Charge Asymmetries in Semi-Leptonic B Decays

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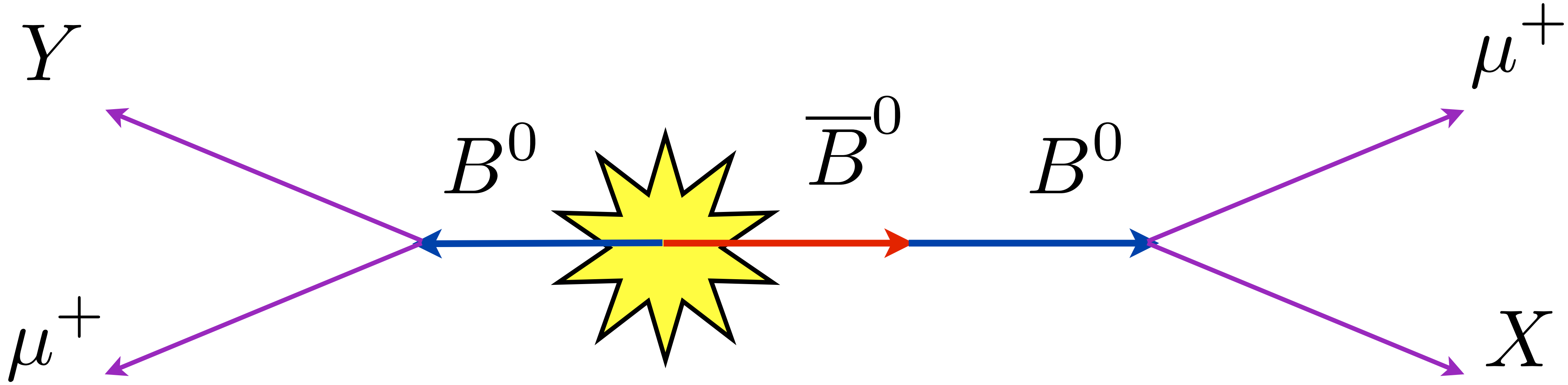
for the D0 Collaboration

Beauty 2013 - Bologna

8 April 2013

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

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

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

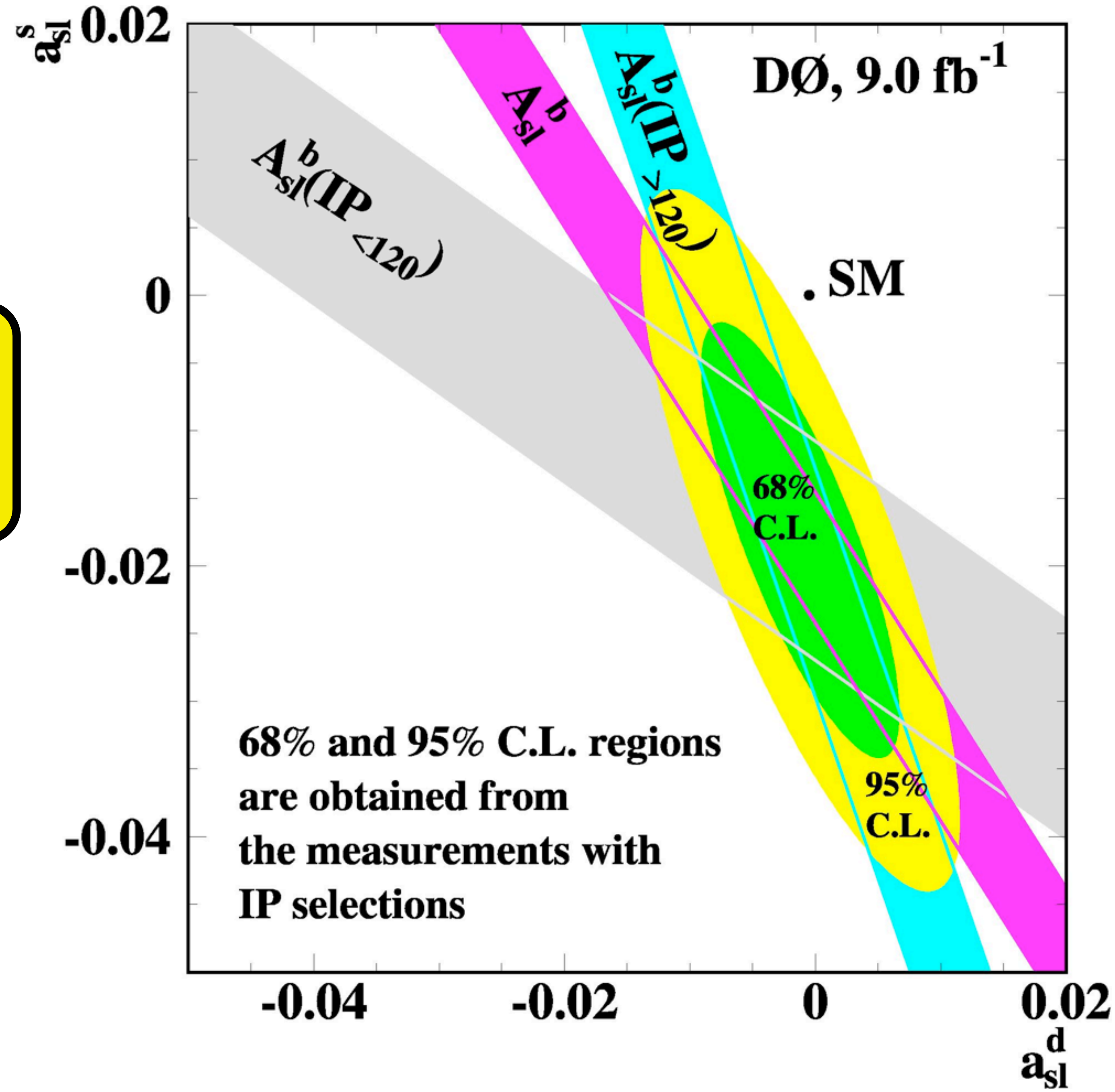
- Anomalous Dimuon - 3.9σ deviation from SM expectations
- Split the data (blue band, grey band):

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

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

SM Prediction

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



(arXiv:1102.4274)

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

Semi-leptonic Charge asymmetries

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

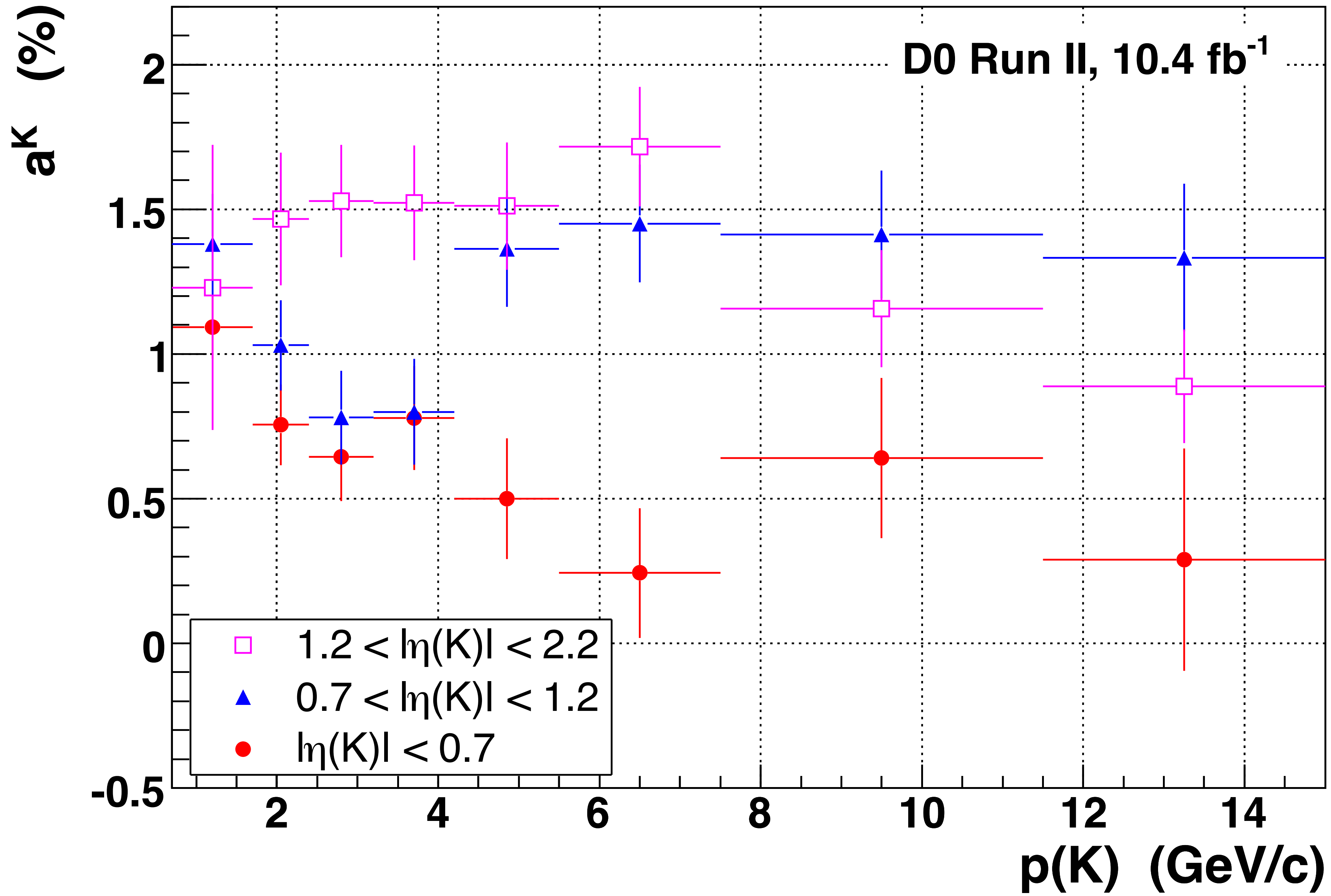
$$a_{\mathrm{sl}}^{q} = \frac{A - A_{\mathrm{bg}}}{F_{B_q^0}^{\mathrm{osc}}}$$

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

- 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.

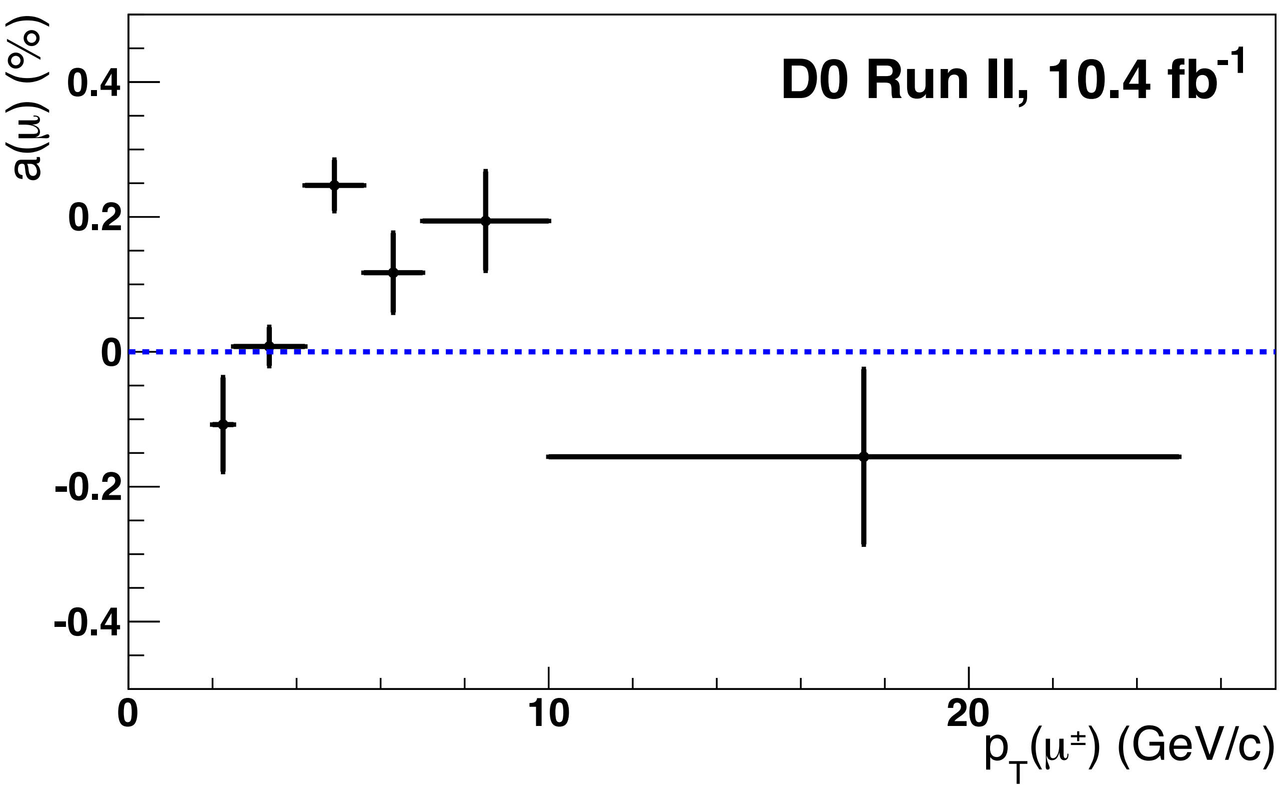
Kaon Corrections

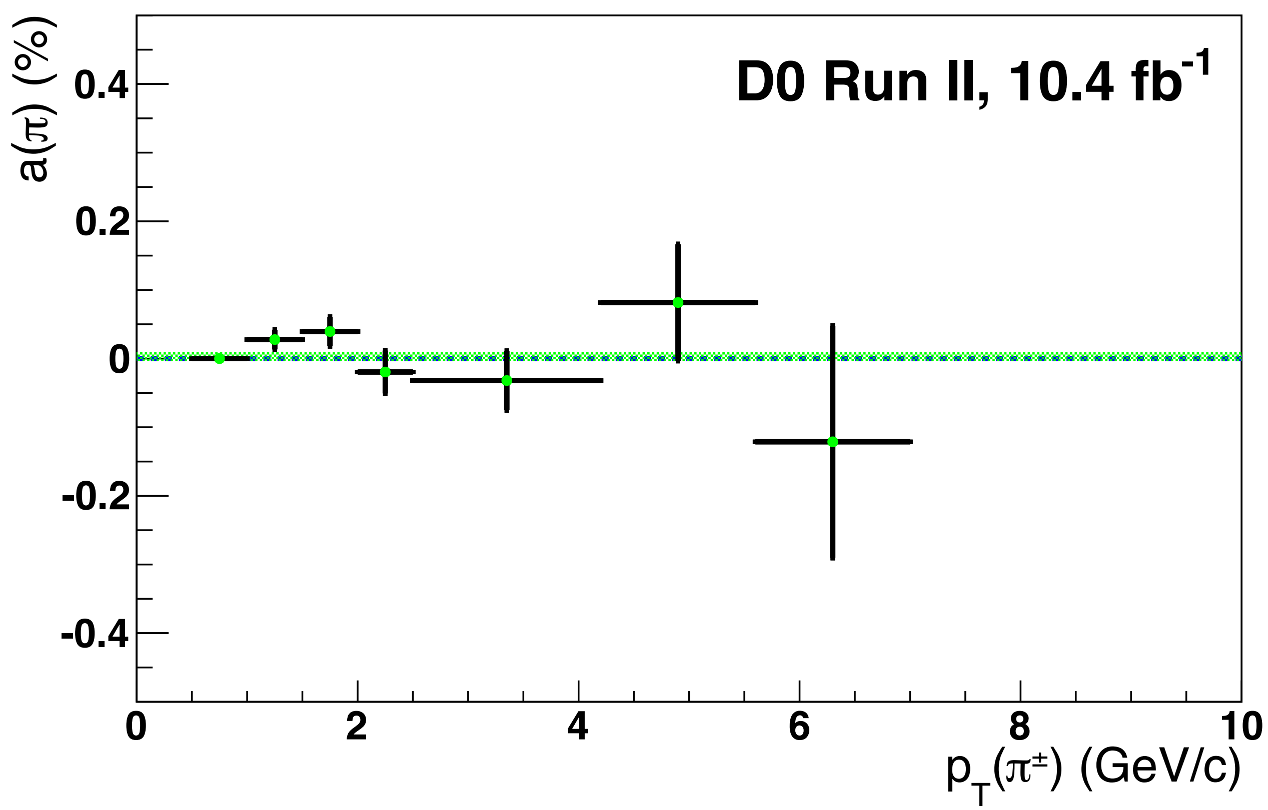
- K^+ and K^- have very different interaction cross sections
- Use the decay $K^* \rightarrow K\pi$ to measure the asymmetry as a function of momentum and η



Residual Muon and Track Asymmetries

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

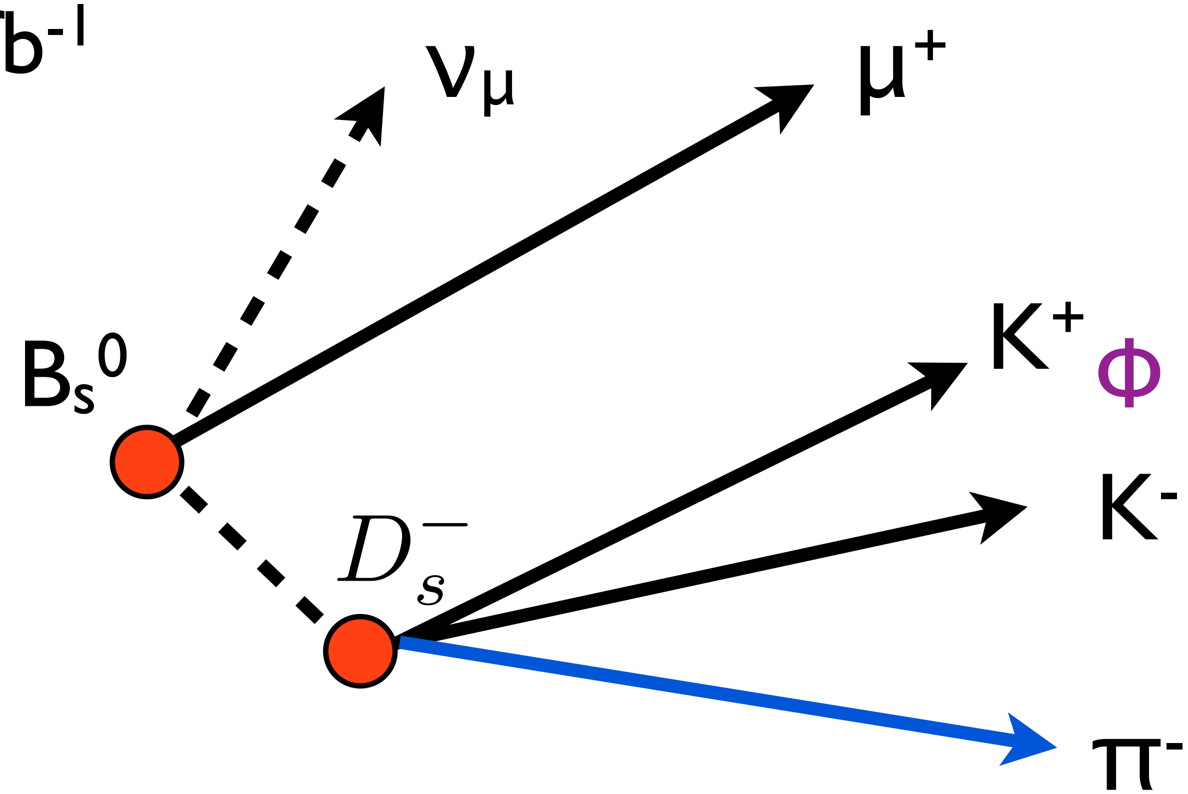




a^s_{sl} in $B_s^0 \rightarrow \mu^+ D_s^-$

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

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



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

$$a^s_{sl} \cdot F^{\rm osc}_{B_s^0} = A - A_\mu - A_{\rm track} - A_{KK}$$

Small Kaon correction due to Φ-f_0(980) interference.
Belle: PRL 108, 071801 (2012)

The raw asymmetry A

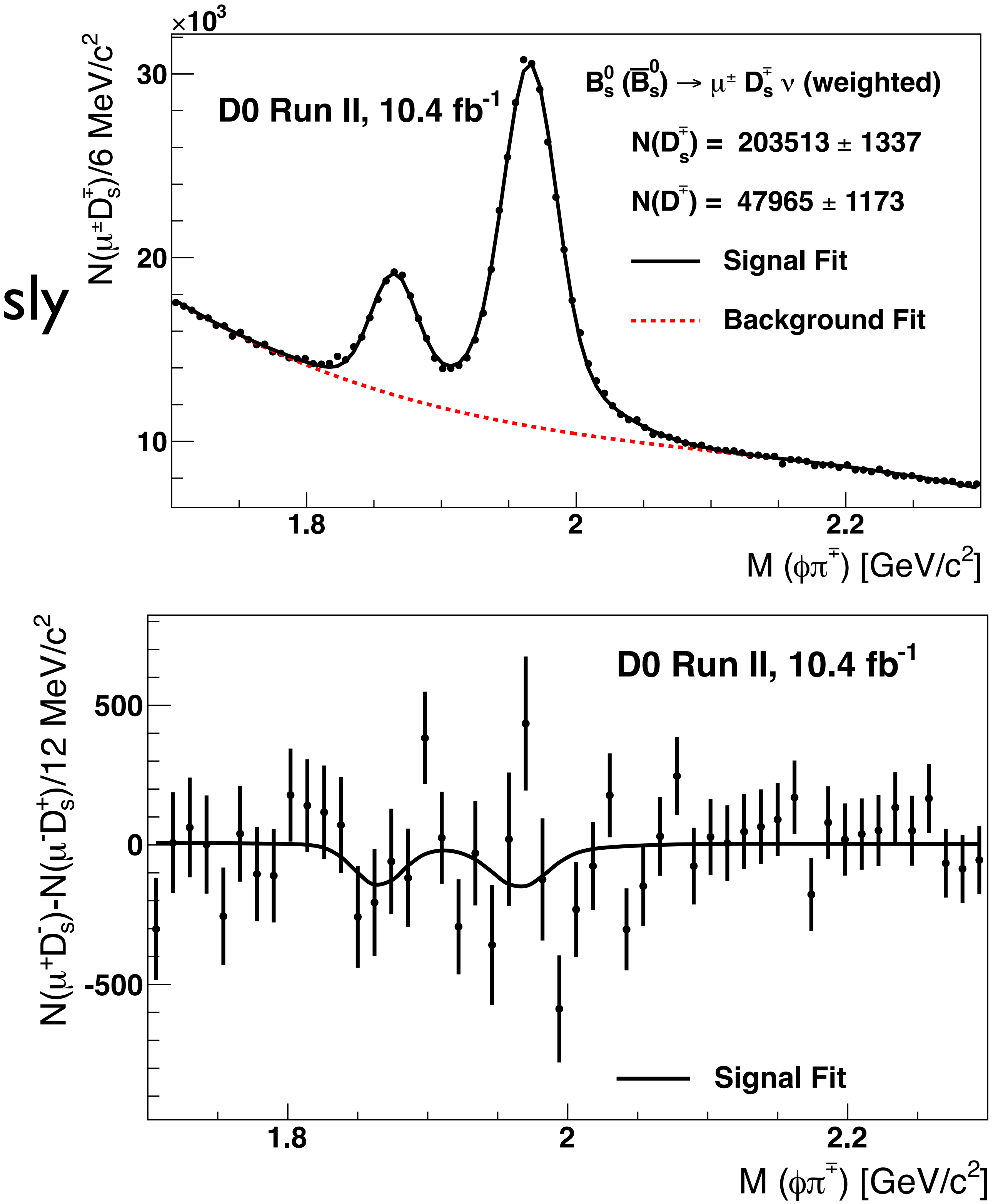
- Non-lifetime biasing cuts + Log Likelihood ratio cut
- Blinded sensitivity tests performed
- Sum and difference fitted simultaneously
- $F(\text{sum}) = F_s(D_s) + F_s(D) + F_b$
- $F(\text{diff}) = AF_s(D_s) + A_D F_s(D) + A_b F_b$

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

- Apply corrections of

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

$$A_{KK} = [0.020 \pm 0.002(\text{syst})]\,\%$$



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

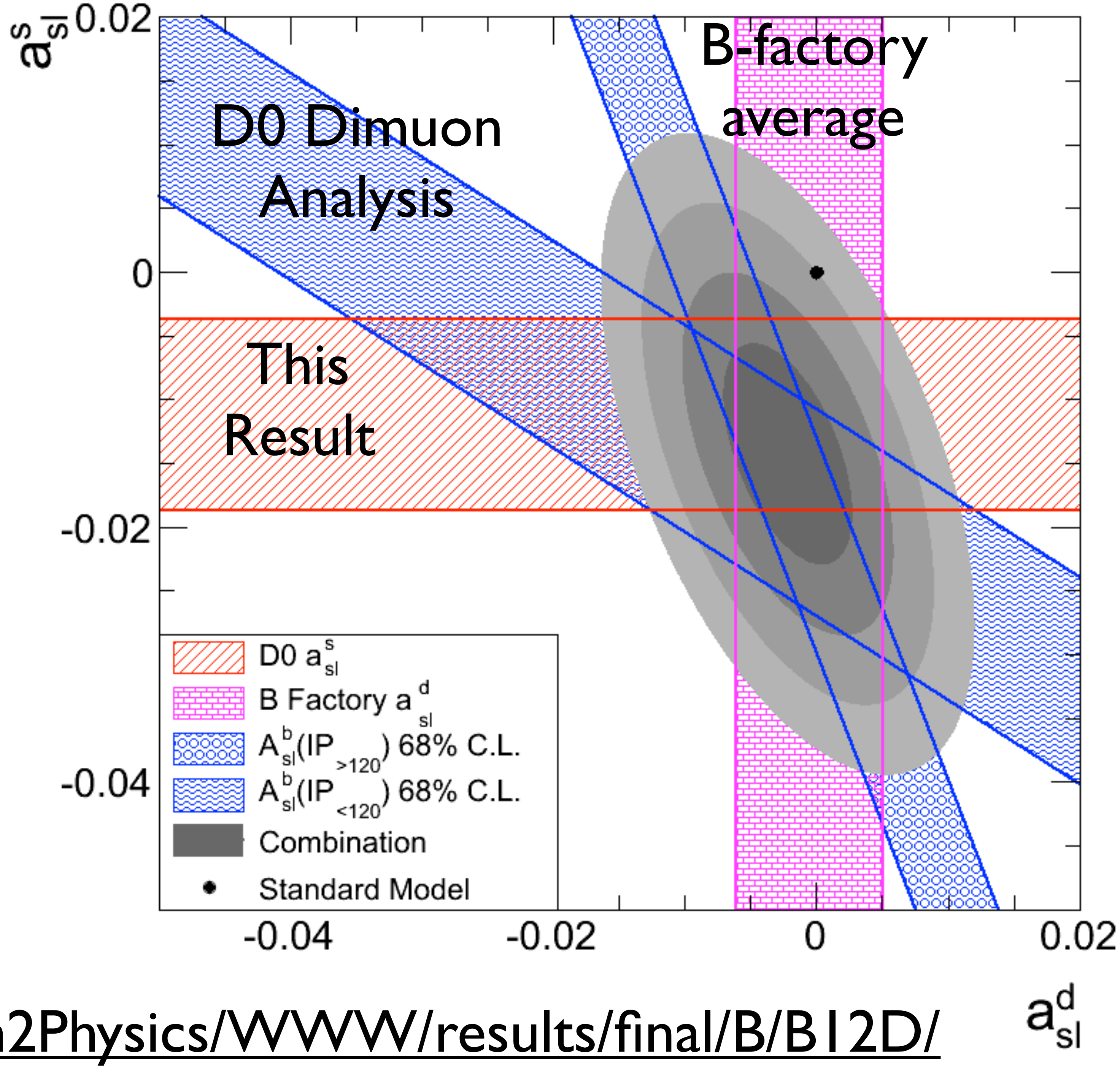
- Model μD_q events with Pythia , EvtGen, & Geant
- Weight events to match
  - B meson lifetimes and mixing parameters
  - B_s fraction that have mixed is essentially 50%.
  - In B_s analysis contamination from oscillated B_d's is 0.5% (assuming a 1% asymmetry in B_d implies a 0.005% effect)

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

$$F_{B_s^0}^{\mathrm{osc}} = 0.465 \pm 0.017$$

$$a_{\rm sl}^s = [-1.12 \pm 0.74\,(\rm stat) \pm 0.17\,(\rm syst)]\,\%$$

- World's best published measurement
- Consistent with like-sign dimuon result
- PRL 110, 011801 (2013)

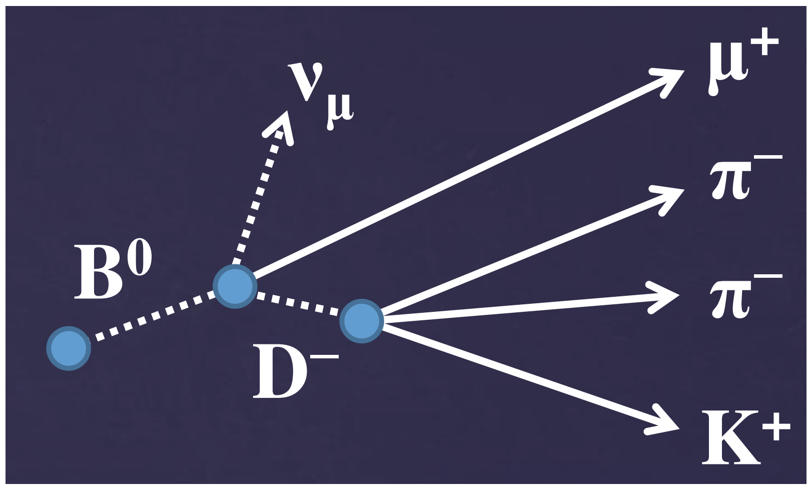


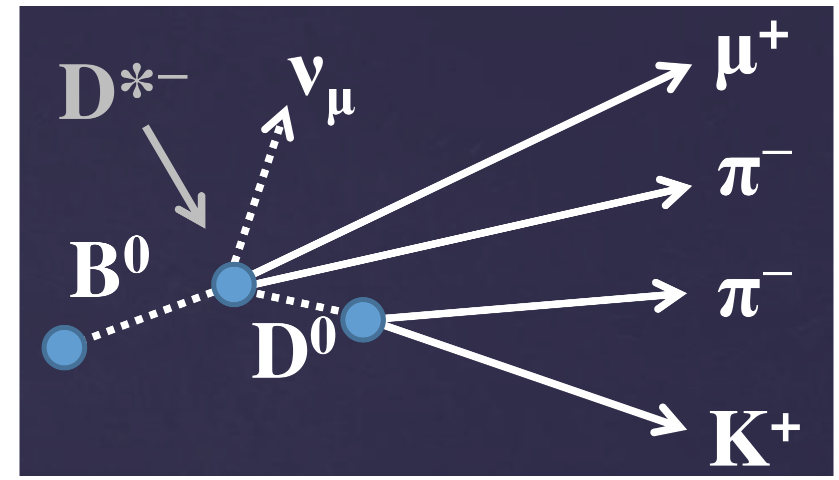
http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B12D/

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

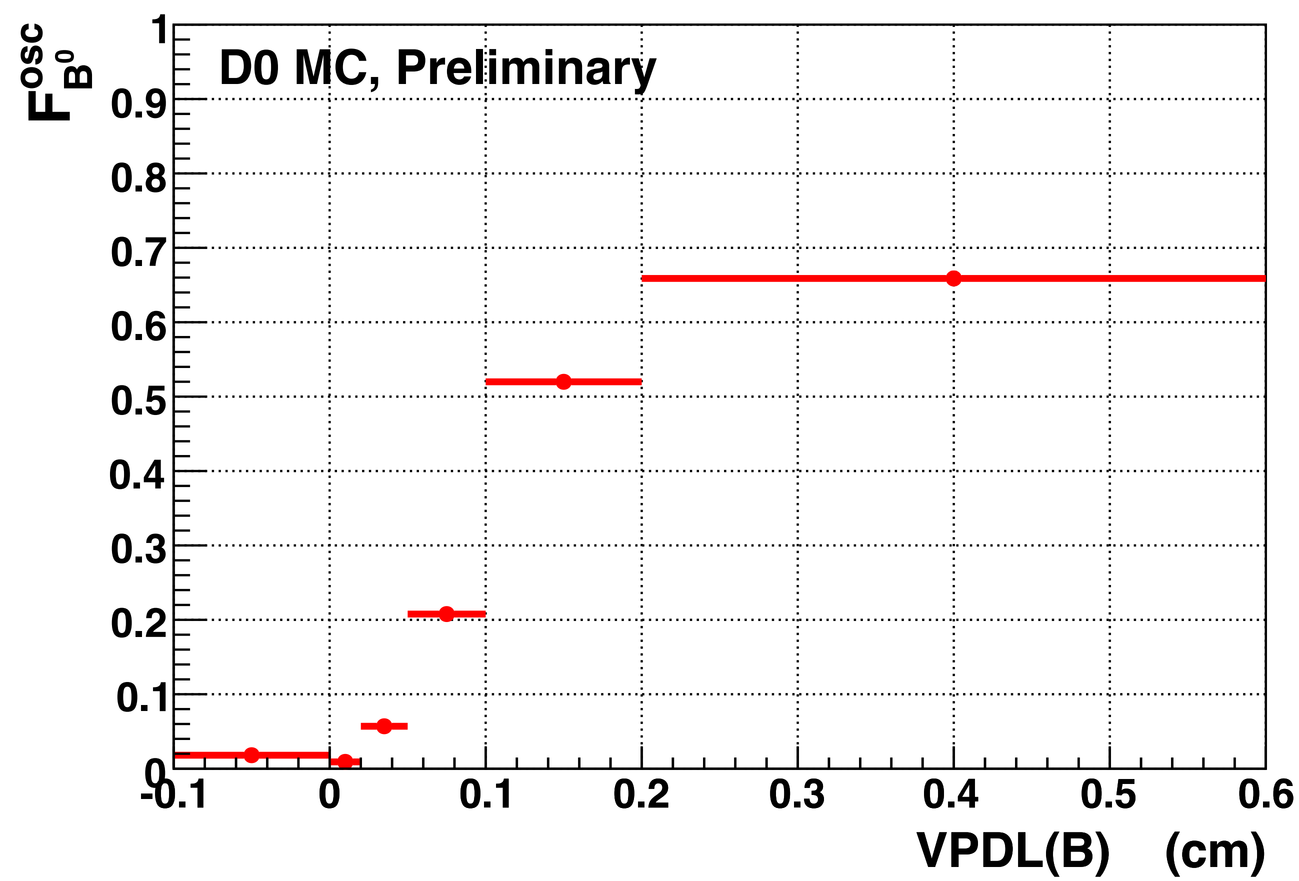
- Measure a^d_{sl} in two channels in a binned lifetime analysis.

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





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



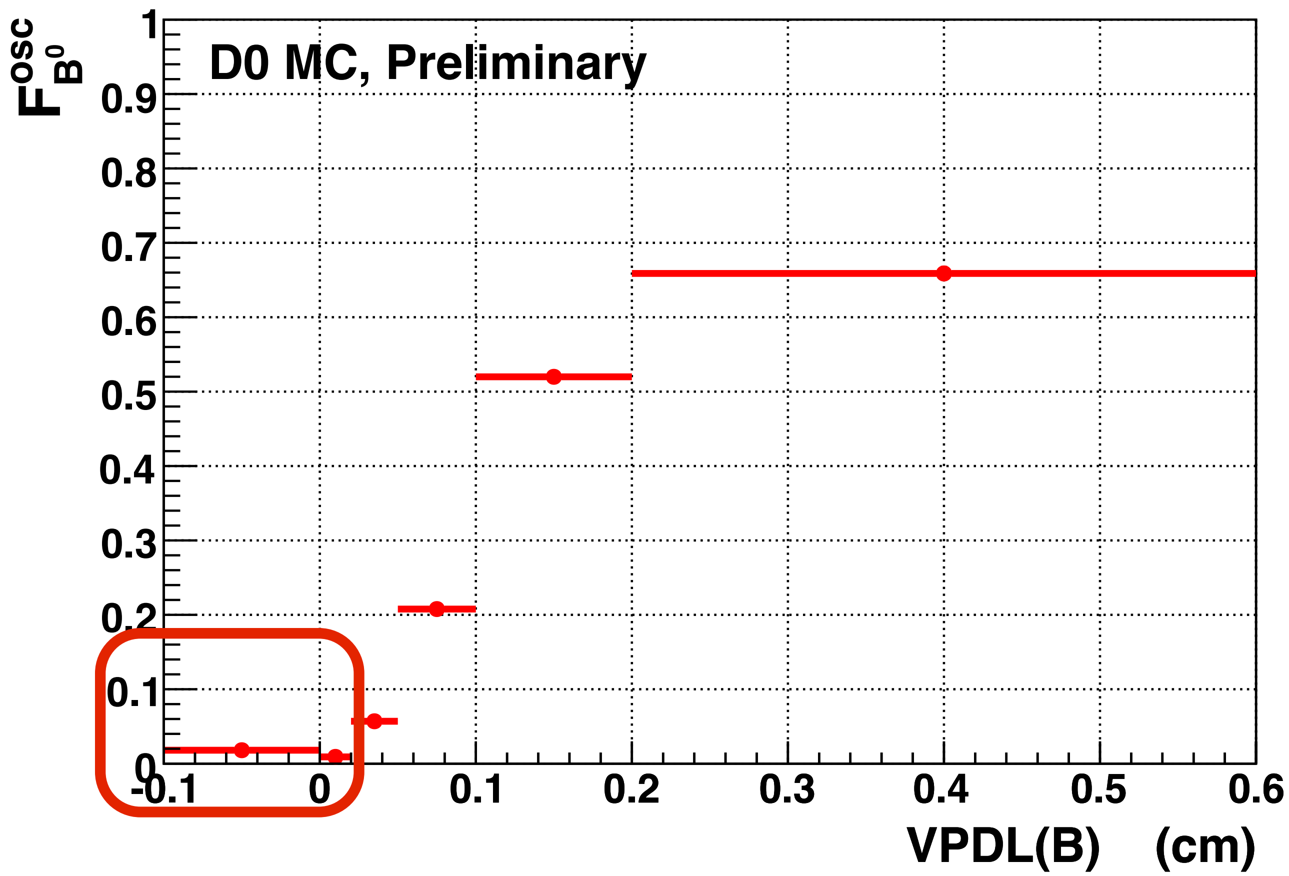
a^d_{sl} in $B_d^0 \to \mu^+ D^{(*)-}$

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

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

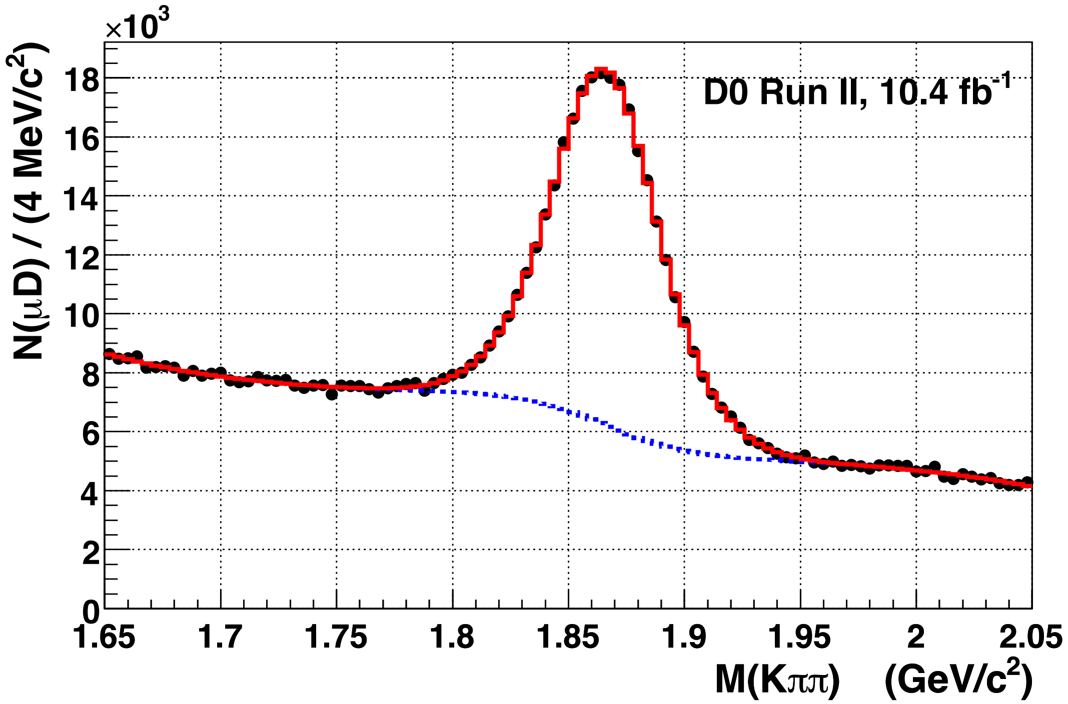
- Use the first two lifetime bins as a control region to test corrections as expect no mixing.

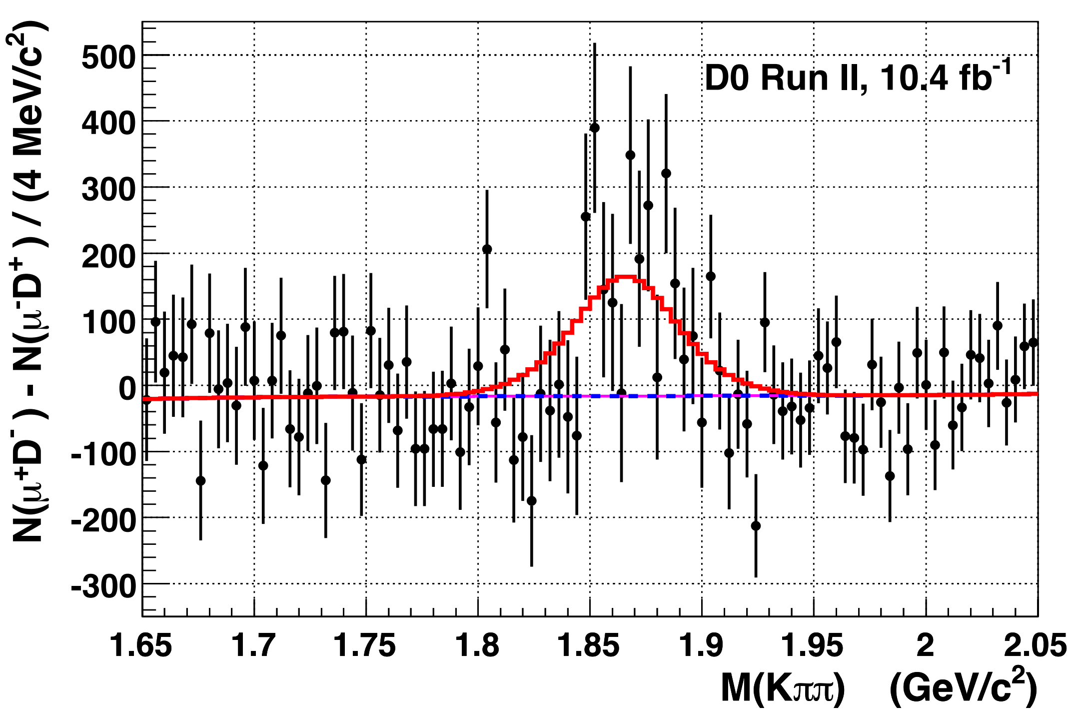
Lifetime Bins
-0.10 - 0.00 cm
0.00 - 0.02 cm
0.02 - 0.05 cm
0.05 - 0.10 cm
0.10 - 0.20 cm
0.20 - 0.60 cm



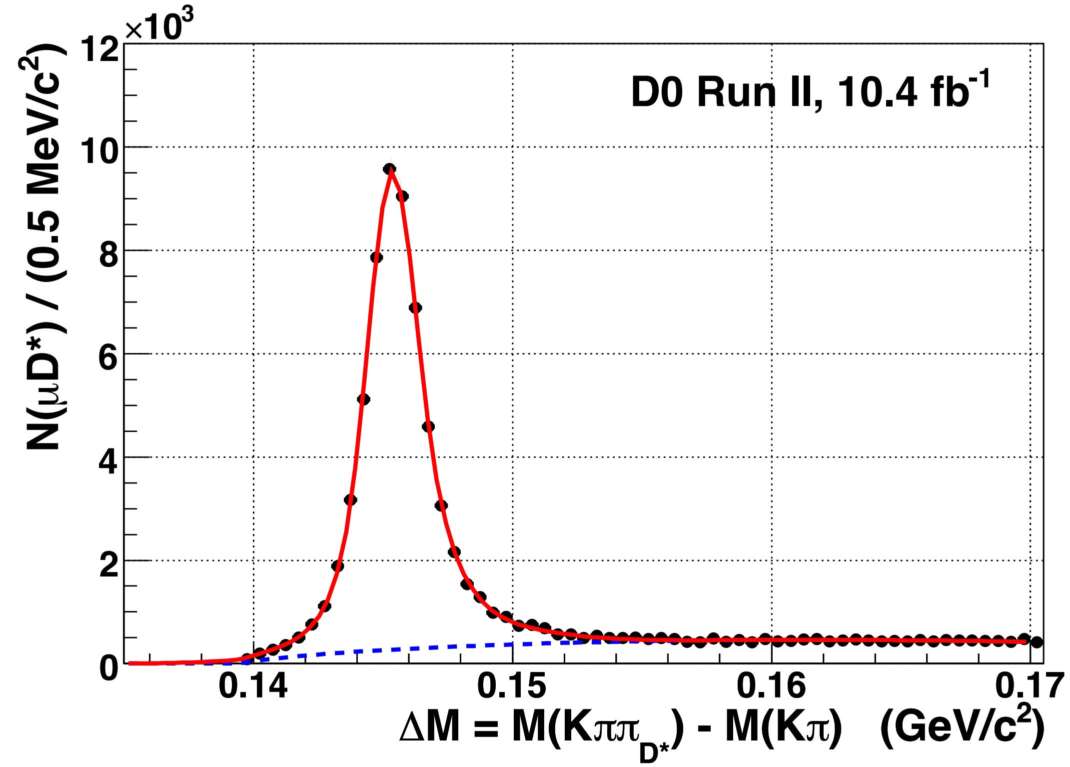
Mass Distributions - 0.10 - 0.20 cm

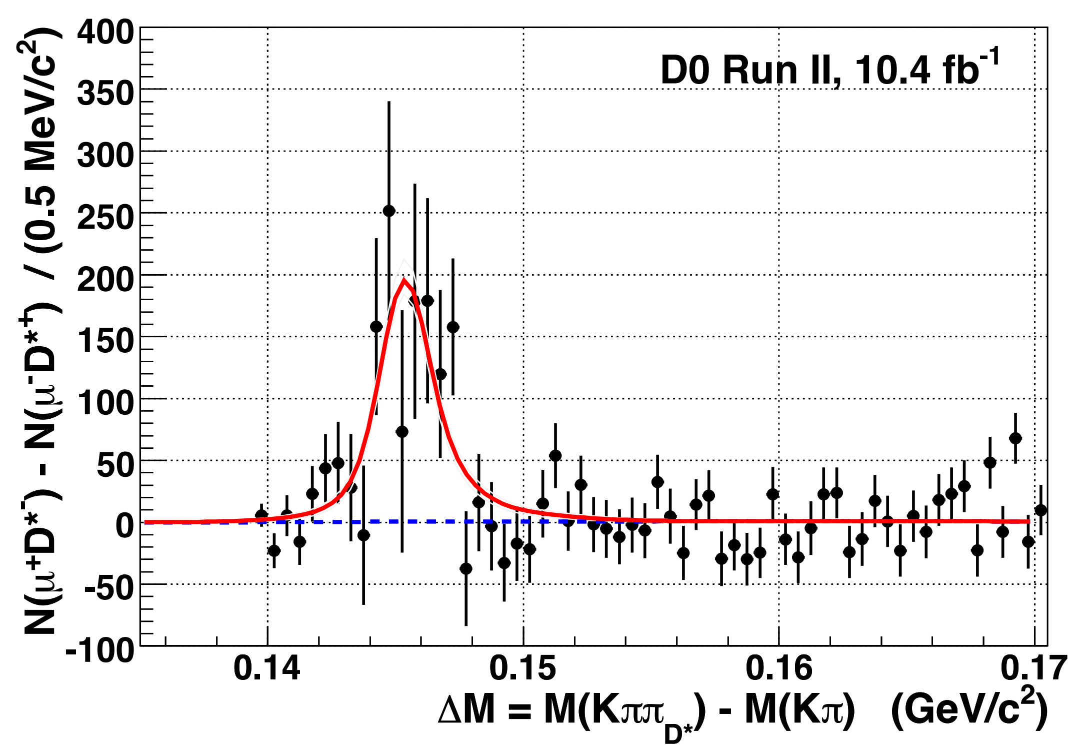
$B_d^0 \to \mu^+ \nu D^- X$





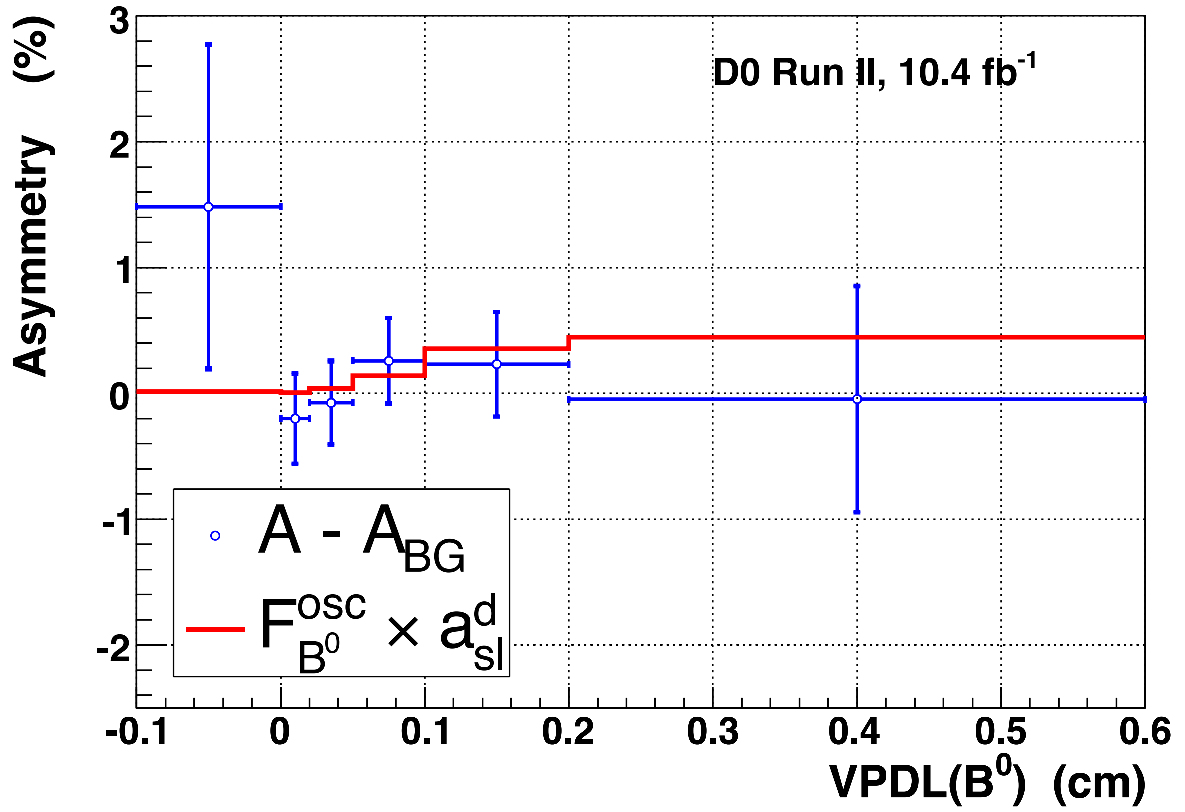
$B_d^0 \to \mu^+ \nu D^{*-} X$



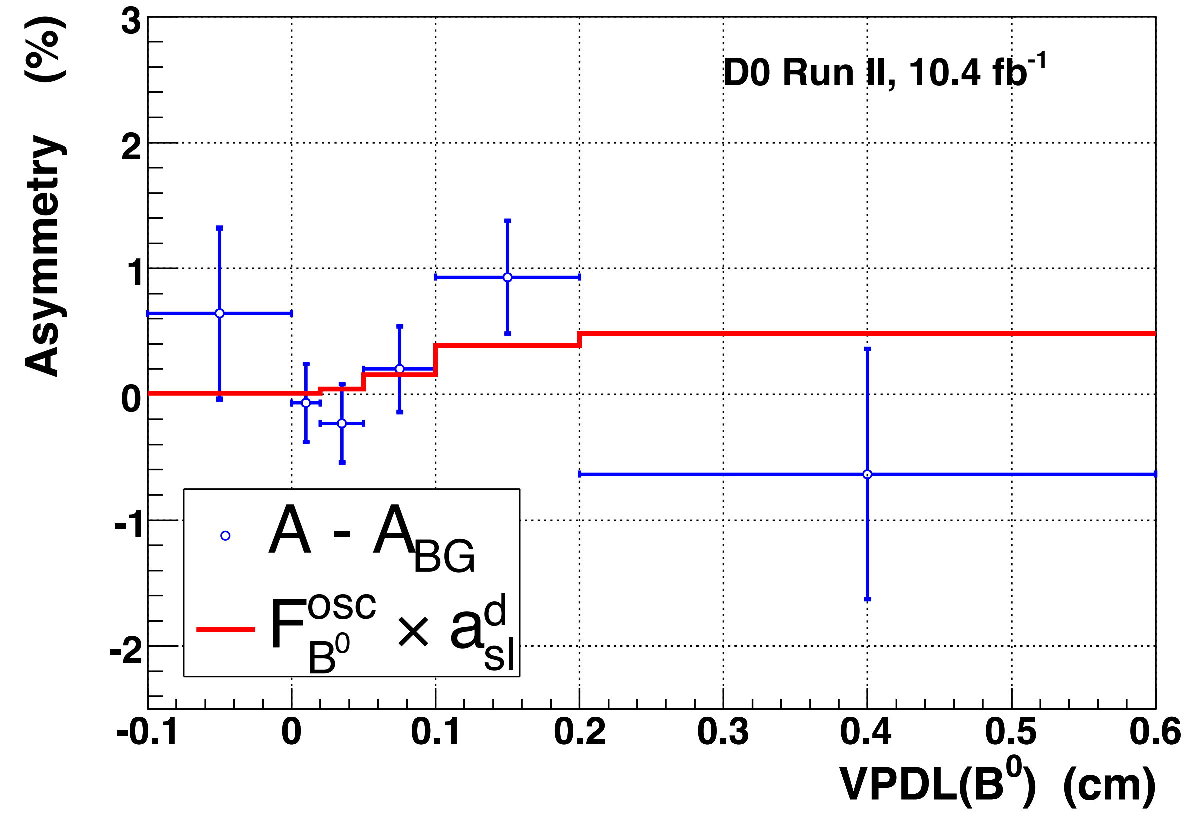


Extract a^d_{sl}: PRD 86, 072009 (2012)

$$B^0_d \to \mu^+ \nu D^- X$$



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



$$a^d_{\rm sl}(\mu D) = [0.43 \pm 0.63\,(\text{stat}) \pm 0.16\,(\text{syst})]\,\%$$

$$a^d_{\rm sl}(\mu D^*) = [0.92 \pm 0.62\,(\text{stat}) \pm 0.16\,(\text{syst})]\,\%$$

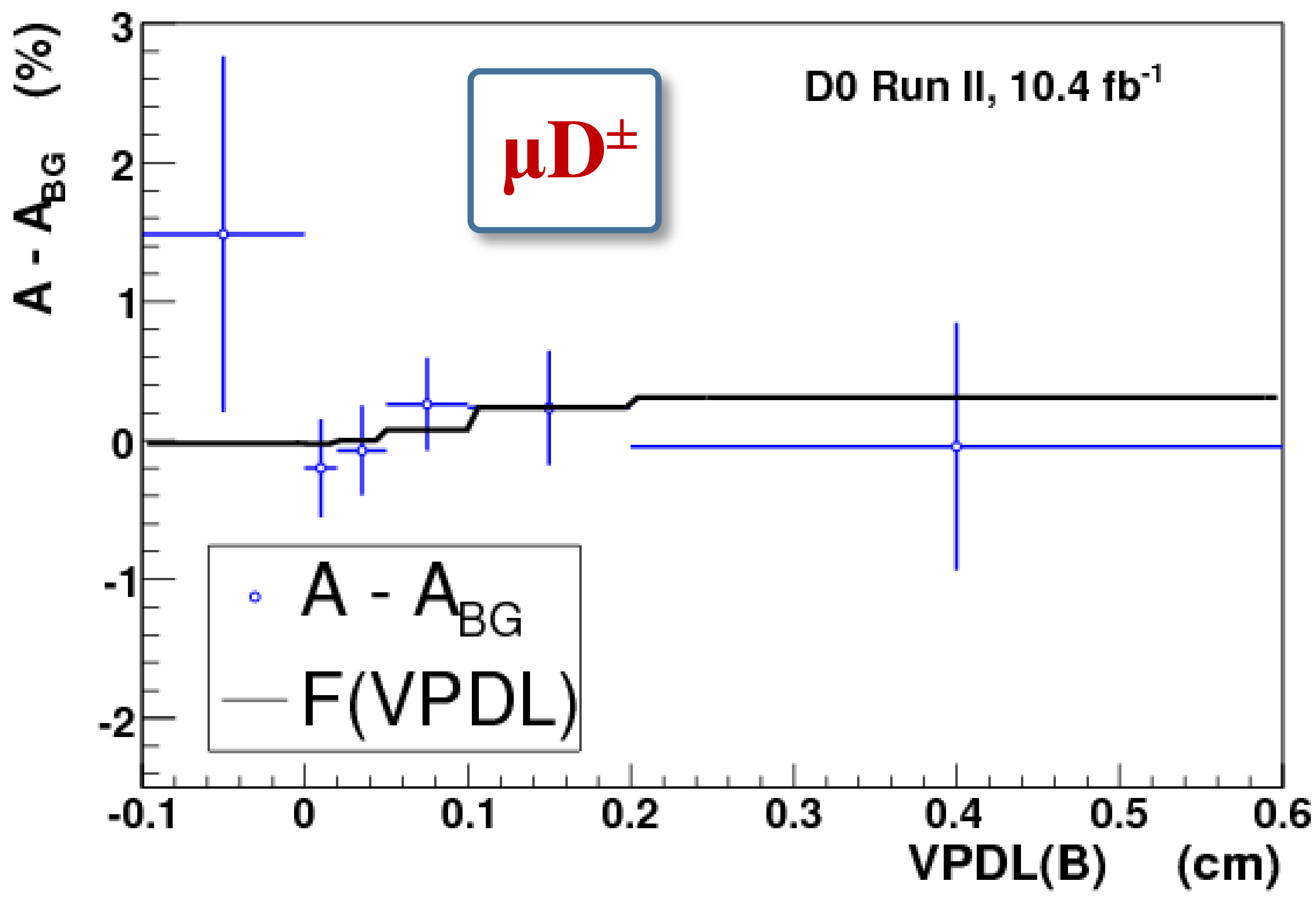
Weighted Average

$$a^d_{\rm sl} = [0.68 \pm 0.45\,(\text{stat}) \pm 0.14\,(\text{syst})]\,\%$$

Alternative Extraction

- Fit observed asymmetry ($A - A_{bg}$) to expected VPDL dependence

$$F(\mathrm{VPDL}) = A_{\mathrm{const}} + F^{\mathrm{osc}}_{B^0}(\mathrm{VPDL}) \cdot a^d_{\mathrm{sl}}$$



$$a^d_{\mathrm{sl}} = (0.51 \pm 0.86)\,\%$$

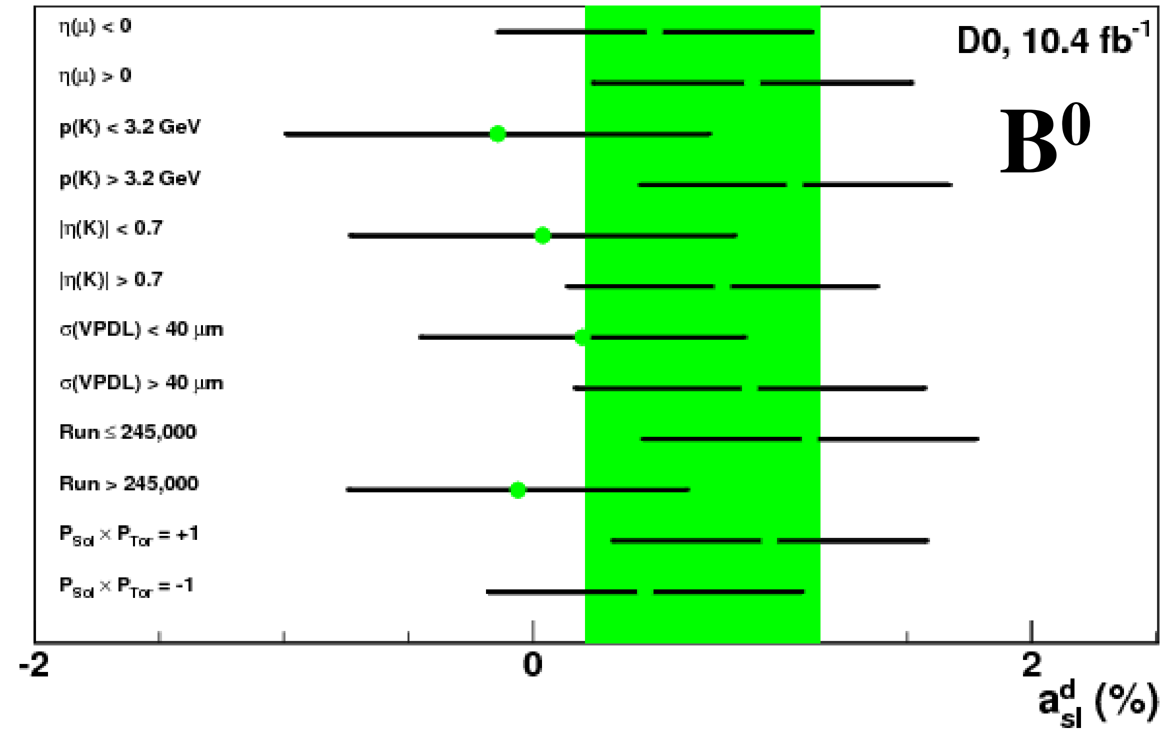
Compare with (0.43 ± 0.65)% from nominal method

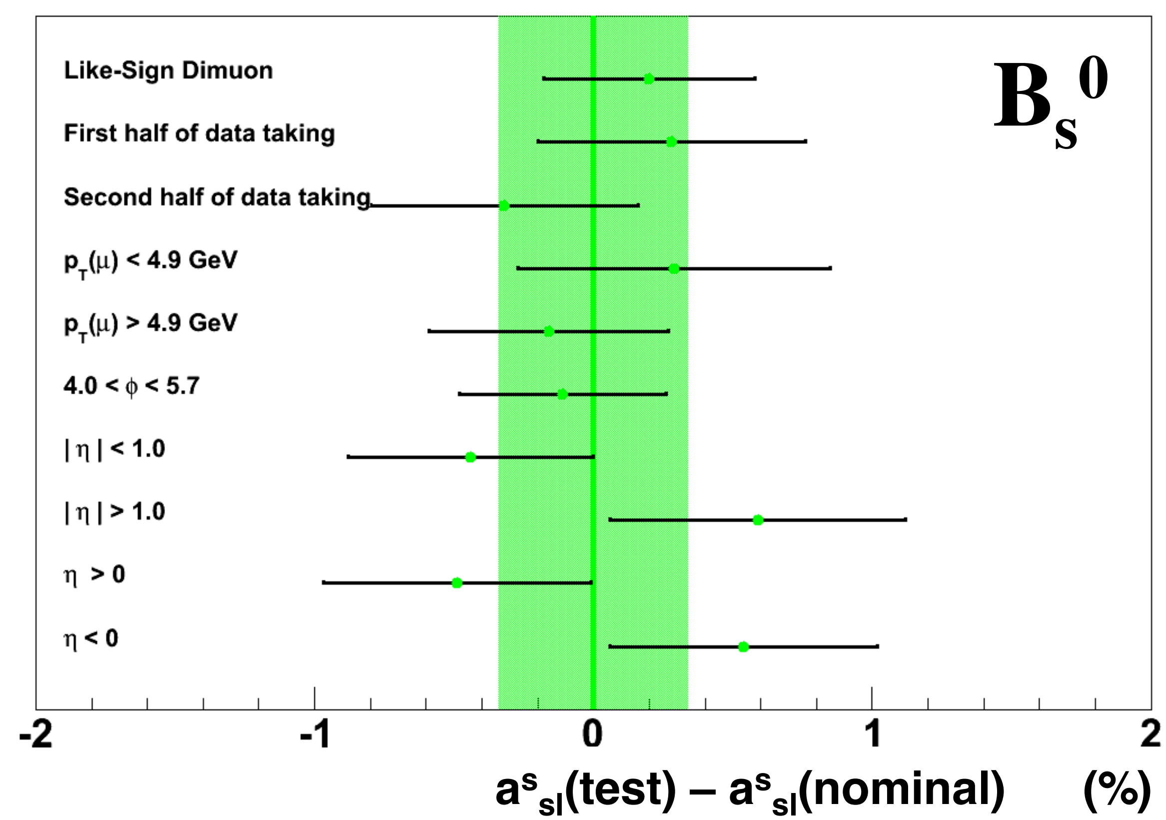
$$A_{\mathrm{const}} = (-0.03 \pm 0.23)\,\%$$

Consistent with no residual asymmetries.

Cross Checks

- Repeat analysis using pairs of orthogonal sub-sets of the data to check stability
  - Forward/Backward
  - Forward/Central
  - Low/High Momentum
  - Early/Late Running
  - Also different muon selections, and detector coverage
- All measurements are consistent



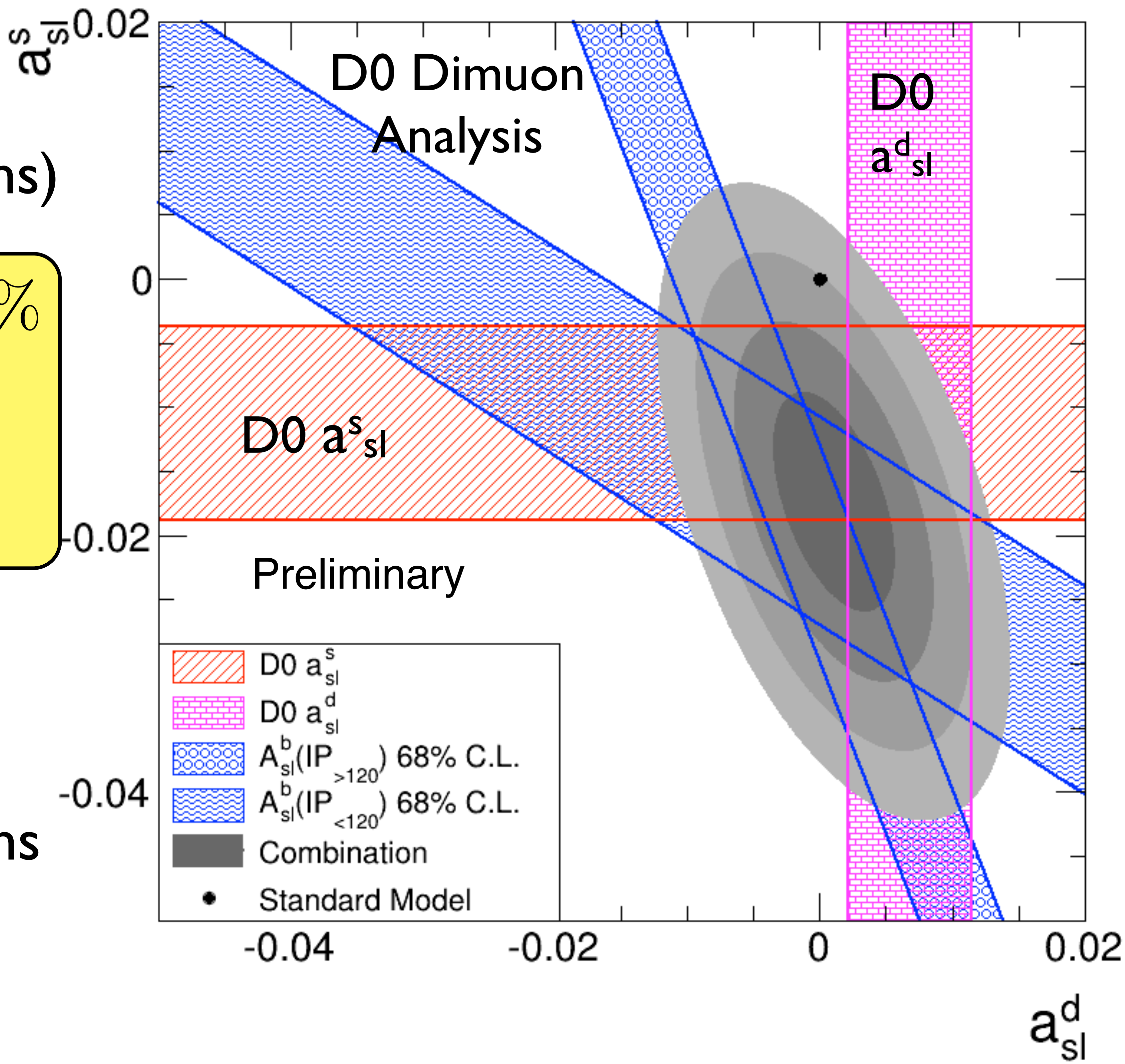


Combination of D0 Results

- Combine all three D0 measurements (including correlations)

$$a_{\mathrm{sl}}^{s} = (-1.73 \pm 0.56)\,\%$$
$$a_{\mathrm{sl}}^{d} = (0.11 \pm 0.30)\,\%$$
$$\rho = -0.51$$

- $\chi^2 = 2.80/2$ dof
- p-value(SM) = 0.33% 2.9 standard deviations
- a^s_{sl} is 3.1 standard deviations from zero

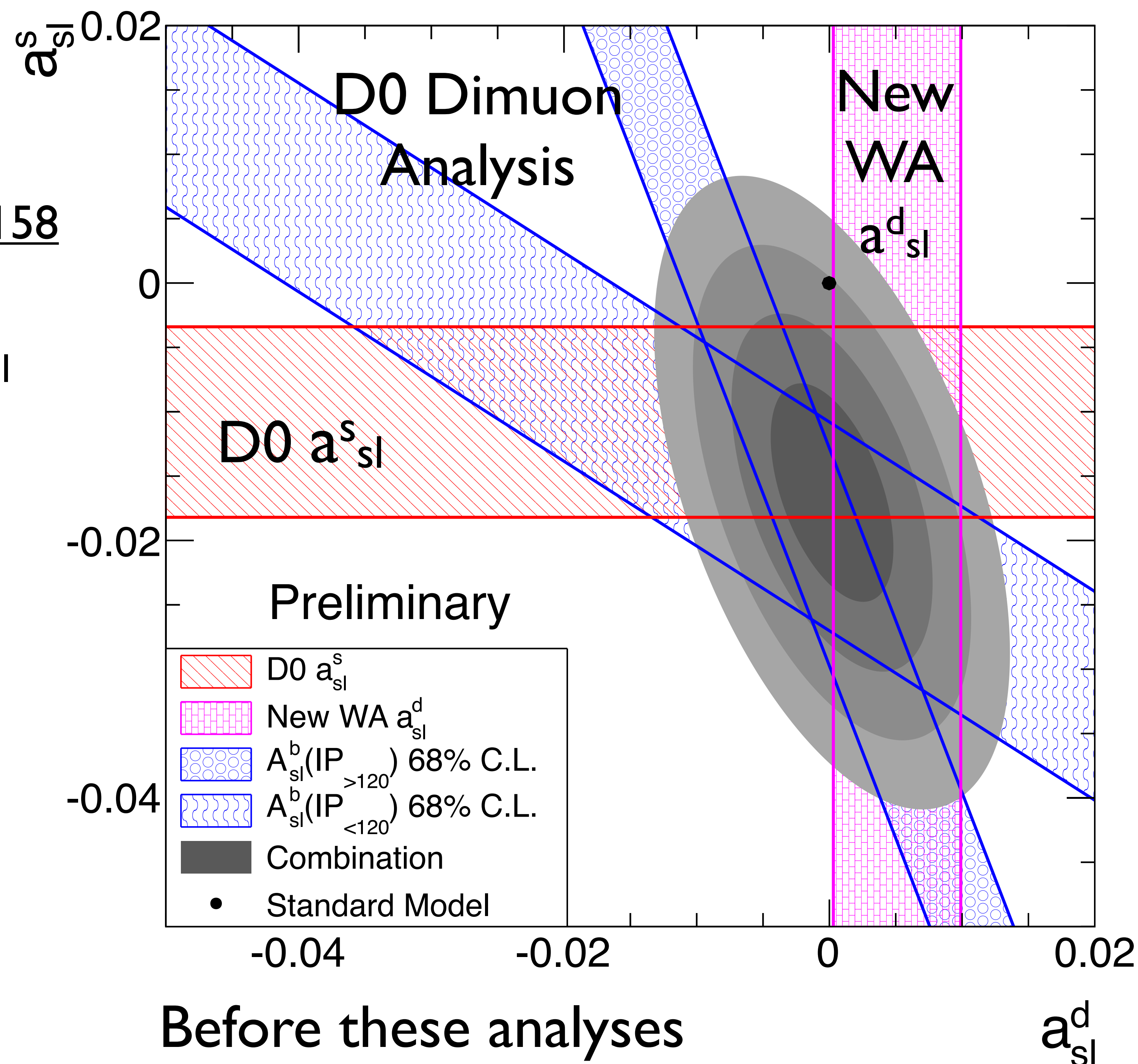


Including B-Factory a^d_{sl}

- Average new D0 result with HFAG PDG 2012 average of B-Factory results: $a^d_{sl} = (0.38 \pm 0.36)\%$ arXiv:1207.1158
- Combine with D0 dimuon and a^s_{sl}

$$a^s_{\rm sl} = (-1.71 \pm 0.55)\,\%$$
$$a^d_{\rm sl} = (0.07 \pm 0.27)\,\%$$
$$\rho = -0.46$$

- χ^2 = 1.89/2 dof
- p-value(SM) = 0.34%, 2.93 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.

$$a^s_{\mathrm{sl}} = [-1.12 \pm 0.74\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})]\,\%$$

$$a^d_{\mathrm{sl}} = [0.68 \pm 0.45\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst})]\,\%$$

- Both measurements are consistent with the anomalous like-sign dimuon charge asymmetry
- Combined value of a^s_{sl} is significantly different from the SM (-1.73 ± 0.56)% : 3.1 standard deviations from zero.
- Final update on anomalous like-sign dimuon asymmetry this summer hopefully (effectively doubling statistics for IP measurement).

- D0 a^s_{sl} result *PRL 110, 011801 (2013)*

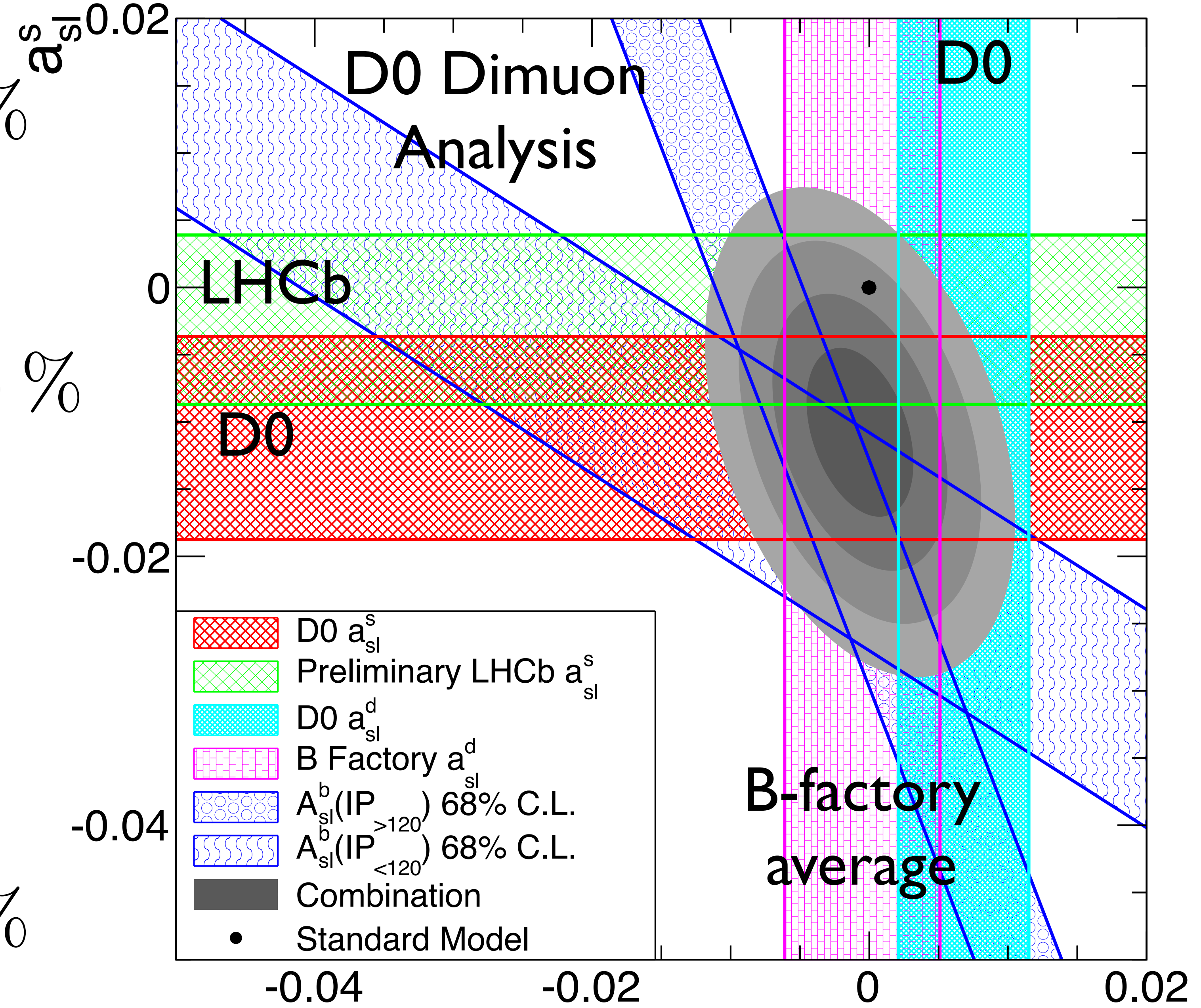
$$a^s_{\rm sl}({\rm D0}) = (-1.12 \pm 0.75)\,\%$$

- Preliminary LHCb result *LHCb-CONF-2012-022*

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

- All results are consistent
- χ^2 = 0.80 for a^s_{sl} combination
- Average of $B_s^0 \rightarrow \mu^+ D_s^-$ a^s_{sl} results:

$$a^s_{\rm sl}(B^0_s) = (-0.60 \pm 0.49)\,\%$$



- Combine with preliminary D0 and B-Factory a^d_{sl} and D0 like sign dimuon charge asymmetry

$$a^s_{\rm sl} = (-1.07 \pm 0.41)\,\%$$
$$a^d_{\rm sl} = (-0.07 \pm 0.25)\,\%$$
$$\rho = -0.36$$

p-value(SM) = 1.4%
2.5 standard deviations
χ^2 = 4.14/2 dof

Backup

Combination Details

- Page 16: 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.
  - The combined D0 and B-Factory values of a^d_{sl} is:

$$a^d_{\mathrm{sl}} = (0.38 \pm 0.36)\,\%$$

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

$$a^s_{\rm sl} = (-1.73 \pm 0.56)\,\%$$
$$a^d_{\rm sl} = (0.11 \pm 0.30)\,\%$$
$$\rho = -0.51$$

$$|q/p|_s = 1.0115 \pm 0.0028$$
$$|q/p|_d = 0.9980 \pm 0.0015$$

Combination with LHCb

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

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

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