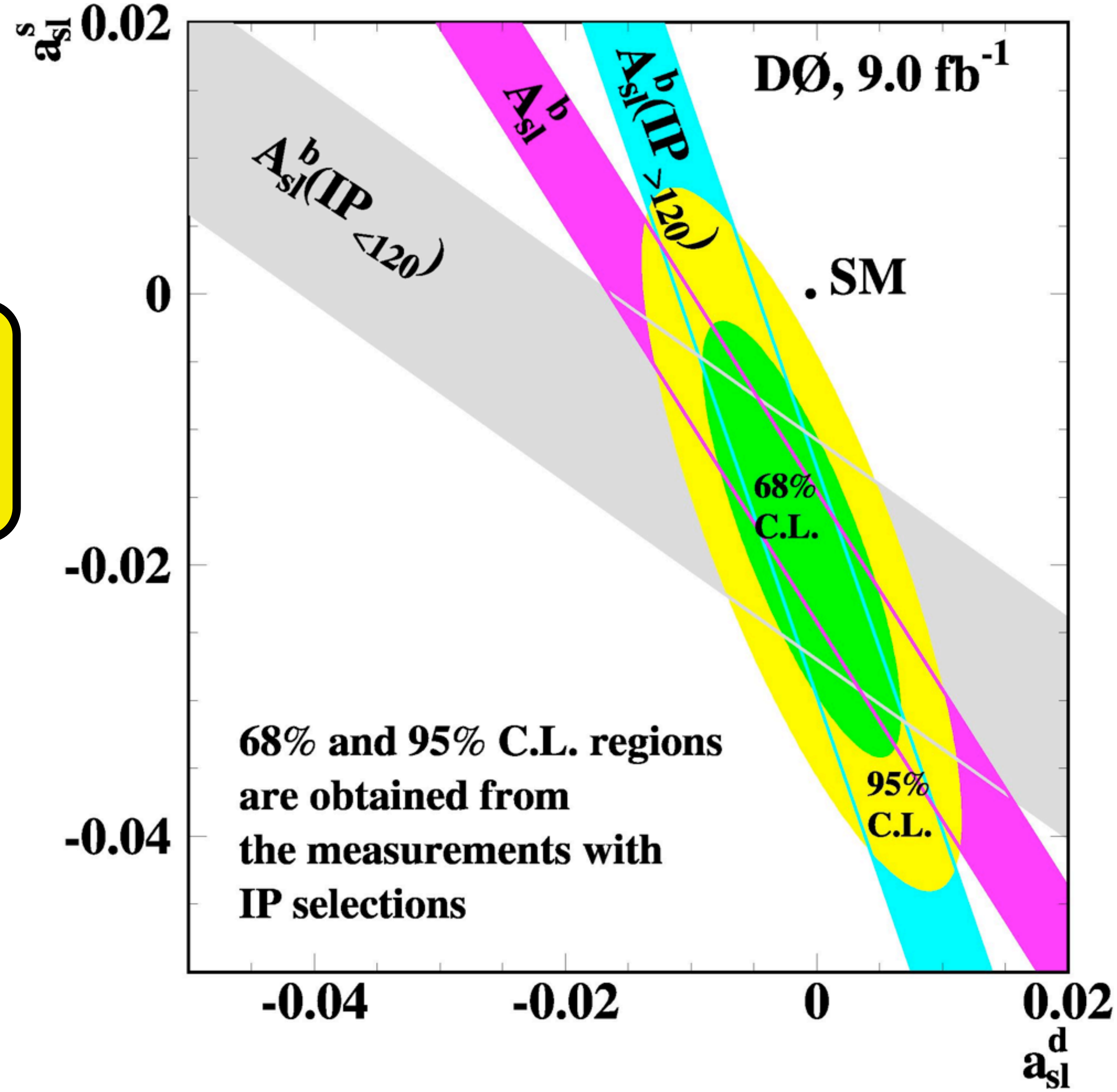
- Anomalous Dimuon - 3.9σ deviation from SM expectations
- Split the data (blue band, grey band):

$$a^d_{\text{sl}} = (-0.12 \pm 0.52)\%,$$
$$a^s_{\text{sl}} = (-1.81 \pm 1.06)\%.$$

- Need to investigate in as many different ways as possible.

SM Prediction

$$a^d_{\text{sl}} = (-4.1 \pm 0.6) \times 10^{-4},$$
$$a^s_{\text{sl}} = (1.9 \pm 0.3) \times 10^{-5}.$$



(arXiv:1102.4274)

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

Semi-leptonic Charge asymmetries

$$a_{\rm sl}^q = \frac{\Gamma\left(\bar{B}_q^0 \to B_q^0 \to \ell^+\nu X\right) - \Gamma\left(B_q^0 \to \bar{B}_q^0 \to \ell^-\bar{\nu}\bar{X}\right)}{\Gamma\left(\bar{B}_q^0 \to B_q^0 \to \ell^+\nu X\right) + \Gamma\left(B_q^0 \to \bar{B}_q^0 \to \ell^-\bar{\nu}\bar{X}\right)},$$

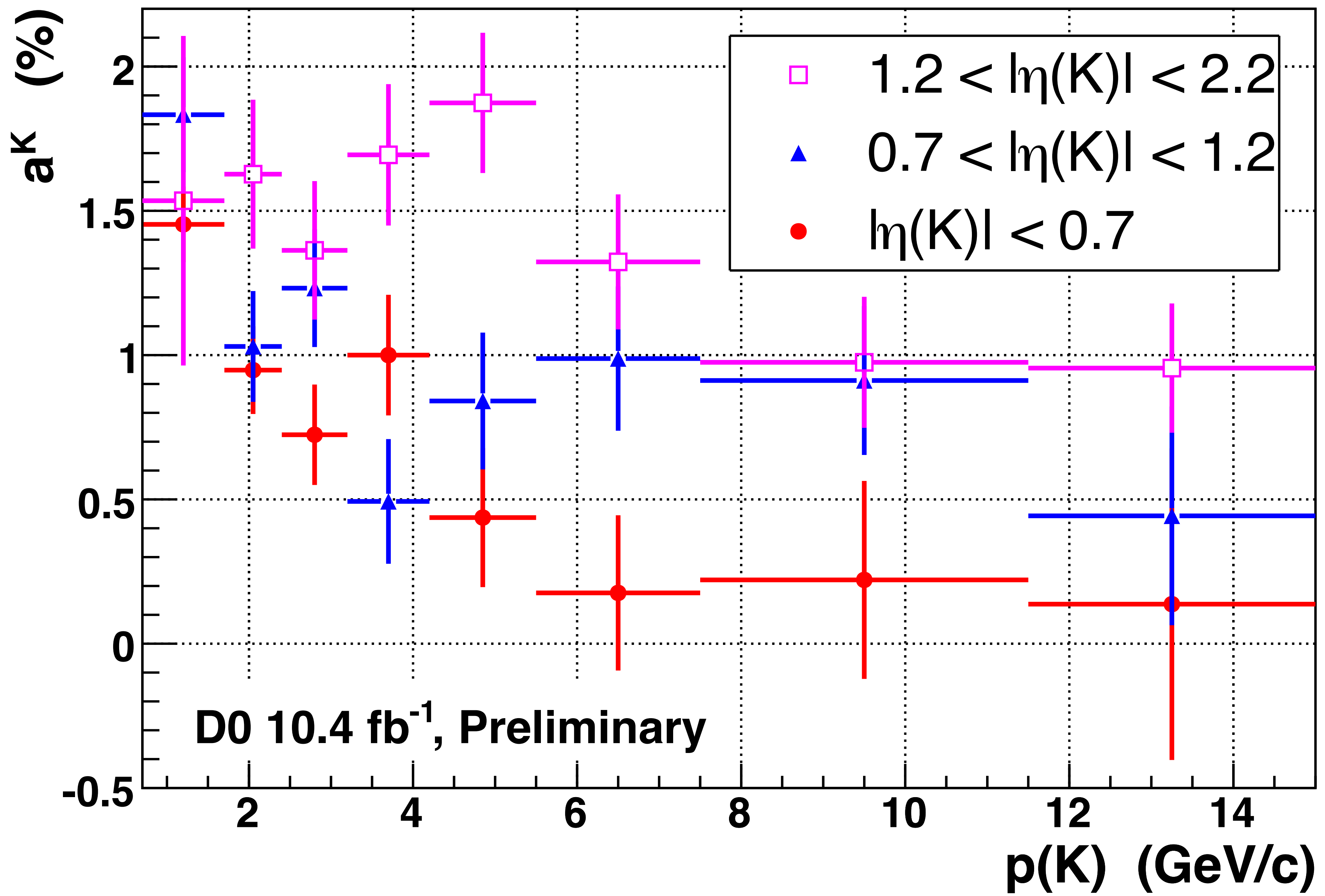
$$a_{\rm sl}^q = \frac{A - A_{\rm bg}}{F_{B_q^0}^{\rm osc}}$$

$$A = \frac{N(\mu^+ D_q^{(*)-}) - N(\mu^- D_q^{(*)+})}{N(\mu^+ D_q^{(*)-}) + N(\mu^- D_q^{(*)+})}$$

- Use lepton charge to identify the B-meson flavour
- Correct for detector and physics background asymmetries
- Scale by the fraction of mixed events (using MC simulations)
- Assume no production asymmetry, no direct CP violation in charged D-mesons or B-meson semileptonic decay, only CP violation in mixing for B mesons.

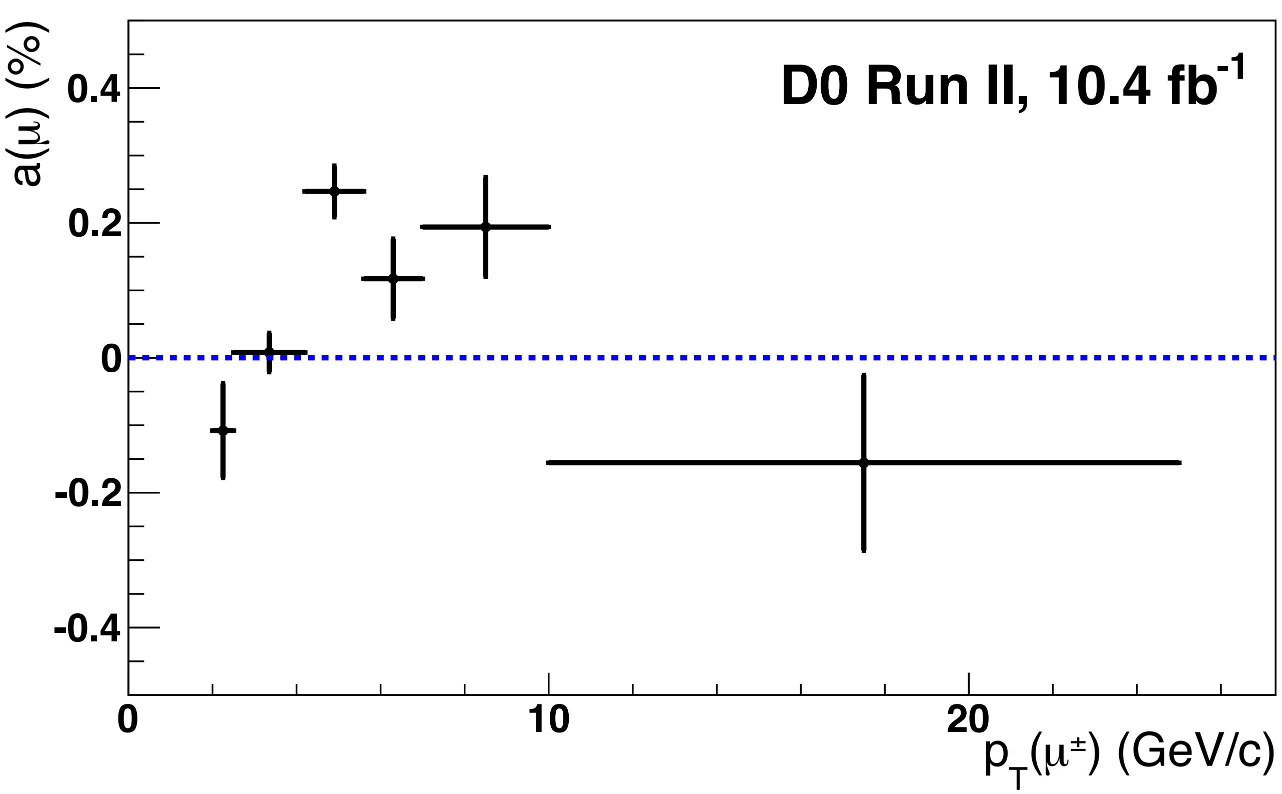
Kaon Corrections

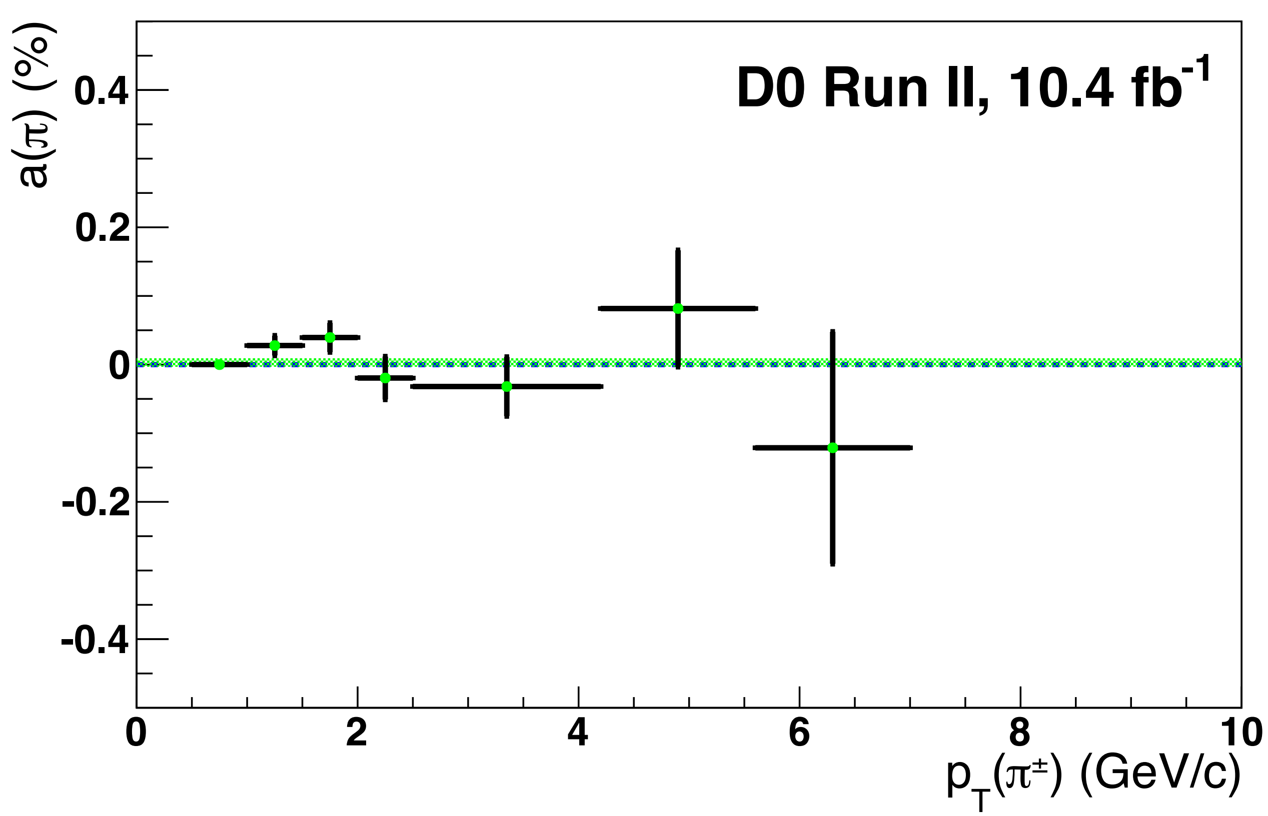
- K^+ and K^- have very different interaction cross sections
- Use the decay $K^* \rightarrow K\pi$ to measure the asymmetry as a function of momentum and η



Residual Muon and Track Asymmetries

- The residual muon p_T dependent reconstruction asymmetry between +ve and -ve tracks is measured using $J/\psi \to \mu\mu$ in a tag and probe analysis.
- Tracking asymmetry studied with $K_s \to \pi\pi$, $K^* \to K_s\pi$, plus other resonances showing no measurable correction
- See <0.05% effects in MC for pions - apply as a systematic



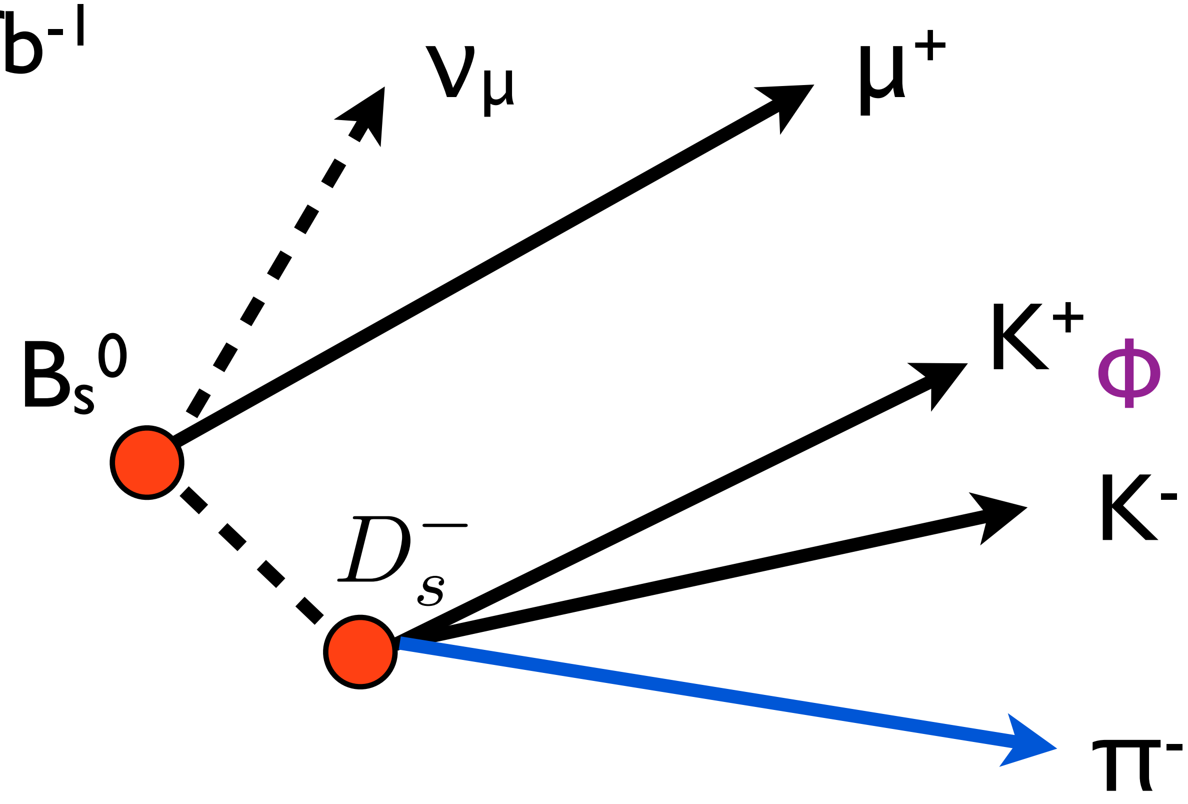


a^s_{sl} in $B_s^0 \to \mu^+ D_s^-$

- Select Data Sample from 10.4 fb^{-1}
- Extract raw asymmetry by fitting D_s resonance in the invariant mass spectrum:

$$\boxed{A = \frac{N_{\mu^+ D_s^-} - N_{\mu^- D_s^+}}{N_{\mu^+ D_s^-} + N_{\mu^- D_s^+}},}$$

- Correct for residual muon and tracking reconstruction asymmetries.
- Correct for dilution.
- Unblind after corrections are finalised



$$\boxed{a^s_{\mathrm{sl}} = \frac{A - A_\mu - A_{\mathrm{track}}}{F_{B_s^0\,\mathrm{osc}}},}$$

No need for kaon correction

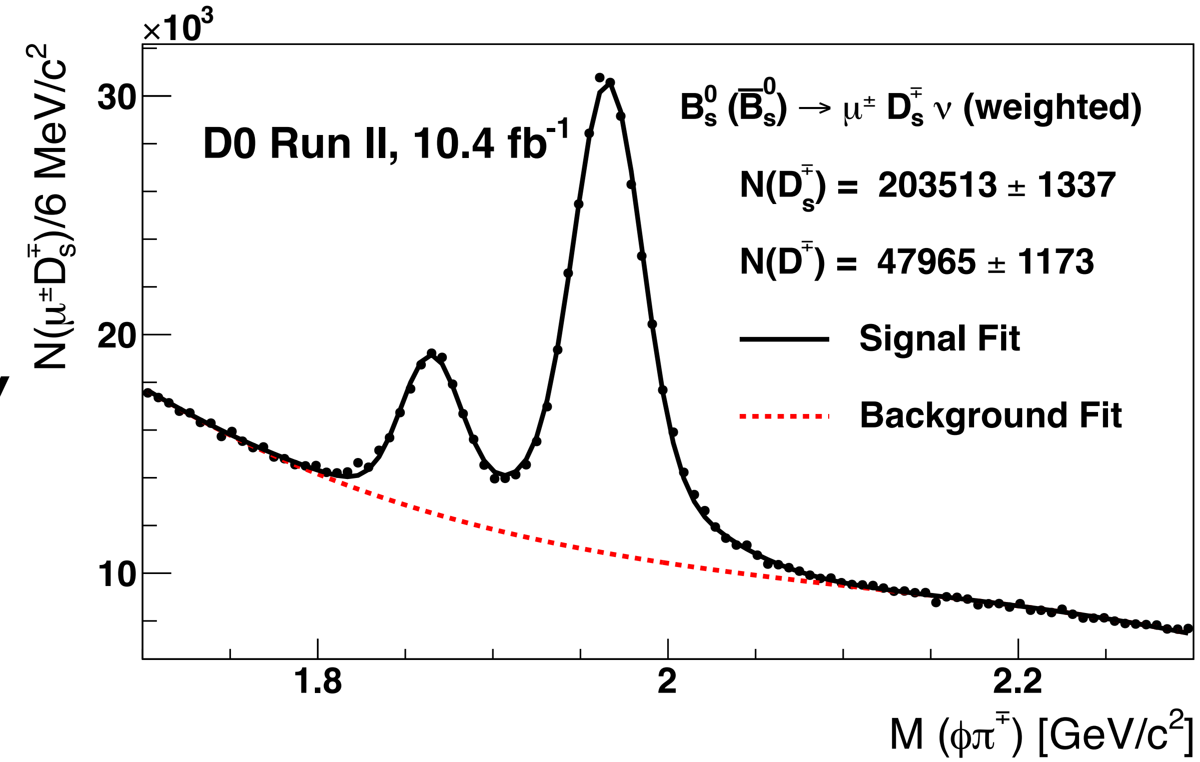
The raw asymmetry A

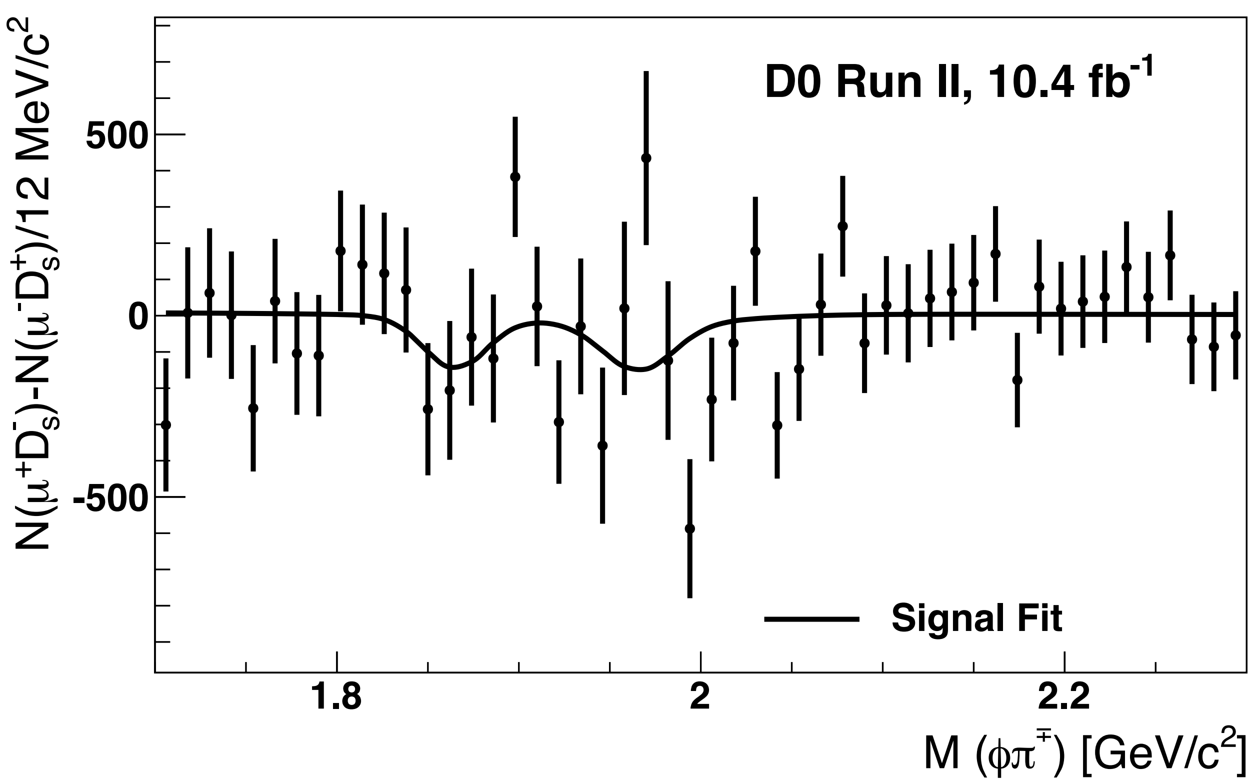
- Non-lifetime biasing cuts + Log Likelihood ratio cut
- Blinded sensitivity tests performed
- Sum and difference fitted simultaneously
- $F(\text{sum}) = F_s(D_s) + F_s(D) + F_b$
- $F(\text{diff}) = AF_s(D_s) + A_D F_s(D) + A_b F_b$

$$A = [-0.40 \pm 0.33\,(\text{stat.}) \pm 0.05\,(\text{syst.})]\,\%.$$

- Apply corrections of

$$A_{\text{bg}} = [0.11 \pm 0.06\,(\text{syst.})]\,\%$$





Dilution - ($B_{s/d}$)

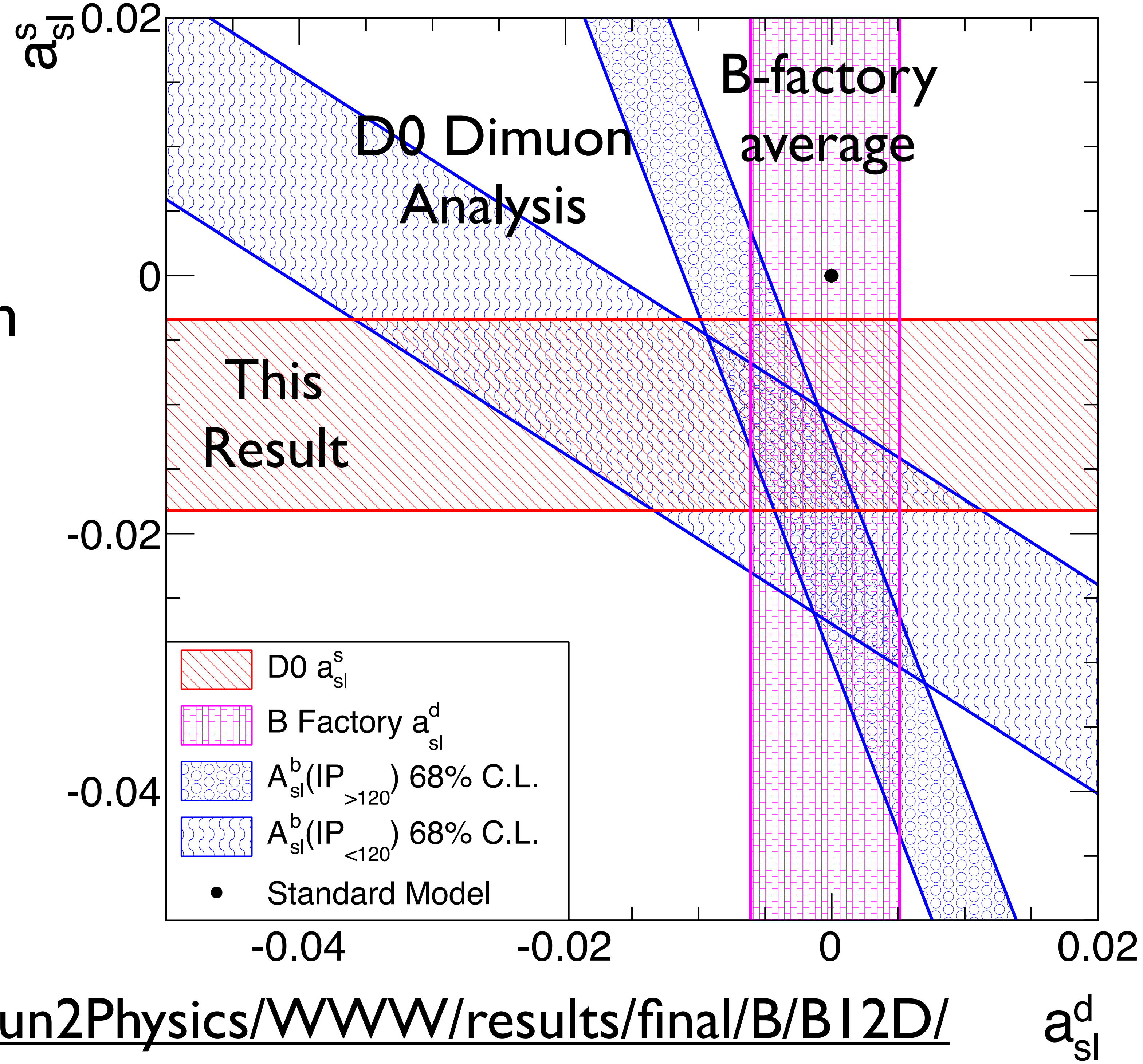
- Model μD_q events with Pythia , EvtGen, & Geant
- Weight events to match
  - B meson lifetimes and mixing parameters
  - B_s fraction that have mixed is essentially 50%.
  - In B_s analysis contamination from oscillated B_d's is 0.5% (assuming a 1% asymmetry in B_d implies a 0.005% effect)

$$P\left(B_s^0 \to \bar{B}_s^0\right) = \frac{1}{2}\left[1 - \frac{\cos(\Delta M_s \cdot t)}{\cosh(\Delta\Gamma_s \cdot t)}\right], \quad P\left(B_d^0 \to \bar{B}_d^0\right) = \frac{1}{2}\left[1 - \frac{\cos(\Delta M_d \cdot t)}{\cosh(\Delta\Gamma_d \cdot t)}\right]$$

$$\boxed{F^{\mathrm{osc}}_{B_s^0} = 0.465 \pm 0.017}$$

$$a_{\rm sl}^{s} = [-1.08 \pm 0.72\,(\text{stat}) \pm 0.17\,(\text{syst})]\,\%,$$

- World's best measurement
- Consistent with like-sign dimuon result
- Submitted to PRL and will appear on arXiv on Sunday night



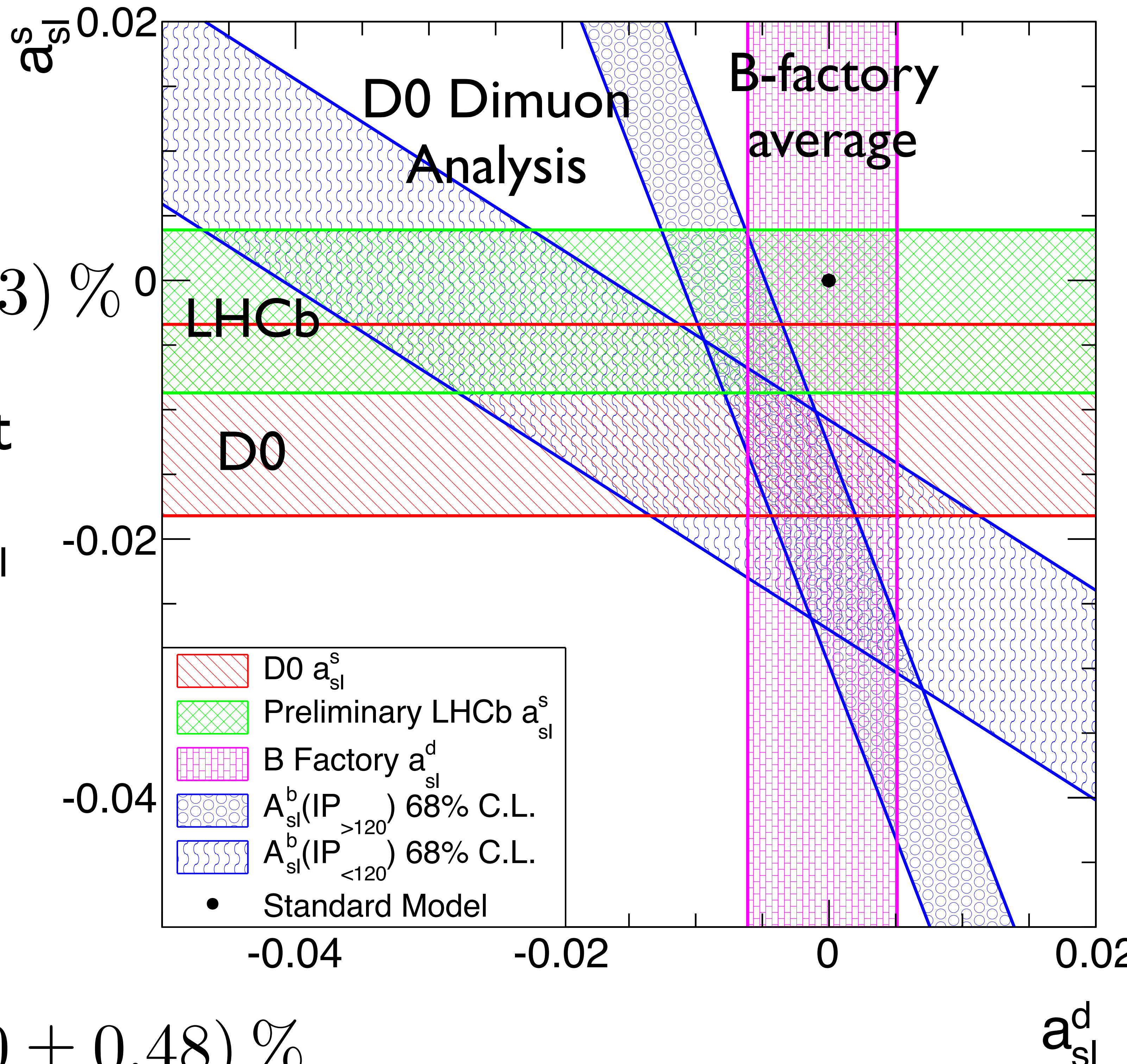
http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B12D/

Comparison with LHCb

- New preliminary LHCb result released today

$$a_{\rm sl}^{s}(\rm LHCb) = (-0.24 \pm 0.63)\,\%$$

- All results are consistent
  - $\chi^2 = 0.77/1$ dof for a^s_{sl} combination
- Average of $B_s^0 \to \mu^+ D_s^-$ a^s_{sl} results:

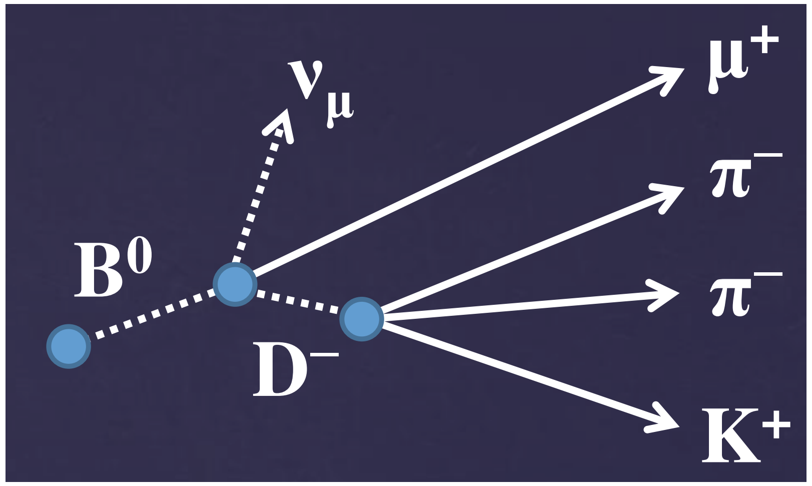


$$a_{\rm sl}^{s}(B_s^0 \to \mu D_s) = (-0.60 \pm 0.48)\,\%$$

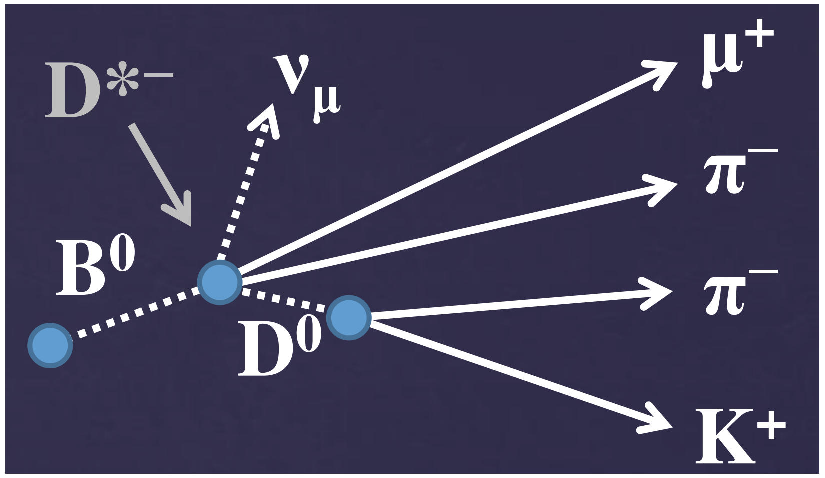
a^d_{sl} in $B_d^0 \to \mu^+ D^{(*)-}$

- Measure a^d_{sl} in two channels in a binned lifetime analysis.

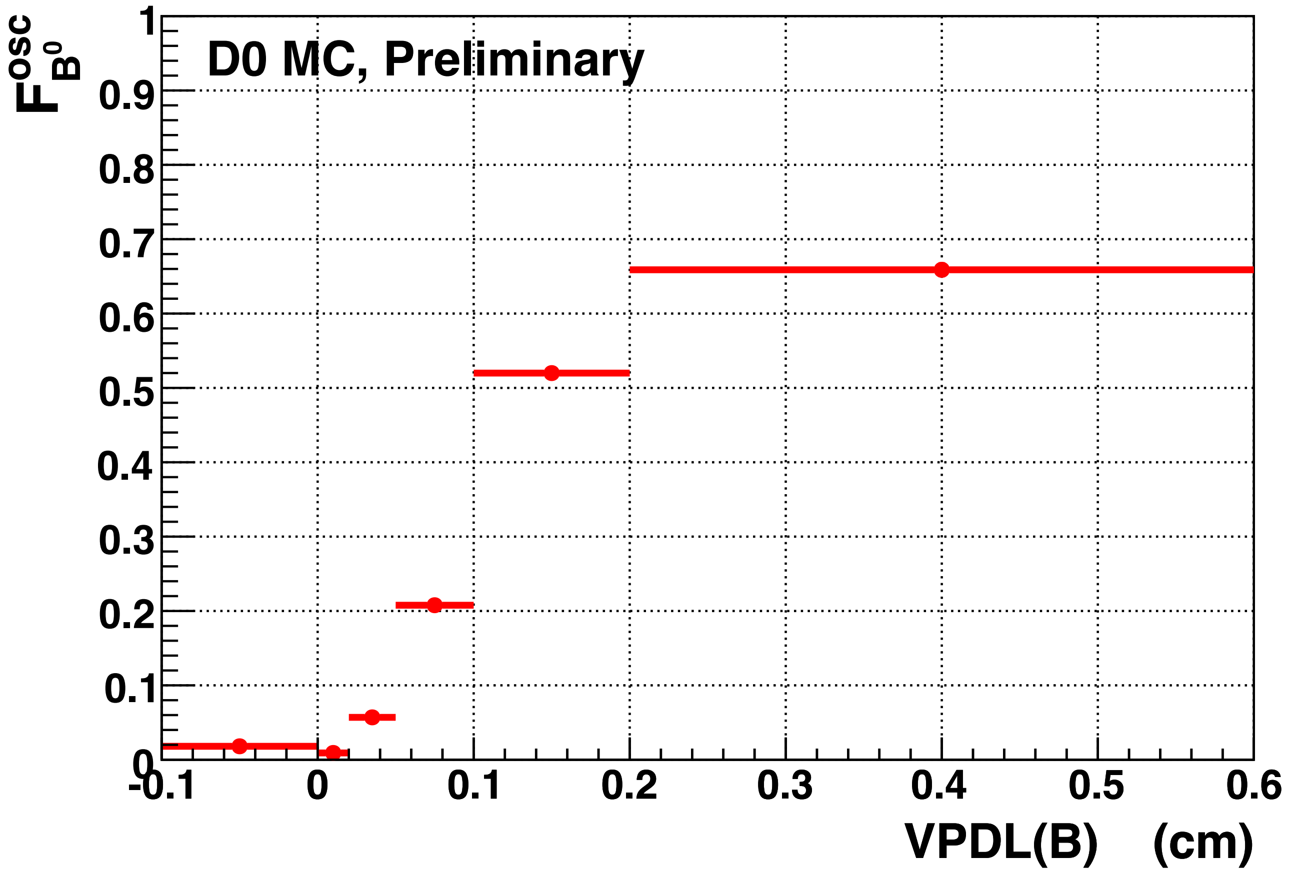
$B_d^0 \to \mu^+ \nu D^- X$



$B_d^0 \to \mu^+ \nu D^{*-} X$



Lifetime Bins
-0.10 - 0.00 cm
0.00 - 0.02 cm
0.02 - 0.05 cm
0.05 - 0.10 cm
0.10 - 0.20 cm
0.20 - 0.60 cm



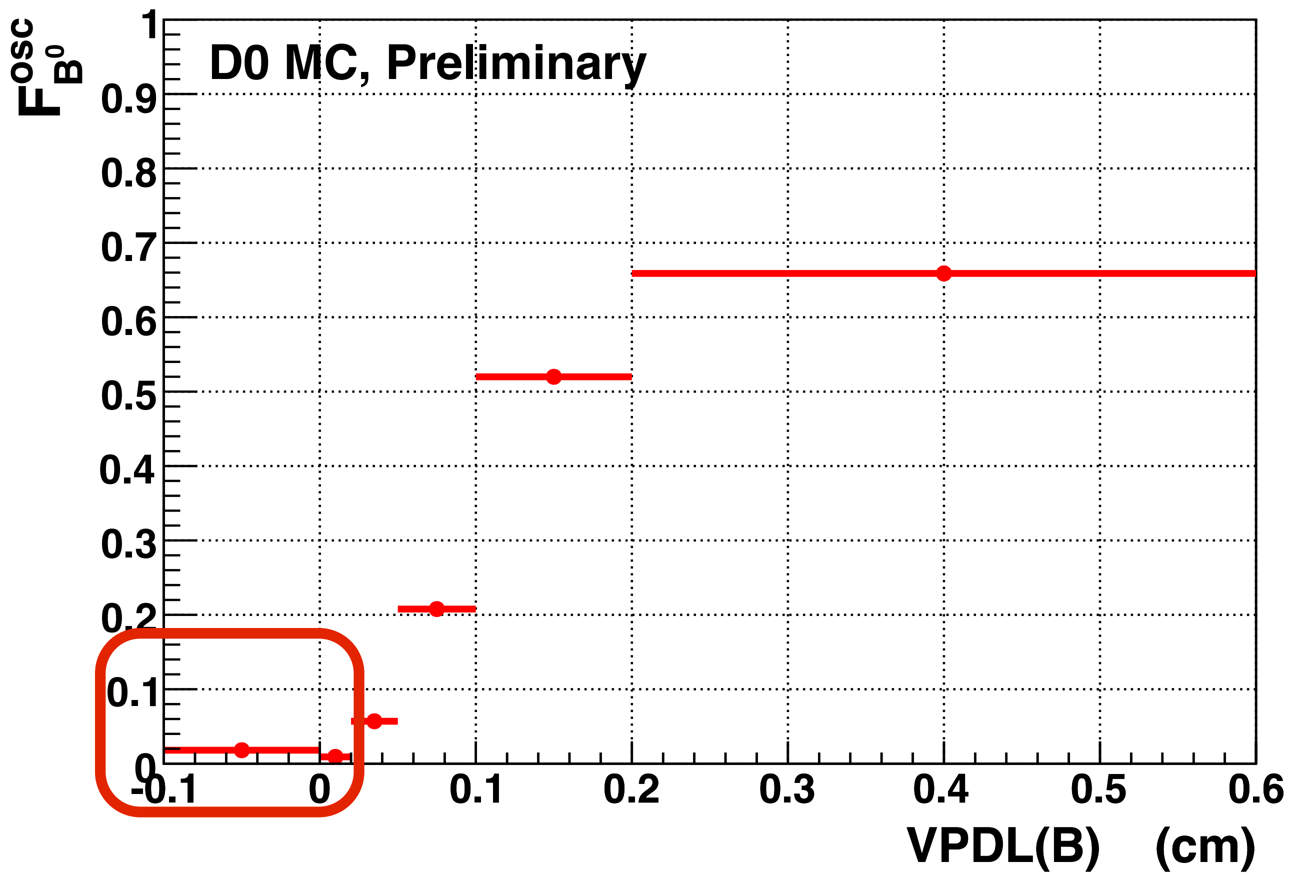
a^d_{sl} in $B_d^0 \rightarrow \mu^+ D^{(*)-}$

- Measure a^d_{sl} in two channels in a binned lifetime analysis.

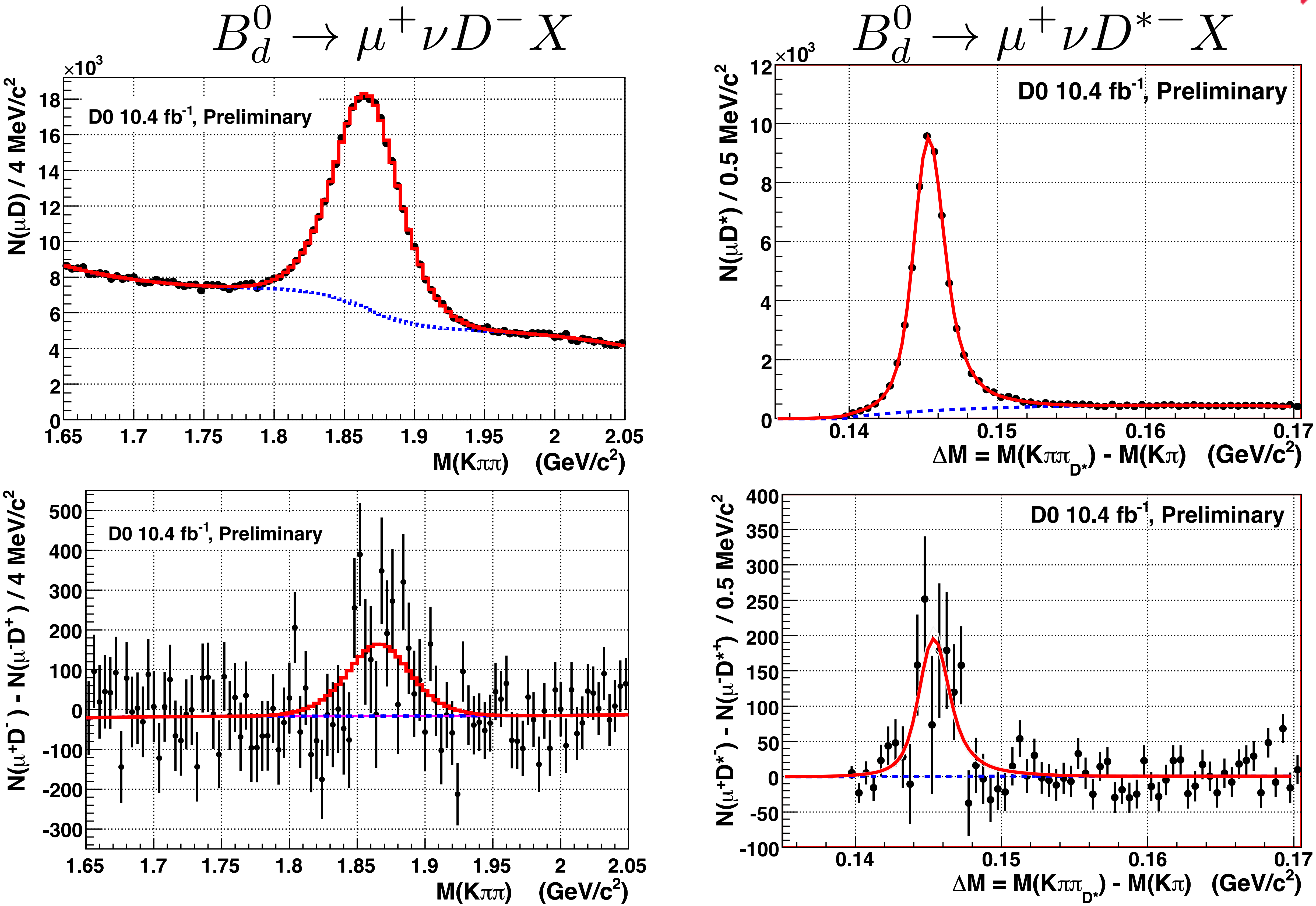
$$B_d^0 \rightarrow \mu^+ \nu D^- X \qquad\qquad B_d^0 \rightarrow \mu^+ \nu D^{*-} X$$

- Use the first two lifetime bins as a control region to test corrections as expect no mixing.

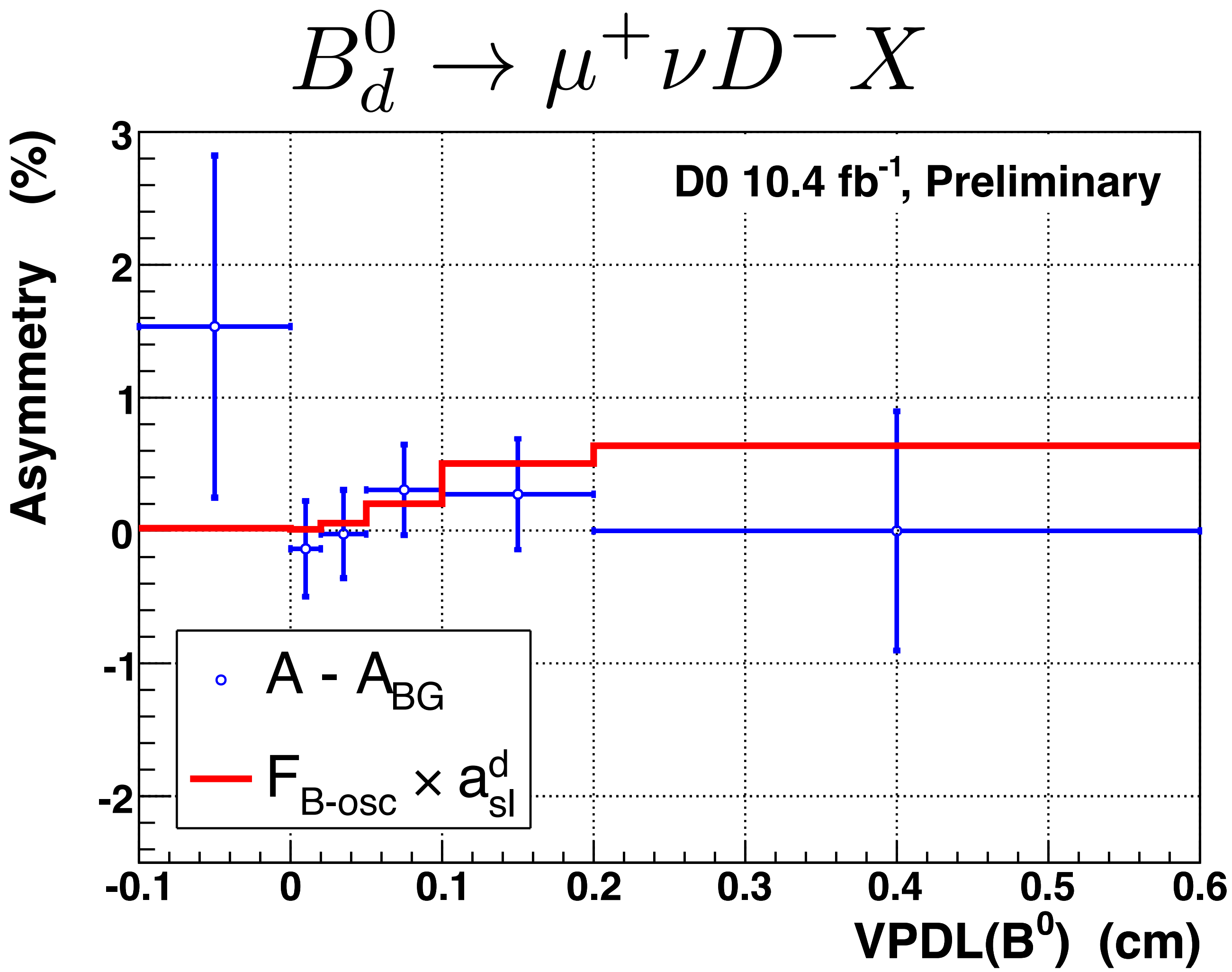
Lifetime Bins
-0.10 - 0.00 cm
0.00 - 0.02 cm
0.02 - 0.05 cm
0.05 - 0.10 cm
0.10 - 0.20 cm
0.20 - 0.60 cm

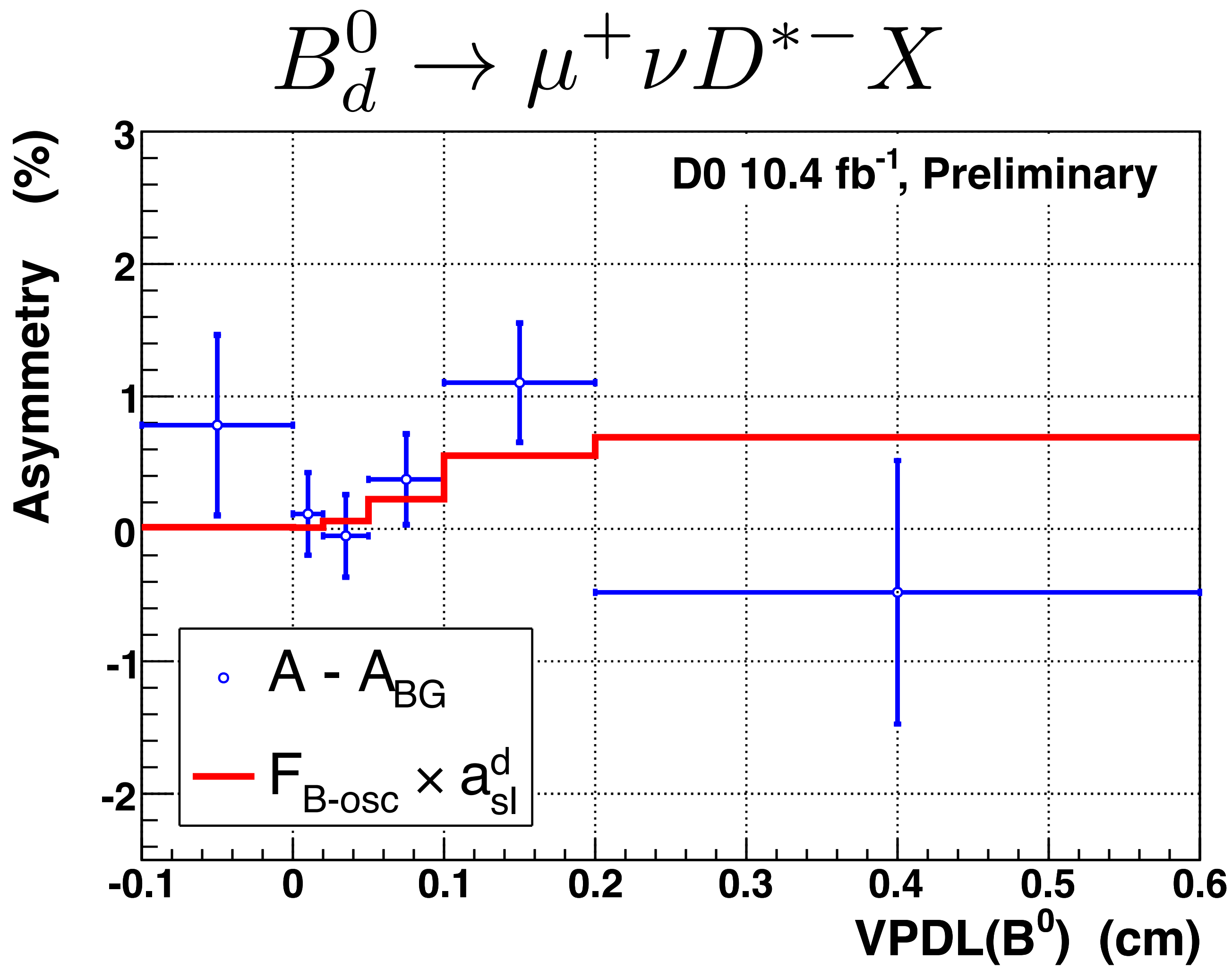


Mass Distributions - 0.10 - 0.20 cm



Extract a^d_{sl}





$$a^d_{\rm sl}\,(\mu D) = [0.53 \pm 0.63\,(\text{stat.}) \pm 0.16(\text{syst.})]\,\%$$

$$a^d_{\rm sl}\,(\mu D^*) = [1.32 \pm 0.62\,(\text{stat.}) \pm 0.16(\text{syst.})]\,\%$$

Weighted Average

$$\boxed{a^d_{\rm sl} = [0.93 \pm 0.45\,(\text{stat.}) \pm 0.14(\text{syst.})]\,\%}$$

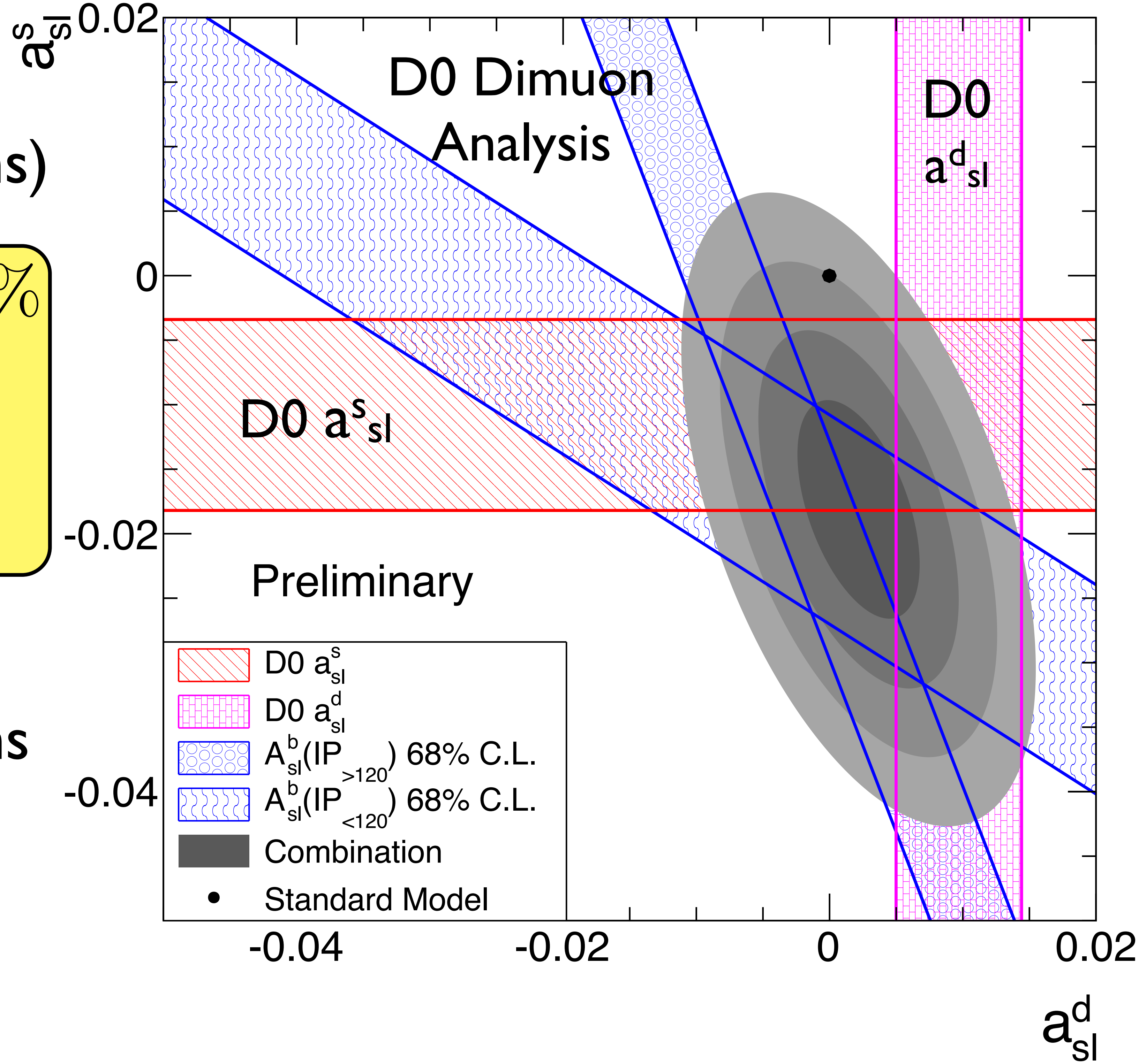
Combination of D0 Results

- Combine all three D0 measurements (including correlations)

$$a_{\mathrm{sl}}^{s} = (-1.81 \pm 0.56)\,\%$$
$$a_{\mathrm{sl}}^{d} = (0.22 \pm 0.30)\,\%$$
$$\rho = -0.50$$

- p-value(SM) = 0.29%
3.0 standard deviations
$\chi^2 = 4.66/2$ dof

- a^s_{sl} is 3.2 standard deviations from zero

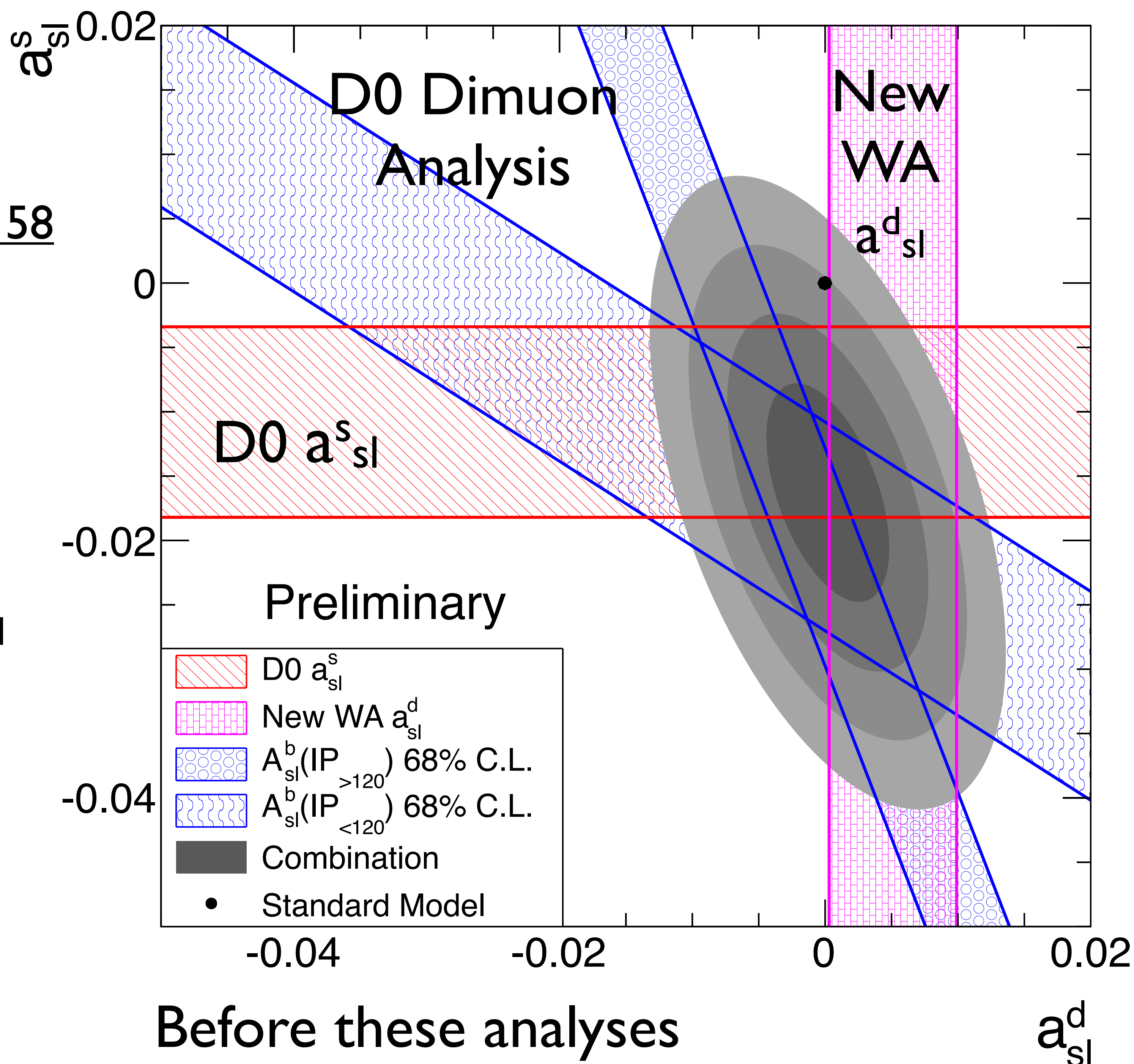


Including B-Factory a^d_{sl}

- Average new D0 result with HFAG PDG 2012 average of B-Factory results:
  $a^d_{sl} = (-0.05 \pm 0.56)\%$ arXiv:1207.1158
- Combination of two values of a^d_{sl} has $\chi^2 = 1.79$ so we scale up the uncertainty
- Combine with D0 dimuon and a^s_{sl}

$$a^s_{\rm sl} = (-1.63 \pm 0.56)\ \%$$
$$a^d_{\rm sl} = (0.02 \pm 0.30)\ \%$$
$$\rho = -0.51$$

- p-value(SM) = 0.26%, χ^2 = 2.06/2 dof 2.90 standard deviations from SM



Before these analyses

$$a^d_{\rm sl} = (-0.12 \pm 0.52)\%,$$
$$a^s_{\rm sl} = (-1.81 \pm 1.06)\%.$$

- Presented new measurements of a^d_{sl} and a^s_{sl} in exclusive final states.
- Both are the world's most precise single experiment measurements.

$$a^s_{\mathrm{sl}} = [-1.08 \pm 0.72\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})]\,\%,$$

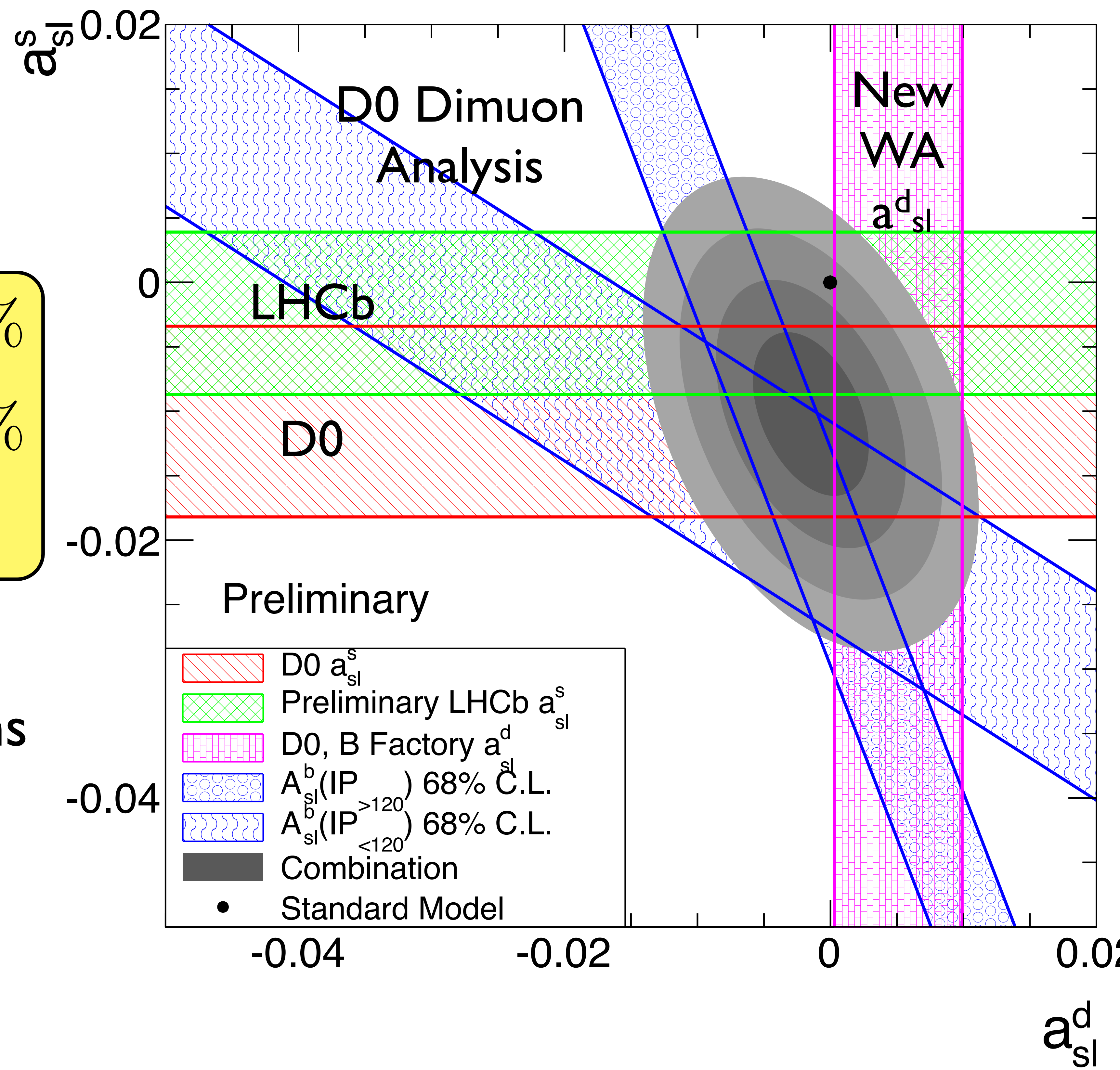
$$a^d_{\mathrm{sl}} = [0.93 \pm 0.45\,(\mathrm{stat.}) \pm 0.14(\mathrm{syst.})]\,\%$$

- Both measurements are consistent with the anomalous like-sign dimuon charge asymmetry
- Combined value of a^s_{sl} is significantly different from the SM (-1.63 ± 0.56)% : 2.91 standard deviations from zero.
- Final update on anomalous like-sign dimuon asymmetry this summer (effectively doubling statistics for IP measurement).

- Combine with D0 and B-Factory average a^d_{sl}.

$$a^s_{\rm sl} = (-1.02 \pm 0.42)\,\%$$
$$a^d_{\rm sl} = (-0.15 \pm 0.29)\,\%$$
$$\rho = -0.40$$

- p-value(SM) = 1.3%
  2.5 standard deviations
  χ^2 = 4.00/2 dof
- a^s_{sl} is 2.5 standard deviations from zero



Backup

Combination Details

- Page 15: Only using D0 Results
    - Make full use of the correlations between uncertainties of the IP dependence of the like sign dimuon anomalous like-sign dimuon charge asymmetry.
    - The a^d_{sl} and a^s_{sl} measurements are assumed to be independent as they are dominated by the statistical uncertainty (There is correlation in some of the systematic uncertainties).

$$a^q_{\mathrm{sl}} = \frac{|p/q|^2_{d(s)} - |q/p|^2_{d(s)}}{|p/q|^2_{d(s)} + |q/p|^2_{d(s)}}$$

Combination Details

- Page 16: D0 Anomalous Dimuon Asymmetry, D0 a^d_{sl} and a^s_{sl} and B-factory combination of a^d_{sl}.
  - We combine the D0 and B-Factory values of a^d_{sl} before carrying out the 2-D combination.
  - Combination of two values of a^d_{sl} has $\chi^2 = 1.79$ so we scale up the uncertainty by $\sqrt{(1.79)}$ as is used in the PFG. I.e. $\sqrt{(1.79)} \times 0.36\% = 0.48\%$
  - The combined D0 and B-Factory values of a^d_{sl} is:

$$a^d_{\mathrm{sl}} = (0.52 \pm 0.48)\%$$

Combination Details

- Page 16: D0 Anomalous Dimuon Asymmetry, D0 a^d_{sl} and a^s_{sl} and B-factory combination of a^d_{sl}.
  - Current HFAG average has uncertainties of a^d_{sl}: 0.33% and a^s_{sl}: 0.64% including previous D0 measurements.
  - Our combination

$$\boxed{\begin{aligned} a^s_{\rm sl} &= (-1.63 \pm 0.56)\,\% \\ a^d_{\rm sl} &= (0.02 \pm 0.30)\,\% \\ \rho &= -0.51 \end{aligned}}$$

$$|q/p|_s = 1.0082 \pm 0.0028$$

$$|q/p|_d = 0.9999 \pm 0.0015$$

Combination with LHCb

- HFAG PDG 2012 average of B-Factory results: $a^d_{sl} = (-0.05 \pm 0.56)\%$

$$a^s_{\rm sl} = (-0.88 \pm 0.42)\ \%$$
$$a^d_{\rm sl} = (-0.37 \pm 0.30)\ \%$$
$$\rho = -0.42$$

- p-value(SM) = 0.69%
  2.7 standard deviations
  χ^2 = 1.57/2 dof
- a^s_{sl} is 2.1 standard deviations from zero