Semileptonic Charge Asymmetry in the $B^0{}_d$ System using

$$B^0_d \rightarrow D^{*+}\mu^-(\nu_\mu),\ D^{*+} \rightarrow D^0\pi^+,\ D^0 \rightarrow K^-\pi^+$$

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CPV

- The Universe is matter dominated - matter anti-matter asymmetry?
- Charge-Parity (CP) violating processes produce an asymmetry - different interaction amplitudes for particle/antiparticles.
- Standard Model predictions too small for the observable Universe.
- Oscillation from B^0_d to antiB^0_d results in difference in decay width
- The effect is described in the CKM matrix as a complex phase

$$\mathbf{V} = \begin{pmatrix} \mathbf{V}_{ud} & \mathbf{V}_{us} & \mathbf{V}_{ub} \\ \mathbf{V}_{cd} & \mathbf{V}_{cs} & \mathbf{V}_{cb} \\ \mathbf{V}_{td} & \mathbf{V}_{ts} & \mathbf{V}_{tb} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix}$$

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

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Charge Asymmetry

$$a_{sl}^d = \frac{A_{\rm raw} - A_K - A_\mu - A_{\rm track}}{f_{B_d^0}({\rm osc})}$$

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

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

SM theoretical value:

$$a_{sl}^d = (-4.8^{+1.0}_{-1.2}) \times 10^{-2}\%$$

B factory results average:

$$a_{sl}^d = (0.47 \pm 0.46)\%$$

- CPV can be measured as charge asymmetry in flavour specific semi-leptonic *B* decays.
- Use the lepton charge to flag the flavour of B^0_d at decay
- $A_{\rm background}$ is comprised of A_K, A_μ and $A_{\rm track}$: kaon, muon and charged track reconstruction asymmetries.
- f_{B0d}(osc), the fraction of candidates that originated from an oscillated B^0_d, is a dilution factor.
- Probability of B^0_d oscillation lifetime dependent; use regions of visible proper decay length (VPDL) of the *B* candidate.

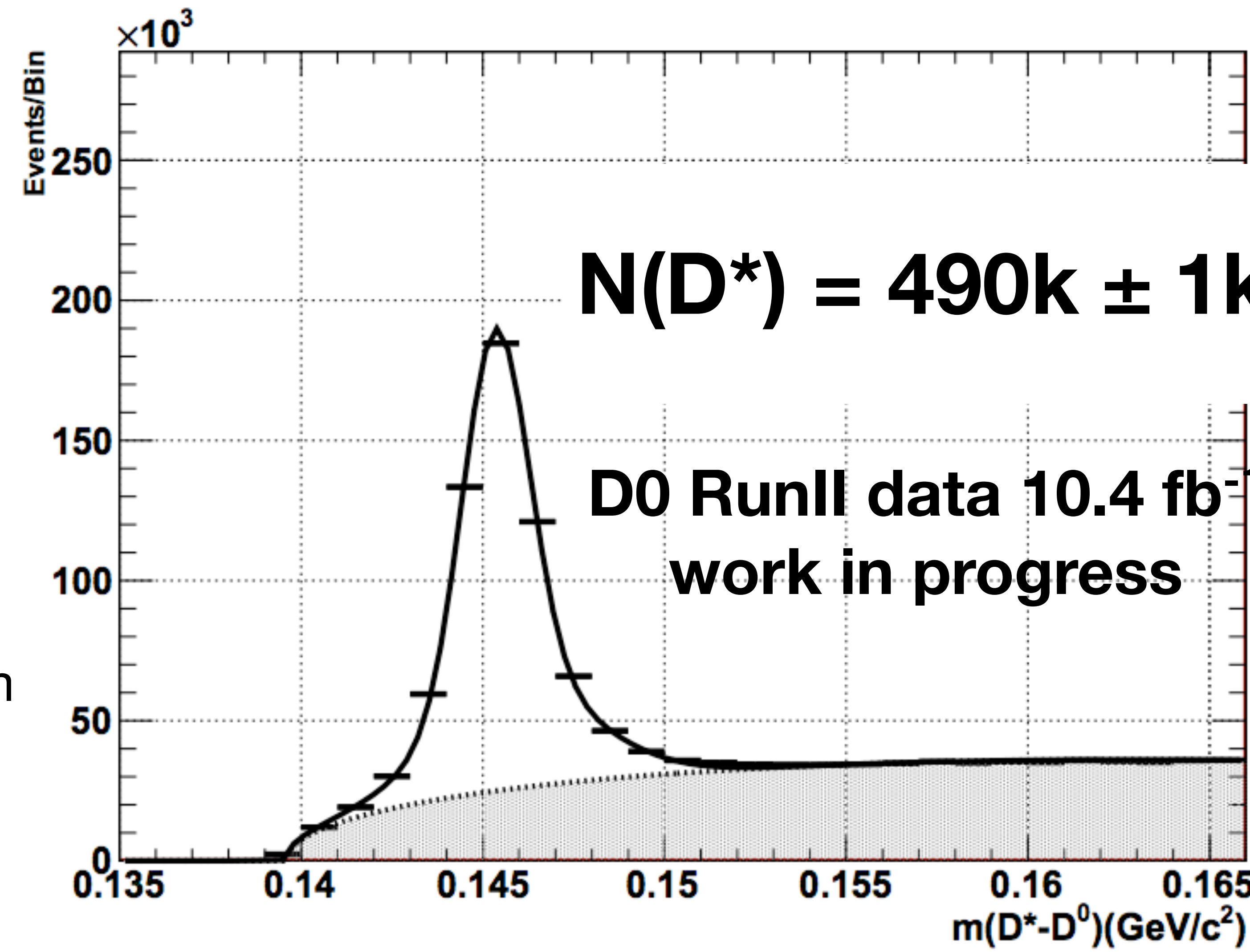
$$\text{VPDL} = L_{xy}(B)\frac{cM(B_d^0)}{pT(\mu D^*)_{\rm reco}}$$

Motivation

$$a_{sl}^{d} = \frac{A_{\text{raw}} - A_K - A_\mu - A_{\text{track}}}{f_{B_d^0}(\text{osc})}$$

- Measure a^{d}_{sl} from N+ - N- difference yields / N+ + N- sum yields in the chain:

$$B_d^0 \to D^{*-}\mu^+(\nu),$$
$$D^{*-} \to D^0\pi^-,$$
$$D^0 \to K^+\pi^-$$

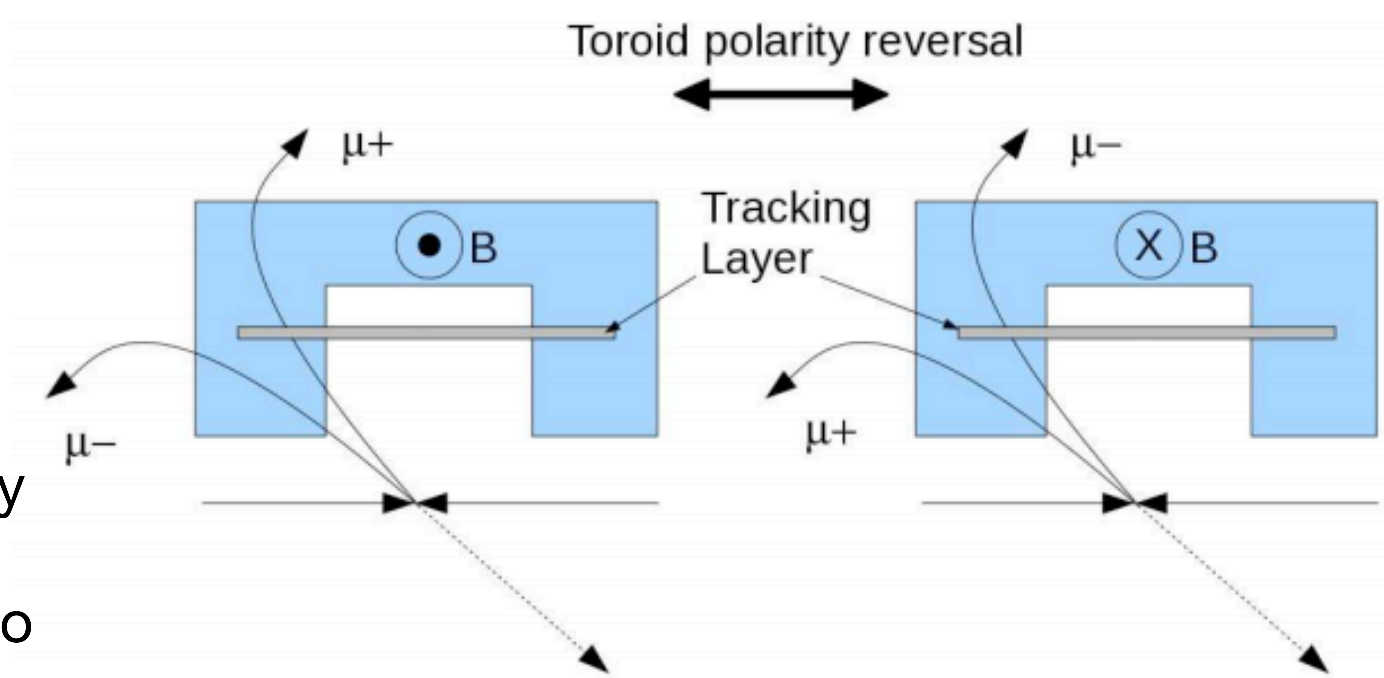


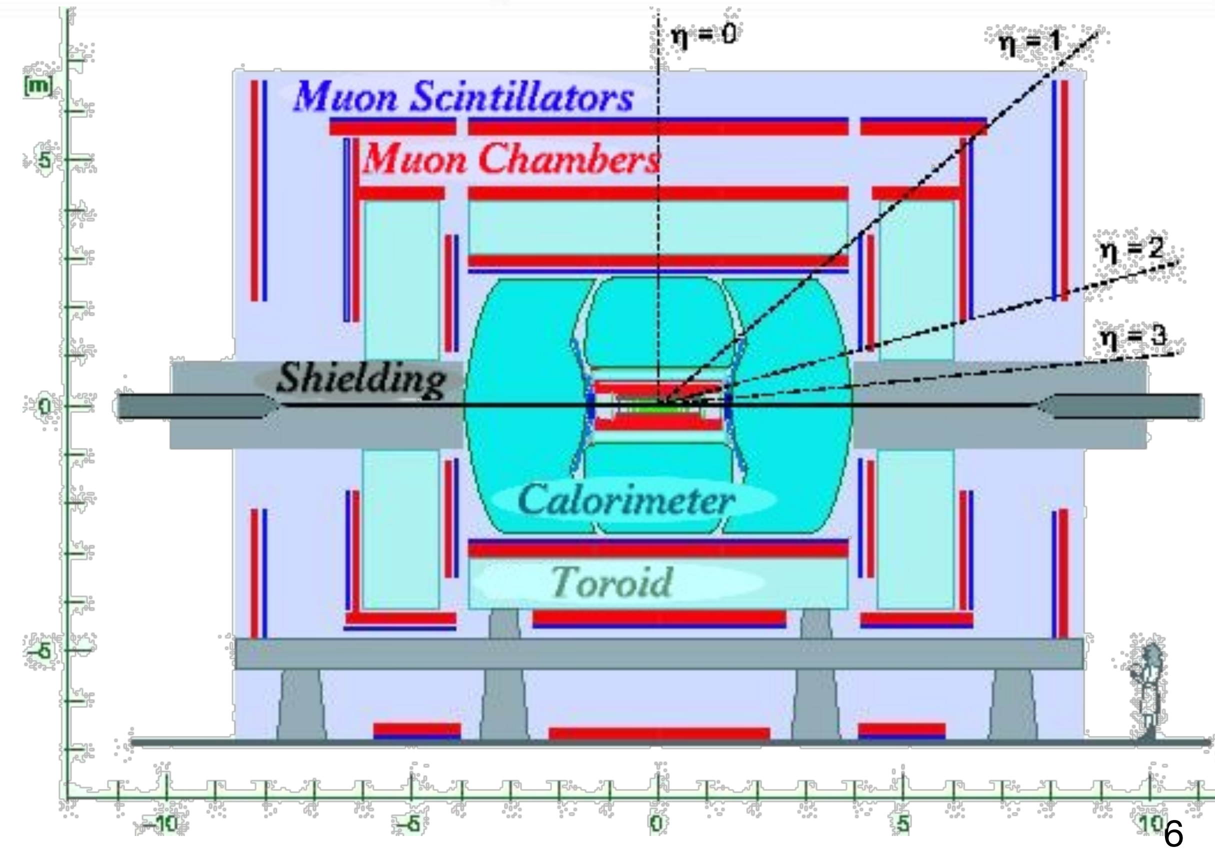
- Using 10.4 fb^{-1} of integrated luminosity from D0 detector, ~490k D* are found
- Large sample - relatively small statistical uncertainty expected
- Analysis runs parallel to a B^0_d -> $D^- mu^+$ study, results can be combined

Detector Asymmetries

$$a_{sl}^{d} = \frac{A_{\mathrm{raw}} - A_K - A_\mu - A_{\mathrm{track}}}{f_{B_d^0}(\mathrm{osc})}$$

- **D0** inner detector - silicon microstrip tracker, central fibre tracker, **solenoidal magnet**
- **D0** muon system - Three layers of muon detectors, **toroidal magnet** outside of first
- Magnets polarities individually reversed regularly
- The layout of the detector equipment can lead to local and global detectable charge asymmetries
- First order detector asymmetries can be cancelled using polarity reversals
- Expose each section of the detector to approx. the same flux of particles and antiparticles
- Weight each event so contribution from each **toroid/solenoid (±,±)** combination equal - first order detector asymmetries are removed when constructing N_{diff}



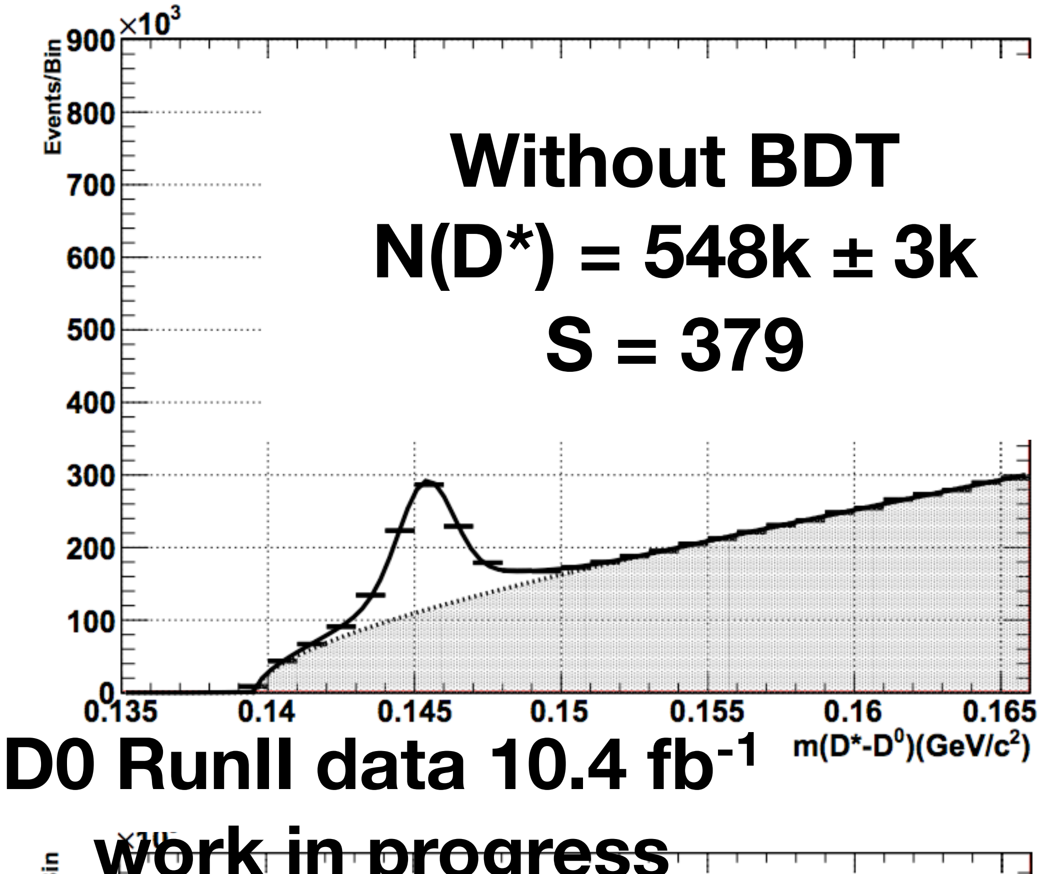


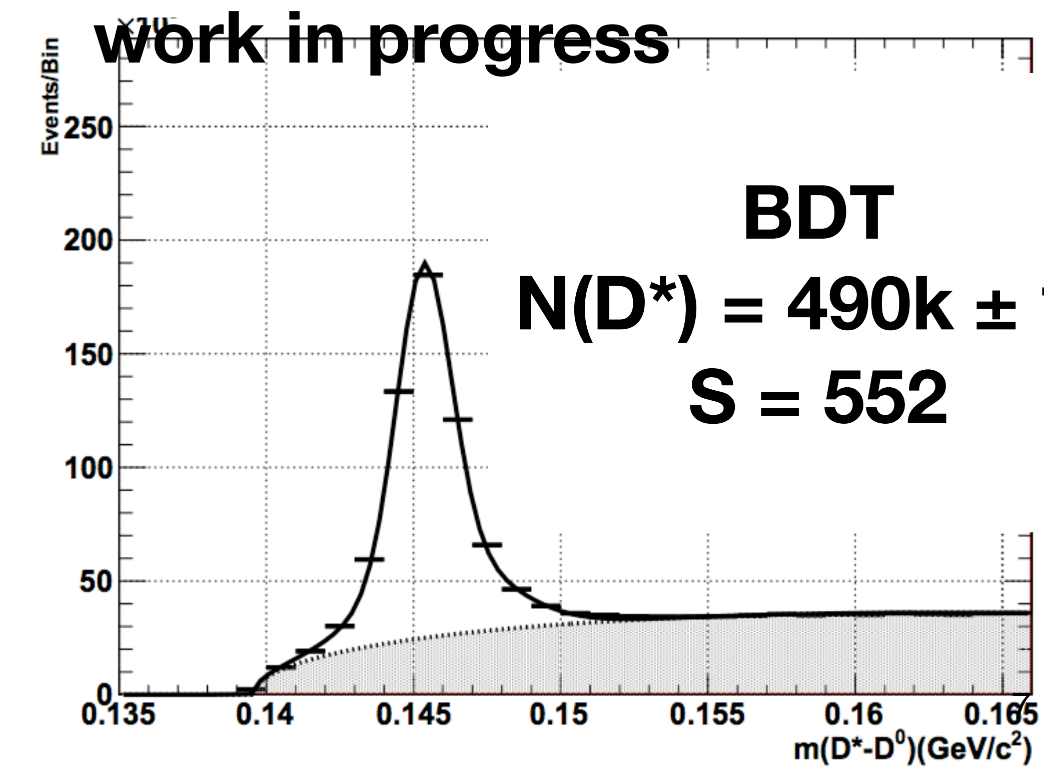
http://www.etap.physik.uni-mainz.de/Bilder_allgemein/

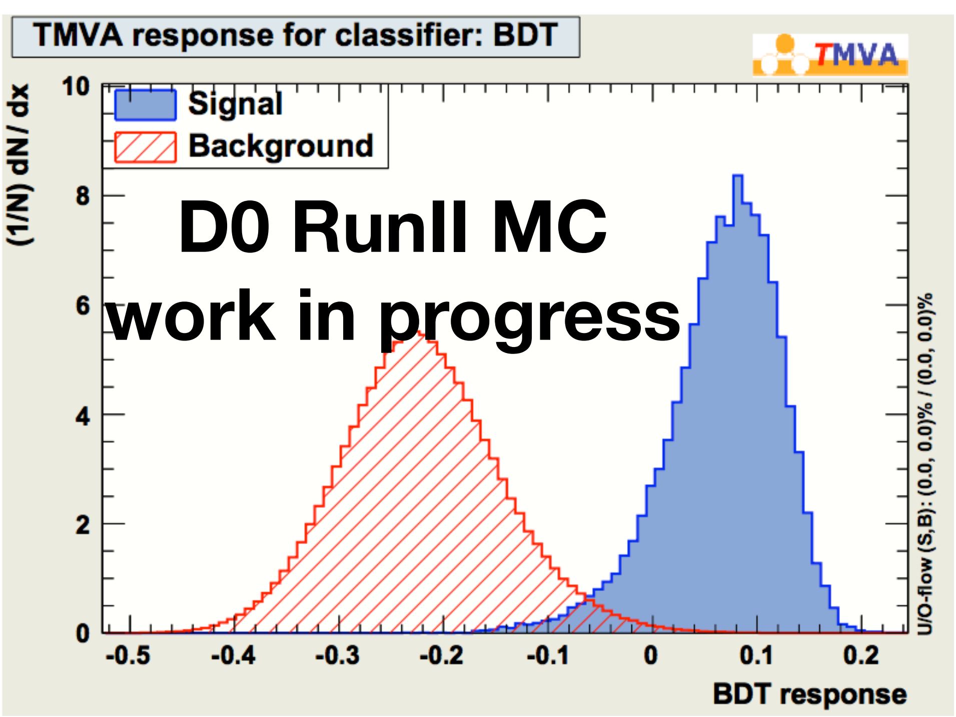
Event Selection

$$a_{sl}^{d} = \frac{A_{\text{raw}} - A_K - A_\mu - A_{\text{track}}}{f_{B_d^0}(\text{osc})}$$

- Loose quality cuts on the muon, kinematic cuts on tracks.
- Boosted decision tree (BDT) with 22 parameters is used to reduce background.
  - Monte-Carlo signal channel sample compared to wrong sign data sample
- BDT cut is optimised per VPDL region and data taking era





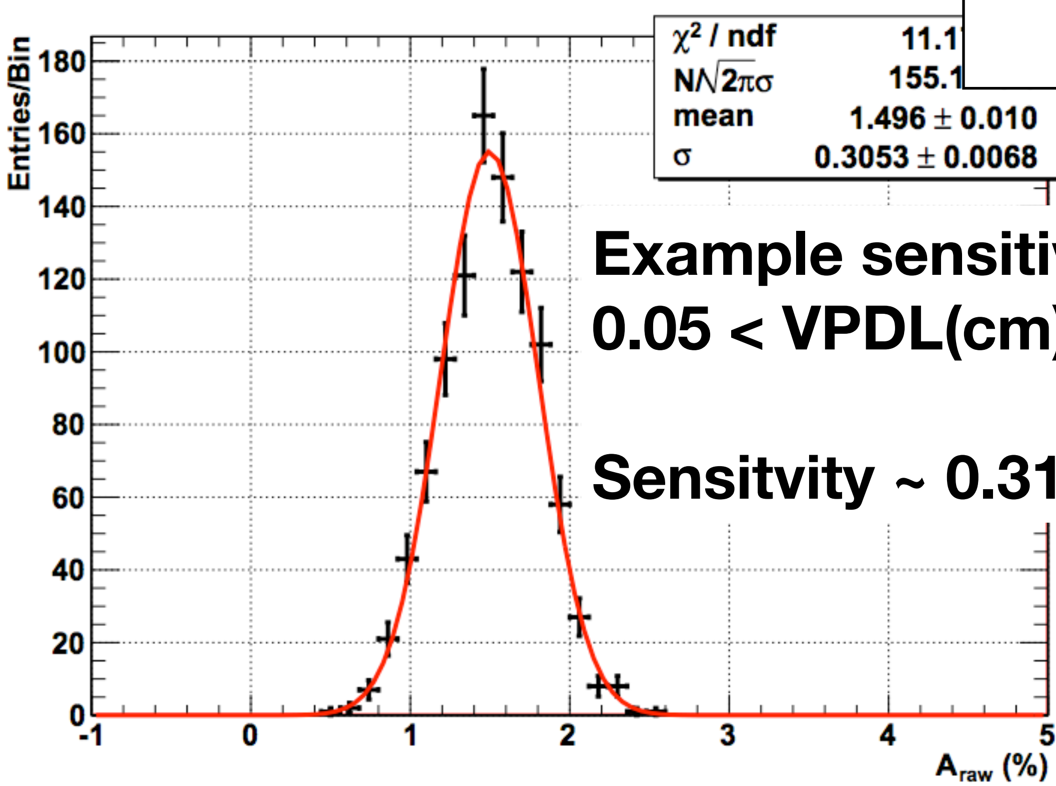


Sensitivity

$$a_{sl}^d = \frac{A_{\rm raw} - A_K - A_\mu - A_{\rm track}}{f_{B_d^0}({\rm osc})}$$

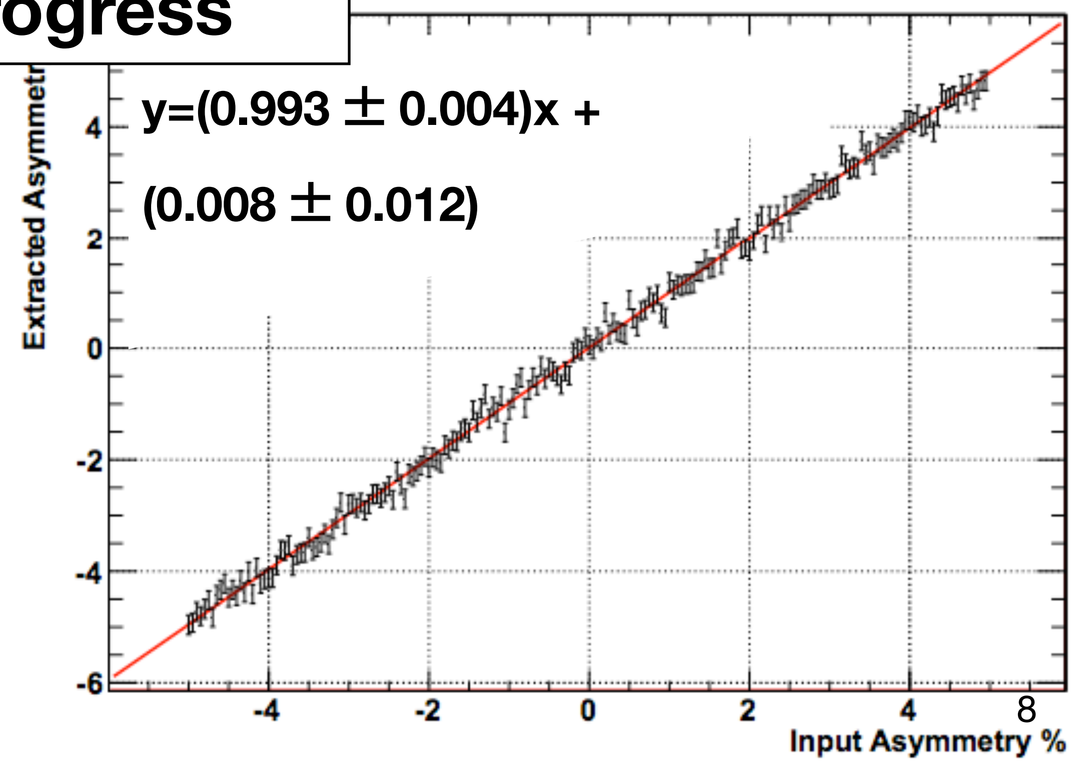
- Fit is skewed double Gaussian signal/(turn-on*linear) BG function (more on next slide)
- Difference and sum plots are fitted simultaneously, all parameters apart from signal and background normalisation
- Test biasing and expected statistical sensitivity in the fitting method by performing ensemble test on full dataset with muon charge randomised to give A = 1.5%
- Input Asymmetry vs Extracted Asymmetry plot shows good agreement

D0 RunII data 10.4 fb^{-1} work in progress



Example sensitivity plot
0.05 < VPDL(cm) < 0.10

Sensitvity ~ 0.31%

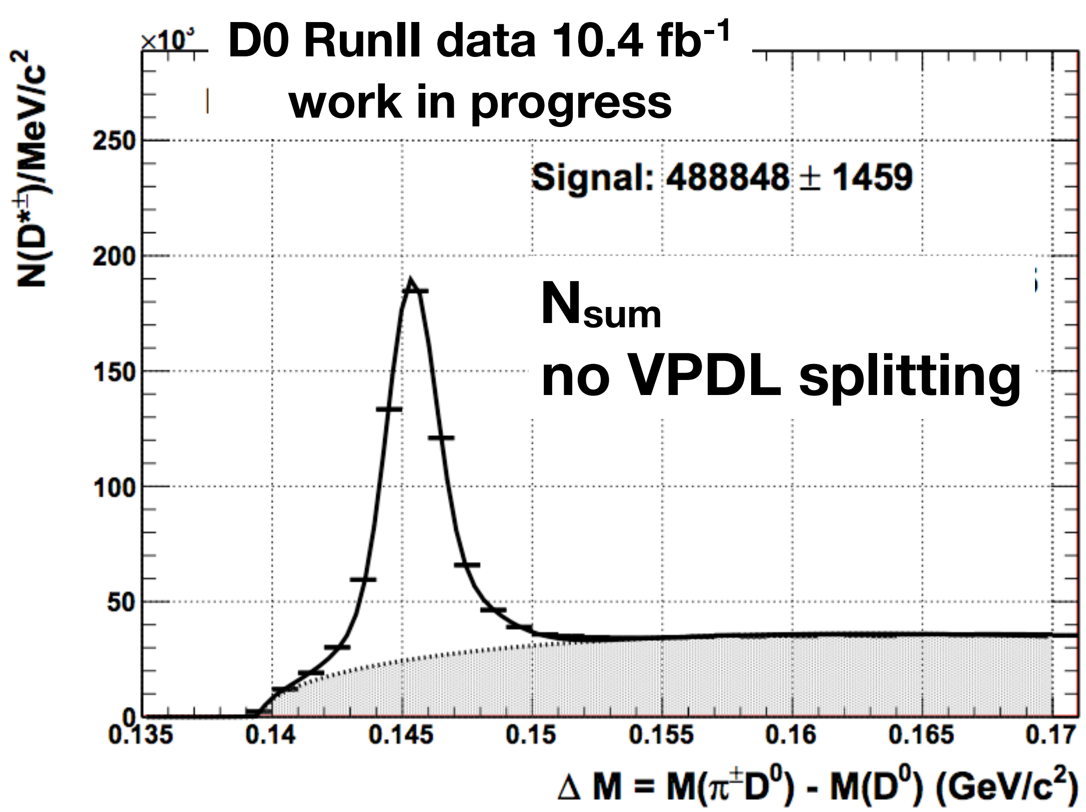


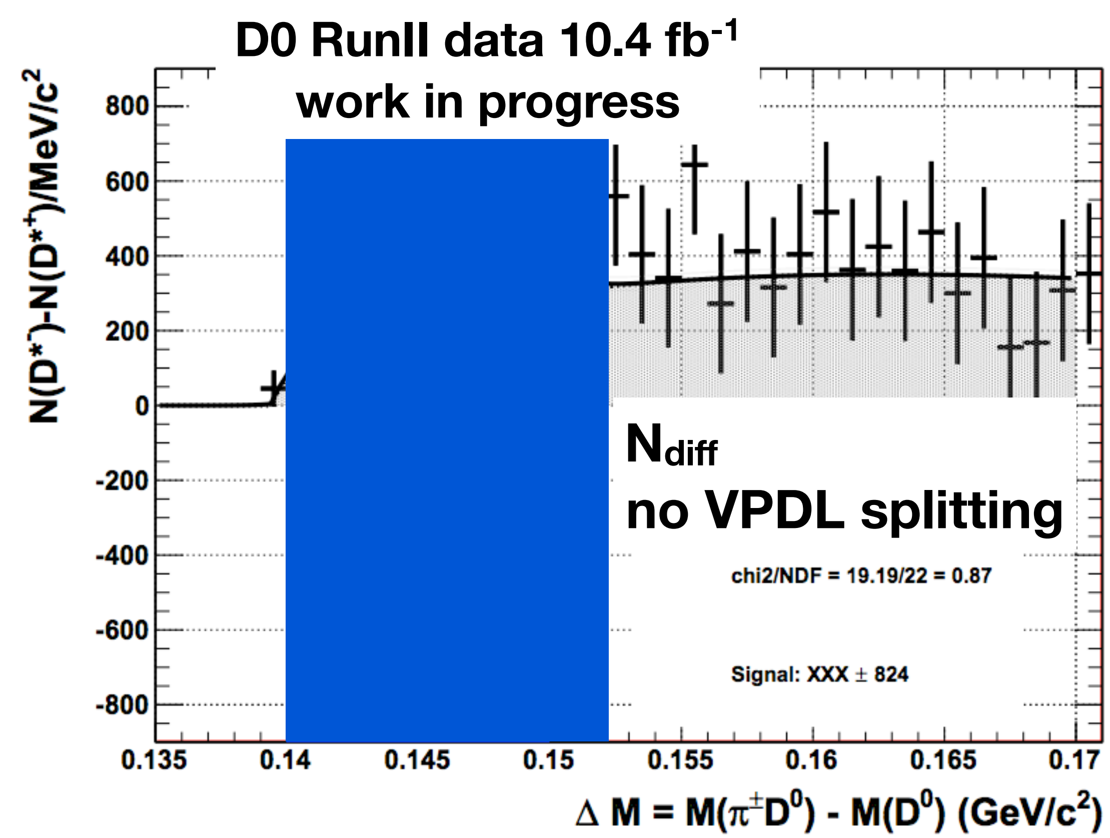
Raw Asymmetry Extraction

$$a^d_{sl} = \frac{A_{\rm raw} - A_K - A_\mu - A_{\rm track}}{f_{B^0_d}(\rm osc)}$$

$$f_{\rm signal} = N\left\{r\,{\rm erfc}\left[-s\frac{(m-\mu)}{\sqrt{2}\sigma_1}\right]\frac{1}{\sqrt{2\pi}\sigma_1}\exp\left[\frac{(\mu-m)^2}{2\sigma_1^2}\right] + (1-r){\rm erfc}\left[-s\frac{(m-\mu)}{\sqrt{2}\sigma_2}\right]\frac{1}{\sqrt{2\pi}\sigma_2}\exp\left[\frac{(\mu-m)^2}{2\sigma_2^2}\right]\right\}$$

$$f_{\rm background} = C(m-m_\pi)^a(1+bm)$$





central values are blinded

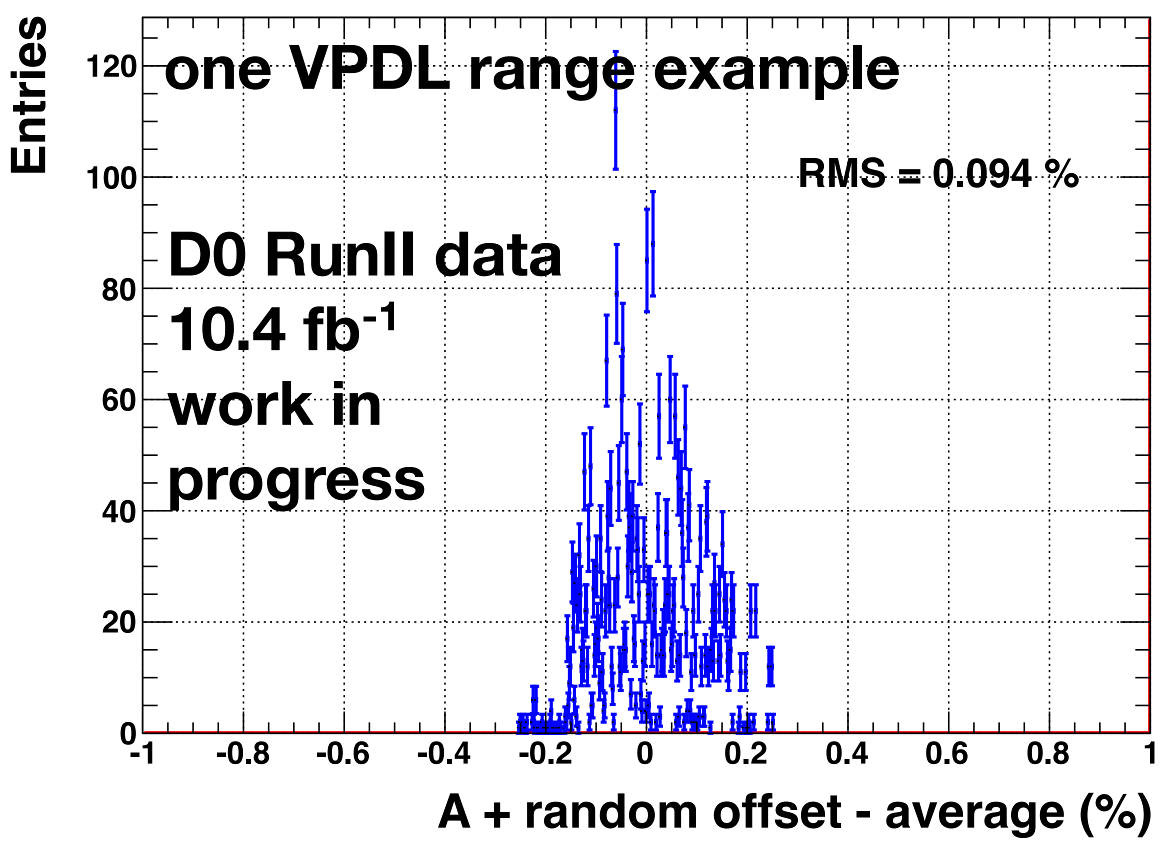
VPDL range (cm)	Sensitivity (%)	$\sigma A_{\rm raw}$ (%)
-0.10 → 0.00	0.65	0.71
0.00 → 0.02	0.30	0.31
0.02 → 0.05	0.31	0.31
0.05 → 0.10	0.34	0.33
0.10 → 0.20	0.43	0.45
0.20 → 0.60	0.99	1.01

$\sigma A_{\rm raw}$ (stat) with VPDL splitting

Raw Asymmetry Systematics

$$a_{sl}^{d} = \frac{A_{\text{raw}} - A_K - A_\mu - A_{\text{track}}}{f_{B_d^0}(\text{osc})}$$

VPDL (cm)	Bin 1 -0.10 → 0.00	Bin 2 0.00 → 0.02	Bin 3 0.02 → 0.05	Bin 4 0.05 → 0.10	Bin 5 0.10 → 0.20	Bin 6 0.20 → 0.60
Magnet weighting	±0.01%	±0.01%	±0.00%	±0.00%	±0.00%	±0.01%
BG shape	±0.13%	±0.01%	±0.00%	±0.01%	±0.07%	±0.01%
Bin width	±0.06%	±0.03%	±0.02%	±0.02%	±0.01%	±0.08%
m(D^0) cut range	±0.01%	±0.01%	±0.01%	±0.01%	±0.02%	±0.02%
Fit range	±0.05%	±0.01%	±0.01%	±0.01%	±0.06%	±0.06%
Combined systematic	±0.12%	±0.04%	±0.02%	±0.03%	±0.06%	±0.09%



(f) 0.20 < VPDL (cm) < 0.60

- Event weighting, difference BG shape, bin width, m(D^0) cut range, fit range
- 37 individual parameter changes per VPDL bin
- Total of 3744 alternative fit ensemble test per VPDL bin - this accounts for correlations

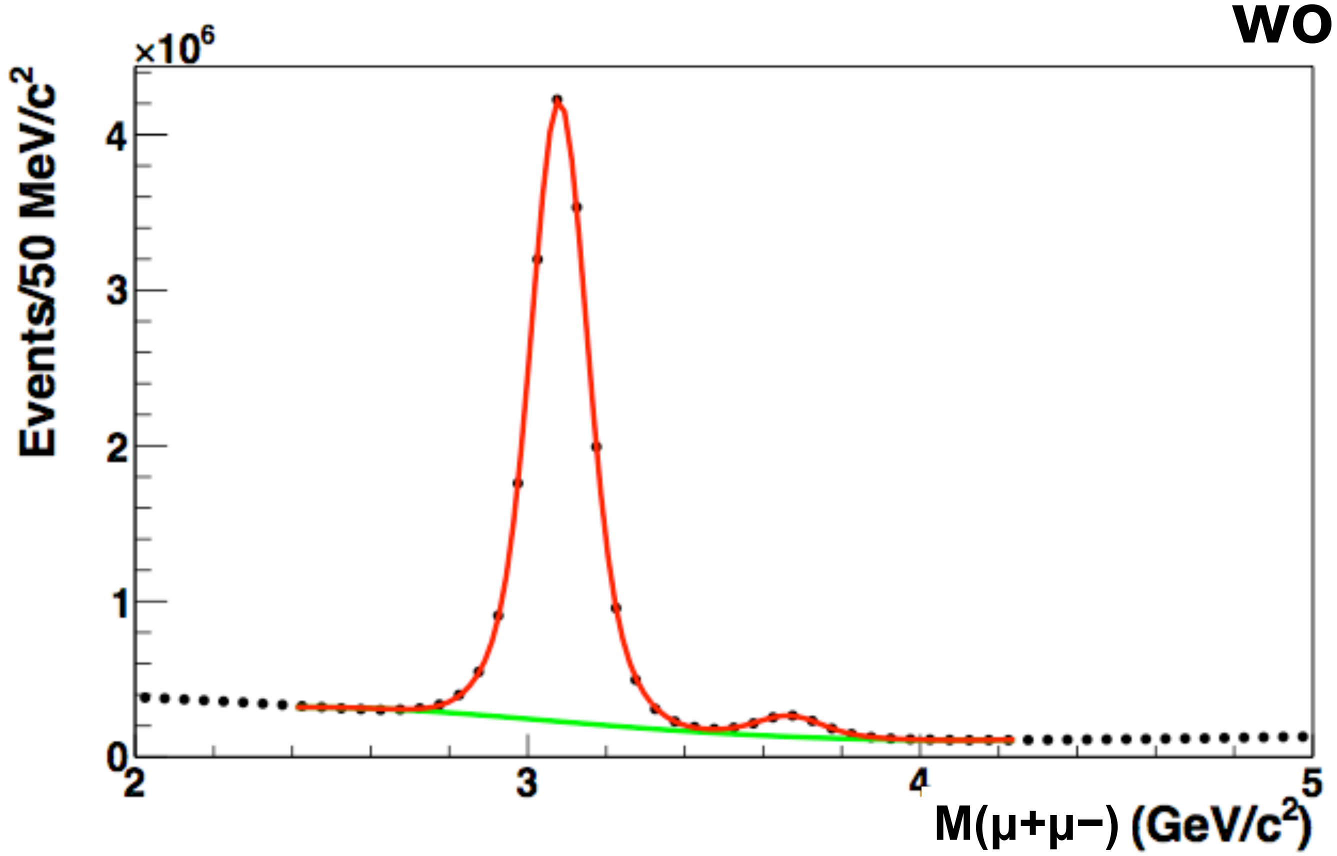
Muon/Track Asymmetry

$$a_{sl}^d = \frac{A_{\text{raw}} - A_K - A_\mu - A_{\text{track}}}{f_{B_d^0}(\text{osc})}$$

- Muon-antimuon reconstruction efficiency asymmetry corrections per VPDL bin were calculated in a separate analysis by Dr. Iain Bertram using ~16M $J/\psi \to \mu^+\mu^-$ candidates. A_μ is $p_T(\mu)$ dependent, so convolute $A_\mu(p_T)$ with f $p_T(\mu)$.

- **~ 0.1% A_μ correction per VPDL bin**

D0 RunII data 10.4 fb^{-1} work in progress



- Additional track reconstruction efficiency asymmetries were also investigated, but were found to be negligible -> $A_{\text{track}} = 0$

Kaon Asymmetry

$$a_{sl}^d = \frac{A_{\rm raw} - A_K - A_\mu - A_{\rm track}}{f_{B_d^0}(\rm osc)}$$

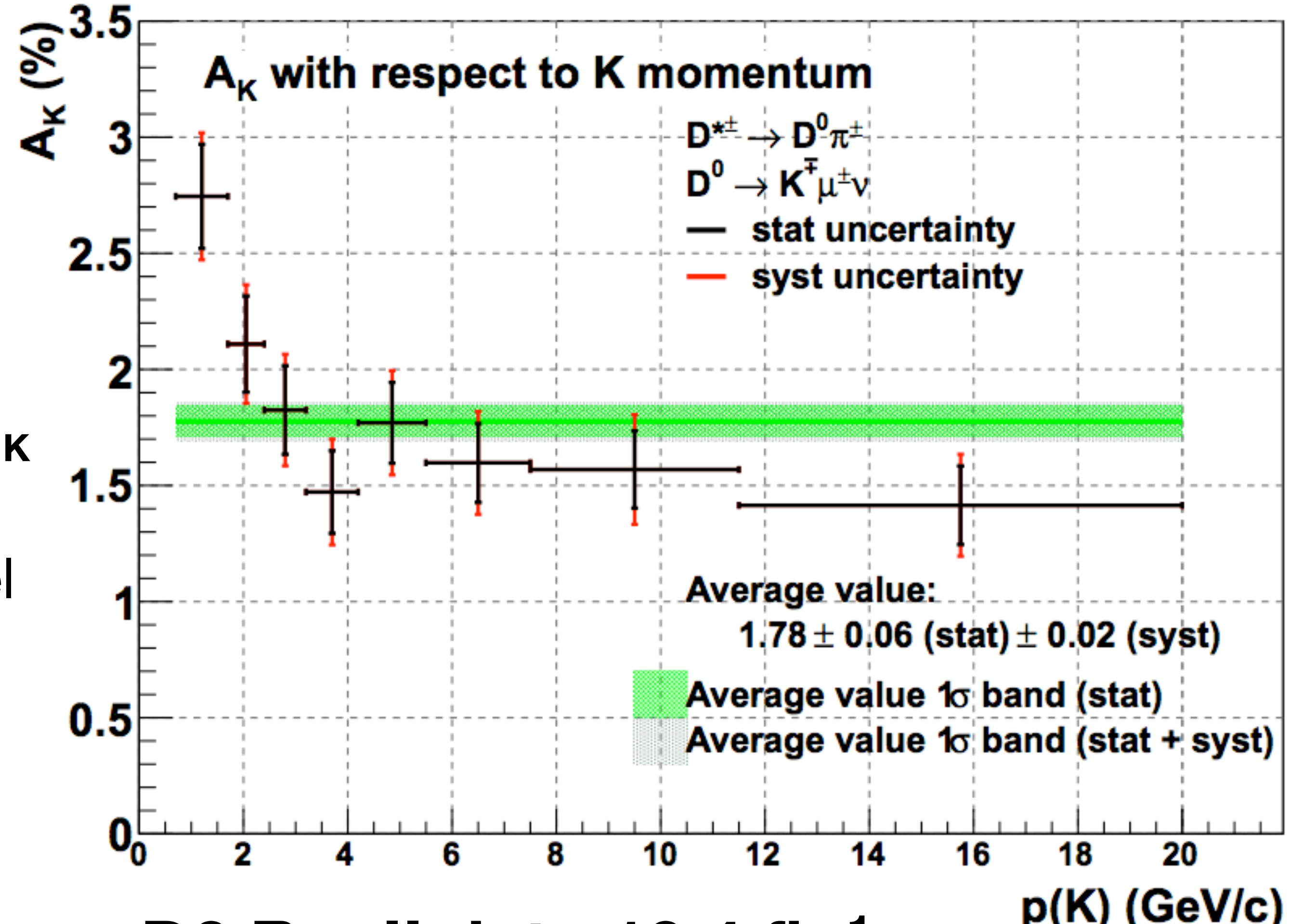
- Largest background asymmetry

$$K^-(s\bar{u}) + \text{detector}(uud, ddu) \rightarrow \text{hyperon}$$
$$K^+(\bar{s}u) + \text{detector}(uud, ddu) \not\rightarrow \text{hyperon}$$

- K^+ longer path length, larger reco eff, **+ve A_K**

- Extract asymmetry using dedicated channel

$$D^{*\pm} \rightarrow D^0\pi^\pm$$
$$D^0 \rightarrow K^\mp\mu^\pm(\nu)$$



D0 RunII data 10.4 fb^{-1}
work in progress

- 3.5M D* signal yield from 10.4 fb^{-1} data

- Δm = m(D^* - D^0) signal shape difficult to fit due to missing neutrino smearing and sharp turn on

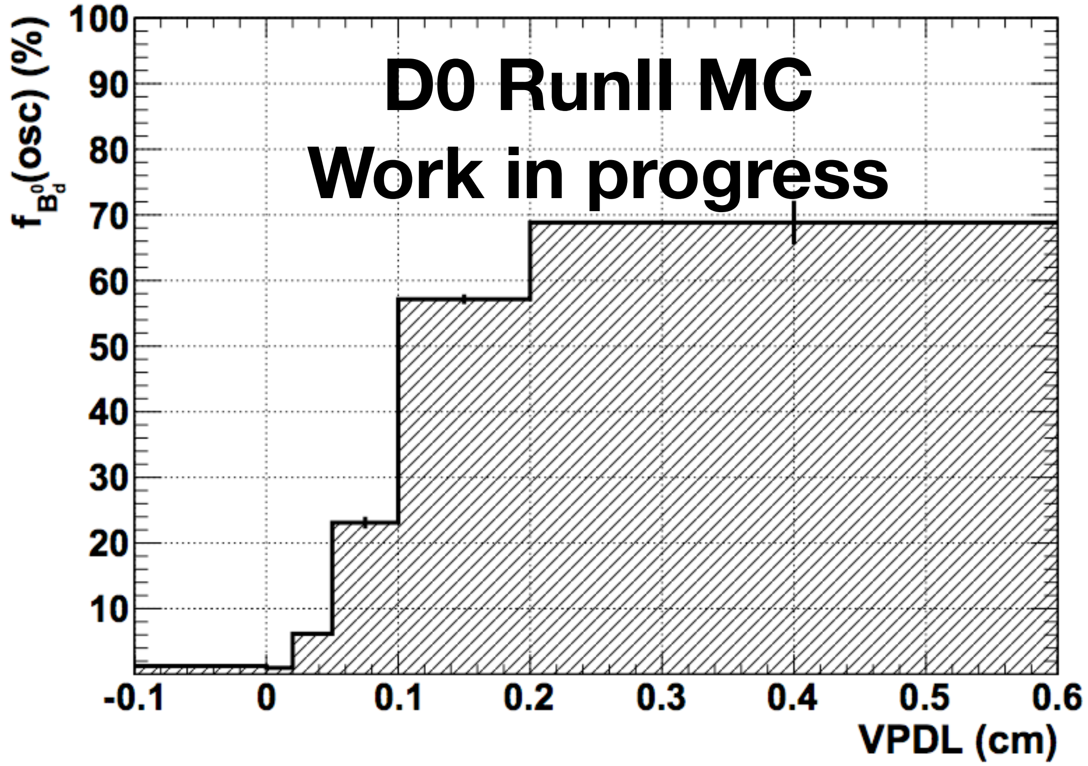
- Sum yields found using sideband scaled wrong sign subtraction to a Δm best significance cutoff - Same asymmetry extraction process as slide 4.

Dilution

$$P(\text{mix}) = \frac{1}{2}[1 - \cos(\Delta M t)]$$
$$t = \frac{m(B)d}{p(B)c}$$
$$\Delta M = (3.337 \pm 0.033) \cdot 10^{-10}\ \text{MeV}$$

$$a^d_{sl} = \frac{A_{\text{raw}} - A_K - A_\mu - A_{\text{track}}}{f_{B^0_d}(\text{osc})}$$

- Only oscillated $B^0{}_d$ parents contribute, all others wash out the asymmetry
- Find dilution fraction per VPDL region, $f_{B0d}(\text{osc})$
- MC: D^* + exclusive μ from quark level (2M generated, ~30k reconstructed)
- Match reconstructed D* candidate tracks to truth information, note parent, true lifetime -> P(mix)



	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
VPDL (cm)	-0.10 → 0.00	0.00 → 0.02	0.02 → 0.05	0.05 → 0.10	0.10 → 0.20	0.20 → 0.60
$f_{B^0_d}$(osc) %	1.25 ± 0.09	0.97 ± 0.04	6.17 ± 0.18	23.10 ± 0.91	57.15 ± 0.74	68.83 ± 3.33
$f_{B^0_d}$(non-osc) %	54.84 ± 1.33	82.57 ± 2.05	84.05 ± 2.14	67.24 ± 2.10	30.89 ± 0.38	11.05 ± 0.31
$f_{B^0_d}$(total) %	56.10 ± 0.00	83.55 ± 0.00	90.22 ± 0.00	90.34 ± 0.00	88.03 ± 0.00	79.88 ± 0.00
$f_{B^0_s}$(osc) %	0.44 ± 0.10	0.70 ± 0.05	0.72 ± 0.06	0.64 ± 0.02	0.76 ± 0.07	1.65 ± 0.46
$f_{B^0_s}$(non-osc) %	0.22 ± 0.13	0.46 ± 0.08	0.58 ± 0.08	0.58 ± 0.07	0.80 ± 0.07	1.65 ± 0.46
$f_{B^0_s}$(total) %	0.66 ± 0.00	1.16 ± 0.00	1.29 ± 0.00	1.22 ± 0.00	1.56 ± 0.00	3.30 ± 0.00
$f_{B^\pm}$ %	6.19 ± 0.44	7.34 ± 0.27	7.95 ± 0.30	8.44 ± 0.35	10.35 ± 0.46	16.81 ± 1.46
f_{prompt} %	37.05 ± 0.43	7.95 ± 0.35	0.53 ± 0.07	0.00 ± 0.00	0.05 ± 0.04	0.00 ± 0.00

Current Status

$$a^d_{sl} = \frac{A_{\rm raw} - A_K - A_\mu - A_{\rm track}}{f_{B^0_d}({\rm osc})}$$

- Central values are blinded pending analysis review
- First two bins should show zero asymmetry due to negligible f_{B0d}(osc)
- a^d_{sl} will be extracted using the four VPDL bins, 0.02 -- 0.60 cm
- Using last four bins, final expected precision:

$$a^d_{sl} = [X.XX \pm 0.64({\rm stat}) \pm 0.09({\rm syst})]\%$$

B factory results average:

$$a^d_{sl} = (0.47 \pm 0.46)\%$$

- Combining with the $B^0_d \rightarrow D^- \mu^+(\nu)$ sister analysis

$$a^d_{sl}({\rm combined}) = [X.XX \pm 0.49({\rm stat}) \pm 0.08({\rm syst})]\%$$

- Would be best single measurement, close to combined precision from all previous results
- Systematic uncertainties include contributions from A_{raw}, $A_{background}$ and f_{B0d}(osc)

Conclusion

- An almost finished measurement of the semileptonic charge asymmetry in $B^0{}_d$ decay, $a^d{}_{sl}$
- Requires the extraction of the kaon asymmetry caused by interactions with the D0 detector material
- When combined with sister analysis - close to world average precision
- Measurement is statistically limited
- Dominant systematic from behaviour of difference plot background close to turn-on