Search for CP Violating Charge Asymmetry in $B^- \rightarrow \mu^- \nu_\mu D^0$ decays at D0

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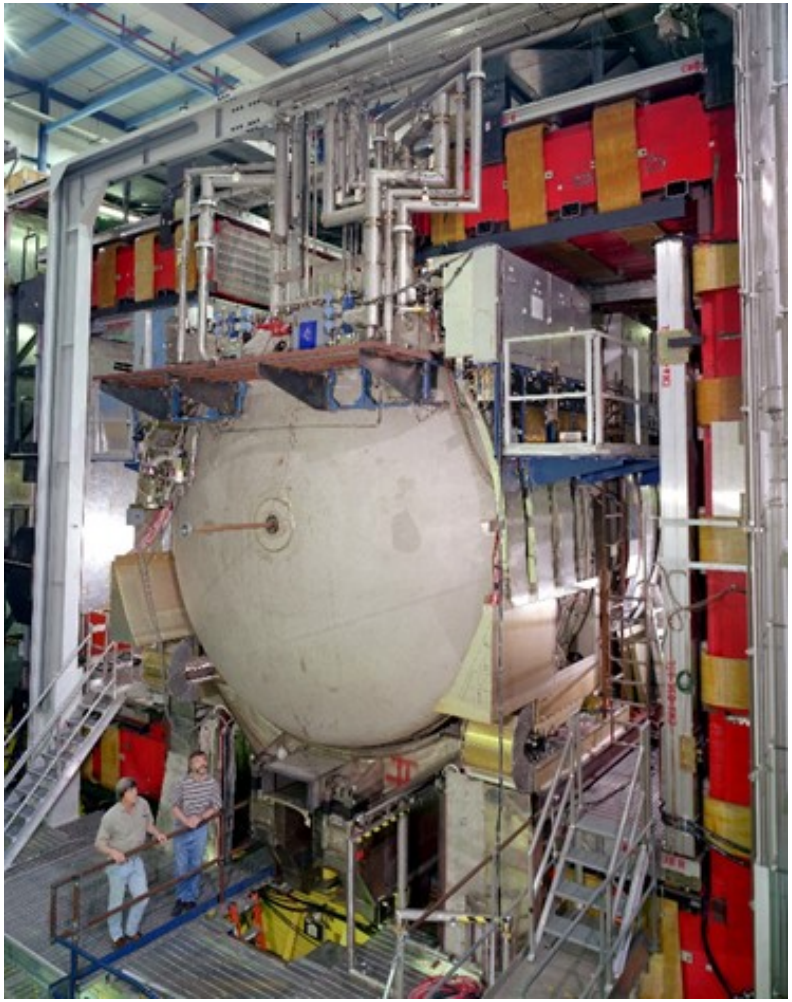
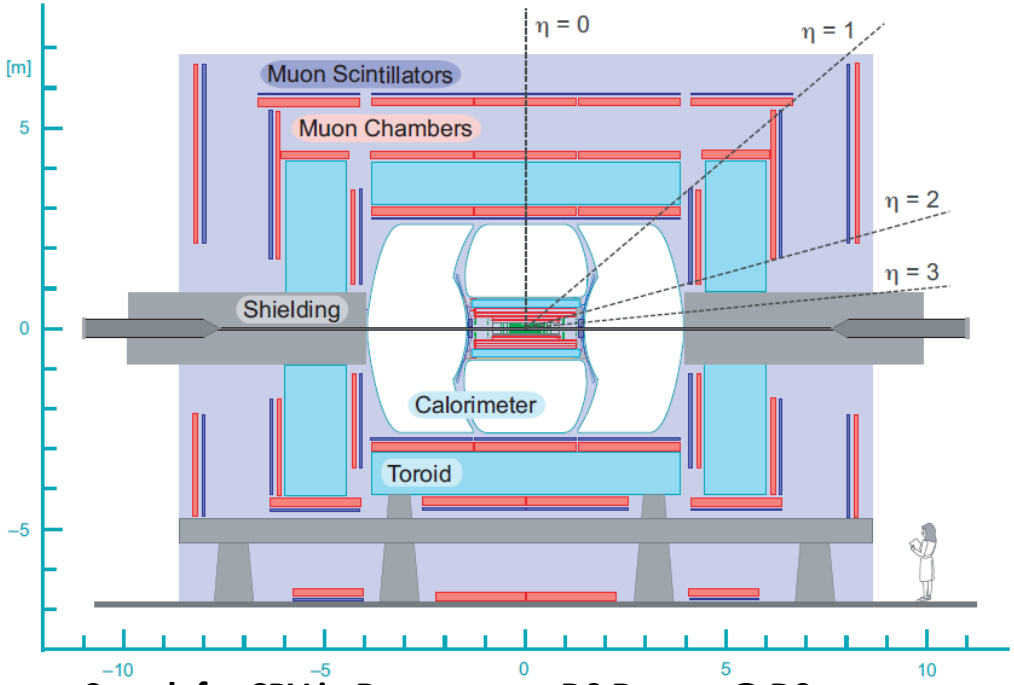
Tevatron $p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV
shutdown at end of September 2011 $\int \mathcal{L}\, dt$ = 10 fb^{-1}
***FINAL* analyses based on Run II data sets 2001-2011**
***uniquely* $p\bar{p}$ *!* like # produced B^+ = # produced B^-**



DØ: excellent μ-id and coverage
flip solenoid & toroid polarities
for Asymmetry measurements



D0: Measurement of direct CP violating charge asymmetry in $B^{\pm} \rightarrow \mu^{\pm} \nu D^0$ decays

V.M. Abazov *et al.*, Phys. Rev. D 95, 031101 (2017)

Such direct CP violation in $B^{\pm} \rightarrow \mu^{\pm} \nu D^0$ decay

does not occur in Standard Model,

so any observation would indicate

existence of *non-SM* physics.

Anomalously large CP violation in

semileptonic decays of $B^{\pm}$ could explain

D0's like-sign dimuon asymmetry measurement.

First measurement! Other studies often assume $A_{CP}(B^{\pm}) \equiv 0$

D0: CPV in SL B±

CPV charge asymmetry:

$$A^{\mu D^0} = \frac{\Gamma(B^- \to \mu^- \bar{\nu}\, D^0) - \Gamma(B^+ \to \mu^+ \nu\, \bar{D}^0)}{\Gamma(B^- \to \mu^- \bar{\nu}\, D^0) + \Gamma(B^+ \to \mu^+ \nu\, \bar{D}^0)}$$

what you measure:

$$A_{raw} = \frac{N(\mu^- D^0) - N(\mu^+ \bar{D}^0)}{N(\mu^- D^0) + N(\mu^+ \bar{D}^0)}$$

neglecting second- and higher-order terms in A

$$= f(B^+) A^{\mu D^0} + A_{det} + A_{phys}$$

A_{phys}: decays of other particles

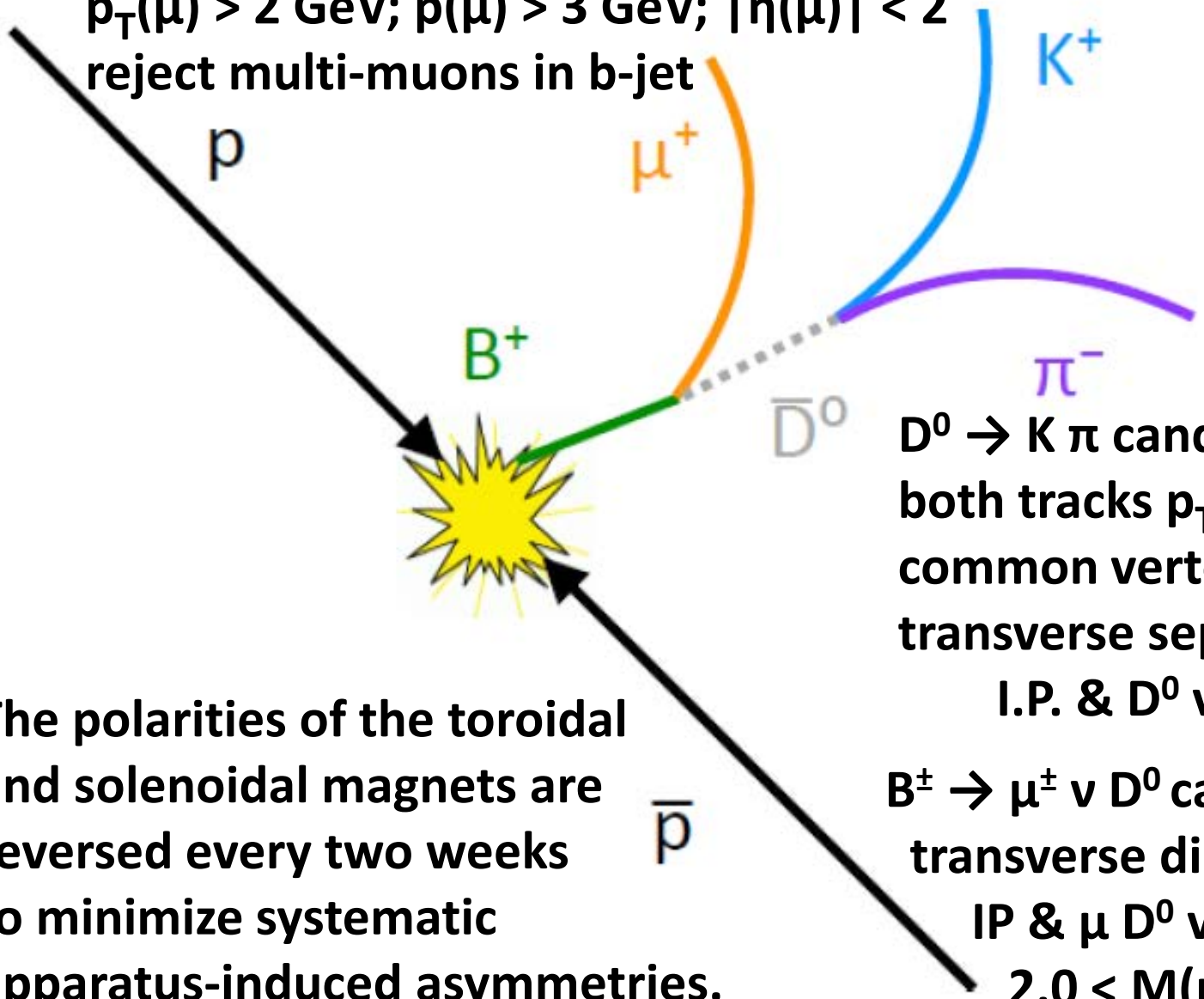
A_{det}: detector induced Asymmetry

$f(B^+)$: fraction of $\mu^+ \nu\, \bar{D}^0$ produced by decay of B^+

muons: 12.8-14.5 hadronic interaction lengths

$p_T(\mu) > 2$ GeV; $p(\mu) > 3$ GeV; $|\eta(\mu)| < 2$

reject multi-muons in b-jet



$D^0 \rightarrow K\,\pi$ candidates:

both tracks $p_T > 0.7$ GeV

common vertex w $\chi 2 < 16$

transverse separation of

I.P. & D^0 vertex $> 3\,\sigma$

$B^{\pm} \rightarrow \mu^{\pm}\,\nu\,D^0$ candidate

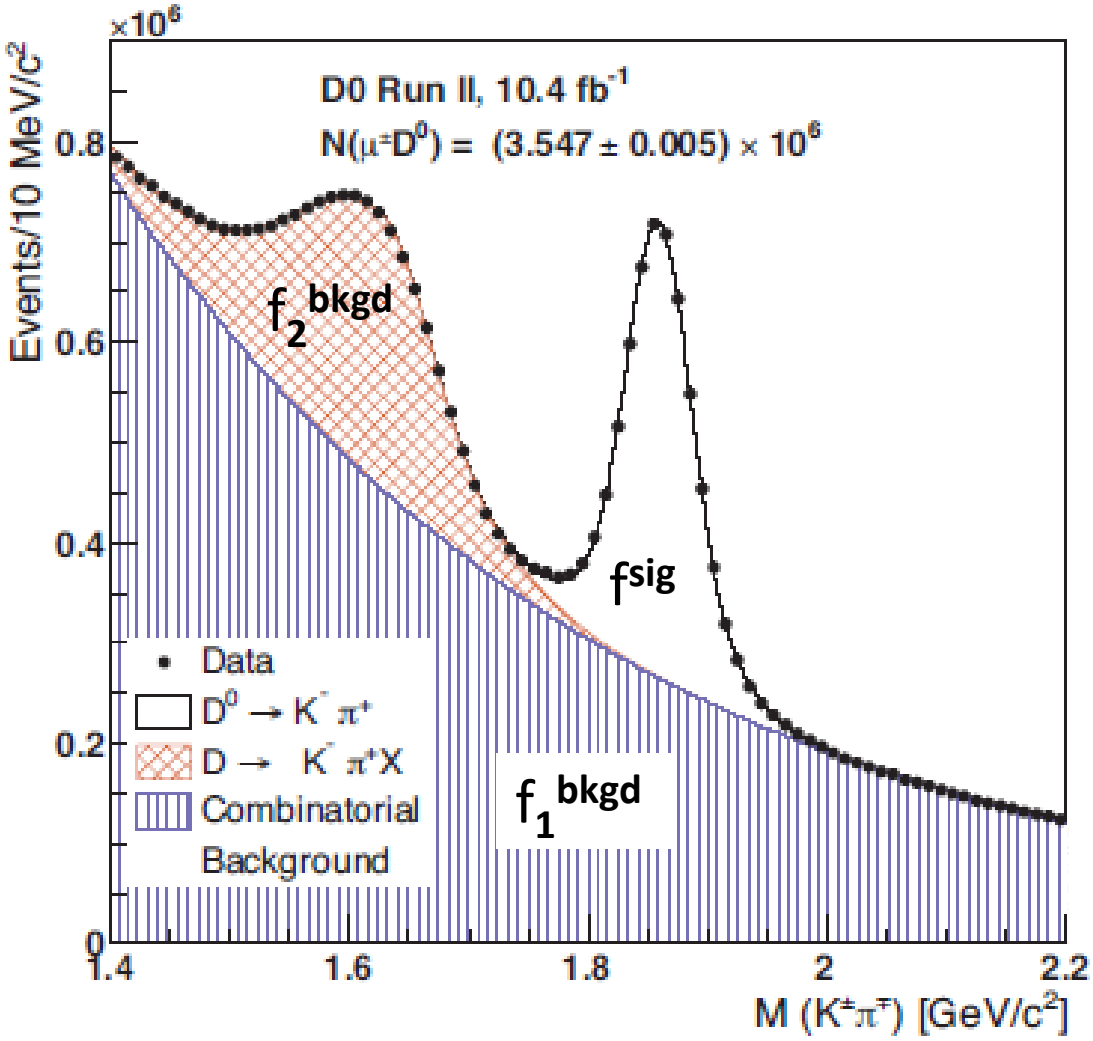
transverse distance between

IP & μ D^0 vertex $> 3\,\sigma$

$2.0 < M(\mu\,D^0) < 5.5$ GeV

The polarities of the toroidal and solenoidal magnets are reversed every two weeks to minimize systematic apparatus-induced asymmetries.

D0: CPV in SL $B^{\pm}$



charge correlation:

$B^- \rightarrow \mu^- \nu D^0 (\rightarrow K^- \pi^+)$

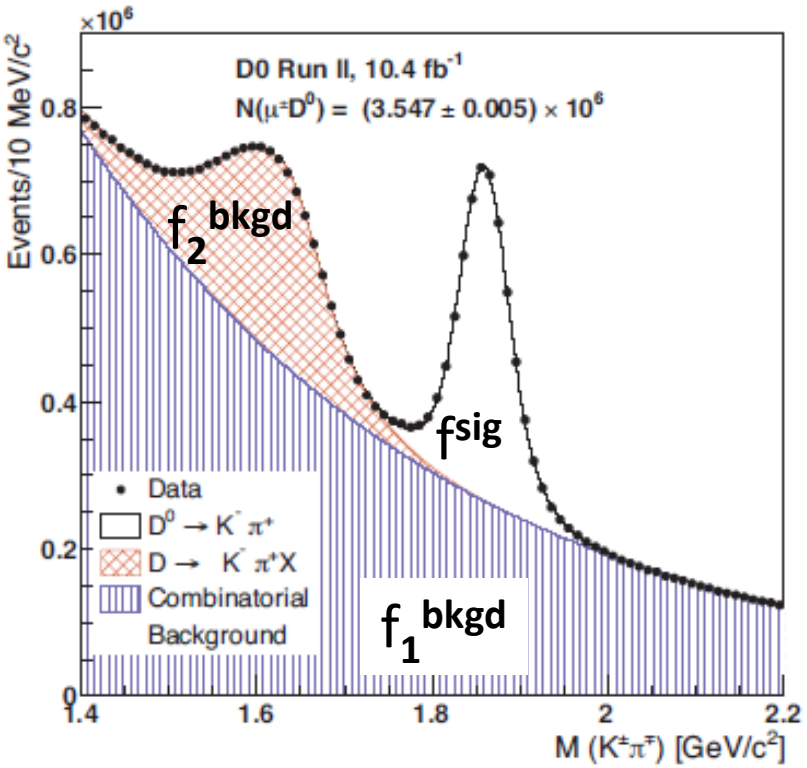
3.5 x 10^6 SL $B^{\pm}$ decays

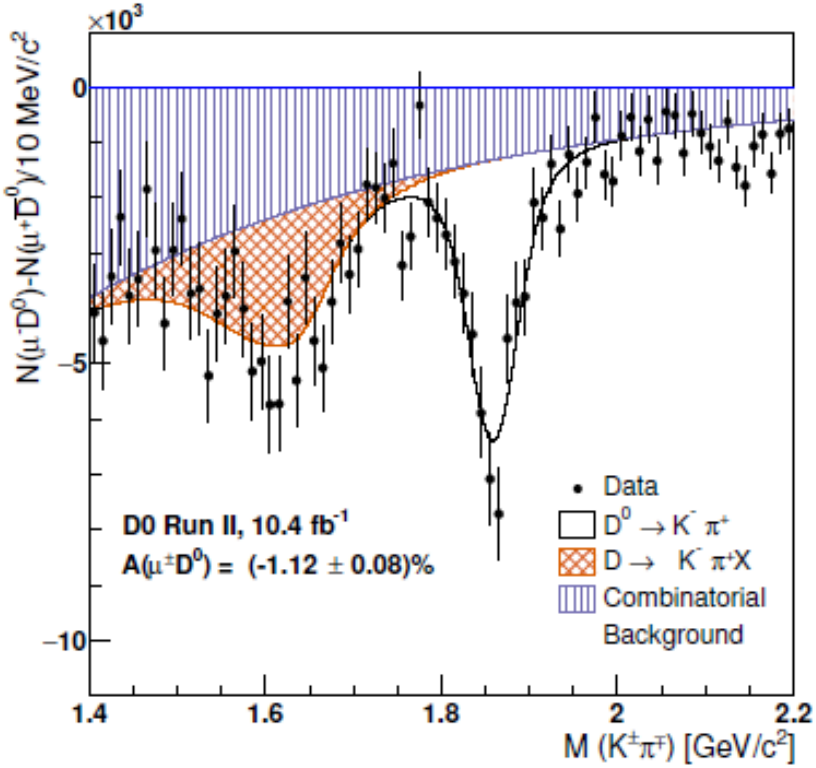
f^{sig}(M) = signal
~sum of two Gaussians

f_1^{bkgd}(M) = combinatorial bkgd ~ exponential

f_2^{bkgd}(M) = partially reconstructed $D \rightarrow K \pi X$ bkgd
~ bifurcated Gaussian function

SUM = $N(\mu^- D^0) + N(\mu^+ \bar{D}^0)$ DIFF = $N(\mu^- D^0) - N(\mu^+ \bar{D}^0)$



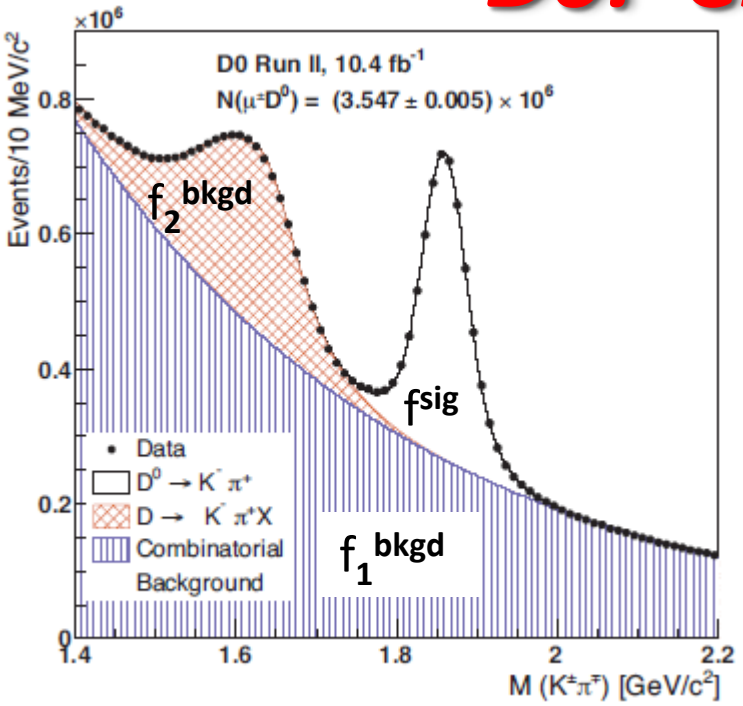


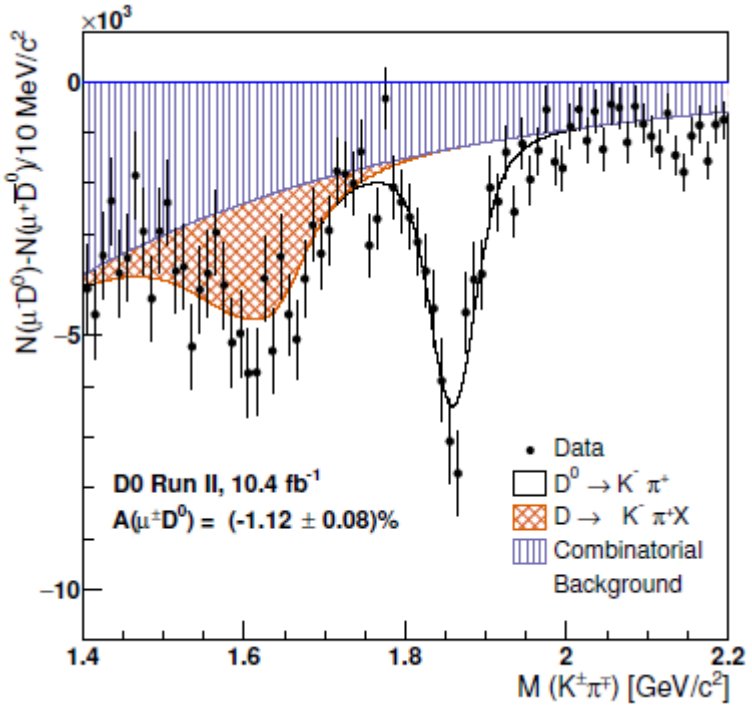
$$f_{sum}(M) = f^{sig}(M) + f_1^{bkgd}(M) + f_2^{bkgd}(M)$$

$$f_{diff}(M) = A_{raw} f^{sig}(M) + A_1 f_1^{bkgd}(M) + A_2 f_2^{bkgd}(M)$$

simultaneously fit $f_{sum}(M)$ & $f_{diff}(M)$ distributions

sum D0: CPV in SL $B^{\pm}$ diff





$$f_{diff}(M) = A_{raw} f^{sig}(M) + A_1 f_1^{bkgd}(M) + A_2 f_2^{bkgd}(M)$$

results: A_{raw} = [-1.12 ± 0.08 (stat) ± 0.008 (syst)]% - signal

A_1 = (-0.50 ± 0.03)% - combinatorial background

A_2 = (-0.87 ± 0.12)% - partially reconstructed $D \rightarrow K \pi X$

correction terms!

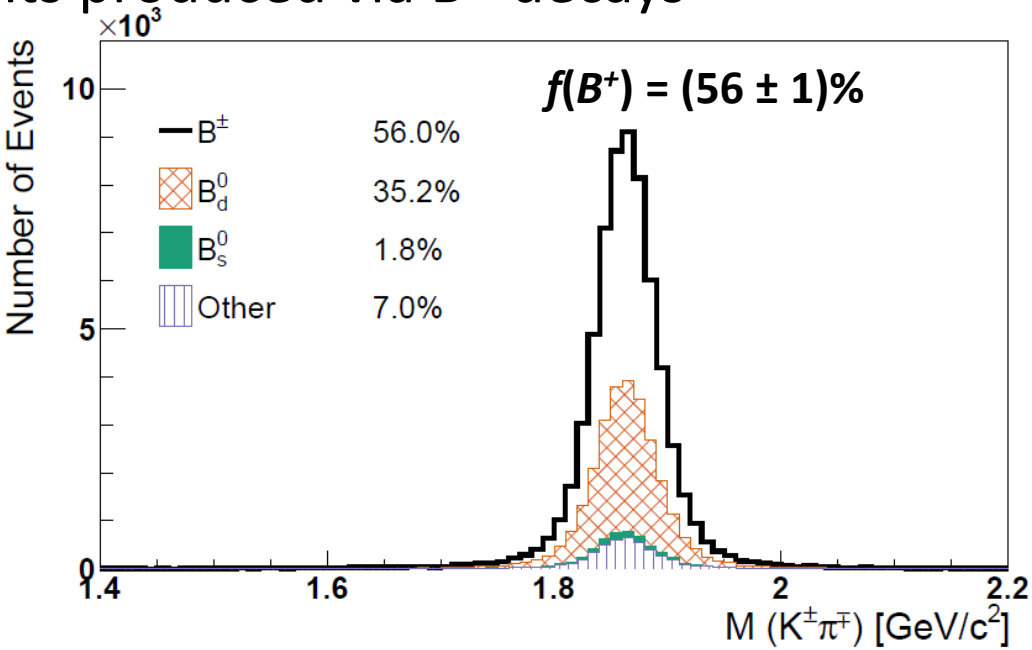
$$A^{\mu D^0} = \frac{\Gamma(B^- \to \mu^- \bar{\nu}\, D^0) - \Gamma(B^+ \to \mu^+ \nu\, \bar{D}^0)}{\Gamma(B^- \to \mu^- \bar{\nu}\, D^0) + \Gamma(B^+ \to \mu^+ \nu\, \bar{D}^0)}$$

$$A_{raw} = \frac{N(\mu^- D^0) - N(\mu^+ \bar{D}^0)}{N(\mu^- D^0) + N(\mu^+ \bar{D}^0)} = [-1.12 \pm 0.08\ (\text{stat}) \pm 0.008\ (\text{syst})]\%$$

$$A_{raw} = f(B^+)\, A^{\mu D^0} + A_{\text{det}} + A_{\text{phys}}$$

$f(B^+)$ = fraction of $\mu\ \nu\ D^0$ events produced via B+ decays

= [56 ± 1(syst)]% from PYTHIA & EVTGEN MC calculation reweighted to match data p_T and η distributions



more correction terms

$A_{raw} = f(B^+)\, A^{\mu D^0} + A_{det} + A_{phys} = [-1.12 \pm 0.08\ (stat) \pm 0.008\ (syst)]\%$

$A_{det} = -A_{\mu} - A_K + A_{track} = [-1.02 \pm 0.08\ (syst)]\%$

$A_{\mu} = [\epsilon(\mu^+) - \epsilon(\mu^-)]/[\epsilon(\mu^+) + \epsilon(\mu^-)] = [0.10 \pm 0.06\ (syst)]\%$

directly measured in D0 via $J/\psi \rightarrow \mu^+\mu^-$

$A_K = [\epsilon(K^+) - \epsilon(K^-)]/[\epsilon(K^+) + \epsilon(K^-)] = [0.92 \pm 0.05\ (syst)]\%$

directly measured in D0 via $K^{*0} \rightarrow K^-\pi^+$ ($K^{*0} \rightarrow K^+\pi^-$)

$A_{track} = 0$ no tracking asymmetry observed in

$K_s^0 \rightarrow \pi^+\pi^-$ and $K^{*\pm} \rightarrow K_s^0\,\pi^{\pm}$

$A_{phys} = [-0.02 \pm 0.02]\%$ SL charge asymmetries from mixing of neutral B mesons

$= a^d_{sl}\, P(B_d^0 \rightarrow \overline{B}_d^0)\, f(B_d^0) + a^s_{sl}\, P(B_s^0 \rightarrow \overline{B}_s^0)\, f(B_s^0)$

(see notes)

D0: CPV in SL $B^{\pm}$

Summary:

$A_{raw} = f(B^+)\, A^{\mu D^0} + A_{det} + A_{phys} = [-1.12 \pm 0.08\ (stat) \pm 0.008\ (syst)]\%$

$A^{\mu D^0} = [A_{raw} - A_{det} - A_{phys}]/f(B^+)$

$f(B^+) = [56.0 \pm 0.03]\%$

$A_{det} = [-1.02 \pm 0.08\ (syst)]\%$

$A_{phys} = [-0.02 \pm 0.02]\%$

$$\rightarrow A^{\mu D^0} = [-0.14 \pm 0.14\ (stat) \pm 0.14\ (syst)]\%$$

First measurement of direct CPV parameter $A^{\mu D^0}$ in $B^{\pm} \rightarrow \mu^{\pm}\, \nu\, D^0$ decays

No Charge Asymmetry Observed

consistent with Standard Model!

D0 like-sign dimuon Asymmetry

The dimuon asymmetry is given by $\frac{N^{++} - N^{--}}{N^{++} + N^{--}}$

This can be caused by a charge asymmetry in B^+ semileptonic decays

Get same sign muons when a neutral B meson mixes.

If B^0 asymmetry is zero get an asymmetry from opposite side.

Require an effective neutral B meson semileptonic charge of asymmetry of 0.5%

$$A^b_{\rm sl}({\rm eff}) = f_{B^+_{\rm sl}} A^{\mu D^0} = 0.5\%$$

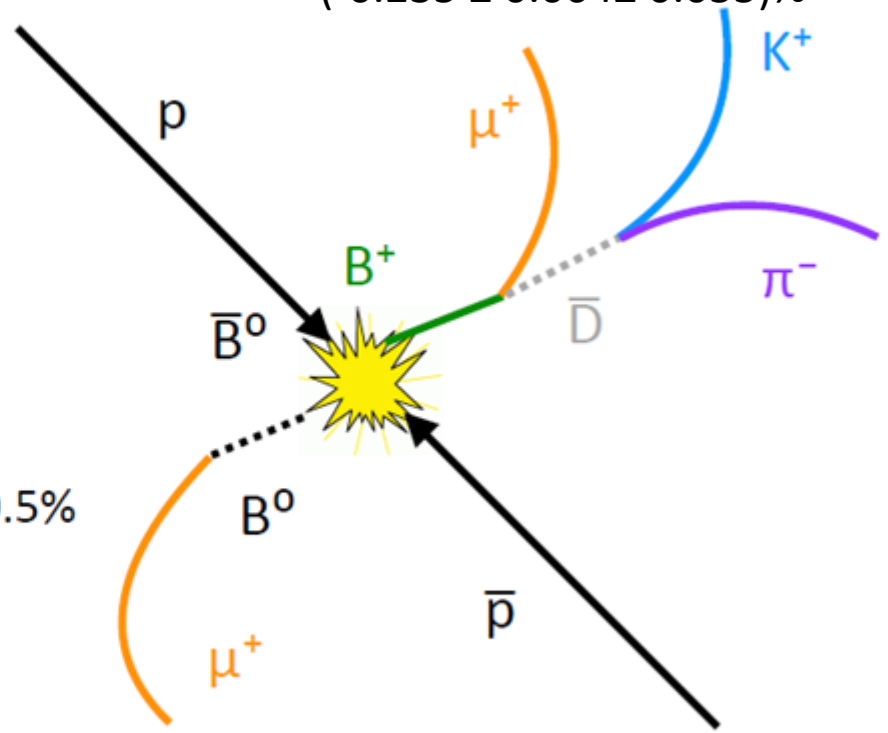
$$A^{\mu D^0} = 0.5\% / f_{B^+_{\rm sl}}$$

Or $A^{\mu D^0} \approx 0.8\%$

Which is inconsistent with our result

Phys. Rev. D89, 012002 (2014)

(-0.235 ± 0.064± 0.055)%



$A^{\mu D^0}$ = [-0.14 ± 0.14 (stat) ± 0.14 (syst)]%

Many Thanks to all who supported the Tevatron program over parts of 5 decades (1970's thru present)

Peter

D0: CPV in $B^{\pm}$ SL notes (1)

- Systematic Uncertainties on A_{raw}
  - Vary fitted mass range 1.40-2.20 → 1.43-2.17 MeV in steps of 10 MeV
  - Changed form of combinatorial background from exponential to $\mathcal{O}(2)$ polynomial
  - Vary width of mass bins between 5 and 20 MeV

D0: CPV in $B^{\pm}$ SL notes (2)

A_{phys} SL charge asymmetries from mixing of neutral B mesons

$A_{Bq0} = a_{sl}^{q}\, P(B_q^0 \rightarrow \overline{B}_q^0)\, f_{Bq0}$ for $q = d$ and s

a_{sl}^{d} = (-0.15 ± 0.17)% - world average – PDG-2016 p 767

$P(B_d^0 \rightarrow \overline{B}_d^0)$ = 0.211 – MC PYTHIA EVTGEN

f_{Bd0} = (35.2 ± 1.0)% - MC PYTHIA EVTGEN

A_{phys}^{d} = -0.011%

a_{sl}^{s} = (-0.75 ± 0.41)% - world average – PDG-2016 p 767

$P(B_s^0 \rightarrow \overline{B}_s^0)$ = 0.5 – MC PYTHIA EVTGEN

f_{Bs0} = (1.8 ± 1.0)% - MC PYTHIA EVTGEN

A_{phys}^{s} = -0.007%

$A_{phys} = A_{phys}^{d} + A_{phys}^{s}$ = (-0.02 ± 0.02)%

D0: CPV in $B^{\pm}$ SL notes (3)

How much $A^{\mu D^0}$ would be needed to reproduce anomalous D0 like sign di-muon charge asymmetry?

- From V.M. Abazov *et al.*, Phys. Rev. D 89,012002 (2014) - D0 like-sign dilepton charge asymmetry
- Alternative calculation (maybe this is what Gennady wanted):

(82) $a_{CP} = f_S\, a_S$ = -0.032 % from Table XIII

(83) $A_{CP} = F_{SS}\, A_S + F_{SL}\, a_S$ = -0.235 % from Table XIV

Combining (82) & (83) f_S = 0.4997 from Table V

$A_{CP} = F_{SS}\, A_S + F_{SL}\, a_{CP}/f_S$ F_{SS} = 0.6914 from Table VI

F_{SL} = 0.2269 from Table VI

$A_S = \{A_{CP} - F_{SL}\, a_{CP}/f_S\}/F_{SS}$

$A_S = \{-0.235\% - (0.2269/0.4997)*(-0.032\%)\}/0.6914$

$A_S = \{-0.2205\%\}/0.6914 = -0.3189\%$

(67) $A_S = A_S^{mix} + A_S^{int}$ A_S^{int}(SM) = -0.050% from Table XVI

$A_S^{mix} = A_S - A_S^{int}(SM)$

$A_S^{mix} = -0.3189\% - (-0.050\%) = -0.2689\%$

(68) $A_S^{mix} = C_b\, A_{sl}^b$ C_b = 0.524 from Table XVI

$A_{sl}^b = A_S^{mix}/C_b = -0.2689\%/0.524 = -0.513\%$

close to (86) $A_{sl}^b = (-0.496 +/- \ldots)\%$

D0: CPV in $B^{\pm}$ SL notes (*)

$A_{\mu} = [\epsilon(\mu^+) - \epsilon(\mu^-)]/[\epsilon(\mu^+) + \epsilon(\mu^-)] = [0.10 \pm 0.06\ (syst)]\%$

directly measured in D0 via $J/\psi \rightarrow \mu^+\mu^-$

V.M. Abazov *et al*., Phys. Rev. D 82, 032001(2010) Sec. 10

V.M. Abazov *et al*., Phys. Rev. D 74, 092001(2006)

$A_{K} = [\epsilon(K^+) - \epsilon(K^-)]/[\epsilon(K^+) + \epsilon(K^-)] = [0.92 \pm 0.05\ (syst)]\%$

directly measured in D0 via $\overline{K}^{*0} \rightarrow K^-\pi^+$ and $K^{*0} \rightarrow K^+\pi^-$

V.M. Abazov *et al*., Phys. Rev. D 82, 032001(2010)

D0: CPV in $B^{\pm}$ SL notes (*)

D0: V.M. Abazov *et al*., Phys. ReV. Lett. 110, 241801 (2013)
Measurement of direct CP violation parameters in $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ and $B^{\pm} \rightarrow J/\psi\, \pi^{\pm}$ decays with 10.4 fb^{-1} of Tevatron data

$A^{J/\psi K} = [0.59 \pm 0.37]\%$

$A^{J/\psi \pi} = [-4.2 \pm 4.5]\%$

LHCb: R. Aaij *et al*., Phys. Rev. D 95, 052005 (2017)
Measurement of the $B^{\pm}$ production asymmetry and the CP asymmetry in $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ decays

$A^{J/\psi K} = [0.09 \pm 0.27 \pm 0.07]\%$