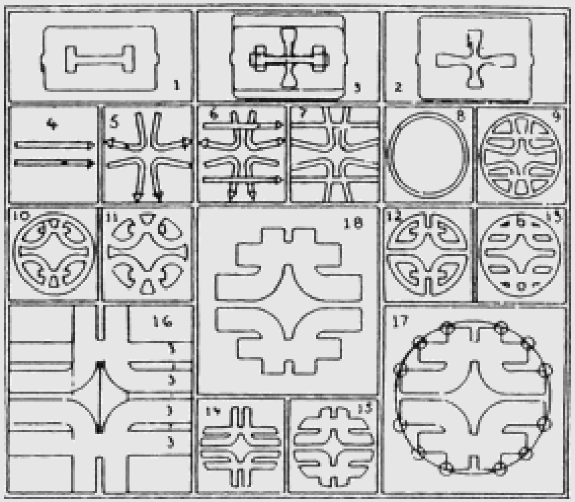
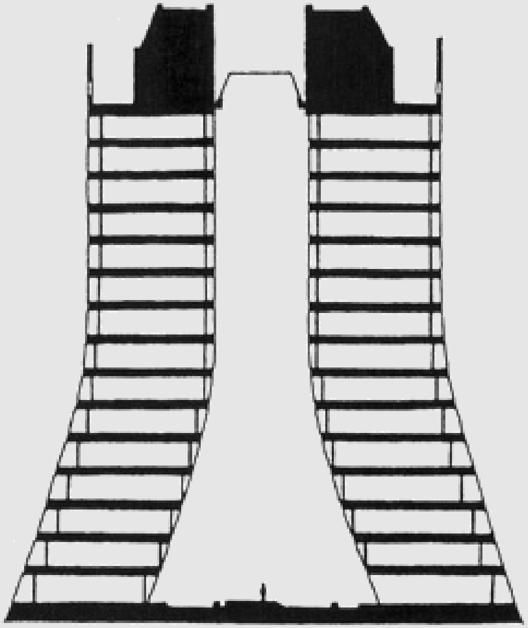
B_s CP-odd lifetime in $B_s \to J/\psi f_0$ and A_{fb} for baryons at D0

HQL 2016

Virginia Tech



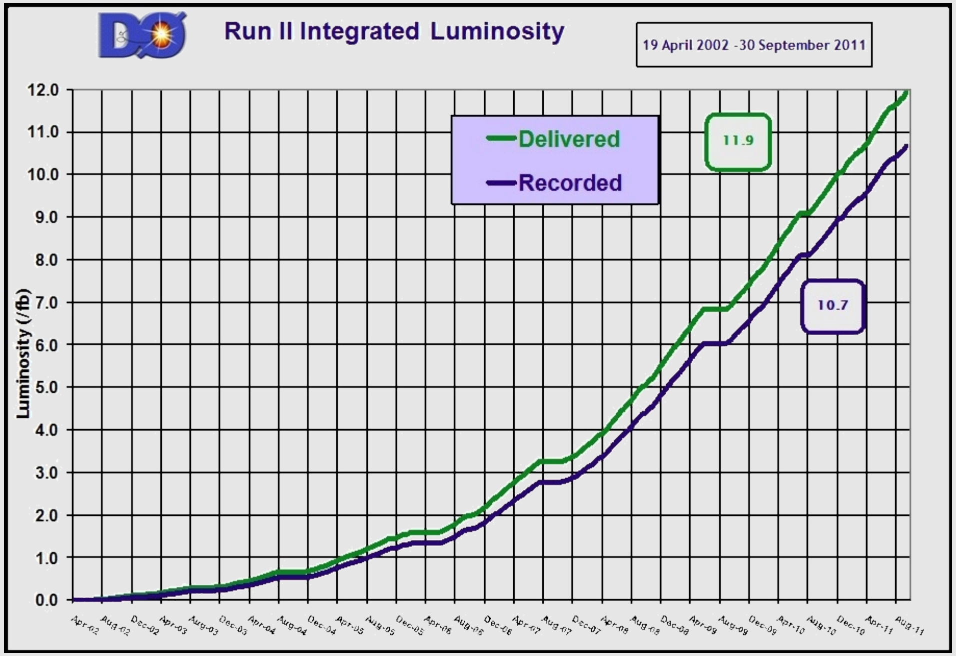


Bob Hirosky
for the D0 Collaboration

Tevatron Data

D0 continues a rich physics program analyzing ~10fb^{-1} of recorded data from ~2001-2011

- World's highest energy p-$\bar{p}$ data set (2 TeV C.O.M.)
- Unique physics studies
- Many complementary/competitive results in LHC era



The D0 Detector

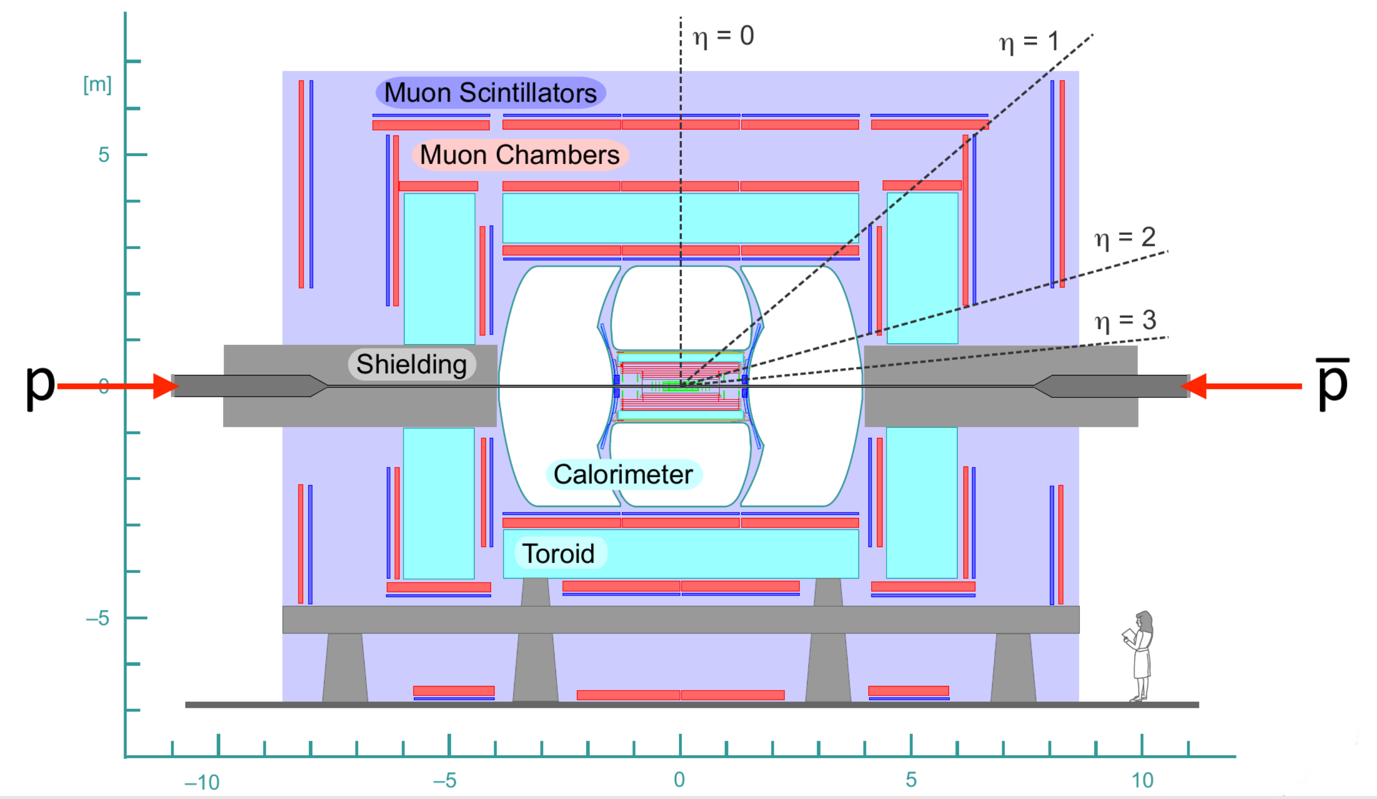
Multipurpose, large acceptance, well understood detector.

Tracking & Muon System

• Scintillator counters and drift tubes
• Thick calorimeter and iron toroids
Excellent muon triggering and ID

• Silicon Microstrip Tracker
Excellent vertex resolution

• Central Fiber Tracker
Good mass resolution



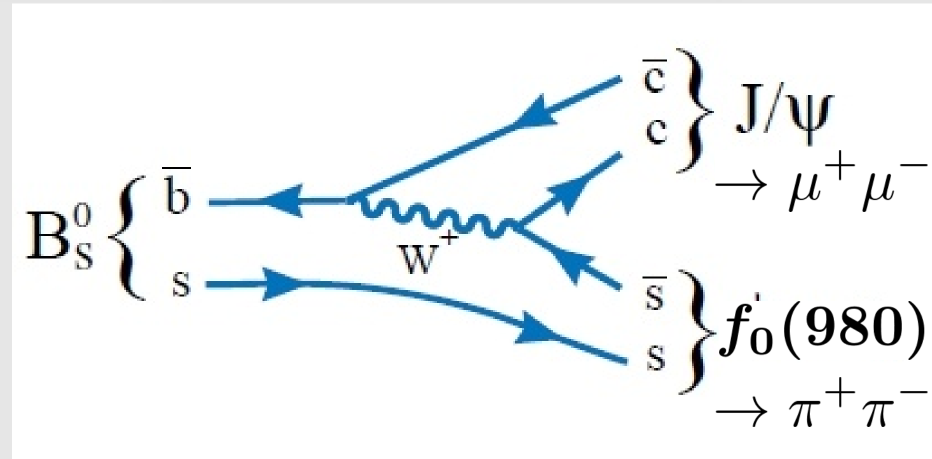
Excellent for B physics with muons

arXiv:1603.01302 [hep-ex]

Bs CP-odd lifetime in Bs→$J/\psi f_0$

Measure the purely CP-odd eigenstate decay:

$$J/\psi:\ J^{PC}=1^{--}$$
$$f_0(980):\ J^{PC}=0^{++}$$



In absence of CP-violation, mass and CP eigenstates coincide

$$|B^0_{sL}\rangle = p\,|B^0_s\rangle + q\,|\bar{B}^0_s\rangle$$
$$|B^0_{sH}\rangle = p\,|B^0_s\rangle - q\,|\bar{B}^0_s\rangle$$

=> lifetime measurement provides a measurement of the decay width of the heavy mass eigenstate.

Only two previous measurements:

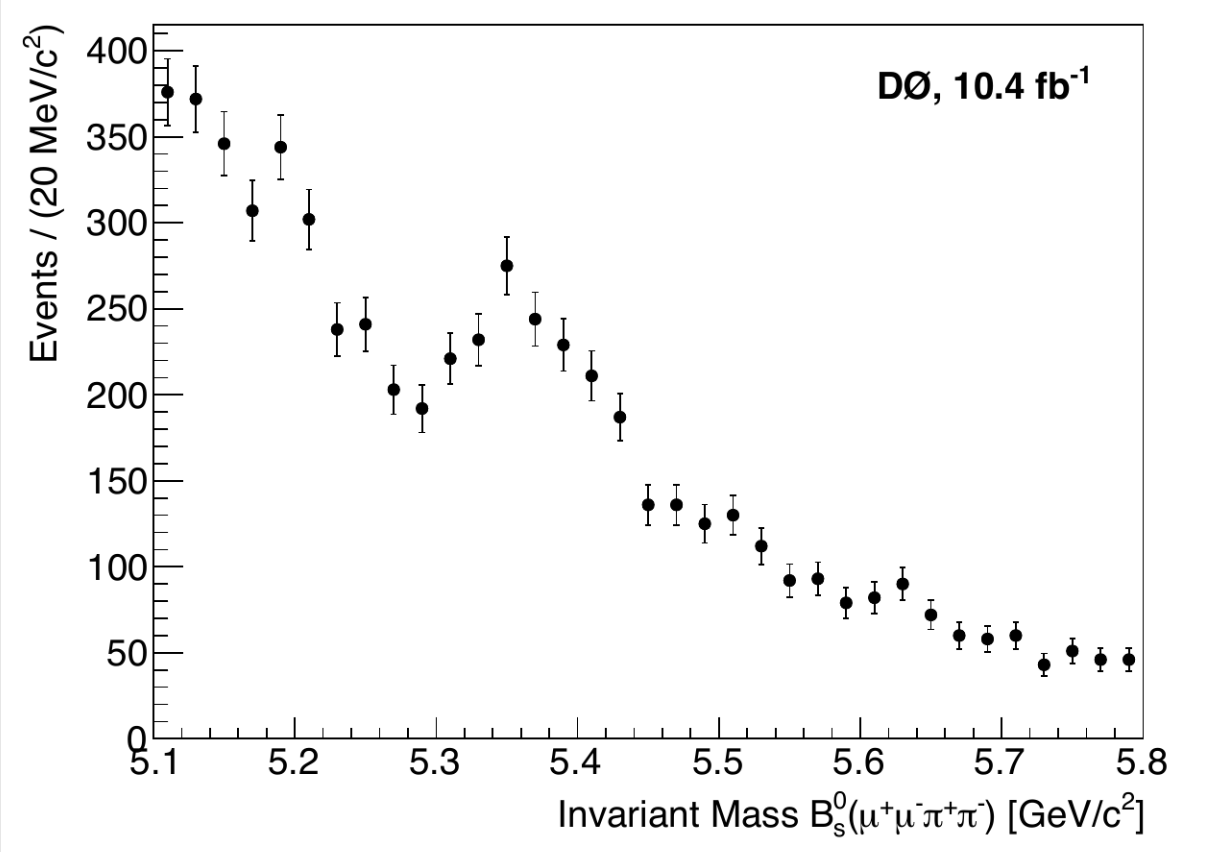
– CDF : cτ = (510 ± 36 ±9) μm PRD 84, 052012 (2011)

– LHCb: cτ = (510 ± 12 ±8) μm PRL 109, 152002 (2012)

Bs CP-odd lifetime in Bs→$J/\psi f_0$

Based on full Run2 data set of 10.4 fb^{-1} of integrated luminosity

Yields 6,031 events after data selection requirements



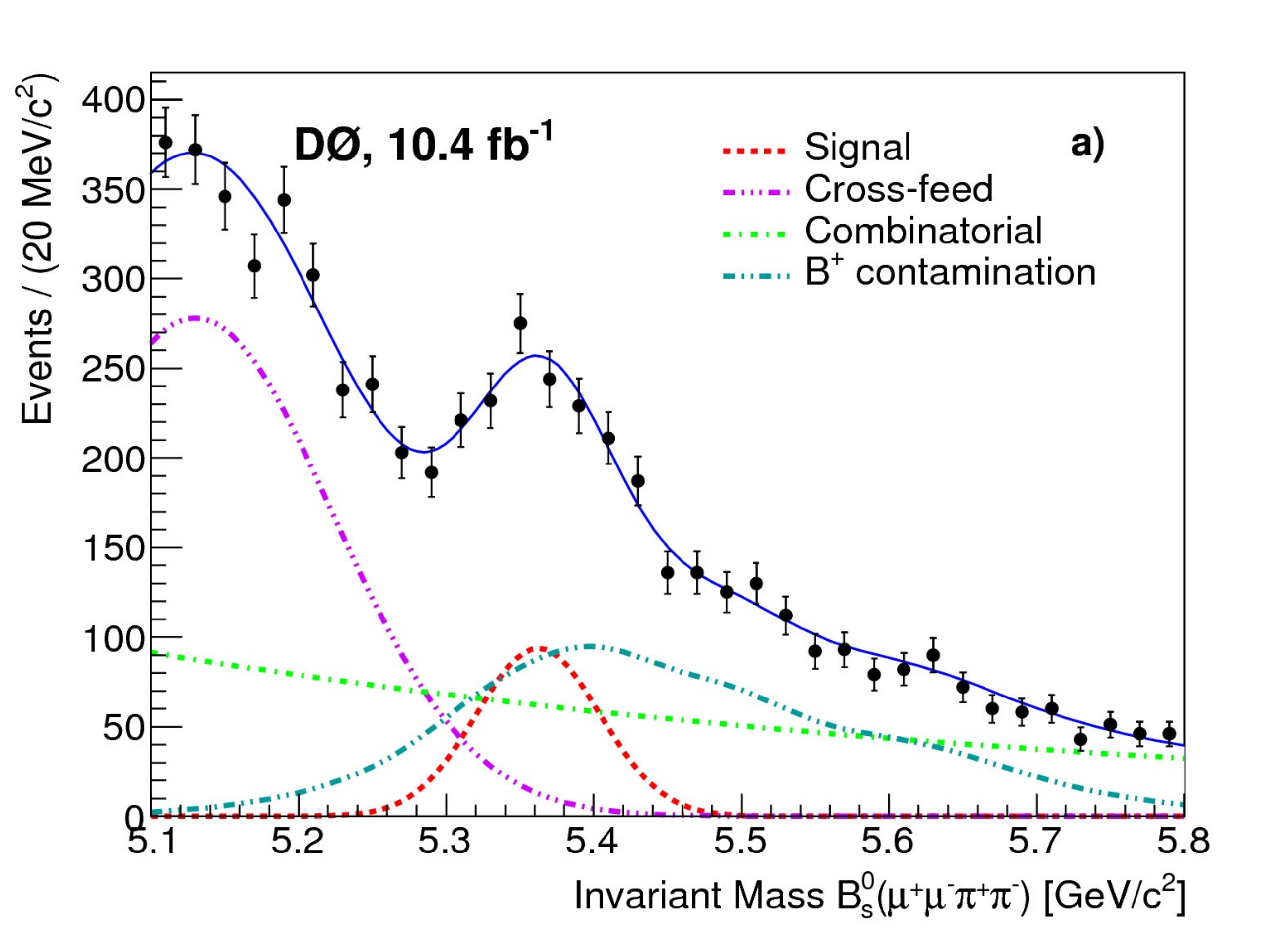
- 5.1 GeV < M(Bs) < 5.8 GeV
- 0.02 cm < PDL(Bs) < 0.3 cm
- 2.8 GeV < M(J/Ψ) < 3.35 GeV
- 880 MeV < M(ππ) < 1080 MeV
- pT(Bs) > 6.0 GeV
- pT (f0) > 1.5 GeV,
  pT(J/Ψ) > 1.5 GeV
- pT (μ) > 2.5 GeV,
  pT(π) > 1.5 GeV

Bs CP-odd lifetime in Bs→$J/\psi f_0$

Backgrounds

1) Cross-feed contamination from $B^0(s) \rightarrow J/\Psi + X$
Gaussian model verified in MC

2) Misreconstructed B+ decays B+ → J/Ψ K+ (+ extra track).
Use events in B+ mass peak, assigning π mass to determine shape

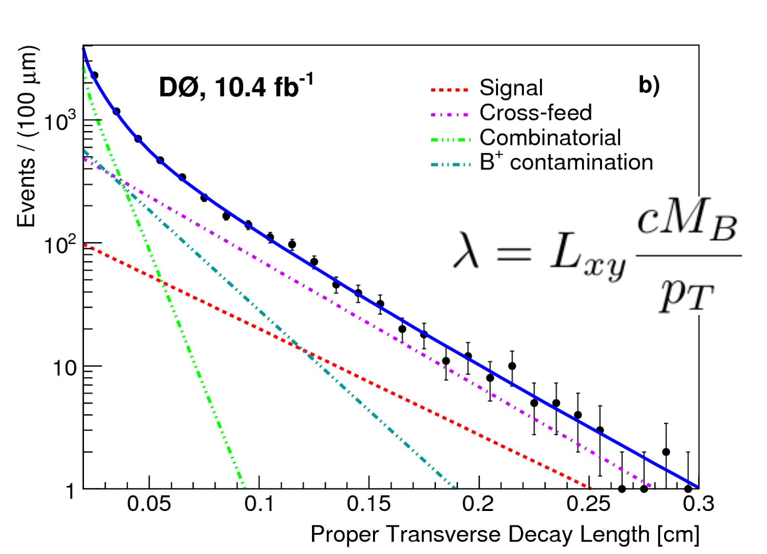


3) Combinatorial background: Random combinations of J/Ψ w/ addtl' tracks, modeled by exponential distribution

Bs CP-odd lifetime in Bs→$J/\psi f_0$

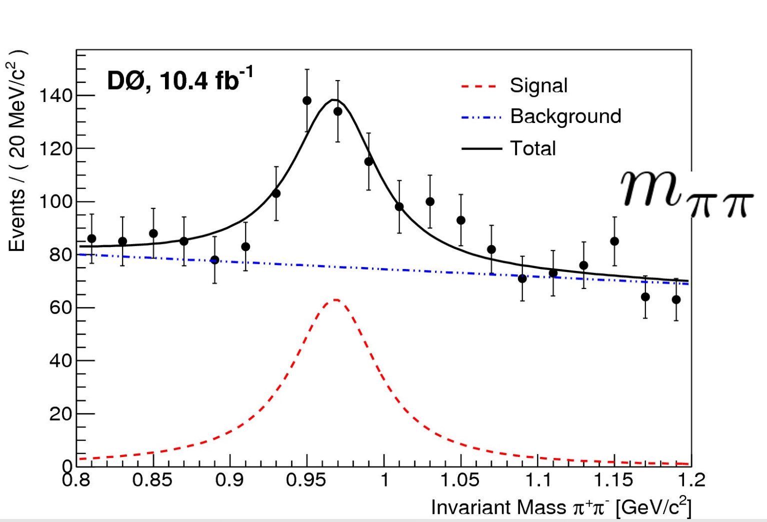
Lifetime is measured using a simultaneous unbinned maximum likelihood fit to the mass and proper decay length distributions.

$$\mathcal{L} = \prod_{j=1}^{N} \left[N_{\rm sig}\mathcal{F}^j_{\rm sig} + N_{\rm comb}\mathcal{F}^j_{\rm comb} + N_{\rm xf}\mathcal{F}^j_{\rm xf} + N_{B+}\mathcal{F}^j_{B+} \right]$$



$$\lambda = L_{xy}\frac{cM_B}{p_T}$$

The functions $\mathcal{F}$ include PDFs that model distributions of the mass, the proper transverse decay length, and the uncertainty on the proper decay length for signal and background.



$m_{\pi\pi}$

Fit Result cτ (Bs0) = 504 ± 42 μm

After bias correction: **cτ (Bs0) = 508 ± 42 μm**

Bs CP-odd lifetime in Bs→$J/\psi f_0$

Systematic uncertainties

Source	Variation (μm)
Alignment	5.4
$\pi^+\pi^-$ invariant mass window	8.0
Fit bias	4.4
Distribution models	12.5
Total	16.4

Results:

$c\tau\ (B_s^0) = 508 \pm 42\ \text{(stat)} \pm 16\ \text{(syst)}\ \mu\text{m}$

$\tau\ (B_s^0) = 1.70 \pm 0.14\ \text{(stat)} \pm 0.05\ \text{(syst)}\ \text{ps}$

$\Gamma_H = 0.59 \pm 0.05\ \text{(stat)} \pm 0.02\ \text{(syst)}\ \text{ps}^{-1}$

- Good agreement with previous measurements (HFAG mean τ=1.656 ± 0.033)
- Provides an independent confirmation of the longer lifetime for the CP-odd eigenstate of the $B_s^0/\bar{B}_s^0$ system.

Submitted to PRD-RC

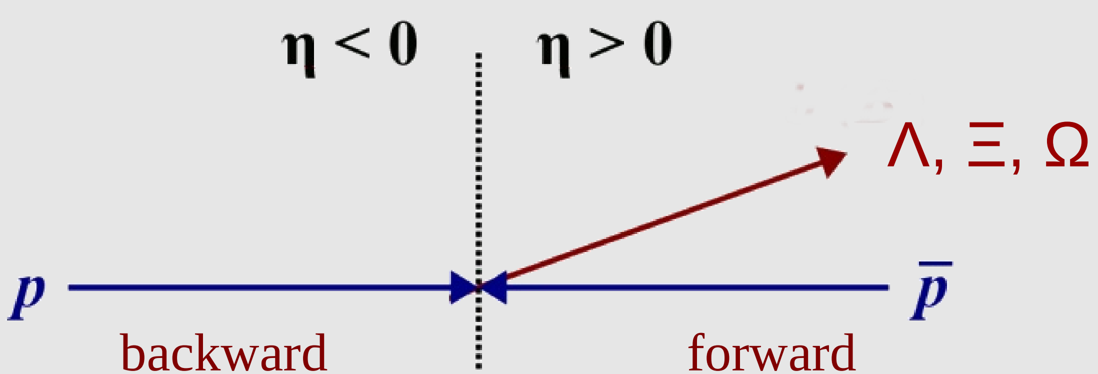
Forward-backward asymmetries of Λ, Ξ and Ω in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV

The DØ detector is well suited to measure forward-backward asymmetries A_{FB}:

- initial state is $p\bar{p}$ (CP symmetric)
- the solenoid and toroid magnetic fields are reversed periodically (canceling many important systematics)

Search for Violation of CPT and Lorentz invariance in B0s meson oscillations	Phys. Rev. Lett. 115, 161601 (2015)
Measurement of the direct CP-violating parameter ACP(D+→K-π+π+)	Phys. Rev. D 90, 111102(R) (2014)
Measurement of the direct CP-violating charge asymmetry in Ds±→φπ±	Phys. Rev. Lett. 112, 111804 (2014)
Study of CP-violating charge asymmetries of single muons and like-sign dimuons in pp collisions	Phys. Rev. D 89, 012002 (2014)

For many measurements, no other experiment has comparable sensitivity



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

(directions reversed for antiparticles)

Phys. Rev. D93, 032002 (2016)

Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

Illustrates common method used in these analyses

- "Forward":

Forward Λ have longitudinal momentum in the p direction
Forward $\bar{\Lambda}$ have longitudinal momentum in the $\bar{p}$ direction

- Forward-backward asymmetry in a bin of |y|:

$$A_{FB} \equiv \frac{N_F - N_B}{N_F + N_B}$$

\# of reconstructed Λ plus $\bar{\Lambda}$ or K_S with pT > 2.0 GeV in each data set

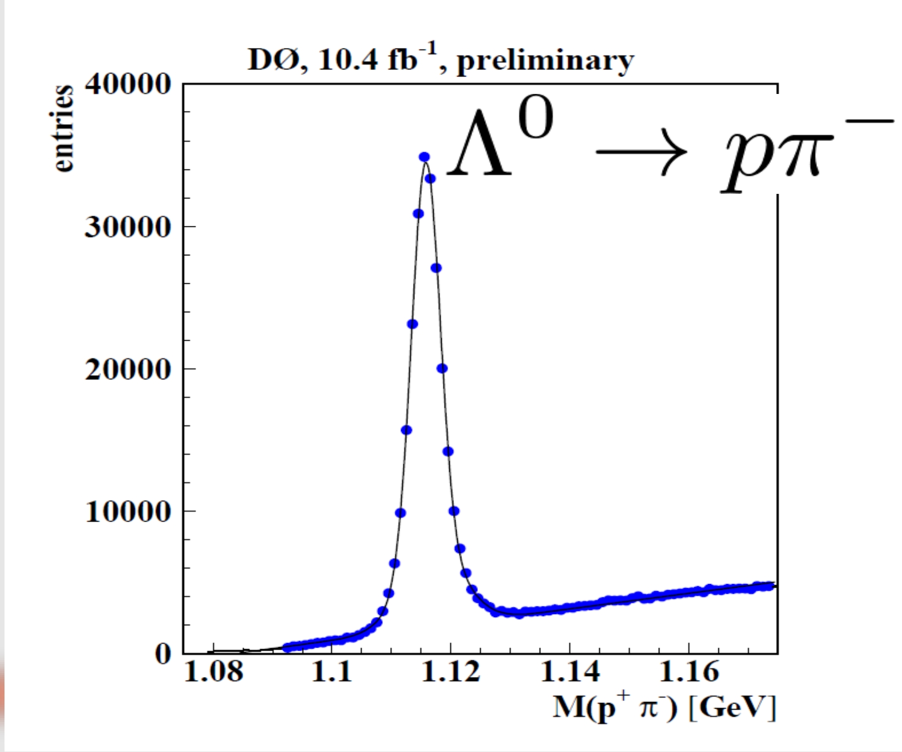
		Data set	Number of events
Data set	Signal	(i) $p\bar{p} \to \Lambda(\bar{\Lambda})X$	5.85×10^5
		(ii) $p\bar{p} \to J/\psi\Lambda(\bar{\Lambda})X$	2.50×10^5
		(iii) $p\bar{p} \to \mu^{\pm}\Lambda(\bar{\Lambda})X$	1.15×10^7
	Control channel	(i) $p\bar{p} \to K_S X$	2.33×10^6
		(ii) $p\bar{p} \to J/\psi K_S X$	6.55×10^5
		(iii) $p\bar{p} \to \mu^{\pm} K_S X$	5.34×10^7

Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

Illustrates common method used in these analyses

• "Forward":
Forward Λ have longitudinal momentum in the p direction
Forward $\bar{\Lambda}$ have longitudinal momentum in the $\bar{p}$ direction

• Forward-backward asymmetry
in a bin of |y|: $A_{FB} \equiv \frac{N_F - N_B}{N_F + N_B}$



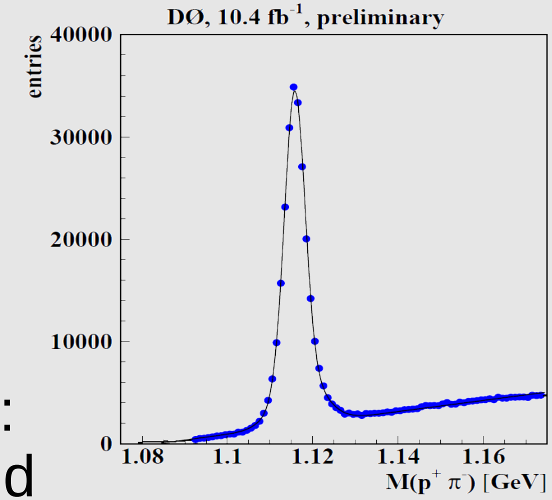
Example of invariant mass of
$\Lambda \rightarrow p\pi^-$ candidates

Phys. Rev. D93, 032002 (2016)

Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

- Count Λ and $\bar{\Lambda}$ candidates in a signal region and subtract background determined from two sidebands.

- Weighting data by luminosity and magnet polarities cancels detector geometric effects.



- The double difference*

$$A'_{FB} = \frac{N_F(\Lambda) - N_B(\Lambda) + N_F(\bar{\Lambda}) - N_B(\bar{\Lambda})}{N_F(\Lambda) + N_B(\Lambda) + N_F(\bar{\Lambda}) + N_B(\bar{\Lambda})}$$

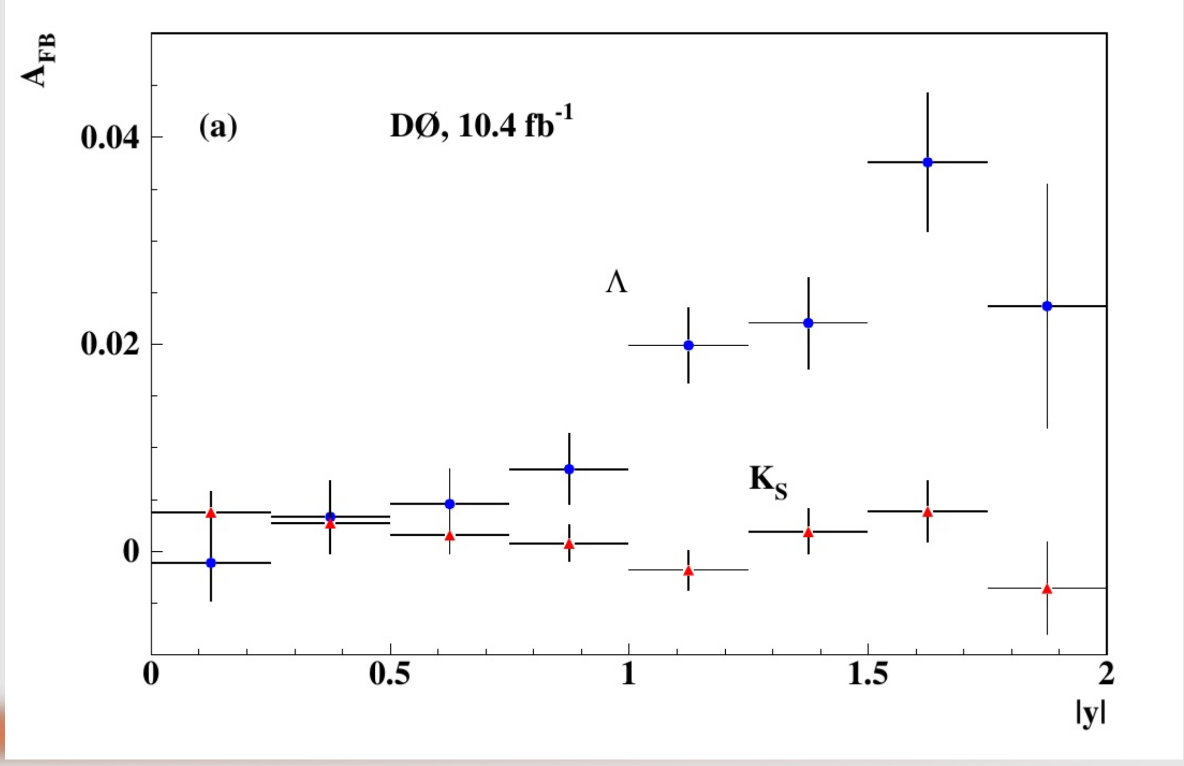
cancels 1st order contributions of two detector effects:
$A_{\Lambda\bar{\Lambda}}$: relative difference of efficiencies for Λ and $\bar{\Lambda}$, and
A_{NS} : relative difference of efficiencies of the north and south sections of the DØ detector (the $\bar{p}$ beam propagates north).

*primed quantities are “raw” asymmetries

Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

- The control channel $p\bar{p} \to K_S X$ has $A_{FB} = 0$ (see figure) because $K_S \to \pi^+\pi^-$ do not distinguish their parent K^0 or $\overline{K}^0$. Verify no additional corrections to needed arising from north-south asymmetries.

Asymmetry A_{FB} of $(\Lambda, \bar{\Lambda})$ with pT > 2.0 GeV for $p\bar{p} \to \Lambda(\bar{\Lambda})X$ events,
and
control sample with K_S



Phys. Rev. D93, 032002 (2016)

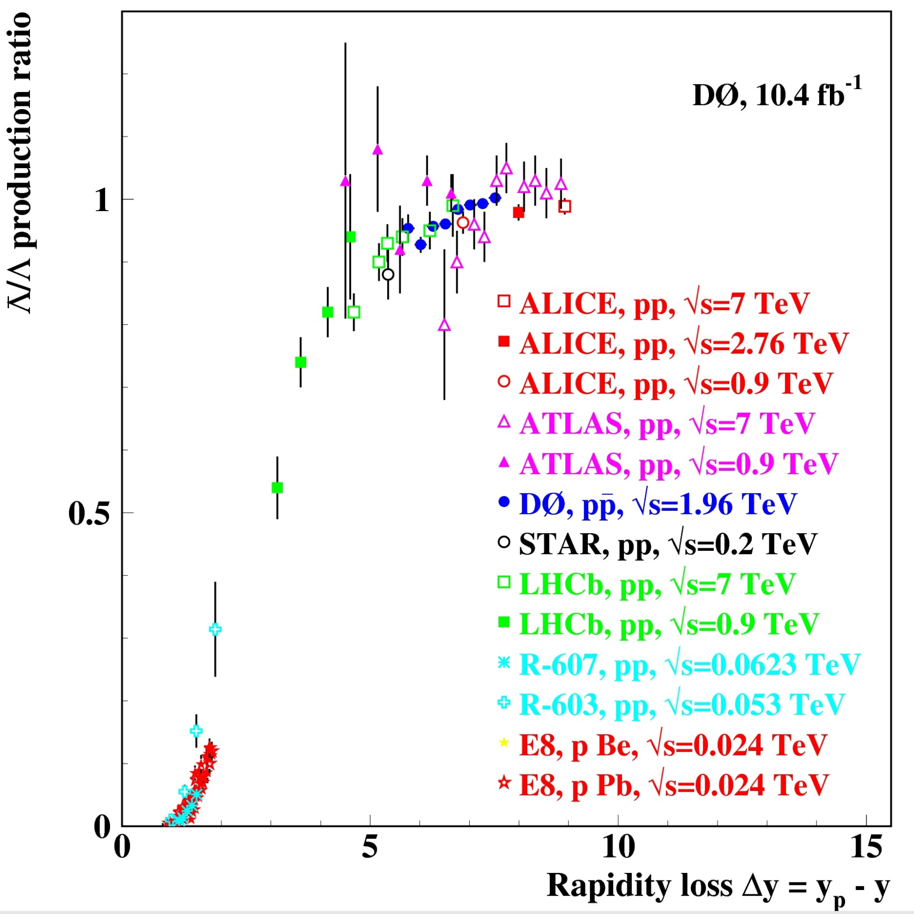
Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

The measurement of A_{FB} in $p\bar{p}$ collisions can be compared with the $\bar{\Lambda}/\Lambda$ production ratio f measured by a wide range of proton scattering experiments:

$f = (1 - A_{FB})/(1 + A_{FB})$

This production ratio f is confirmed to be approximately a universal function of the "rapidity loss" $y_p - y$, that does not depend significantly on the total center of mass energy $\sqrt{s}$, or target p, $\bar{p}$, Be or Pb

$\bar{\Lambda}/\Lambda$ production ratio vs "rapidity loss" yp − y for pZ → $\Lambda(\bar{\Lambda})$X

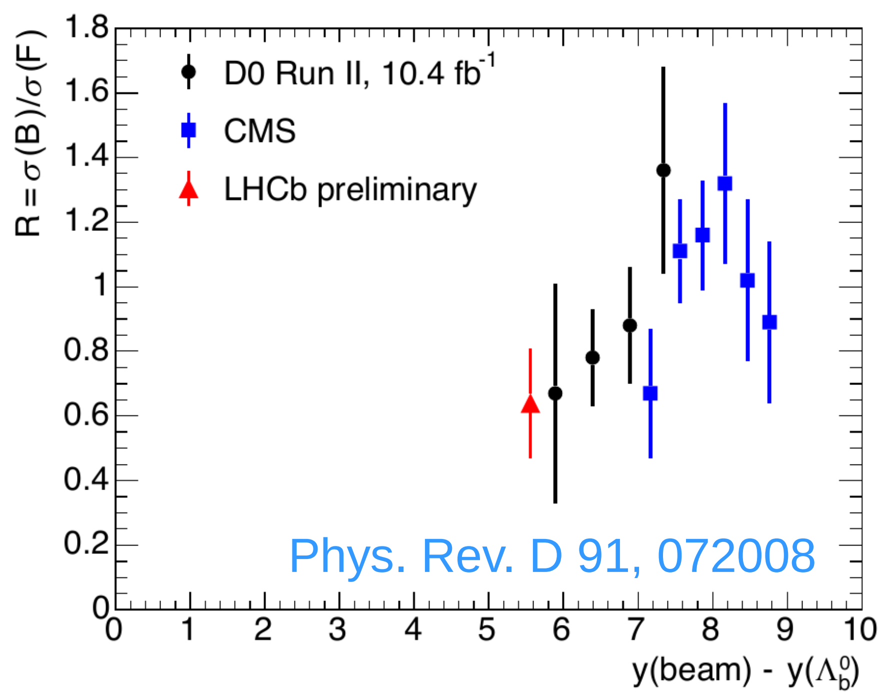


Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

This result supports the view that a strange quark produced in the scattering can coalesce with a ud diquark remnant of the beam particle to produce a lambda

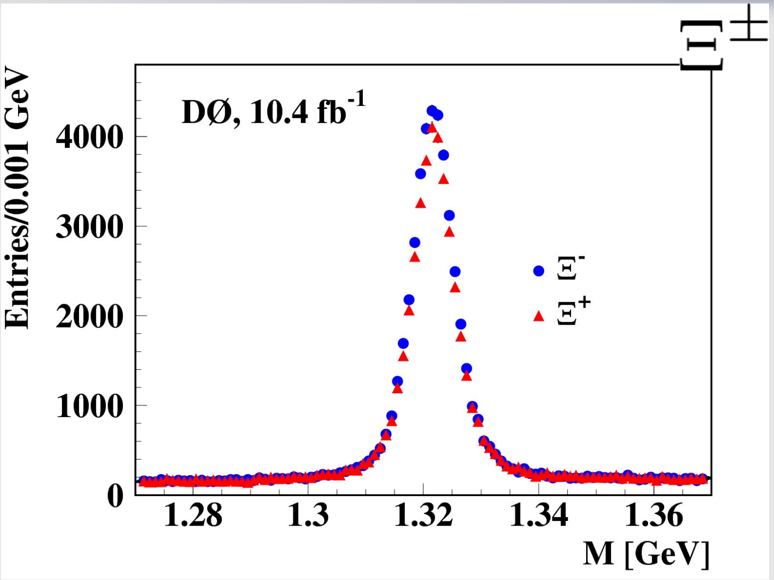
If this hypothesis is correct, we expect
$A_{FB} > 0$ for $(\Lambda, \bar{\Lambda})$, $(\Lambda_c^+ , \Lambda_c^-)$
and $(\Lambda_b , \bar{\Lambda}_b)$, and
$A_{FB} \approx 0$ for (B^- , B^+), (Ξ^- , Ξ^+)
and (Ω^- , Ω^+) since these particles do not share a diquark with the proton.

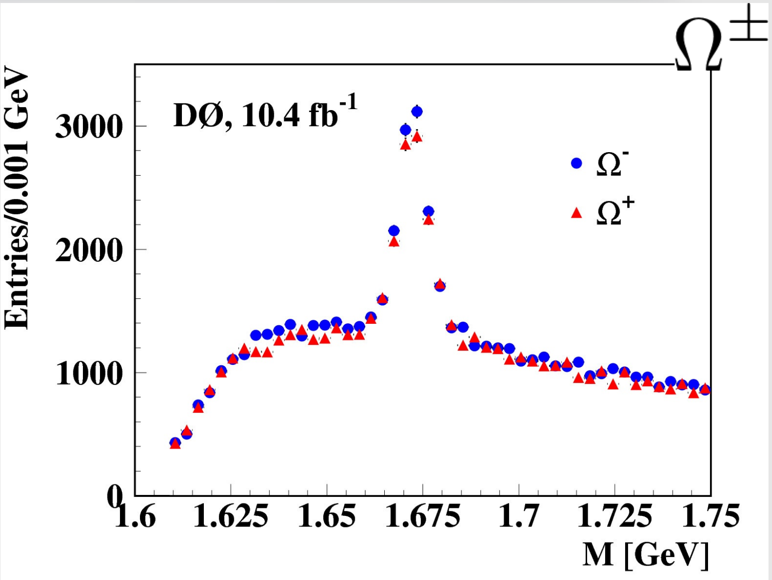
In fact
$\bar{\Lambda}_b/\Lambda_b$ and $\bar{\Lambda}/\Lambda$ vs "rapidity loss" are similar.

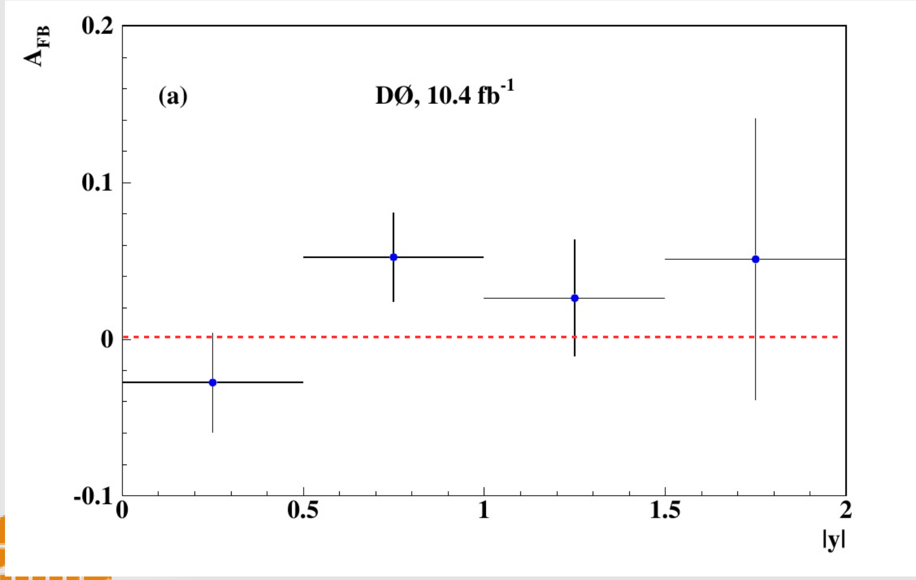


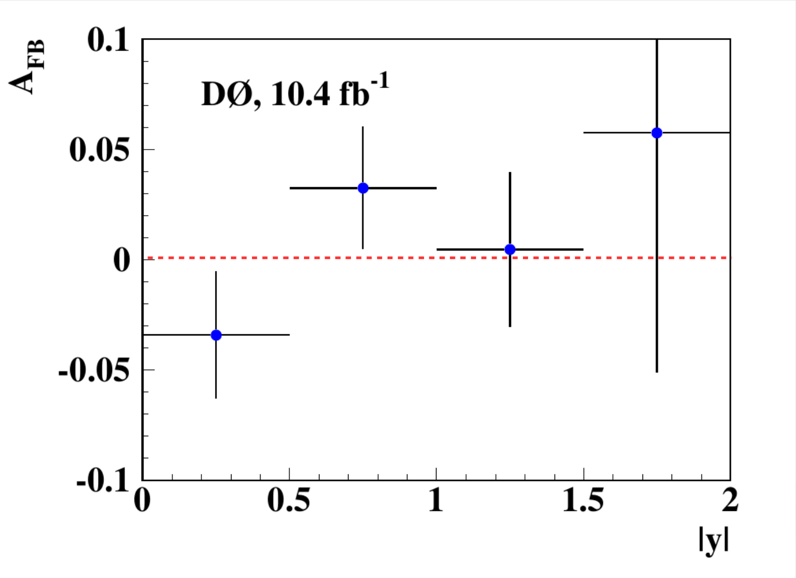
arXiv:1605.03513

Forward-backward asymmetry of $(\Xi^-, \Xi^+)(\Omega^-, \Omega^+)$









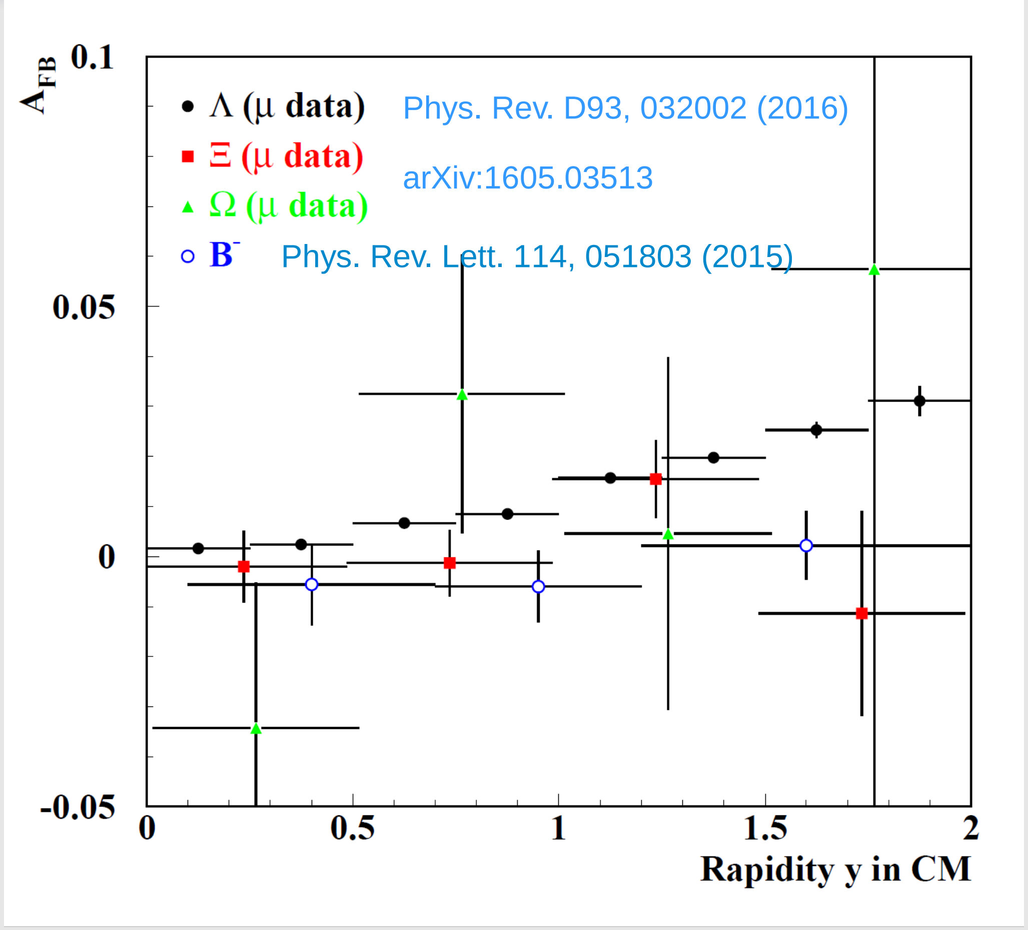
Forward-backward Summary

Suite of results consistent with hypotheses:

strange quark produced in the scattering can coalesce with a ud diquark remnant of the beam particle to produce a Λ

For particles that do not share a diquark with the proton

Find $A_{FB} \approx 0$ for (B^-, B^+)
And, within statistics, consistent with 0 or $A_{FB}(\Lambda)$ for (Ξ^-, Ξ^+) and (Ω^-, Ω^+)



Summary

The D0 detector continues to provide an excellent test bench for heavy flavor physics measurements

Large muon acceptance, efficient triggering, good mass resolution

CP symmetric initial states and excellent compensation for any detector non-uniformities

Offers unique opportunities to study rare processes
(eg production/decay asymmetries, new CPV studies), new states
(see Tuesday's D0 talk), …

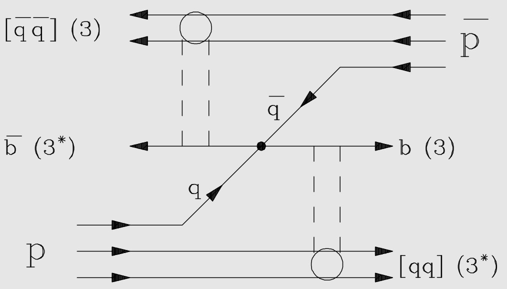
More is yet to come!

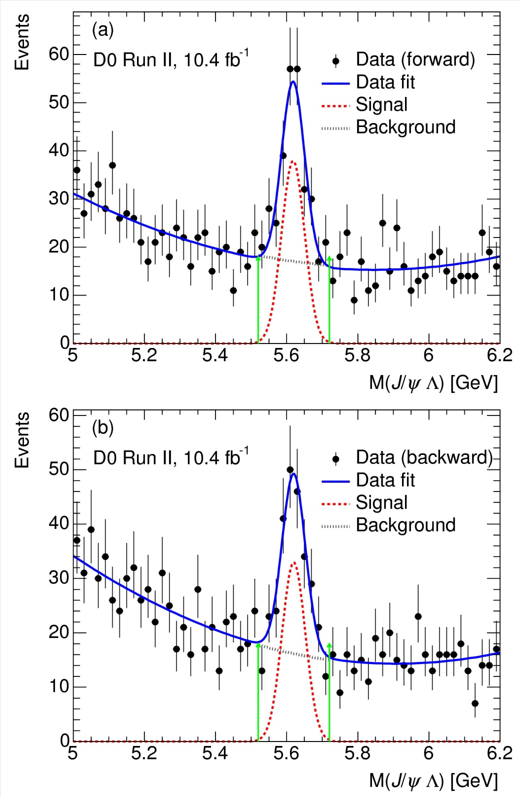
10.4 fb^{-1}

Λ^0_b and $\overline{\Lambda}^0_b$ baryon production

Production through $q\bar{q}$, gg has small asymmetry (~1%) from NLO corrections

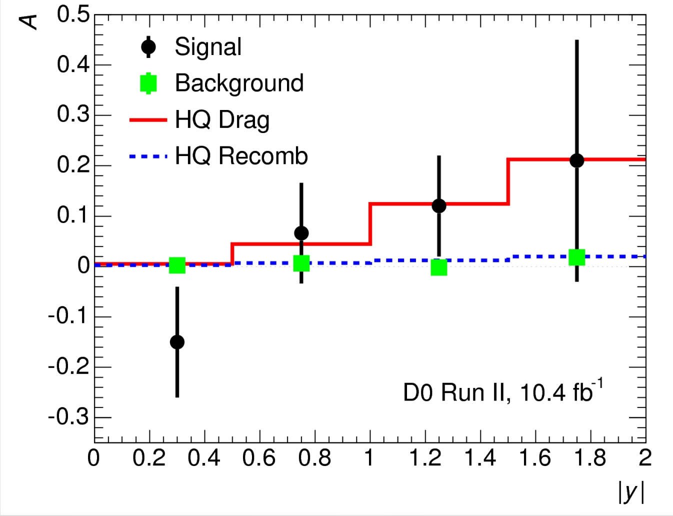
=> Study hadronization effects, eg "string drag" model (Rosner)
favor production of $(\overline{\Lambda}_b)\Lambda_b$ in (anti)proton beam direction





Clean signals
Forward/backward
events shown

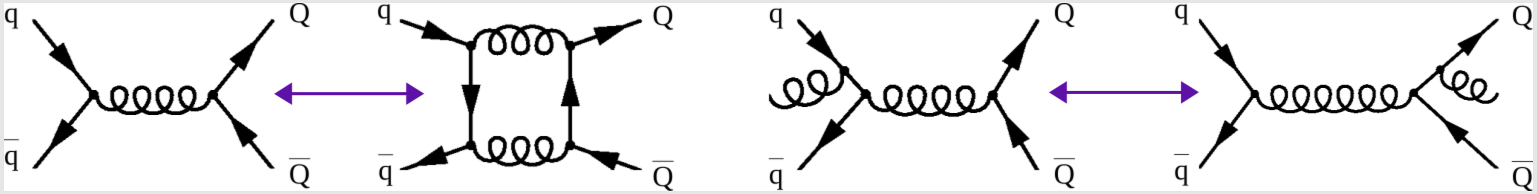
General agreement with
heavy quark drag model =>



arXiv:1503.03917

b production

Production mechanism dominated by gluon-gluon fusion → no A FB
A_{FB} receives contribution in $q\bar{q}$ and qg interactions from interference:



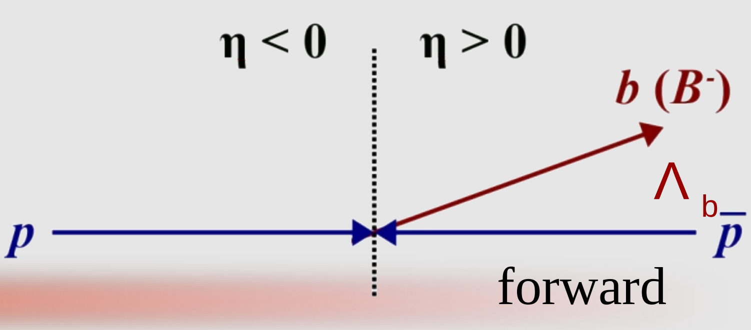
- initial and final-state radiative gluon diagrams
- box diagram + Born
- different amplitudes in flavor excitation
- electro-weak process ($qq \to Z/\gamma \to b\bar{b}$)

In $p\bar{p}$ collisions $b(\bar{b})$ quark follows $p(\bar{p})$ direction

$$A_{FB} \simeq \frac{N_F - N_B}{N_F + N_B}$$

A_{FB} depends on $m(b\bar{b})$

A_{FB} using fully reconstructed B meson and Λ_b (also Λ)



Forward-backward asymmetry of $(\Lambda, \bar{\Lambda})$

Observables

$$
\begin{aligned}
N_F(\Lambda) &\equiv N(1 + A'_{FB})(1 - A'_{NS})(1 + A'_{\Lambda\bar{\Lambda}}), \\
N_B(\Lambda) &\equiv N(1 - A'_{FB})(1 + A'_{NS})(1 + A'_{\Lambda\bar{\Lambda}}), \\
N_F(\bar{\Lambda}) &\equiv N(1 + A'_{FB})(1 + A'_{NS})(1 - A'_{\Lambda\bar{\Lambda}}), \\
N_B(\bar{\Lambda}) &\equiv N(1 - A'_{FB})(1 - A'_{NS})(1 - A'_{\Lambda\bar{\Lambda}}).
\end{aligned}
$$

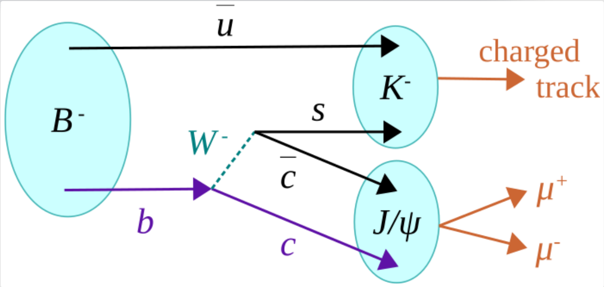
primed quantities are "raw" asymmetries

A'_{NS}: measures the relative excess of reconstructed Λ's plus $\bar{\Lambda}$'s with longitudinal momentum in the $\bar{p}$ direction (north) with respect to the p direction (south).

$A'_{\Lambda\bar{\Lambda}}$: measures the relative excess of reconstructed Λ's with respect to $\bar{\Lambda}$'s

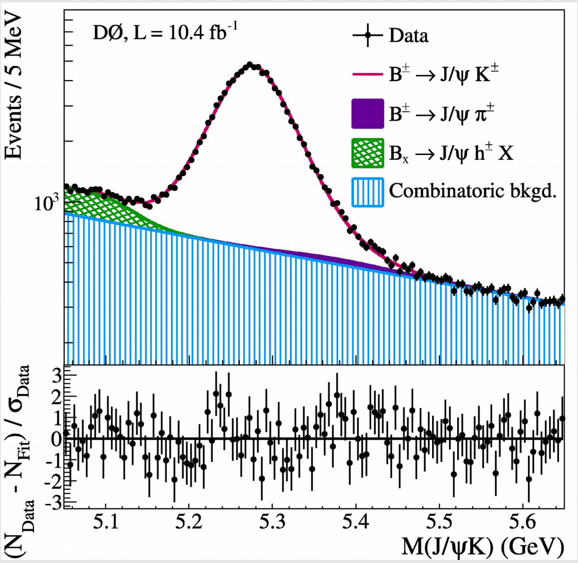
PRODUCTION ASYMMETRIES OF B±

$$A_{FB}(B^{\pm}) = \frac{N(-q_B\eta_B > 0) - N(-q_B\eta_B < 0)}{N(-q_B\eta_B > 0) + N(-q_B\eta_B < 0)}$$

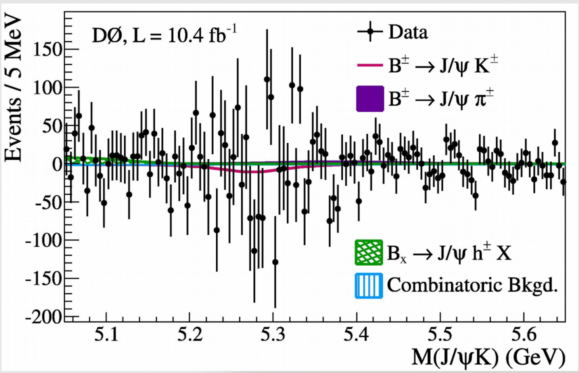


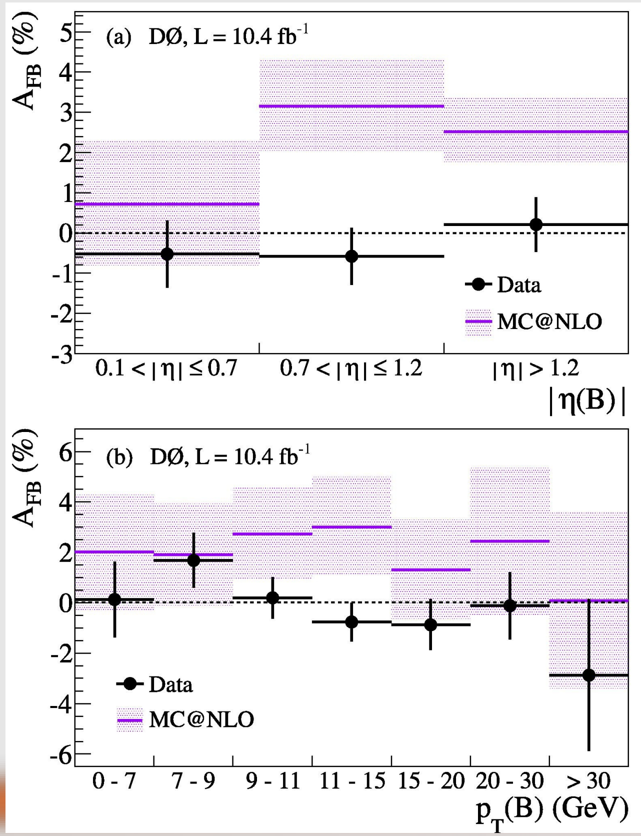
Fully reconstructed B meson

Sum F+B



Difference F-B





$A_{FB}(B^{\pm})$ = $(-0.24 \pm 0.41 \pm 0.19)\%$

Systematically lower than calculated in MC@NLO

More rigorous determination of the SM prediction needed to interpret results

Less room for new physics causing anomalous F-B asymmetries (top and bottom)

Phys. Rev. Lett. 114, 051803 (2015)
arXiv:1411.3021