Recent D0 Measurements of Forward-Backward Asymmetries for $p\bar{p} \rightarrow B^{\pm}$, Λ_b^0, & Λ_s^0 Production

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for the D0 Collaboration

APS Division of Particles and Fields Meeting

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or

do secondary particles retain some "memory" of the direction of the primary parent particles?

Of course they do in the beam fragmentation region studied in Fixed Target and ISR experiments

What about for the central region near $y = 0$ for hadron colliders?

What mechanisms are at play for A_{FB}?

What is the transition between the central and beam fragmentation regions?

Outline

- p-$\bar{p}$ collisions at the Fermilab Tevatron

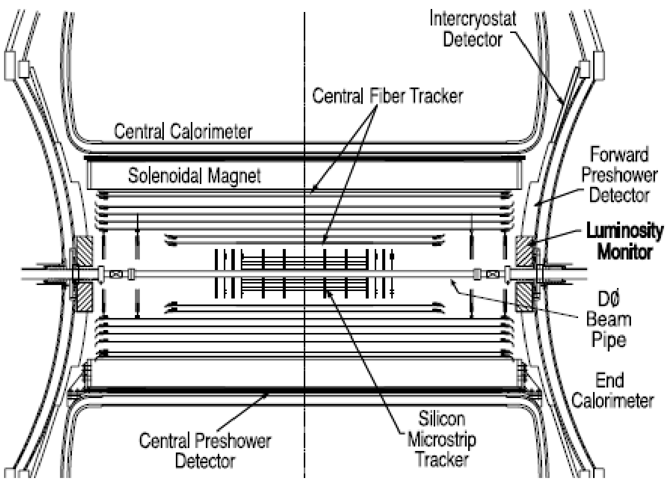
  $\sqrt{s}$ = 1.96 TeV   *D0*: 10.4 fb^{-1} = full data set
- *D0* is good place to study A_{FB}
- Motivation: interest in $A_{FB}(t\text{-}\bar{t}) \rightarrow A_{FB}(b\text{-}\bar{b})$
- $A_{FB}(B^{\pm})$:   Phys. Rev. Lett. 114, 051803 (2015)   arXiv
- $A_{FB}(\Lambda_b^0)$:   Phys. Rev. D 91, 072008 (2015)   arXiv
- *preliminary* $A_{FB}(\Lambda_s^0)$:   D0 Note 6464-CONF (2015)

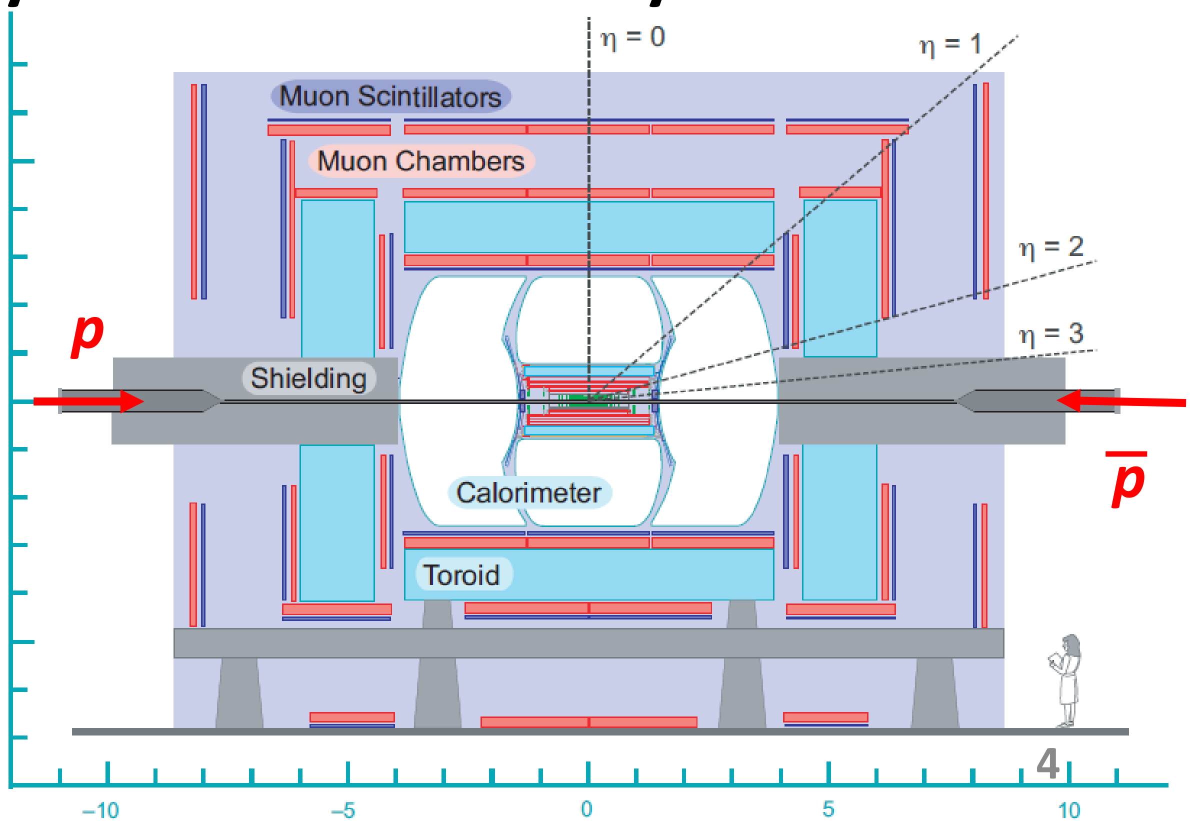
  http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B65/B65.pdf

  relation to some old-timey Fixed Target & ISR Physics

D0 is good place to study A_{FB}

- Symmetry of initial p-$\bar{p}$ state: $B = 0$, $C = 0$
  two "fragmentation" hemispheres
- Symmetric detector (at least to first order…)
- Regularly flip polarities of solenoid & toroid magnets
  cancels many detector-related asymmetries

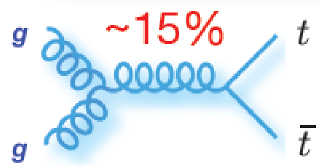




Motivation: (stolen from) Rick Van Kooten at the Fermilab Users Meeting, June, 2015

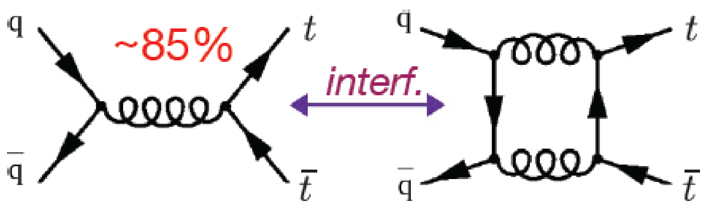
Forward-Backward $t\bar{t}$ Asymmetries

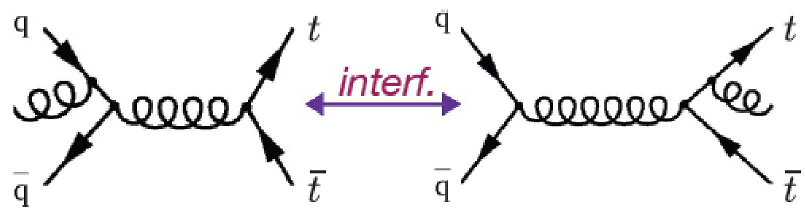
$Q = t$



No A_{FB}

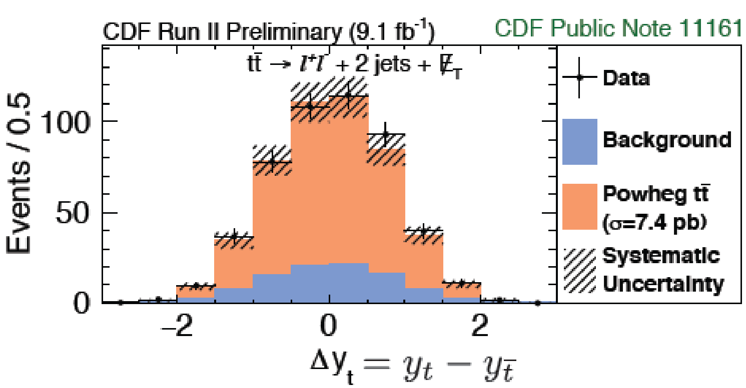
- Forward-backward top quark asymmetry expected to be significant



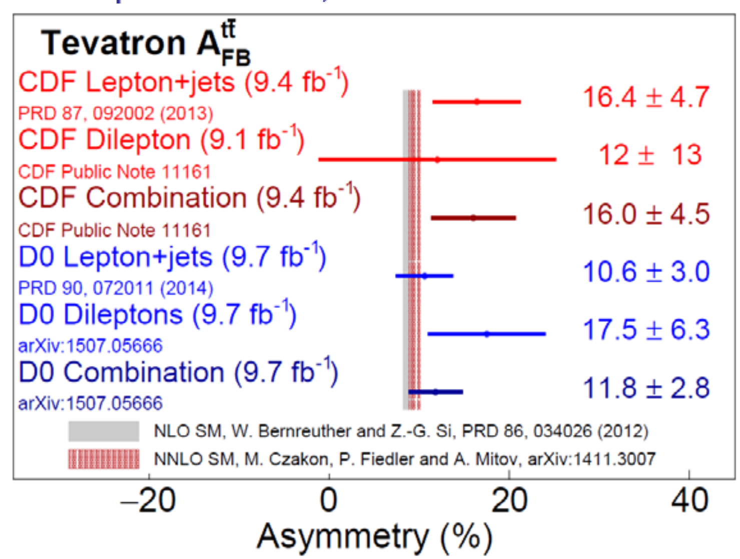


- CDF: both t and $\bar{t}$ decaying leptonically
- Once both CDF and DØ publish final dilepton results, then final Tevatron comb.

$$A_{\mathrm{FB}}^{t\bar{t}} = \frac{N_{\Delta y_t > 0} - N_{\Delta y_t < 0}}{N_{\Delta y_t > 0} + N_{\Delta y_t < 0}}$$



New

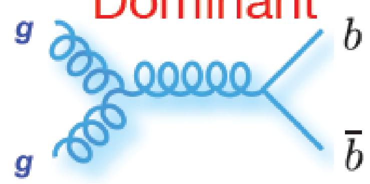


7/22/2015

Forward-Backward $b\bar{b}$ Asymmetries

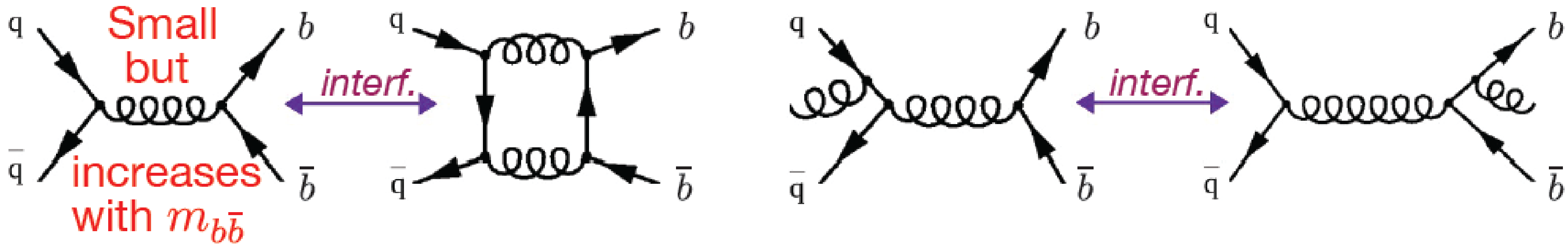
$Q = b$

Dominant



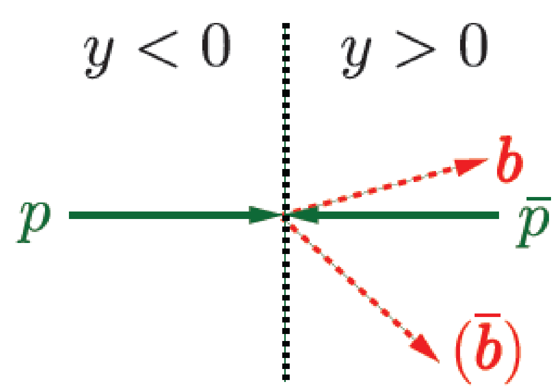
No A_{FB}

- Forward-backward *b* quark asymmetry expected to be small



anti-proton fragmentation hemisphere

proton fragmentation hemisphere



D0 fully reconstructs

B^- ($b\,\bar{u}$) → J/ψ K^- (forward b in p direction)

Λ_b^0 (u d b) → J/ψ Λ_s^0 (forward baryons in

Λ_s^0 (u d s) → p π^- in proton direction)

production and/or fragmentation?

Forward particles:

B^-, Λ_b^0, Λ_s^0 with y > 0

B^+, $\bar{\Lambda}_b^0$, $\bar{\Lambda}_s^0$ with y < 0

Backward particles:

B^+, $\bar{\Lambda}_b^0$, $\bar{\Lambda}_s^0$ with y > 0

B^-, Λ_b^0, Λ_s^0 with y < 0

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{Diff}{Sum}$$

we measure both *Particle* and *anti-Particle*
and y < 0 and y > 0 hemispheres
simultaneously

$$A_{FB} = \frac{\sigma_F(Particle) + \sigma_F(anti\text{-}P) - \sigma_B(Particle) - \sigma_B(anti\text{-}P)}{\sigma_F(Particle) + \sigma_F(anti\text{-}P) + \sigma_B(Particle) + \sigma_B(anti\text{-}P)}$$

to assure no mixing of forward and backward hemispheres
due to reconstruction errors,
we do not include particles with $|y| < 0.1$ or $|\eta| < 0.1$
> 99.9% of $B^{\pm}$ have same sign of η or y as the parent b-quark
The distribution of $(\eta_{b\text{-}quark} - \eta_B)$ has an rms width of 0.11 unit.

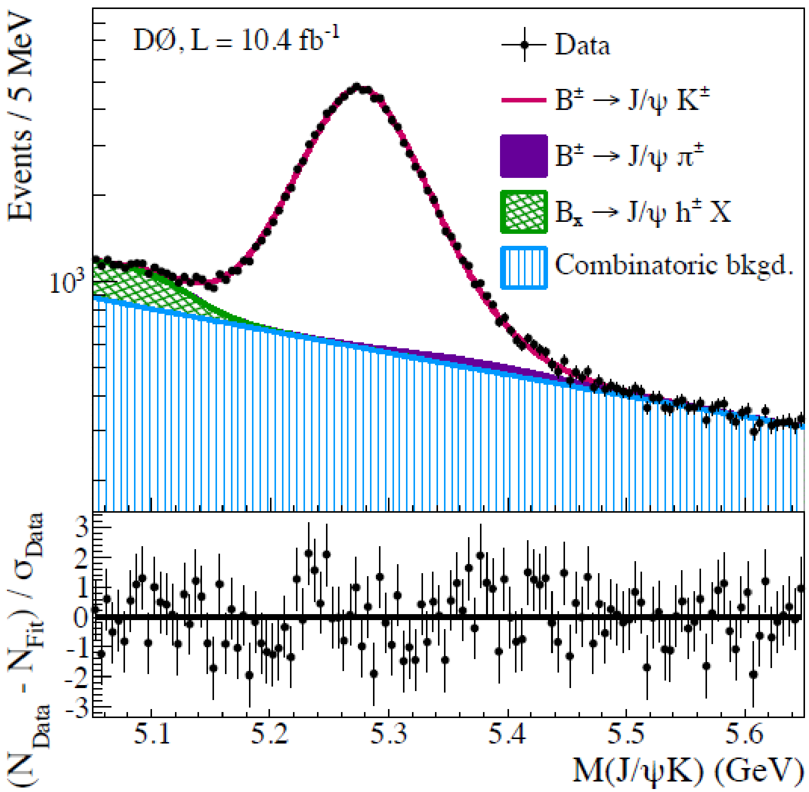
$A_{FB}(B^{\pm})$ $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ $J/\psi \rightarrow \mu^{+} \mu^{-}$

p_T(each μ) > 1.5 GeV $p_T(K)$ > 0.7 GeV 89,000 $B^{\pm}$

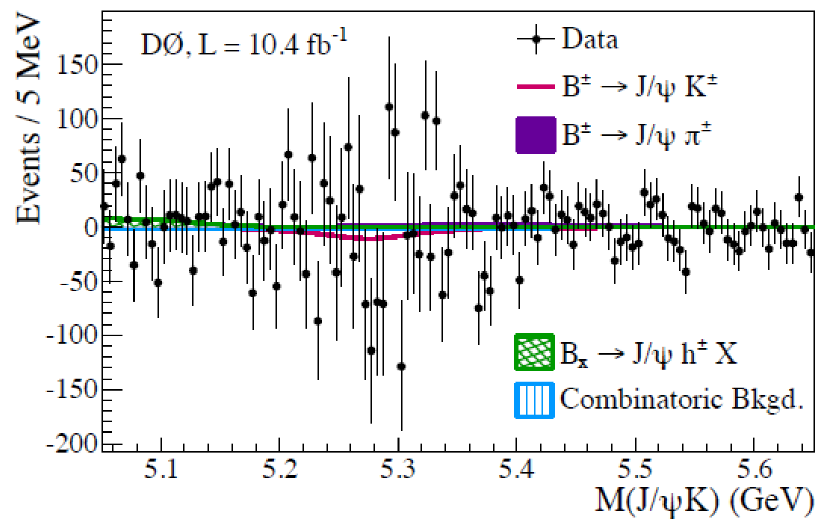
unbinned likelihood fit, simultaneously for SUM and DIFF

binned just for illustration purposes

SUM = Forward + Backward



DIFF = Forward - Backward



Correct for F-B reconstruction asymmetries, muon and kaons using weights: A_{corr} = -0.06%.

This $A_{FB}(B^{\pm})$ measurement is limited by the statistical uncertainty

TABLE I: Summary of uncertainties on $A_{\mathrm{FB}}(B^{\pm})$ in data.

Source	Uncertainty
Statistical	0.41%
Alternative BDTs and cuts	0.17%
Fit Variations	0.06%
Reconstruction Asymmetries	0.05%
Fit Bias	0.02%
Systematic Uncertainty	0.19%
Total Uncertainty	0.45%

integrated over $0.1 < |\eta| < 2$

$A_{FB}(B^{\pm})$ = [-0.24 ± 0.42 (stat) ± 0.19 (syst)]%

no significant FB asymmetry

comparing $A_{FB}(B^{\pm})$ with MC@NLO

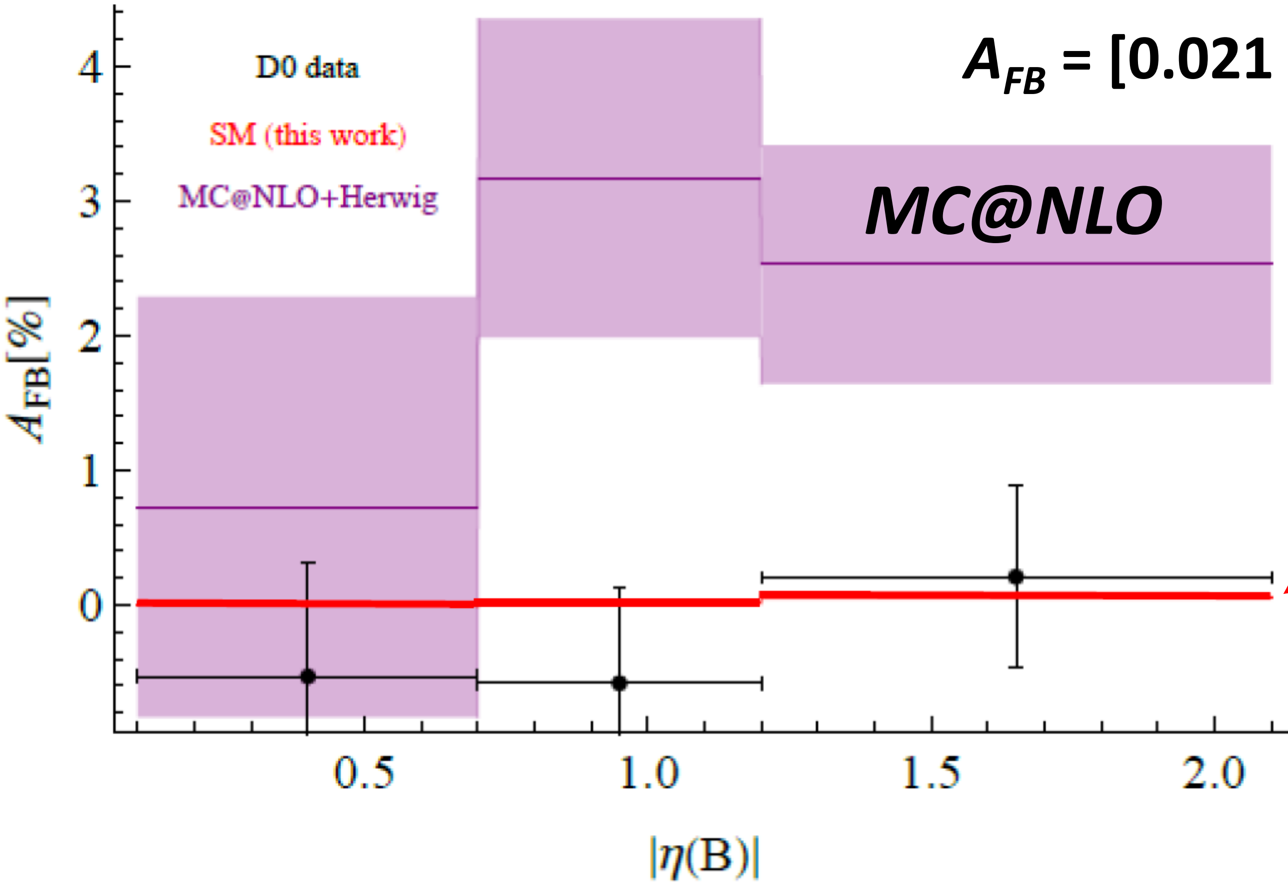
Integrated over the range 0.1 < |η| < 2

D0 measures $A_{FB}(B^{\pm})$ = [-0.24 ± 0.42 (stat) ± 0.19 (syst)]%

MC@NLO simulates = [+2.31 ± 0.34 (stat) ± 0.44 (syst)]%

3.5 σ discrepancy! data is systematically < MC@NLO

A_{FB} = [0.021 ± 0.008] %



improved calculation

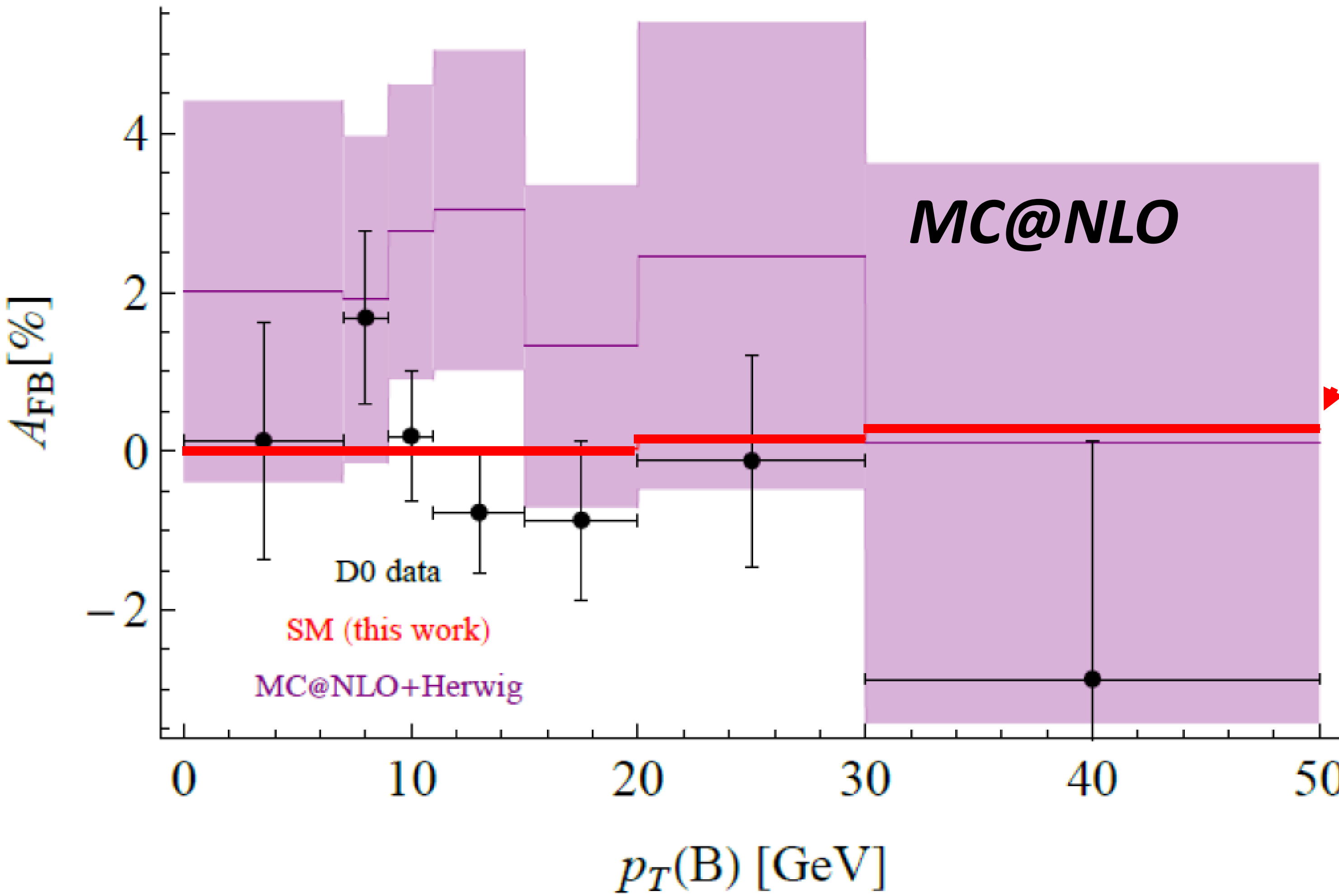
by C. Murphy (Pisa)

arXiv: 1504.02493

comparing $A_{FB}(B^{\pm})$ with MC@NLO

Integrated over the range 0.1 < |η| < 2

data is systematically < MC@NLO



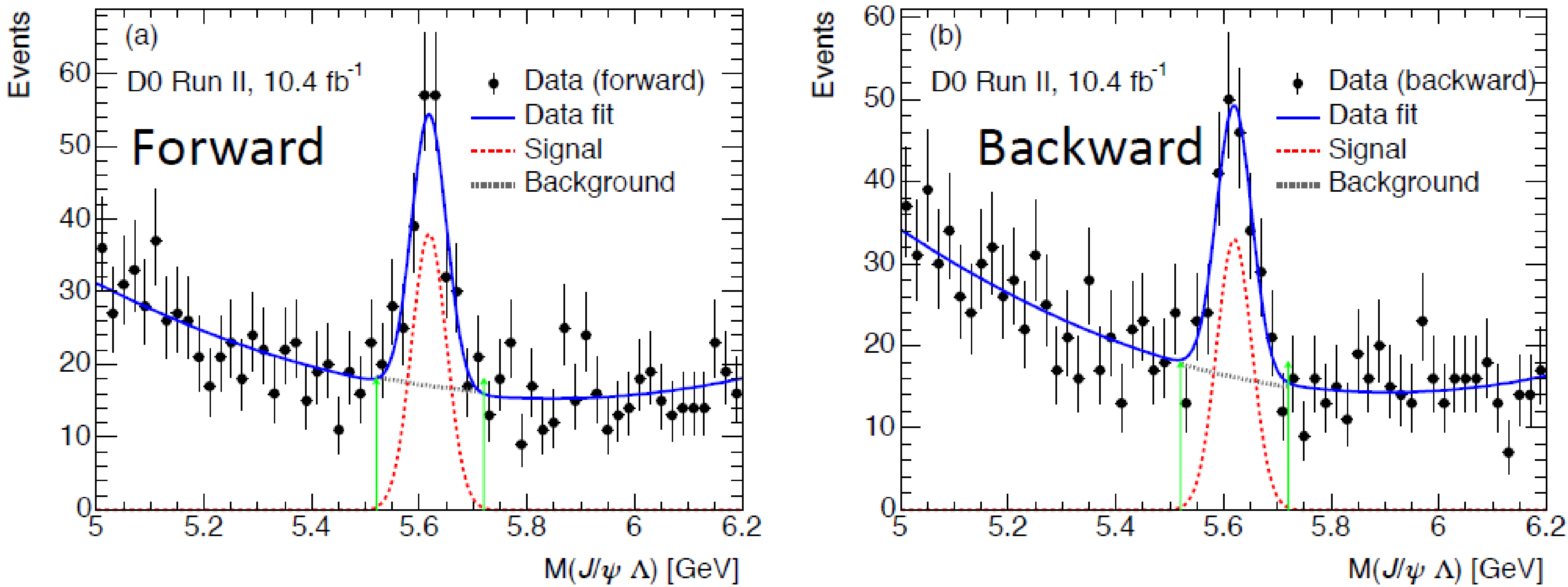
improved calculation by C. Murphy

arXiv: 1504.02493

$A_{FB}(\Lambda_b^0)$ $\Lambda_b^0 \rightarrow J/\psi\, \Lambda_s^0$

$J/\psi \rightarrow \mu^+ \mu^-$
$\Lambda_s^0 \rightarrow p\, \pi^-$

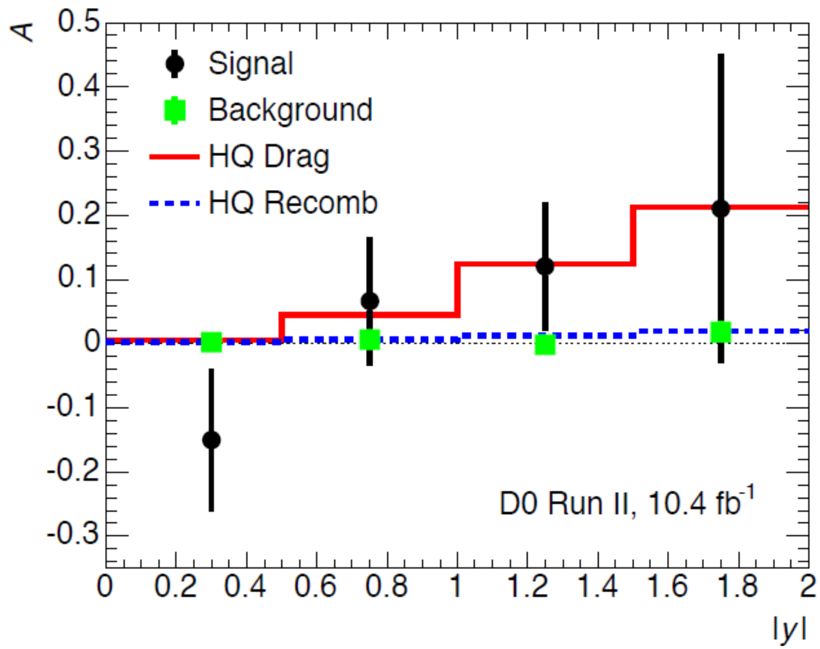
Fit with binned maximum likelihood
Gaussian signal + 2nd order Chebyshev polynomial background
Example of mass plots for 0.5 < |y| < 1 bin



fitted # Λ_b^0 + # $\bar{\Lambda}_b^0$ = 842 ± 49

$A_{FB}(\Lambda_b^0)$ = 0.04 ± 0.07 (stat) ± 0.02 (syst)

Integrated over
0.1 < |y| < 2
for <p$_T$> = 9.9 GeV

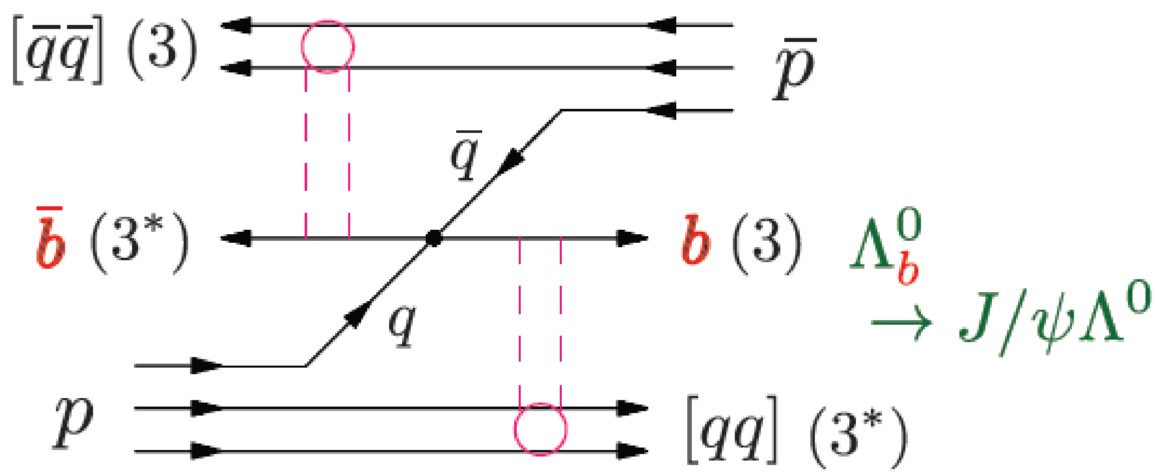


trend follows HQ Drag, but consistent w Recombo or $A_{FB}(|y|) = 0$

baryons are more complicated
Jon Rosner's

String Drag

$\langle \Delta p_z \rangle$ =
+1.4 GeV for Λ_b
-1.4 GeV for $\overline{\Lambda}_b$

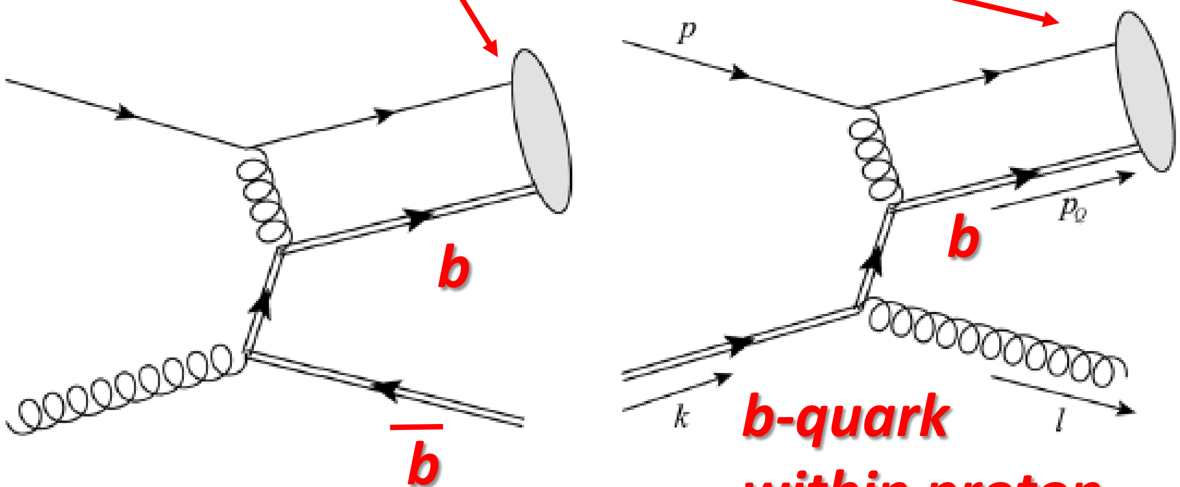


Rosner, PRD 90, 014023 (2014)

Heavy Quark Recombination Model

W.K. Lai and A.K. Leibovich, Phys. Rev. D91 054022 (2015)

recombination with beam di-quark into Λ_b^0



b-quark within proton promoted to valence quark

compare $y(\Lambda_b^0)$ to $y(\text{beam}) \rightarrow$ rapidity loss
we find similar behavior for D0, CMS, LHCb

we plot

$R_{pp} = \sigma(\bar{\Lambda}_b)/\sigma(\Lambda_b)$

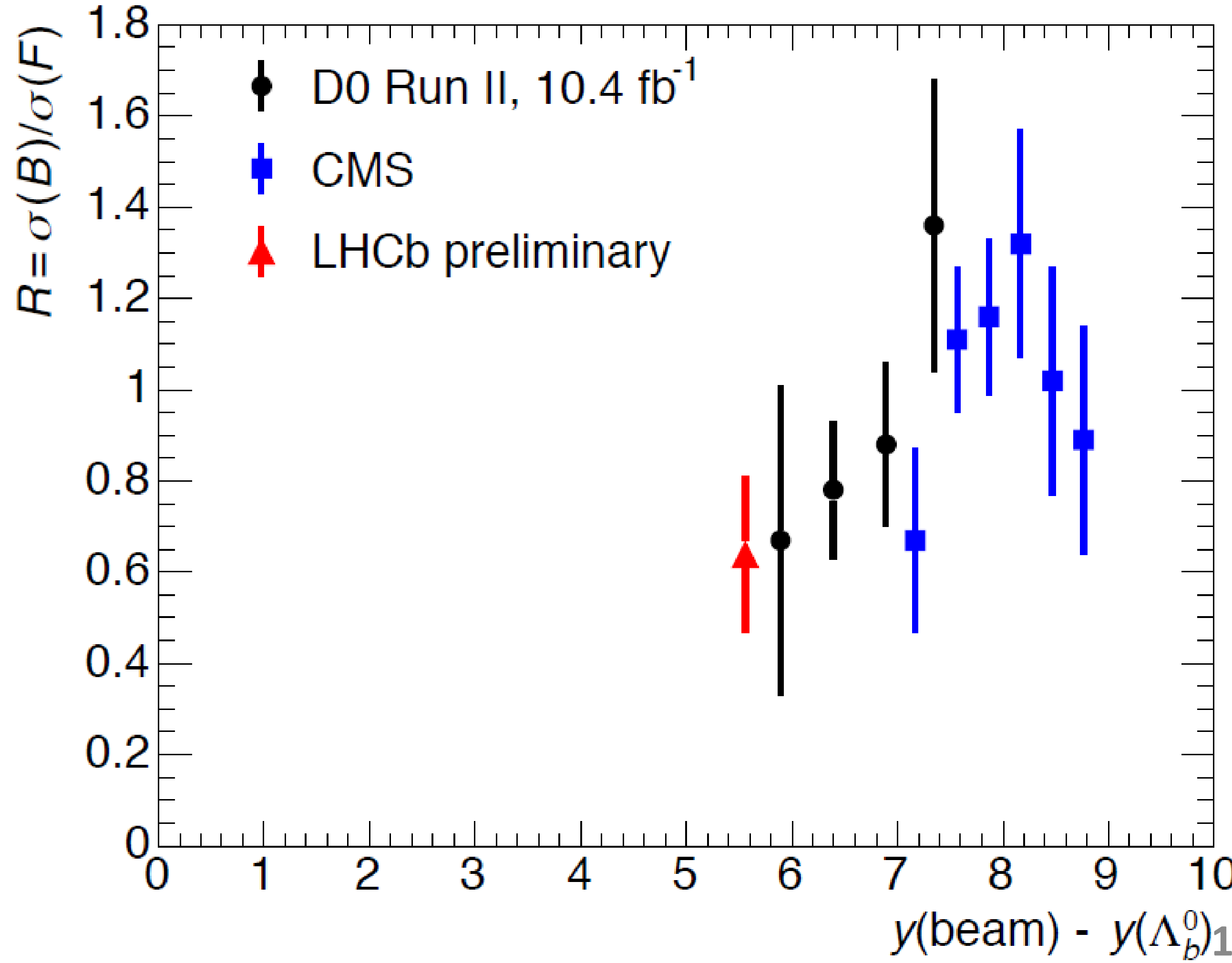
$R_{p\bar{p}} = \sigma(B)/\sigma(F)$

by $p\bar{p}$ charge symmetry:

$\sigma(\Lambda_b, y) = \sigma(\bar{\Lambda}_b, -y)$

$$R = \frac{1 - A_{FB}}{1 + A_{FB}}$$

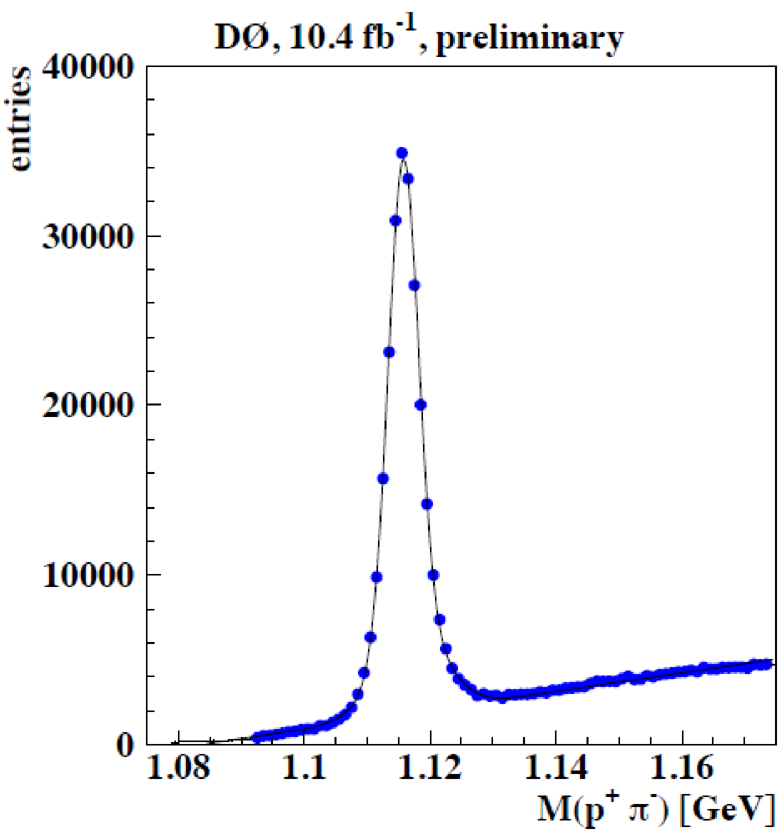
Ratio of $\bar{\Lambda}_b/\Lambda_b$ vs rapidity loss $y(\text{beam}) - y(\Lambda_b)$

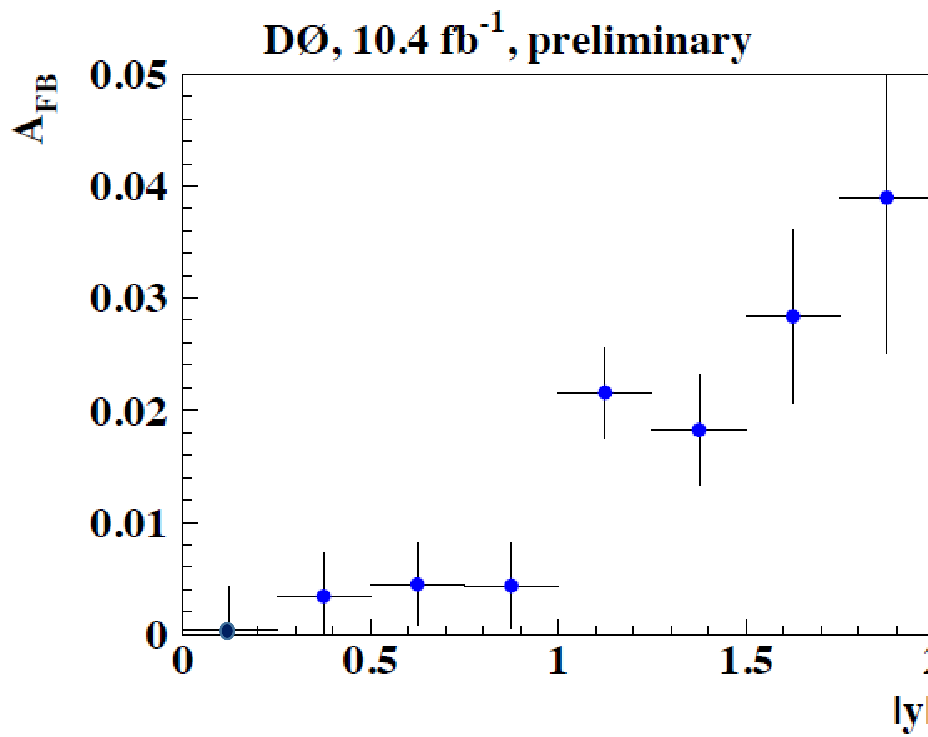


$A_{FB}(\Lambda_s^0)$ $\Lambda \rightarrow p\,\pi^-$ plain, old Λ

PRELIMINARY – yet not submitted for publication

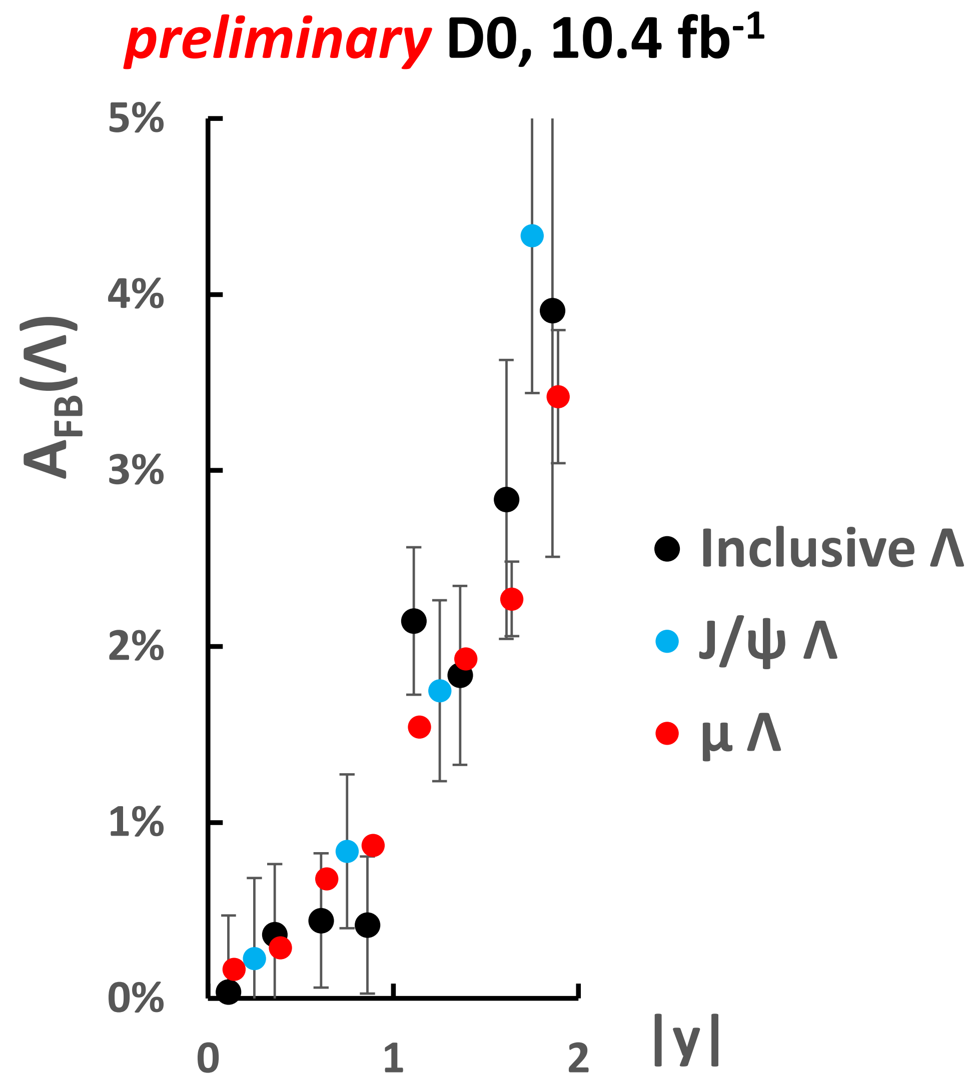
Inclusive Λ for prescaled beam crossing or minimum bias triggers
identify higher momentum particle as baryon (p or pbar)
example of $p\,\pi^-$ mass spectrum **$2 < p_T(\Lambda) < 25$ GeV**





$A_{FB}(\Lambda_s^0)$ for $\mu^\pm \Lambda$ and $J/\psi\ \Lambda$ combos

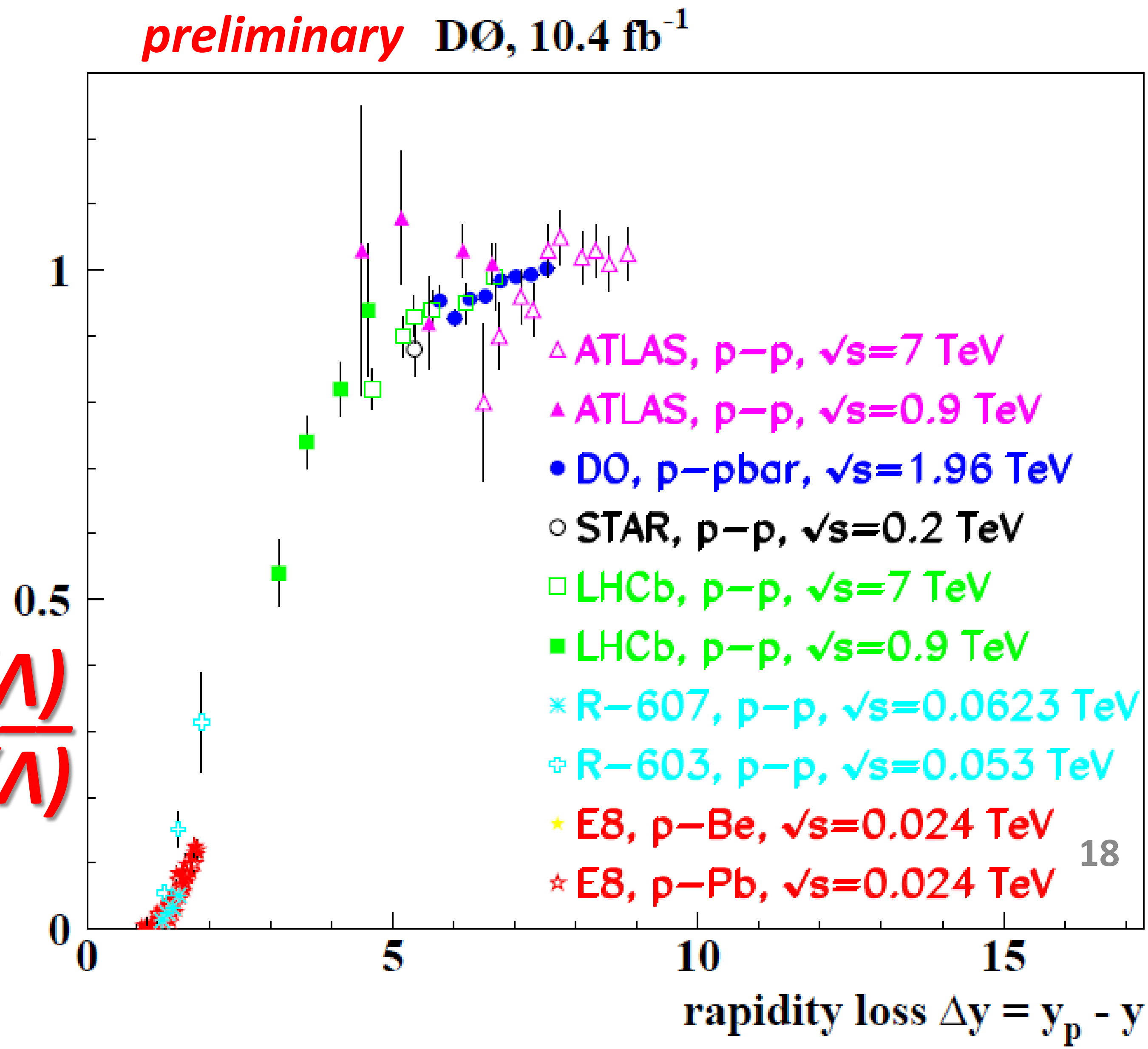
- **2.3 M inclusive Λ**
  0.7 M $J/\psi\ \Lambda$
  53 M $\mu\ \Lambda$
- **We combine all $\mu^+ + \mu^-$ with all $\Lambda + \overline{\Lambda}$ to form $A_{FB}(\mu\Lambda)$**
- **Very high $\mu\Lambda$ statistics! There are some correlations between charge of $\mu^\pm$ and Λ or $\overline{\Lambda}$ So what's the physics?**
- **Inclusive Λ, $\mu^\pm\Lambda$, and $J/\psi\ \Lambda$ all have similar behavior for $A_{FB}(|y|)$**



universal curve? limiting fragmentation?

$$R = \frac{\sigma(\bar{\Lambda},y)}{\sigma(\Lambda,y)}$$

$$R = \frac{1 - A_{FB}(\Lambda)}{1 + A_{FB}(\Lambda)}$$



things to remember about these D0 p-$\bar{p}$ measurements of A_{FB}

- $A_{FB}(t\text{-}\bar{t})$ ~ + 13% over same rapidity range
  - motivated higher order calculations of SM to produce agreement with data
- $A_{FB}(B^{\pm})$ ~ 0
  - MC@NLO predicts ~ 2%, C. Murphy calculation ~ 0
- $A_{FB}(\Lambda_b^0)$ is consistent with 0
  - need more statistics to differentiate between |y| dependence of String Drag or HQ Recombination
  - $R(\Lambda_b^0)$ consistent w $R(\Delta y)$ dependence for CMS & LHCb
- $A_{FB}(\Lambda_s^0)$ increases with increasing rapidity |y|
  - Beginning of transition from central region at colliders to beam fragmentation region (FT and ISR)
  - Hints at a universal curve as function of $\Delta y = y_{beam} - y_{\Lambda}$

D0 continues to produce results complementary to those of the LHC especially those unique to $p\text{-}\bar{p}$ collisions

stay tuned for more!

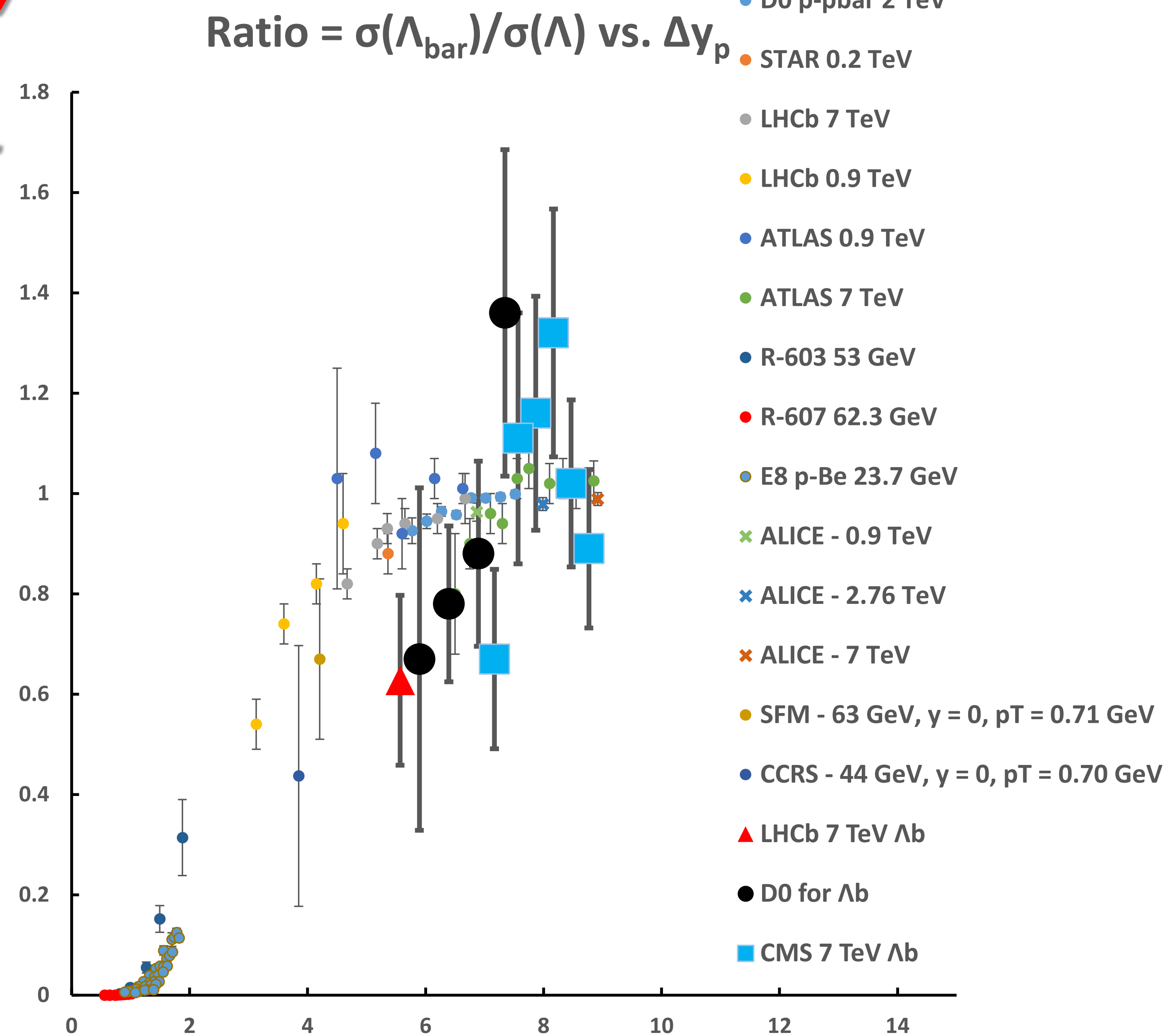
backup slides

adding $R(\Lambda_b^0)$

(bold points)

to $R(\Lambda_s^0)$ plot

preliminary R(Λ) for D0 10.4 fb^{-1}



expected symmetries

for *pp* collisions

$$\sigma_{pp}(\Lambda,y) = \sigma_{pp}(\Lambda,-y) \quad \textbf{and} \quad \sigma_{pp}(\bar{\Lambda},y) = \sigma_{pp}(\bar{\Lambda},-y)$$

for *p$\bar{p}$* collisions

$$\sigma_{p\bar{p}}(\Lambda,y) = \sigma_{p\bar{p}}(\bar{\Lambda},-y)$$

Comparing to p-p at LHC and ISR (or p-Nucleus @ Fixed Target)

for fragmentation, not necessarily for central production

proton beam fragmentation hemisphere | **$\bar{p}$ beam fragmentation hemisphere**

$$R = \frac{\sigma_{p\text{-}p}(\bar{\Lambda})}{\sigma_{p\text{-}p}(\Lambda)} = \frac{\sigma_{p\text{-}\bar{p}}(\bar{\Lambda},B)}{\sigma_{p\text{-}\bar{p}}(\Lambda,F)} = \frac{\sigma_{\bar{p}\text{-}p}(\Lambda,B)}{\sigma_{\bar{p}\text{-}p}(\bar{\Lambda},F)}$$

if independent of target (p, pbar, nucleus)

expected if charge symmetric

note that

$$R = \frac{1 - A_{FB}}{1 + A_{FB}}$$

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